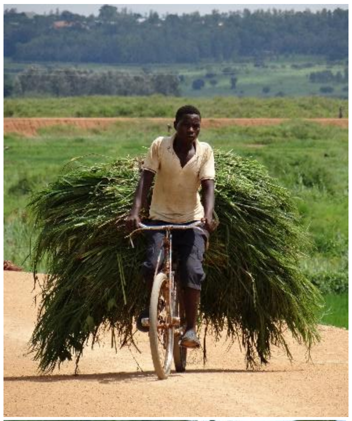
TECHNICAL ASSISTANCE IN ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT

Guidelines for Water Quality Management in Rwanda



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Guidelines for Water Quality Management in Rwanda

UNIVERSITY of RWANDA

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ABBREVIATIONS AND ACRONYMS

BMPs	Best Management Practices
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EAC	East African Community
EDCs	Endocrine Disrupting Chemicals
EDPRS-2	Economic Development Poverty Reduction Strategy - 2
EIP	Early Implementation Project
EUCL	Energy Utility Cooperation Ltd
GIS	Geographical Information System
GoR	Government of Rwanda
IWRM	Integrated Water Resources Management
LVB	Lake Victoria Basin
LVEMP	Lake Victoria Environmental Management Project
M&E	Monitoring and Evaluation
MIDIMAR	Ministry of Disaster Management and Refugee Affairs
MIGEPROF	Ministry of Family and Gender Promotion
MINAFFET	Ministry of Foreign Affairs and Cooperation
MINAGRI	Ministry of Agriculture and Animal Resources
MINALOC	Ministry of Local Government
MINECOFI	Ministry of Finance and Economic Planning
MINEDUC	Ministry of Education
MINICOM	Ministry of Commerce
MININFRA	Ministry of Infrastructure
MINIRENA	Ministry of Natural Resources
MIS MoE	Management Information System Ministry of Environment
NGO	Non-Governmental Organization

NWRMP	National Water Resources Master Plan
OrgN	Organic nitrogen
OrgP	Organic phosphorus
PhACs	Pharmaceutically Active Compounds
POPs	Persistent Organic Pollutants
RDB	Rwanda Development Board
REMA	Rwanda Environment Management Authority
RNRA	Rwanda Natural Resources Authority
RWFA RWB	Rwanda Water and Forestry Authority Rwanda Water Resources Board
SDG	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SoIN	Soluble inorganic nitrogen
SoIP	Soluble inorganic phosphorus
SS	Suspended sediments
TN	Total nitrogen
TP	Total phosphorus
WASAC	Water and Sanitation Corporation

GLOSSARY OF TERMS

Adaptation In human systems, the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate. (IPCC, P: 556)

Catchment The area of land that contributes water to a particular river. Includes the natural resources, people and land use activities on the area of land.

Climate Change Climate Change A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. See also Climate variability and Detection and attribution. (IPCC, P: 557)

Climate Variability Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also Climate change. (IPCC, P: 557)

Disaster Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. (IPCC, P: 558)

Ecosystem function Ecosystem functions are the physical, chemical, and biological processes or attributes that contribute to the self-maintenance of an ecosystem; in other words, what the ecosystem does. The products of ecosystem functions are the goods and services humans use on a daily basis e.g. clean air, food, timber, etc.

Erosion The action of surface processes (water or wind) that remove earth materials from one location and transport it to another. Rainfall, and the resulting runoff from rainfall, produces soil erosion. The different forms of soil erosion are: splash, sheet, rill, and gully erosion. The impact of a falling raindrop creates splash erosion - once surface runoff occurs, loosened soil particles, termed sediment, will be transported. Sheet erosion is the transport of sediment by overland flow, with rill erosion occurring as concentrated flow paths. Gully erosion occurs as a certain threshold is reached and flow paths become deeper channels.

Forest Forest patches in savannah landscapes: the natural forests in the savannah and gallery-forest of the Akagera National Park and remnants of gallery-forests and savannahs of Bugesera, Gisaka and Umutara;

• Tree plantations: plantations dominated by exotic species (Eucalyptus sp, Pinus sp, Grevillea robusta);

• Other trees and shrubs outside natural forests and tree plantations, including tree stands scattered on Farmlands (agroforestry) and serving to prevent erosion.

Gender roles A gender role is a set of societal norms determining the types of behaviors which are generally considered acceptable, appropriate or desirable for people based on their actual or perceived gender or sexuality, i.e. Gender roles refer to society's expectations for how men and women should act.

Governance The way government is understood has changed in response to social, economic, and technological changes over recent decades. There is a corresponding shift from government defined strictly by the nation-state to a more inclusive concept of governance, recognizing the contributions of various levels of government (global, international, regional, local) and the roles of the private sector, of nongovernmental actors, and of civil society. (IPCC, P: 560)

Land use and land use change Land use refers to the total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus have radiative forcing and/or other impacts on climate, locally or globally. (IPCC, P: 561)

Mitigation (of climate change) A human intervention to reduce the sources or enhance the sinks of greenhouse gases. (IPCC, P: 561).

Pollution The Organic Law (Organic Law 04/2005, 2005) defines pollution as the contamination caused by waste, harmful biochemical products derived from human activities that may alter man's habitat and cause adverse effects on the environment like man's social wellbeing, animals, flora and fauna and the world he or she lives in. The law describes three types of pollution namely: Marine (water) pollution; Atmospheric pollution; and Transboundary pollution.

Runoff That part of precipitation that does not evaporate and is not transpired, but flows through the ground or over the ground surface and returns to bodies of water. See Hydrological cycle. (IPCC, P: 563)

Sedimentation (Refer to Erosion above) Once loosened soil is picked up by either wind or water, it is termed "sediment". In terms of soil erosion, sediments collected by the flow of water may be transported by rolling or sliding along the floor of a river (bedload) or by suspension in the moving fluid (suspension) before being deposited. A catchment may be considered to be made up of a patchwork of sediment source zones (source of sediment) and sink zones (sediment deposition areas), with sediment spending most time in storage. Management of sedimentation therefore needs to be at the catchment scale in order to effectively manage the irregular pattern of sources and sinks throughout the catchment.

Soil moisture Water stored in or at the land surface and available for evapotranspiration. (IPCC, P: 563)

Watershed A catchment boundary is called a watershed, which is usually on the highest point between 2 catchments e.g. on top of a ridge, hill or mountain. A watershed divides the pathways that water will follow/drain into the catchments on either side of it. A watershed is therefore referred to as the source area of catchments.

CHAPTER 1 INTRODUCTION

1.1 Background and context

LDCF II Project entitled "Building resilience of communities living in degraded wetlands, forests and savannas of Rwanda through an ecosystem-based adaptation approach"

The Least Developed Countries Fund (LDCF) II Project titled "Building resilience of communities living in degraded forests, savannahs and wetlands of Rwanda through an Ecosystem-based Adaptation (EbA) approach“ is funded by Global Environment Facility (GEF) through United Nations Environment Programme (UNEP) under climate change adaptation GEF focal area for total duration of four years..

The main objective of the project is to increase capacity of Rwandan authorities and local communities to adapt to climate change by implementing Ecosystem based Adaptation (EbA) interventions in degraded forests, savannahs and wetlands ecosystems. The above objective will be achieved through

i) increasing the technical capacity to plan and implement E-bA at national and local levels;

ii) strengthening the national and local policies, strategies and plans to facilitate the national implementation of E-bA;

iii) restoring degraded savanna, forests and wetlands to provide proof-of-concept for the role of ecological infrastructure in increasing climate resilience and providing alternative livelihoods for local communities

The project has three components:

1. The National and local institutional capacity development for the use of an EbA approach.

2. Policies, strategies and plans for adaptation to climate change.

3. Ecosystem based Adaptation (EbA) interventions that reduce vulnerability and restore natural capital.

The LDCF II Project was designed to demonstrate The LDCF- demonstrates the benefits of EbA by using intervention sites in the most vulnerable areas in Rwanda. To maximise the sustainability and upscaling of the interventions, the project will:

(i) train national- and local-level authorities as well as local communities at intervention sites on the use of EbA;

(ii) increase scientific knowledge on the benefits of EbA and identify best practices for EbA;

(iii) provide guiding documents to mainstream EbA into policies, plans and strategies in Rwanda; and

(iv) increase local community awareness on the role of ecological infrastructure in increasing climate resilience.

Technical Assistance in Environment and Natural Resources Management (this project)

With aim to collate current knowledge on status and health of the environment within catchments that include forest, savannah, and wetland ecosystems in Rwanda, to develop systematic mapping and monitoring tools to identify basin management needs and track progress towards addressing them as well as to develop an understanding of the drivers of their degradation and to prepare a range of plans based on the results of the analyses and in response to climate threats, LDCF II/REMA

In accordance with the Term of References, the Technical Assistance in Environmental Management consists of a number of tasks:

- Strategic Plan for Ecosystem Based Adaptation and Wetland Management which includes a status quo description, national wetland management plan, guidelines for wetland management, and technical support with implementation of the plan.
- Water Quality Management which includes identification of pollution hotspots in Rwanda, develop water quality management guidelines, develop water quality management plan for Rwanda, a water quality modelling tool, and integrated urban pollution management plans for five urban areas.
- Develop integrated catchment management for some catchments in Rwanda (Nile-Akagera upper, Nile-Nyabarongo lower and Nile-Nyabarongo upper including Nyiramuhondi watershed), and
- Capacity building and training

This report is part of Water Quality Management task and presents best practices and options for managing point sources, non-point sources ,options to cope with the impacts of pollution and options that water users can employ to treat water in order to meet water quality requirements or standards

1.2 Scope and purpose

Terms of Reference for Guidelines for

The term of reference for this task required the consultant team to "*Develop Guidelines for Water Quality Management that indicate the options for*

Water Quality Management	*improving water quality both in urban areas (esp. for point sources in cities and towns) and in rural areas (esp. for non-point sources especially agriculture) for key water quality indicators of concern (e.g. Faecal coliforms, BOD, DO, COD, Nitrates, etc.)*".

1.3 Layout of the Guidelines Document

The Guidelines for Water Quality Management consists of the following chapters:

Chapter 1	…..gives an introduction to the study through presenting the general background of the WQM guidelines, its scope of as well as the layout of the report
Chapter 2	provides a brief overview of the water pollutants of concern and the sources of pollution in Rwanda.
Chapter 3	… provides an overview of a water quality management framework for Rwanda.
Chapter 4	… describes a number of options for treating point sources of pollution. These include options for treating domestic, industrial, and mining wastewater.
Chapter 5	… describes a number of options for treating nonpoint sources of pollution. These include options for urban nonpoint sources, and agricultural nonpoint sources.
Chapter 6	… describes a number of in-stream and in-lake management options for mitigating the impacts of pollutants in the receiving water bodies.
Chapter 7	… describes options for coping with the impacts of pollution and options that water users can employ to treat the water to meet their water quality requirements or standards.
Chapter 8	… provides guidance on criteria to consider when drawing up a prioritised list of water pollution management options.

CHAPTER 2 INTRODUCTION TO WATER QUALITY ISSUES IN RWANDA

Overview	This chapter is a brief summary of the Water Quality Management: Identification of pollution hotspots report and serves as background to the type of water quality pollution issues faced in Rwanda and the key causes of these concerns.

2.1 Overview of key water quality concerns

Introduction	Rwanda is experiencing a range of water pollution problems. In this section these are introduced and the situation in Rwanda briefly described in one or two sentences. Detailed information is available in the Water Quality Management: Identification of pollution hotspots report.
Suspended sediment and turbidity	Many Rwandan rivers carry a naturally high suspended solids load, but it is aggravated by changes in land-use. Sediment loads have further increased through extensive agricultural activities and practices, construction activities, silviculture practices, over-grazing, destruction of the riparian vegetation, and the physical disturbance of land by industrial and urban developments.
	High sediment loads are readily visible in Rwanda's readily visible in Rwanda's highly turbid and muddy streams and rivers, particularly during the rainy season. Total Suspended Solids were especially elevated in water samples taken from the Sebeya and Nyabarongo Rivers, which registered from 500 to 660 mg/L and 320 to 350 mg/L, respectively. Sediment concentrations vary considerably with run-off patterns. High levels of suspended sediment have led to considerable economic losses due to siltation of rivers, lakes and reservoirs that generate almost half of Rwanda's electricity.
Microbiological pollution and pathogens	Human settlements, inadequate sanitation and waste removal practices, stormwater wash-off and sewage spills are the major sources of deteriorating microbiological water quality in Rwanda.
	The high E coli counts in Rwandan rivers mean that the water poses a real health risk to users that take water directly from the river for drinking water and for other domestic uses. It also poses a health risk children swimming and playing in rivers and streams, and there is a risk of contracting diseases if vegetables are eaten raw if it was irrigated with river water high in pathogens.
Organic material and dissolved oxygen	.A review of the average dissolved oxygen concentrations recorded by RWFA from 2011-2017 indicate that many of the rivers in Rwanda had DO concentrations below the lower limit of 6 mg/l (or 68% saturation). Of the 39 sampling points, DO concentrations less than 6 mg/l were recorded at 25 points.
Nutrients	In Rwanda there are concerns of nutrient enrichment, eutrophication and nuisance algal growth in some of the lakes that serve as a source of domestic water for surrounding communities and towns. Nutrient enriched water also promotes the growth of invasive aquatic water plants such as water hyacinth.

Hydrocarbon pollution	Hydrocarbon pollution is not routinely monitored in Rwanda. However, many district environmental officers have commented on the irresponsible dumping of used motor oil by garages and workshops, often onto the soil, into stormwater drains, or nearby streams and wetlands. This appears to be problem wherever workshops are located.
Heavy metals	.In Rwanda some rivers and lakes are affected by elevated metal concentrations, often associated with industrial activities in their catchments. Limited measures of lead, cadmium, and zinc exceeded international guideline values. The main sources of trace metals in water bodies are geological weathering, the atmosphere, industrial effluents, leaching from solid waste dumps, agricultural runoff, and drainage from mining activities (from both direct discharge and leaching from the spoils of operational and abandoned mines). Many trace metals are employed in, and result from, industrial activities
Solid waste and litter	As in many other countries, the presence and magnitude of solid waste in water courses are not monitored actively in Rwanda. Although Rwanda has a reputation for being the cleanest country in the region solid waste management and litter in urban water bodies is still a issue of concern. This was strongly linked to the lack of solid waste removal services in many areas, especially in informal settlements and slums located in urban areas.
Agrochemicals	Concerns have been expressed about the potential impacts of irresponsible use of agrochemicals on aquatic ecosystems, but little data exists about the concentrations and impacts of agrochemicals in Rwanda.

2.2 Overview of pollution sources

Pollution and pollution sources	Sources of pollution are generally divided into two categories, namely point sources and nonpoint sources.

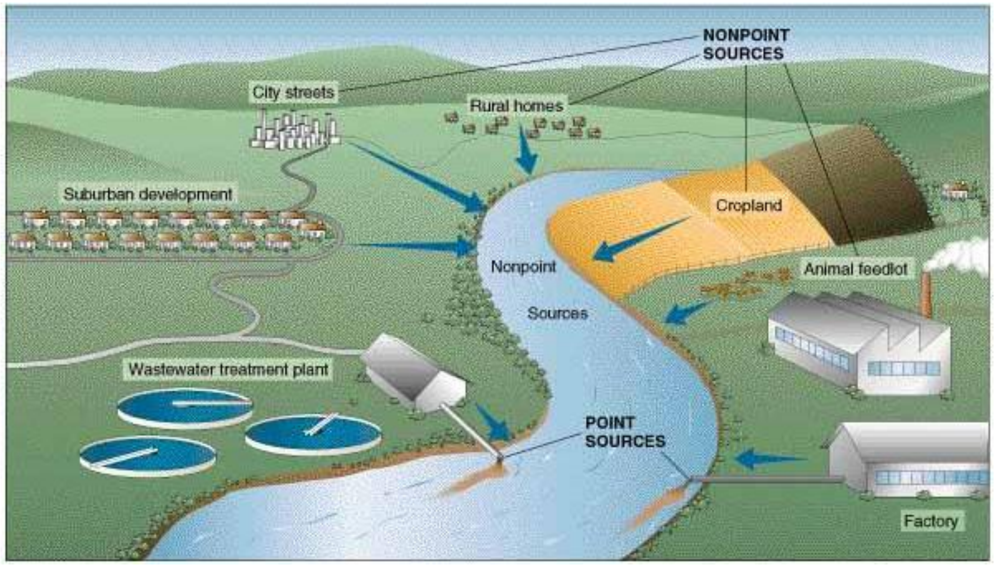

Figure 1: Illustration of Point and Nonpoint sources of pollution

Point sources

A point sources of pollution is one whose initial impact on a water resource is at a well-defined local point (such as a pipe or canal). The US EPA describes point sources of pollution as any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.

Nonpoint sources

Nonpoint sources (also called diffuse sources) of pollution whose initial impact on a water resource occurs over a wide area or long river reach (such as un-channelled surface runoff from agricultural land or stormwater and dry-weather runoff from a dense settlement). The US EPA describes nonpoint source pollution resulting from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, and ground waters.

1.1.1 Nonpoint sources

Agricultural nonpoint sources

Agriculture is the predominant land use in most of rural Rwanda and is a major source of sediments in Rwanda. The Rwandan economy is primarily based on rudimentary agriculture where over 80% of the population is dependent on subsistence agriculture. With a hilly and mountainous relief, coupled with a fragile soil and a high average rainfall intensity of 1156 mm per annum that concentrates in the wet season, the lands of Rwanda are highly susceptible to soil erosion.

Agriculture is also a major source of nutrient enrichment of rivers and lakes. The Crop Intensification Program (CIP), that begun 2007, has promoted increased agricultural productivity of high-potential food crops by creating incentives for producers to adopt new production technologies, especially fertilizer, seed and irrigation. The program has emphasized improving the availability, access and use of fertilizers. There has been a resultant increase in fertilizer access and use, and productivity of major staples. However, fertilizers applied to a field are not all taken up by the crop. Leachate losses, especially nitrogenous fertilizers which are highly soluble, are strongly influenced by when and how fertilizers are applied. Timing of application in relation to rainfall, season and crop growth is crucial.

Urban nonpoint sources

High levels of non-point sources of contamination, particularly organic material (BOD/COD), hydrocarbons, pathogens, and sediments are associated with formal urban areas and industrial activities with the urban boundaries.

In most urban areas in Rwanda, the storm-water drainage systems which was designed to mitigate the impacts of flooding during heavy rainfall events, were found to be inadequate and not keeping pace with the rapidly growing urban population. Localised impacts have been erosion of unstable land and water courses, increased flooding, and threats to private and public infrastructure. When flooding was combined with poor liquid and solid waste collection in urban settlements, it was found that urban runoff carried high loads of pollutants such as hydrocarbons, heavy metals, bacteria, sediment, pesticides and fertilizers into streams or groundwater, threatening environmental and human health.

Gravel roads and erosion

Roads, and gravel roads can be a significant source of erosion and fine sediments. When roads are constructed, they create an interference with the natural drainage systems and collect water, channel it through culverts, increasing its volume and velocity, resulting in accelerated erosion downstream of a bridge or culvert. One of the area's most prone to erosion and gully formation is along the side of roads, especially gravel roads. Roads also act as a source of oil pollution due to vehicle maintenance often conducted next to a road. Most rural roads in Rwanda are unpaved gravel roads with the exception of the national roads that are paved. Data from the RTDA shows that in 2016 Rwanda had 1,305 km of national paved roads, 1,444 km of national unpaved roads, 3,818 km of district unpaved roads Class 1 and 88 km of district paved roads Class 1.

Many roads in urban areas are also unpaved roads and the dust generated by vehicle traffic accumulate and are washed off as sediment during the first rain events. For example, in the City of Kigali there are 153 km of paved classified roads and 864 km on unpaved classified road.

1.1.2 Point sources

Industrial point sources	Effluent discharges from industries can have a significant impact on receiving water bodies. These can include high concentrations of BOD/COD, nutrients, heavy metals, suspended solids, oils and grease, bacterial pathogens, etc. A countrywide survey of some 88 factories and industries producing different items, was undertaken in 2017. It was found that some of the industries treat their wastewater by using alternative means not mentioned in the questionnaire that was used in the survey. In general, more than 30 % of the industries did not treat their wastewater due to insufficient capacity to treat their wastes, or treatment not being required. It was concluded that, depending on the complexity of processes occurring at some specific industrial sites, special attention needed to be taken into account during the monitoring of on-site wastewater treatment facilities as well as for any wastewater monitoring plan. Based on the 2016 and 2017 surveys undertaken for the Resource Efficient and Cleaner Production Project of the Ministry of Trade and Industry, high organic loads characterised by high BOD and COD concentrations that exceed effluent standards, appears to be a common pollution concern amongst many industries.
Wastewater treatment works (WTWs)	Wastewater treatment works (WWTWs) that discharge treated effluent into surface water streams are important point sources of pollution if they do not meet effluent standards. However, if there is a high density of WWTWs, all meeting effluent standards, their cumulative impacts might also be significant. A comprehensive survey of wastewater treatment systems in Rwanda for REMA in 2016 found that there were about 161 wastewater treatment systems in Rwanda with most of the systems concentrated in Kigali City (some 119 of the 161 WWTWs). However, these tended to be small, often on-site, treatment systems designed to treat the wastewater of a hospital, hotel, resort, training institution, office complex, etc. The study also sampled the final effluent from some of the WWTWs and found that, of the 13 treatment works sampled, 5 exhibited no environmental or public health problems, 4 posed no environmental problems but required chlorination of the final effluent, 3 posed a serious health risk and urgent interventions were recommended, and 1 had an odour problem.
Mining and quarrying operations	Mines can be significant source of pollution and pollutants such as heavy metals, suspended solids, salinity, sulphates, and acidification are associated with mining activities. The impacts of mining on water quality is a major concern in Rwanda, especially on suspended sediments, but also arsenic in soils and stream sediments. There are some 102 mines registered with the

	Mining Authority (2015 count). The impacts of the many small mining operations are more difficult to control than the impacts from large mines that can afford to implement pollution control measures.
Coffee washing stations	Coffee plays a major role in the economy of Rwanda, contributing significantly to foreign exchange earnings and to the monetisation of the rural economy. However, concerns have been expressed about the impacts of coffee washing stations on receiving water streams. Coffee washing stations contribute significantly to the organic loads in receiving rivers and streams during the coffee harvesting season which runs from 15 March to 30 June each year.
Solid waste dumps and landfills	Solid waste dumps and landfills can also be regarded as point sources of pollution. Pollutants associated with landfills include organic wastes from decomposing organic wastes, heavy metals from corroding metallic objects and old batteries, waterborne pathogens from discarded diapers and sewage sludge, acidic waters, hydro-carbons and oils from used motor and cooking oils, etc. In Rwanda, unlined and unprotected landfills and solid waste disposal facilities pose a water and air pollution risk to nearby communities and ecosystems. It was highly recommended that properly designed landfills be installed for major urban centres to ensure that waste is properly collected, transported and safely disposed of, recycled or reused. These designs should specifically focus on preventing or mitigating liquid and gaseous emissions from landfills.

CHAPTER 2 WATER QUALITY MANAGEMENT IN RWANDA

Introduction	In this section we present information on legal and institutional framework guiding the management of water quality in Rwanda. We start with the fundamental law, key policies and strategic documents related directly to environment (including water quality) and finally to institutions involved in its management, as there is no specific law related to the management of the quality of water in the country.

2.1 Laws related to water quality management

Introduction	The constitution of Rwanda as amended in 2015 highlights the right of each citizen to live in a clean and healthy environment. The same constitution gives to the population of Rwanda the duty of safeguarding; protecting and promoting of environment while the state will ensure overall protection of environment (See Articles 22, 53 and 169 of the constitution).
Law on Environment (Law No 48/2018 of 13/08/2018)	This Law determines modalities protecting, conserving and promoting the environment. It provide for provide guidance on conservation and protection of built environment, focusing on the management of liquid and solid wastes, management of hazardous and toxic wastes and the management of electronic wastes.(Articles 17, 18, 19 and 20) as well as for prohibited acts, including prohibited acts in wetlands and protected areas, prohibited emission of noise, prohibited acts in protection of biodiversity and prohibitions related to chemicals and wastes (Article 42, 43, and 45))
Law determining the use and management of Water Resources in Rwanda (Law N°49/2018 of 13/08/2018)	This Law determines the use and management of water resources in Rwanda. It defines 'water' as a good belonging to the state public domain, recognizing the right to water for all. The Water Law provides a clear framework for the principles of integrated water resources management, including the prevention of pollution, and the principle of "user pays" and "polluter pays
Other laws and regulations in line with water quality management	Other laws and regulations such as the Code of Criminal Procedure, the Law governing the preservation of air quality and prevention of air pollution in Rwanda; Ministerial Order establishing the list of projects that must undergo environmental impact assessment, instructions, requirements and procedures to conduct environmental impact assessment; Ministerial Order Establishing Modalities of Inspecting Companies or Activities that Pollute the Environment and Ministerial Order Determining the list of Water Pollutants are in line with water quality management with key provisions that are directly related to water quality management. .

National strategies and policies relevant to water quality management

National Strategy for transformation (NST 1 2017-2024), Vision 2020 and EDPRSs	. The National Strategy for Transformation (NST1) aims to achieve economic growth and development founded on the private sector, knowledge and Rwanda's natural resources. NST 1 was developed based on EDPRS 2, Vision 2020 and SDGs. NST 1 recognises the importance of sustainable management and protection of environment as a driving force to achieve its targets. The wise utilisation of the natural resources was emphasised on in EDPRS 2 (2013-2018) in which the GoR planned to reach 100% of access to safe clean water and adequate sanitation countrywide. It is understood that by putting in place appropriate water supply, hygiene and sanitation infrastructure in rural and urban areas, the country will improve the quality of its water bodies. EDPRS 2 also complies with the targets of Vision 2020. Vision 2020 envisages to provide to all Rwandans with clean water, to protect water resources for pollution and to improve the collection, transport and disposal services of waste management across the country.
Other sectoral policies and strategies	Other sectoral policies and strategies in line with water quality management plan include: Vision 2020, the National Environment and Climate Change, National Water Resources Management Policy, National Water Supply Policy, National Sanitation Policy, Sustainable Development Goals (SDGs), among others. Detailed description of the above policies and strategies can be found in Water Quality Management: Identification of pollution hotspots report.

2.2 Institutions involved in water quality management

Water quality monitoring	In Rwanda, there are limited information on the collection and management of water quality data. Inconsistencies were noted in water quality sampling in terms of sampling sites, frequency of sampling and even in terms of the water quality variables to monitor. Some water quality data were collected by the University of Rwanda in collaboration with the former Ministry of Natural Resources and or with the former Rwanda Natural Resources Authority (RNRA).The newly created Rwanda Water Board will be the sole institution in charge of coordinating water quality monitoring in Rwanda
Institutions involved in aspects of water quality management	Many public institutions such as the Ministry of Environment, Ministry of Agriculture and Animal Resources, the Ministry of Health, Ministry of Infrastructure, Rwanda Water Resources Board, Rwanda Standards Board (RSB), Rwanda Environment Management Authority (REMA), Rwanda Green Fund (FONERWA) Water and Sanitation Corporate (WASAC), Rwanda Utility Regulatory Authority (RURA) are directly or indirectly involved in the management of water quality in Rwanda. Thus, this multi-

sectorial nature of managing of water quality in Rwanda makes it difficulty. However, recent reform made in by restructuring Ministry of Environment and establishment of RWB from dissolution of former RWFA, will speed up the envisaged targets in water quality management resulting to budget allocation.

CHAPTER 3 FRAMEWORK FOR WATER QUALITY MANAGEMENT

3.1 Framework for water quality management

Water quality management framework

The Source/pathway/receptor/use framework provided a useful framework to integrate the process and response components of water quality management, and for grouping water quality management options (Figure 4-2):

1. Production or **sources** of pollutants,
2. Delivery or **pathways** that pollutants follow to a surface water resource,
3. Transport and storage of pollutants within the receiving water resource (**receptor**), including transport in rivers and storage/transformations within lakes and reservoirs.
4. **Use** of the resource for various consumptive or non-consumptive uses.

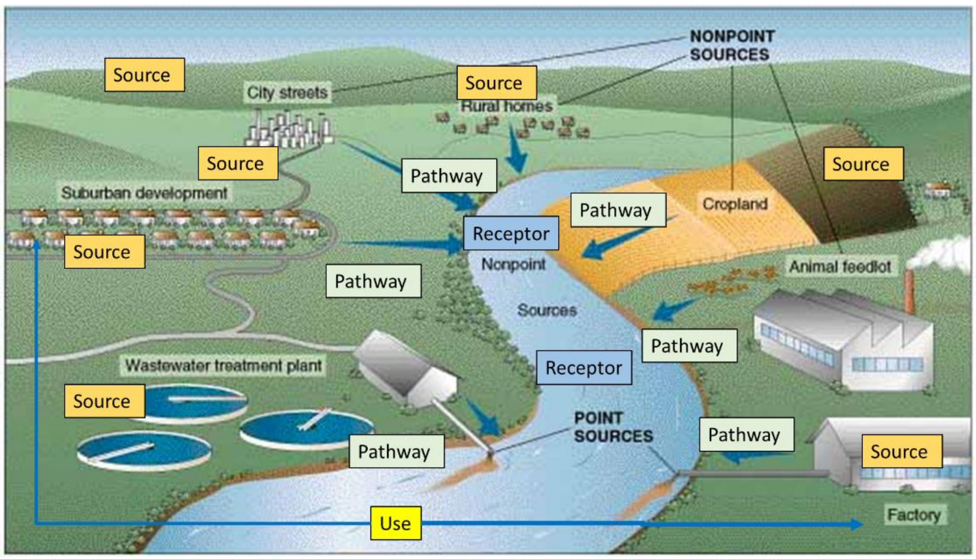

Figure 2: Illustration of the source / pathway / receptor / use framework for water quality management

Treatment train concept

Debo & Reese (2003) refers to this concept as the Treatment Train Concept within the context of urban runoff management. This is a useful approach because it recognises that it is only through a combination of various pollution management options employed within a particular catchment that pollution can be reduced to the maximum extent possible. The Treatment Train Concept is thought to have five major components: Education and prevention programmes, Runoff and load generation, Conveyance and pre-treatment, End treatment and/or attenuation, and In-stream and habitat programmes.

3.2 Selecting a suite of water quality management options

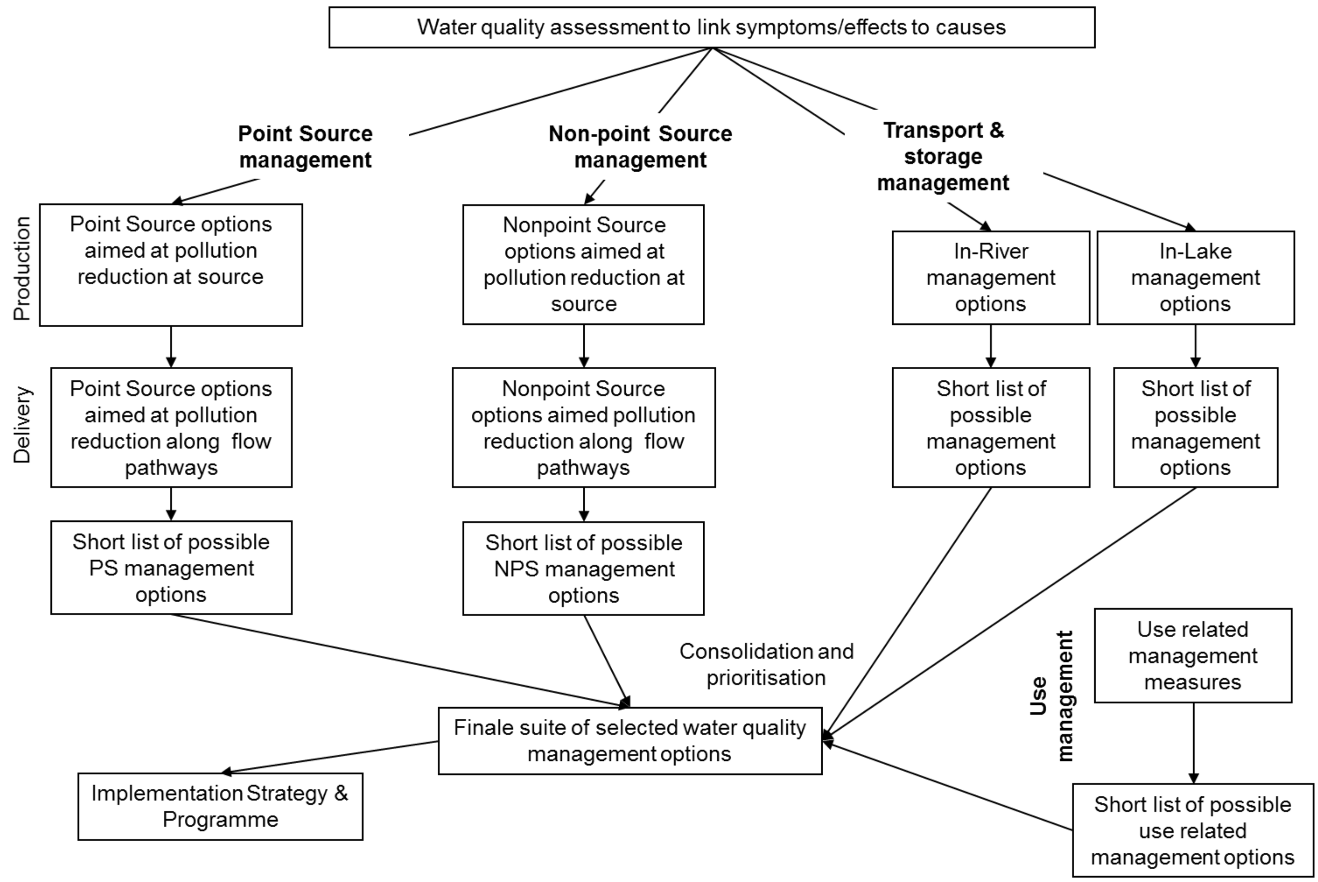

Figure 3: The process of identifying and selecting a suite of water quality management options

Water quality management framework

The process of selecting a suite of water quality management options is illustrated in Figure 4-2. The assessment of the water pollution and linking them to their root causes determines where attention should be focused in the treatment train (sources & pathways/transport & storage/use). The next basic step is to develop a first-cut laundry list of management options that address all the components of the water quality management framework. The different laundry lists are then combined and prioritised and a shortened list of options is then organised, analysed and prioritised to become the strategy and programme of actions that will be implemented in the short to medium term.

Production sources and pathways

The hierarchy of water quality management decision-making encourages managers to start at pollution prevention (source management) and waste minimization (pathway management). This is done by identifying a short list of possible options to manage point and/or nonpoint sources at source, and/or along the flow pathways. A water quality assessment study will provide guidance on how much of the pollutant loads originated from point or non-point sources and how much of effort should be expended to control these sources and the pathways. In general, it was found that sources and pathways are considered as a group. For example, to reduce point source impacts, advanced wastewater treatment (source reduction) is designed in combination with artificial wetlands (pathway reduction) to meet a final effluent discharge limit. The overall objective of these activities is to identify a short list of possible options to manage pollutant sources and pathways.

Transport and storage	A water quality assessment study also provides guidance on whether management in the receiving water body (transport and storage management) should be considered. These include in-river management options where the assimilative capacity of the river to reduce pollutant concentrations (transport management) or in-lake management options designed to reduce impacts, suppress internal loading, or reduce water retention time where possible (flushing). The objective of these activities is to identify a short list of possible in-river and in-lake options to manage the impacts of pollution.
Use modification	A water quality assessment study will also provide guidance on whether the use of the water resource should be modified to accommodate, in the short term, the negative impacts of pollution. These include options such as restricting certain activities in the receiving river or lake, or designing modular water treatment systems that can cope with high sediment loads during certain times of the year. The objective of this activity is to identify a short list of possible use modification options to cope with the negative impacts of poor water quality.
Suite of management options	The last step is to consolidate and prioritise the various management options identified in the previous steps. The previous steps considered mostly the technological merits of various management options. In this step aspects such as social and economic considerations, urgency for taking action, available resources, and institutional arrangements are also considered to derive a suite of options that can be implemented at various stages of the treatment train. This list forms the foundation for an implementation strategy and programme.
Time horizon	The time horizon for control should also be considered. In the short term, it may be more practical to implement in-river or in-lake controls because it often yields immediate results and mitigation of pollution symptoms. At the same time, catchment control measures such as structural and non-structural nonpoint source control measures can be implemented. These often take a long time to develop and implement but have longer-term positive impacts.

3.3 Role of a water quality assessment study

3.4 How to use the guideline document

Introduction	The following chapters broadly follows the treatment train described in the previous section. The chapters describe options for managing point sources, options for managing nonpoint sources, options for managing water quality in in receptor water bodies, and lastly options that water users can consider for dealing with polluted water. Each chapter also describes the criteria that can be used to evaluate different water quality management options.
Common chapter layout	The chapters and sections that describe management options have a common layout. The first part provides a brief introduction to the chapter topic, this is followed by a list of common management options. For each management option a short description is provided, if an example of the management option is provided in the Appendices, followed by a reference to information sources that be consulted for more detailed information. The last section of the chapter provides a summary assessment of the different management options described in the chapter.

3.5 What is not in this guideline document

No detailed design criteria	This document cannot be used to design a specific intervention because the design depends on site specific situation, i.e. the nature of the problem, the load reduction required, high tech of appropriate technology requirements, etc. Design information should be sourced from books or reports, some of which are listed in this document.

3.6 Knowledge base of Water Quality Management options

Below are sources of information on water quality management options that the authors have found to be useful in the compilation of this guideline document. This list is by no means exhaustive and the reader is encouraged to visit the web sites listed, consult some of the references listed in the books and reports referred to below, as well as those listed in the Reference list of this report.

Rwandan reports

REMA practical tools series (2010):

- Practical Tools for Sectoral Environmental Planning.
- Practical Tools on Land Management - GPS, Mapping and GIS.
- Practical Tools on Restoration and Conservation of Protected Wetlands.
- Practical Tools on Sustainable Agriculture _Final Version.
- Practical Tools on Soil and Water Conservation Measures.
- Practical Tools on Agroforestry.

- Practical Tools on Irrigated Agriculture on Non-protected Wetlands.
- Practical Tools on Soil Productivity and Crop.
- Practical Technical Information on Low-cost Technologies - Composting Latrines & Rainwater Harvesting Infrastructure.
- Practical Tools on Water Monitoring Methods and Instrumentation.
- Practical Tools on Small-scale Incinerators for Biomedical waste management.
- Practical Tools on Solid Waste Management of Imidugudu, Towns and Cities
- General guidelines and procedures for Environmental Impact Assessment (EIA).

Fresner, Johannes (Dr.). 2017. Resource efficient and cleaner production investment guidelines for new industries. Final Report Part 2 (Pages 122-149). STENUM GMBH, Graz, Austria.

Rwanda Cleaner Production Center (RCPC). 2015. Resource efficient and cleaner production guidance manual for wet textile processing industry.

International reports/books

Campbell, N, D'Arcy, B., Frost, A., Novotny, V. and Sansom, A. (2004). Diffuse Pollution - An introduction to the problems and solutions. IWA Publishing, London.

Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). Restoration and management of lakes and reservoirs. 3rd Edition. CRC Press, Taylor & Francis Group, Boca Raton.

Debo, T.N. and Reese, A.J. (2003). Municipal Stormwater Management. Lewis Publishers, Boca Raton.

Evans, B.M. & Corradini, K.J. (2001). BMP pollution reduction guidance document. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: www.predict.psu.edu/downloads/BMPManual.pdf

Haestad Methods & Durrans, S.R. (2003). Stormwater conveyance modelling and design. First edition. Haestad Methods, Haestad Press, Waterbury.

Holdren, C., Jones, W. and Taggert, J. (2001). Managing Lakes and Reservoirs. North American Lake Management Society and Terrene Institute, in cooperation with the Office of Water Assessment, Watershed Protection Division, USEPA, Madison, WI.

Moss, B. (1998). Shallow lakes, Biomanipulation and Eutrophication. Scope Newsletter Number 29. Available online: http://www.ceep-phosphates.org/

Mudgeway, L.B., Duncan, H.P., McMahon, T.A. & Chiew, F.H.S. (1997). Best practice environmental management guidelines for urban stormwater.

Background report to the Environmental Protection Authority, Victoria, Melbourne Water Corporation and the Department of Natural Resources and Environment, Victoria. Cooperative Research Centre for Catchment Hydrology. Available online: http://www.catchment.crc.org.au

Muthukrishnan, S., Madge, B., Selvakumar, A., Field, R. & Sulivan, D. The use of Best Management Practices (BMPs) in Urban Watersheds. EPA/600/R-04/184. Online: http://www.epa.gov/ORD/NRMRL/pubs/600r04184/600r04184.pdf

Ryding, S-O. and Rast, W. (Eds.) (1989). The control of Eutrophication of Lakes and Reservoirs. Man and the Biosphere Series. UNESCO, Paris.

Von Sperling, M. & Chernicharo, C.A.L. (2005). Biological wastewater treatment in warm climate regions. IWA Publishing, London. 1460 pp.

Internet resources

SCOPE Newsletter - Centre European d'Etudes des Polyphosphates (promotes the sustainable use of phosphates through recovery and recycling).

Online: http://www.ceep-phosphates.org/

Land and Water Australia. National Eutrophication Management Program.

Online: http://www.rivers.gov.au/research/nemp/index.htm

Massachusetts Nonpoint Source Pollution Management Manual - BMP Selector tool.

Online: http://projects.geosyntec.com/megamanual/default.html

Natural Environment Research Council, Centre for Ecology and Hydrology - compendium of some diffuse pollution control web sites.

Online: www.dorset.ceh.ac.uk/River_Ecology/River_Systems/Diffuse_Pollution.htm

The Ohio State University. College of Food, Agricultural, and Environmental Sciences. Ohioline Factsheets.

Online: http://ohioline.osu.edu/lines/facts.html

UN Environmental Programme, Division of Technology, Industry, and Economics. Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication. Available

Online: http://www.unep.or.jp/ietc/Publications/techpublications/TechPub-11/index.asp

[Other related articles in the UN IETC archive can be found at http://www.unep.or.jp/ietc/knowledge/index.asp#start]

US Department of Agriculture. Agricultural Research Service. Agricultural Phosphorous and Eutrophication.

Online: http://www.unep.or.jp/ietc/kms/data/604.pdf

US Department of Agriculture. Natural Resources Conservation Service. National Conservation Practice Standards.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

US Department of Agriculture. Natural Resources Conservation Service. Nutrient & Pest Management.

Online: http://www.nrcs.usda.gov/technical/nutrient.html

US Department of Agriculture. Natural Resources Conservation Service. Water Related Best Management Practices in the Landscape.

Online: http://www.wsi.nrcs.usda.gov/products/UrbanBMPs/

US Department of Agriculture. National Agricultural Library. Water Quality Information Centre.

Online: http://www.nal.usda.gov/wqic/

US Environmental Protection Agency - Nonpoint Source News-Notes

Online: http://www.epa.gov/OWOW/info/NewsNotes/

World Overview of Conservation Approaches and Technologies.

Online: http://www.wocat.org/default.asp

Wyoming Department of Environmental Quality. Water Quality Division. Watershed Program. Online: http://deq.state.wy.us/wqd/watershed/

CHAPTER 4 OPTIONS TO MANAGE POINT SOURCES

5.1. Introduction

Point sources of pollution within the context of catchment management, usefully refers to a continuous discharge of effluent to a water body, such as a municipal sewage effluent, or an industrial effluent. The term ‘point source’ also means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are discharged. The term does not include agricultural stormwater and return flows from irrigated agriculture.

A wastewater treatment system is generally designed to meet a specific effluent standard specified by Rwanda Standards Board. In setting the effluent standard, the Buro generally considers the impact on the receiving water body. The design of the treatment works to meet pollutant removal targets considers both the removal of pollutants during the treatment process as well as any removal that can be accomplished along the discharge pathway before the effluent reaches the receiving water body. Pollutant reduction at source and pathway are therefore considered at the same time.

Guidelines described here below apply for facilities that have either direct or indirect discharge of wastewater from utility operations or stormwater to the environment. These guidelines are also applicable to industrial discharges to sanitary sewers that discharge to the environment without any treatment. Effluent discharge may include contaminated wastewater from utility operations, stormwater, and sanitary sewage. It provides information on common techniques for wastewater management, water conservation, and reuse that can be applied to a wide range of industry sectors. Annex I provides common approaches for Industrial Wastewater Treatment while Annex VI provides detail options and the techniques for managing each category of point source.

5.2. Guidelines for management approach to all wastewater generating facilities

Facilities with the potential to generate wastewater, sanitary (domestic) sewage, or stormwater should incorporate the necessary precautions to avoid, minimize, and control adverse impacts to human health, safety, or the environment.

Facilities should:

- Understand the quality, quantity, frequency and sources of liquid effluents in its installations. This includes knowledge about the locations, routes and integrity of internal drainage systems and discharge points;
- Plan and implement the segregation of liquid effluents principally along industrial, utility, sanitary, and stormwater categories, in order to limit the volume of water requiring specialized treatment. Characteristics of individual streams may also be used for source segregation;
- Identify opportunities to prevent or reduce wastewater pollution through measures such as recycle/reuse within their facility, input substitution, or process modification (e.g. change of technology or operating conditions/modes);
- Assess compliance of their wastewater discharges with the applicable: (i) discharge standard (if the wastewater is discharged to a surface water or sewer), and (ii) water quality standard for a specific reuse (e.g. if the wastewater is reused for irrigation).

Additionally, the generation and discharge of wastewater of any type should be managed through a combination of:

- Water use efficiency to reduce the amount of wastewater generation;
- Process modification, including waste minimization, and reducing the use of hazardous materials to reduce the load of pollutants requiring treatment;
- If needed, application of wastewater treatment techniques to further reduce the load of contaminants prior to discharge, taking into consideration potential impacts of cross-media transfer of contaminants during treatment (e.g., from water to air or land)

When wastewater treatment is required prior to discharge, the level of treatment should be based on:

- Whether wastewater is being discharged to a sanitary sewer system, or to surface waters;
- National and regional (EAC) standards as reflected in permit requirements and sewer system capacity to convey and treat wastewater if discharge is to sanitary sewer;
- Assimilative capacity of the receiving water for the load of contaminant being discharged wastewater if discharge is to surface water;
- Intended use of the receiving water body (e.g. as a source of drinking water, recreation, irrigation, navigation, or other); and
- Presence of sensitive receptors (e.g., endangered species) or habitats

5.3. Guidelines for maintaining the quality of receiving environment

5.3.1. Discharge to Surface Water

Discharges of treated wastewater, wastewater from utility operations or stormwater to surface water should not result in contaminant concentrations in excess of national ambient water quality criteria or, in the absence of local criteria, other sources of ambient water quality. Additional considerations that should be included in the setting of utility-specific performance levels for wastewater effluents include:

- Compliance with national or regional standards for wastewater discharges ;
- Temperature of wastewater prior to discharge does not result in an increase greater than 3°C of ambient temperature at the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use and assimilative capacity among other considerations.

5.3.2. Discharge to Wastewater Treatment Systems

Discharges of industrial wastewater, sanitary wastewater, wastewater from utility operations or stormwater into public or private wastewater treatment systems should:

- Meet the pre-treatment and monitoring requirements of the wastewater treatment system into which it discharges;
- Not interfere, directly or indirectly, with the operation and maintenance of the collection and treatment systems, or pose a risk to worker health and safety, or adversely impact characteristics of residuals from wastewater treatment operations;
- Be discharged into municipal or centralized wastewater treatment systems that have adequate capacity to meet local regulatory requirements for treatment of wastewater generated from the utility. Pretreatment of wastewater to meet regulatory requirements before discharge from the utility site is required if the municipal or centralized wastewater treatment system receiving wastewater from the utility does not have adequate capacity to maintain regulatory compliance.

5.3.3. Land Application of treated effluent

The quality of treated wastewater, wastewater from utility operations or stormwater discharged on land, including wetlands, should be established based on national regulatory requirements. . Where land is used as part of the treatment system and the ultimate receptor is surface water, wastewater discharge standards should apply.

Potential impact on soil, groundwater, and surface water, in the context of protection, conservation and long term sustainability of water and land resources should be assessed when land is used as part of any wastewater treatment system.

5.3.4. Use of Septic Systems for treatment and disposal of domestic sewage

Septic systems are the commonly used for treatment and disposal of domestic sewage in areas with no sewerage collection networks (general case in Rwanda). Septic systems should only be used for treatment of domestic sewage and unsuitable for industrial wastewater treatment. When septic systems are the selected form of wastewater disposal and treatment, they should be:

- Properly designed and installed in accordance with local regulations and guidance to prevent any hazard to public health or contamination of land, surface or groundwater.;
- Well maintained to allow effective operation;
- Installed in areas with sufficient soil percolation for the design wastewater loading rate.; and
- Installed in areas of stable soils that are nearly level, well drained, and permeable, with enough separation between the drain field and the groundwater table or other receiving waters

5.4. Guideline for Wastewater Management

Wastewater management includes water conservation, wastewater treatment, stormwater management, and wastewater and water quality monitoring.

5.4.1. Industrial Wastewater

Industrial wastewater generated from industrial operations includes wastewater from utility operations, runoff from process and materials staging areas, and miscellaneous activities including wastewater from laboratories, equipment maintenance shops, etc. Table in Annex II shows the common pollutants found in industrial wastewater while Table in annex I proposes industrial wastewater treatment technologies

On the other hand, wastewater from industrial utility operations such as cooling towers and demineralization systems may result in high rates of water consumption, as well as the potential release of high temperature water containing high dissolved solids, residues of biocides, residues of other cooling system anti-fouling agents, etc. Recommended water management strategies for utility operations include:

- Adoption of water conservation opportunities for facility cooling systems as provided in the section below;

i. Use of heat recovery methods (also energy efficiency improvements) or other cooling methods to reduce the temperature of heated water prior to discharge to ensure the discharge water temperature does not result in an increase greater than 3°C of ambient temperature at the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity among other considerations;

ii. Minimizing use of antifouling and corrosion inhibiting chemicals by ensuring appropriate depth of water intake and use of screens. Least hazardous alternatives should be used with regards to toxicity, biodegradability, bioavailability, and bioaccumulation potential. Dose applied should accord with national or international regulatory requirements and manufacturer recommendations;

iii. Testing for residual biocides and other pollutants of concern should be conducted to determine the need for dose adjustments or treatment of cooling water prior to discharge.

5.4.2. Stormwater Management

Stormwater includes any surface runoff and flows resulting from precipitation, drainage or other sources. Typically stormwater runoff contains suspended sediments, metals, petroleum hydrocarbons, Polycyclic Aromatic Hydrocarbons (PAHs), coliform, etc. Rapid runoff, even of uncontaminated stormwater, also degrades the quality of the receiving water by eroding stream beds and banks. In order to reduce the need for stormwater treatment, the following principles should be applied:

- Stormwater should be separated from process and sanitary wastewater streams in order to reduce the volume of wastewater to be treated prior to discharge;
- Surface runoff from process areas or potential sources of contamination should be prevented;
- Where this approach is not practical, runoff from process and storage areas should be segregated from potentially less contaminated runoff;
- Runoff from areas without potential sources of contamination should be minimized (e.g. by minimizing the area of impermeable surfaces) and the peak discharge rate should be reduced (e.g. by using vegetated swales and retention ponds);
- Where stormwater treatment is deemed necessary to protect the quality of receiving water bodies, priority should be given to managing and treating the first flush of stormwater runoff where the majority of potential contaminants tend to be present;
- When water quality criteria allow, stormwater should be managed as a resource, either for groundwater recharge or for meeting water needs at the facility;
- Oil water separators and grease traps should be installed and maintained as appropriate at refueling facilities, workshops, parking areas, fuel storage and containment areas.;
- Sludge from stormwater catchments or collection and treatment systems may contain elevated levels of pollutants and should be disposed in compliance with local regulatory requirements, in the absence of which disposal has to be consistent with protection of public health and safety, and conservation and long term sustainability of water and land resources.

5.4.3. Municipal wastewater

Municipal wastewater may include effluents from domestic sewage, food service, and laundry facilities serving site employees. Miscellaneous wastewater from laboratories, medical infirmaries, water softening etc. may also be discharged to the sanitary wastewater treatment system. Recommended municipal wastewater management strategies include:

- Segregation of wastewater streams to ensure compatibility with selected treatment option (e.g. septic system which can only accept domestic sewage);
- Segregation and pretreatment of oil and grease containing effluents (e.g. use of a grease trap) prior to discharge into sewer systems;
- If sewage from municipal areas is to be discharged to surface water, treatment to meet national or regional standards for wastewater discharges is required;
- If sewage from the municipal areas is to be discharged to either a septic system, or where land is used as part of the treatment system, treatment to meet applicable national or regionall standards for wastewater discharges is required;
- Sludge from sanitary wastewater treatment systems should be disposed in compliance with national regulatory requirements, in the absence of which disposal has to be consistent with protection of public health and safety, and conservation and long term sustainability of water and land resources, a non-hazardous waste.

5.5. Effluent Quality Monitoring

A wastewater and water quality monitoring program with adequate resources and management oversight should be developed and implemented to meet the objective(s) of the monitoring program. The wastewater and water quality monitoring program should consider the following elements:

- ***Monitoring parameters***: The parameters selected for monitoring should be indicative of the pollutants of concern from the process, and should include parameters that are regulated under compliance requirements. Table II shows key parameters to consider for different industrial wastewater processes while Table III shows parameters to consider for municipal wastewater;

- ***Monitoring type and frequency***: Wastewater monitoring should take into consideration the discharge characteristics from the process over time. Monitoring of discharges from processes with batch manufacturing or seasonal process variations should take into consideration of time-dependent variations in discharges and, therefore, is more complex than monitoring of continuous discharges. Effluents from highly variable processes may need to be sampled more frequently or through composite methods. Grab samples or, if automated equipment permits, composite samples may offer more insight on average concentrations of pollutants over a 24-hour period. Composite samplers may not be appropriate where analytes of concern are short-lived (e.g., quickly degraded or volatile);
- ***Monitoring locations:*** The monitoring location should be selected with the objective of providing representative monitoring data. Effluent sampling stations may be located at the final discharge, as well as at strategic upstream points prior to merging of different discharges. Process discharges should not be diluted prior or after treatment with the objective of meeting the discharge or ambient water quality standards;
- ***Data quality***: Monitoring programs should apply internationally approved methods for sample collection, preservation and analysis. Sampling should be conducted by or under the supervision of trained individuals. Analysis should be conducted by entities permitted or certified for this purpose. Sampling and Analysis Quality Assurance/Quality Control (QA/QC) plans should be prepared and, implemented. QA/QC documentation should be included in monitoring reports.

CHAPTER 5 OPTIONS TO MANAGE NON-POINT SOURCES

5.1 Introduction

What are non-point sources? Nonpoint source (NPS) pollution refers to pollution that cannot be traced to a specific origin or starting point but flow from many different sources. NPS pollutants are generally carried off the land surface by stormwater runoff. Examples of nonpoint sources are return flows from irrigated agriculture, stormwater runoff from other agricultural lands and concentrated agricultural operations, runoff from unconfined animal pastures and range land, runoff from urban areas and informal settlements, seepage from failing septic tanks and leaching from septic tank effluent into groundwater, wet and dry atmospheric deposition over water surfaces, and flow from abandoned mines and road surfaces.

Key characteristics of nonpoint sources (D'Arcy, 2013)

- Diffuse discharges enter the receiving surface waters in a diffuse manner at intermittent intervals that are related mostly to the occurrence of meteorological events;
- Waste generation (pollution) arises over an extensive area of land and is in transit overland before it reaches surface waters or infiltrates into shallow aquifers;
- Diffuse sources are difficult or impossible to be monitored at the point of origin;
- Unlike traditional point sources where treatment is the most effective method of pollution control, abatement of diffuse load is focused on land and runoff management practices;
- Compliance monitoring is carried out on land rather than in water;
- Water quality impacts are assessed on a catchment scale;
- Waste emissions and discharges cannot be measured in terms of effluent limitations;
- The extent of diffuse waste emissions (pollution) is related to certain uncontrollable climatic events, as well as geographic and geologic conditions and may differ greatly from place to place and from year to year;
- The most important pollutants from diffuse sources subject to management and control are suspended solids, nutrients, faecal pathogens and toxic compounds.

Activities associated with NPS pollution

The sources of nonpoint nutrient pollution include activities such as fertilisation of crops and urban parks and lawns, leaking or surcharging sewers, washoff of animal manure, etc. The pathways are generally overland flow resulting from irrigation or stormwater runoff, stormwater canals, etc.

Nonpoint sources can be characterised as follows (Campbell et al., 2004):

- Diffuse discharges that enter receiving water bodies in a diffuse manner at intermittent intervals, mostly related to the occurrence of rainfall events,
- Pollution that arises over an extensive area of land and is in overland transit before reaching surface waters,
- The origin of diffuse sources are difficult to monitor,
- Abatement of nonpoint source loads is focussed on land and runoff management practices,
- Water quality impacts are generally assessed on a catchment scale, and

- Waste emissions and discharges cannot be measured in terms of effluent limitations.

Key non-point sources of pollution in Rwanda

Landuse activities such as road construction, mine drainage, rainwater runoff from city streets (that is not collected instorm drains), from agriculture and from many rural villages, produce water pollution that does not come from any specific pipe or channel but instead tends to be dispersed across the landscape. Therefore it cannot be easily measured because of the 'diffuse' nature of this type of pollution, which is collectively called 'non-point source' (NPS) pollution. This guideline will be limited to sources such diffuse urban storm water and agriculture non-point sources.

5.2 Guidelines for controlling agriculture pollution

As Rwanda modernizes into a knowledge-based economy, agriculture remains the backbone for sustained economic growth, providing high quality livelihoods, and living standards for the population. However, agriculture has much to contribute to water pollution through land tillage, application of pesticides and fertilization. The need to increase crop productivity has led to extensive use of pesticides, fertilizers and promotion of irrigated agricultural practices. Livestock keeping also has similar kind of activities that pollute water bodies by degrading river and lakes banks in the cause of watering process, and through contamination with acarasides and pesticides used in livestock. On the other hand, fishery sector pollutes water through wastewaters released from aquaculture effluents and illegal use of organicides. Table in annex VII provides common pollutants from agricultural activities

6.2.1. Guidelines for erosion control at farm level

Landuse such as increased land cover vegetation generally leads to decreased runoff and reduced soil erosion. A small change in land-use practices (crop type, field size, ploughing, moving field boundaries away from streams, etc.) can significantly affect soil erosion rates (Van Rompaey et al., 2002). Below is a variety of land management approaches that farmers and cooperatives can apply to reduce soil erosion and soil loss from agricultural land. Extensive information on integrated soil management and conservation practices can be found in FAO (2000) and CROM DSS (RWB, 2019

6.2.1.1. Conservation agriculture

Conservation agriculture combines minimum or no-till-systems with measures to optimize the protective cover of living vegetation (including cover crops), mulch and resulting litter layer, as well as crop diversification to make better use of the soil profile for moisture and nutrients through alternating species. It is characterized by three linked principles, namely:

(i) minimum mechanical soil disturbance,

(ii)permanent organic soil cover, and

(iii) diversification of crop species grown in sequences and/or associations

Conservation agriculture uses a variety of techniques to reduce soil erosion during all stages of ploughing, planting, harvesting and fallowing. This can include:

- ***Contour farming***: Farmers should avoid ploughing up and down the slope on smaller plots on sloping land, but rather should plough parallel to the slope. This provides an effective barrier to runoff that would otherwise run downhill and carry eroded sediment.

Figure 4: An effective contour ploughing to control erosion

- ***Mulching and crop residue*** – This is the practice of spreading straw, crop residue, or other organic matter over the soil. Use of mulch and crop residue has four major advantages for farmers:(i) it conserves water in the soil by reducing evaporation; (ii) organic mulch and crop residues add carbon to the soil; (iii) it reduces runoff and increases water infiltration into the soil and (iv) reduces erosion and soil loss. Mulch is usually organic material such as straw but in some cases, plastic mulch is used,

- ***Terracing*** – has been carried out in Rwanda for last decades. Terracing on mountainous and steep land is the most effective way to control erosion. Figure below shows narrow cut terracing which is appropriate to a land with slope varying between 40-60%

- ***Buffer strips and field borders* –** are vegetated strips of land used to prevent eroded soil from being carried off the field or from one field to the next. Buffer strips may be grass, or hedgerows of shrubs or bushes);
- ***Grassed waterways*** – are broad, shallow channels, vegetated with grass or legumes. They are designed to carry large volumes of water from parcels of land to nearby water bodies and to prevent rills and gully formation. Badly managed drainage channels cause large amounts of erosion and soil loss, whereas well-managed drainage channels minimize soil loss.

Figure 6: Grasses planted on the ridges helps to stabilize it and prevent erosion

6.2.1.2. Consolidated plots

On consolidated plots, field surfaces become larger and farmers should pay attention to drainage channels. Recommendations for the maintenance of grassed waterways may include:

- Repair any eroded spots as soon as possible and check the waterway after heavy rains.
- Trim grass to promote a good, strong sod and to prevent the waterway from becoming blocked.
- Keep cattle out of the waterway. Their hooves can puncture the sod, giving erosion a place to start.
- Do not use your waterway as a road. Tyre ruts damage the sod where erosion can begin.
- Keep an uncultivated strip, at least 3 m wide, on each side of the waterway for stability.
- Do not dump rocks, dead trees, or other items into the waterway

6.2.1.2. Large Scale erosion Control

Recently, the Government of Rwanda has embarked with large-scale catchment management practices in key catchments with serious water erosion problems. A comprehensive soil erosion control system was developed that is suited to the socio- economic conditions of the catchments and further details can be found through CROM DSS developed and operated by Rwanda Water Resources Board.

6.2.2. Reasonable fertilisation

6.2.2.1. Combined organic and chemical fertilizer use

In recent years, coordinated use of chemical and organic fertilizers is very popular in Rwanda with crop intensification program. Although lower in nutrients, organic fertilizer releases nutrients more slowly and provides long-term nutrient supply not only of N and P but also of calcium, sulphur, boron, iron and other micronutrients required by crops. Because organic fertilizer is slow acting, its use alone may not satisfy all nutrient needs for the rapid growth of crops. Therefore the combination of organic and inorganic fertilizers makes excellent sense for farmers and reduces costs relative to use of only mineral fertilizers

6.2.2.2. Balanced fertilization and economic benefits

Balanced fertilization refers to the combination of agronomic measures that support high levels of crop production, maintains soil fertility, minimizes nutrient losses to groundwater, surface water and to the air, and protects the ecological environment. Additionally, farmers can obtain economic benefits from balanced fertilization

6.2.2.3. Composting to produce organic fertilizer

Use of organic fertilizer is an important measure to increase crop production and income. Manure should not be applied before composting, especially for leaf vegetables because of the possible contamination of food with pathogens. Manure can be divided into three types – 'fresh' (non-composted), composted and aerobic or anaerobic digested manure. Composted manure should have a light, fluffy texture; anaerobic digested manure is handled as a semi-liquid (slurry). Rwanda needs to develop Manure Composting Standard to illustrate specific requirements for composted manure.

Figure 7: Quality compost has no odder, feels spongy, and is friable when clenched with fingers in your palm

6.2.2.4. Developing a fertilizer application programme at the farm level

Type of fertilizer – Nitrogen, phosphorus and potassium are the three important elements for crop growth. These are applied in a scientific way according to the actual needs of each type of crop, soil condition, and according to the farming system used. An important means of maintaining soil fertility is the use of organic fertilizer such as organic manure and crop residues (such as straw) in combination

6.2.2.5. Other factors to be considered by farmer

- *Crop and yield target* – Different crops have varying nutrient needs for nitrogen, phosphate or potassium. The higher the crop-yield target, the higher the fertilizer rate because the crop needs more nutrient to achieve the higher yield.
- *Soil nutrient content* – Soil contains many essential nutrients required by crops. However, not all the nutrients in soil are available to crops; the amount of nutrient in soil that a crop can utilize is called 'available nutrients'. Available nutrients are determined by soil testing, which are then specified in 'milligram of nutrient per kilogram of soil'. Soil testing should be carried out before deciding on fertiliser application.
- *Fertilizer nutrient recovery* – The amount of fertilizer applied should be the difference between the amount of nutrient required by the crop and the amount of nutrient found in the soil. Fertilizer applied to soil is never fully used by crops; the percentage of fertilizer nutrients utilized is variable and is called 'nutrient recovery efficiency'. Nutrient recovery efficiency is generally about 30–40 percent for nitrogen, 15–25 percent for phosphate and 60–80 percent for potash by the first field crop. Information on nutrient efficiency can be obtained from Rwanda Agriculture Board.

- *Fertilization scheduling*: Crops require nutrients at specific times in their growth cycle. These are referred to as ‘crop critical periods’. If there is a deficit of nutrient at these critical periods, the crop suffers and usually cannot make up the loss with the later addition of extra nutrient. Therefore, scheduling fertilizer application in the correct amounts is an essential part of fertilizer management.

6.2.3. Guidelines for application of commonly-used pesticides

The environmental and human-health impacts of pesticides abuse can be severe, with farmers’ use of pesticides greatly exceeding the amount required to control pests. This is an unnecessary expense for farmers, environmentally damaging and adds to farmers’ health problems.

6.2.3.1. Integrated pest management (IPM)

IPM is a pest control strategy that uses a variety of complementary strategies that together, reduce pests, costs and the use of chemical pesticides. Farmers practising IPM follow four steps (USEPA, 2010):

- *Set action thresholds:* Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest does not mean control is needed. The level at which pests will become an economic threat is critical to guide future pest control decisions.
- *Monitor and identify pests*: Not all insects, weeds or other living organisms require control. Many organisms are innocuous, some even beneficial. IPM programmes work to monitor and accurately identify pests, so appropriate decisions can be made for their control in conjunction with action thresholds. This monitoring and identification ensures that pesticides will be used only when they are needed and that only the right pesticide will be used.
- *Prevention*: The first step in an IPM programme is to take preventative measures such as rotating between different crops, selecting pest-resistant varieties and planting pest-free rootstock. These control methods can be effective and cost- efficient and present little to no risk to people or the environment.
- *Control*: Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programmes evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identification, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

6.2.3.2. Disposal of pesticides and pesticide containers

Storage and disposal of pesticide waste and empty containers is a major source both of environmental pollution and of impacts on farmers’ health. This is a particular problem in developing countries, including Rwanda. The key factors include:

Storage:

- Unused pesticides should be kept in their original packaging, sealed and stored in a locked, secure location to prevent accidental use by unqualified people, especially children.
- Pesticides should never be stored in other containers. It is strictly prohibited to use empty drinking bottles to store pesticides.

  Disposal

- Never dispose of old or unused pesticides near wells, watercourses, ponds or irrigation channels and follow label instructions;
- Old pesticide containers should never be used for other purposes;
- Obsolete pesticides should be recovered by government, sales store, or manufacturers. Consult your local agricultural station for information;
- Follow 'The regulation for safe application of pesticides ;
- Use recycling facilities if these exist; otherwise: glass containers should be washed three times then smashed and buried. Burial sites should be far away from homes and farm buildings; metal cans and containers should be rinsed three times then pressed flat and buried;
- plastic containers should be rinsed three times, smashed, flattened or cut up, then buried
- paper containers should be washed three times and then burned or buried. Burning should be carried out far away from homes and farm buildings; farmers and family members should stay far away from the smoke

6.2.4. Guidelines to prevent and remedy water pollution from aquaculture.

6.2.4.1. Prevention: Best management practices for aquaculture (FAO, 2009).

Best management practices ensure both development of the fishery and protection of the surrounding aquatic environment include:

- Establishment of a suitable production biomass based on the environmental capacity of the water body.
- Rational planning of cage aquaculture to prevent eutrophication of local waters. When fish are grown in cages, the bottom under the cage and the water body will be cleaned naturally when the cage is removed if the current is strong enough, or there are adequate water exchange rates.
- Standardized feed inputs to prevent pollution of the surrounding water, which is usually caused by excess feed. This is achieved by: (i) selection of the correct type of feed; (ii) carrying out feeding according to the aquaculture manual and or technical guidance, for example feeding tables or use simple sensors that inform when the fish are not eating anymore; and (iii) not using excessive amounts of feed. Waste feed pollutes water quality and is an extra expense for the operator.
- Prevention of water pollution by correct use of fish drugs for prevention and control of fish diseases. Do not use prohibited substances, select the appropriate fish drugs and use these correctly. Most

important, measures should be taken to prevent disease. For example, avoid stressing the fish by maintaining reasonable fish densities and ensuring a biosecurity framework is in place.

- Creation of non-infected aquaculture areas. This involves the combination of modern breeding techniques and control of fish diseases that minimize or avoid the use of drugs. This may include the use of biological and ecological control techniques to control fish diseases.
- Developing industrial-scale aquaculture based on water recycling. Uncontrolled, large-scale aquaculture can lead to severe water pollution.

6.2.4.1. Remediate by removing pollutants from the aquaculture system

- It is possible to precipitate nutrients and suspended particles from fishponds using salts containing cations such as iron, calcium and aluminum. These combine with the inorganic phosphorus or phosphorus-rich particles in the water and precipitate these to the bottom of the pond or cage. Commonly, chemical additives used for this purpose include ferric chloride, aluminum salts, clay and lime. With lime, however, care must be taken to ensure that the pH does not become excessively basic (high pH).;
- When the pond is drained the accumulated sludge on the bottom of the pond is removed and may be placed on the field as a source of organic fertilizer. These techniques require, however, special knowledge and skills that are beyond the subject matter in this guideline;
- Use aquatic vegetation for effective removal of nutrients from water. For example, macrophytes in lakes and ponds can assimilate large quantities of nutrients. However, at the time of year when these plants begin to die, they must be taken out of the water to ensure that the nutrients are not re-released back into the water during plant decay;
- Use floating rafts for biocleaning. Plants are grown on rafts; their roots in the water absorb phosphorus and nitrogen. These plants can be commercially harvested and can include flowers and some types of vegetables.

6.2.5.. Monitoring of agricultural pollution

6.2.5.1. Introduction

According to water quality monitoring data, some water bodies in Rwanda are threatened by eutrophication and reduced qua of drinking water (RWFA, 2019). Groundwater quality is not well known however, there is fear that its quality is deteriorating. Monitoring of nutrients, other agricultural chemicals (such as pesticides), and suspended matter is important not only to reveal the physico-chemical composition of water, but also to assist decision-makers identify the causes and to implement appropriate remedial action.

Monitoring and assessment of agricultural non-point sources pollution is inexistent in Rwanda because there is no long term non-point sources monitoring network or measurement at national or catchment levels.

6.2.5.2. Indicators used to assess water pollution

Currently, indicators used for regular monitoring of surface water in Rwanda include: water temperature; pH; dissolved oxygen; EC, Turbidity, COD; BOD5; NH3-N; TP; TN; Cu; Zn; Fluoride; arsenic; Cd; Cr; Pb; nitrate, sulfate, chloride, Fe and Mn.

There is a need to develop a programme to monitor supplement measurements for the following parameters related to agricultural pollution: volatile phenol, petroleum, paracolon, etc. Table in Annex III: Common pollutant from agricultural practices and indicative parameters to monitor

6.2.5.3. Monitoring methods for water quality in aquatic environments

Here below it is described the general guidance for monitoring of water that has possibly been polluted by agricultural runoff.

6.2.5.3.1. Collect basic data

There is a need to collect basic data before starting monitoring excise. Basic data to collect include:

- land use (what types, areas of each land use);
- topographic and hydrological information from the area of interest;
- physical and chemical properties of the soil in planting areas;
- cropping systems; plant species in the area;
- the quantity and types of chemical fertilizers and pesticides used in the monitoring area;
- types and number of livestock and whether these are in large, medium or family-farm sized livestock units, etc

6.2.5.3.2. Identification of problems

In some cases, there are specific reasons for carrying out monitoring. This might include intense algal blooms, fish kills resulting from lack of oxygen, physical pollution from solid waste. In some cases, such as for solid waste, the cause and effect is obvious. In other cases where, for example, there have been fish kills, the cause is not readily apparent, so there needs to be a more sophisticated approach to identifying the problem.

There is a current need for Rwanda to develop an effective monitoring programme of pollution control with improved knowledge of the loading of nitrogen, phosphorus and agrochemicals in ambient water bodies and environment.

6.2.5.3.3. Establishing a sampling programme

Based on the comprehensive analysis of the surveyed results and related information the type of cross-sections and the number of sampling points can be determined. When surface water is collected from farmland, dead zones, backwater areas, the outfall of sewage should be avoided and an attempt made to select a straight, wide section with a smooth flow. In rivers, a sample is usually taken from the centre or in the zone of maximum flow; water near riverbanks is avoided, as this is often contaminated by nearby shore activities (e.g. animals drinking from the river; clothes washing upstream).

6.2.5.4. Water quality monitoring at the farm and field level

Monitoring at the farm level is different from monitoring rivers and lakes. At the farm level, the focus is on specific farming activities such as paddy rice, field crops, animal husbandry, and rural living.

6.2.5.4.1. Monitoring of irrigation supply water

Monitoring of irrigation supply water is much like monitoring small rivers. A sample is taken, often at weekly intervals, from the mid-point of the canal. If the canal has a flow gauge, then the volume of flow should also be recorded.

6.2.5.4.2. Monitoring of water quality on farmland (paddy and dry fields)

This kind of monitoring involves monitoring the quality of water going onto the field (or paddy), the water that runs off the field or paddy, and groundwater; sampled in bores (wells

In paddies, a large amount of rainfall will cause the water in the paddy dyke (berm) to flow over the top and the water will run off. Paddies, however, are also drained at specific points in the rice growing cycle, and it is at this time that water quality can be assessed as it is drained from the paddy.

Sampling at the field level for scientific studies requires extensive instrumentation, measurement of soil porosity and soil water, seepage rates. To do this a lysimeter is used.

6.2.5.4.3. Background values

Background values are useful to know the 'natural' background levels of pollution such as from the air and natural erosion processes. This is established by monitoring an area that is not directly contaminated by fertilizers or other agrochemicals. This tells us what the 'normal' runoff of nutrients will be when there is no direct use of agrochemicals. Generally, the background must be monitored at least once per year at several locations. The average value will indicate the background values for runoff characteristics.

6.2.5.4.4. Determination of sampling time and frequency

Sampling time and frequency is determined by several factors, including variability in rainfall and runoff; fertilizer application; and manure management as part of feedlot operations.

In areas where sewage water is used to irrigate, the sampling frequency should reflect the major periods of irrigation.

- Monitoring of drainage channels should not be less than three times per year so that the main period of irrigation runoff is contained in the collected data;
- Monitoring of pesticides should be carried out soon after, within one week of pesticide application. Modern pesticides tend to degrade after use, therefore monitoring for these long after they have been applied usually results in non-detectable amounts.;
- Groundwater sampling should be carried out during wet and dry seasons or twice per year. Water sources used for irrigation should be monitored at least twice per year.

6.2.5.5. Sampling methods

Paddy fields and dry land crops are the two main forms of agricultural land use. There are three methods for monitoring runoff water quality in dry fields:

6.2.5.5.1. Dry fields

- A drainage ditch around the field is used to collect runoff. A flow meter can be used to calculate the volume of runoff. Water samples are collected twice during the period of runoff and the results are averaged;
- The second method is to place clean, wide-mouth, sample bottles directly into the soil so that the top of the bottle (the mouth of the bottle) is level with the field surface. The soil around the mouth of the bottle must be tamped down so that no loose soil will fall into the bottle. The space between every two water-sampling bottles is no more than 5 m, and the bottles should be located in furrows rather than on mounds so that water will naturally flow into the bottle;
- The number of sampling bottles depends on the size of the field; generally one should use at least four bottles per hectare. During runoff the water will flow into the bottles. Collect the runoff water at the end of the runoff period and record time and date of sampling. This method will not be used to estimate the amount of runoff, but will provide a reasonable estimate of water chemistry. A method to determine the volume of runoff is noted below;
- The third method can be used when there is subsoil drainage. The water that passes through the soil and into the drainage pipes can be collected where the pipes discharge into a drainage canal. This method cannot be used to determine runoff volume because the area that the pipe is draining may be unknown.

6.2.5.5.2. Paddies

To monitor the water quality in runoff from paddy fields, a collection device can be installed on the paddy dyke at points where water is drained or where excess rainfall is allowed to run over the dyke. For research purposes, the collector is usually made of plastic pipe or PVC pipe and installed every 5 m along the berm. Continuous recording of flow from the paddy will provide a value for total volume of runoff. For more practical monitoring, the water can be sampled inside the paddy when there is runoff over the dyke. The volume of runoff can be estimated using the guidance provided in the following paragraphs. The chemistry of water in the paddy will be the same as that running over the dyke

6.2.5..6. monitoring groundwater

Groundwater travels laterally through the soil and bedrock; therefore it is often difficult to establish a background (control) sampling location. Generally, a control well should be sampled some distance from agricultural fields, which may not be possible. One or more wells that are used to supply water to fields and household drinking water should be selected for routine groundwater monitoring. However, sampling groundwater requires some knowledge of the local hydrogeological conditions to ensure sampled groundwater is relevant to the land-use activity.

6.2.5.7 Methods used to monitor agricultural water quality

There is a current need to develop a comprehensive and practical guide to field sampling and data analysis for water quality monitoring in Rwanda. However, analytical methods for analysis of pollution in water and sediments can be found in a variety of manuals including those from APHA, AWWA, WEF (2012) Design of field sampling programmes and quality control including correct preservation of samples collected in the field are essential elements of a successful water quality-monitoring program

6.3. Guidelines for management of non-point urban stormwater

Four major runoff management themes dominate the management practices presented in this guidance document:

- Minimize the amount of impervious land coverage and disconnect impervious areas.
- Promote infiltration.
- Prevent polluted runoff by not allowing pollutants and runoff to mix.
- Remove pollutants from runoff before allowing it to flow into natural receiving waters.

The management practices can be grouped into two basic categories: non-structural and structural practices

6.3.1. Nonstructural practices

Nonstructural practices prevent or reduce urban runoff problems in receiving waters by reducing potential pollutants or managing runoff at the source. These practices can take the form of regulatory controls (e.g., laws, orders, regulations, standards, or guidelines) or voluntary pollution prevention practices. Nonstructural controls can be further subdivided:

- Land use practices. Land use practices are aimed at reducing impacts on receiving waters resulting from runoff from new development by controlling or preventing land use in sensitive areas of the watershed. They can also be used to minimize total land used for development while accommodating growth.

- Source control practices. Source control practices are aimed at preventing or reducing potential pollutants at their source before they come into contact with runoff or aquifers. Some source controls are associated with new development. Others are implemented after development occurs and include pollution prevention activities that attempt to modify aspects of human behavior, such as educating citizens about the proper disposal of used motor oil and application of lawn fertilizers and pesticides.

6.3.2. Structural practices.

Structural practices are engineered to manage or alter the flow, velocity, duration, and other characteristics of runoff by physical means (USEPA, 1993).

In doing so they can control storm water volume and peak discharge rates and, in some cases, improve water quality. They can also have ancillary benefits such as reducing downstream erosion, providing flood control, and promoting ground water recharge. Practices described here below are those that may be upscaled in Rwanda.

6.3.2.1. Infiltration practices

Infiltration facilities are designed to capture a treatment volume of runoff and percolate it through surface soils into the ground water system. This process:

- Reduces the total volume of runoff discharged from the site, which, in turn, decreases peak flows in storm sewers and downstream waters;

- Filters out sediment and other pollutants by various chemical, physical, and biological processes as runoff water moves through the bottom of the infiltration structure and into the underlying soil; and

- Augments ground water reserves by facilitating aquifer recharge. Groundwater recharge is vital to maintain stream and wetland hydrology. During dry weather, ground water recharge helps to assure baseflow necessary for survival of biota in wetlands and streams.

Design variants include: Infiltration basins; Infiltration trenches; and pervious or porous pavements.

Figure 8: Infiltration trenches to reduce runoff

Note: Infiltration facilities require porous soils (i.e., sands and gravels) to function properly. Generally, they are not suitable in soils with 30 percent or greater clay content or 40 percent or greater silt/clay content They are also not suitable:

- In areas with high water tables;
- In areas with shallow depth to impermeable soil layers;
- On fill sites, which have low permeability, or on steep slopes;
- In areas where infiltration of runoff would likely contaminate ground water;
- In areas where there is a high risk of hazardous material spills; or
- Where additional groundwater could form sinkholes.

6.3.2.2. Vegetated Open Channel Practices

Vegetated open channels are explicitly designed to capture and treat runoff through infiltration, filtration, or temporary storage.

Grass channels: These have dense vegetation, a wide bottom, and gentle slopes .Usually they are intended to detain flows for 10 to 20 minutes, allowing sediments to filter out.

Dry swales: As with grass channels, runoff flows into the channel and is subsequently filtered by surface vegetation.

Figure 9: Swales like the above is good for runoff infiltration (Source: https://brocku.ca/unesco-chair/2020/01/27/meopar-blog-swales-the-silent-stormwater-sweepers/)

6.3.3. Filtering Practices

Filtering practices capture and temporarily store runoff and pass it through a filter bed of sand, organic matter, soil, or other media. Filtered runoff may be collected and returned to the conveyance system, or allowed to exfiltrate into the soil. Design variants include: Surface sand filter; Underground sand filter or Bioretention areas.

6.3.4. Detention /retention practices

6.3.4.1. Retention ponds

These practices use a permanent pool, extended detention basin, or shallow marsh to remove pollutants and can include: Micropool extended detention ponds; wet ponds or wet extended detention ponds;

6.3.4. 2.Constructed wetlands

Constructed wetlands are engineered systems designed to treat runoff. They are typically designed to provide some of the functions of natural wetlands, e.g., wildlife habitat, in addition to controlling runoff volumes and pollutant loadings.

CHAPTER 6 OPTIONS TO MANAGE WATER QUALITY IN RECEPTOR WATER BODIES

6.1 Introduction

The primary objective of managing water pollution in rivers, lakes or reservoirs is to limit, divert or treat poor quality water i.e. prevent pollutants from entering the water body. Because lakes and reservoirs can trap and recycle pollutants and organic matter, reducing loads from the catchment may not reverse the impacts of pollution as rapidly as stakeholders expect. Hence, it may be necessary to initiate in-lake or in-river management options by manipulating internal physical, chemical or biological processes.

This chapter provides a short introduction to in-stream or in-lake management techniques that can be employed to deal with the symptoms of water pollution.

6.2 In-stream or in-river management options

6.2.1 Diversion of wastewater

Brief overview	Reducing high pollution loads to a river or lake should always be the first step in the selection of restoration options. If that is not possible, then diverting effluents or poor quality water away from the receiving water body is an option. This option may not be feasible because effluent return flows can be an important source of water for downstream users. Diverting effluents to downstream of an ecologically sensitive river, wetland or lake will have a positive impact on water quality in that water body but it may have a negatively affect the yield of the system.
Sources of information	Holdren, C., Jones, W. and Taggert, J. (2001). *Managing Lakes and Reservoirs*.
	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.2.2 Pre-impoundments

Brief overview	Pre-impoundments are comparatively small reservoirs or weirs with an average water retention time of a few days. These are situated upstream of a lake or reservoir whose water quality they are designed to improve. Water quality is improved by reducing the load of suspended matter and dissolved pollutants, especially dissolved nutrients. Dissolved nutrients and other pollutants are often chemically bound or adsorbed onto suspended sediment particles and are removed from the water when these participles settle out. This option may be ineffective on rivers that carry a high suspended sediment load because the pre-impoundment would probably silt up rapidly.

Sources of information	Holdren, C., Jones, W. and Taggert, J. (2001). *Managing Lakes and Reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.2.3 Dilution and flushing

Brief overview	Dilution/flushing has been documented as an effective restoration technique. Good quality water is released from an upstream reservoir to dilute or flush a downstream river, lake or reservoir. This option is often viewed as a last resort due to the negative impact it has on water supply within a catchment or sub-catchment. Increased river flow or reservoir inflow also has the effect of decreasing the water retention time which can have a positive impact on, for example, reducing algal blooms which result from nutrient enrichment.
Sources of information	Holdren, C., Jones, W. and Taggert, J. (2001). *Managing Lakes and Reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3 In-lake or in-reservoir management options

- e.g. biomanipulation, shoreline management, biological controls, augmented circulation, dredging

6.3.1 Biomanipulation: Coarse fish eradication

Brief overview	Biomanipulation refers to the deliberate management of undesirable or imbalanced layers or elements of the aquatic food web in order to restore a balanced flow of energy through the system. This process is also termed "species composition management" when referring to the management of fish or other aquatic fauna. Coarse fish refers to species such as carp or catfish that are introduced for aquaculture rather than indigenous species. Species composition management refers to a group of conservation and restoration measures that include selective harvesting of undesirable fish species and stocking of desirable species designed to enhance the fishing resource value of a lake. In reservoirs, these measures also include water level manipulation both to aid in the breeding of desirable species, for example, increasing water levels in spring to provide additional breeding habitat and to disadvantage undesirable species, for example, drawing a lake down to concentrate forage fish and increase predation success and also to strand juveniles and desiccate the eggs of undesirable species. Costs, as with water

level management above, are primarily associated with loss of water; effectiveness is good, but by no means certain; and side effects include collateral damage to desirable fish populations.

More extreme measures include organized fishing events and selective cropping of certain fish species and breed stock (targeting recruitment), poisoning using rotenone, and enhancement of predation by stocking predatory fish species. In lakes with an unbalanced fishery, dominated by carp and other rough fish, chemical eradication has been used to manage the fishery. Lake drawdown is often used along with chemical treatments to expose spawning areas and eggs and concentrate fish in shallow pools, thereby increasing their availability to fishermen, commercial harvesters, or chemical eradication treatments. Fish barriers are usually used to prevent reintroduction of undesirable species from up- or downstream, and the habitat thus created will benefit the desired fish populations.

Sources of information

Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*.

Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.2 Biomanipulation: Floating wetlands

Brief overview

An integral component of an aquatic food web is the habitat, nesting and food source provided by riparian and submerged vegetation. This type of vegetation is typically absent in manmade impoundments with widely fluctuating shoreline water levels, high-energy shorelines or where the littoral zone geology is unsuited to the establishment of rooted plants.

Floating wetland structures provide a means of establishing permanent littoral vegetation planted in anchored, floating frames or structures at appropriate points in the waterbody. The technique is especially suited to small impoundments. The semi-submerged structure allows the root zones of the plants to be continually wet and provides shelter for aquatic organisms and animals.

Sources of information

Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*.

Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3.3 Biomanipulation: Riparian wetlands

Brief overview	An integral component of an aquatic food web is the habitat, nesting and food source provided by riparian and submerged vegetation. This type of vegetation is typically absent in impoundments with widely fluctuating shoreline water levels, high-energy shorelines or where the littoral zone geology is unsuited to the establishment of rooted plants. In reservoirs with a paucity of shoreline vegetation the deliberate planting and establishment of shoreline vegetation (littoral zone vegetation) and/or wetlands in small extant or purpose-created embayments serves to offset this deficiency. Rwanda is rich in riparian wetlands adjacent to its rivers and these should be protected for the role it plays in improving water quality. Its lakes are also rich in marginal vegetation which plays an active role in taking up nutrients and the trapping of metals in its dense root systems. See also Shoreline Maintenance
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3.4 Shoreline Management

Brief overview	Shoreline maintenance refers to a group of measures designed to reduce and minimize shoreline erosion by waves, boat wakes or related erosion-causing actions. Four common shoreline erosion control techniques are in use: vegetative buffer strips, rock revetments, wooden and concrete bulkheads, and beaches. Maintenance of a vegetated buffer strip immediately adjacent to the lake is the simplest, least costly, and most natural method of reducing shoreline erosion. This technique employs natural vegetation, within two to five meters of the lakeshore and the establishment of emergent aquatic vegetation from one to two meters lakeward of the shoreline. Vegetated buffers zones can also reduce the impacts of trampling when cattle and livestock are brought to the lake for watering. See also Riparian wetlands.
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.5 Chemical water treatment

Brief overview	Nutrient inactivation is a restoration measure that is designed to limit the biological availability of phosphorus by chemically binding the element in the lake sediments and/or the water column using a variety of divalent or trivalent cations – highly, positively charged elements. Aluminium sulphate (alum), ferric chloride, and ferric sulphate are commonly used cation sources. The use of these techniques to remove phosphorus from nutrient-rich lake waters is an extension of common water supply and wastewater treatment processes. Costs depend on the lake volume and type and dosage of chemical used.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.6 Partitioning (Mesocosms, corrals)

Brief overview	The physical partitioning of small areas of a lake or embayments in a lake provides a means whereby the enclosed areas can be chemically treated and used to establish plants, fish stocks or other elements of a desirable aquatic ecosystem. Once the enclosed community is established and stable the mesocosm may be removed and the released community, together with adjacent similar communities, recruited to the greater portion of the waterbody. This approach is analogous to the use of grass plugs which once established then grow together. Alternatively, physical partitions can be used to isolate contaminated water from the rest of the lake.
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3.7 Biological Controls: Habitat Protection

Brief overview	Habitat protection refers to a range of conservation measures designed to maintain existing fish spawning habitat, including measures such as restricting fishing activities and other intrusions into gravel-bottomed shoreline areas during the spawning season. Use of natural vegetation in shore management zones and other "soft" shoreline protection options aids in habitat protection. Costs are generally low, unless the habitat is already degraded. Modification of aquatic plant harvesting operations may be considered to support restoration and protection of native aquatic plant beds and maintenance of fish

	breeding habitat during the early breeding period. Effectiveness is variable depending in part on community acceptance and enforcement.
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3.8 Biological Controls: Natural Predators

Brief overview	Classical biological control has been successfully used to control both invasive aquatic weeds and herbivorous insects. The use of weevils to control water hyacinth (*Eichhornia crassipes*) and the red water fern, *Azolla filiculoides,* has been extremely successful across the country – but much less so against water hyacinth. The use of the grass carp, *Ctenopharyngodon idella,* for aquatic plant control is used in many countries but is strictly controlled then only for fish that have been sterilized.
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

6.3.9 Bottom Sealing (Physical)

Brief overview	Lake bottom covers and light screens provide limited control of rooted plants by creating a physical barrier which reduces or eliminates the sunlight available to the plants. They are especially useful in providing effective levels of control in embayments and small to medium ponds (e.g. farm dams that have become overgrown with rooted macrophytes). They have been used to create swimming beaches on muddy shores, and to improve the appearance of lakefront property (e.g. tourist lodges. Sand and gravel are usually readily available and relatively inexpensive to use as cover materials, but plants readily decolonise areas so covered in about a year. Synthetic materials, such as polyethylene, polypropylene, fibreglass, and nylon, can provide relief from rooted plants for several years. The screens are flexible and can be anchored to the lakebed in spring or draped over plants in summer. This option is impractical for large lakes and water bodies.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.10 Sediment Treatment using Chemicals

Brief overview	Nutrient inactivation is a restoration measure that is designed to limit the biological availability of phosphorus by chemically binding the element in the lake sediments using a variety of divalent or trivalent cations – highly, positively charged elements. Aluminium sulphate (alum), ferric chloride, and ferric sulphate are commonly used cation sources. Costs depend on the lake volume and type and dosage of chemical used. Due to the cost of chemicals, this option may only be feasible for small ponds or small water supply reservoirs that are affected by nuisance algal blooms.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.11 Macrophyte harvesting

Brief overview	Aquatic plant management refers to a group of management and restoration measures aimed at both removal of nuisance vegetation and manipulation of species composition in order to enhance and improve fish harvesting or access to open water for launching boats. Generally, aquatic plant management measures are classified into three groups: physical measures, which include lake-bottom coverings and water level management; mechanical removal measures, which include harvesting and manual removal; and chemical measures, which include using aquatic herbicides and biological control measures, which in turn include the use of various organisms, including insects. Of these, chemical and biological measures are usually stringently regulated and require a permit. Aquatic macrophytes are mechanically harvested by hand in shallow areas or with specialized equipment consisting of a cutting apparatus which cuts up to two meters feet below the water surface and a conveyor system that picks up the cut plants and hauls them to shore.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.12 Aeration

Brief overview	Forced (deliberate) aeration is indicated in specific cases where there is an identified need to disrupt stratification or increase dissolved oxygen concentrations in the bottom layers to support aquatic life. Various techniques are available – installed piped aeration or vertical lift mixer/aerators. In Rwanda this would be regarded as an expensive management option and best suited for small ponds or water supply reservoirs.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.13 Augmented Circulation

Brief overview	Forced (deliberate) aeration/mixing is indicated in specific cases where there is an identified need to disrupt stratification, aerate bottom waters, or enhance water movement into and out of small bays and channels. Various circulation techniques are available – generally determined by the specific situation and size of the water body that needs to be aerated.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.14 Algaecides

Brief overview	Chemical treatment with aquatic herbicides is a short-term method of controlling heavy growths of aquatic macrophytes and algae. Chemicals are applied to the growing plants in either liquid or granular form. The advantages of using chemical herbicides to control aquatic macrophyte growth are the relative ease, speed, and convenience of application. Herbicides also offer a degree of selectivity, targeting specific types of aquatic plants.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*.

	Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.15 Dilution/flushing

Brief overview	This option is generally not desirable in water scarce countries. Effective dilution/flushing of man-made reservoirs is generally only effective provided that 10% of the water volume can be exchanged on a weekly basis.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.16 Dredging

Brief overview	Removal of contaminated sediments is a restoration measure that is carried out using a variety of techniques, both land-based and water-based, depending on the extent and nature of the sediment removal to be carried out. For larger-scale applications, a barge-mounted hydraulic or cutter-head dredge is generally used. For smaller-scale operations a shore-based dragline system is typically employed, although the option for using pontoon-mounted sludge pumps has potential in shallow lakes and deltas. Both methods are expensive, especially if a suitable disposal site is not located close to the dredge site. In this regard options for nearby disposal of dredged material back to farmlands, or for use in backfilling or rehabilitation (e.g. infilling of borrow pits or quarries). The effectiveness of dredging varies with the effectiveness of watershed controls in reducing or minimizing the sediment sources.
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.17 Light inhibiting dyes

Brief overview	The use of dyes may be used in small dams to reduce light available for photosynthesis and so reduce the level of algal biomass. This technique is not commonly used. In turbid lakes and rivers the high suspended sediment loads

	severely limit light penetration into the water and thereby inhibit photosynthesis of algae.
Sources of information	Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.3.18 Water level controls (Drawdowns)

Brief overview	Drawdown refers to a the manipulation of man-made reservoir water levels to change or create specific types of habitat and thereby manage species composition within a waterbody. Drawdown may be used to control aquatic plant growth and to manage fisheries. With regard to aquatic plant management, periodic drawdowns can reduce the growth of some shoreline plants by exposing the plants to climatic extremes, while the growth of others is unaffected or sometimes enhanced by the spread of seed over exposed sandbanks. Both desirable and undesirable plants are affected by such actions. In the southern hemisphere, with the exception of extreme southern latitudes (e.g. New Zealand) the use of reservoir drawdown to expose and kill plant rootstocks, is common. Drawdown is seldom an option for raw potable water storage impoundments due to the risk that the reservoir may remain empty .
Sources of information	Cooke, G.D., Welch, E.B., Peterson, S.A. & Nichols, S.A. (2005). *Restoration and management of lakes and reservoirs*. Hart, R. & Hart, R.C. (2006). *Reservoirs and their management: A review of the literature since 1990*. Holdren, C., Jones, W. & Taggart, J. (2001). *Managing lakes and reservoirs*.

6.4 Guidance for selecting a suite of receptor water body management options

Brief overview	Guidance in the selection of options to treat the symptoms of pollution in a receptor water body is presented in this section. Consideration is given to the reason for choosing a particular intervention, the degree of technical difficulty in implementing a particular intervention, the relevance and efficacy of a control option, its relative cost, and constraints and side effects of a particular intervention.

Table 1: Evaluation of different in-lake management options (sorted alphabetically)

IN-LAKE AND IN-RIVER MANAGEMENT OPTIONS								
Management Options	Relevance H,M,L	Reason for choosing	Degree of Technical Challenge	Relevance & efficacy (Strategic Control Value)			Cost	Constraints & Side Effects
				Short term	Medium term	Long term	H,M,L	
Aeration	L	Stagnation/bloom disruption	H	L	L	M	H	Installation of aeration system
Augmented circulation	L	Stagnation/bloom disruption	H	L	L	M	H	Installation of mixing system.
Algaecides	L	Control of algal blooms	L	L	L	L	L	Cumulative effects/longevity of toxic components
Biological controls	M	Macrophyte control using biocontrols such as insects or grasscarp	L	L	L	L	L	Requires permitting. Use of grass carp only valid in controlled isolated environments. Efficacy against water hyacinth has been very poor in some regions.
Biomanipulation								
-Riparian wetlands	M-H	Create macrophyte habitat and riparian buffers	M	L	M	H	M	Only for small and/or sheltered areas
-Floating wetlands	H	Augment habitat in dams with widely fluctuating water levels	M-H	L	M	H	M	Only for small and/or sheltered areas
-Habitat protection	M	Ensure nursery areas for invertebrates and fish, as well as sediment stabilization and oxygenation	L-M	M	H	H	L	Valid in dams with relatively stable water levels
-Fish management	See Coarse Fish Eradication							
Bottom sealing (physical)	L-M	Control of internal nutrient loading and/or fine particle turbidity	M	H	H	H	M	Size dependent, works well in small environments that can be drained, cleaned and lined.
Chemical sediment treatment	L-M	Control of internal nutrient loading	M-H	L	M	M	H	Size and volume dependent.
Chemical water treatment	M-H	Control of nutrient availability (water column)	M	M	M	M	H	Only effective in poorly-flushed (long retention time) systems
Coarse fish eradication	H	Impaired food web with sustained algal dominance	M-H	H	H	H	M	3-5 years to attain full effect but immediate positive impact if first harvesting is severe.

Dilution/flushing	L	Dilute nutrients or algal biomass	H	M	L	L	H	Only effective where a source of water is readily available. Flushing of less than 10% total volume per week likely to be ineffective.
Dredging	L	Nutrient load reduction	M-H	M	H	M	H	Only practical in shallow systems or ones which can be completely drained.
Light inhibiting dyes	L	Limit light available for algal and/or macrophyte growth	M	L	L	L	M	Only valid in small systems, not effective against buoyant cyanobacteria.
Macrophyte harvesting	L-M	Biomass removal, maintenance of open waterways.	L-M	L	M	H	M-H	Easy for pondweeds, less so for reeds
Partitioning	M-H	Isolate, protect, chemically treat and/or vegetate shorelines or embayments	M	L	M	M	M	Depends on dam profiles, water level ranges, wind action
Water level control/drawdowns	L	Macrophyte control/flushing/habitat provision	M-H	M	M	M	H	Only for small, rapidly-filling systems not used for bulk water supply. Significant problems may occur during the drawdown period.

Key - L = Low, M = Moderate, H = High

CHAPTER 7 WATER USERS OPTIONS TO MANAGE WATER QUALITY

7.1 Introduction

Coping with the consequences of water pollution

Water users are often the first to be affected by the consequences of water pollution and management interventions are generally undertaken in response to complaints from water users.

It may not always be possible to rehabilitate a polluted water body to a state where all the user water quality requirements are met. Restoration to a more desirable state can also take a long time even after external loads have been curtailed because internal loads (pollutants trapped and released from the sediments) now become the dominant source of pollutant loads, thereby prolonging the time water users are exposed to pollution problems. Under these circumstances it may be necessary to consider further measures to deal with the consequences of pollution and to modify the consumptive or non-consumptive use of the water body.

The water users considered in this chapter are the recreational water users, agricultural water users, domestic water users, and industrial water users. Domestic and industrial water users were combined into one user group because the majority of industries get their water from domestic water treatment works.

The focus of this guideline document is focused on addressing the causes of pollution and on measures to deal with the impacts on rivers and reservoirs. This chapter only introduces measures that water users can take to alleviate the consequences of using water that does not meet their requirements. It is not a comprehensive review of water use mitigation measures as this is not the focus of this document.

7.2 Water used for recreation, fishing and for aesthetic appeal

Pollution impacts on recreational water users

A distinction is made between contact (adults and children bathing, swimming or playing in a river or lake, or cultural activities such as baptisms), limited contact (fishing from the side or using a boat where you can get wet), and non-contact recreation water users (aesthetic enjoyment of a river or lake). Water pollution and its symptoms affects recreational water users in a number of ways. These include:

- Algal blooms interfere with contact recreation such as swimming, and other activities. Ingesting algal laden waters during these activities can lead to stomach ailments and to skin rashes.

- Concerns have been raised about toxic algae and ingesting it during contact recreation activities.
- Contact with water that has been contaminated with untreated or partially treated sewage increases the risk of water borne diseases such as typhoid and cholera. Nutrient enriched water also promote suitable habitat for parasitic diseases such as schistosomiasis and dracunculiasis or guinea-worm infection.
- Algal scums cause odours that are offensive to fishermen, recreation users and communities that live on the shores of lakes. These scums are also unsightly.
- Anoxia resulting from high organic loads and algal blooms can cause fish kills and the communities often associated these events with pollution or potentially toxic substances in the water.
- Excessive growth of aquatic water plants such as water hyacinth interferes with fishing, restrict access to open water, and conceal hazardous underwater obstructions.
- Nutrient enrichment can cause a change in fish species away from desirable species caught for consumption and selling. This is viewed as a negative impact by fishermen.

Measures that can be taken to alleviate the impact on recreational end users, include:

Limit recreation activities

In cases of severe algal blooms, contact recreation activities can be curtailed in areas where these severe blooms occur. An alternative is to change the surface water use zoning of the dam.

Warning signs

In areas where potentially harmful algal blooms occur, warning signs should be erected to warm recreation users against this possibility.

Public awareness and education

An awareness programme can be launched to make the public aware of and educate them about eutrophication and harmful algal blooms. This is especially important at dams or urban ponds that show severe signs of eutrophication.

Removing algal scums

In sensitive areas such as waterfront developments and high-value marinas algal scums can be harvested and/or pumped away to bring about short-term improvements in water quality. However, the effectiveness of such measures has not been proven yet.

Institute an aquatic plant management programme

Where excessive growth of nuisance aquatic plants occur as a result of nutrient enrichment and it interferes with recreational use, an aquatic plant management programme should be initiated to control the proliferation of rooted quality plants in areas of the water body where recreation occurs.

7.3 Domestic drinking water treatment

Advanced water treatment

Conventional water treatment plants are designed to remove particulate matter from the water (water clarity) and to make the water safe to drink by disinfecting the water. Conventional treatment of water with high algal concentrations can cause taste and odour problems. Advanced water treatment technologies such as dissolved air floatation, powered or granular activated carbon, etc. may be required to treat water for domestic or high quality industrial use. The bottled water and beverage industry is especially sensitive to taste and odour problems and they need very advanced treatment systems to purify their water, even if they use municipal water supplies.

7.4 Agricultural user treatment

Eutrophication impacts on agricultural water users

Agricultural water users include irrigation water users, water used for livestock watering, and water used for aquaculture. Agricultural water users are affected by eutrophic waters in a variety of ways which include:

- Abstracting nutrient rich water into irrigation dams can lead to secondary growth in the irrigation dams. Filamentous algae can block the inlets to irrigation pumps and can lead to damage to the pumps if they run dry. Free-floating algae interfere with irrigation equipment causing blockages in especially drip irrigation equipment.
- Farmers that add fertiliser to their irrigation water can over-fertilise if they don't compensate for the nutrient content of their raw water supply.
- Water containing toxic algae can cause livestock deaths if used for the purpose of livestock watering. This is also true for wildlife watering.
- Eutrophication is sometimes associated with the discharge of raw sewage into rivers. Producers of export crops such as grapes or deciduous fruit have great difficulty obtaining or retaining export accreditation if their irrigation water is affected by untreated sewage.
- Aquaculture farmers are affected by anoxia and the build-up of ammonia in their water if their dams are not sufficiently flushed to remove waste products or if the feed water is already eutrophic.

Measures that can be taken to alleviate the impacts of high sediments, nutrient enrichment, and pollution on agricultural end users, include:

Irrigation use	Farmers abstracting water for irrigation from eutrophic farm dams or canals with high algal concentrations should take precautions against filter blockages or blockages in their irrigation equipment. This is especially relevant where drip irrigation or micro jet irrigation systems are used as algal cells that pass through conventional filter systems can easily block these. Self-cleaning screens should be installed because free-floating and filamentous algae easily block conventional fixed screens. Farmers who add fertilizer to their irrigation water should also monitor the nutrient concentration of their raw water to prevent over-fertilization of their crops.
Livestock watering	Where there is the danger of toxic algal blooms, alternate sources of water should be used for livestock watering and the affected water body should be fenced off to prevent cattle from drinking the affected water. This is also applicable to watering of game in conservation areas that are affected by eutrophic dams and watering holes.

7.5 Industrial user treatment

Advanced in-take water treatment	Conventional treatment of water with high algal concentrations can cause taste and odour problems, or cloudy water if the suspended sediment concentration exceeds the capacity of the treatment plant to remove turbidity. The bottled water and beverage industry is especially sensitive to taste and odour problems and they need very advanced on-site treatment systems to purify their intake water, even if they use municipal water supplies as their primary source. Advanced water treatment technologies such as ultra-filtration, reverse osmosis, membrane filtration, UV disinfection, etc. may be required to treat the water to a higher quality required by brewing, soft drink, canning and other food industries.

CHAPTER 8 GUIDE FOR DERIVING A SUITE OF WATER QUALITY MANAGEMENT OPTIONS

8.1 Generic criteria for evaluating WQM options

The purpose of evaluation criteria

A large number of water quality management options are presented in this document and as part of developing an appropriate response to catchment pollution problems, these options need to be screened in order to select a short list of options that would be investigated in more detail. Each chapter that follow on this one is concluded with a list of criteria that can be used to do the initial screening. These criteria differ depending on whether the options are targeting point sources, non-point sources, or in-river/in-lake management options.

8.1.1 Point source selection criteria

Point source evaluation criteria

The following criteria can be used in the evaluation of point source management options (Von Sperling & Chernicharo, 2005).

- Average removal efficiency (% removal of BOD_5, COD, Ammonia, Total N and Total P, Faecal coliforms, E coli)
- Economy (Land & energy requirements, Construction and Operation & Maintenance costs, Generation of sludge)
- Resistance capacity to the inflow variations and shock loads (Flow, quality, and toxic compounds)
- Reliability
- Simplicity in operation & maintenance
- Independence from other characteristics (climate, and soil)
- Lower possibility of environmental problems (bad odours, noise, aerosols, insects & worms)

8.1.2 Nonpoint source selection criteria

Nonpoint source evaluation criteria

The following criteria can be used in the evaluation of nonpoint source management options (NALMS, 1990).

- Effectiveness
- Longevity
- Confidence
- Applicability
- Potential negative impacts
- Capital costs and Operation & Maintenance costs

Effectiveness	Effectiveness refers to how well a specific management option meets its goals. A management option may be partially effective if not all its goals are met. For some management options, the initial assessment of effectiveness may be based on the specific design and extent (track record) of the option. Effectiveness must therefore be based on past experience of the effectiveness of the option, the commitment to implement part or all of the required option, and an analysis of the risks and variability involved.
Longevity	Longevity refers to the duration of the treatment or management option effectiveness. Longevity is normally categorised as short, medium or long term. A management option is defined as short term if it is effective for one seasonal cycle (wet & dry cycle) or less. A management option is defined as long term if it is effective for between one and five seasons, and long term if it is effective for more than 5 seasons. Longevity depends on the proper design and maintenance of a management option. A option may have a long-term effect if it is designed for the specific environmental conditions and if it is properly maintained.
Confidence	Confidence refers to the number and quality of reports and studies supporting the effectiveness rating of a specific management option. Confidence is high if an option when there are a large number of studies describing the success of an option or if it its application has become standard option in certain situations. Confidence is low if an option has a variable record of success or has only been applied in few applications.
Applicability	Applicability refers to whether or not a management option directly affects the causes of the problem or whether it is suitable for the region in which it is considered for application. Some options may solve the problem partially by reducing the symptoms (e.g. solve the algal problem) but not address the causes (nutrient enrichment in the catchment).
Potential negative impacts	Reservoirs are dynamic ecosystems and changing one component of the ecosystem can have a positive or negative impact on another component of the system. A holistic view should be taken when developing a lake management programme that considers the potential negative impacts on the ecosystem.
Capital costs and Operation & Maintenance costs	Standard methods should be used to evaluate the cost effectiveness of various management options. Assessment of the costs should include the capital costs (if any) of a particular option as well as the annual costs to operate and maintain the management option.

8.2 Deriving a suite of management options

Combining lists of management options	In the preceding chapters, lists of suitable management options were identified for each component of the water quality management framework (source and

pathways - point and nonpoint source management options, transport and storage - in-river and in-lake management options, use - options to cope with symptoms of water pollution). The different lists now need to be combined and prioritised so that a shortened list of options can be included in the water quality management plan. The management plan becomes the strategy and programme of actions that will be implemented in the short to medium term using various management instruments.

Subjective judgement

In the development of the short lists of water quality management options, the development of priorities and trade-offs between different options are based more on a feel for relative costs and other resources than on detailed estimates. In the last step, cost estimates for the final suite of options need to be firmed up to maximise the cost-effectiveness of the overall management plan.

The evaluation of management options is regarded as more an art than a science. There is no "best" method to evaluate different options.

A good method of screening the combined list of options is in a workshop situation where a combination of intuition, scientific and engineering judgement, and cost assessment is applied to develop a short list of options. This method can be effective but it requires the involvement of experienced staff from a number of disciplines and from political leadership. A committee consisting of implementing agencies and their technical advisors can develop a set of objective criteria that is suitable for the particular catchment and they then go through a process to arrive at a final list, strategy and programme of action.

Other evaluation methods

Other more conventional evaluation methods include cost-benefit analysis, optimization methods and multi-criterion decision-making tools.

Matrix comparison

A matrix comparison is a more subjective method. With this method a table is constructed of various management options along the vertical axis and evaluation criteria along the horizontal axis. These evaluation criteria can be developed by the committee and can take into account aspects such as the ability to control the targeted pollutants, acceptability to stakeholders, fit with the mandate of implementing agencies, etc. Each management option is then rated in terms of each of the criteria. The rating can be a on a scale of 1 - 5 (low - high) or a simple + or - rating can be used.

Evaluation criteria

In addition to the criteria listed in the preceding section, Debo & Reese (2003) also listed a number of evaluation criteria that can be used to assess different management options. These include:

- Human risk, public safety, and potential liability
- Physical and regulatory suitability
- Ability to control key targeted pollutants

- Costs to implement and maintenance costs
- Acceptability to the public, stakeholders, staff and political leadership
- Equitability to impacted persons
- Reliability and consistency over time
- Sustainability in terms of maintenance or programme management
- Ability to be applied universally throughout the local authority or on a specific catchment
- Fit with other operations and programmes
- Relationship to other state, provincial or local regulatory requirements
- Environmental risk and implications
- Amenity or multiuse value.

Detailed design and costing

Once a suite of management options has been identified, an initial design and costing can be undertaken. The aim is to estimate the overall costs of the programme and to assess the pollutant reduction effectiveness. This information will enable decision makers to fine-tune the programme of action. At this stage the overall water quality management plan needs to be reviewed by examining each of its components. The plan may need to be adjusted, actions combined and compromises made in order to finalise the plan.

Roles and responsibilities

The second step is to describe the role and responsibilities to implement the water quality management plan. The key components of the plan must be identified and clear direction be given to who is responsible for its implementation and what the expected outcomes are. The objective is to get all the parties involved to take ownership of their portion of the programme and instil a sense of teamwork in the overall execution of the overall plan.

Implementation schedule

The final step is to develop a schedule for implementing the water quality management plan. The schedule should allow for feedback loops that may prompt a change of direction or emphasis in any of the components of the plan.

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CHAPTER 9 ANNEX I COMMON INDUSTRIAL WASTEWATER TREATMENT APPROACHES

Pollutant/Parameter	Control Options / Principle	Common End of Pipe Control Technology
pH	Chemical, Equalization	Acid/Base addition, Flow equalization
Oil and Grease / TPH	Phase separation	Dissolved Air Floatation, oil water separator, grease trap
TSS - Settleable	Settling, Size Exclusion	Sedimentation basin, clarifier, centrifuge, screens
TSS - Non-Settleable	Floatation, Filtration - traditional and tangential	Dissolved air floatation, Multimedia filter, sand filter, fabric filter, ultrafiltration, microfiltration
Hi - BOD (> 2 Kg/m^3)	Biological - Anaerobic	Suspended growth, attached growth, hybrid
Lo - BOD (< 2 Kg/m^3)	Biological - Aerobic, Facultative	Suspended growth, attached growth, hybrid
COD - Non-Biodegradable	Oxidation, Adsorption, Size Exclusion	Chemical oxidation, Thermal oxidation, Activated Carbon, Membranes
Metals - Particulate and Soluble	Coagulation, flocculation, precipitation, size exclusion	Flash mix with settling, filtration - traditional and tangential
Inorganics / Non-metals	Coagulation, flocculation, precipitation, size exclusion, Oxidation, Adsorption	Flash mix with settling, filtration - traditional and tangential, Chemical oxidation, Thermal oxidation, Activated Carbon, Reverse Osmosis, Evaporation
Organics - VOCs and SVOCs	Biological - Aerobic, Anaerobic, Facultative; Adsorption, Oxidation	Biological : Suspended growth, attached growth, hybrid; Chemical oxidation, Thermal oxidation, Activated Carbon
Emissions – Odors and VOCs	Capture – Active or Passive; Biological; Adsorption, Oxidation	Biological : Attached growth; Chemical oxidation, Thermal oxidation, Activated Carbon
Nutrients	Biological Nutrient Removal, Chemical, Physical, Adsorption	Aerobic/Anoxic biological treatment, chemical hydrolysis and air stripping, chlorination, ion exchange
Color	Biological - Aerobic, Anaerobic, Facultative; Adsorption, Oxidation	Biological Aerobic, Chemical oxidation, Activated Carbon
Temperature	Evaporative Cooling	Surface Aerators, Flow Equalization
TDS	Concentration, Size Exclusion	Evaporation, crystallization, Reverse Osmosis
Active Ingredients/Emerging Contaminants	Adsorption, Oxidation, Size Exclusion, Concentration	Chemical oxidation, Thermal oxidation, Activated Carbon, Ion Exchange, Reverse Osmosis, Evaporation, Crystallization
Radionuclides	Adsorption,Size Exclusion,	Ion Exchange, Reverse Osmosis, Evaporation, Crystallization

	Concentration	
Pathogens	Disinfection, Sterilization	Chlorine, Ozone, Peroxide, UV, Thermal
Toxicity	Adsorption, Oxidation, Size Exclusion, Concentration	Chemical oxidation, Thermal oxidation, Activated Carbon, Evaporation, crystallization, Reverse Osmosis

CHAPTER 10 ANNEX II: COMMON POLLUTANTS IN INDUSTRIAL WASTEWATER AND INDICATIVE PARAMETERS

Type industry	Industrial opeation	Type of pollutant	Indicative parameters
Textile	Weaving	Fibres	Suspended particle
		Dust	Turbidity
	Beaching	Calcium hypochlorite	Chlorine
		Sodium Hypochlorite	Chlorine
	Dyeing	Synthetic dye	Chromium
			Colour
			COD
			BOD_5
	Washing	Synthetic dye	Chromium
			Colour
			COD
Beverages	Washing	Bleaching	pH BOD5 COD
Brewing	Fermentations		pH BOD5 COD
Metal plating	Electrolysis	Metals	Cu

Milk processing			
Pulp &Paper industries	Pulping	Black liquor	
	Bleaching		
Fish processing			

CHAPTER 11 ANNEX III: COMMON POLLUTANT FROM MUNICIPAL ACTIVITIES AND INDICATIVE PARAMETERS

Item	Source	Type of pollutant	Indicative parameters
Municipal wastewater	Domestic/ Residential	Municipal solid wastes	BOD, COD and Turbidity
		Sewerage (Liquid waste)	Nutrients (N and P) and Faecal matters
	Institutions	Municipal solid wastes	BOD, COD and Turbidity
		Sewerage (liquid waste)	Nutrients (N and P) and Faecal matters
	Public services	Municipal solid wastes	Add BOD, COD and Turbidity
		Hazardous solid wastes (Hospitals)	Heavy metals and PH
		Hazardous liquid wastes (Hospitals)	Heavy metals and PH
		Sewerage (Liquid waste)	Nutrients (N and P) and Faecal matters

CHAPTER 12 ANNEX IV: COMMON POLLUTANTS FROM AGRICULTURAL PRACTICES AND INDICATIVE PARAMETERS

Type of economic activity	Activity	Source of water pollution	Indicative parameters
Agriculture	Land tillage	Sediments due to loose soil and grasses	• Turbidity • Total Suspended Solids (TSS) • Total Dissolved Solids (TDS) at 100°C • BOD_5 at 20°C • Colour • Odour
	Application of pesticides	Organo chlorine pesticides (Cl^-)	• Chlorides (Cl^-)
		Pesticides other than Organo chlorines	• Phosphorus Total (as P) • Nitrates (NO^{3-})
	Fertilization	Phosphate fertilizers	• Phosphorus Total (P)
		Nitrate fertilizers	• Nitrates (NO^{3-})
		Organic manures	• Total Suspended Solids (TSS) • Total Dissolved Solids (TDS) at 100°C • BOD_5 at 20°C • Turbidity • Color • Odour • pH
	Irrigation	Salinity and hardness	• pH • Total Filterable Residue • Total Hardness ($CaC0_3$) • Calcium Ca • Magnesium Mg • Magnesium and Sodium sulphates [Mg^{2+} and Na^+ SO_4^{2-}] • Sulphate ($S0_4^{2-}$) • Chloride (CI^-)
		Algae	• BOD_5 at 20°C
		Nitrogen Leaching to ground H_2O	• Nitrates (NO^{3-})
		Phosphorus leaching to ground water	• Phosphorus Total (P)

	Livestock keeping	Contamination/pathogens	• Total Coliform Organisms
	Release of waste water from aquaculture effluents	Contamination	• Total Coliform organisms

CHAPTER 13 ANNEX V: APPLICABLE NATIONAL AND REGIONAL STANDARDS

13.1 V.1. Potable water – Specification – maximum permissible limits (FDEAS 12: 2018)

Table1 — Physico-chemical requirements for potable water

Sl. No.	Parameter	Limit		Test method
		Treated potable water	Natural potable water	
a)	Colour, TCU[a], max.	15	50	ISO 7887
b)	pH	6.5 – 8.5	5.5 - 9.5	ISO 10523
c)	Conductivity, µS/cm, max.	1500	2500	ISO 7888
d)	Suspended matter, mg/l	Not detectable	Not detectable	ISO 11923
e)	Total dissolved solids, mg/l, max.	1000	1500	ASTM D 5907-13
f)	Sodium, (Na), mg/l, max.	200	200	ISO 9964
g)	Sulphate (SO4), mg/l, max.	400	400	ISO 10304-1
h)	Zinc (Zn), mg/l, max.	5	5	ISO 8288
i)	Potassium (K), mg/l, max.	50	50	ISO 9964
[a] True colour units (TCU) mean hazen units after filtration.				

Table 2 — Limits for inorganic substances in natural and treated potable water

Sl. No.	Contaminant	Maximum limit (mg/l)		Test method
		Treated potable water	Natural potable water	
a)	Lead (Pb)	0.01	0.01	ISO 8288
b)	Copper (Cu)	1.000	1.000	ISO 8288
c)	Total Chromium (Cr)	0.05	0.05	ISO 9174
d)	Phosphates ($PO4^{3-}$)	2.2	2.2	ISO 15681

13.2 V.2. Discharged standards for industrial effluents into water bodies-maximum permissible limits (EAS, 2012)

	Parameter	Permissible limits
2	Total suspended solids (mg/l)	50.0
3	Total Dissolved Solids (mg/l)	2000.0
4	Oil and grease (mg/l)	10.0
5	BOD5 (mg/l) (20°C)	50.0
6	COD (mg/l)	250.0
7	Faecal Coliforms (MPN/100ml)	400
12	Hexavalent Chromium (mg/l)	0.05
13	Copper (mg/l)	3.0
16	Lead (mg/l)	0.1
20	Sulphide (mg/l)	1.0
21	Zinc (mg/l)	5.0
22	pH	5-9

The total amount of heavy metals shall not exceed 10.0 mg/l

13.3 V.3. Tolerance limits for discharged domestic wastewater (RS, 2017)

Table1 — Chemical requirements for discharged domestic wastewater

S/N	Parameter	Permissible limits (max.)	Test methods
1.	pH	5-9	RS ISO 10523
2.	Total suspended solids mg/l	50	RS ISO 11923
3.	Total Dissolved Solids mg/l	2000	RS ISO 7888
4.	Oil and grease mg/l	10	ISO 9377
5.	BOD5 mg/l (20°C)	50	RS ISO 5815
6.	COD mg/l	250	RS ISO 6060
7.	Phosphates mg/L	10	Analytical tests (capillary electrophoresis)
8.	Cadmium mg/l	0.1	ISO 5961
9.	Hexavalent Chromium mg/l	0.05	ISO 23913
10.	Copper mg/l	3	ISO 8288
11.	Lead mg/l	0.1	ISO 8288
12.	Sulphide mg/l	1.0	ISO 13358
13.	Zinc mg/l	5	ISO 8288

Table 2 — Microbiological requirements for discharged domestic wastewater

S/N	Parameter	Permissible limits	Test methods
1	Faecal Coliforms cfu /100ml	400	RS ISO 4831

CHAPTER 14 ANNEX V: OPTIONS FOR TREATING POINT SOURCES WASTEWATER

14.1 V.1. Options for treating domestic wastewater

- **VI.1. 1. Pond treatment systems**

What are pond treatment systems?

Stabilisation ponds is one of the most important natural methods for wastewater treatment. Wastewater stabilisation ponds are relatively shallow man-made basins and can be anaerobic, facultative or aerobic. A pond system normally comprises a series of one or more of these types of ponds. The characteristics of the wastewater to be treated normally define the configuration of pond system. It is preferable that the wastewater be screened before it is treated in the ponds. There are however systems where no initial screening takes place and the floating material is intermittently removed from the primary pond. Although it might not achieve the same quality of effluent as more sophisticated technologies is area intensive, wastewater stabilisation pond technology is the most cost-effective wastewater treatment technology. The treatment is achieved through natural mechanisms although it is in some cases enhanced through the use of artificial aeration and recycling of pond content. Pond systems are particularly well suited for tropical and subtropical climates because the intensity of sunlight and temperature are key factors for the efficiency of the treatment processes. This system does not remove nitrogen and phosphorus.

Types of ponds

There are three general types of wastewater ponds. All use microorganisms to degrade and detoxify organic and inorganic constituents; the types of organisms differ among the four categories. Basic classification involves the description of the dominant biological reaction that takes place in the pond. The three principle types are:

- Facultative Ponds
- Anaerobic Ponds
- Aerobic Ponds

- *VI.1.1.1. Facultative ponds*

Brief overview

Facultative ponds are the most common type of pond used for wastewater treatment. Ponds are usually 1.2 to 2.5 meters in depth. Three zones exist in facultative pond, namely:

- A surface zone where aerobic bacteria and algae exists in a symbiotic relationship;
- An anaerobic bottom zone in which accumulated solids are actively decomposed by anaerobic bacteria;
- An intermediate zone that is partially aerobic and partly anaerobic in which decomposition of organic waste is carried by facultative bacteria (i.e. aerobic-anaerobic bacteria).

In these ponds, the suspended solids in the wastewater are allowed to settle to the bottom. The crux of facultative operation is oxygen input into the water by surface re-aeration and photosynthetic algae. The maintenance of the aerobic zone in the upper layer of the pond serves to minimize odour problems because many of the liquid and gaseous anaerobic decomposition products, carried to the surface by mixing currents, are utilised by aerobic organisms. These ponds require large land areas.

Since the ponds are relatively shallow and the retention time in the ponds is usually relatively long, exposure of the water to ultraviolet lead to a significant die-off of coliforms in the water.

Sources of information

Dawes, J. The Pond Owners Problem Solver. Tetra Press. Blacksburg, Virginia; 1999.

Middlebrooks, E. Municipal Wastewater Stabilisation Ponds. Washington, D.C. Office of Water. 1983

May, PJ. The Perfect Pond Detective Book 1. Kingdom Books. Waterlooville, England; 1998.

- *VI.1.1.2. Anaerobic Ponds*

Brief overview

The organic loading in these ponds is that high that no aerobic zone can develop. These ponds have average detention times of 20 to 50 days. Two dominant biological reactions are acid formation and methane fermentation. These ponds are typically used for the treatment of wastewater with a high organic concentration, typically wastewater from industrial and agricultural origin. These wastewaters tend to produce odorous compounds. The crust that naturally forms on these types of ponds often assist in reducing the risk for odours. Odour release can also be combated through the addition of chemicals such as Sodium nitrate on the surface of the pond or the recycle of oxygen rich water from downstream ponds to the surface of the pond. These ponds should preferably be sealed since the content of the ponds, such as the acidic compounds formed through fermentation, can be damaging to soil and groundwater if the pond leaks.

Sources of information

Dawes, J. The Pond Owners Problem Solver. Tetra Press. Blacksburg, Virginia; 1999.

Middlebrooks, E. Municipal Wastewater Stabilisation Ponds. Washington, D.C. Office of Water. 1983

May, PJ. The Perfect Pond Detective Book 1. Kingdom Books. Waterlooville, England; 1998.

- *VI.1.1.2.Aerobic Ponds*

Brief overview

Aerobic ponds maintain dissolved oxygen throughout. They are typically 300 to 450 mm deep which allows sunlight to penetrate at full depth. Detention time is usually 3 to 5 days. Because the detention time is so short, very little coliform destruction will result. These coliforms pose a hazard to soil and groundwater if the pond leaks.

Algal Ponds in which the growth of algae is encouraged to assist in the treatment process is a specific form of aerobic pond.

Sources of information

Dawes, J. The Pond Owners Problem Solver. Tetra Press. Blacksburg, Virginia; 1999.

Middlebrooks, E. Municipal Wastewater Stabilisation Ponds. Washington, D.C. Office of Water. 1983

May, PJ. The Perfect Pond Detective Book 1. Kingdom Books. Waterlooville, England; 1998.

- *VI.1.1.4..Reed beds*

Brief overview

A reed bed is an artificially created wetland planted with specially selected species of reeds that have the ability to absorb oxygen from the air and release it through their roots. This creates ideal conditions for the development of huge numbers of micro-organisms which are able to break down any soluble material present.

Two different basic types of reed-beds have been developed and used for the treatment of polluting waste water effluents over the last 20 years or so:

- Horizontal flow reed-beds
- Vertical flow reed-beds

From these in more recent years a third type of reed bed system, that is highly efficient, has evolved:

- Combination vertical and horizontal flow reed beds

The flow configuration of reed beds can also be sub-surface or “on-surface”.

Horizontal Flow Reed-Bed Systems:

Horizontal flow reed beds work particularly well for low strength effluents, or effluents that have undergone some form of pre-treatment.

Whilst not effective in reducing ammonia they will almost always reduce COD (Chemical Oxygen Demand) and SS (Suspended Solids) levels. These systems are also ideally suited for tertiary treatment and polishing of effluents.

A typical application would be to treat the discharge from a wastewater treatment plant which is unable to meet the discharge consent standard.

Vertical Flow Reed-Bed Systems: Vertical flow reed-bed systems are much more effective than horizontal flow reed-beds not only in reducing COD and SS levels but also in reducing ammonia levels and eliminating smells. They can be considerably smaller and will also cope with much stronger effluents.

Combination Systems: Multi-stage reed-bed systems, incorporating one or two stages of vertical flow followed by one or more stages of horizontal flow, and large single stage vertical flow reed-beds, when properly designed, are used for example, for the full treatment of domestic sewage - black and grey water - and, sludge, if required.

Sources of information	Online: http://www.johnstonsmith.co.uk/fact17.html Von Sperling, M. & Chernicharo, C.A.L. (2005). Biological wastewater treatment in warm climate regions. IWA Publishing, London. 1460 pp.

- *VI.1.1.5.Trickling filters*

Brief overview	A trickling filter consists of a bed of highly permeable media on which surface a mixed population of micro-organisms is developed as a slime layer. The word "filter" in this case could be misleading as there is no straining or filtering action involved. Passage of wastewater through the filter causes the development of a gelatinous coating of bacteria, protozoa and other organisms on the media. It is this biological system on the media that effect the treatment of the wastewater as it flows in a thin layer over the "slime layer" on the filter media. With time, the thickness of the slime layer increases preventing oxygen from penetrating the full depth of the slime layer. In the absence of oxygen, anaerobic decomposition becomes active near the surface of the media. The continual increase in the thickness of the slime layer, the production of anaerobic end products next to the media surface, and the maintenance of a hydraulic load to the filter, eventually causes sloughing of the slime layer. This cycle is continuously repeated throughout the operation of a trickling filter. Trickling filters is normally followed by secondary sedimentation to remove the sloughed solids and to produce a clear effluent. For economy, and to prevent clogging of the distribution nozzles above the filter media, primary sedimentation tanks equipped with scum collecting devices should precede trickling filters.
Sources of information	Von Sperling, M. & Chernicharo, C.A.L. (2005). Biological wastewater treatment in warm climate regions. IWA Publishing, London. 1460 pp.

- **VI.1.2.Activated Sludge Process**

What is an activated sludge process?	The activated-sludge process is a biological method of wastewater treatment that is performed by a variable and mixed community of micro-organisms which is kept in suspension in the water to be treated. These micro-organisms derive energy from carbonaceous organic matter in wastewater for the production of new cells in a process known as synthesis, while simultaneously releasing energy through the conversion of this organic matter into compounds that contain lower energy, such as carbon dioxide and water, in a process called respiration. As well, a variable number of micro-organisms in the system obtain energy by converting ammonia nitrogen to nitrate nitrogen in a process termed nitrification. This consortium of micro-organisms, the biological component of the process, is known collectively as activated sludge.
Purpose of activated sludge processes	The main goal of the activated-sludge process is to remove substances that will have an oxygen demand on natural systems as well as to reduce the amount of nutrients released into nature. This is accomplished by the metabolic reactions (synthesis-respiration, nitrification and denitrification) of the micro-organisms.

Configuring activated sludge processes	There are three different "modes" in which an activated sludge process can be configured namely, aerobic, anoxic and anaerobic. The functions of these different "modes" are described below.

- *VI.1.2.1.Aerobic systems*

Brief overview	An aerobic system has free (dissolved) oxygen available in the mixed liquor in the bioreactor. This is a biological system mainly reduces organic pollution which has an oxygen demand. Under specific conditions an aerobic system will also oxidise ammonia nitrogen to nitrate and nitrite. The only nitrogen and phosphate removed from the wastewater under totally aerobic conditions are those required for normal metabolism of the sludge (i.e. for cell growth). In typical domestic wastewater this mode of nutrient uptake is not sufficient to reduce the nutrient level to below the maximum allowable levels for release of the treated effluent into nature.
Sources of information	Von Sperling, M. & Chernicharo, C.A.L. (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

- *VI.1.2.2.Anoxic-Aerobic systems*

Brief overview	This is a biological system in which biological nitrogen removal is accomplished in two distinctly different processes. An anoxic process is a biological process that has no free oxygen, but bound oxygen is available from nitrate and nitrite. In the aerobic zone nitrogen in the wastewater is converted from organic nitrogen and ammonia to nitrite and nitrate. This is referred to as nitrification. In the anoxic zone nitrate and nitrite is reduced to nitrogen gas, effectively removing the nitrogen from the wastewater. This is referred to as denitrification. There are a number of configurations for wastewater treatment plants involving these two processes. The most appropriate and economic configuration will be dictated by the wastewater characteristics and quality required for the treated effluent.
Sources of information	Von Sperling, M. & Chernicharo, C.A.L. (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

- *VI.1.2.3.VAnaerobic – Anoxic - Aerobic systems*

Brief overview	An anaerobic process is a biological process in which no oxygen, free or bound, is available to the biological system. Anaerobic processes is normally included in an activated sludge system where biological phosphorous removal is a requirement. It has been found that when aerobic organisms is put under stress by depriving them from oxygen, some of the organisms has the propensity to assimilate more phosphorous than what is required for normal biological metabolism. It should be noted that an anaerobic process should be accompanied by an anoxic process to prevent any nitrate or nitrite to enter the anaerobic zone which would effectively convert it to an anoxic zone.

Sources of information Von Sperling, M. & Chernicharo, C.A.L. (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

- *VI.1.2.3.Chemical precipitation*

Brief overview Chemical precipitation is a widely used, technology for the removal of metals and other inorganics as well as some organic substances (including organic phosphate) from wastewater. Chemical precipitation is a method of causing contaminants that are either dissolved or suspended in solution to form a solid precipitate, which can be settled, filtered or centrifuged, or otherwise separated from the liquid portion. Precipitation can be assisted through the use of a coagulant, an agent which causes smaller particles suspended in solution to gather into larger aggregates. Frequently, high molecular weight anionic polymers are used as coagulant to aid the flocculation of particles.

Sources of information Von Sperling, M. & Chernicharo, C.A.L. (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

- **VI.1.3.Post-treatment systems**

- *VI.1.3.1.Constructed wetlands*

Brief overview Wetlands are constructed areas in which vegetation is planted to facilitate the treatment of water flowing through the system. In the wetland system, plants and soils remove organics and nutrients for growth, provide a surface for micro-organisms and bacteria to break down waste and promote settling of solids. Wetlands are normally lined (mostly with clay) to prevent contamination of groundwater.

Sources of information Von Sperling, M. & Chernicharo, C.A.L. (2005). *Biological wastewater treatment in warm climate regions*. IWA Publishing, London. 1460 pp.

- **VI.1.4.Small community wastewater treatment system**

Overview There are several small-scale treatment systems that can be used to treat the wastewater of small communities. These are often referred to as package plants. A package plant is any onsite, waterborne, domestic wastewater treatment system; whether it consists of one or many modules; with a total capacity less than 2 000 m^3/day. It typically includes equipment largely constructed and packaged off site and brought onsite for installation.

In general, the impact of small communities on pollution in rivers and reservoirs tend to be small provided these communities have access to an appropriate wastewater treatment system and solid waste removal. However, the cumulative impact of a large number of small wastewater treatment systems with no or minor nutrient removal may lead to localised eutrophication problems in a river or reservoir receiving treated effluent from these communities.

Septic tank	A traditional on-site system for the treatment and disposal of domestic wastewater from individual households or establishments is a septic tank followed by a soil absorption bed. The system consists of a buried tank where wastewater is collected and scum, grease, and settleable solids are removed by gravity followed by a subsurface drainage system where wastewater percolates into the soil.
Septic tank mound system	Used as an alternative to the conventional septic system tank-soil absorption system in areas where soil conditions preclude the use of subsurface trenches or seepage beds.
Facultative lagoon	A shallow (1 - 2.5m) pond in which the wastewater is stratified into three zones. These zones consist of an anaerobic bottom layer, an aerobic surface layer, and an intermediate zone.
Oxidation ditch	An activated sludge biological treatment process. The typical oxidation ditch treatment systems consist of a single or closed loop channel 1.5 - 2m deep, with 45° sloping sidewalls. Some form of preliminary treatment such as screening or removing normally precedes the process. After pre-treatment, the wastewater is aerated in the ditch using mechanical aerators that are mounted across the channel.
Trickling filter	The trickling filter process consists of a fixed bed of rock media over which wastewater is applied for aerobic biological treatment. Slimes form on the rocks and treat the wastewater and the treated wastewater is collected by an underdrain system.
Spray irrigation	Wastewater is sprayed on crops or ground cover and the water is treated as it percolates through the soil. An under drainage system recovers the effluent.
Treatment wetlands	Artificial wetlands are constructed specifically to function as wastewater treatment systems. In the wetland system, plants and soils remove nutrients for growth, provide a surface for micro-organisms and bacteria to break down waste, and promote settling of solids. Treatment wetlands often serve as tertiary treatment for many small communities.
Sources of information	Van Niekerk, A, Seetal, A, Dama-Fakir, P, Boyd, L, and Gaydon, P. 2009. Guideline document: Package plants for the treatment of domestic wastewater. Prepared by Golder Associates for the Department of Water Affairs, South Africa. ENGIN, 2016. Integrated study of wastewater treatment systems in Rwanda. Report for Rwanda Environment Management Authority.

VI.1.5.Household scale wastewater treatment systems

VI.1.5.1.Composting latrines

Brief overview	A composting latrine is a structure (usually small, holding a single person, and freestanding) for defecation and urination. Composting latrines allow for safer and more hygienic disposal of human waste than open defecation. They are used in rural areas and low income urban communities. Many variations exist, but at its simplest, the reason for using a composting latrine is that waste is controlled and decomposed into safer by-products. Design considerations for different composting latrines are

documented in the REMA Tool and Guideline # 9. Examples of composting latrines include:

Pit toilets or pit latrines	These are the simplest and cheapest type, minimally defined as a hole in the ground. The most basic improvement is installation of a floor plate. A dry pit does not penetrate the water table, while a wet pit does. Composting variations of the pit toilets are: Arborloo is a portable superstructure with no urine diversion. A tree can be planted in the filled pit. Fossa Alterna has dual pits and is a portable superstructure. Digested contents of pit not in use can be emptied after a year. Fossa Alterna and Arborloos work best when quantities of soil, wood ash and leave are added periodically to produce balanced compost.
Skyloo	The Skyloo is a raised latrine with urine diversion and separate collection of urine and faeces. Skyloo technology is seen as an alternative to the use of pit latrines in areas where the water table is high and the community relies on shallow wells for their water needs. In hilly areas with thin soil cover under hard rock, the Skyloo eco-san composting latrine is a good option. The Skyloo latrine is a permanent feature that requires periodic (6-12 months) emptying of the receptacle and transportation to a composting site. Not only is it constructed at ground level, it also turns human waste into compost. The Skyloo composting latrine consists of two brick pits, constructed above ground level with a latrine squatting slab and superstructure on top. Human waste drops through a hole into the vaults and ash is thrown on top, increasing alkalinity to a level that kills pathogens. The temperature in the vaults is raised by the sun beating down on metal vault covers and the decomposition of the faeces. This also neutralizes pathogens. After several months the first pit is dug out and the fertile compost is used to grow crops. The second pit is then used until it becomes full and the process is repeated. The hygienic latrines generate free compost and pose no threat to groundwater resources. Hygienic latrines that generate free compost and pose no threat to groundwater resources are a real benefit to the community.
A Ventilated Improved Pit (VIP) Latrine	This latrine reduces two of the most common problems with a simple pit latrine: odour and fly/mosquito breeding. Adding a ventilating pipe is the key improvement of the ventilated improved pit latrine. The Doublevault Ventilated Composting Latrine is the most advanced, free-standing latrine. Apart from offering significant reduction in risk from waterborne disease, this type of ecological sanitation provides the closure of some nutrient cycles by allowing the safe, composted waste to be used as a "free" soil treatment in agriculture.
Single vault composting latrine	The first makes use of anaerobic bacteria to decompose the excreta, with two vaults alternatively storing excreta and a separate receptacle for storing urine. The urine should be diluted with 3-6 parts water before being used. This can be done by pouring a small amount of water on to the urine collection area (squatting plate, or specific part of the pedestal) after use. In many applications the urine is then diverted directly to a plot of land where it acts as a soil conditioner for plants and/or crops. Control of

moisture content in the stored excreta is vital for correct operation of the latrine. Such latrines are therefore not appropriate where water is used for anal cleansing. An advantage of this type of latrine is that since the vault contents are kept dry, there is no pollution to the surrounding ground provided the system is correctly operated and maintained.

Double-vault composting latrine

The second type is a continuous composting latrine, which makes use of aerobic bacteria to break down the excreta. These tend to be more "commercially" manufactured systems that incorporate the full functioning of the latrine into a single unit, or can be built using local materials under good supervision and with experienced builders.

The method of separating the urine from the faeces at the squatting plate or pedestal is something of a technical challenge and a number of designs have been tried and tested.

Advantages of composting latrines

The advantages of composting latrines are:

- Nutrients in human excreta can be reclaimed and used in plant/crop growing when composted;
- Urine can be used as a soil conditioner / fertilizer;
- Treating and handling human waste on-site protects the environment from the pollution potential from untreated waste, or waste that is transported off-site and then treated; and
- Ecological composting sanitation latrines can be easier to empty than other on-site options (such as pit latrines).

Sources of information

REMA (2010) Practical Technical Information on Low-cost Technologies such as Composting Latrines and Rainwater Harvesting Infrastructure. Tool and Guideline #9.

Ministry of Agriculture, Irrigation and Water Development (2015). Malawi National Guidelines: Integrated Catchment Management And Rural Infrastructure Volume II: Village Level Catchment Management Guideline Part B1: Toolbox.

14.2 VI.2. Options for managing industrial wastewater

- **VI.2.1.Brewing industries**

Brief overview

Beer is a low alcohol content beverage produced by fermenting sugars extracted from various types of cereals Historically beer was produced from malted barley..

Production methods differ by brewery, as well as according to beer types and equipment. although the overall beer production method is similar: the sugar is extracted from the cereal into the water, hops are added, and the mixture boiled. After cooling, the mix is fermented with yeast to produce alcohol. This raw beer is then matured and packed. Some beers are filtered and pasteurized. Brewery operations also involve heating and cooling, cleaning agents, and packaging materials.

The brewing industry has a high water input requirement in its production value-chain; hence, industry location and operational efficiencies are paramount considerations in minimising potential economic viability and environmental impact risks

Environmental issues associated with the operation phase of breweries primarily include the following:

- Water consumption
- Wastewater management
- Solid waste and by-products generation
- Emissions to air
- Energy consumption

Good practices: Resource use and wastewater and waste generation

The brewing industry has been compelled to reduce costs and environmental impacts by increasing process efficiencies through intensifying and optimising their production and waste management practices.

Summary of recommended best practices for reducing the environmental impact from the brewing industry

Environmental issues	**Recommendations**
Water consumption	Measure and monitor the water use in all different processes. Adopt water saving technologies that promote prevention, control, minimisation and recycling to the extent possible without compromising the hygienic standards, for example: ● use flash pasteurization instead of tunnel pasteurization to reduce water requirement ● adopt Clean-in-place (CIP) methods for decontaminating equipment ● Use equipment cleaning with high-pressure and low-volume hoses ● Install recirculating systems on cooling water circuits
Wastewater management	Adoption of cleaner production principles reduces waste and this in turn results in lower environmental impact and occupational risks. Cleaner production reduces the cost of wastewater disposal by reducing the volume and strength of effluents that need to be treated. The following preventive management measures can be taken to reduce the organic load of brewery effluent: ● Collect weak wort in a tank equipped with heating jackets and a slow speed agitator for use in the next brew. This reduces the organic load in the wastewater, saving raw materials and conserving water. Weak wort collection is particularly important for high-gravity brewing;

	● Undertake procedural improvements to reduce the amount of residual beer, such as the emptying of tanks, good housekeeping, and efficient monitoring systems; ● Avoid overfilling of fermenting vessels which causes loss of partially-fermented wort and yeast; ● Ensure sedimentation of caustics from the bottle washer; ● Collect and reuse of rinsing water from the last cleaning in the first cleaning-in-place (CIP) cycle.
Solid waste and by-products generation	Recommended management measures to reduce solid waste production and increase by-product sales include: ● Optimal use of raw materials to increase yield and reduce generation of solid and liquid waste, including: ○ Avoidance of poor quality raw materials ○ Optimizing milling of the grist ○ Optimizing lautering, including sufficient sparging of the spent grains, to gain as much extract as possible ○ Collection and use of weak wort for mashing in the next brew ○ Optimizing clarification through use of a whirlpool as poor clarification results in a high trub volume ○ Recovery of the wort from the hot trub ○ Recovery of beer from surplus yeast ○ Collection and reuse of residual beer. Pre-run and after-run beer is of high quality, and may be dosed directly into the beer flow in the filter line. Other residual beer from the packaging area should be returned to the whirlpool ● Where feasible, the commercial value of the waste streams should be exploited by: ○ Collecting spent brewers grains from mashing for sale as animal feed by-product ○ Avoiding discharge of hot trub into the sewer system. ○ The hot trub should be returned to the mash kettle or lauter tun and mash filter. The trub then forms part of the brewers grains and can in this way be utilized as animal feed ○ Collecting and reusing yeast from the fermentation process as a by-product. Yeast can be collected from fermentation and storage tanks, the yeast storage plant, and the filter line. Only part of the yeast can be reused in the next batch. As much surplus yeast as possible should be collected to avoid high chemical oxygen demand (COD) in the wastewater stream and resold for commercial use. Traditionally, surplus yeast has been sold as feed to pig livestock facilities. Other uses include yeast extract, yeast pills, cosmetics, and use by the pharmaceutical industry ○ Recycling broken glass from returned bottles to produce new glass

	○ Disposing of label pulp generated from washing of returned bottles. Where feasible, label pulp should be recycled or composted. Label pulp should be disposed of at a landfill facility if it contains high levels of caustic liquid from the washing process or heavy metals from label ink ○ Utilization of sludge from the brewery wastewater treatment plant through its application as an agricultural fertilizer, or disposal in an appropriate landfill facility
Emissions to air	To reduce odour emissions from wort boiling, a heat recovery system should be used to collect and condense the vapours and the recovered energy used in process or utility systems. The main sources of dust emissions are the use and storage of grains and sugar. The cereal handling areas should be designed to control excessive dust production and minimize sources of ignition including sparks to prevent explosions. Additionally, cyclones and bag filters should be used to collect and recover dust in the following manner: ● Dust generated from the unloading of raw materials and transport of malt and adjuncts should be conveyed to the mash or adjunct kettle and the extract recovered; ● Dust arising from malt and adjuncts may be used as animal feed. The following management measures should be taken to reduce dust explosion hazards: ● Frequent sweeping to control dust accumulation, and use of dust extraction and recycling systems to remove dust from work areas; ● Provision of electrical grounding, spark detection and prevention; ● Use of explosion proof electrical motors, lights, switches, and connections in high risk areas; ● Integration of explosion relief vents in facility design and construction; ● Elimination of external ignition sources; ● Implementation of hot-work permits; ● Control of all smoking materials; ● Prohibition of cell phone use.
Energy consumption	Install solar panels/wind turbines to reduce the total electricity burden and/or generate additional electricity. Electricity can be generated from biogas that is captured through wastewater treatment. However this is only reserved for very large breweries that can afford to have a wastewater treatment plant at the brewery itself.

	[*Sources: (1) NATSURV 1 – Water and Wastewater Management in the Malt Brewing Industry. Edition 2. WRC Report No. TT 676/16 AND* *(2) Environmental, Health, and Safety Guidelines. International Finance Corporation / World Bank Group*]
Good practices: Benchmark values	The wastewater generation should be aligned and not exceed the tolerance limits provided on the updated version (latest edition) of the Rwanda Standards for Water Quality for Discharged industrial wastewater.
Good practices: Monitoring	Environmental monitoring programs for this sector should be implemented to address all activities that have potentially significant impacts on the environment. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analysed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken.
Good practices: Health and safety	The prevention, mitigation of impacts, such as traffic and hazardous materials safety from raw material delivery and from finished product shipments, among others, should be considered. Occupational health and safety performance should be evaluated against internationally published exposure guidelines. Odour and dust are the most significant air emissions from breweries. Greenfield projects should consider the location and distance of a proposed facility with regards to residential or other community areas.
Sources of information	Fresner, J (Dr.). 2017. Resource efficient and cleaner production investment guidelines for new industries. Final Report Part 2 (Pages 33-60). STENUM GMBH, Graz, Austria. International Finance Corporation. 2007. Environmental, Health, and Safety General Guidelines. World Bank Group, Washington, United States of America International Finance Corporation. 2007. Environmental, Health, and Safety Guidelines for Breweries. World Bank Group, Washington, United States of America Ramukhwatho, F. Seetal, A. & Pienaar, H. 2016. NATSURV 1 – Water and Wastewater Management in the Malt Brewing Industry. Edition 2. WRC Project No. K5/2285 Report No. TT 676/16. Water Research Commission, Pretoria, South Africa. Technical Committee of Rwanda Bureau of Standards (RBS) / TC 13. 2014. RS109-2009 Water quality – Discharged industrial wastewater: Tolerances limits (EDITED). Rwanda Bureau of Standards , Kigali, Rwanda

▪ VI.2.2. Soft drink industries

Brief overview

The soft drink processing sector covers a wide range of beverages, that can be carbonated, flavoured and coloured, which water is the main raw material and often contain an amount of fruit juice, fruit pulp or other natural ingredients. The soft drink can be grouped in three different categories:

- Cola and non-cola carbonated soft drinks
- Non-carbonated soft drinks
- Bottled water

Environmental issues associated with the operation phase of the soft drink industries primarily include the following:

- Water consumption
- Wastewater management
- Solid waste and by-products generation
- Emissions to air
- Energy consumption

Good practices: Resource use and wastewater and waste generation

The soft drink industry has been compelled to reduce costs and environmental impacts by increasing process efficiencies through intensifying and optimising their production and waste management practices.

Summary of recommended best practices for reducing the environmental impact from the soft drink industry

Environmental issues	Recommendations
Water consumption	Measure and monitor the water use in all different processes. Adopt water saving technologies that promote prevention, control, minimisation and recycling to the extent possible without compromising the quality and hygienic standards Opportunities for the optimisation of water use begin at the start of the process at the water treatment plant. Options include: ● Sand filter backwash recovery ● Carbon filter backwash recovery ● Carbon back filter backwash based on pressure drop or chlorine concentration ● Implementing a program to monitor reverse osmosis recovery rate, reject rate, transmembrane pressure, silt density index, pH across membrane modules, and maximise recovery rate ● Re-use reverse osmosis reject water
Wastewater management	In order to effectively treat wastewater from the soft drink industry, it is important to segregate the various wastewater streams. This will allow for optimum treatment for either reuse or disposal.

Solid waste and by-products generation	Recommended measures to prevent and control solid waste generation include the following: ● Minimize inventory storage time for raw materials to reduce losses from putrefaction; ● Monitor and regulate refrigeration and cooling systems during storage and processing activities to minimize product loss, optimize energy consumption, and prevent odours; ● Consider use of enclosure techniques to minimize damage to raw materials stored outdoors; ● Monitor and optimize process yields, e.g. during manual grading or cutting activities, and encourage the most productive employees to train others in efficient processing. ● Clean, sort, and grade raw foodstuffs at an early stage (e.g. at the farm site), in order to reduce organic waste and substandard products at the processing facility; ● Contain solid waste in dry form and consider disposal through composting and / or use for soil amendment; ● Organic and non-organic debris / soil, solid organic matter, and liquid effluents, including sludge from wastewater treatment, which remain after the implementation of waste prevention strategies should be recycled as a soil amendment (based on an assessment of potential impacts to soil and water resources) or other beneficial uses such as energy production; ● Collect and reuse rejected raw materials for manufacturing other products; ● Provide leak-proof containers for collected solid and liquid waste; ● Segregating individual by-products from each other and from waste to maximize their use and minimize waste; ● Implementing best practices in the packaging of soft drinks can result in cost savings to the company, as well as a reduction in the environmental impact of the product post-consumer.
Emissions to air	Recommended techniques to prevent and control particulate matter emissions include: ● Cover skips and vessels, and stockpiles, especially outdoors; ● Enclose silos and containers used for bulk storage of powders and fine materials; ● Where enclosure is not feasible, use sprays, windbreaks, sweeping, sprinkling, and other stockpile management techniques to suppress dust ; ● Use closed conveyors equipped with filters to clean transport air prior to release;

	• Use cyclones and, if necessary, and fabric filters to remove dust from exhaust air; • Remove particulate matter from the gas stream using dry cyclones, *venturi* scrubbers, electrostatic precipitators or dry filter systems, as necessary. Recommended techniques to prevent and control point source odour emissions include:: • Use exhaust stack heights that are consistent with Good Engineering Practice (GEP) [see IFC General EHS Guidelines]; • If the plant is in close proximity to residential areas consider the use of wet scrubbers to remove odour emissions. Wet scrubbers are used to remove odours with a high affinity to water, such as ammonia emitted during the rendering process; Recommended techniques to prevent and control fugitive emissions of odour include: • Minimize storage duration for solid waste to avoid putrefaction; • Operate facilities under partial vacuum to prevent fugitive odour emission; • Regular inspection of chilling and freezing equipment to monitor loss of refrigerants.
Energy consumption	Food and beverage processing activities may require high levels of thermal energy consumption in process heating, cooling, and refrigeration. Recommendations on energy conservation include: • Implement operational, maintenance and housekeeping • insulation measures • Optimize plant processes for energy efficiency • Recover energy from thermal processes where possible

[*Sources: (1) NATSURV 3 – Water and Wastewater Management in the Soft Drink Industry. Edition 2. WRC Report No. TT 640/15. AND (2) Environmental, Health, and Safety Guidelines. International Finance Corporation / World Bank Group*]

Good practices: Benchmark values

The wastewater generation should be aligned and not exceed the tolerance limits provided on the updated version (latest edition) of the Rwanda Standards for Water Quality for Discharged industrial wastewater.

Good practices: Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have potentially significant impacts on the environment. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analysed and reviewed at

	regular intervals and compared with the operating standards so that any necessary corrective actions can be taken.
Good practices: Health and safety	The prevention, mitigation of impacts, such as traffic and hazardous materials safety from raw material delivery and from finished product shipments, among others, should be considered. Occupational health and safety performance should be evaluated against internationally published exposure guidelines. Odour and particulate matter (PM) are the most significant air emissions from soft drink industries. PM may arise from solids handling, solid reduction and drying. Odour may be released by thermal processing steps such as steam peeling, blanching and dehydrating and by microbial action in stored solid waste. Greenfield projects should consider the location and distance of a proposed facility with regards to residential or other community areas.
Sources of information	Fresner, Johannes (Dr.). 2017. Resource efficient and cleaner production investment guidelines for new industries. Final Report Part 2 (Pages 33-60). STENUM GMBH, Graz, Austria. International Finance Corporation. 2007. Environmental, Health, and Safety General Guidelines. World Bank Group, Washington, United States of America International Finance Corporation. 2007. Environmental, Health, and Safety Guidelines for Food and Beverage Processing. World Bank Group, Washington, United States of America Pollution Research Group from University of KwaZulu-Natal, Durban. 2015. NATSURV 3 – Water and Wastewater Management in the Soft Drink Industry. Edition 2. WRC Project No. K5/2286/3 Report No. TT 640/15. Water Research Commission, Pretoria, South Africa. Technical Committee of Rwanda Bureau of Standards (RBS) / TC 13. 2014. RS109-2009 Water quality – Discharged industrial wastewater: Tolerances limits (EDITED). Rwanda Bureau of Standards , Kigali, Rwanda

▪ VI.2.3.Tanning and leather finishing industries

Brief overview	The tanning industry processes hides and skins into leather. This is a chemical process that uses large quantities of water, and hence tanneries produce considerable amounts of both liquid and solid wastes. Though tanneries use a by-product or waste from the meat industry, namely, the hides and skins, the potential negative environmental impacts of tanning are significant. The environmental problems facing the tannery industry are mostly related to wastewater discharge, air emissions, solid waste disposal, and employee health and safety. Leather production usually involves four distinct phases: ● Pre-storage / storage and beamhouse operations; ● Tanning operations ● Dyeing operations

- Finishing operations

A large quantity and wide range of proprietary products and chemicals, including chrome salts, are used in the tanning and finishing processes. The effluent from tanneries usually contains high organic loads as measured by chemical oxygen demand (COD), and high concentrations of dissolved and suspended solids as measured by total dissolved solids (TDS) and total suspended solids (TSS). Effluent might also contain varying levels of sulphates, sulphides, chlorides, chromium, ammonium salts, and calcium salts, which add to the pollutant load on the environment of the wastewater streams discharged.

Major pollutants generated at various stages of leather production

Origin	**Pollutant***
Beamhouse	● Salt washed out of cured hides and skins. ● High COD/solids from dissolved hair, skin proteins and process chemicals. ● Sulphide used to remove the hair from hides and skins. ● Ammonium ions released from the raw hide or skin and released from the process chemicals during deliming and bating.
Tanning	● Salt used in the pickling process. ● Chrome tanning salts that are were not chemically bound to the leather.
Dyehouse	● High COD caused by incomplete exhaustion of chemicals. ● Chromium salts that are extracted from the wet blue during processing. ● Inorganic salts originating from chemicals and dyes. ● Dyestuffs not chemically bound to the leather.
Leather finishing	● Organic solvents released from finishing auxiliaries. ● Heavy metals from pigments.

* Typical pollutants found on the tanneries' effluent during a survey done on Southern African tanneries

[*Source: NATSURV 10 – Water and Wastewater Management in the Tanning and Leather Finishing Industry. WRC Report No. TT 713/17*]

Water quality standards for the industrial effluent discharges, and the occupational safety and health exposure limits are being analysed and adjusted for the tanning and leather finishing industries worldwide. Moreover, there is international advocacy to adopt technologically cleaner production methods and reduce waste generation.

Good practices: Resource use and wastewater and waste generation

Reuse/upcycle by-products from the meat industry into the tanning industry.

Reuse/upcycle the tanning industry by-products into other industries (for example: wool and hair may be used to manufacture textiles).

Reduction in water use can be achieved by decreasing the volume of water used in particular processes and/or recycling/reusing process water, however the quality of the end product may be compromised.

Establishing cleaner production technologies improves the wastewater quality, as well may also reduce water consumption. The potential for increased efficiency through process change is significant and should be clearly identified in the design of the facilities and processes.

Summary of a selection of alternative 'best available' technologies and their environmental benefits

Alternative 'cleaner' technologies	**Environmental benefit/s**
Processing of fresh hides	● Less salt in the final effluent. ● Savings in water consumption
Recycling of soak floats	● Savings in water consumption. ● Savings in chemical usage.
Use of enzymatic soaking chemicals	● Less use of surfactants. ● Reduced soaking times leading to less energy consumption.
Use of biodegradable surfactants	● Less chance of surfactants persisting in the environment. ● Reduced impact on aquatic organisms
Hair-save unhairing	● A 60% reduction in COD of effluent. ● A 50% reduction in sulphide usage. ● A 35% reduction in nitrogen content of effluent.
Low-sulphide/sulphide-free unhairing	● No sulphides in effluent. ● Reduced odours. ● Reduced COD in effluent. ● Better settling of suspended solids in effluent.
Recycling of liming floats	● Savings in water consumption. ● No sulphides in final effluent. ● Reduced COD in effluent.
Low ammonia deliming/CO2 deliming	● Reduced ammonium ions in the effluent. ● Less odour.
ThruBlue process	● No salt in effluent. ● No sulphate ions in effluent
Salt-free pickling process	● No salt in effluent.
Pickle recycling	● Reduced salt in effluent. ● Savings in water consumption.

High-exhaustion chrome tanning	• Reduced chrome in effluent
Chrome recycling	• Reduced chrome in effluent • Savings in water consumption.
Chrome-free leathers	• No chrome in effluent.
High-exhaustion retanning chemicals, dyes and fatliquors	• Less COD in effluent. • Less dyestuffs in effluent.
Aqueous finishing systems	• Solvent-free air emissions.

[*Source: Jackson-Moss, personal communication in NATSURV 10 – Water and Wastewater Management in the Tanning and Leather Finishing Industry (Edition 2). WRC Report No. TT 713/17*]

Good practices: Benchmark values

The wastewater generation should be aligned and not exceed the tolerance limits provided on the updated version (latest edition) of the Rwanda Standards for Water Quality for Discharged industrial wastewater.

Good practices: Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have potentially significant impacts on the environment. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analysed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken.

Good practices: Health and safety

The prevention, mitigation of impacts, such as traffic and hazardous materials safety from raw material delivery and from finished product shipments, among others, should be considered. While odours from leather tanning are not generally hazardous, they can constitute a nuisance to the surrounding community. Thus, greenfield projects should consider the location and distance of a proposed facility with regards to residential or other community areas.

Sources of information

Fresner, Johannes (Dr.). 2017. Resource efficient and cleaner production investment guidelines for new industries. Final Report Part 2 (Pages 122-149). STENUM GMBH, Graz, Austria.

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▪ VI.2.5. Sugar mills

Brief overview

The sugar industry is unusual in that the main raw material (sugar cane) contains very large quantities of water (about 70% by mass). As the main process in both a mill and a refinery is concerned with extracting sugar crystals from solution, the vast majority of this and any other water entering a plant is evaporated and can be recovered as condensate. Water from other sources (typically boreholes or river abstraction) is used only in applications such as cooling for condensation of vapours or domestic consumption. Specific water intake (SWI) was found to be 30 to 100 m^3/100t of cane processed with a mean SWI of 60 m^3/100t.

Wastewater volumes are relatively small compared to the total volumes of water in circulation at any one time. Typically 750 to 1500 m^3/d of waste water (about 30% of the water intake) is generated with a chemical oxygen demand of 1500 to 2000 mg/l. The main source of this chemical oxygen demand (COD) is sugar lost in washing and in cooling water overflows. Sugar plant waste waters are problematic in that the COD load present is almost totally soluble leading to sludge bulking and sludge loss problems in conventional biological treatment systems. They also tend to be deficient in nitrogen and phosphorus.

By-products from a sugar processing plant are molasses, which goes to animal feed or further processing to fermentation products, and bagasse which is burnt in the sugar plant boilers or can be further processed to paper and chemical products.

Solid wastes arising from sugar processing are boiler ash and smuts which go to landfill and filter cake (from the milling process) which may be used as fertilizer in some areas or alternatively is also disposed of as landfill.

Wastewater from sugar mills

Sugar plant waste waters are problematic for a number of reasons:

- Shutdown takes place for a brief period each week during which time waste-water pollution load can be minimal or very high if cleaning of process units is taking place (COD levels of up to 20 000 mg/£ can be discharged during these periods), making operation of biological treatment systems very difficult.

- Sugar mill waste waters are difficult to treat biologically as they are deficient in nitrogen and phosphorus so nutrient addition is usually required.
- Since sugar plant waste waters contain almost totally soluble pollutants, sludge bulking and sludge loss problems are encountered.

By-products and solid waste associated with sugar mills

The materials which arise as a result of sugar processing are not regarded as wastes. The main materials include:

- bagasse
- smuts
- filter cake
- molasses.

Bagasse is usually burnt by the plant in its own boilers. It is not, however, a particularly clean fuel and large quantities of smuts arise as a result of wet scrubbing operations.

Smuts is often disposed of in a mixture with filter cake which is sought after as a fertilizing mulch for cane fields. However, smuts has no fertilizer value and thus is problematic for plants which operate with diffuser mills as these produce very little filter cake for mixing with the smuts. In some of these cases smuts is disposed of as landfill.

Bagasse can also be used to produce paper or alternatively, chemical by-products. Molasses has many uses as a raw material, for instance in animal feeds or as a fermentation substrate for the production of ethanol, acetone, butyl alcohol, glycerol and citric acid.

Good pollution control practices

Some good housekeeping methods at sugar mills include:

- bunding of molasses storage areas;
- removal of solids onto cultivated land at least 20 m from a river bank; and
- ensuring that there is runoff of effluent used for irrigation and that stormwater runoff from the factory area does not enter nearby watercourses.

Treatment technologies

In order to cope with the tremendous variation in waste-water quality and quantity sometimes encountered, sugar plants usually utilize large pond systems and in this regard, are fortunate to have large areas of land available for this purpose. Common technologies to treat sugar mill effluents include:

Anaerobic treatment because it has the advantage that no capital or running cost for mechanical aerators; the nutrient requirements are lower than for aerobic digestion; and the large anaerobic dams buffer the hydraulic flow to the downstream aerobic system. A disadvantage is that it tends to produce unpleasant odours. Sophisticated enclosed anaerobic digestors can consume as much as 25 kg of COD/m^3/d.

Aerobic treatment include Pasveer ditch, activated sludge, and trickling filters.

- The Pasveer ditch consists of a "race track" ditch with surface aerators which circulate the effluent round the ditch. Older ditches use Kessener aerators ("brushes") consisting of rows of paddles rotating about a horizontal axis which is above the water. More modern aerators involve sets of perforated discs rotating on the axis. The ditches have two internal settlers which can be used alternatively for settling the effluent whilst clear overflow is drawn off.
- Activated sludge consists of an aeration tank and separate clarifier. Aeration intensity and sludge concentration are higher than in Pasveer ditches, enabling a shorter retention time. Excessive sludge must be "wasted", unlike in a Pasveer ditch where it is produced more slowly and digested internally. Aerators are vertical spindles which draw the effluent upwards and throw it outwards through the air.
- Trickling filter consists of a tank filled with broken rock onto which the effluent is sprayed. Airvents at the base of the tank enable air to move counter-current to the effluent as it trickles over the microbial sludge on the rocks. The effluent is usually partially recirculated, this being dependent on its concentration. Trickling filters can be operated either as high rate filters or as polishing filters. The major advantage of trickling filters for the sugar industry is that the sludge is attached to the rocks and is therefore not difficult to keep in the system. With sugar factory effluent (mainly soluble) the formation of bulking sludge, which will not settle, is a persistent and serious problem with Pasveer ditches and activated sludge systems.

Sources of information

NATSURV 11. 1990. Water And Waste-Water Management In The Sugar Industry. WRC report TT47/90. Water Research Commission, South Africa.

▪ VI.2.6.Textile industries

Brief overview

The textile industry comprises a group of related industries engaged in processing activities ranging from yarn and fabric production and finishing through to the manufacture of clothing and other soft goods items. The factories concerned are often referred to as mills and the terms "factory" and "mill" are often used interchangeably, depending on the context.

About 70 to 80% of the water intake to a textile factory is discharged as industrial effluents. The industrial waste waters generated are characteristically high in dissolved solids, heavy metals and colour, and contain relatively poorly degradable organic components.

Effluent management

Pollutant loads in final effluents of textile factories can be minimized by limiting and controlling pollutants at source. Areas that should be given attention include the following:

- Segregation and appropriate separate treatment of high-strength effluents such as dyeing, mercerizing, scouring and dyebath effluents.

- Dry collection techniques for chemical spillages, rather than flushing to drain.
- Minimizing effluent volume by reducing water use, while concomitantly reducing pollutant losses to drain to ensure that effluent quality discharge limits are not exceeded.
- Identification and control or elimination of pollutant sources that pose special discharge problems, for example detergents, oils, solvents, dyes and finishing agents.
- Substitution wherever possible of less aggressive processing chemicals as alternative for toxic or highly polluting chemicals.
- Proper inventorying and control of the large quantities of chemicals routinely handled on site.

Wastewater treatment

On-site effluent treatment methods that can be implemented using established technology to achieve significant improvement in the final waste-water quality discharged from textile processing operations include the following:

- Sodium hydroxide recovery from highly alkaline mercerizing effluents; in addition to reducing the excessively high pH of some final effluents, the high sodium content of the final effluent is also reduced.
- Fine screening to remove lint etc. to reduce suspended solids in the effluent.
- Balancing and/or storage of the final effluent to smooth out inter alia variations in quality.
- Adjustment of the pH of the waste water discharged using adequate pH control and chemical dosing systems, to ensure permissible discharge limits are not exceeded.
- Consideration can be also be given to the use of advanced waste-water treatment systems for economically treating individual effluent streams, to reduce the pollution loads discharged as well as offering potential benefits in terms of recovered and re-useable materials.

Sources of information

Fresner, Johannes (Dr.). 2017. Resource efficient and cleaner production investment guidelines for new industries. Final Report Part 2 (Pages 122-149). STENUM GMBH, Graz, Austria.

NATSURV 13. 1990. Water And Waste-Water Management in the Textile Industry. WRC report TT50/90. Water Research Commission, South Africa.

Rwanda Cleaner Production Center (RCPC). 2015. Resource efficient and cleaner production guidance manual for wet textile processing industry.

14.3 VI.3.Options for managing agro-processing industries

▪ VI.3.1.Coffee washing stations

Brief overview

Coffee plays a major role in the economy of Rwanda, contributing significantly to foreign exchange earnings and to the monetisation of the rural economy.

Coffee washing stations (CWS) contribute significantly to the organic loads in receiving rivers and streams. The traditional wet-milling process begins when the pulp is removed from freshly harvested coffee cherry. The cherry is poured into a funnel that leads to a depulper, where the outer skin, or pulp is removed. This leaves the seeds, or coffee beans, covered in sticky, gelatinous mucilage. The mucilage is then removed from the bean through a fermentation process that can last anywhere from 12 to 36 hours or more depending on local conditions and practices.

One traditional method of depulping involves running a continuous stream of water through the depulper as it is operating. Then following fermentation, the coffee is washed to remove the mucilage, a process that can require large volumes of water. The wastewater from the wet milling process is one of the leading contaminants of local water sources in coffee-growing communities. The mucilage is high in sugars and pectin. The sugars and pectin in the water ferment into acetic acid which are released into local receiving streams, where they can only be broken down by oxygen in the water. The amount of oxygen needed to break down the organic pollutants in the coffee washing wastewater, commonly measured as the biochemical oxygen demand (BOD), often exceed the rate at which oxygen is replaced in the receiving stream This results in anaerobic conditions developing which threatens aquatic life and creates favourable conditions for the production of bacteria harmful to human health.

Effluent treatment

Kazoora (2011) recommended the Anaerobic Digestion Coffee Waste System (AD-CWS) as a technology can use waste generated by coffee processing to generate biogas and fertilizer. Biogas can be used at source to dry coffee beans, thereby saving on energy costs and fertilizer can be sold to generate additional income. The other saving is associated with reduced pollution into receiving streams and commitment costs of water treatment, loss of riverine biodiversity, etc.

The AD-WCS uses the waste generated by depulping and washing, containing coffee pulp, mucilage, and water. The waste is collected in mixing tanks which is sent to a digester. The biogas (methane) generated in the digester can be burned to produce heat and the can be used amongst other, for drying coffee beans.

Sources of information

Kazoora, C. 2011. Costs and benefits of addressing environmental impacts in the wet coffee processing in Rwanda. Report to REMA, funded by UNEP.

▪ VI.3.2.Dairies

Brief overview

The discharge of untreated or partially treated wastewater from dairies can have a significant impact on surface water bodies. The major concerns in milk processing industries are wastes and emission produced during the processing operation and resources required.

The general wastes produced depend on the type of milk products produced, process involved, packaging systems and material; and also on the source and nature of the waste. Source of waste in a dairy plant includes:

- The washing and cleaning out of product remaining in tank trucks, cans, piping, tanks, and other equipment performed routinely after every processing cycle.
- Spillage produced by leaks, overflow, freezing- on, boiling- over, equipment malfunction, or careless handling.
- Detergents and other compounds used in the washing and sanitizing solutions that are discharged as waste,
- Entrainments of lubricants from conveyors, stackers and other equipment in the wastewater from cleaning operations.
- Waste constituents that may be contained in the raw water which ultimately goes to waste.

Processing losses which include sludge discharged from clarifiers, product wasted during pasteurizer start-up, shut-down, and product change- over, evaporation entrainment, discharges from bottles and case washers, splashing and container breakage in automatic packaging equipment, and product change-over in filling machines.

Diary wastes are high in BOD, Chemical Oxygen Demand (COD), suspended solids (SS), pH, temperature, phosphorus, nitrogen, chlorides, fat, oil greases (FOG) and sludges. Negatives environmental impacts will therefore result in the release of high amount of one of these parameters (BOD, COD, SS, P, N, Cl, and FOG) in the environment.

Negative impacts which are generally observed due to the above pollutants are nutrient enrichment and eutrophication, toxic algal blooms, toxicity, deposits into water bodies, oxygen depletion, odour problems, contamination and degradation of soils, emissions of gases which carbon dioxide (CO_2), Methane gas (CH_4), sulfur dioxide (SO_2), and nitrates compounds (NOx).

Management options

Options to manage dairy impacts include:

In plant control measure: the control of dairy wastes requires many in- plant measures which combine to effectively reduce wastes:

- See that the entire program has the active support of the management,
- Install modern equipment and piping in order to reduce wastes,
- The people working in the plant with the importance of reducing wastes
- Secure the proper separation of wastes into process wastes, sanitary wastes and clean water,

- Provide for recovery of by- products,
- Select and install the waste disposal system best suited to the plant,
- Follow through with good operation and maintenance in both the dairy plant and wastewater treatment plant.

Plant Management Improvement: Management is one key to the control of water resources and waste within any given dairy plant. It has been proven that a clear understanding of the relative role of engineering and management supervision in plant losses is needed by management.

- Management has to their part to have an effective water and waste control program in dairy processing. Management roles include:
- Understanding water and waste control in dairy processing including the need of such program, the economic benefits that can be accrued and being cognizant of all interrelated factors,
- Developing job descriptions for all plant personnel,
- Providing an environment that permits supervisors to supervise waste management and
- Utilizing a continuing education program.

Segregation of dairy wastes: when planning renovating existing facilities, consideration should be given to the segregation of those sewers expected to receive high BOD wastewaters. These wastewaters could be restored to a tank for waste load equalizations or subjected to pre-treatment. These wastes include lubricants, milk from filling areas, solid particles from cottage and cheese operations (if applicable).

By product and waste product utilization: the dairy industry must be aware of the significance of using whey as a food or feed product to minimize pollution and to gain a profit from such operations.

Water use reduction: the amount of water use will simultaneously reduce wastewater discharge. Among techniques used to reduce the amount of water there are:

  - Controlling water use at those stations with shut- off nozzles,
  - Water regulating valves used for refrigeration system where the volume of water needed can be influenced by the system head pressure.
  - Use of evaporative condensers for refrigeration systems to achieve as much as 95% water reduction when an evaporative condenser replaced a shell and tube condenser.

Proper design and utilization: proper design of the plant and processes can afford material reduction in waste load

If the dairy does not discharge to a central wastewater treatment works, then suitable effluent treatment processes be installed and operated by the dairy. Both activated sludge and biofilter systems are suitable for this application with the majority of treatment coming from aerobic reactions. The choice of the most appropriate system depends on the specific effluent quality and quantity. The resulting final effluent is normally suitable for disposal to the surface water environment, or may even be recycled to the factory for further use.

Sources of information

Steffen, Robertson And Kirsten Inc. 1989. NATSURV 4 – Water and Waste-Water Management in the Dairy Industry. WRC Report No. TT 38-89. Water Research Commission, Pretoria, South Africa.

MINAGRI, (no date). Updating the Master Plan of the Milk Chain in Rwanda. Report prepared by Development & Management Solutions.

- **VI.3.3.Abattoirs**

Brief overview

Internationally, red meat abattoirs are known to be consumers of high volumes of water. Similarly, they are also serious polluters of wastewater. The wastewater contains high concentrations of waste products, high in chemical oxygen demand (COD) and suspended solids content. Typically, raw blood generates exceptionally high COD levels, while cleaning and carcass washing operations normally account for more than 80% of total water use and wastewater volume. The wastewater emanating from red meat abattoirs depends to a great extent on the size of the operation.

COD concentrations (mg/L) of abattoir wastewater

Abattoir Capacity	Lowest COD measured	Average COD	Highest COD measured
>100	731	1217	5859
50-100	761	2650	8942
20-15	1325	5025	9924

The abattoir process flow, water use and wastewater quality generated in the process is indicated below:

Process Area	Water Use	Effluent Production	Flow Rate	Strength
Lairages 10%	Washdown	ORGANIC Pollution, High	Medium	High
	Livestock drinking	Urine		
Stunning / Bleeding 17%	Washdown	Very High COD Blood High Pollution	Medium	High
	Sterilisation	Slight Pollution		
	Plant washdown	Very High COD		
Carcass Dressing 25%	Carcass washdown	Medium Pollution	High	Medium
	Sterilisation	Slight Pollution		
	Plant washdown	Large Volume & Med		
Red Offal 5%	Offal rinse-down	Slight Pollution	Low	Medium
	Sterilisation	Slight Pollution		
	Plant washdown	Slight Pollution		
Rough Offal 20%	Rough Offal Cleaning	Very High COD Blood High Pollution	High	High
	Sterilisation	Slight Pollution		
	Plant washdown	Very High COD		
Heads & Hooves 1%	Washdown	Slight Pollution	Low	Low
	Sterilisation	Slight Pollution		
Hides & Skins	Plant washdown	Slight Pollution	Low	Low
Condemned Area	Sterilisation	Slight Pollution -	Medium	Medium
By-products Rendering 15%	Processing	Very High COD Blood High Pollution	Low	High
	Sterilisation	Slight Pollution		
	Plant washdown	Very High COD		
LEGEND:	Normal Use	OrganicPollution, High COD		
	Use as Sterilising	Slight Pollution		
	Use as Processing	High COD, High Pollution		

Good management practices

Water use in red meat abattoirs is intrinsically high because of the need to meet stringent hygiene requirements. However, many companies waste for more water than is necessarily required.

Abattoirs The aim should be to minimize waste generation, and systems should be put in place to:

- Reduce water consumption
- Minimise quantities of waste generated
- Minimise spillages
- Remove solids before entering waste streams
- Institute dry-cleaning regimes prior to wash-down

Storm water contaminated by organic materials should be collected in storage reservoirs (dams) for re-use as irrigation supply.

Livestock receiving areas, wastewater treatment plants and all processing areas should be roofed over to minimize the volume of wastewater.

Clean storm water should be separated from contaminated water/wastewater.

High water pressure with adequately designed spray nozzles should be utilized, as water conservation measures.

Process areas should be permanently paved and adequately sloped to facilitate proper drainage to the wastewater treatment plant, and to avoid contamination of storm water.

In the NATSURV report referred to below, a phased approach to instituting water and wastewater improvements is described in greater detail. These include:

- Improving of operational measures
- Scheduling of livestock arrivals
- Washing of vehicles – installation of metered truck-wash dispenser
- Reduction in lairage holding times
- Dry cleaning of lairages before wash-down
- Removal of manure in solid form
- Probable re-use of clear water for primary washing
- Improved collection of raw blood
- Pig scalding
- Carcass washing
- Dry cleaning of gut before washing
- Dry cleaning of meat scraps and solids from process floor
- Control of water use
- Appropriate use of cleaning chemicals
- Constantly maintaining and cleaning of screens for optimal performance
- Consider primary as well as secondary wastewater treatment

Sources of information

Muller, J. 2017. NATSURV 7 – Water and Wastewater Management in the Red Meat Abattoir Industry. WRC Report No. TT 701/16. Water Research Commission, Pretoria, South Africa.

14.4 VI.4. Options for managing mining wastewater

Brief overview

The National policy on mining places emphasis on the exploration for minerals, their industrial processing and their value addition as part of exports and national revenue diversification and job creation. The current mining policy promotes the need to use modern mining techniques that minimise harm to land, forests, water, wetlands and the environment. One of the five pillars of the policy had the objective of reduced environmental impact through no artisanal treatment in rivers. However, due to inadequate implementation of the policy, mining activities cause deterioration and pollution of water bodies. The National Policy for Water Resources Management underscores the need for appropriate minerals exploration and exploitation techniques to prevent pollution and deterioration of the quality and quantity of water bodies.

The impacts of small-scale and artisanal mining operations include bank destabilization, chemical contamination, increase in sedimentation/turbidity, watercourse alteration or channel hydraulics, riparian vegetation loss, and impacts on aquatic life such as smothering of riverine habitat by silt, and fish gill clogging.

Wastewater management at small mining operations should be focussed on preventing pollution of water resources. Three key management areas for pollution prevention and impact minimization are:

- storm water management
- erosion and sediment control
- waste management

Stormwater management

Stormwater runoff can contaminate nearby streams and rivers. The following can be implemented to mitigate the impacts:

- Clean water must be kept clean and be routed to a natural watercourse by a system separate from the dirty water system while preventing or minimizing the risk of spillage of clean water into dirty water systems.
- Dirty water must be collected and contained in a system separate from the clean water system and the risk of spillage or seepage into clean water systems must be minimized.
- Storm water management must be sustainable over the life cycle of the mine.

Erosion and sediment control

Successful control of erosion and sedimentation from mining activities should target each stage of the erosion process.

The most efficient approach involves minimizing the potential sources of sediment from the outset. This means limiting the extent and duration of land disturbance to the minimum needed, and protecting surfaces once they are exposed.

The second stage involves controlling the amount of runoff and its ability to carry sediment by diverting incoming flows and impeding internally generated flows.

The third stage involves retaining sediment, which is picked up on the project site through the use of sediment capturing devices. On most sites successful erosion and sedimentation control requires a combination of structural and vegetative practices.

Measures for erosion and sediment control include runoff and conveyance control, sediment traps, and barriers:

- Berm/Contour hump/Cut-off: A narrow earth or stone ridge built along or across roads to divert rain away from the roads into vegetated areas.

- Dust Control: Watering, mulching, sprigging, or applying geo-textile materials to construction area to prevent soil loss as dust. Control measures should be applied routinely and thoroughly in drier seasons for effective dust control.
- Mulching: A protective blanket of grass or other plant residue, gravel, or synthetic material applied to the soil surface to minimize raindrop impact energy and runoff, foster vegetative establishment, reduce evaporation, insulate the soil, and suppress weed growth.
- Riprap: A layer of stone designed to protect and stabilize areas subject to erosion, slopes subject to seepage, or areas with poor soil structure.
- Top soiling: Preserving and subsequently using the upper, biologically active layer of soil to enhance final site stabilization with vegetation.

Runoff and conveyance control include the installation of:

- Energy Breaks: Rocks or gabions are placed on a slope to guide the run-off and slow it down.
- Grass-Lined Channel: A swale vegetated with grass, which is dry except following storms, and serves to convey specified concentrated stormwater runoff volumes, without resulting in erosion.
- Hardened Channels: Channels with erosion-resistant linings of riprap, paving, or other structural material designed for the conveyance and safe disposal of excess water without erosion.
- Paved Flume: A small concrete-lined channel to convey water down a relatively steep slope without causing erosion.
- Bush barriers: Temporary sediment barriers constructed of bush, weeds, vines, root mat, soil, rock, or other cleared materials piled together to form a berm, and located across or at the toe of a slope susceptible to sheet and rill erosion.
- Sediment Trap: A small, temporary ponding basin formed by an embankment or excavation to capture sediment from runoff.

Waste management

Mining related wastes generally contain pollutants and present a potential risk to the water environment. These include sewage, garbage, wash-water, spent oils and grease; diesel or lubricant spills etc.

Good waste practices include:

- No camp or office site should be located closer than 100 metres from a stream, river or lake.
- Toilet facilities such as a septic drain, should be used and sited on the camp site in such a way that they do not cause water or other pollution.
- The vehicle maintenance yard and secured storage area will be established outside of the high flood level mark within the boundaries of the mining area.

Good resource protection practices at small mining operations	● Minimise access roads or paths into the river and put in erosion protection measures ● Use only one access road to the river at a time ● Control run-off and erosion ● Put in storm water drainage trenches to divert clean storm water from your site ● Collect and treat dirty water from your operations ● Leave a buffer zone i.e. a strip of natural area between the mine site and the body of water ● Store oil, fuel and chemicals safely in designated area outside of the buffer zone ● Locate toilets outside of the buffer zone ● Keep topsoil for rehabilitation ● Keep topsoil separate from other soil/waste rock material ● Protect topsoil by keeping in a secure bunded area on high ground ● Stabilize pit walls ● Stabilize banks and beds of a river ● Rehabilitate as you go – it will save you time, energy and money ● Backfill ponds, pits or roads created ● Leave area as you found it
Sources of information	Department of Water Affairs and Forestry, 2006. Best Practice Guideline A1: Small-Scale Mining (Standard Format). Department of Water and Sanitation, Pretoria, South Africa.

VI.5. Options for managing Landfills & dump sites

Brief overview	The term 'landfilling' refers to the deposition of waste on land, whether it be the filling in of excavations or the creation of a landfill above grade, where the term 'fill' is used in the engineering sense. Landfilling is environmentally acceptable if properly carried out. Unfortunately, if not carried out to sufficiently high standards, landfilling has the potential to have an adverse impact on the environment. Impacts can be divided into short term impacts and long term impacts: ● Short term impacts - Short term impacts include problems such as noise, flies, odour, air pollution, unsightliness and windblown litter. Such nuisances are generally associated with a waste disposal operation and should cease with the closure of the landfill. ● Long term impacts - Long term impacts include problems such as pollution of the water regime and landfill gas generation. Such problems are generally associated with incorrect landfill site selection, design, preparation or operation and may persist long after the landfill site has been closed.

The general objective of environmentally acceptable landfilling, is to avoid both short or long term impacts or any degradation of the environment in which the landfill is located. More specific objective is to pro-actively prevent pollution of the surface and ground water.

The GoR undertook close down uncontrolled dumpsites and to replaced it with environmentally sound landfills. Identification of future landfill sites and technologies shall be undertaken based on selection processes considering technical, financial, social and operational criteria (http://www.mininfra.gov.rw).

Good design practices

To avoid water pollution, it is essential that significant leachate generation from landfills be managed by means of leachate collection and treatment systems.

Any landfill has the capacity to generate sporadic leachate in excessively wet weather conditions. However, all landfills generate some form of leachate due to the organic material in the waste. It is therefore necessary to install leachate management systems (underliners, drains and removal systems) to prevent adverse impacts on the environment.

It is good practice to classify the waste that is deposited at the landfill to assess the risk to the environment of chemical substances present in the waste. Most countries have standardised on the Globally Harmonised System of Classification and Labelling of Chemicals (GHS) that is promoted by the UNECE. The classification of waste is based on sampling and analysis of the total concentrations and leachable concentrations of the chemical substances in the waste. As an example, the South African national norms and standards for the assessment of waste for landfill disposal can be examined.

A leachate drainage system should be designed based on the hazard posed by the waste to surface and groundwater. The design of the containment barrier system should be based on the type of landfill and waste that will be accepted at the site. A landfill for hazardous waste has more stringent design requirements than a landfill for general waste. The same applies for managing the operations at different types of landfills.

Recycling waste

Recycling can reduce waste to landfill but also provide positive economic, environmental and social impacts. The GoR undertook to assist private sector and community initiatives in establishing markets for recyclable products with priority for materials which are currently being recycled and/or can find sustained market demand. Such support may include training and the provision of reimbursable funding or grants.

A document by the CSIR provides guidance on good practices or recycling co-operatives to initiate and manage recycling activities. The guide is focussed on three areas where intervention could assist in creating sustainable co-operatives. These include access to materials, access to markets, and business development.

Sources of information

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Department of Water Affairs & Forestry, 1998. Waste Management Series. Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste. Department of Water and Sanitation, Pretoria, South Africa.

Government Gazette, 2013. National norms and standards for the assessment of waste for landfill purposes. Regulation 635, South African Government Gazette Vol 22 No 36784 of 23 Aug 2013.

Government Gazette, 2013. National norms and standards for disposal of waste to landfill. Regulation 636, South African Government Gazette Vol 22 No 36784 of 23 Aug 2013.

Council for Scientific and Industrial Research (CSIR). 2015. Co-operative good practice guide in the waste sector: A guideline for co-operatives by co-operatives. Prepared by Wilma Strydom and Linda Godfrey. CSIR: Pretoria.

V.6. Guidance for selecting a suite of Point Source Management options

Selecting a short list of point source management options

The following tables provide information that can be used to develop an initial short list of point source management options.

Criteria for selecting domestic wastewater treatment system

ENGIN (2016) listed criteria to consider when selecting a biological wastewater treatment system for treating domestic wastewater. These included:

- Level of treatment required, performance, concentration
- Capacity of facility
- Final destination of sludge
- Floor space available
- Seasonal variation in the pollution loads
- Environmental constraints
- Investment Costs
- Operating constraints
- Quality of the land
- Reliability of the sector - Tertiary treatment
- Wastewater source

They also listed the advantages and disadvantages of Activated Sludge treatment systems, and pond/lagoon treatment systems:

Activated sludge treatment systems

Advantages

- Suitable for any size of community
- Excellent removal of all carbonaceous parameters, nitrogen, and phosphorus.
- Suitable for the protection of sensitive environments.
- Implementation ease of phosphate removal.

Disadvantages

- Significant investment cost
- High energy consumption
- Need for qualified personnel
- Sensitivity to hydraulic and pollutant loads

Pond/lagoon treatment systems

Advantages

- Simple to use
- Simple construction
- Supports variations in loads
- Good removal of N
- Good bacteriological quality

Disadvantages

- TSS higher in the treated effluent
- Variable discharge quality
- Requires higher maintenance
  More difficult to comply with stringent standards (no adjustment possible).
- Sensitivity to septic and concentrated effluents.

Table 2: An overview of the nutrient and carbon removal potential of different wastewater treatment options

TREATMENT	REMOVAL OF NUTRIENTS AND ORGANIC CARBON			OUTPUT
	Nitrogen	Phosphorus	Carbon	
Pond Treatment				
Facultative Ponds	No	No	Relatively High	Effluent needs disinfection / Higher pH / Higher ammonia
Anaerobic Ponds	No	No	Partial	does not nitrify leaving free nitrogen in the effluent / Higher ammonia
Aerobic Ponds	Very low	No	Relatively High	Reduces ammonia and produces nitrates/nitrites
Reed Beds	No	No	Partial	Effluent not suitable for discharge. Performance often erratic.
Trickling Filters	No	No	Yes	Nitrifies some ammonia, extent depend on carbon load.
Activated Sludge Process				

Aerobic System	No	No	Yes	Higher nitrates/nitrites and phosphorus
Anoxic-Aerobic System	Yes	No	Yes	Higher phosphorus
Anaerobic-Anoxic-Aerobic System	Yes	Yes	Yes	Nitrites/nitrates not of better quality. Should be able to reduce P-level to 1 mg/l under favourable conditions.
Chemical precipitation can be applied to any of the activated sludge processes to remove phosphorus to levels of less than 1 mg P/ℓ.				
Urban Run-off				
Wetlands	Very low	Very low	Partial	
Detention Ponds	No	No	Partial	
Vegetated drainage canal	No	No	Partial	
Soak-ways run-off / French drains	No	No	Partial	Only applicable to low flows. Possibility of groundwater contamination.

Table 3: Relative evaluation of the main domestic sewage treatment systems showing removal efficiency for nutrients and other considerations (Von Sperling & Chernicharo, 2005).

Treatment system	Removal efficiency			Economy					Resistance capacity to influent variations and shock loads			Reliability	Simplicity in O&M	Independence from other characteristics [3]		Lower possibility of environmental problems			
	BOD	Nutrients	Coliforms	Requirements		Costs		Generation	Flow	Quality	Toxic compounds			Climate	Soil	Bad odours	Noise	Aerosols	Insects & worms
				Land	Energy	Const [1]	O & M[2]	Sludge											
Preliminary treatment	0	0	0	*****	*****	*****	****	*****	*****	*****	*****	****	***	*****	*****	*	****	*****	***
Primary treatment	*	*	*	*****	****	***	***	***	****	*****	****	****	***	****	*****	**	****	*****	***
Advanced primary treatment	**	*/****	**	*****	****	**	**	*	****	*****	****	****	***	*****	*****	***	****	*****	***
Facultative pond	***	**	**/****	*	*****	*****	*****	*****	****	****	***	****	*****	**	***	***	*****	*****	**
Anaerobic pond - facultative pond	***	**	**/****	**	*****	*****	*****	*****	****	****	***	****	*****	**	***	*	*****	*****	**
Facultative aerated lagoon	***	**	**/****	**	***	****	****	*****	****	****	***	****	****	**	***	****	*	*	***
Compl. Mix aerated - sedm. Pond	***	**	**/****	***	***	***	***	***	***	***	***	***	***	**	****	***	*	*	**
Pond - maturation	***	***	*****	*	*****	*****	*****	*****	****	****	***	****	*****	**	***	***	*****	*****	**
Pond - high rate pond	***	****	****	**	****	****	****	*****	****	****	***	****	***	***	***	***	**	**	**
Pond - algae removal	****	**	**/****	**	*****	****	****	***	****	****	***	****	***	***	***	***	*****	*****	**
Slow rate treatment	*****	****	****	*	*****	*****	*****	*****	****	****	****	****	****	**	*	**	*****	*/*****	**
Rapid infiltration	*****	****	****	*	*****	*****	*****	*****	****	****	****	****	****	**	*	**	*****	*****	**
Overland flow	****	***	**/***	*	*****	****	****	*****	****	****	***	****	*****	***	**	**	*****	*/*****	**
Constructed wetlands	****	**	***	*	*****	****	****	*****	****	****	***	****	*****	**	**	**	*****	*****	**
Septic tank - anaerobic filter	***	*	**	*****	*****	***	***	****	***	***	**	***	****	**	*****	**	****	*****	****
UASB reactor	***	*	**	*****	*****	****	****	****	**	**	**	***	****	**	*****	**	****	*****	****
UASB reactor - post-treatment	a	a	a	a	a	a	a	a	b	b	b	a	a	a	a	b	a	a	a
Conventional activated sludge	****	**/****	**	****	**	*	**	*	***	***	**	****	*	***	*****	****	*	*/*****	****
Act. Sludge (extended aeration)	*****	**/****	**	****	*	**	*	**	****	****	***	****	**	****	*****	*****	*	*/*****	****
Trickling filter (low rate)	****	**/****	**	***	****	*	***	**	***	**	**	****	***	**	*****	****	****	****	**
Trickling filter (high rate)	****	**/***	**	****	***	**	***	*	****	***	***	****	***	**	*****	****	****	****	***
Submerged aerated biofilter	*****	**/***	**	*****	**		***	*	***	***	**	****	**	****	*****	*****	**	*****	****
Rotating biological contactor	****	**/***	**	****	***	*	***	*	***	***	**	***	***	**	*****	****	****	*****	***

ANNEXVII: DETAILED OPTIONS FOR NON-POINT POLLUTION SOURCES MANAGEMENT

14.5 VII.1. Urban nonpoint sources (e.g. stormwater)

<table>
<tr><td>Character of urban pollution</td><td>Some of the highest levels of nonpoint sources of pollution are associated with urban land use and industrial activities (Pegram & Görgens, 2001).
Urban areas include:
● Formal residential areas range from sparse smallholdings on the outskirts of cities through to high-density settlements. These areas are often associated with problems such as litter, nutrients, sediment, pathogens, organic matter, heavy metals, hydrocarbons and toxic substances. This is especially in areas with an aging or under designed sanitation infrastructure leading to grey water discharges into stormwater drains blocked or leaking septic tanks discharging raw sewage into stormwater drains.
● Commercial and light industrial areas located near or in urban areas are often viewed as sources of heavy metals due to increased pedestrian and vehicle traffic.
● Heavy industrial areas located near urban areas are often important sources heavy metals, toxic organics and nutrients depending on the industrial processes and management practices at the zone.
● Roads within and between urban areas are often a high source of heavy metals, hydrocarbons, and fine sediments from unpaved roads..
● Construction and urban development sites also represent a large source of sediment loads and adsorbed pollutants such as nutrients and heavy metals.
● Quarries, whether active or abandoned and dumps are often sources of high loads of sediments.
● Waste disposal sites such as solid waste dumps, sludge disposal sites and irrigated effluent field are sources of organic matter, nutrients, heavy metals and toxic substances.
● High density settlements with no or rudimentary sanitation infrastructure and informal settlements with basic or no a poor or are often regarded as major sources of pathogens, organic pollution and nutrients resulting from dumping of domestic waste water (grey water or sullage), overloaded sanitation systems, night soil dumping, and human and animal excreta from bush toilets.</td></tr>
<tr><td>Pollutants commonly found in stormwater</td><td>The pollutants commonly found in urban stormwater and the forms in which they occur, include (Shaver et al., 2007):
● Solids (Settleable solids, Total suspended solids (TSS), Turbidity (NTU))
● Oxygen-demanding material (Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Organic matter (OM), Total organic carbon (TOC))</td></tr>
</table>

- **Phosphorus** (P) (Total phosphorus (TP), Soluble reactive phosphorus (SRP), Biologically available phosphorus (BAP))
- **Nitrogen** (N) (Total nitrogen (TN), Total kjeldahl nitrogen (TKN), Nitrate + nitrite-nitrogen (NO_3+NO_2-N), Ammonia-nitrogen (NH3-N))
- **Metals** (Copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), arsenic (As), nickel (Ni), chromium (Cr), mercury (Hg), selenium (Se), silver (Ag)
- **Pathogens** (Fecal coliform bacteria (FC), Enterococcus bacteria (EC), Total coliform bacteria (TC), Viruses)
- **Petroleum hydrocarbons** (Oil and grease (OG), Total petroleum hydrocarbons (tph)
- **Synthetic organics** (Polynuclear aromatic hydrocarbons (PAH), Pesticides and herbicides, Polychlorobiphenols (PCB)

Sources of urban stormwater pollutants

Urban pollutants can be traced to the following sources (Shaver et al., 2007):

- **Hydrocarbons** (gasoline, oil, and grease) - Internal combustion engines, Automobiles, Industrial machinery, Workshops and garages
- **Copper** (Cu) - Building materials, Paints and wood preservatives, Algicides, Brake pads
- **Zinc** (Zn) - Galvanized metals, Paints and wood preservatives, Roofing and gutters, Tires
- **Lead** (Pb) – Gasoline, Paint, Batteries
- **Chromium** (Cr) - Electro-plating, Paints and preservatives
- **Cadmium** (Cd) - Electro-plating, Paints and preservatives
- **Pesticides** – Urban agriculture and grazing, Residential and commercial use
- **Herbicides** – Urban agriculture and grazing, Residential and commercial use, Roadside vegetation maintenance
- **Organic compounds** - Industrial processes, Power generation
- **Bacteria and pathogens** - Human sewage, Livestock manure, Domestic animal faecal material
- **BOD** - Agriculture and grazing, Human sewage
- **Nutrients** (N and P) - Agriculture and grazing, Parks, lawn and landscape fertilizer

- **Fine sediment** – Unpaved urban roads, Agriculture and grazing, Pavement wear, Construction sites, Quarries

Classification of urban stormwater management options

The need for pollution reduction has led to an emphasis on a stormwater management approach that focuses on keeping pollutant our of receiving streams by upstream control; that is attenuation and treatment measures close to where the runoff is generated (Abbott Grobicki, 2001). Most urban stormwater management measures can be classified as structural or non-structural (Abbott Grobicki, 2001, Debo & Reese, 2003):

- **Non-structural BMPs**[1] are almost exclusively focussed on pollution prevention and the objective is to minimise the pollutant load from urban areas. These include a variety of institutional and educational measures focussed on land development, public awareness to modify behaviour that contribute to urban pollution, detection of illicit wastewater discharges, and enforcement of ordinances designed to prevent the deposition of nutrient containing waste and products on urban landscapes. Non-structural BMPs are generally grouped into educational BMPs, planning and procedures BMPs, and site-based local control BMPs (Abbott Grobicki, 2001, Debo & Reese, 2003). *Educational BMPs* refer to measures that are devised to sensitise citizens about their role in water quality degradation, protection and enhancement. *Planning & procedures* refer to minimising urban stormwater pollution through effective planning procedures (e.g. master plans, comprehensive plans, and zoning ordinances) designed to promote improved water quality by restricting certain types of activities in sensitive areas. *Site-based local controls* refer to ordinances and by-laws that require the inclusion of buffer strips, preservation of riparian zones, minimising disturbance and impervious areas, and maximising open spaces.

- **Structural BMPs** are generally measures that act as a backup for non-structural BMPs by providing attenuation or treatment facilities before transportation of polluted water to receiving streams and rivers. Structural BMPs can be grouped into storage practices, infiltration practices, and vegetative practices (Debo & Reese, 2003). *Storage and detention* BMPs refer to measures to collect urban runoff in wet ponds, dry basins or multi-chamber catch basins and slowly releasing to a receiving stream or river or stormwater canal. *Infiltration practices* refer to BMPs that facilitate infiltration of urban runoff through the soil to groundwater. *Vegetative practices* refer to landscaping BMPs that

[1] Within an urban context, best management practices (BMPs) are also referred to as SUDS, sustainable urban drainage systems.

enhance pollutant removal, maintain and promote natural site hydrology, promote healthy habitats and increase aesthetic appeal.

Stormwater control focus

Although a number of structural BMPs have been designed as stormwater control structures, they also have a positive impact on sediments and associated nutrients.

▪ VII.2. Structural stormwater BMPs

What are structural stormwater management options?

Structural stormwater management options are engineered devices implemented to control, treat, or prevent stormwater runoff pollution.

● VII.2.1. Grass buffer areas

Brief overview

A grass buffer, or filter strip or vegetated filter strip is a uniformly graded and densely vegetated area of grass or vegetation. Overland sheet flow over the grass tends to infiltrate and particulate matter and attached pollutants tend to filter out and settle. These are generally contracted adjacent to watercourses and water bodies or in the area surrounding infiltration structures. It is also constructed between parking lots and stormwater management structures where drainage is primarily sheet flow. These strips provide marginal pollutant removal, mostly for particulate fractions of phosphorus and nitrogen adsorbed onto suspended sediment, soil or organic material. Buffer strips needs to be maintained because the accumulation of sediment can cause ponding on the adjacent impervious area. Larger buffer areas are sometimes referred to as stream buffers or greenways.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

● VII.2.2. Grass swales

Brief overview

Grass swales are small drainage ways or slow flowing grassed channels that reduce runoff volumes and peaks and traps pollutants. They are sometimes used to convey flow along road edges or through parks settings. Grass swales are densely vegetated with grass which slows down the flow, facilitating infiltration and sedimentation.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

VII.2.2.1. Porous pavement and porous pavement detention

Brief overview

Modular porous paving blocks consists of open-void concrete block units are placed on gravel bedding in parking lots, footways or other open spaces. The open-voids are filled with sand or sandy-turf. This reduces the impervious area by encouraging rainfall and runoff to infiltrate. Porous pavements can significantly reduce runoff rates and volumes and pollutant loads.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

VII.2.2.2. Porous landscape detention

Brief overview

Porous landscape detention, also called infiltration basins, consist of slightly depressed areas for temporary detainment of stormwater runoff. The low-lying vegetated areas are underlain by a sand filter bed and in some cases, and underdrain system. Designed to store a selected design storm and it maintains or increases groundwater recharge by infiltration through the bed and sides of the basin.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

VII.2.3. Dry ponds and extended detention basins

Brief overview

Dry ponds are designed to hold water for a few hours or a day only. It can be used in combination with other retention and infiltration facilities. The objective is to temporarily store stormwater runoff to reduce downstream flooding and promote the settling of pollutants. Extended detention basins are similar to dry ponds but the outlet is smaller to meet outflow design criteria.

The outlet is sized to provide residence time necessary for suspended sediments in the stored water to settle. Extended detention ponds are effective in removing suspended sediment and nutrients associated with the sediment.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design.*
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

- **VII.2.4.Wet detention ponds**

Brief overview

Wet detention ponds are structural controls for large drainage basins. The application is similar to that for dry ponds except that retention of a permanent water body also permits water quality treatment, through removal of sediments and reduction of pollutants (e.g. by exposure to sunlight and absorption / binding of nutrients /other pollutants by plants and soil particles. Maintenance of a permanent pool requires a continual or near continual base flow to replenish evaporation and infiltration losses.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

- **VII.2.4.1.Natural or artificial wetlands**

Brief overview

A constructed artificial wetland is a shallow retention pond and is appropriate for large drainage areas where a continual base flow is present to sustain the growth of wetland vegetation. They are effective pollution filters through the absorptive and assimilative capacities of the wetland plants and their soils. Sedimentation is encouraged through filtration by plants and spreading out of flows. Retention of water in the wetland educes stormwater volumes. A variation on this is artificial wetland channels. These are not designed to store water but to rather facilitate slow and shallow flow. The residence time in the channel is long enough to promote biological uptake by plants as well as sedimentation of particulate matter.

Sources of information

- City of Cape Town (2002). *Stormwater management planning and design guidelines for new developments*
- Haestad & Durrans (2003). *Stormwater conveyance modelling and design*.
- USDA, NRCS, Urban BMP's - Water Runoff Management. Online: http://www.wsi.nrcs.usda.gov/products/urbanBMPs/water.html

VII.3. Non-structural BMP's

What are non-structural urban BMPs?	Non-structural BMPs are a range of institutional and pollution prevention practices that are designed to prevent or minimise pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management (Taylor & Wong, 2002). Public works practices are commonly considered to be non-structural stormwater controls.

VII.3.1.Maintenance and Upgrading of sewer infrastructure

Brief overview	This option entails measures to institute and sustain a programme to maintain and upgrade the sewer infrastructure. None of Rwanda's urban areas have centralised wastewater treatment works yet but it is being considered for a number of towns. It is important that the sewer network that collect domestic sewage be maintained to ensure that raw sewage don't overflow into the stormwater network. Sewer cleaning and maintenance programmes and efficient fault reporting systems can reduce the frequency of surcharging or blocked sewers substantially.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds*

VII.3.2.Litter and livestock waste control ordinance

Brief overview	Municipal ordinances can be used to control the accumulation of litter and livestock wastes on streets and residential, commercial, industrial, and recreational areas.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds.*

VII.3.3.Street sweeping

Brief overview	Litter in urban runoff can be washed into streams where organic matter will decompose releasing nutrients, and consuming oxygen in the process of decomposition. Basic street cleaning should be conducted from time to time (at least four times per year is recommended) or more frequently in areas having high pedestrian traffic, bus depots, or two-wheel taxi stands. Additional street sweeping should be scheduled in heavily vegetated areas, especially before the onset of the rainfall season.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds.*

- **VII.3.4.Catch basin cleaning**

Brief overview	Stormwater catch basins should be cleaned on a regular basis. The frequency and efficiency of catch basin cleaning should be increased to cleaning these at least twice per year or more frequently.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds.*

- **VII.3.5.Public education programmes**

Brief overview	A public education programme is an important and common non-structural component of stormwater (and stormwater quality) control programmes. It is designed to create an awareness of pollution activities such as the disposal to the stormwater system of pollutants such as used oil, pesticides, pet wastes, grey water and household wastes. Education programmes inform the public and provide technical information on the need for proper land management practices on private land, the effects of implemented measures. It also develops local awareness for citizens and public officials. The practice of Umuganda is an excellent opportunity for community education and the clean roads in Rwanda is testimony of the success of such initiatives.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds.*

- **VII.3.6.Refuse collection and disposal**

Brief overview	Solid waste management is an important function to reduce pollutant loads from urban areas. Street maintenance and repair programmes should be designed and implemented to prevent erosion and sediment runoff (and the nutrients adsorbed onto those sediment particles). It includes the provision of rubbish bins in public areas; improving garbage collection schedules, especially in informal and semi-formal settlement, and the clean-up of parks and commercial centres.
Sources of information	Muthukrishnan et al (2004) *The use of Best Management Practices (BMPs) in Urban Watersheds.*

14.6 VII.4. Agricultural Nonpoint source management options

Agricultural NPS	The transfer and deposition of nutrients and contaminants in river systems is strongly controlled by the transport, deposition and remobilisation of suspended sediment due to the association of nutrients with sediment particles.

Concern about the use of chemical fertilisers	Worldwide there has been shift away from smaller farms using organic fertiliser to large, monoculture, intensively operated farm units. To sustain the increase in farm yields and productivity, farmers have been using large quantities of chemical fertilisers. Concerns have been raised about the impact on streams and rivers that are showing signs of eutrophication caused by the off of fertiliser from fields and organic pollution from intensive animal feeding units.
Nature of nutrient export	The nature of nutrient export differs for different types of agriculture. For example: The nutrients exported from *dryland (rainfed) crops* are mostly associated with sediment erosion processes and infiltration and leaching. Phosphorus exports are largely adhered onto soil particles and washed of along with sediment. Nitrogen is more mobile. From field case studies, it was found that dryland cropping on deep soils that provide a buffer, like those found in most of our maize producing areas, it was unlikely to be a significant contributor to nitrate leaching. On the other hand, dryland production on shallow soils, like those found in the Western Cape, nitrogen leaching could be problematic (Rossouw & Görgens, 2005). *Irrigation return flows* can also be a major source of nutrients. In this case, most of the nutrients are in a dissolved form rather than adhered onto suspended sediment particles. Nutrients in the *runoff from pastures* that are intensively grazed are mostly in a dissolved form or in an organic form (animal waste). The organic material also has an impact on the dissolved oxygen concentrations of receiving streams. Low DO concentrations increase the breakdown of organic waste and co-release release of nutrients. *Intensive Animal Feeding Units* not only include agricultural activities such as feedlots, piggeries, and poultry farms but also large dairy farms and wastes from food processing such as dairy processing, meat processing and fruit and vegetable processing on these farms. Runoff and uncontrolled waste streams can add significant nutrient loads to receiving streams, rivers and reservoirs.
Focus of agricultural NPS management options	Options aimed at managing the export of nutrients from agricultural nonpoint sources are focused on: Reducing the input of fertiliser (nutrients) at the source, where it is applied, or by containing the nutrients produced in animal waste, and/or

Intercepting and containing nutrients along the pathways by which they reach receiving surface streams and rivers. Then use plant uptake to remove the nutrients.

Many of the BMPs that are applied in agriculture are aimed at reducing the impact of erosion and sediment washoff. These BMPs also have a positive impact on nutrient management because phosphorus from agricultural sources is often associated with sediment particles.

Other BMPs available in the literature

An examination of agricultural Best Management Practices (BMPs) such as the National Conservation Practice Standards published by the US Department of Agriculture will yield as much as 166 different practices. Only those that are generally regarded as relevant to nutrient management have been described in this document.

▪ VII.4.1. Fertilizer Application Management

Brief overview

The objective with Fertilizer Application Management is to make the best possible match between the amount of N and P needed by a crop and the amount available from all sources during the growing season in order to limit either over (or under) fertilization. Fertilizer Application Management is a source management option aimed at reducing nutrient inputs. This goal can be achieved through a series of sequential steps, some of which are relatively complex. These major steps are more or less similar for N and P, and are followed to a large extent by South African commercial farmers to limit either over or under fertilization.

This practice involves managing the amount, placement, and timing of plant nutrients to obtain optimum yields and minimize the risk of surface and groundwater pollution. Nutrient management may be used on any area of land where plant nutrients are applied to enhance yields and maintain or improve chemical and biological condition of the soil. The source of plant nutrients may be from organic wastes, commercial fertilizer, legumes, or crop residue. The objective is to apply the proper amount of nutrients at the proper time to achieve the desired yield and minimize entry of nutrients into surface or groundwater supplies. Over fertilization is generally not regarded as a problem in subsistence farming areas.

Sources of information

National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture - Nutrient Management (590)

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

- ## VII.4.2.Riparian buffer strips

Brief overview	Riparian buffer strips refer to the ecosystems that occur next to stream and river courses and the plant cover consist of grasses, shrubs and other indigenous vegetation. These buffer strips provide habitat for aquatic and terrestrial organisms, they help stabilise the channel bed and stream bank, they provide geomorphic stability, and improve and protect water quality by reducing the amount of sediment and nutrients in surface water runoff and shallow groundwater flow. In Rwanda legislation limits agricultural and pastoral activities around bodies of water, activities need to be undertaken at a distance of 10 meters from the banks of streams and rivers and 50 meters from the banks of lakes. In order to demarcate this a vegetation buffer may be planted. The plants used for riparian buffer strips are usually agroforestry trees, reeds or bamboo. The vegetation buffer needs to be monitored and maintained in order to ensure that it continues to provide benefits.
Sources of information	Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture. Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html REMA. (2010). Practical Tools on Agroforestry. Kigali, Rwanda. REMA. (2010). Practical Tools on Soil and Water Conservation Measures. Kigali, Rwanda.

- ## VII.4.3.Vegetated filter strips

Brief overview	Filter strips are land areas of either planted or indigenous vegetation, situated between a potential, pollutant-source area and a surface-water body that receives runoff. The term “buffer strip” is sometimes used interchangeably with filter strip, but filter strip is the preferred usage. Runoff may carry sediment and organic matter, and plant nutrients and pesticides that are either bound to the sediment or dissolved in the water. A properly designed and operating filter strip provides water-quality protection by reducing the amount of sediment, organic matter, and some nutrients and pesticides, in the runoff at the edge of the field, and before the runoff enters the surface-water body. Filter strips also provide localized erosion protection since the vegetation covers an area of soil that otherwise might have a high erosion potential.

The roots of plants also increase resistance to erosion therefore the use of grasses or bamboo is preferable. Multiple use grass such as Napier is beneficial as it can be used as a vegetation filer strip as well as for fodder, or *Pennissetum* (vetiver grass) can be used for mulch. Bamboo provides other important uses such as for building or crafts, although this can only be used after about 10 years and the bamboo may outcompete natural vegetation. The benefits of using grass is that it is not competitive with other crops, and is not a host to pests. It also requires limited cost and labour requirements.

Sources of information

Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa.

Leeds, R, Brown, L.C., Sulc, M.R. & Van Lieshout, L. (2006). Vegetative Filter Strips: Application, Installation and Maintenance. Fact Sheet AEX-467-94. Ohio State University. Available online: http://ohioline.osu.edu/lines/facts.html

National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

REMA. (2010). Practical Tools on Soil and Water Conservation Measures. Kigali, Rwanda.

- **VII.4.4.Contour cultivation**

Brief overview

Contour farming refers to tillage, planting and other farming operations on or near the contour of a field slope. This farming is most effective on slopes of between 2 - 10 percent. The method involves ploughing across a slope following its elevation contour lines. The contour rows slow down runoff on the slope, allowing the water to percolate into the soil. This reduction of the energy of runoff also acts to limit sheet and rill erosion, as well as the transport of sediment and other water-borne nutrients and contaminants. It conserves soil moisture and fertility and increases groundwater recharge.

The practice of contour cultivation can also be incorporated with vegetation filter strips (i.e. strip cropping as defined in section 6.3.6).

Sources of information

Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa.

Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf

National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

REMA. (2010). Practical Tools on Soil and Water Conservation Measures. Kigali, Rwanda.

- **VII.4.5. Stream and river bank protection**

Brief overview	Some of the most productive farming areas are on stream or river banks owing to the fertile silt and ease of access to water. However this practice results in the loss of riparian vegetation which provide important services such as cleaning water, reducing flood flows, trapping sediments, providing food and habitat for biodiversity. Stream and riverbank protection refers to a number of practices that are used to mitigate the impact of riverbank erosion. In Rwanda legislation limits agricultural and pastoral activities around bodies of water, activities need to be undertaken at a distance of 10 meters from the banks of streams and rivers. In accordance with this law, and in order to reduce riverbank erosion it is proposed that a vegetation buffer of reeds and bamboo be planted on the banks of certain rivers.
Sources of information	Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa. Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture. Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

- **VII.4.5.1.Strip cropping**

Brief overview	Strip cropping refers to growing crops in a systematic arrangement of strips or bands across the general slope to reduce water and soil erosion, and to intercept sediments and nutrients. The crops are arranged so that a strip of grass or close growing crop is alternated with crops like maize. Depending on the slope grass strips ae about 2-4m wide and he cropped area about 15-45m wide. The vegetated strips provides a natural damming effect for water, allowing for filtration of the nutrients attached to sediment. This type of method is not suitable for mechanised farming as the land is fragmented.
Sources of information	Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of

Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf

National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

REMA. (2010). Practical Tools on Soil and Water Conservation Measures. Kigali, Rwanda.

- **VII.4.5.2.Management of grazing**

Brief overview

Overgrazed land leads to increased soil erosion and loss of soil nutrients. Mechanisms to rest grazing land allow vegetation to recover and protect the soils while other areas are being grazed in rotation. Rotational grazing involves dividing the grazing area according to natural features (rivers, steep slopes, gentle slopes, wetlands and agricultural lands), community boundaries and roads. Portions to be grazed and portions to be rested are to be allocated in different seasons and different years. Other methods include planting grasses or legumes to use as feed for livestock. Grasses and legumes also protect land from excessive soil erosion and add nitrogen to the soil.

In Rwanda, there are three types of cattle management systems based on feeding methods.

- Open-grazing – Animals freely graze on individual or communal grazing lands. This type of system is dominant in lowland Eastern Province, where 40% of the national cattle population is found and the relative availability of grazing land is superior to other areas. Grazing is also practiced in the western part of the country. Diminishing grazing land, however, is forcing people to gradually shift from open grazing to semi-grazing and zero-grazing, which is most common in the highland areas.
- Semi-grazing – The semi-grazing system is a hybrid between open-grazing and zero-grazing. It is characterized by a shortage of land that results in a farmer needing to keep his few cows in stalls. Such farmers, however, do not always have sufficient money and/or knowledge to feed their cows properly and so they may allow their herd to graze on nearby land part of the time. This is a transitory state from open-grazing system to zero-grazing.
- Zero-grazing – The zero-grazing system is characterized by keeping animals in a shed and feeding by cutting and carrying forage and crop residues to the cows. This production system is increasing in proportion due to the shrinkage of grazing land, which has been widely turned over to crop cultivation in response to increasing population. The Government

of Rwanda encourages zero-grazing because it avoids over-grazing and subsequently reduces land degradation.

Open-grazing occurs when animals freely graze on individual or communal grazing lands. This type of system is dominant in lowland Eastern Province part of the country. Zero-grazing is characterized by keeping animals in a shed and feeding by cutting and carrying forage to the cows. The Government of Rwanda encourages zero-grazing because it avoids over-grazing and subsequently reduces land degradation.

Sources of information	Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa. Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture. Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

- **VII.4.5.3.Accurate fertiliser application**

Brief overview	Great improvements have been made in the design of fertiliser spreaders to make accurate, uniform application of fertiliser onto crops and not onto the surrounding land or water easier. Methods such as microdosing of fertiliser provides precision techniques leading to increased yields for the smallholder farmer. Microdosing involves the application of small, affordable quantities of fertilizer with the seed at planting time or as top dressing 3 to 4 weeks after emergence. This enhances fertilizer efficiency compared to spreading the fertilizer over the field.
Sources of information	Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa. Campbell, N, D'Arcy, B., Frost, A., Novotny, V. and Sansom, A. (2004). *Diffuse Pollution - An introduction to the problems and solutions*. IWA Publishing, London.

- **VII.4.5.4.Grassed waterways**

Brief overview	Grassed waterways refer to natural or constructed channels that are shaped or graded to required dimensions and established with suitable vegetation. They are established in areas that need to be protected from concentrated runoff. Grassed waterways convey runoff from terraces and diversions without causing erosion or flooding and the vegetation protects and improves water quality.

Sources of information

Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf

National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture.

Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html

- **VII.4.6.Management of livestock manure**

Brief overview

There has been interest in the management of animal manure due to claims that animal manure may contribute to nonpoint nutrient loads. There are two strategies for manure use: (1) management for maximum nutrient efficiency, and (2) management for maximum application rate of manure.

If maximum nutrient efficiency is the goal, rates of application need to be based on the nutrient present at the highest level in terms of crop needs. In most cases this is phosphorus. Manure should be applied at a rate which will meet the crop's requirement for P. Additional nitrogen and potassium can be supplied with commercial fertilizers. This strategy is least likely to cause undesirable environmental effects, and makes the most efficient use of all nutrients in manure.

The other strategy for utilizing manure on cropland is to determine a rate of application that will satisfy the crop's requirement for nitrogen without causing environmental problems. This strategy maximizes the rate of applications, making less efficient use of P and K than the other strategy. A manure application strategy based on crop N requirements will lead to an accumulation of P in the long term, especially with repeated applications. Excessive soil test levels of P can result in surface water quality problems.

In Rwanda manure may be collected in a pit and put on crop lands as a fertilizer. It can also be used for biogas production for households and some households sell manure to generate extra income.

Sources of information

Johnson, J. Loux, M., Ropp. G, and Adams, J. (2006). Best Management Practices: A Manure Nutrient Management Program. Fact sheet AGF-207-95. Ohio State University. Available online: http://ohioline.osu.edu/lines/facts.html

- **VII.4.6.1.Onsite management of waste from intensive animal feeding units**

Brief overview

A waste management system is a planned system that is installed to manage liquid and solid waste, including runoff from concentrated waste areas in a manner that does not negatively affect water resources. Some of the components of a waste management system for liquid waste and contaminated runoff include debris basins, lining waste ponds, waste storage and treatment lagoons, grassed waterways and outlets, surface and subsurface drains, etc.

Integrated Development Program (IDP) Model Villages, is a pilot project for the promotion of integrated socio-economic development in Rwanda through sustainable development principles, have provided an example of how to effectively manage waste from animal feeding units by connecting feedlots to biogas units. The floor of animal feedlots is made of concrete and sloped with channels linked to the biogas unit. This effectively removes animal waste, and provides gas for cooking.

Sources of information	Evans, B.M. & Corradini, K.J. (2001). *BMP pollution reduction guidance document*. Bureau of Watershed Conservation, PA Department of Environmental Protection. Available online: http://www.predict.psu.edu/downloads/BMPManual.pdf National Conservation Practice Standards of the Natural Resources Conservation Service of the US Department of Agriculture. Online: http://www.nrcs.usda.gov/technical/Standards/nhcp.html REMA. 2015. A toolkit for the development of smart green villages in Rwanda. UNDP-UNEP Poverty Environment Initiative.

▪ VII.5. Agricultural stormwater runoff from kraals & feedlots

Brief overview	A waste management system is necessary when livestock are involved as there are associated nutrients which could pollute runoff from these areas. The objective of stormwater runoff management at intensive animal feeding units or activities such as dairies is to separate contaminated runoff from clean runoff and treating the contaminated runoff as if it is wastewater (anaerobic/aerobic/polishing ponds). Runoff which has emerged from the kraal and feedlot should have vegetation filter strip, to filter nutrients before runoff reaches the drainage system.
Sources of information	Ohio State University, Agricultural Engineering Fact Sheet

▪ VII.5.1. Waterborne pathogens from agricultural sources

Brief overview	Waterborne pathogens may originate from agricultural areas or from open defecation or badly managed sanitation systems. Pit latrines are one of the oldest forms of formal sanitation in the world. They can be built by using local materials and skills. The end use of a latrine once closed up may be as a composting toilet or could provide space for a new tree. These uses provides an end-use that reduces groundwater contamination and provides beneficial use. When an old used pit latrine is filled up, it needs to be emptied or closed and relocated. The pit needs to be topped up with a good layer of soil to cover the waste, and on top a layer of 30 cm thick layer of fertile soil. Do not put garbage in the pit, since this method should not be used to dispose of things

	that will not break down, such as cans, bottles or plastic. The soil layer should be piled up above ground level, as the contents of the pit will reduce in volume during composting process and the soil level will drop. Additional soil may be needed to level the ground. The pit can then be left to settle until the rains arrive. If water is not freely available the young tree is best planted at the start of the rainy season.
Sources of information	Braid, S.G. and Lodenkemper, L.K. (2017). Water Research Commission Green Village: Draft Catchment Management Guidelines and Training. Water Research Commission, South Africa.

14.7 VII.6.Guidance for selecting a suite of Nonpoint Source Management options

Selecting a short list of agricultural NPS BMPs	In the “Lake and Reservoir Restoration Guidance Manual” by Olem & Flock (1990), a matrix is provided for evaluating different nonpoint source best management practices. This matrix was used as the basis for compiling Table 3. The evaluation criteria are described in Section 9.1.2. The nutrient and sediment removal efficiency of different agricultural BMPs are presented in (Evans & Corradini, 2001).

Table 4 Agricultural best management practice evaluation matrix (modified from Olem & Flock, 1990).

BMP	Effectiveness	Longevity	Confidence	Applicability	Potential negative impacts	Capital expenditure	O & M
Fertilizer Application Management	E	E	G	G	E	E	G
Riparian buffer strips	E	E	E	E	E	G	E
Vegetated filter strips	E	E	E	E	E	G	E
Contour cultivation	F-G	P	F	G	E	E	E
Stream and river bank protection							
Strip cropping	F-G	P	P	G	E	E	E
Management of pastures	F-G	E	E	G	E	E	E
Accurate fertiliser application	E	E	G	G	E	E	G

Grassed waterways	E	E	G	G	E	G	E
Management of livestock manure	E	E	E	E	E	F	F
Onsite management of waste from intensive animal feeding units	E	E	E	E	E	F	F
Stormwater runoff management							

Key - E = Excellent, G = Good, F = Fair, P = Poor

Table 5 Estimated BMP reduction efficiencies (as a percentage) by pollutant type (Evans & Carrodini, 2001)

Agricultural BMP	Nitrogen	Phosphorus	Sediment
Crop residue management	50	38	64
Vegetated buffer strips	54	52	58
Crop rotations	7	40	55
Cover crops	43	32	15
Terraces and diversions	44	42	71
Pasture land management	43	34	13
Streambank protection	65	78	76
Nutrient management	19(75)	28(75)	*

Notes: The values represents estimated reductions in surface runoff-associated loads only. No value is reported for sediment for nutrient management since this BMP is typically not used for sediment reduction.

Selecting a short list of urban runoff management BMPs	In order to select a short list of urban nonpoint source BMPs, a number of factors are considered. In terms of developing a catchment eutrophication management plan, the nutrient removal effectiveness of a BMP is an important consideration. Structural stormwater controls can be very effective for the reduction of stormwater pollutant concentrations if they are correctly designed, constructed and maintained. Table 5 provides the summary values for USA studies and Table 6 provides the values for Australian studies.
Other criteria that are considered when selecting an urban runoff BMP	The nutrient removal efficiency is often not the main consideration for installing an urban runoff BMP. Factors related to the control of stormwater runoff (Table 5) often affect the choice of one specific control practice over another.

Table 6 Pollutant concentration removal efficiency, in percentage, for common stormwater controls (Haestad & Durrans, 2003)

Urban runoff BMP	TSS %	TP %	TN %	TZn %	TPb %	BOD %	Bacteria %
Grass buffer	10-50	0-30	0-10	0-10	N/A	N/A	N/A
Grass swale	20-60	0-40	0-30	0-40	N/A	N/A	N/A
Modular block porous pavement	80-95	65	75-85	98	80	80	N/A
Porous pavement detention	8-96	5-92	-130-85	10-98	60-80	60-80	N/A
Porous landscape detention	8-96	5-92	-100-85	10-98	60-90	60-80	N/A
Extended detention basin	50-70	10-20	10-20	30-60	75-90	N/A	50-90
Constructed wetland basin	40-94	-4-90	21	-29-82	27-94	18	N/A
Retention pond	70-91	0-79	0-80	0-71	9-95	0-69	N/A
Sand filter extended detention	8-96	5-92	-129-84	10-98	60-80	60-80	N/A
Constructed wetland channel	20-60	0-40	0-30	0-40	N/A	N/A	N/A

Note: TSS = total suspended solids, TP = total phosphorus, TN = total nitrogen, TZn = total zinc, TPb = total lead, BOD = biochemical oxygen demand, negative values reflect an increase in pollutant concentrations.

Table 7 Australian BMP pollutant concentration reduction (percent of inflow concentrations) (extracted from Abbott Grobicki, 2001).

Urban BMP	SS	Phosphorus			Nitrogen			Pb	Zn	Cu	Cd	Fe	BOD	COD	Bacteria	Litter
		TP	OrgP	SolP	TN	OrgN	SolN									
Extended detention	50-75 64	10-66 18			10-35 19			70-90 83	24-62 45					20-41 30	50-90 70	
Wet pond	39-98 69	0-80 51	20	70-80 75	30-85 60	14-20 17	24-60 42	9-95 68	0-71 51	40		17	0-69 44	20-70 30	90-95 93	
Wetland	40-98 81	-33-97 50		0-75 59	-9-43 25	32	13-90 50	6-94 72	-29-97 50	40-99 66	33-99 66	12-62 37	18-34 26			
Infiltration trench	71-99 83	60-75 65			60-70 63			25-99 61	51-99 74				90		98	
Infiltration basin	75-99 87[1]	50-75 63[1]			45-70 58[1]			75-99 87[1]	75-99 87[1]	75-99 87[1]	75-99 87[1]	75-99 87[1]	70-90 80[1]		75-98 87[1]	
Porous pavement	50-95 89	50-71 65			<0-85	29	<0	50-98 86	62-99 85	42-50	-33		80	82		
Sand filter	60-90 80	35-80 57			40-70 55		-110-0 <0	65-90 74	10-80 53	20-60 40			60-80 70	35-70 53		
Filter & buffer strips	5-95 74	50-79 66		62	50-73 62											
Grassed swale	80	4-25 15		8-24 16	-4-11 4	-4-13 5	-5-22 9	0-91 80	34-90 70	-14-60 50	20-50 29	3-67 35		25		
CDS	100[3]	1[2]			1[2]											95-100 98
Floating boom																12-50

																24
Trash racks																5-14 10
Filter baskets																65
Street sweeping	37-50 41	9-28 28		45		12-45 27		5-48 32	45	45	45	13-60 45		34-45 35		95-100 98

Notes - Lower figure in cells is median, [1] - values may not be from measured data, and are estimated from mean of range, [2] - given vegetative matter contains less than 1% of all TN and TP and all is captured. TP and TN is Total Phosphorus & Nitrogen respectively, OrgP and OrgN is Organic phosphorus and nitrogen respectively, and SoIP and SoIN is Soluble Inorganic Phosphorus and Inorganic Nitrogen.

Table 8 Effectiveness of different structural urban best management practices (derived from City of Cape Town, 2002)

Urban runoff BMP	Flood protection	Volume	Downstream effects	Water quality	Velocity	Sedimentation	Peak	Natural habitats	Multi-functionality	Sustainability	Health & Safety	Maintenance
Grass buffer areas	L	M	H	M	L	M	L	L-M	M	H	H	H
Grass swales	L	M	H	M	L	M	L	L-M	M	H	H	H
Porous pavement and porous pavement detention	L	M	L-M	L-M	M	L	M	L-M	H	H	H	H
Porous landscape detention	L	M	M	M	M	L	M	L-M	M	H	H	H
Dry ponds and extended detention basins	H	H	M-H	M	M	M	H	L-M	H	H	M	M
Wet detention ponds	H	H	H	H	M	H	H	M-H	M	H	L-M	M
Sand filter extended detention basins	L	M	M	M	M	L	M	L-M	M	H	H	H
Natural or artificial wetlands	M	M	H	H	M	H	M	H	H	H	H	M
Interception trench	L	M	M	M	M	L	L	M	M	M	M	L

Key - L = Low, M = Moderate, H = High