Kingdom of Cambodia

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Ministry of Public Works and Transport

National Council for Sustainable Development
Ministry of Environment

Green Infrastructure Guide

2019

Green Infrastructure Guide

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FOREWORD

Cambodia has been identified as one of the most vulnerable countries to natural disasters such as floods, droughts, storms and typhoons. The incidence and impacts of such natural disasters are increasing and becoming more severe with climate change. As such, current climate hazards and long-term climate change have been identified as significant environmental and developmental issues in Cambodia, while poverty leaves the country with limited capacity to adapt.

The TA 8179-CAM Mainstreaming Climate Resilience into Development Planning project, funded by Asian Development Bank (ADB) and coordinated by Ministry of Environment (MOE), has assisted the Ministry of Public Works and Transport (MPWT) to develop a **Green Infrastructure Guide** for public works and transport sectors. This guide provides an overview of green adaptation measures as a first step towards mainstreaming climate change into the planning of the ministry.

Green infrastructure entails the use of vegetation, soils and natural processes to manage water, temperature and air to create a healthier, resilient and beautiful environment. At all scales, green infrastructure emphasises nature-based solutions and the use of local resources and materials to build community self-reliance and resilience. Green infrastructure measures often make sound sense for climate change adaptation: they are resilient, often cheaper than conventional construction methods, and use traditional methods that can be managed by the community.

Green infrastructure involves the greening of conventional infrastructure and expanding the networks of natural and semi-natural areas within cities and towns. It involves changing the way urban infrastructure – roads, drains, flood gates, riverbanks, and water and sanitation facilities – is designed and managed to be sustainable, cost-effective and resilient to climate change. It combines actions and methods to bring nature back into areas as a foundation for resilience and to enhance the quality of life for residents. In many situations, green infrastructure provides the best solutions to town development, leaving hard engineering to complement it, or make up any shortfalls. If grey infrastructure is put in place first, it often rules out green options and reduces sustainability and resilience. This guide provides an overview of the available green measures, in order to help decision makers choose those that are most suitable to specific circumstances. In this way, opportunities will be maximised.

The measures presented in this guide were chosen as they relate specifically to Cambodia's development needs. Many of them have been tested and demonstrated in Cambodia and have already been applied by ministries on an ad hoc basis. Some are traditional approaches to water and soil management that have proven effective in building resilience to floods and drought. The guide also features adaptation measures to be promoted and built into sector policies and design standards. Each measure has multiple applications, and can be used in combination with others.

On behalf of MOE and MPWT, we would like to express our sincere gratitude to all stakeholders for their support and cooperation in developing this toolkit through constructive engagement and consultations.

We strongly believe that all relevant agencies and development partners will continue to work together to contribute actively to poverty reduction and sustainable development of Cambodia.

Phnom Penh, 05 August, 2019

Senior Minister
Minister of Public Works and Transport

Sun Chanthol

Phnom Penh, 05 August, 2019

Chair of National Council for Sustainable Develoment and Minister of Environment

Say Samal

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Phnom Penh, 05 August , 2019

Secretary of State of Ministry of Environment

and SPCR Program Coordinator

H.E Prof. Dr. Sabo Ojano

Acronyms

ADB	Asian Development Bank
CCAMM	Climate change adaptation and mitigation methodology (ICEM)
CMDG	Cambodia Millennium Development Goals
ICEM	International Centre for Environmental Management
MCRDP	Mainstreaming Climate Resilience into Development Planning
MOE	Ministry of Environment
MPWT	Ministry of Public Works and Transport
NCSD	National Council for Sustainable Development
NSDP	National Strategic Development Plan
PPCR	Pilot Program for Climate Resilience
RGC	Royal Government of Cambodia
SPCR	Strategic Program for Climate Resilience
TA	Technical Assistance

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A INTRODUCTION TO THE GUIDE

1. INTRODUCTION

A first step towards mainstreaming climate change in the Ministry of Public Works and Transport (MPWT) is to provide an overview of green adaptation measures. Green infrastructure measures, in many cases, make good and sound sense for climate change adaptation as they are resilient, often cheaper, and use traditional methods that can be managed by the community.

Green infrastructure uses vegetation, soils and natural processes to manage water, temperature and air quality to create healthier, resilient and beautiful urban environments. At the town scale, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, clean air, clean water, food and recreation. At the local level, green infrastructure includes stormwater and drainage management systems that mimic nature by soaking up and storing water, and by improving its quality. For specific infrastructure systems, most importantly, it improves engineering by including natural components and bioengineering methods. At all scales, green infrastructure emphasises nature based solutions and uses of local resources and materials to build community self-reliance and resilience.

The measures presented in this guide were chosen as they relate specifically to Cambodia's development needs. Many of these measures have been tested and demonstrated in Cambodia and have already been applied by the ministries on an ad hoc basis. Some are traditional approaches to agriculture, water and soil management that have proven effective in building resilience to floods and drought. The preparation of this green infrastructure guide will provide an initial set of adaptation measures appropriate for projects to be prepared for climate financing. This guide also features adaptation measures to be promoted and built into sector policies and design standards.

The emphasis on bioengineering in this guide is a reaction to the extreme engineering often taking place in development projects, requiring high implementation, operation and maintenance costs, when cheaper traditional methods are available. Furthermore, these measures are multi-use options that present an opportunity to deliver and enhance green spaces that benefit the community.

To maximise the benefits and minimise the negative impacts, these measures need to be considered from the early phase of the development planning process and throughout. Green infrastructure should be included in design standards and safeguards in order to be recognised as a complement and alternative to conventional or 'grey' infrastructure development. Green infrastructure planning should be closely coordinated with planning for grey infrastructure as integrated planning and design connects the two – grey and green – in a more effective, economic and sustainable network. Green infrastructure can contribute significantly to the delivery of other forms of infrastructure and services and should be given the same emphasis in planning and budgeting. Each adaptation measure has multiple applications and ways it may be used in combination with other measures. This guide provides an overview of available green measures to enable decisions to be made that suit specific circumstances that maximise opportunities.

Green infrastructure involves the greening of conventional infrastructure as well as expanding the networks of natural and semi-natural areas within towns. It involves changing the way urban infrastructure – roads, drains, flood gates, riverbanks, water and sanitation facilities, electricity supply, and buildings – are designed and managed to be sustainable, cost effective, and resilient to climate change. It combines actions and methods to bring nature back into urban areas as a foundation for resilience and to enhance the quality of life for urban residents. In many situations, green infrastructure provides the best solutions to town development, leaving hard engineering to complement or make up any shortfall. If grey infrastructure is put in place first, it often rules out green options and reduces urban sustainability and resilience.

Design engineers wishing to explore different approaches to grey infrastructure should ask themselves the following questions:

1. Can you meet the requirements with a completely natural approach?
2. If not, how can you use natural elements to strengthen the conventional infrastructure?
3. If you cannot act directly on site, how can you reinforce the life and effectiveness of the conventional infrastructure by acting on the surroundings?

In summary, green infrastructure should:

- Be a foundation for planning, developing and maintaining Cambodian towns and transport infrastructure.
- Be shaped by existing or past natural systems in the area, including its local landscapes, drainage patterns, habitats and biodiversity.
- Be a strategically planned and interconnected network set out in master plans.
- Be multi-purpose, seeking to serve many functions and uses as well as building resilience in town areas and structures.
- Involve local communities in design, construction, management, maintenance and use.

- Be established permanently with financial support for continued maintenance and adaptation.

2. MINISTRY OF PUBLIC WORKS AND TRANSPORT

2.1 MANDATE

The MPWT was established in 1996 and is decreed by the Royal Government of Cambodia (RGC) to lead and manage the public works and transport sector in the Kingdom of Cambodia. It has the following mission and functions:

Manage the implementation of national policy concerning all public works construction by establishing the principles of law and cooperating with various organizations to develop the country.

- Build, maintain and manage transportation infrastructure such as roads, bridges, ports, railways, waterways and buildings.
- Establish the regulations for the development of the roads, ports, railways and waterways infrastructure.
- Establish the regulations for and control transport by road, railway and waterway.
- Participate and cooperate to establish laws, regulations, and standards concerning the construction of transport infrastructure.
- Realize the other constructions that the RGC entrusts to it.
- Cooperate with the Secretariat of Civil Aviation concerning all airport construction works.

2.2 LEGISLATION AND POLICIES

The law and policies include: (i) National Road Safety Policy (February 2014); (ii) Law on Road (April 2014); (iii) Law on Land Traffic (January 2007).

The MPWT is responsible for developing specific national policy concerning all public works construction, by establishing the principles of law and relevant regulations and cooperating with diverse organisations to develop the country. It is also responsible for building, maintaining and managing all transport infrastructures of national and provincial roads, bridges, ports, railways and waterways.

Existing policy and plans in transport sector:

- Over the past 15 years, the government strategy has been to restore, reconstruct and modernize the country’s core transport system. Early government strategies focused on restoring the arterial transport system and on supporting regional and global integration of the national economy. In 2000, the government prepared a five-year master plan for roads (2000-2005) that pursued three objectives: (i) rehabilitate and reconstruct the main national roads, thereby improving land transport throughout Cambodia;
(ii) build road-links to neighbouring countries, opening up some of the more

remote areas of the country to international trade and tourism; and (iii) develop a sustainable road maintenance program, thereby ensuring that investment in road rehabilitation and reconstruction would generate sustainable benefits.

- In June 2006, the government adopted the National Strategic Development Plan (NSDP), which spells out its strategies to reduce poverty rapidly and to achieve the Cambodia Millennium Development Goals (CMDGs). The NSDP included the following road subsector priorities: (i) finalize and enact a Road Law; (ii) prioritize, rehabilitate and reconstruct as many roads as possible; (iii) expand the rural road networks; (iv) address, in a humane manner, resettlement issues and the plight of people affected by road construction works; (v) ensure proper, prioritized maintenance of all roads; (vi) use labour-intensive measures as much as possible, especially for constructing and maintaining rural roads; and (vii) involve the private sector in constructing and maintaining roads and bridges in cases where costs could be recovered by tolls.
- The quantitative target to be achieved during the NSDP period (2006-2010) was to upgrade an additional 2,000 km of national and provincial roads, raising the total of such upgraded roads to 4,100 km. In the railway subsector, the priority was to rehabilitate the Southern Line to handle higher volumes of cargo traffic from Sihanoukville Port.

To reduce greenhouse gas emissions in the transport sector, and to cope with the impact of climate change on transport infrastructure in Cambodia, the MPWT has formulated a National Strategic Plan for Climate Change Adaptation (consisting of four strategies) and Greenhouse Gas Mitigation (consisting of 10 strategies) in the Transport Sector.

- **Strategic Framework for Climate Change Adaptation in Transport Infrastructure:**

Strategy 1: Repair and rehabilitate the existing road infrastructure and ensure effective operation and maintenance system

Strategy 2: Design and construct a road drainage system to meet changing conditions expected with climate change

Strategy 3: Enhance adaptation capacity of road networks to extreme climate events

Strategy 4: Capacity building and institutional strengthening

- **Strategic Framework for Greenhouse Gas Mitigation in Transport Sector:**

Strategy 1	Raise public awareness about climate change caused by greenhouse gas emissions from the transport sector
Strategy 2	Enhance inspection and maintenance of vehicles
Strategy 3	Promote public transport in major cities
Strategy 4	Mitigation and low carbon development
Strategy 5	Capital-intensive urban transport infrastructure development and planning
Strategy 6	Efficient and proven transport technology
Strategy 7	Improve petroleum-based fuel
Strategy 8	Shift long distance freight movement from trucks to trains
Strategy 9	Enhance traffic management
Strategy 10	Promote efficient driving

2.3 DESIGN STANDARDS

The Cambodian Road and Bridge Design Standard and Construction Specifications were established in 1999 by MPWT and are to be used for the design and construction of all new roads and bridges, and related rehabilitation work in Cambodia. This covers road geometry standards, road pavement standards, road drainage standards, bridge design standards and bridge construction specifications, which are useful for climate preparedness activities in transport infrastructure in Cambodia.

- Road Design Standard – Part 1. Geometry, CAM PW 03.101.99, Year 2003
- Road Design Standard – Part 2. Pavement, CAM PW 03.102.99, Year 2003
- Road Design Standard – Part 3. Drainage, CAM PW 03.103.99, Year 2003
- Bridge Design Standard, CAM PW 04.102.99, Year 2003
- Construction Specification, Year 2003

3. HOW TO USE THIS GUIDE

3.1 SCOPE OF GUIDE

The MPWT Green Infrastructure Guide provides an initial set of adaptation measures appropriate for transport and public works projects. The guide looks at how green infrastructure measures can maximise both amenity and biodiversity benefits, and deliver the key objectives of the MPWT mandate. It features adaptation measures that can be promoted and built into sector policies and design standards.

The guide does not require technical understanding but is written for a wide range of MPWT professions and roles. This guide is divided into three colour-coded sections: Part A: Introduction, Part B: Transport Measures, and Part C: Urban Measures. It is important to recognise that green infrastructure measures often work best when used in combination. There is extensive overlap in the possible application of each measure across sectors: geotextiles, for instance, have extensive applications, being used to stabilise a slope along a road embankment, to rooftop greening in urban areas.

3.2 INFRASTRUCTURE MATRIX

To help policy makers and practitioners begin implementing green infrastructure options, we have provided a matrix to illustrate how different measures may pair and interact with other complementary technologies.

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

	Bridges	Bridge abutments	Buildings	Canals	Commercial area redevelopment	Culverts and drains	Dykes	Drainage	Flood gates	Highways	Industrial areas	Markets	Parking areas	Port redevelopment	Railway cutting & embankments	Residential areas	River embankments	Road embankments	Roads and footpaths	Seawalls	Stormwater outfall	Wastewater treatment plants
Biological geotextiles	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Bioretention pond		■	■		■			■			■	■	■	■		■			■		■	■
Bioswales		■	■		■			■			■	■	■	■		■			■		■	■
Brush mattress	■			■		■	■		■								■	■			■	
Constructed wetlands					■			■			■	■				■					■	■
Drainage corridors				■				■													■	
Erosion control measures for roads and drains	■					■		■		■								■	■		■	
Grey water recycling			■		■						■	■		■		■						■
Green roofs and walls		■	■		■			■			■	■	■	■		■			■			■
Live crib wall	■			■			■	■			■							■	■			■
Live fascines	■			■			■	■			■							■	■			■
Live staking	■			■			■	■			■							■	■			■
Log terracing	■			■			■	■			■							■	■			■
Palisades	■			■			■	■			■							■	■			■
Permeable paving			■		■			■			■	■	■	■		■			■			
Rain gardens			■		■			■			■	■	■			■					■	
Solid waste management			■		■			■			■	■		■								
Stormwater tree pits			■		■			■			■	■	■			■			■			
Urban river terracing				■	■													■			■	
Urban tree canopy			■		■						■	■	■	■				■	■			
Vegetated gabions		■		■		■	■		■				■		■	■	■	■		■	■	
Vegetated geotextiles	■			■	■	■	■		■		■	■	■	■		■	■	■	■		■	
Vegetated revetment				■		■	■		■								■	■			■	
Vegetated riprap				■		■	■		■								■	■			■	
Vetiver grass	■			■		■		■	■		■			■		■	■	■			■	

B TRANSPORT INFRASTRUCTURE

4. INTRODUCTION

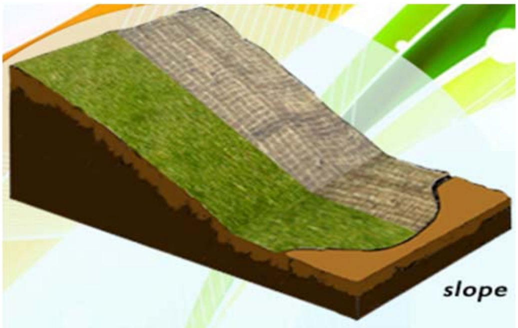
Green infrastructure measures for transport include those that can be used in the construction or improvement of roads, bridges, ports, railways, waterways and buildings. Risks to transport infrastructure, such as flooding, erosion and pollution can be managed using a combination of the measures described in this section. Those relating specifically to urban areas are discussed in Part C, however, the measures described in this section are multi-use and can be used in numerous urban contexts (see Infrastructure Matrix in Part A).

5. SLOPE STABILISATION

As with green infrastructure on the whole, slope stabilisation measures are often most effective when used in combination to maximise benefits.

5.1 BIOLOGICAL GEOTEXTILES

Application	Bridges, bridge abutments, canals, culverts and drains, dykes, drainage, embankments, floodgates, highways, industrial areas, parking areas, port development, railways, residential areas, seawalls, stormwater outfall
Description	A sustainable and local alternative to conventional synthetic fibres used for ground cover geotextiles. Geotextiles serve the purpose of protecting seeds and soil in the initial stages of vegetation growth that stabilise slopes. Natural fibres such as water hyacinth, coir, bamboo, jute, sugarcane, palm, etc., for woven limited life geotextiles, can be used to effectively control soil erosion. These economic and renewable resources are widely available and currently under-utilised, and can be manufactured by local communities. The natural fibres are woven, and then laid on the slope surface. Within two to three years vegetation establishes within the openings of the geotextile and covers the ground, its roots anchoring the soil, and the geotextile is no longer needed to prevent erosion.
Contribution to climate resilience	Biological geotextiles reduce erosion by increasing slope protection, acting as a drain for water and consolidating soft soil (thereby increasing slope stability). By these means they increase the resilience of streambanks to extreme climatic events. Because they are developed using local labour and locally available 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	Limitations
➢ Reduces runoff rate, retains soil and protects exposed earth from sun, rain and wind. ➢ Can be used on steep hilly terrains, as well as riverbanks and coastlines. ➢ An economic and simple measure that can be produced locally. ➢ Facilitates rapid vegetation growth and rehabilitation. ➢ Easy to install as they are laid on the ground, not buried like synthetic geotextiles. ➢ The high moisture retention rate of water hyacinth can promote vegetation growth. ➢ Benefits are enhanced when used in combination with vegetation.	➢ Can be labour intensive. ➢ Knowledge of how to undertake it correctly – appropriate opening sizes, installation, channelling of surface water, accompanying vegetation, etc. – is critical or can result in further erosion and failure. ➢ Currently a lack of experience, and little application, of biological geotextiles in Cambodia.

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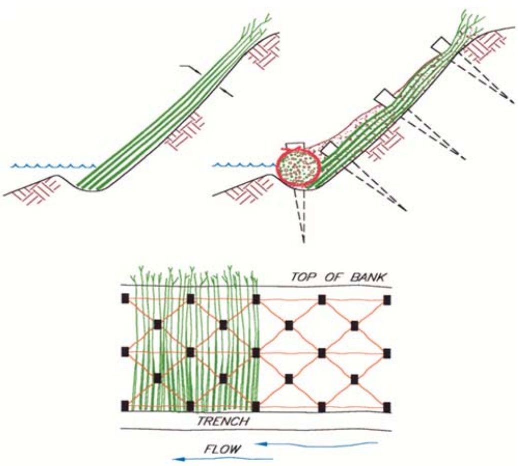
https://www.deepdyve.com/lp/elsevier/properties-and-potential-application-of-the-selected-natural-fibres-as-XiFXIjl1st

5.2 BRUSH MATTRESS

Application	Bridges, canals, culverts and drains, dykes, embankments, floodgates, stormwater
Description	Also known as live brush mats or brush matting, a brush mattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize slopes and embankments. Brush mattresses are used to form an immediate, protective cover over the slope. A thick mat of dormant cuttings is placed on the bank and held down with stakes. The purpose of a brush mattress is to protect the soil surface on slopes from erosive forces through the generation of a dense stand of woody vegetation that will eventually root and provide vegetative stabilization.
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 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	Limitations
➢ Works well on steep fast-flowing streams. ➢ Restores riparian vegetation and streamside habitat rapidly. ➢ Forms an immediate, protective cover	➢ Not recommended for streambanks steeper than 2.5:1 nor should they be used on streambanks where mass wasting occurs. ➢ Only effective on upper slopes.

Strengths	Limitations
over the slope or embankment. ➢ Captures sediment during flood conditions. ➢ Enhances conditions for colonization of native vegetation. ➢ Serves as habitat for birds, small animals, and insects.	➢ A large amount of live material is required to cover the bank.

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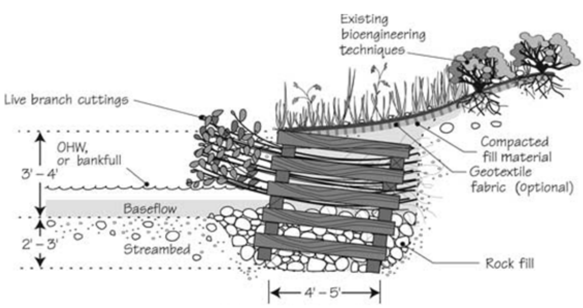
5.3 LIVE CRIB WALL

Application	Bridges, canals, dykes, drainage, industrial areas, road embankments, roads and footpaths, wastewater treatment plants
Description	A hollow, box-like structure made of live materials to reconstruct a bank where extreme erosion has occurred, and to stabilise the base of cut or fill slopes. Live crib walls protect exposed or eroded banks from the erosive forces of flowing water and reduce steepness. Once completed, it acts as a retaining wall. The structure is filled with suitable earth-fill materials and layers of live branch cuttings which take root inside the structure and extend into the slope. The timbers provide immediate protection and stability for the structure. Over time, their importance gradually decreases as they decompose. Meanwhile, the live cuttings grow, and the resulting root mass binds the internal fill and the adjacent undisturbed soil together.
Contribution to climate resilience	Live crib walls prevent erosion, and can reconstruct eroded banks by acting as a retaining wall and the development of a root mass that reinforces the banks. By these means they increase the resilience of streambanks to extreme climatic events. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Strengths	Limitations
➢ A live crib wall requires minimal space. ➢ Provides stability above and below the water surface. ➢ The toe of the slope is stabilised. ➢ Live crib walls can provide a natural habitat for wildlife. ➢ Immediate slope protection is provided. ➢ Can be used instead of gabions or concrete blocks.	➢ The height of the crib wall should not exceed 2 m, and the width should not exceed 6 m. ➢ Should not be used where the integrity of a road or structure is dependent on the crib wall as it is not designed to resist large lateral earth pressure.

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http://riparianhabitatrestoration.ca/575/livecribwalls.htm

http://www.ctre.iastate.edu/erosion/manuals/streambank/live_cribwall.pdf

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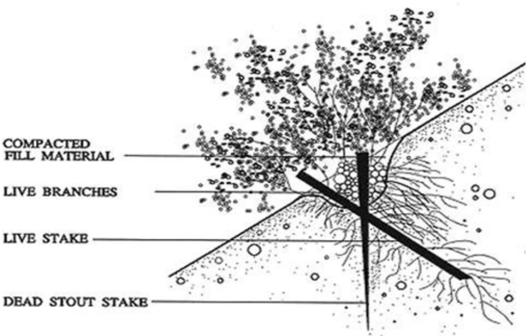
5.4 LIVE FACINES

Application	Bridges, canals, dykes, drainage, industrial areas, road embankments, roads and footpaths, wastewater treatment plants
Description	Live fascines are bundles of dormant, live cuttings bound together in a long, cylindrical form. They are used to protect banks from washout and seepage, particularly at the edge of a stream, where water levels fluctuate moderately. Live fascines are used from the base-flow elevation and up along the face of an eroded bank, acting principally to protect the bank toe and bank face. They are also useful over the crown to improve erosion control, infiltration, and other riparian zone functions. Construction of live fascines is a fairly labour intensive process, however it requires no heavy machinery, which makes it a good option at remote, or inaccessible sites where major earthmoving is not neccesary. Live fascines are planted horizontally, typically level, in order to develop into a terrace as they grow and soil is deposited behind them. The stair-steps formed by these terraces help slow the movement of water down the slope, which reduces its potential to cause erosion. Live fascines are most effective when combined with live staking and riprap, and can also be used in conjunction with many other soil bioengineering techniques.
Contribution to climate resilience	Live fascines are most useful in controlling erosion in weak and unconsolidated materials, where deep gullies might form, and are often used to stabilize long slopes. By these means, they increase the resilience of streambanks to extreme climatic events.



Strengths	Limitations
➢ Immediately reduces surface erosion or riling. ➢ Suited to steep, rocky slopes where digging is difficult. ➢ Capable of trapping and holding soil on the slope face, thus reducing a long slope into a series of shorter steps. ➢ Can manage mild gully erosion and can serve as slope drains when bundles are slightly angled.	➢ Only appropriate on slopes that are not undergoing mass movement ➢ Only appropriate on slopes that are above bankfull (the water level at the top of the bank) discharge levels. ➢ Should not be used in artificially-controlled streams for hydropower.

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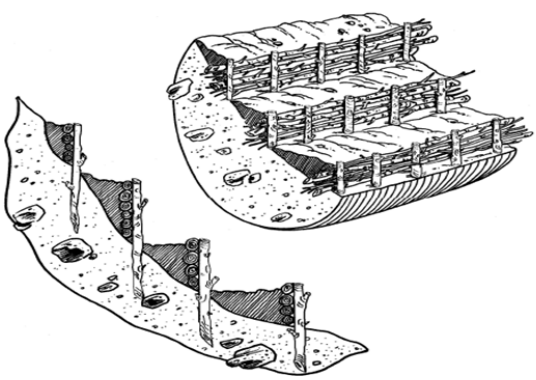
5.5 LIVE FENCING

Application	Bridges, canals, dykes, drainage, industrial areas, road embankments, roads and footpaths, wastewater treatment plants
Description	Live fencing, also called wattle fencing, is a retaining structure installed along the contour of a slope. It is comprised of flexible boards or wattle interwoven between living or dead posts to form a series of narrow terraces across a slope. When placed in shallow trenches across the slope of a bank, these structures provide protection from erosion and create a sediment trap. They can be used to support failing slopes or to reduce slope angles and allow other vegetation to be established. Wattle fences are used for securing dams and slope cuttings. They secure the top soil layer until the area in between is fixed by grasses, forbs, planted trees or bushes that root in deeper layers. Live fences are most effective on lower angle slopes, and on sites with thin soils where excavation would be difficult. They are used where site moisture conditions will allow the living cuttings to sprout and grow. They can also be used to protect the slope toe.
Contribution to climate resilience	Live fences reduce erosion of slopes by reducing slope angles and allowing other vegetation to be established. Because they are constructed using local labour and materials, they can be repaired quicker than traditional civil engineering structures. They also require less energy to produce, are far more sustainable, and can be applied quickly. By these means they increase the resilience of slopes to extreme climatic events. If planned properly and planted at the right time, live fencing can be valuable in preparing for likely changes in climate.




Strengths	Limitations
➢ Living cuttings used to make the walls sprout and grow, further strengthening the structure. ➢ Rooted fences retain and stop moving soil to establish terraces that slow runoff velocity and reduce erosion. ➢ Enhance conditions for native vegetation growth. ➢ Easily combined with other measures.	➢ Easily damaged and therefore insufficient for persistent rockfall. ➢ A labour intensive method.

Sources

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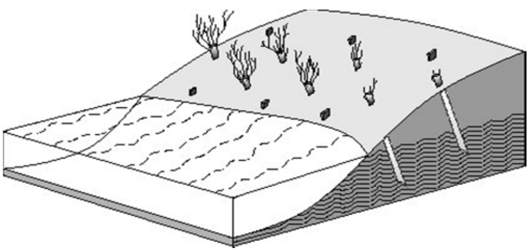
5.6 LIVE STAKING & PALISADE

Application	Bridges, canals, dykes, drainage, industrial areas, road embankments, roads and footpaths, wastewater treatment plants
Description	Live staking and joint planting involves the insertion of woody shrub cuttings into the ground in a manner that allows the cutting (stake) to take root and grow. Live stake cuttings can be used to repair small earth slips and slumps. The stakes can help buttress the soil, and to anchor and enhance the effectiveness of willow wattles, straw rolls, coir rolls, turf reinforcement mats, coir mats, continuous berms and other erosion control materials. A palisade, also called a stake wall, is typically a wall consisting of living uniform stakes of live material driven into the ground, close to each other to form a palisade.
Contribution to climate resilience	Live stakes reduce erosion by stabilizing the streambank through physical reinforcement and formation of a root network. By these means, they increase the resilience of streambanks to extreme climatic events. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can be applied quickly. If planned properly and planted at the right time, live staking can be valuable in preparing for likely changes in climate.



Strengths	Limitations
➢ Stakes can improve aesthetics and provide wildlife habitat. ➢ Staking helps to stabilise and dry out a wet, unstable bank. ➢ Most useful in conjunction with other more complex erosion control methods. ➢ Quickly and easy to build. ➢ Palisades form a strong barrier to reinforce the slope, especially once cuttings have taken root. ➢ Inexpensive where materials are available.	➢ Live staking must be carried out when plants are dormant. ➢ Live stakes provide very little initial site protection during the establishment period, though palisades provide more immediate stabilisation. ➢ Palisades are only effective up to 6 m wide and 24 m long.

Sources

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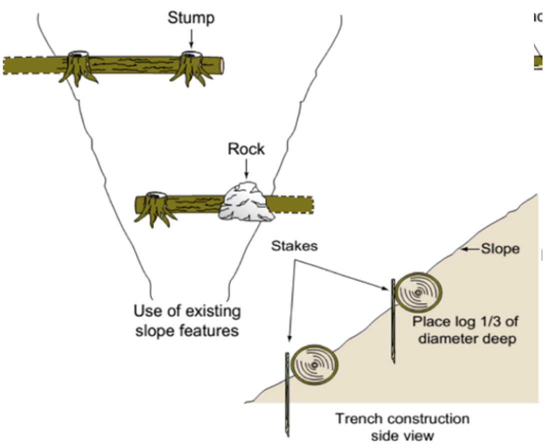
https://www.crd.bc.ca/education/our-environment/concerns/erosion

5.7 LOG TERRACING

Application	Bridges, canals, dykes, drainage, industrial areas, road embankments, roads and footpaths, wastewater treatment plants
Description	Log terraces reduce the length and steepness of slope, as well as providing stable areas for establishment of other vegetation such as trees and shrubs. 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 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	Limitations
➢ Reduces length and steepness of the slope. ➢ Provides stable areas for establishment of other vegetation such as trees and shrubs. ➢ Provides immediate slope stabilisation and helps to store sediment.	➢ Implementing log terracing is labour intensive. ➢ It can pose possible safety hazards due to the use of logs on a slope.

Sources

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http://www.blm.gov/or/programs/nrst/files/Soil%20bioeng.pdf

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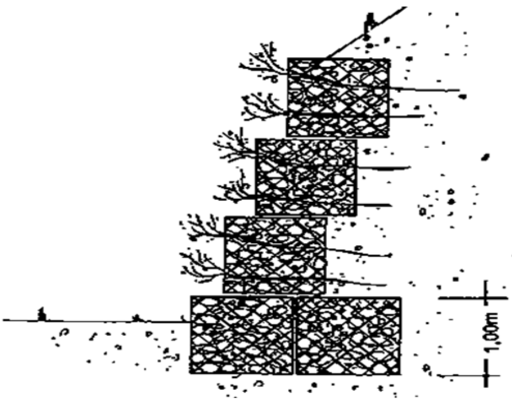
5.8 VEGETATED GABIONS

Application	Bridge abutments, canals, culverts and drains, dykes, floodgates, parking areas, residential areas, river and road embankments, stormwater outfall
Description	A gabion is a rectangular basket made of heavily galvanized wire mesh filled with small to medium size rocks. Combinations of gabions are intertwined with deep-rooted living branches to provide stabilisation at the base of steep slopes or river embankments. The gabion is a geotextile, either natural (jute), or synthetic (wire) that serves to hold soil and/or rocky backfill in place until roots from live cuttings can grow. The gabions are laced together and installed at the base of a bank to form a structural toe or sidewall. Gabions are used to stop undercutting and/or scouring at the base of steep slopes. Live cuttings are placed on each gabion layer.
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 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	Limitations
➢ Fast and simple construction. Can be installed without special skills or equipment. ➢ Useful on steep slopes where grading is not possible. ➢ Can withstand higher shear stress. ➢ Gabions adjust to stresses and soil settlements. ➢ Simple field maintenance is feasible without the use of heavy equipment. ➢ Elastic structure with multi-purpose use – can be combined with other measures. ➢ No danger of water impoundment, used also for wet sites with fine soil material. ➢ Used for unstable slopes endangered by erosion, especially along streams or in debris areas.	➢ When the baskets are not completely filled, flexing occurs, which leads to wire fatigue and eventual failure. ➢ Vegetating after the construction of the gabion is difficult. ➢ Vegetated gabion construction is height restricted.

Sources

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http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/cetn-iii-31.pdf

5.9 VEGETATED GEOTEXTILES

Application	Bridges, canals, commercial area redevelopment, culverts and drains, dykes, floodgates, industrial areas, markets, parking areas, port redevelopment, residential areas, river and road embankments, roads and footpaths, stormwater outflow
Description	A geotextile is a permeable textile material made of natural or synthetic fibres that is used with foundation, soil, rock and earth to increase stability and decrease wind and water erosion. Geotextiles are designed to be permeable to allow the flow of fluids through or within them. Natural fibre geotextiles are more environmentally friendly, but they degrade faster and have a shorter shelf life. Woven geotextiles are generally preferred where high strength properties are needed, but where filtration requirements are less critical and planar flow is not a consideration. Live cuttings can be placed between geogrids, and root structure is established to bind the soil within and behind the geogrids. The toe of the bank is stabilised by placing a layer of rock on top of the fabric. Plant growth and the penetration of these textiles by roots or shoots depend on the characteristics of the geotextile (pore diameter, thickness, structure, etc.); site conditions (climate, altitude, exposure, precipitation, moisture, nutrients); and plant characteristics. The selection of geotextile will depend on the slope of area to be secured; soil characteristics; weathering factors until overgrowth occurs; type of vegetation; time of planting; and the duration until the development of a root-system occurs.
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	Limitations
➢ Live cuttings provide rapid vegetation growth, which slows water during high water stages. ➢ Quick and effective protection against erosion. ➢ Slows rill and gully erosion and stabilizes fill banks. ➢ A wide variety of geotextile products are available to match specific needs.	➢ Can be labour intensive and expensive depending on the choice of geotextile material. ➢ Require numerous stakes or live stems to hold the geotextile blanket in place. ➢ When placing live cuttings in the geogrid, plants must be installed during their dormant season in order for them to properly take root.

Sources

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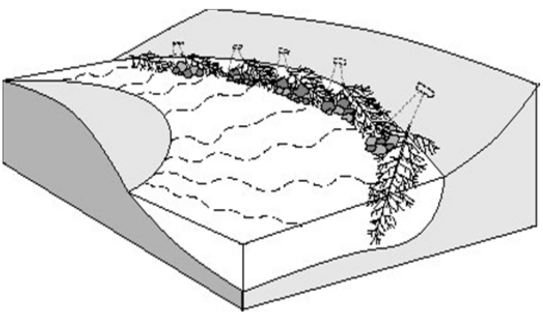
http://www.ctre.iastate.edu/erosion/manuals/streambank_erosion.pdf

5.10 VEGETATED REVETMENTS

Application	Canals, culverts and drains, dykes, floodgates, river embankments, stormwater outflow
Description	Revetments are sloping structures placed on banks or cliffs to reduce slope erosion by absorbing energy and reducing velocity or water, capturing sediment, and enhancing conditions for planting or colonization of native species. The lower portion of an eroding bank is stabilised by burying or securing non-erosive materials below and slightly above the waterline. Natural stabilisation materials include logs, trees, root wads, and boulders. Footer boulders or logs are installed at the base parallel to the streambank. Boulders can be used to anchor the footer log. Trenches excavated into the streambank allow root wads to face slightly toward the direction of the flow so that brace roots can be flush with the streambank.
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 constructed with local labour and materials, they require less energy to produce, are sustainable, and can be applied in as quick a timeframe as traditional civil engineering works.



Strengths	Limitations
➢ Reduced erosion and shear stress along banks. ➢ Established root systems help strengthen soil behind the bank. ➢ Lowered stream temperatures. ➢ Decreased stream velocity. ➢ Increased habitat for aquatic and other wildlife.	➢ Vegetation incorporated into the revetment must be planted at medium density to avoid excessive sediment deposition and projection into the stream. ➢ This measure should not be used near bridges or other structures where there is a potential for downstream damage if a revetment dislodges. ➢ Limited application to non-flashy streams where the needs for future maintenance are not important.

Sources

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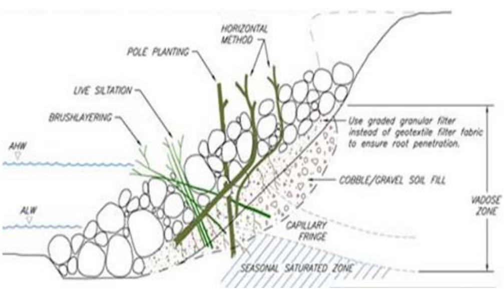
5.11 VEGETATED RIPRAP

Application	Canals, culverts and drains, dykes, floodgates, river embankments, stormwater outflow
Description	Vegetated riprap comprises a combination of rock and native vegetation in the form of live cuttings. This combination of biological and technical shore protection techniques allows excellent waterside erosion protection with natural scenic beauty similar to biological shore protection. 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. Five methods for constructing vegetated riprap that have proven effective are: vegetated riprap with willow bundles; vegetated riprap with bent poles; vegetated riprap with brush layering and pole planting; and vegetated riprap with soil cover, grass and ground cover and joint or live stake planted riprap.
Contribution to climate resilience	Vegetated riprap prevents bank erosion by protecting the surface and strengthening the slopes. It also increases the resilience of local communities to drought by creating a habitat for fish (a source of food alternative to agriculture), and supplying fodder for local livestock. Because they are constructed with local labour and materials, they require less energy to produce, are more sustainable, and can be applied in as quick a timeframe as traditional civil engineering works.



Strengths	Limitations
➢ Resists hydraulic forces, increases geotechnical stability, and prevents soil loss. ➢ Creates habitat for both aquatic and terrestrial wildlife. Provides shade and improves aesthetic and recreation. ➢ Roots, stems, and shoots will help anchor the rocks and resist 'plucking' and gouging by debris.	➢ Installing plants that can survive various submersions during the normal cycle of low, medium, and high stream flows is critical to the success of vegetative riprap.

Sources

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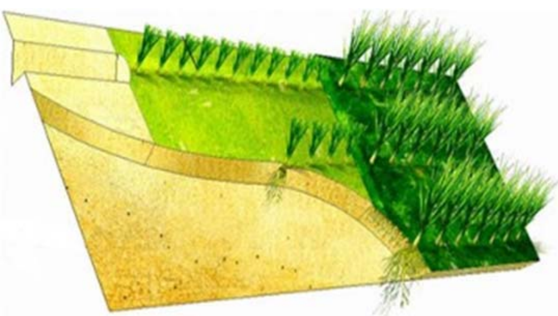
http://dev.sustainabletechnologies.ca/wp/wp-content/uploads/2013/01/Pierre_Raymond_Vegetated-Riprap-Installation-Techniques-Mar-28-2012.pdf

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

5.12 VETIVER GRASS COVERAGE

Application	Bridges, canals, culverts and drains, drainage, floodgates, industrial areas, port development, residential areas, river and road embankments, stormwater outfall
Description	Vetiver grass (*Chrysopogon zizanioides)* is planted as a hedgerow across a slope to form a very dense vegetative barrier that slows and spreads rainfall runoff and provides significant soil reinforcement through its roots. Combined with a deep and strong root system, a wide range of pH tolerance, a high tolerance to most heavy metals, an ability to remove nitrates, phosphates and farm chemicals from soil and water, the vetiver plant can be used for soil and water conservation, engineered construction site stabilization, pollution control (constructed wetlands), and other functions where soil and water come together. Vetiver originates from South India, is sterile, non-invasive and has to be propagated by clump subdivision. It is a low cost, labour intensive technology. When used for civil works protection its cost is about 1/20 of traditional engineered systems and designs. Engineers liken the vetiver root to a "living soil nail" with an average tensile strength of 1/6 of mild steel.
Contribution to climate resilience	The planting of vetiver grass reduces erosion by protecting the soil from the impact of intense rainfall, slowing run-off, facilitating water absorption and strengthening the soil with its roots. By these means it increases the resilience of roadside slopes to extreme climatic events. Because it is planted using local labour and materials, it requires less energy, is far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Strengths	Limitations
➢ Will not turn into an invasive species or weed. ➢ Detoxifying capacity helps clean toxic areas. ➢ Drought and frost tolerant, can withstand brief periods of submergence. ➢ Requires little maintenance once the hedge is established.	➢ Vetiver is intolerant to shade, especially in its establishment phase. It must be grown in full sun to be successful.

Sources

http://www.vetiver.org

http://www.vetiversystems.co.nz/

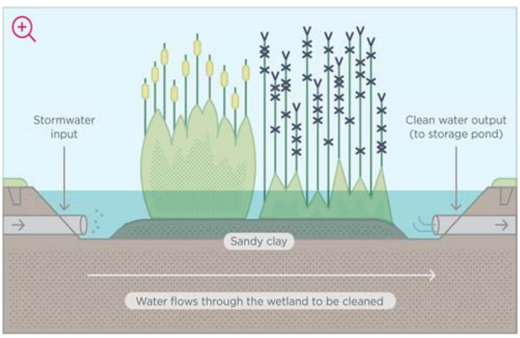
http://www.betuco.be/coverfodder/Vetiver%20System%20%20-Technical%20reference%20manual%202007.pdf

6. WATER AND FLOOD MANAGEMENT

Managing water runoff, storage and flood risk is an important aspect of any transport infrastructure. Measures described in this section are best used in combination to maximise benefits. The below matrix indicates which measures in this section are complementary, a red box highlights two measures that are suitable to be used together. Water and flood management is also a critical aspect of urban adaptation and therefore all of these measures are applicable in Part C, and can be used in combination with many of the further measures described there.

6.1 CONSTRUCTED WETLANDS

Application	Commercial redevelopment areas, drainage, industrial areas, markets, residential areas, roads and footpaths, stormwater outfall, wastewater treatment
Description	A constructed wetland is an artificial wetland created as a new or restored habitat for native and migratory wildlife, for discharge such as wastewater, stormwater runoff, or sewage treatment, and for land reclamation in natural areas impacted by development. They are generally built on seriously degraded wetlands or new areas where there are problems with drainage and water quality. They can substitute for conventional stormwater and grey water treatment plants. Wetlands are frequently constructed by excavating, backfilling, grading, diking and installing water control structures to establish desired hydraulic flow patterns. They consist of shallow (usually less than 1 m deep) ponds or channels that have been planted with aquatic plants. Nutrients, such as nitrogen and phosphorous, are deposited into wetlands from stormwater runoff, from areas where fertilizers or manure have been applied and from leaking septic fields. These excess nutrients are often absorbed by wetland soils and taken up by plants and microorganisms.
Contribution to climate resilience	Constructed wetlands reduce the impacts of floods by retaining large volumes of water and then discharging it slowly. They also provide wastewater treatment services, and can be used by humans, livestock and wildlife as a source of water during drought.



Strengths	Limitations
➢ Cost-effective water treatment. ➢ Provides food and habitat for wildlife. ➢ Improves water quality. ➢ Aesthetically pleasing. Offers flood protection, drought relief and opportunities for recreation.	➢ Constructed wetlands appear simple but are complex to design and require on-going management.

Sources

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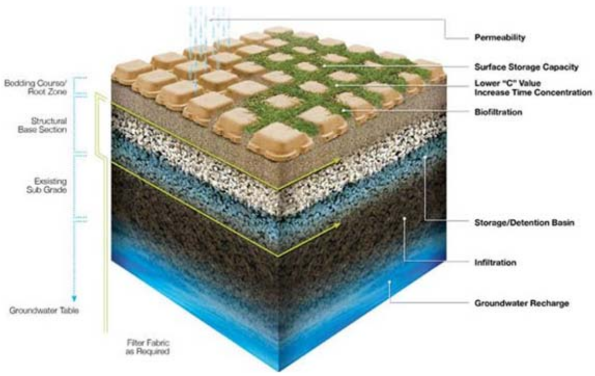
6.2 PERMEABLE PAVING

Application	Buildings, commercial redevelopment areas, drainage, industrial areas, markets, parking areas, port redevelopment, residential areas, roads and footpaths
Description	Permeable pavements are a method of paving that allows stormwater to seep into the ground as it falls rather than into stormwater drains or waterways. They infiltrate, treat, and/or store rainwater where it falls to stop stormwater from pooling and flowing away; help recharge underlying aquifers; reduce peak flows and flooding; and prevent erosion. They may be constructed from pervious concrete, porous asphalt, permeable interlocking pavers, and several other materials. Permeable pavements function similarly to sand filters in that they filter the water by forcing it to pass through different aggregate sizes and filter fabric. As precipitation falls on the pavement it infiltrates down into the storage basin where it is slowly released into the surrounding soil.
Contribution to climate resilience	Permeable pavements absorb stormwater and permit its movement into the soil below. By reducing surface run-off, they contribute to groundwater recharge and reduce flood flows. They also improve the quality of the water before it enters the soil by trapping suspended solids and pollutants. This approach ensures 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	Limitations
➢ Increase road safety and durability by increasing skid resistance, preventing water splash and spray from passing vehicles, and reducing noise. ➢ Reduces flooding during storm events. ➢ Stormwater pollutants are broken down in the soil instead of being carried to surface waters. ➢ Allows water seepage to groundwater recharge. ➢ Helps prevent stream erosion problems. ➢ Takes pressure off existing drainage and stormwater management systems. ➢ Securing high visibility at the time of rain. ➢ Water quality improvement: pollutants are captured during infiltration thus reducing the pollutant load in local waterways.	➢ Permeable paving is only suitable for areas of light vehicle traffic such as parking lots, road shoulders, sidewalks, and driveways.

Sources

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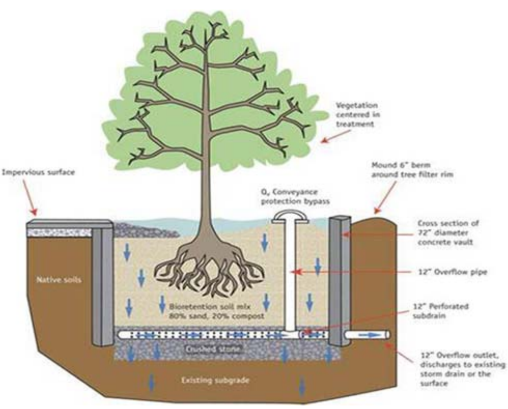
https://extension.umd.edu/sites/default/files/_docs/programs/master-gardeners/Howardcounty/Baywise/PermeablePavingHowardCountyMasterGardeners10_5_11%20Final.pdf

6.3 STORMWATER TREE PITS

Application	Buildings, commercial redevelopment areas, drainage, industrial areas, markets, parking areas, residential areas, roads and footpaths
Description	This technology entails above-ground vegetation with an underground structure that works to collect and treat stormwater using bio-retention. Treated stormwater then infiltrates into the ground or, if infiltration is not appropriate, discharges into a traditional stormwater drainage system. Stormwater, or bioretention, tree pits are set into the kerb to intercept and clean stormwater that runs off road surfaces into gutters before it goes into the drain. Ideally, they are used in conjunction with other stormwater best-management practices. Their usefulness is enhanced with greater soil volume and by connecting individual pits with trenches.
Contribution to climate resilience	Stormwater tree pits collect and filter stormwater before it percolates into the soil below or flows into stormwater drainage systems. By reducing surface run-off, they contribute to groundwater recharge and reduce flood flows. By trapping suspended solids and pollutants, they also improve the quality of the water before it enters the soil or drainage system. 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	➢ Limitations
➢ Reduces stormwater runoff volume, flow rate and temperature. ➢ Increases groundwater infiltration and recharge. ➢ Treats stormwater runoff. ➢ Improves quality of local surface waterways. ➢ Improves aesthetic appeal of streets and neighbourhoods. ➢ Provides wildlife habitat. ➢ Requires limited space. ➢ Simple to install.	➢ 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.

Sources

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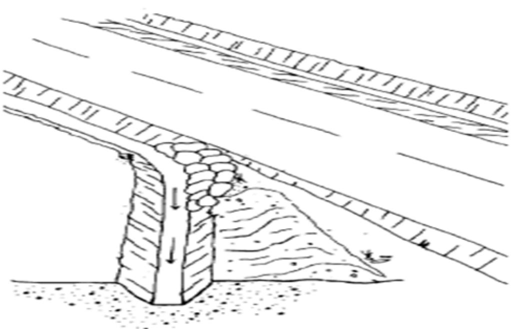
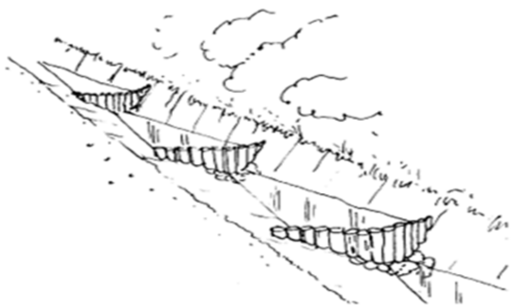
6.4 EROSION CONTROL MEASURES FOR ROADS AND DRAINS

Application	Bridges, culverts and drains, highways, roads and footpaths
Description	Roads invariably intercept natural streams and rivers and redirect rainwater flows. Construction of roads thus requires cross-drainage structures (bridges, culverts and floodways) to safely convey water from one side of a road to the other. Overland flow of rainfall runoff also needs to be collected and safely conveyed to a point at which the water can enter a stream or other safe outlet (e.g., a natural pond). The handling of stream flow and rainfall runoff needs to be given careful consideration during the design phase to avoid erosion. The outlets of cross-drainage structure are critical points of critical erosion potential because it is here where the velocity of flowing water will be highest. Examples of erosion protection measures are shown in the photos below. Where drainage flow exits from or enters a culvert, the velocity of flow will be relatively high. To prevent erosion at such locations, it is often necessary to line the channel within the location of maximum flow velocity. Aprons constructed using rock-filled gabion mattresses can be installed at these outlets to absorb energy, calm turbulence and reduce the velocity of the discharged flow. Continuation of the gabion lining of bed and banks may be necessary for some distance before the drainage channel can be transitioned back to a natural earth channel. The side drain located on the uphill side of a road collects rainwater runoff and conveys it to a cross-drainage culvert or bridge installed in the road formation. Side drains tend to increase the peak flow at such structures by providing a more hydraulically efficient channel than occurs in nature. Hence it is common practice to reduce the velocity of flow by widening the side drain. However, a better way to reduce flow velocity and control erosion is by reducing the amount of water flowing in the side drain. This can be achieved by diverting a part of the flow to surrounding natural land using mitre drains – open drains designed to divert water away from the main channel of the drain. Another method to control erosion is to include check structures in the side drains. These are particularly beneficial in hilly terrains where steep drains would otherwise be vulnerable to erosion and where the terrain may preclude the use of mitre drains. Mitre

	drains (figure below, left) control erosion by reducing the amount of water flowing through the outlet drain, while check structures (figure below, right) control erosion by reducing the velocity of flow in steep drains. The gabions stabilize soil sufficiently for natural vegetation to re-establish. In time, much of the channel will be covered in vegetation and regain a pleasing, natural appearance. Furthermore, the network of plant roots provides additional erosion protection.
Contribution to climate resilience	The above-mentioned erosion control measures make roads and nearby structures more resilient to increased rainfall and flooding anticipated with climate change.



Mitre drain



Scour check

Strengths	Limitations
➢ Trapezoidal channels are suitable for drainage flow because they closely resemble the shape of natural streams. ➢ They are well adapted to lining with gabion mattresses. ➢ Trapezoidal drains perform well even when submerged since downstream conditions restrict the free flow of water out of the drain.	➢ Although these drains are designed to operate under a wide range of conditions, it is important to put in place an effective program for routine and periodic maintenance to ensure continued functioning at all times, particularly with respect to blockages caused by sediment or debris.

Sources

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C URBAN INFRASTRUCTURE

7. INTRODUCTION

Complex urban systems make securing public works and transport infrastructure more difficult, but the opportunity also exists for using green infrastructure across sectors to link together actions and benefits. Urbanisation has also reduced wildlife, as green spaces often exist in isolation from each other, meaning that some species are unable to move between them. This can eventually lead to some species being lost from these green spaces, to the detriment of the local ecosystem and the human population. The measures described in this section are multi-use and can, and should, be used in combination with those described in the previous section (see Infrastructure Matrix in Part A) to maximise co-benefits.

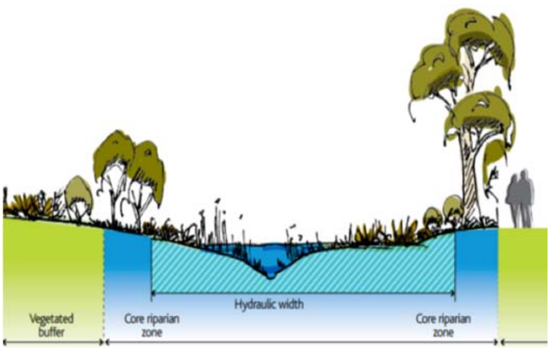
Green roofs for instance, contribute to the reduction of greenhouse gas emissions and the urban heat island affect, but they also help to increase biodiversity, improve aesthetics and community pride, while also reducing surface water runoff. These benefits impact multiple sectors, making it important to ensure green infrastructure measures are considered first in the planning process.

8. WATER AND FLOOD MANAGEMENT

Maximising the opportunities and benefits available from surface water management generally requires managing and using rainwater close to where it falls. The capture, storage and use of water using green infrastructure measures provide water and flood management, pollution management, and many other complementary services. The water and flood management measures described in Part B are also appropriate for urban infrastructure. Furthermore, many measures that are categorised in this guide as pollution management measures, such as bioswales, are also important for water management. Bioswales and bioretention ponds slow the flow of water and store and treat the runoff, while draining it through the site and encouraging biodiversity, which has numerable additional benefits.

8.1 DRAINAGE CORRIDORS

Application	Canals, drainage, stormwater outfall
Description	A drainage corridor consists of a waterway and its surrounding area that is 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 to 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 the climate changes.



Strengths	Limitations
➢ Improved drainage during minor and major storms. ➢ Reduced flooding. ➢ Natural drainage corridors help direct stormwater flows, thus reducing flooding in built and residential areas. ➢ Natural stormwater and pollution filtration. ➢ Increased habitat for native plant and animal species. ➢ Improved flow, which reduces stagnant water and associated odour and disease vectors.	➢ Natural drainage corridors require sufficient land allocation, and 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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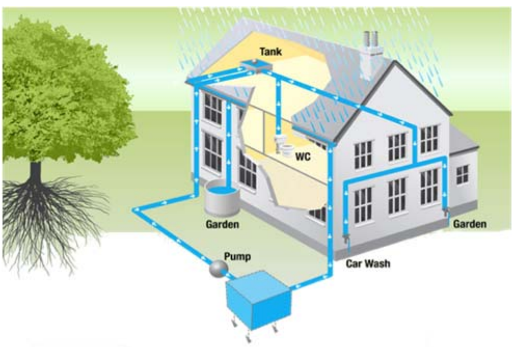
8.2 RAINWATER HARVESTING

Application	Buildings, commercial development areas, industrial areas, markets, parking areas, port development, residential areas
Description	Rainwater harvesting is the use of various technologies to collect and store rainwater from rooftops, the land surface, or rock catchments using simple techniques such as jars and pots as well as more complex techniques such as underground check dams. The harvested water can be used as drinking water, for domestic needs, and for irrigation. It can be implemented both at a rural and urban level. It is a traditional method that can be traced back to the 9th century in Asia, when small-scale collection of rainwater from roofs and simple brush dam constructions took place.
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	Limitations
➢ Simple technologies that do not require skilled manpower to install and operate. Locals can be easily trained to implement such technologies, 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. ➢ An accessible replacement for groundwater. ➢ Reduces pollutants and flow into surrounding surface waters. ➢ Serves as a backup water supply during emergencies and natural disasters. ➢ Reduces size of traditional stormwater management practices.	➢ In case of rooftop harvesting, the rooftops should be constructed of chemically inert materials such as wood, tiles, aluminium, or fiberglass, and cleaned regularly to avoid adverse effects on water quality.

Sources

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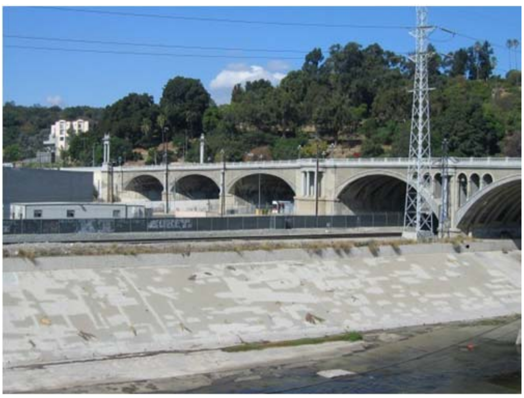
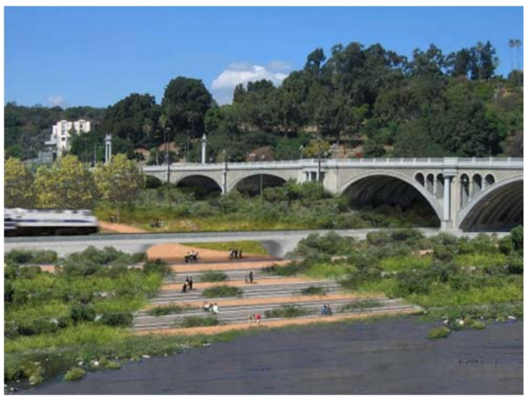
http://www.akvopedia.org/wiki/Rooftop_rainwater_harvesting
http://water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm#rainwaterharvesting

8.3 URBAN RIVER TERRACING

Application	Canals, commercial redevelopment areas, road embankments, 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 floodplain is widened and deepened, allowing it to fill during rain events and preventing stormwater 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 stormwater 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 changes.





Strengths	Limitations
➢ Reduced flood risk in inhabited areas. ➢ Increased ecological functions such as water filtration. ➢ Fish, bird, and wildlife habitat. ➢ Recreational and tourism opportunities.	➢ Urban river terracing can require large investments to dredge and stabilise the area.

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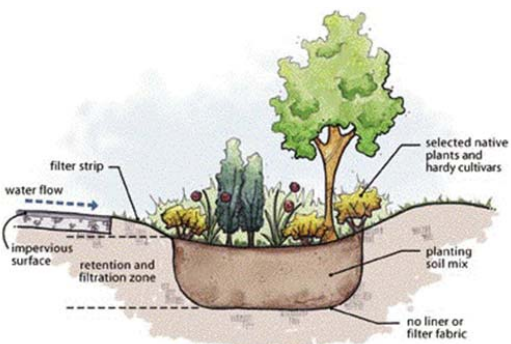
9. POLLUTION MANAGEMENT

9.1 BIORETENTION POND

Application	Bridge abutments, buildings, commercial area redevelopment, drainage, industrial areas, markets, parking areas, port redevelopment, residential areas, roads and footpaths, stormwater outfall, wastewater treatment plants
Description	A bioretention pond is a shallow planted depression designed to retain or detain storm water before it is infiltrated or discharged downstream. Bioretention basins retain, filter and treat stormwater runoff using a shallow depression of conditioned soil topped with a layer of mulch or high carbon soil layer and vegetation tolerant of short-term flooding. 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. Improved management of water is one of the best ways to improve resilience to likely changes in climate.



Strengths	Limitations
➢ Provide a variety of pollutant removal mechanisms, including filtration, adsorption to soil particles, and biological uptake by plants. ➢ Provide storm water peak flow and volume control as well as water quality control where stormwater infiltration is used. ➢ Reduces temperature impacts of runoff.	➢ Bioretention areas should only be used on small sites (i.e., five acres or less) as larger ponds tend to clog.

Sources

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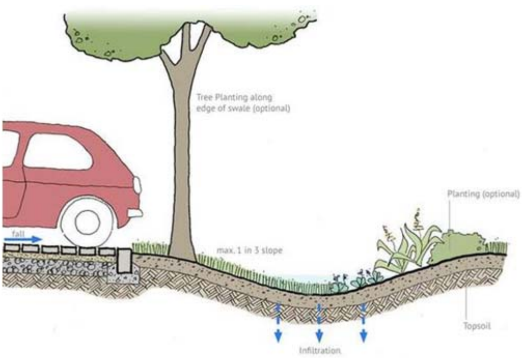
http://www.leesburgva.gov/modules/ShowDocument.aspx?documentid=5057

http://www.fxbrowne.com/html/gs-facts/gs-factsheet05v9.pdf

9.2 BIOSWALES

Application	Bridge abutments, buildings, commercial area redevelopment, drainage, industrial areas, markets, parking areas, port redevelopment, residential areas, roads and footpaths, stormwater outfall, wastewater treatment plants
Description	Bioswales are vegetated channels designed to remove silt and pollution from surface runoff water. The water's flow path, along with the wide and shallow ditch, is designed to maximise the time water spends in the swale, which aids the trapping of pollutants and silt. Depending upon the land available, a bioswale may have a meandering or almost straight channel. A common application is around parking lots, where substantial automotive pollution is collected by the pavement and then flushed by rain. The bioswale wraps around the parking lot and treats the runoff before releasing it to the watershed or storm sewer. Bioswales may be designed to contain check dams that facilitate pond formation, further increasing infiltration and decreasing storm water flows.
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. Improved management of water is one of the best ways to improve resilience to likely changes in climate.



Strengths	Limitations
➢ Traps and breaks down common pollutants. ➢ Improves water quality in surrounding water bodies. ➢ Reduces stormwater runoff rates and flood prevention. ➢ Increased green space and aesthetic appeal. ➢ Recharges surrounding groundwater. ➢ Provides habitat for aquatic and other wildlife.	➢ A bioswale is primarily a conveyance system and must be designed to transport water of a specific storm severity without flooding.

Sources

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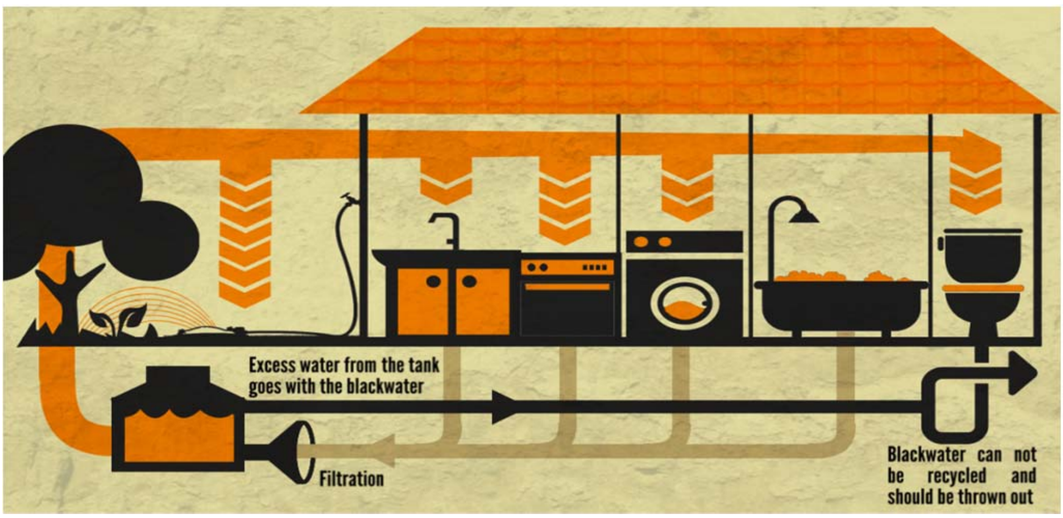
9.3 GREYWATER RECYCLING

Application	Buildings, commercial area redevelopment, industrial areas, markets, port redevelopment, residential areas, and wastewater treatment plants
Description	Grey water 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 outside taps. The easiest way to use grey water is to pipe it directly outside and use it to water decorative plants or fruit trees, or to clean pavements, cars, and dust. Grey water recycling systems have been successfully adapted to suit large commercial buildings such as hotels and even industrial plants. Unlike a rainwater harvesting system, which relies on rainfall, grey water is replenished daily.
Contribution to climate resilience	Greywater recycling increasing the availability of fresh water for consumption and agriculture by reducing the demand for it for other uses (toilets, washing machines, pavement cleaning, etc.). Greywater recycling is also more reliable than rainwater harvesting, but does require a steady supply of fresh water. Improved management of water is one of the best ways to improve resilience to likely changes in climate.



Strengths	Limitations
➢ Keeps dirty water from polluting sensitive ecosystems. ➢ Grey water can be used to enhance nearby wetlands. ➢ Reduces demand on municipally supplied freshwater. ➢ Reduces strain on water treatment plants. ➢ Provides water for groundwater recharge. ➢ Reduces cost and energy required to pump municipal water.	➢ Grey water recycling produces water for non-potable uses. Grey water can be used for irrigation, but it should not touch edible parts of the plant.

Sources

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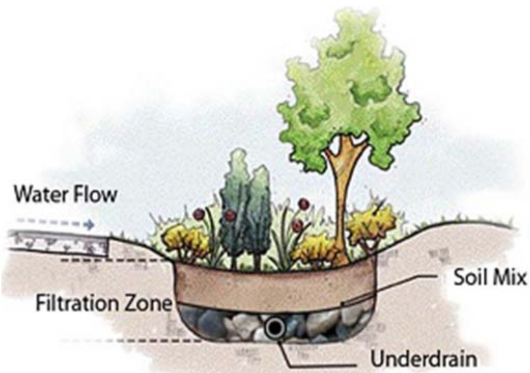
http://www.whollyh2o.org/graywater/item/348-uses-and-benefits-of-graywater.html

9.4 RAIN GARDENS

Application	Buildings, commercial area redevelopment, drainage, industrial areas, markets, parking areas, residential areas, stormwater outfall
Description	A rain garden detains rainfall and stormwater runoff to slow flow, reduce pollution and increase infiltration. Usually, it is a small garden designed to withstand the extremes of moisture and concentrations of nutrients, particularly nitrogen and phosphorus, which are found in stormwater runoff. Rain gardens are ideally located close to the source of the runoff and serve to slow the stormwater as it travels downhill, giving it more time to infiltrate and less opportunity to gain momentum and erosive power.
Contribution to climate resilience	A rain garden cleans stormwater, thus improving water quality for nearby waterbodies. 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	Limitations
➢ Keeps dirty water from polluting sensitive ecosystems. ➢ Greywater can be used to enhance nearby wetlands. ➢ Reduces demand on municipally supplied freshwater. ➢ Less strain on water treatment plants. ➢ Provides water for groundwater recharge. ➢ Reduces cost and energy required to pump municipal water.	➢ Water should only pool for a maximum of a few hours to protect plant species and prevent the formation of mosquito breeding ground.

Sources

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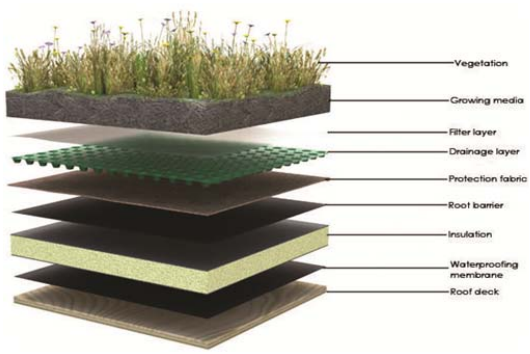
10. ENERGY, HEAT & GREEN HOUSE GAS MANAGEMENT

10.1 GREEN ROOFS AND WALLS

Application	Bridge abutments, buildings, commercial area redevelopment, drainage, industrial areas, markets, parking areas, port development, residential areas, roads and footpaths, wastewater treatment plants
Description	A green roof system is an extension of the existing roof which involves a high quality waterproofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants. Green roofs are particularly cost effective in dense urban areas where land values are high and on large industrial or office buildings where stormwater management costs may be high. They can be as simple as a 5 cm covering of hardy groundcover or as complex as a fully accessible park complete with trees. Through the dew and evaporation cycle, plants are able to cool cities and reduce the Urban Heat Island effect: the light absorbed by vegetation would otherwise be converted into heat energy. On hot days, the surface of a green roof can be cooler than the air temperature, while the surface of a conventional rooftop can be up to 50°C warmer.
Contribution to climate resilience	Green roof systems mitigate the impact of storms by reducing and delaying stormwater runoff. They also reduce energy used for air conditioning by reducing city air temperature, thus in a small way mitigating the temperature increases expected from climate change. The systems also contribute to climate change mitigation by acting as carbon sinks.



Strengths	Limitations
➢ Retains rainwater, moderates water temperature, and acts as natural filters. ➢ Reduces and delays stormwater runoff. ➢ Captures airborne pollutants and filters noxious gases. ➢ Increased green space. ➢ Insulates buildings and moderates building temperature. ➢ Provides wildlife habitat. ➢ Reduced greenhouse gases	➢ The additional mass of the soil substrate and retained water places a large strain on the structural support of a building.

Sources

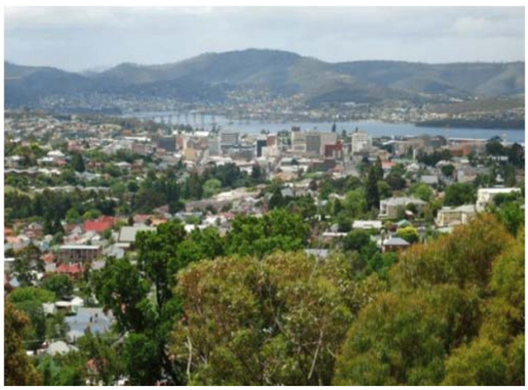
http://water.epa.gov/infrastructure/greeninfrastructure/gi_what.cfm#greenroofs

http://www.greenroofs.org/index.php/about/aboutgreenroofs

http://www.epa.gov/heatisland/mitigation/greenroofs.htm

10.2 URBAN TREE CANOPY

Application	Buildings, commercial area redevelopment, industrial areas, markets, parking areas, port redevelopment, road embankments, roads and footpaths
Description	The urban tree canopy is the layer of leaves, branches, tree trunks and shrubs, including those in parks, streets, ravines and private properties that cover the ground when viewed from above. Tree cover can mitigate climate change by reducing the levels of greenhouse gases in the atmosphere, and help to reduce the Urban Heat Island effect. A tree is a natural air conditioner. The evaporation from a single tree can produce the cooling effect of ten room-size, residential air conditioners operating 20 hours a day. Ideally, a city should maintain a tree canopy cover of 35-40%.
Contribution to climate resilience	Urban tree canopy reduces city air temperature, thus mitigating temperature increases expected from climate change and reducing energy consumed for air conditioning. By intercepting and using rainwater, trees help to reduce flooding and stress on urban drainage. They also contribute to climate change mitigation by reducing the levels of greenhouse gases in the atmosphere.



Strengths	Limitations
➢ Reduced greenhouse gases, improved air quality. ➢ Lowers temperatures in streets and in buildings under shade by reducing solar radiation reaching the ground. ➢ Reduced cooling costs in residential and commercial buildings. ➢ Filters particles and pollution from the air and prevents pollutants from entering water supply during rain events. ➢ Provides wildlife habitat. ➢ Creates green public spaces for local people and tourists. ➢ Trees intercept and store rainwater, relieving stress on storm water systems and reducing flooding.	➢ Trees and shrubs require maintenance. Failing to maintain trees can lead to interference with other infrastructure like electricity line and building foundations.

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