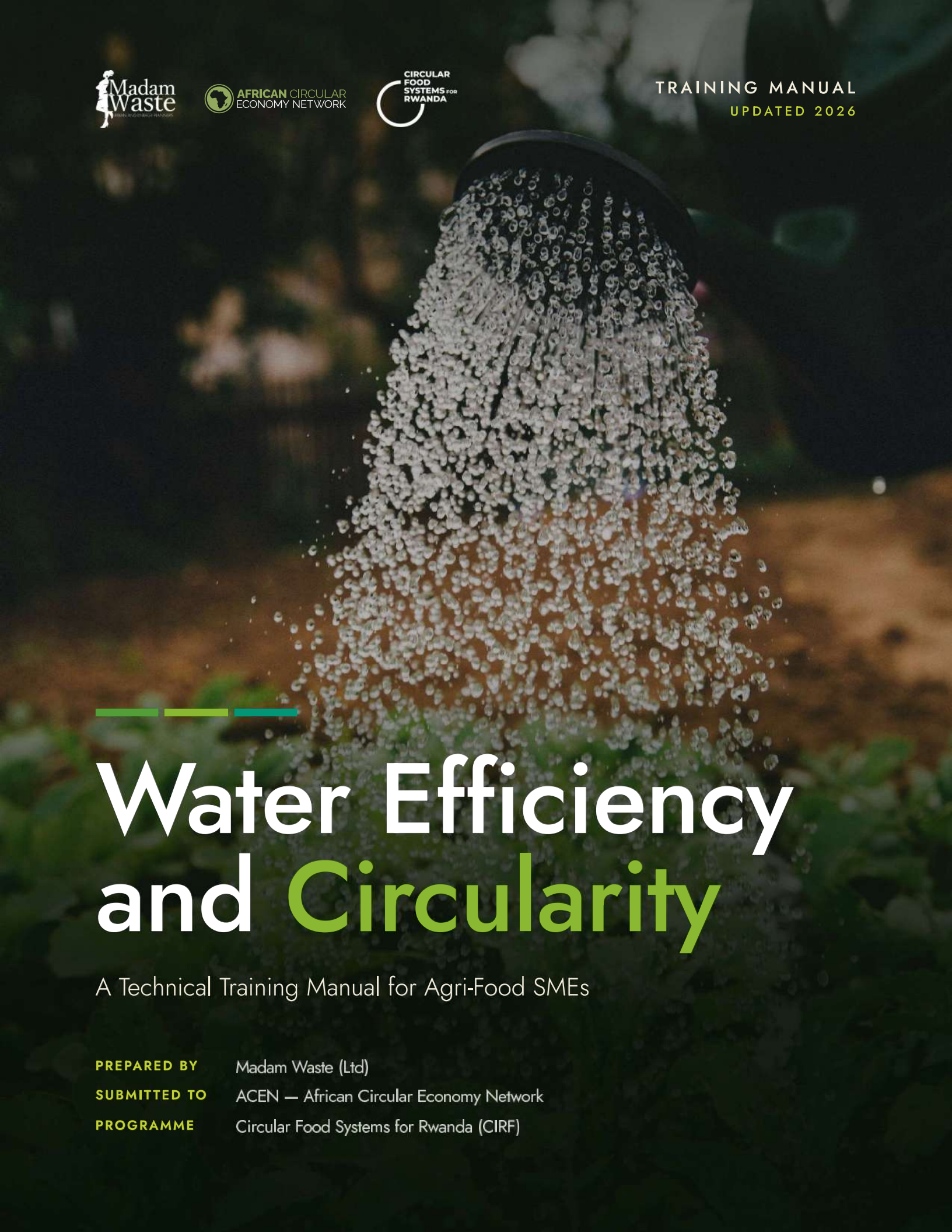


TRAINING MANUAL
UPDATED 2026

Water Efficiency and Circularity

A Technical Training Manual for Agri-Food SMEs

PREPARED BY Madam Waste (Ltd)

SUBMITTED TO ACEN — African Circular Economy Network

PROGRAMME Circular Food Systems for Rwanda (CIRF)

About This Manual

As part of the Circular Food Systems for Rwanda (CIRF) programme — a four-year initiative funded by the IKEA Foundation to accelerate the transition to circular agri-food systems in Rwanda — specialized Technical Assistance Providers (TAPs) were engaged to deliver tailored, on-the-ground support to participating small and medium enterprises (SMEs). TAPs conducted Gap and Needs Assessments with each SME to identify circular economy opportunities specific to their business, and used these findings to customise solutions that enhance circularity while empowering staff and highlighting the economic benefits of adopting circular practices.

For one agri-based SME operating in a peri-urban setting, **water efficiency was identified as a critical circular economy need**. Water is not simply an input — it is a resource whose efficient management directly underpins circularity across the entire agri-food system. Improving how water is captured, treated, and redistributed reduces waste, lowers costs, supports soil health, and strengthens a farm's resilience to climate variability. Specifically, water efficiency supports circular economy principles by:

- **Minimising water usage** and reducing dependency on external or conventional water sources.
- **Mitigating water scarcity** through storage, reuse, and smart distribution.
- **Promoting ecological balance** by reducing runoff, erosion, and nutrient pollution.
- **Enabling resource recovery —** treated wastewater can be safely returned to agricultural or livestock use, closing the loop on water as a resource.
- **Creating economic value** through cost savings on water procurement and energy.

This manual is designed to be **practical and hands-on**, with tangible examples, step-by-step guidance, and ready-to-use frameworks. While it was originally developed for a specific SME context, it has been refined here for use by any agri-based SME or practitioner working to improve water management and circularity on their farm or operation.

Sections

§	TOPIC	WHAT IT COVERS
1	**Rainwater Harvesting**	What rainwater harvesting is, types of systems, step-by-step planning and installation guidance, and maintenance.
2	**Bio-remediation to Clean and Recirculate Water**	How bio-remediation works, techniques for treating contaminated water, and preparing treated water for agricultural or livestock use — including the use of Aquatabs for purification.
3	**Circular Reticulation Systems and Smart Monitoring**	Components of a circular water reticulation network, how the Chameleon soil moisture sensor works, and additional tools including the hydraulic ram pump and fish species for mosquito management.
4	**Constructing Swales**	What swales are, step-by-step construction guidance, planting recommendations, and their role in water retention and soil health.
5	**Modern Water Management Techniques**	Overview of integrated water resource management, smart irrigation technologies, and future trends.
6	**Agricultural Irrigation and Water Quality Testing**	Types of irrigation systems, how to design an irrigation system, water quality testing parameters and methods, and best practices for sustainable irrigation.

What Is This Manual For?

This manual is prepared for **agri-based small and medium enterprises operating in peri-urban and rural settings** that face water management challenges. It is intended to address those challenges through practical water efficiency and circularity training, and to equip farm operators and staff with the knowledge to implement and maintain improved water systems.

Desired outcomes for users of this manual:

- Knowledge of water-efficient and circular practices linked to available on-farm resources.
- Understanding of modern water management techniques and tools.
- Ability to improve the quality and quantity of water available for agricultural use.
- Confidence to experiment with and adapt these techniques to local conditions.

01 Determine and plan for more rainwater harvesting on the farm.

1.1 What is Rainwater Harvesting?

Rainwater harvesting is the process of **collecting and storing rainwater for practical use**. This method captures runoff from surfaces such as rooftops and paved areas, directing it into storage systems like tanks, ponds, or infiltration basins. The harvested rainwater can be utilised for various purposes, including irrigation for crops and gardens, domestic uses like washing and toilet flushing, and groundwater recharge to enhance aquifer levels.

KEY BENEFITS

- Increases water availability, especially during dry seasons.
- Reduces dependency on conventional water sources.
- Improves soil moisture and enhances crop resilience.

1.2 Types of Rainwater Harvesting Systems

Surface Runoff Collection

Capturing rainwater from rooftops and paved areas using gutters and downspouts.

Infiltration Pits

Pits or trenches that allow water to percolate into the ground and recharge groundwater.

Ponds and Reservoirs

Storage bodies constructed for larger quantities of collected rainwater.

Drip Irrigation Systems

Using harvested rainwater in efficient irrigation setups to minimise waste.

1.3 Planning and Implementation

A Assess the site and design the system

- **Evaluate the roof area.** Measure the catchment area (usually the roof) from which rainwater will be collected. The larger the area, the more water you can collect.
- **Estimate water demand.** Calculate how much water is needed based on household or agricultural needs.
- **Plan the storage capacity.** Based on local rainfall patterns and catchment area, estimate the size of the storage tank required. Professional assistance may be needed to ensure appropriate tank sizing.

B Gather materials

- **Catchment surface:** the roof (preferably non-toxic material like tiles or metal).
- **Gutters and downpipes:** to collect and direct rainwater from the roof to the storage area.
- **First flush diverter:** to discard the first rainwater that washes off the roof, as it may contain debris, dust, and contaminants.
- **Mesh screens:** to prevent debris, leaves, or insects from entering the system.
- **Storage tank or cistern:** above or below ground, made of plastic, concrete, or metal.
- **Pump (optional):** if gravity flow is not sufficient, a pump may be needed to distribute water.
- **Filters:** depending on the water's end use, filters may be required to remove finer particles and contaminants.
- **Overflow system:** to handle excess water when the tank is full.

C Install the catchment system

- **Roof preparation.** Ensure the roof is clean and suitable for water harvesting. Check for any toxic materials (like asbestos) that could contaminate the water.
- **Gutter installation.** Install gutters along the edge of the roof with a correct slope (1–2% gradient) to direct water to the downpipes. Use mesh screens over gutters to prevent debris from entering.
- **Downpipe connection.** Connect downpipes from the gutters to direct rainwater toward the storage tank.

D Install a first-flush diverter

This component diverts the first few litres of rainwater — which may contain dirt, bird droppings, and debris — away from the storage tank. It is typically installed along the downpipe and is designed to automatically bypass the initial water.

E Construct or install the storage tank

- **Above-ground tank.** Position on a stable base close to the downpipes. Connect the downpipe directly into the tank with a mesh screen at the inlet.
- **Below-ground tank.** Dig an appropriately-sized pit, install the tank on a stable level surface, backfill around it, and connect the downpipe and overflow pipe.

F Install filters (if needed)

For potable use, install additional filters such as sand filters, UV treatment, or activated carbon filters before the water enters the tank or at the point of use.

G Set up the overflow mechanism

Install an overflow pipe to direct excess water to a secondary storage tank, recharge pit, or safe drainage area to prevent waterlogging or structural damage.

H Install a pump (if necessary)

If water needs to be pumped to higher areas for irrigation or other uses, install a small electric or manual pump matched to the required flow rate and pressure.

I Maintenance and monitoring

- Periodically clean gutters, the first-flush diverter, and the storage tank.
- Replace or clean filters as necessary to maintain water quality.
- Monitor water levels and usage to identify potential leaks or issues.

1.4 Optional Enhancements

- **Smart sensors and monitoring systems.** Install sensors to monitor tank levels and rainfall to automate water management.
- **Water treatment.** For potable systems, integrate purification methods like reverse osmosis, chlorination, or UV purification.

1.5 Summary

Rainwater harvesting presents a viable solution for addressing water scarcity in agriculture while promoting sustainability. By implementing rainwater harvesting systems, farmers can enhance their water security, reduce dependence on traditional water sources, and improve crop yields — especially during dry seasons.

REFERENCES & FURTHER READING

1. Garg, S.K., & Gupta, A. (2012). *Rainwater Harvesting: A Sustainable Approach.* New Delhi: APH Publishing.
2. United Nations Environment Programme (UNEP). (2016). *Rainwater Harvesting: A Guide for Building Professionals.*
3. Al-Omari, M. A. S. M., & Al-Hassan, A. (2020). "Rainwater Harvesting: An Alternative Water Supply for Agriculture in Arid Regions." *Water*, 12(10), 2850. DOI: 10.3390/w12102850.
4. Adeel, Z., & King, C. D. (2003). "Rainwater Harvesting: A Key to Water Security." *Environmental Management*, 31(2), 214–223.
5. *Online resource:* Steps to an Efficient Rainwater Harvesting System.

02 A bio-remediation system to clean water and circulate it to fields or livestock.

2.1 Understanding Bio-remediation

Bio-remediation is the process of using **living organisms to remove or neutralise contaminants from soil and water**.

In Situ

Techniques applied directly at contaminated sites, often less disruptive.

Ex Situ

Removal of contaminated materials for treatment elsewhere.

Common water contaminants

- **Nutrient pollutants.** Excess nitrogen and phosphorus leading to eutrophication.
- **Heavy metals.** Lead, mercury, and cadmium affecting soil and water quality.

Sources of contamination

- **Agricultural runoff.** Pesticides and fertilisers entering water systems.
- **Industrial discharge.** Release of untreated wastewater into waterways.

Impact on ecosystems and agriculture

- **Water quality.** Deterioration affects aquatic life and human health.
- **Soil health.** Contaminants can inhibit plant growth and soil microbiota.

2.2 Bio-remediation Techniques

Natural attenuation

Utilising indigenous microorganisms that naturally degrade pollutants.

Bioreactors

Engineered systems that enhance degradation using specific microorganisms.

Phytoremediation

Plants like willow and sunflower absorb heavy metals and nutrients.

Mycoremediation

Fungi — such as mushrooms — break down complex organic pollutants.

2.3 Implementation

STEP 1 **Site assessment.**

Test soil and water samples to determine contaminant levels.

STEP 2 **System design.**

Create tailored plans that address specific contaminants and site conditions.

STEP 3 **Monitoring and maintenance.**

Regularly assess system effectiveness through sampling and analysis.

STEP 4 **Water quality standards.**

Understand regulations from relevant bodies regarding safe water reuse.

STEP 5 **Treatment processes.**

Apply additional treatments such as UV disinfection, filtration, and sedimentation post-bio-remediation.

STEP 6 **Irrigation techniques.**

Integrate treated water into existing irrigation systems using drip irrigation, subsurface irrigation, centre pivot, or automated systems.

2.4 Aquatabs for Water Purification



Fig. 3. Aquatab purification tablets in their characteristic foil-backed blister pack.

What are Aquatabs? Aquatabs are water purification tablets used to disinfect and treat contaminated water, making it safe for drinking by humans and livestock. The active ingredient is **sodium dichloroisocyanurate (NaDCC)**, which releases chlorine when dissolved in water to kill harmful bacteria, viruses, and protozoa that cause waterborne diseases.

USAGE

1. Dissolve one tablet per specified volume of water (e.g. 1 tablet per litre).
2. Wait 30 minutes for the purification process to complete.
3. Water is then safe for drinking by humans and livestock.

2.5 Glossary of Key Terms

Bio-remediation	The use of living organisms to remove or neutralise contaminants from soil and water.
In Situ	Techniques applied directly at contaminated sites without excavation.
Ex Situ	Methods involving removal of contaminated material for treatment elsewhere.
Phytoremediation	The use of plants to absorb and detoxify contaminants.
Mycoremediation	The application of fungi to remove pollutants.
Natural attenuation	The natural reduction of contaminants through physical, chemical, or biological processes.
Bioreactor	An engineered system optimising conditions for microorganisms to degrade pollutants.
UV disinfection	A water-treatment process using ultraviolet light to inactivate microorganisms.

2.6 Frequently Asked Questions

What is bio-remediation and how does it work?

Bio-remediation uses living organisms — bacteria, fungi, or plants — to remove or neutralise contaminants in soil and water through natural metabolic processes.

What types of contaminants can be treated?

Bio-remediation can address heavy metals, organic compounds, pesticides, and excess nutrients like nitrogen and phosphorus.

How do I determine the right bio-remediation method for my site?

Conduct a site assessment to evaluate contaminant types, concentrations, and environmental conditions, then select the most suitable technique.

Is treated water safe for agricultural use?

Treated water must meet specific quality standards. Regular testing is essential to ensure it is free from harmful pathogens and contaminants.

What are the advantages of UV disinfection?

UV disinfection is effective against a wide range of microorganisms, is chemical-free, and works quickly — though it requires clear water for optimal effectiveness.

Can bio-remediation be applied to large-scale agricultural operations?

Yes. Bio-remediation methods can be scaled up for larger operations, especially when integrated into existing water management systems.

What are the limitations of bio-remediation?

Limitations include the time required for effective treatment, potential for incomplete contaminant removal, and the need for specific environmental conditions for optimal microbial activity.

How often should I monitor my bio-remediation system?

Regular monitoring is recommended — typically every few weeks or months depending on the method and contamination level. Adjustments should be made based on monitoring results.

REFERENCES & FURTHER READING

1. Vidali, M. (2001). "Bioremediation: An Overview." *Soil Biology & Biochemistry*, 33(10), 1039–1056.
2. McGenity, T.J., et al. (2012). "Bio-remediation of Polluted Environments." *Microbial Biotechnology*, 5(3), 279–287.
3. EPA. (2020). *Guidelines for Water Reuse.* EPA Water Reuse.

03 Circular reticulation systems and smart monitoring tools.

3.1 Circular Reticulation Components

In the context of irrigation and water distribution, **circular reticulation** refers to a network of pipes and components arranged in a loop to provide an efficient and consistent water supply. Key components include:

A Pipes

- **Main supply line.** The primary pipeline connecting the water source to the distribution network.
- **Distribution pipes.** Smaller pipes branching from the main supply line.
- **Looped layout.** The circular configuration ensures even and consistent water distribution across the entire network.

B Valves

- **Control valves.** Regulate water flow within different sections of the network.
- **Pressure-reducing valves.** Maintain stable water pressure across the system.
- **Non-return valves.** Prevent water from flowing backward, avoiding contamination.
- **Zone valves.** Manage water flow to specific sections based on irrigation needs.

C Water source

- **Reservoirs or tanks.** Storage facilities such as tanks, rainwater ponds, or reservoirs.
- **Pumping station.** Moves water from storage into the distribution network where gravity is insufficient.

D Irrigation emitters

- **Sprinklers.** Distribute water evenly across fields.
- **Drip emitters.** Deliver water directly to plant roots for precision irrigation.

E Filtration systems

- **Screen filters.** Basic filtration for surface irrigation systems.
- **Sand filters.** For more complex systems requiring high-quality water distribution.

F Pressure management

- **Pressure regulators.** Ensure even pressure across the system.
- **Booster pumps.** Maintain pressure in areas far from the main water source.

G Sensors and monitoring

- **Soil moisture sensors.** Measure soil moisture at strategic points (e.g. Chameleon sensors) to ensure irrigation occurs only when necessary.
- **Flow meters.** Detect inefficiencies or leaks within the system.
- **Automated controllers.** Manage irrigation schedules based on crop needs or weather data.

H Backflow prevention devices

Prevent contamination of the main water supply by ensuring water does not flow backwards into the source — especially important when chemicals or fertilisers are used.

I Overflow systems

Drainage pipes manage excess water from storage tanks, redirecting it to ponds or other areas to prevent flooding.

3.2 The Chameleon Sensor

Chameleon sensors are soil-moisture monitoring tools used in agriculture to help farmers manage irrigation more efficiently. They provide real-time data on soil moisture levels at different depths, enabling informed decisions about when and how much to irrigate.



Fig. 4a. Chameleon soil-moisture probes ready for installation at multiple depths.



Fig. 4b. The Chameleon reader and a farmer demonstrating its use in-field.

How Chameleon sensors work

- Probes are placed at various soil depths (typically 10 cm, 20 cm, and 30 cm) to measure moisture distribution through the soil profile.
- Sensors measure the electrical conductivity of the soil, which changes with moisture levels — wet soil conducts electricity better than dry soil.
- Real-time data can be read using a handheld device or field display units.



Blue

Wet soil — too much water



Green

Adequate moisture — optimal for crops



Red

Dry soil — time to irrigate

Applications in agriculture

- **Precision irrigation.** Apply water only when and where it is needed, minimising waste and preventing waterlogging or nutrient leaching.
- **Improved water efficiency.** Optimise water use in areas where water is scarce or expensive.
- **Increased crop yields.** Maintaining optimal soil moisture improves crop health and productivity.
- **Cost reduction.** Reduces unnecessary water and energy use — the system is specifically designed to be low-cost and accessible for smallholder farmers.
- **Soil-health maintenance.** Prevents over-irrigation, which can lead to soil compaction and nutrient depletion.

KEY BENEFITS

- Easy to use with no technical expertise required.
- Affordable, particularly for smallholder farmers.
- Provides real-time, actionable data.
- Contributes to sustainable water use and conservation.
- Scalable for both small and large farming operations.

Online resource: Chameleon Sensor Video Guide.

3.3 Hydraulic Ram Pump

A **hydraulic ram pump** uses the kinetic energy of flowing water to pump a portion of that water to a higher elevation — without electricity or fuel, making it especially useful in remote or off-grid settings.

How it works

STEP 1 **Water flows through a drive pipe**
from a higher water source (stream or spring), creating pressure through gravity.

STEP 2 **Pressure forces a waste valve to close,**
creating a pressure spike (water-hammer effect).

STEP 3 **The spike opens a delivery valve,**
sending a portion of water upward into a delivery pipe.

STEP 4 **The cycle repeats continuously,**
pumping water to a storage tank or higher location.



Fig. 5. A hydraulic ram pump in operation at a small stream — no fuel or electricity required.

Key considerations

- Self-powered — requires only a continuous source of flowing water.
- Relatively simple and low-maintenance.
- Best suited to settings with a steady water source and sufficient elevation difference.
- Ideal for irrigating gardens, providing drinking water for livestock, or supplying households in rural areas.

PROS

- Cost-effective.
- Low-maintenance.
- Eco-friendly — no fuel or electricity.

CONS

- Requires sufficient drop in source elevation.
- Limitations on flow rate and height achieved.

3.4 Fish Species for Mosquito Management

Several fish species naturally feed on mosquito larvae and are valuable for biological mosquito control in ponds and water bodies on farm properties. Notable species include:

SPECIES	NOTES
Mosquitofish *(Gambusia affinis)*	Most widely used — small, hardy, and consume large quantities of mosquito larvae.
Guppies *(Poecilia reticulata)*	Effective in smaller bodies of water.
Killifish *(Aplocheilus lineatus, Fundulus spp.)*	Effective in stagnant water.
Minnows *(Pimephales promelas, Cyprinella lutrensis)*	Feed well on larvae in ponds.
Tilapia *(Oreochromis spp.)*	Omnivorous; opportunistically feed on larvae in larger, warmer water bodies. Also harvestable as a food source.
Goldfish *(Carassius auratus)*	Will consume larvae when present, though less focused than other species.

Tilapia in particular are suitable for larger farm ponds in tropical or subtropical regions. They feed primarily on algae and plant material, adding larvae to their diet opportunistically. They adapt well to different environmental conditions, are low-maintenance, and provide the dual benefit of mosquito control and a food source.

04 Constructing swales for water retention and soil health.

4.1 What are Swales?

Swales are shallow, gently sloped trenches or ditches designed to manage water runoff, slow water flow, and promote infiltration into the ground. Used in both permaculture and agriculture, swales prevent soil erosion, capture rainwater, and direct it toward crops or natural vegetation. They are typically filled with organic matter such as mulch or gravel, and often include vegetation to help absorb and filter water.

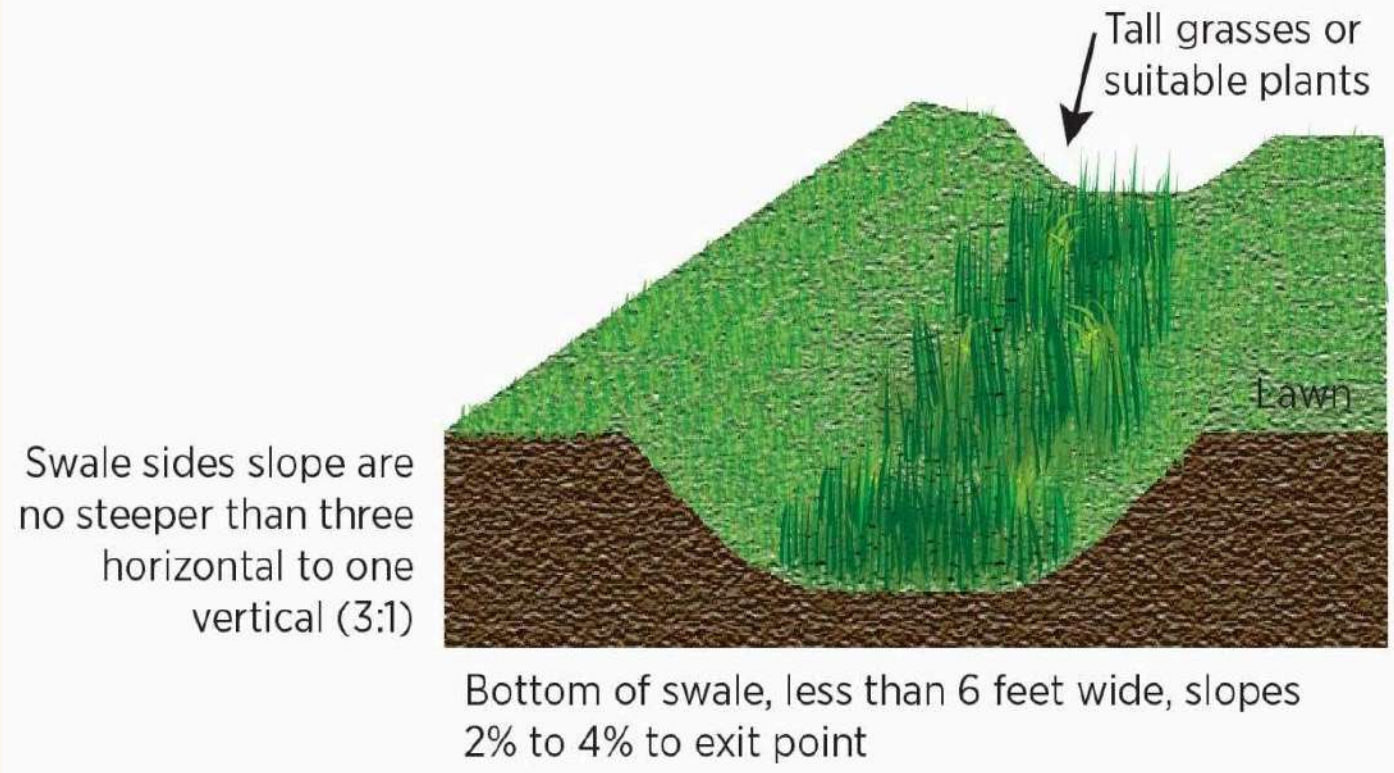


Fig. 6. Cross-section of a typical swale: gentle 3:1 side slopes, a shallow base of less than ~6 ft, and a planted berm on the downslope side.

Key characteristics

- Dug along the contour lines of a landscape to catch and hold water rather than allowing it to rush downhill.
- Collected runoff soaks into the ground, improving soil moisture and reducing erosion.
- A sustainable water management tool that reduces reliance on external irrigation.

Dry Swales

Channel runoff during rain events and allow water to infiltrate quickly afterward.

Wet Swales

Retain water for longer periods, often lined with moisture-tolerant plants that support biodiversity.

4.2 Step-by-Step Guide to Constructing Swales

STEP 1 **Survey the land.**

Identify contour lines using an A-frame level, water level, or laser level. Swales are ideal for gently sloping land; for steep slopes, terraces or smaller, closely-spaced swales may be required.

STEP 2 **Plan swale dimensions.**

A typical swale is approximately 1–2 metres wide and 0.5 metres deep. Size depends on expected water volume and rainfall. On steeper slopes, swales should be spaced closer together to control runoff effectively.

STEP 3 **Mark the swale.**

Use stakes, string, or flags to mark the shape and location of the swale along the contour line to guide digging.

STEP 4 **Dig the swale.**

Excavate along the marked contour line to create a shallow trench. Pile the excavated soil on the downslope side to form a berm — with a gentle slope on the uphill side and a steeper slope on the downhill side. Ensure the bottom of the swale is level from end to end so water spreads and soaks in evenly.

STEP 5 **Test the swale.**

Before planting or mulching, observe how water fills the swale during rainfall or when water is applied with a hose. Make adjustments if necessary to ensure even distribution.

STEP 6 **Add mulch or fill material.**

Apply mulch (e.g. wood chips, straw) to the bottom of the swale to improve water retention and prevent soil erosion. Gravel or rocks may be added to improve infiltration in clay soils.

STEP 7 **Plant the berm.**

Vegetate the berm with deep-rooted grasses, cover crops, trees, or shrubs to stabilise the soil, improve water infiltration, and prevent erosion. Swales are often combined with tree planting in permaculture systems to create food forests. Ground cover plants along swale edges further stabilise soil and absorb excess water.

STEP 8 **Maintain the swale.**

- Periodically check for erosion or sediment buildup and adjust the berm or trench as needed.
- Keep the swale and berm clear of weeds to allow planted vegetation to thrive.
- Reapply mulch or compost as needed to maintain water retention and soil health.



Fig. 7a. A mulched swale acting as both a path and an infiltration channel.



Fig. 7b. Terraced swales on a hillside slow runoff and turn slope into productive land.

4.3 Benefits of Swales in Agriculture

Improved Soil Health

Water infiltration encourages beneficial microorganisms and plant growth.

Water Conservation

Retained rainwater can be used for irrigation or to improve groundwater levels.

Erosion Control

Slows runoff, preventing soil erosion on sloped land.

Increased Crop Yields

Improved soil moisture reduces water stress on plants.

In summary, swales are an effective and eco-friendly tool for managing water on agricultural land — improving soil health, reducing erosion, and conserving water.

05 A workshop overview of modern water management techniques.

5.1 Overview of Modern Techniques

Modern water management encompasses a range of strategies and technologies aimed at **optimising water use, improving water quality, and ensuring sustainable water resources**.

Integrated Water Resource Management (IWRM)

A holistic approach that considers the interconnections between water, land, and related resources. It promotes collaboration among stakeholders to manage water resources sustainably.

Smart Irrigation Technologies

- **Drip irrigation.** Delivers water directly to plant roots, reducing waste and improving efficiency.
- **Automated irrigation systems.** Use sensors and timers to optimise watering schedules based on soil moisture and weather conditions.

Rainwater Harvesting

Collecting and storing rainwater for later use, reducing reliance on external water supply and promoting conservation. *(See Section 1 for detailed guidance.)*

5.2 Importance of Modern Water Management

- Addresses water scarcity and quality challenges in agricultural settings.
- Promotes sustainable practices to ensure water availability for future generations.
- Enhances resilience to climate change impacts.

5.3 Future Trends in Water Management

- Increasing integration of digital tools and sensors for real-time monitoring and decision-making.
- Growing use of nature-based solutions such as constructed wetlands and swales.
- Expansion of water-smart farming approaches that link water efficiency with soil health and circular resource use.

REFERENCES & FURTHER READING

1. United Nations Water. (2021). *Water for Sustainable Living.* UN Water.
2. World Resources Institute. (2020). *Water Risk Finance.* WRI Publications.
3. American Water Works Association. (2019). *Principles of Water Management.* AWWA.
4. Mays, L. W. *Water Resources Engineering.*
5. Loucks, D. P., & van Beek, E. *Integrated Water Resource Management: A Global Perspective.*
6. Hillel, D. F. *The Water We Eat: A Food Policy for the 21st Century.*

06 Agricultural irrigation techniques and water-quality testing.

6.1 What is Irrigation?

Irrigation is the controlled application of water to land to assist in the production of crops. It supplements rainfall, extends growing seasons, and enables farming in areas with insufficient or unpredictable precipitation.

BENEFITS OF IRRIGATION

- Ensures consistent water supply to crops regardless of rainfall variability.
- Supports higher crop yields and better product quality.
- Enables year-round or extended-season farming.

6.2 Types of Irrigation Techniques

TECHNIQUE	DESCRIPTION
Surface Irrigation	Water flows over the soil surface using furrow, flood, or basin methods. Simple and low-cost but can result in uneven water distribution and higher evaporation losses.
Drip Irrigation	Water is delivered directly to plant roots through emitters and tubing. Highly efficient — conserves water and reduces weed growth. Requires filtration systems to prevent emitter blockages.
Sprinkler Irrigation	Water is sprayed over crops in a manner similar to rainfall. Available as fixed, portable, or centre-pivot systems. Flexible and suitable for various terrains and crop types.
Subsurface Irrigation	Water is applied below the soil surface through buried pipes or tubes. Reduces evaporation and surface runoff, improving water-use efficiency.
Rainfed Agriculture	Relies on natural rainfall supplemented by soil moisture conservation practices such as mulching, swales, and conservation tillage. Important in areas where irrigation infrastructure is limited.

6.3 Designing an Irrigation System

When planning an irrigation system, consider the following:

- **Site assessment.** Evaluate soil type, topography, and local climate.
- **Water source identification.** Identify available sources — wells, rivers, rainwater harvesting.
- **System layout planning.** Map out the irrigation design based on field dimensions and crop water needs.
- **Cost–benefit analysis.** Evaluate the economic feasibility of the system relative to yield improvements and water savings.

6.4 Water Quality Testing

Water quality directly affects crop health, soil quality, and the safety of produce. Before using any water source for irrigation, testing is recommended.

Key water quality parameters

pH
Acidity or alkalinity of the water.

Electrical Conductivity (EC)
A proxy measure for dissolved salts.

Salinity
Salt concentration affecting crop tolerance.

Nutrients (N, P, K)
Levels of nitrogen, phosphorus, and potassium.

Pathogens
Bacteria, viruses, and other harmful microorganisms.

Contaminants
Heavy metals, pesticides, and other chemical pollutants.

Water sampling techniques

- Use proper sampling methods — **grab samples** for spot testing, **composite samples** for average quality over time.
- Ensure sampling equipment is clean to avoid contamination.

Testing methods

- **Field tests.** Portable kits for pH and electrical conductivity provide quick, on-site results.
- **Laboratory tests.** More comprehensive analyses for pathogens, heavy metals, and chemical contaminants.

Interpreting results

Test results should be compared against established agricultural water-quality guidelines. Based on findings, adjust irrigation practices, water-treatment approaches, or source selection accordingly.

6.5 Best Practices for Sustainable Irrigation

- **Optimise water use.** Match irrigation volumes and timing to actual crop water requirements using sensors or evapotranspiration data.
- **Crop rotation and cover cropping.** Improve soil health and water retention, reducing overall irrigation needs.
- **Integrate technology.** Use soil-moisture sensors and automated systems to reduce over-irrigation.
- **Adapt to climate variability.** Build flexibility into irrigation systems to manage variable rainfall and temperature conditions.

REFERENCES & FURTHER READING

1. Allen, R.G., Pereira, L.S., Raes, D., & Smith, M. (1998). *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper 56.
2. Hillel, D. (2004). *Introduction to Soil Physics.* Academic Press.
3. Turner, N.C., & Begg, J.E. (1981). *Advances in Irrigation,* Vol. 1. Academic Press.
4. Pereira, L.S., & Oweis, T. (2000). "Advances in Rainfed Agriculture: A Global Perspective." *Agricultural Water Management*, 45(1), 5–20.
5. Shock, C.C., & Yates, S.R. (2003). "Water Quality: Its Impact on Irrigation." *California Agriculture*, 57(2), 57–62.
6. Food and Agriculture Organization (FAO). *Irrigation and Drainage.*
7. International Commission on Irrigation and Drainage (ICID). (2011). *Irrigation Manual: Guidelines for the Planning and Design of Irrigation Projects.*
8. American Society of Agronomy. (2013). *Soil Testing and Plant Analysis.* SSSA Book Series 23.

PREPARED BY MADAM WASTE (LTD)

Submitted to ACEN for the Circular Food Systems for Rwanda (CIRF) programme. This manual may be freely copied, translated, and adapted by TAPs, SMEs, and practitioners.