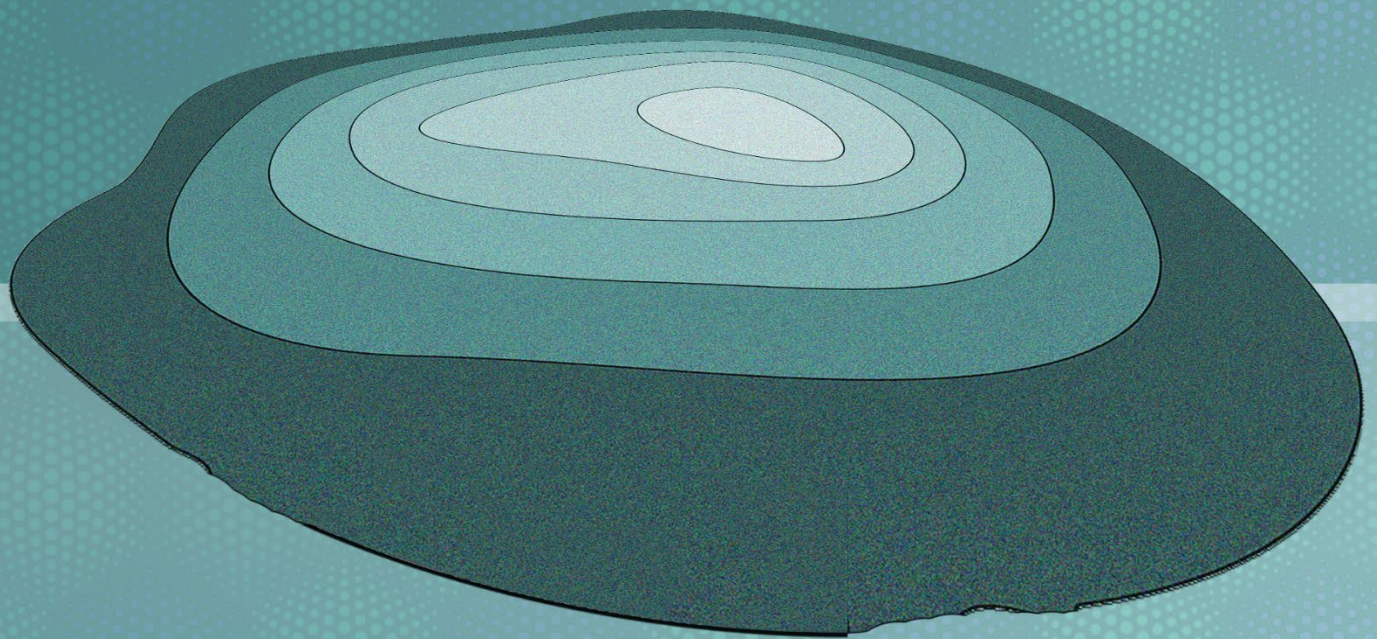




Ministry of Environment, Climate Change and Technology
Republic of Maldives

A Guide to Groundwater Improvement Measures in Small Low-lying Islands of the Maldives



Part II

Pollution Reduction Measures

February 2021



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PREFACE

The “Guide to Groundwater improvement measures in small low-lying islands of the Maldives” aims to provide specific advice on improving groundwater based on many broad strategies derived from the ‘model’ “Island Climate Resilient Groundwater Management Plan”. This is the volume II of the document addressing the sources of groundwater pollution to guide measures to reduce the deterioration of groundwater quality. It covers four areas, namely 1. Household, Guesthouse and Government Building Sewage Management; 2. Hard-standing and road drainage storm run-off collection and disposal; 3. Desalination Plant Brine Disposal and 4. Construction dewatering.

This guide can be used by practitioners, engineers, planners and policymakers (e.g. Island Councils) to assist in the process of design, implementation and management of systems that could contribute to groundwater pollution. It can also be used by academics for education, capacity building and training on sources and prevention of groundwater pollution applicable to low-lying islands of the Maldives.

The content of this guidance document is mostly self-standing with references to existing research, guidance, literature review and international best practices provided. It is recommended that this document be further supplemented with Part I of this guide.

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INTRODUCTION

The current state of groundwater quality in many inhabited islands of the Maldives is poor. Contamination by sewage has been identified to be one of the main sources of groundwater pollution in the Maldives. This is evident from the quality of groundwater in the capital city Male' where groundwater has been deteriorated mainly by leaking on-site sanitation systems. A few examples of the sources of contamination are sewage including pathogens and nutrients from septic tanks, grease and oil from vehicles, improper brine discharge of desalination plants and sediments from construction sites. Improper storage of hazardous chemicals (e.g. agrochemicals and insecticides) and sub-standard practices of solid waste collection and disposal can also contribute. Groundwater in the Maldives should be protected from contamination caused by such sources to preserve and improve its quality so that groundwater can be a resource for island inhabitants and nature. This guide focuses on sewage, stormwater, desalination brine discharge and construction practices. The other sources of pollution like chemicals and solid-waste management will be covered in other guidance documents.

This guide identifies sources of groundwater pollution and discusses various control measures that should be taken to prevent the pollutants from entering the groundwater causing the deterioration of the quality of groundwater. It four chapters: first focusing on pollution by sanitation, the second focusing on pollution by stormwater and the third focusing on pollution from desalination plant brine discharge and the last chapter on pollution from construction de-watering. At the end of each chapter, a conclusion has been drawn and recommendations are presented on the sources contributing to groundwater pollution.

CHAPTER 1:
Household, Guesthouse and Government Building Sewage Management

1.1 Introduction

Open defecation to a designated area in the backyards of houses and bushes near beaches followed by subsequent shallow burial of excreta was the method of sewage disposal traditionally practised within the island communities of Maldives before the introduction of onsite sanitation systems. This method of sewage disposal is still practised in rural and low-income communities across the world where toilet facilities or sanitation technologies such as pit latrines have not been established. Today all citizens of the Maldives, both in cities and outer islands, have access to toilet facilities. Depending on the level of development of each island, the sanitation systems range from pit-latrines to flushing toilets connected to a piped sewer system.

Sewage generated from households, government buildings, businesses (including tourism and industries) consists of a variety of wastewater products that are harmful to the environment and human health. These include human excreta (urine and faeces), flush water, greywater (outflow from kitchens, bathrooms, washing machines etc.) sludge from septic tanks, etc. In many cities of the world, sewage is usually collected by a piped system and treated by a wastewater treatment plant to make the resulting effluent safe for discharge into the environment (centralized handling of wastewater). Many rural areas do not have adequate population numbers and densities to make such a system viable. Many of the islands of the Maldives do not have sewerage systems or centralized disposal facilities and rely on localized sanitation solutions such as soakaways and septic tanks (An onsite sanitation method). Some islands that are equipped with sewerage networks do not have a functioning treatment plant. Malfunctioning septic tanks as well untreated sewage causes environmental hazards, polluting the groundwater and coral reefs of the islands.

Septic tank systems and conventional water-based piped sewerage systems are the most common sanitation technologies used for sewage management in the Maldives. In the case of either onsite (septic tanks) or offsite (piped sewer systems) sewage management systems, proactive sewage disposal plans and methods are required to conserve groundwater resources. Poor sanitation practices should be minimized and the entire sanitation service chain of the island community should be managed using appropriate technologies, to prevent the contamination or pollution of groundwater resources from sanitation in the Maldives.

This chapter discusses the various options available for managing sewage in the islands of Maldives. The following section provides an overview of sanitation in the Maldives. Then a detailed discussion of sewage management by using on-site sanitation options is followed by sewerage sanitation methods. Finally, conclusions and recommendations are given.

1.2 Overview of Sanitation in the Maldives

Historically, groundwater from the shallow aquifers or the thin freshwater body (Freshwater Lens – FWL) floating atop underlying seawater (see Figure 1.1) of the islands have been the primary source of clean water for the residents. Groundwater, which is considered to be a valuable natural commodity by the residents is abstracted through shallow hand-dug wells for various purposes such as for cooking, toilet flushing and washing. However, the freshwater lens in many of the islands is no longer suitable for potable purposes as it has been polluted by direct disposal of wastewater or by leaking sewage from inadequate onsite sewage disposal systems such as septic tanks and soakaways. Following the rapid urbanisation in the late '90s, the quality of groundwater in the capital city of Male' has been highly impacted due to surface pollution and leaching. In addition, saline intrusion due to the depleting freshwater lens has resulted in the groundwater being almost unusable for any purpose other than toilet flushing in the capital city. It has been estimated that the freshwater lens has been at least 21m thick before modern-day development of Male' (Edworthy, 1985). Even under pristine conditions, the thickness of the FWL depends on the width of the island – narrower islands have thinner FWL. The freshwater lenses in most of the outer islands are found to be at an average depth of 1-1.5m below ground surface and is found to be highly polluted (Ibrahim et al., 2020). A country-wide epidemic outbreak has spread throughout the country in the year 1970s and 1980s caused by waterborne diseases such as diarrhoea and cholera has been linked to the consumption of polluted groundwater. Responding to this finding, in the year 1985 government introduced a sanitary sewer system in the capital city. Better sanitation approaches, including piped sanitation in some cases, were incrementally introduced in outer islands as well.

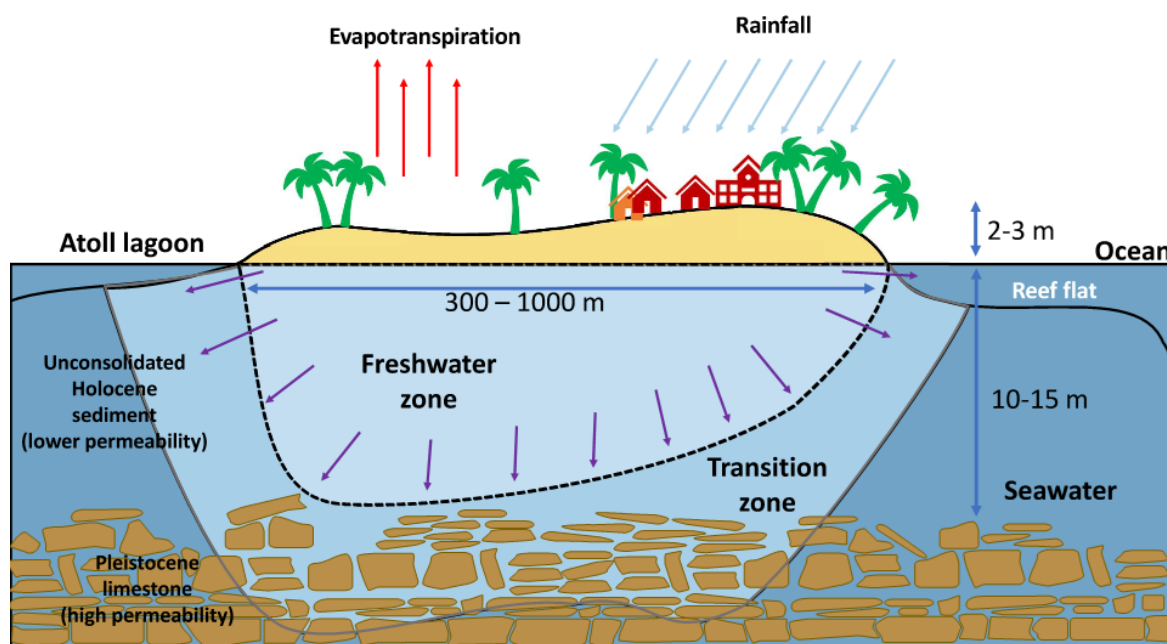


Figure 1.1: Simplified schematic concept of the freshwater lens formed in a typical low-lying small carbonate coral island (Jaleel, et al., 2020)

Wastewater should be safely managed at the source of its generation to the point of safe disposal and should not be released into the environment without adequate treatment. Although wastewater contains mostly water (99%), the remaining 1% of pollutants is a threat to human health and the environment. Hence, it's important to manage sewage at every stage of the sanitation service chain to prevent the risk of communicable disease transmission and hygiene of the community (Figure 1.2) as well as to protect overall environmental health.

The “sanitation service chain” (further explained in the next section) comprises of different stages of sewage management; capture, storage, transport and end-use of sewage (Figure 1.3), Safely managed sewage can be considered as treated wastewater that has been treated by a wastewater treatment plant before the resulting effluent is safely discharged into the environment. A useful tool to assess the overall impact of sanitation service delivery is the SFD (Shit Flow Diagram) schemed developed by Sustainable Sanitation Alliance (SuSanA.org, Figure 1.4) which summarizes the flow and fate of excreta in urban areas and differentiates safely and unsafely managed excreta. When untreated sewage is released untreated into watercourses it pollutes the environment and the water system, causing waterborne diseases.

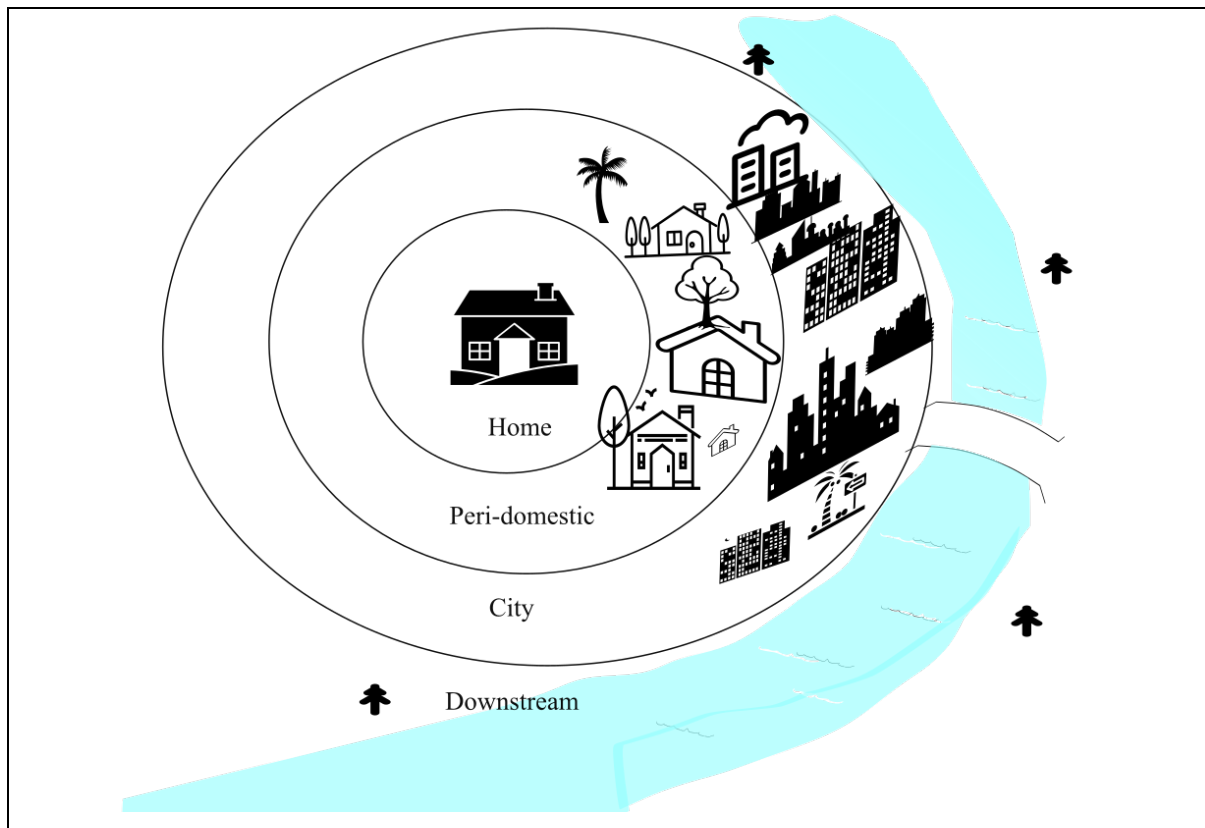


Figure 1.2: Sewage should be managed at each level of the community including household, peri-domestic and city level (Walther, et al., 2014). Home: Transmission of diarrhoeal disease is commonplace in the home environment where sanitation facilities are poorly constructed/maintained. Peri-domestic: In many communities, households have invested in improved toilets but due to the lack of sewerage and septage management, wastes are discharged into the public domain. City: Untreated wastewater discharges into the rivers and natural aquatic systems causing widespread pollution and environmental health risks.

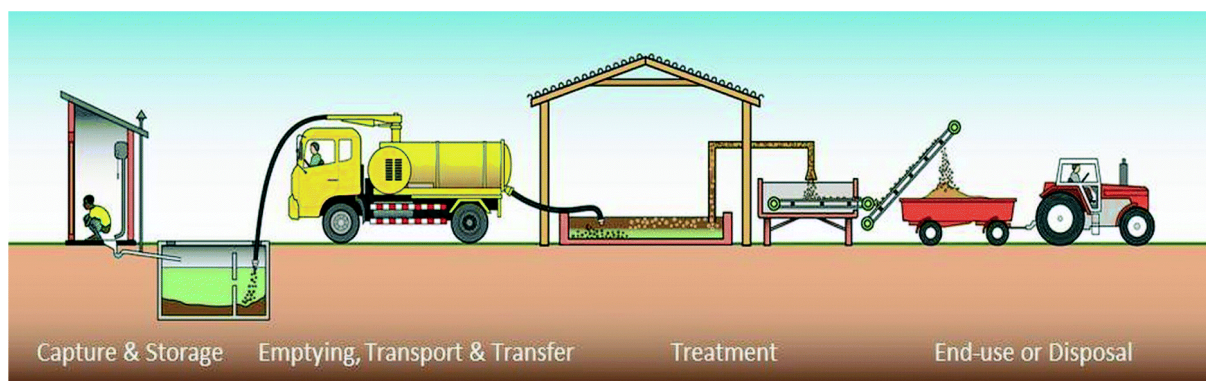


Figure 1.3: Different stages of the sanitation service chain which should be taken into consideration when managing sewage. This example shows the service chain of an onsite sanitation system. (After Medland et al., 2016)

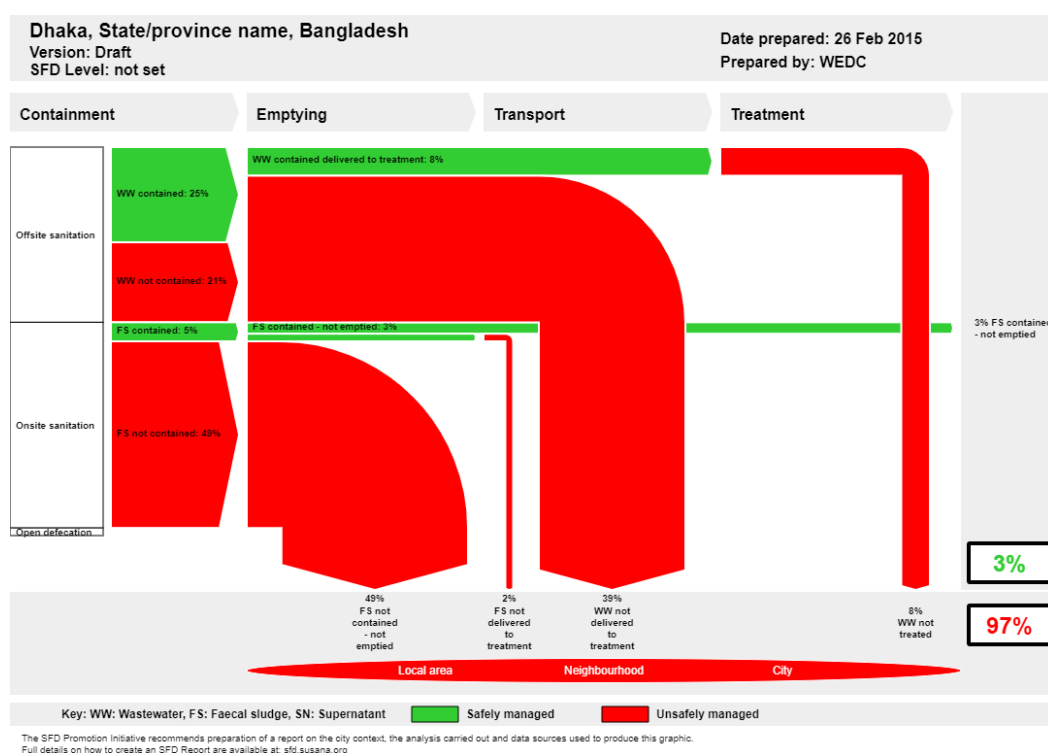


Figure 1.4: An example of an SFD (Shit flow diagram), a very useful tool commonly used to assess the impact of sanitation service delivery (In this example 43% excreta is safely managed while 57% is unsafely managed) – (Source: sfd.susana.org/, City of Dhaka, Bangladesh, base)

Wastewater consists of disease-causing microorganisms or pathogens that can endanger public health. Common classes of waterborne pathogens are bacteria, fungi, protozoa, helminths, and viruses. (ranging between 0.1-15 microns in size). While it is possible to detect, differentiate

and quantify waterborne pathogens using methods like quantitative Polymerase Chain Reaction (qPCR), they are expensive to deploy routinely at the operational scale. *E. coli* bacteria which is found in human and animal intestines which has also been discovered in groundwater of many islands is often used as an indicator for determining the level of faecal contamination of groundwater by human faeces. Incidence of *E. coli* indicates faecal contamination and therefore the possibility of the presence of human contagious pathogens. Water-borne diarrheal diseases such as Cholera and *Shigella* are caused by drinking and ingesting water that is contaminated with pathogens. Other common (partially) waterborne diseases include Polio and Hepatitis A & E. Hence, sewage and the resulting effluent needs to be adequately managed and treated using context-specific sanitation systems and technologies before releasing into a watercourse or groundwater. There are several sanitation systems available globally for managing sewage.

Sewage or wastewater is managed by a sanitation system based on one or a combination of technologies. These technologies can be categorized into five different functional groups. They are user interface, collection/storage, conveyance, (semi-)centralized treatment and use/disposal (See Figure 1.5). Technologies are the methods, services or infrastructure that can contain or transform sanitation products and/ or transport them to another functional group. For example, a flush toilet is an example of a User Interface and the conventional sewer is an example of a technology from the Conveyance/Storage functional group. There are a wide variety of sanitation technologies including onsite and offsite technologies and designed to suit local conditions. However, it is not a requirement for a particular sanitation system to include technology from all five functional groups for the system to be fully functional. Furthermore, a system may include two or more technologies from the same functional group.

U: User Interface **S: Storage**
C: Conveyance **D: Disposal/Use**
T: (Semi-) Centralized Treatment

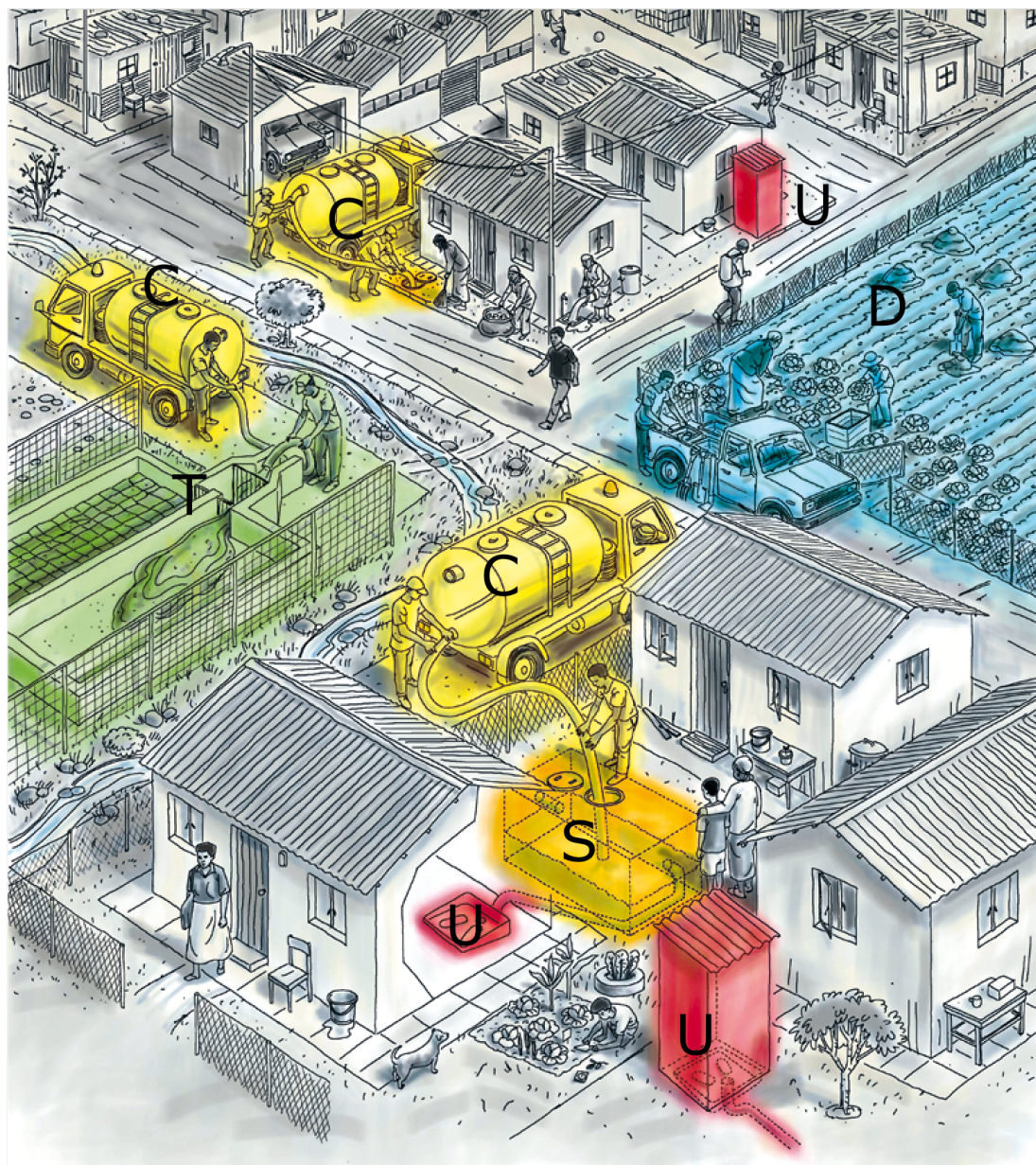


Figure 1.5: Different functional groups of the sanitation service chain – On-site Sanitation Systems for Sewage Management (Adopted from Tilley, 2014)

1.3 On-site Sanitation Systems for Sewage Management

Non-sewered or on-site sewage systems are among the most basic sewage disposal systems commonly used worldwide. They are particularly useful in low population or population density situations like rural areas or small communities. They can be used to dispose and treat wastewater in the same proximity where it is generated and are low-cost, robust and does not require energy to operate. However, the full-service chain of the sanitation method does not stop here. For example, on-plot latrines with septic tanks, whilst not connected to a sewerage system, are the first component in a service chain. The service chain comprises excreta capture and storage in a latrine pit or septic tank; emptying of the pit or tank; transport of the contents; sludge treatment (though not common); and end-use or final disposal. This chain of sanitation services is collectively known as Faecal Sludge Management (FSM). Many outer islands of the Maldives do not have the whole FSM chain implemented. The prevalence of pit latrines has led to profound problems in terms of how to collect and treat the faecal sludge from on-site facilities. The sanitation service chain (Figure 1.3) conceptualises this ever-growing problem and can be a useful framework for understanding the effective management of faecal sludge concerning onsite sanitation in the Maldives.

A few examples of established onsite technologies include pit latrines, aqua-privies, VIP (Ventilated Improved Pit) latrines, bucket-latrines, dry toilets and septic tanks (see Figure 1.7). Among various onsite sanitation systems and technologies available, only septic tanks are used in the Maldives.

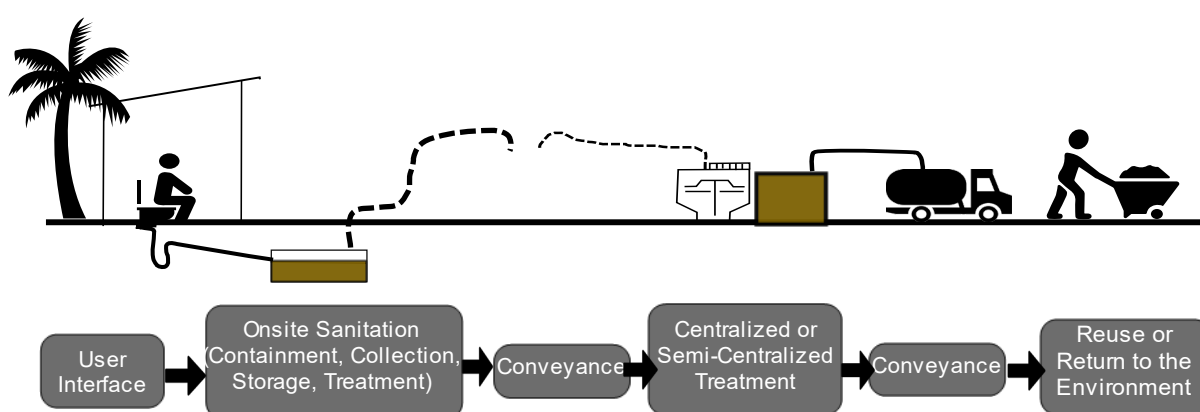


Figure 1.6: Onsite sanitation service value chain – (After Sano et al., 2019)

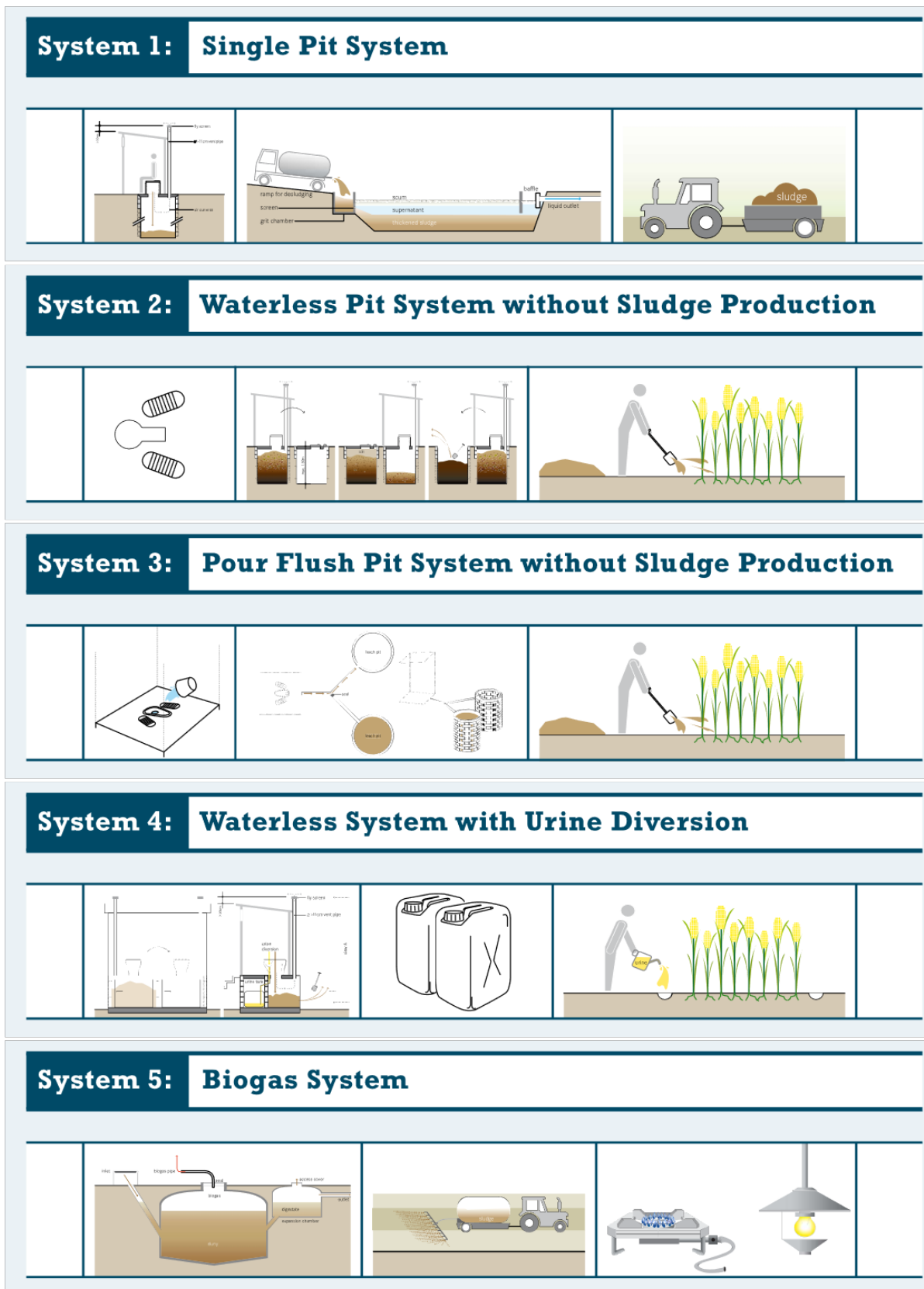


Figure 1.7 – part 1: A classification of sanitation systems (Adopted from Tilley, 2014)

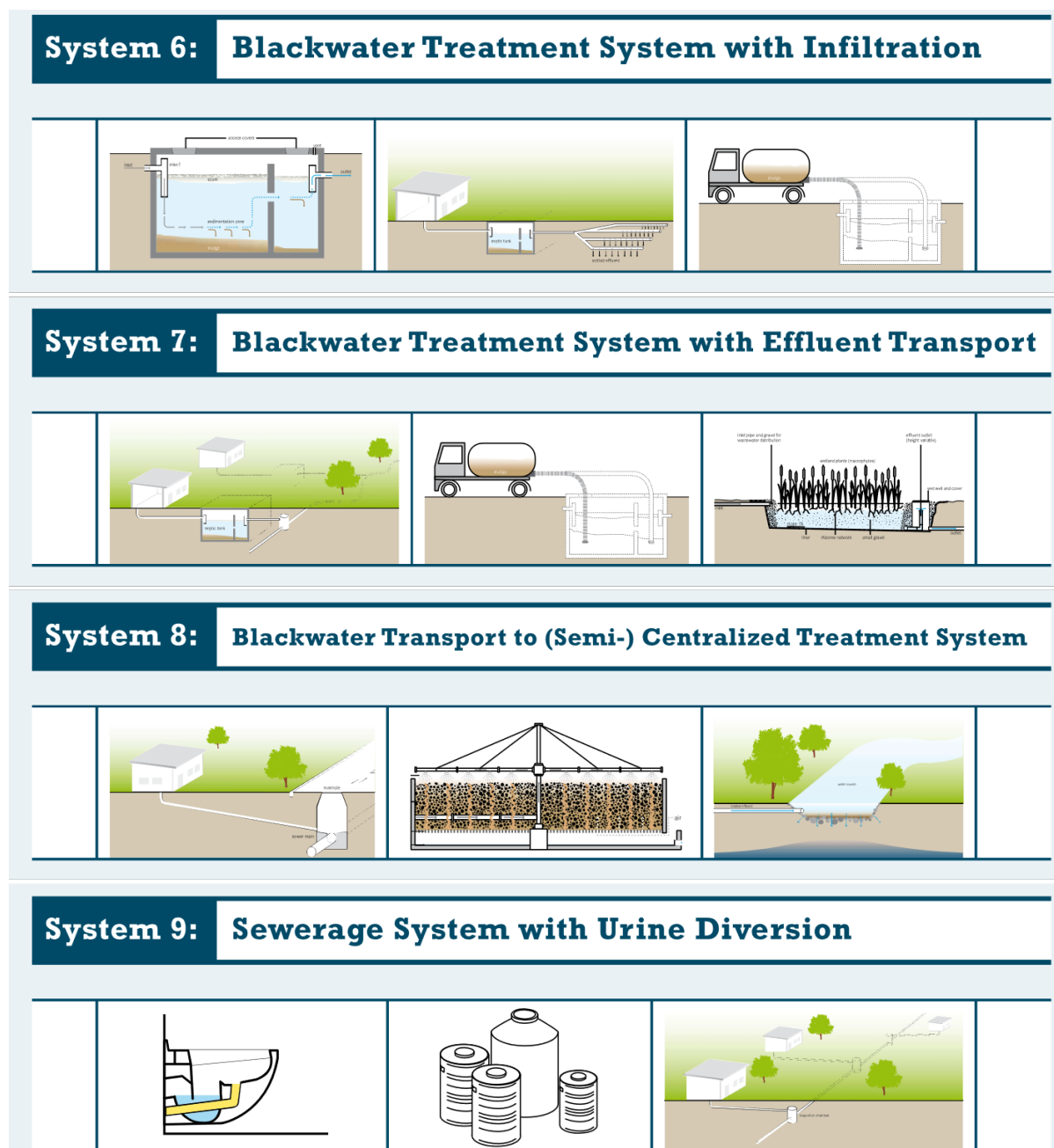


Figure 1.8 – part 2: A classification of sanitation systems (Adopted from Tilley, 2014)

Septic tank is one of the most traditional and widespread on-site sewage disposal and treatment technology used in rural areas and developing countries. This technology consists primarily of a watertight chamber made of reinforced concrete, Polyethylene (PE, HDPE), fibreglass etc., connected to household internal plumbing via an inlet pipe (Figures 1.8 and 1.9). Wastewater from toilets, kitchens, laundry etc. is discharged into the digester (tank) to be treated by anaerobic bacteria (microorganisms that do not need oxygen to digest organic matter) within

the digester. A solid substance called sludge (the thick mucky layer) that settles at the bottom of the compartmentalized underground tank is produced by the sewage broken down by anaerobic bacteria while a hard crust layer of scum floats atop. Liquid effluent is discharged out of the tank through an outlet pipe to an effluent disposal system (soak pit) which ultimately percolates into the subsurface soil (Figure 1.10). Septic tanks together with sanitation user interfaces like toilets, kitchen sinks do not complete the sanitation service chain. The effluent discharge should be handled with care. While the effluent contains far fewer contaminants than the raw sewage, it still has some amounts of pathogens and nutrients making it unsafe to discharge to, for example, surface water. Ideally, the effluent should have time to be further digested and naturally treated in the soil before it reaches the water table (Figure 1.10). Further, the septic tanks have to be periodically desludged when they fill up. This sludge has to be collected and processed (ideally treated, but at least dried) and safely disposed of. This entire system completes the sanitation service chain and should be the focus of managing sanitation.

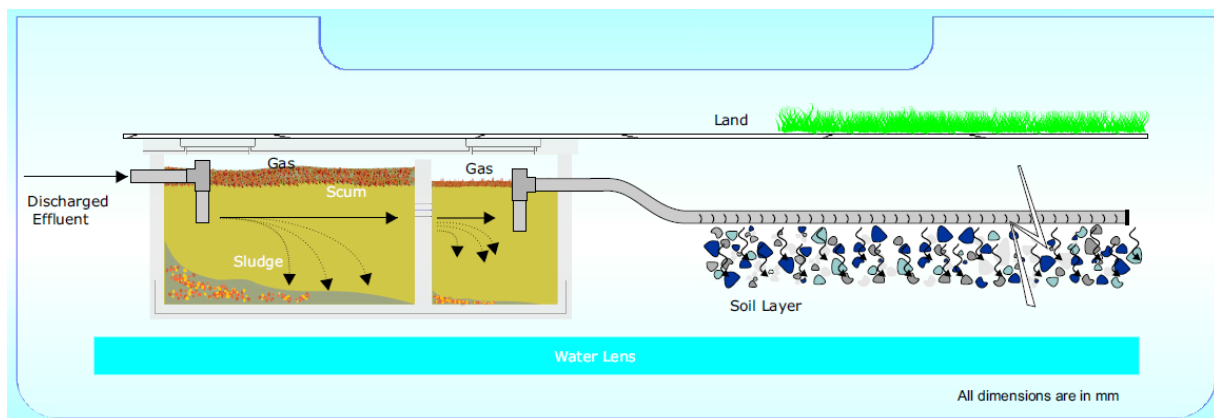


Figure 1.9: Cross-section showing the main features of a typical septic tank (After Maldives Water and Sanitation Authority, 2003)

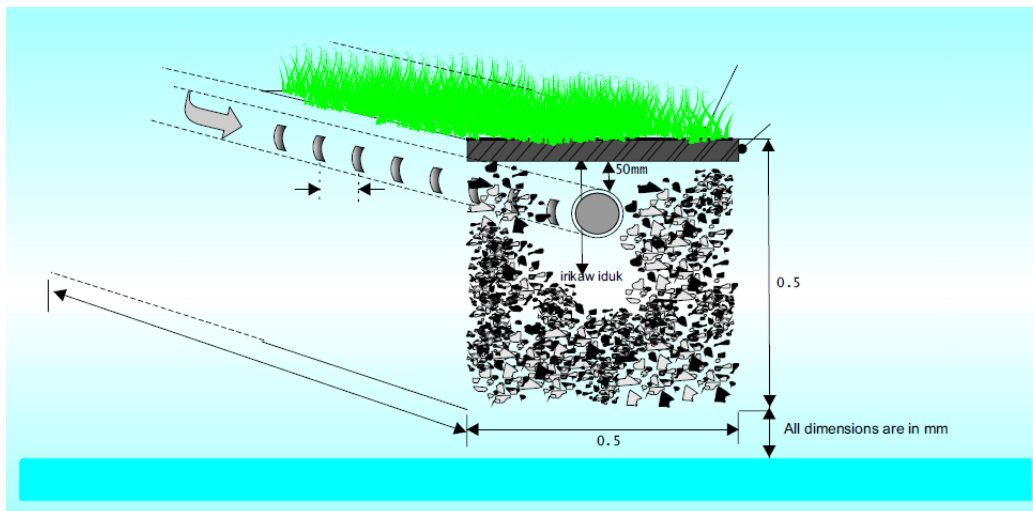


Figure 1.10: Isometric view of a septic tank soakaway (After Maldives Water and Sanitation Authority, 2003)

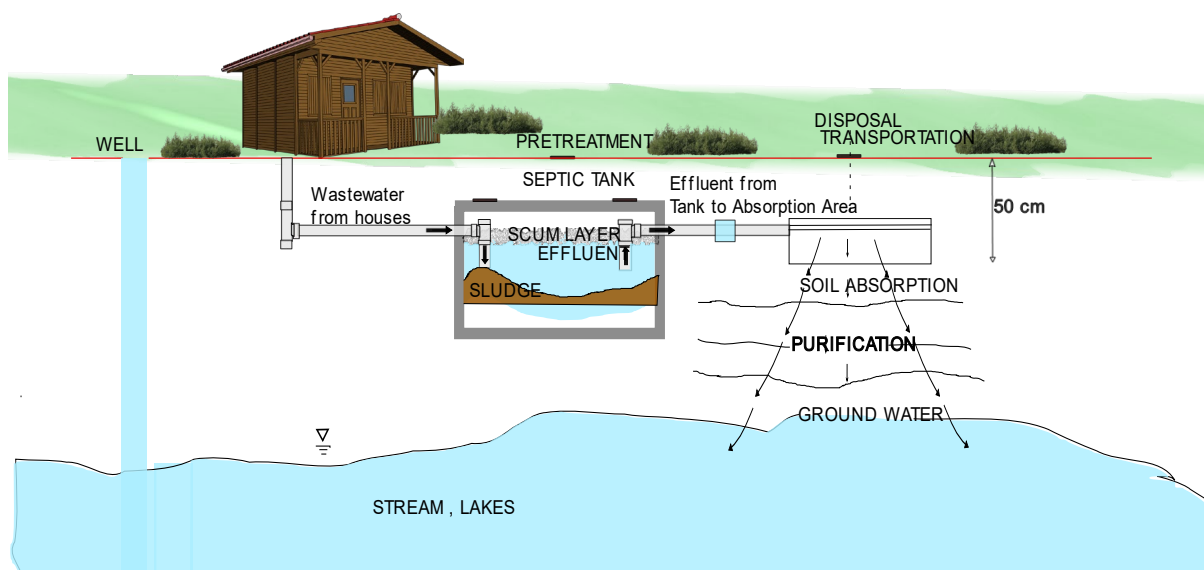


Figure 1.11: Treatment of effluent discharged from a septic tank system by a suitable treatment technology before it infiltrates into the subsurface soil (After Dillion, 1997)

Groundwater contamination from leaking wastewater due to improper installation and poor maintenance of septic tanks have been the primary cause of waterborne disease transmission by sanitation in the islands. Therefore, it's important to properly size septic tanks considering the number of users and the amount of water used per capita. Onsite systems should be sited

away from drinking water wells with sufficient setback from large trees for its roots may break the tanks. It's equally important to make sure sufficient thickness of the unsaturated soil column is available below the septic tank to prevent contamination of groundwater from possible leakage. This is often difficult to achieve in the Maldives as the groundwater level can be as shallow as 0.5m below ground during the wet season. Therefore, avoiding leakage from septic tanks is extremely important in the context of the Maldives to prevent groundwater contamination.

Routine emptying of septic tanks is also important for proper maintenance of the systems. The use of chemicals to unclog septic tanks is not recommended and access shafts should be provided for regular emptying. Moreover, low-lying coral islands are extremely vulnerable to pluvial and coastal flooding which contributes to sewage backup into toilets and overflow from septic tanks.

Septic tank systems should be emptied regularly (usually within every 1-5 years) due to the accumulation of solid material. "Septage" is the liquid and solid material pumped from a septic tank or other primary treatment source. Scum accumulates on the surface while the sludge settles at the bottom, comprising 20 to 50% of the total septic tank volume when pumped. A septic tank will usually retain 60 to 70% of the solids, oil, and grease that passes through the system (U.S. EPA, 1999). Faecal sludge settled at the bottom of the septic tank has a high viscosity and is often difficult to pump. Untreated sludge contains contaminants and excess sludge can cause overflow of the tank which can cause pollution once released into the environment. Hence, it's important to regularly remove and treat faecal sludge from septic tanks (see Figure 1.11). Faecal Sludge Management (FSM) involves storage, collection, transportation, treatment and end-use of faecal sludge from septic tanks. Faecal sludge treatment technologies can be divided into three categories; established, transferring and innovative depending on the level of technology development and must be constructed in a way that it does not pollute groundwater. One example of septic tank faecal sludge treatment technology is unplanted drying beds (see Figure 1.12) which are not common in the Maldives. There are also a wide variety of suitable effluent treatment technologies available such as leach fields (using perforated pipes) for infiltration, planted drying beds etc. However, centralized faecal sludge treatment plants do not exist in the islands and it is often difficult and challenging for the island community to regularly dispose of and properly manage faecal sludge at the

household level. Therefore, sludge is sometimes unsafely managed and dumped into the environment.

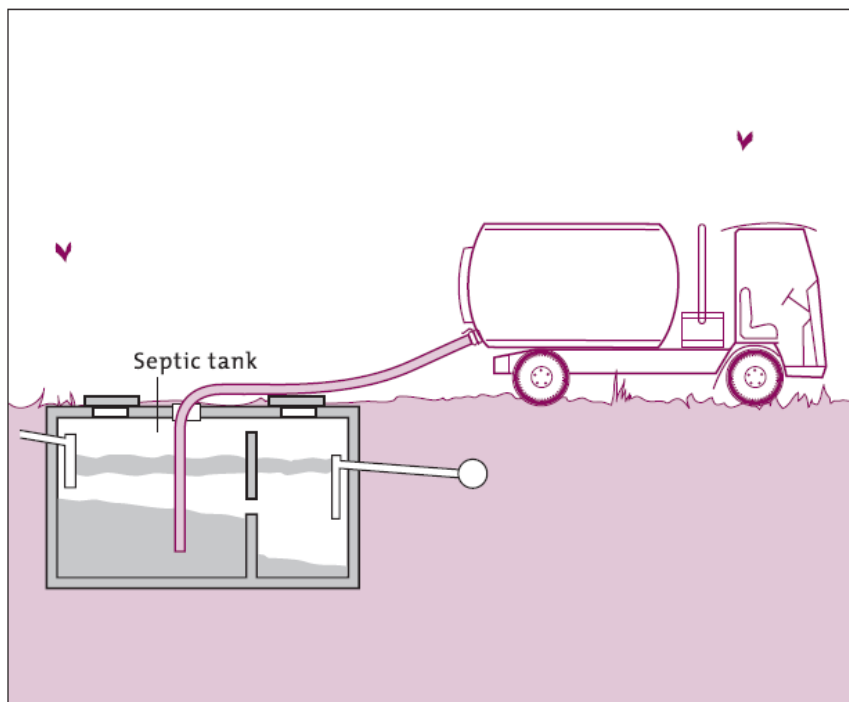


Figure 1.12: Conveyance of sewage from a septic tank using a vacuum tanker for treatment (After World Health Organization and the IRC International Water and Sanitation Centre, 2003)



Figure 1.13: An example of an unplanted sludge drying bed in Dakar, Senegal made of gravel and sand (Ulrich & Luthi, 2014)

Septic tank technology has potential for groundwater pollution if not properly installed, maintained or in case the resulting sludge and effluent is unsafely managed. Although this technology necessitates an additional burden of faecal sludge management, this simple household level sewage disposal technology is suitable for low-income and under-resourced rural areas of the world with high population density. Due to the extremely small sizes of communities in some islands of the Maldives, septic tanks remain the viable option for sanitation. However, septic tanks should not be promoted in areas where sewerage systems are feasible.

1.4 Pollution from On-site Sanitation and its management

One of the major challenges related to on-site sanitation in the Maldives as in many other places is that the system is usually constructed and managed by individual house and property owners. Unlike the sewerage systems, where the bulk of the infrastructure is managed by a utility company, these critically depend on the inhabitants' awareness of and adherence to the best practices.

Septic tanks: Septic tanks should be located as far away as possible from wells. They should be sized appropriately so that the desludging requirement should be around once in five years. (can be shorter for flush toilets as the wastewater volume is high). Tanks should be constructed with high-quality material and craftsmanship to ensure proper functioning. For example, if they are made of concrete, the thickness, reinforcement and quality of the mix should be regulated. Detailed information is given by Utility Regulatory Authority (2021) – see Appendix D. There are PVC septic tanks that can be directly installed. Given the quality standards are good, using such products may prevent many issues related to the in-situ construction of septic tanks.

Soakaways: Due to the shallow groundwater table, the soakaways should not be constructed deep. Utility Regulatory Authority (2021) recommends the soakaway pipes to be at a depth of about 5 cm from the surface and the entire soakaway structure (figure 1.9) ends at a depth of no more than 0.6 m from the surface. This is to maximize the chance of soakaway water being treated by the soil before it entered the freshwater lens.

Desludging: Desludging is one of the situations where acute pollution can potentially take place due to mishandling of the process. It should be done by qualified and regulated

contractors or trained personnel. The amount of sludge that is spilt should be kept to a minimum and sludge should be transported in sealed containers. Ideally, sludge should be treated so that it can be disposed of as solid waste. However, many small islands in the Maldives currently lack sludge treatment facilities, so that the only viable means is to disposal into the sea. In such situations, the disposal should happen away from the shore and ideally outside the reef. Washing back of sludge to the shore can contribute to groundwater pollution. Detailed instructions are provided in Appendix D of General Guideline: Domestic Wastewater Disposal (Utility Regulatory Authority, 2021).

1.5 Sewered Sanitation Systems for Sewage Management

Offsite (centralized) sanitation systems or sewer systems use conveyance technology to transport sewage from an input source to a different location for disposal and treatment. Sewer systems are conveyance technologies and are a good technical solution as a replacement for septic tanks. With proper end-of-pipe treatment and safe disposal, sewer sanitation is environmentally friendly and can reduce groundwater contamination. There are three main categories of sewer systems: simplified sewers, small-bore sewers and conventional gravity sewer systems. Conventional gravity sewer technologies can be further divided into two main types: combined and separate sewer systems. The old combined system collects and conveys both the wastewater and stormwater collected from buildings and roads in one common pipe system. Mixing relatively safe stormwater with hazardous wastewater, increasing treatment volume is the main drawback of combined systems. Further, during heavy rainstorms treatment and conveyance capacity become inadequate for the high flow volume, causing combined sewer overflow events, which are environmental hazards. Combined sewer systems exist in many cities as a holdover from the old days as the cost of building separate systems is high. Almost all the drainage/sewerage systems build today are separate systems where wastewater is conveyed and treated separately from the stormwater. Only separated sewer systems are available in the Maldives (see Figure 1.13 & Figure 1.14).



Figure 1.14: A conventional gravity sewer pipeline being constructed on an island in the Maldives – (Source: mwsc.com.mv)

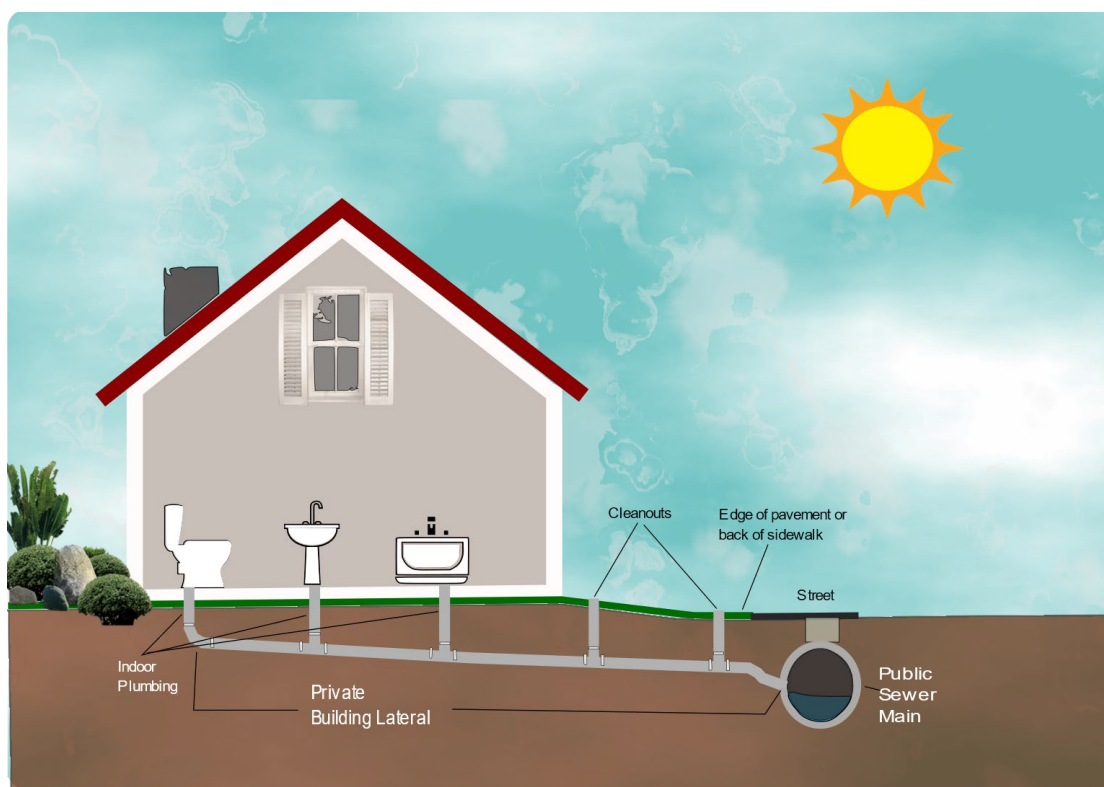


Figure 1.15: Schematic cross-section of a separated conventional gravity sewer system showing the collection and transportation technology – (After, torranceca.gov/our-city/public-works/city-sewer-line-maintenance)

Conventional gravity sewer systems are networks of underground conduits or pipes that convey sewage from houses via gravity to a sewage treatment plant and then discharge via an outfall. Unlike combined sewers which also carry stormwater, separate sewers transport only sewage using the flush water in the pipes. The slope of sewer pipes is determined so that the conduits have a self-cleansing velocity. Sewage is collected by house connections at each household from the neighbourhood and collected by a sewer main running under the access road. These pipes form a connected system (a network) with a suitable gradient to pump stations (see Figure 1.15 & Figure 1.16). Pump stations lift the sewage from lower elevations and transfer it usually via force mains (with pressure) to a treatment plant for treatment. There are many situations in the Maldives where there are no sewerage treatment plants so that collected sewage is discharged to sea without treatment. This is an environmental hazard.

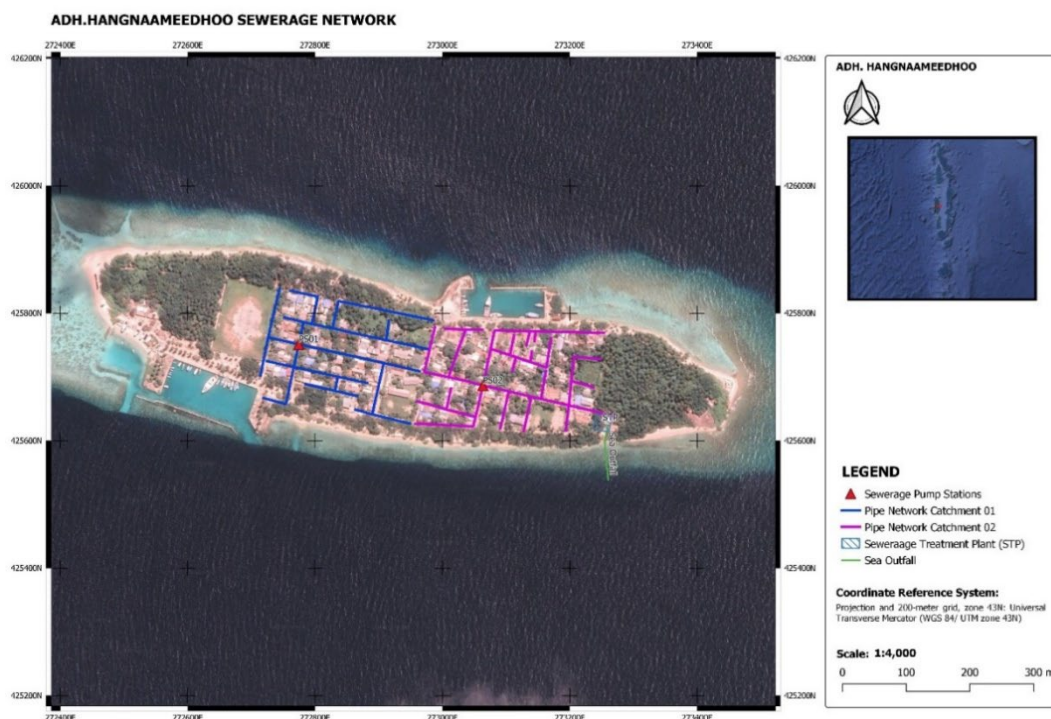


Figure 1.16: Map of a typical sewer network in an island of the Maldives showing the major facilities of the system

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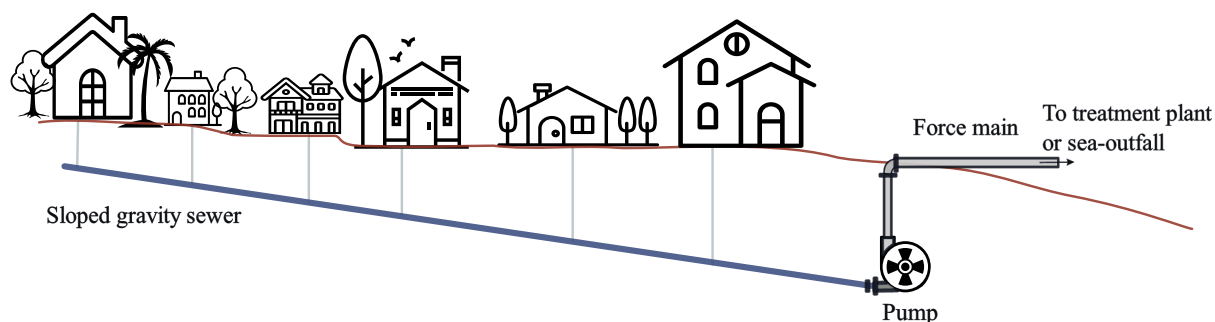


Figure 1.17: Schematic diagram of a typical gravity sewer system. The collection sewer has to be sloped to allow efficient flow under gravity, making the end of it go deep from the surface. Ideally, before reaching the groundwater level, a pumping station should be used to lift water to force mains (or sometimes to gravity mains) that convey the water to a treatment plant or sea outfall.

- House Connections: Lateral pipe connections from houses that transport sewage to the main sewer pipes (See Figure 1.17).

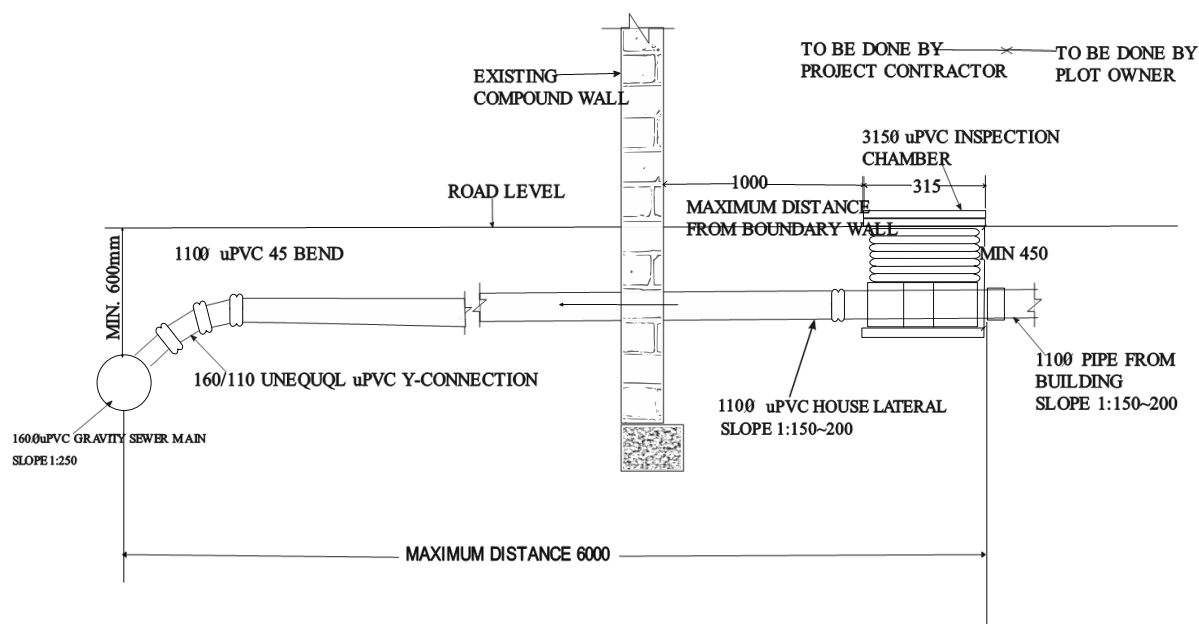


Figure 1.18: Typical Cross-section of a House Connection – (Adopted from an internal Sewerage Design Report)

- Sewer Pipes: A network of subsurface pipes usually laid below road surfaces to convey sewage by gravity from house connections to pump stations.

- Manholes: Vertical shafts located at set intervals usually at pipe junctions and intersections of the main sewer pipes (see Figure 1.18). These are constructed underground and are wide enough to accommodate a person for cleaning and maintenance purposes.



Figure 1.19. Photograph of a typical sewer manhole with the cover removed for inspection (left) and the details of the corrugated shaft pipe (right) – (Source: <https://bcfocus.com/global-sanitary-manhole-covers-market-2020-industry-future-growth-key-player-analysis-and-forecast-2025/>, & <http://www.ekoma.net.pl/oferta/735/tegra-425.html>)

- Pump stations: Sewage collected from sewer pipes are transported to subsurface concrete chambers to be lifted by pumps to higher elevations (see Figure 1.19). Submersible grinder pumps that provide sufficient head to the wastewater are located within the pump stations. Usually, two sewage pumps are provided (one working and one standby) and are connected to an electrical panel board for power. Sewage is periodically pumped out to an outfall.

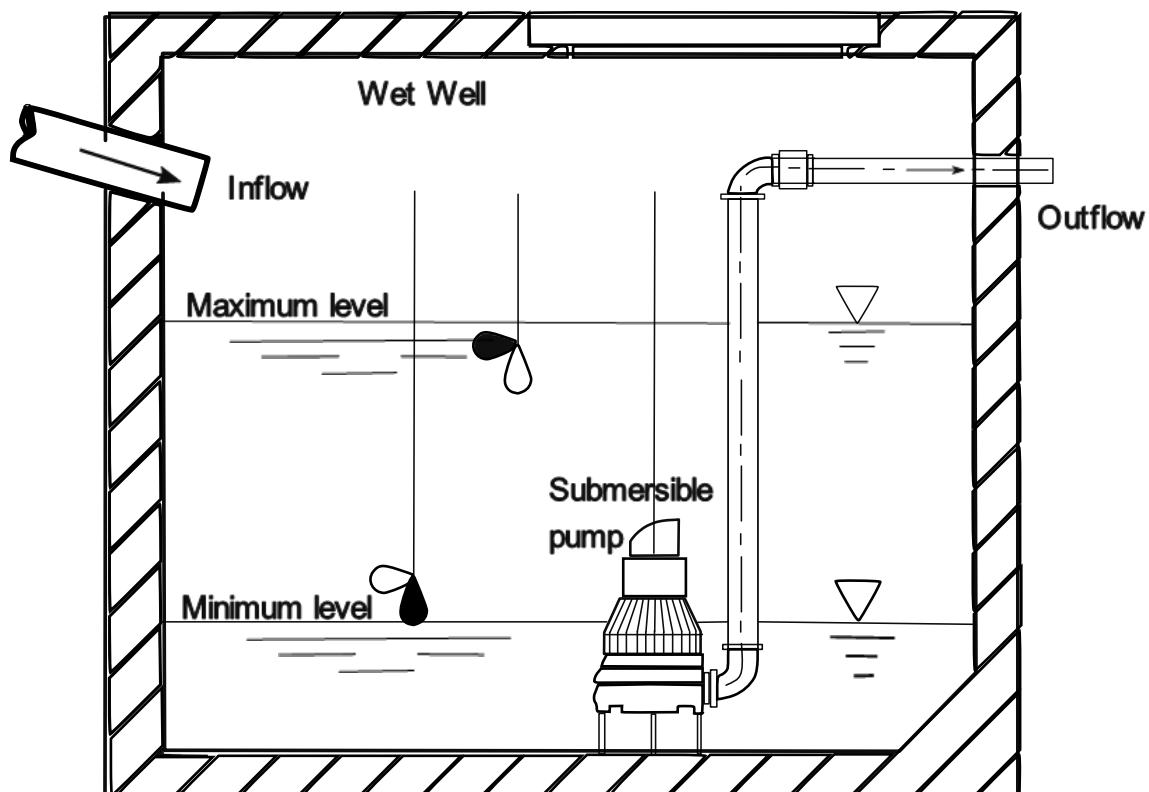


Figure 1.20. Typical cross-section of a sewer pump station with valve chamber – (Adopted from an internal Sewerage Design Report)

- Sewerage Treatment Plant (STP): Raw sewage is treated using a suitable wastewater treatment technology (see Figure 1.20) before discharging the resulting effluent via an outfall (some systems may or may not be equipped with an STP and untreated effluent is directly discharged to the deep sea). However, according to the local regulations, the operator of the system should ensure that the quality parameters or the limiting values of various pollutants found in the effluent discharged to the environment complies with the Waste Water Quality Guidelines published by the EPA.

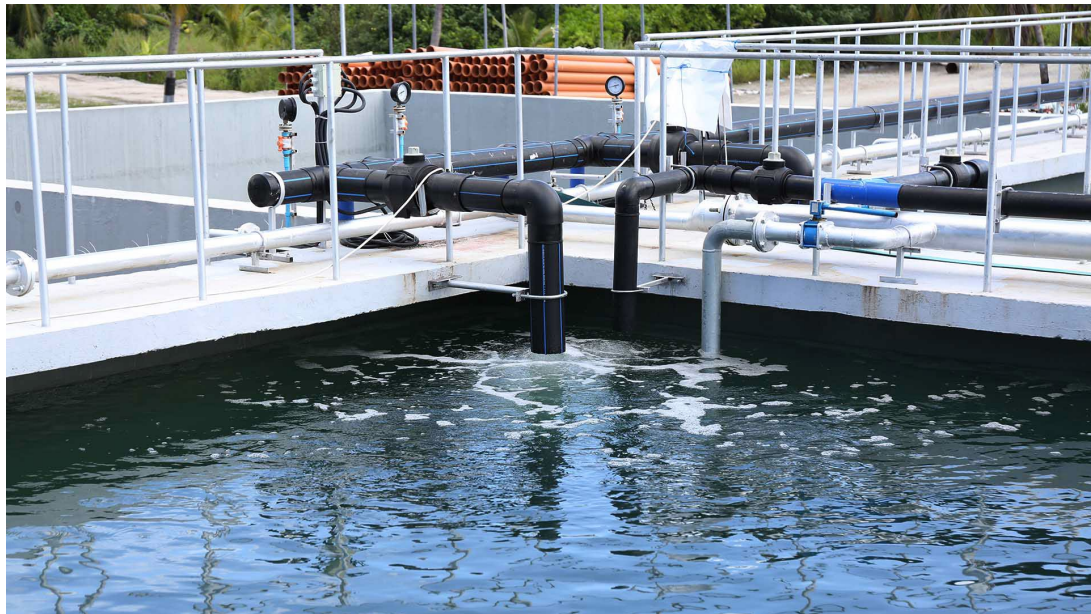


Figure 1.21. A Sewerage Treatment Plant (STP) in operation in a local island – (Source: mwsc.com.mv)

Given below are some of the most common types of wastewater treatment technologies used locally, which are all based on aerobic (by bacteria that requires oxygen) biological processes:

- Sequencing Batch Reactors (SBR) – A technology based on the conventional activated-sludge treatment process where treatment is conducted in batches in the same reactor (see Figure 1.21).

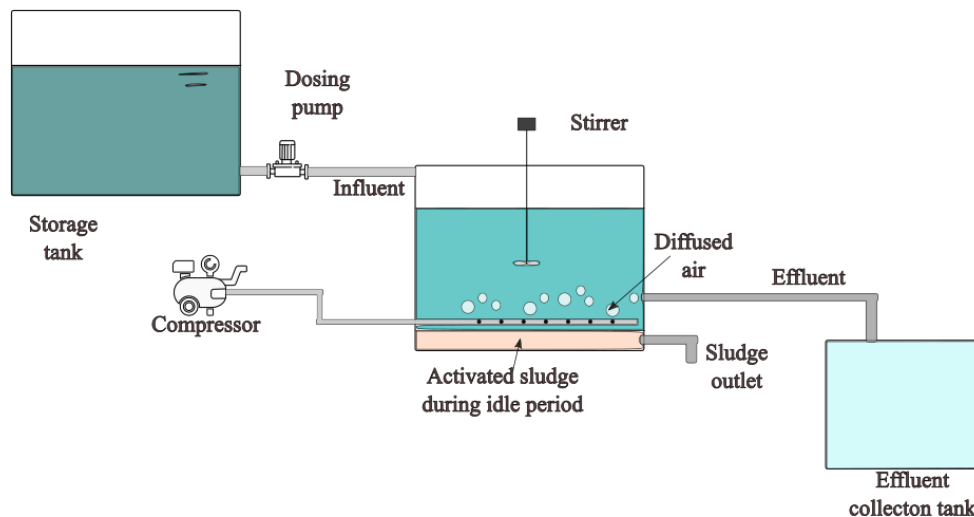


Figure 1.22. Schematic diagram of the SBR treatment process – (Source: https://www.researchgate.net/figure/Schematic-diagram-of-the-SBR-system_fig1_334965537)

- Membrane Bioreactors (MBR) – A combination of the activated-sludge process and a membrane filtration process such as ultrafiltration (see Figure 1.22).

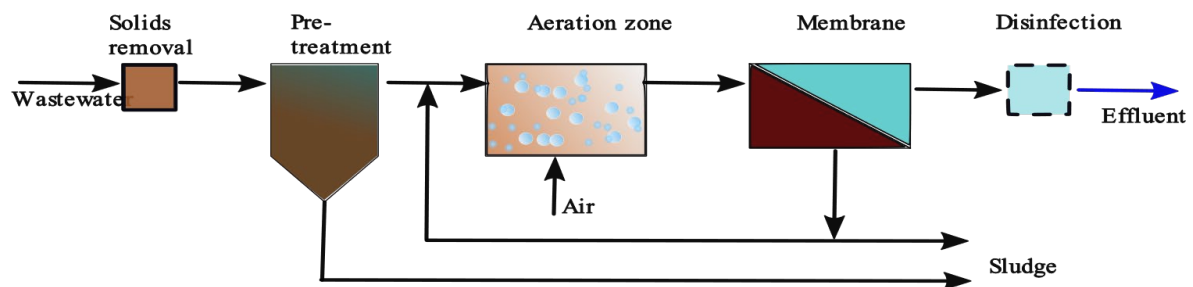


Figure 1.23. Schematic diagram of the MBR treatment process – (After from Pandey & Singh, 2014)

- Moving Bed Biofilm Reactors (MBBR) – A biological treatment process that uses floating plastic media in an aerated environment to decompose the sewage (see Figure 1.23).

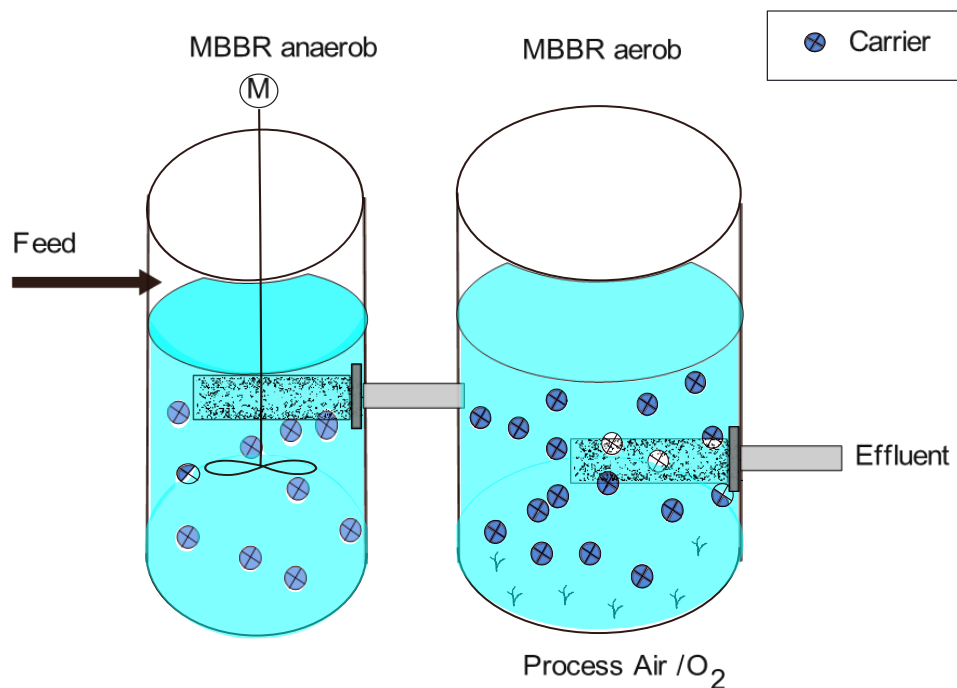


Figure 1.24. Schematic diagram of the MBBR treatment process with carrier media.

- Outfalls: A pipeline laid from a discharge pump station to a natural stream or a water body (to the deep sea in the case of the Maldives) (Figure 1.24). Outfalls are pressure pipes discharging sewage from a discharge pump station that is fixed to the coastal bed using suitably sized anchor blocks.

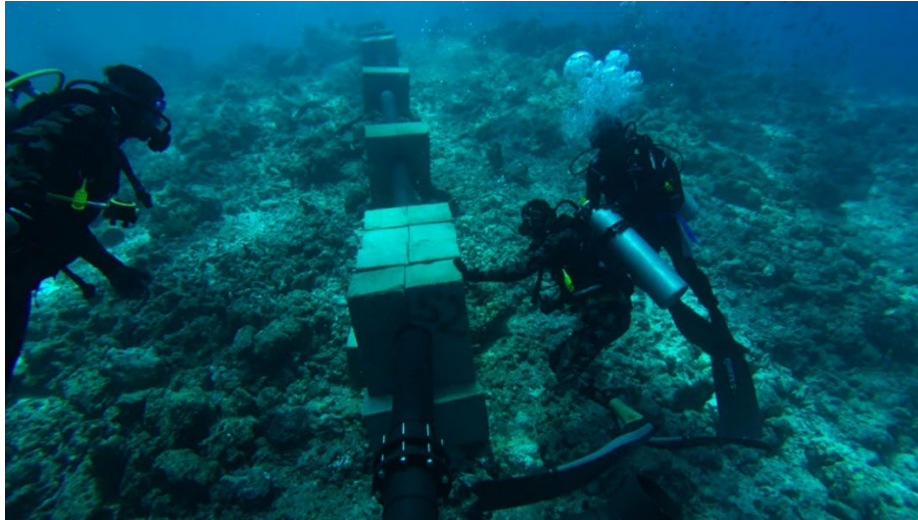


Figure 1.25. A sea outfall system being laid in an island – (Source: mwsc.com.mv)

1.6 Pollution from Sewered Sanitation and its management

Collection of wastewater by separate sewer systems, if properly managed is a very safe process in terms of environmental pollution. However, these complex infrastructures need proper planning, design as well as management for them to remain safe. In practice, there are many potential pollution hazards associated with the sewer systems.

One of the issues often encountered by combined sewer systems is the so-called combined sewer overflow due to the inability of the system to carry the high stormwater load during heavy rainfall. This is a major environmental hazard as it allows the introduction of untreated sewage to the water system. In theory, this should not be a problem in separate sewer systems as they do not have connections for stormwater. However, in many cases, separate sewers can also have the issue of sewage overflow due to the inflow and infiltration of stormwater and groundwater into the system (see Figure 1.25). The inflow of stormwater through manholes during wet weather and via illegal connections from inappropriate plumbing from household roofs can cause raw sewage to back up in the system or overflow from different components

(see Figure 1.26). Moreover, defects at the joints and cracked or faulty pipes and manholes may also contribute to the infiltration of groundwater.

As sewerage systems are designed for a certain amount of loading, any excess water can overload the system leading to failure and ultimate spillage of sewage from various components; namely, pump stations and manholes that may contaminate groundwater. Hence, it's important to ensure that inflow and infiltration are kept within the design limits of the system. Additionally, poor construction, management and maintenance & operations practices also contribute to inflow and infiltration into the sewer.

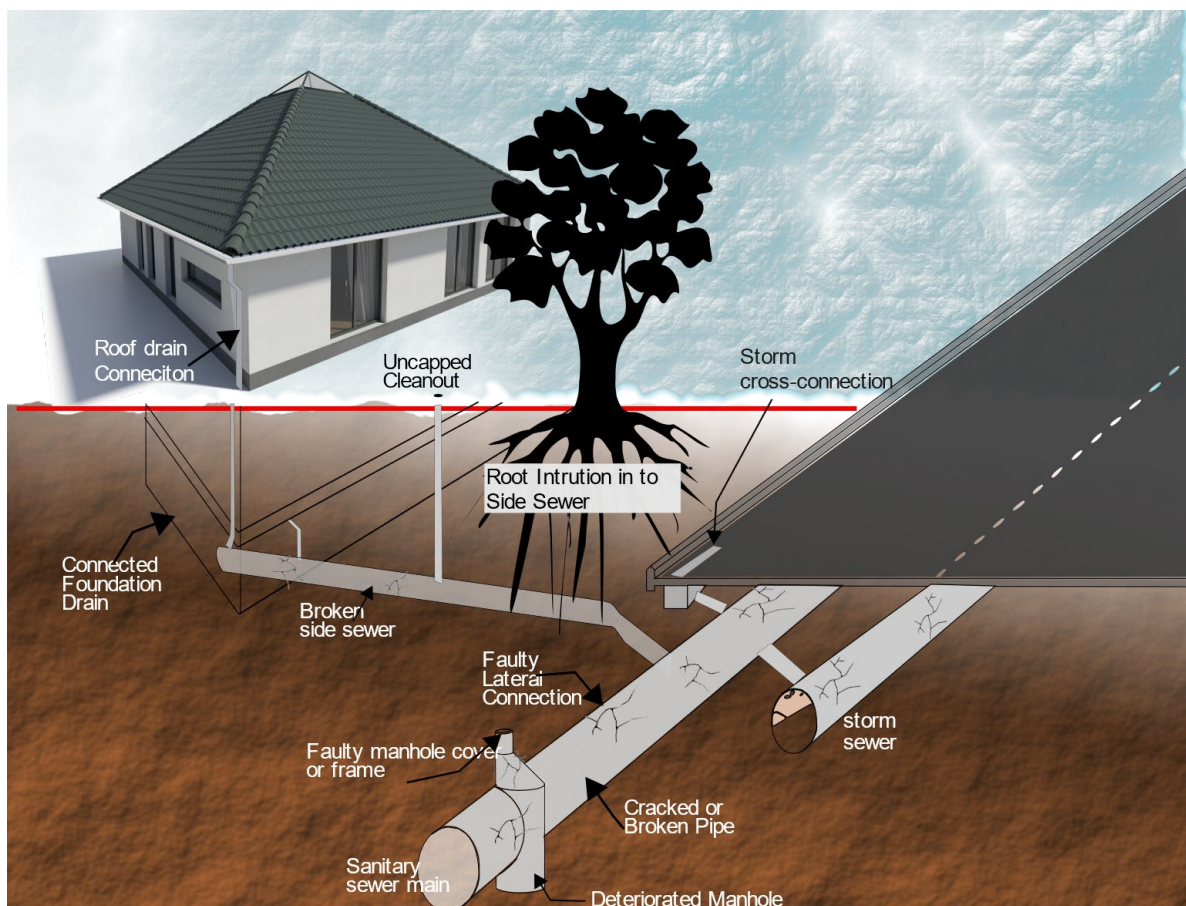


Figure 1.26. Schematic showing inflow and infiltration into a sewer system – (Adopted from <http://www.burksfalls.net/townhall/roads/storm-drain-maintenance>)



Figure 1.27. Sewage overflow from a sewer manhole – (Source: <https://www.apr.org/post/alabama-probes-fish-kill-after-sewage-spilled-near-creek>)

Improper practices that may contribute to groundwater pollution during construction, throughout management, operation & maintenance of a gravity sewer system should be avoided. Sewer systems should not be designed and constructed using components that are of low quality and inadequate size. It's important to use quality pipes and perform suitable leak testing of the pipe network during construction to detect cracks and leakproof the system before commissioning. During the operation of the system, a preventive maintenance programme, as well as routine monitoring, should be in place. A common issue associated with maintenance is the issue of malfunctioning pumps. One common occurrence in the Maldives is the issue of pumps remaining in unserviceable status for a long time until required spare parts have been procured from overseas. The brand and specification of pumps used vary considerably from island to island as sewer systems are designed and constructed by different contractors. Pump failure leads to overflow and spillage of sewage into the surrounding groundwater. Furthermore, there are chances of raw sewage spillage to the surrounding during jetting operations while cleaning blocked sewers and manholes. Hence, emergency maintenance operations should be kept to a minimum by ensuring that the end-user does not directly dispose of any unsuitable products such as grease and garbage into the toilets that may block the sewer, causing the overflow.

1.7 Conclusions & Recommendations

The risk of groundwater contamination and consequent human and environmental health hazards associated with onsite septic tank technology is quite high for low-lying coral islands where freshwater is found in shallow aquifers. This is apparent from the past experiences from the islands of the Maldives where groundwater has been contaminated due to poor onsite sanitation practices. Effluent from septic tanks is released into the high-water table without treatment and allowed to infiltrate into groundwater. Furthermore, septic tanks are not desludge regularly leading to overflow and contamination of groundwater. As there are no proper faecal sludge management methods available in the islands, sludge is often dumped into the environment after emptying from septic tanks. Even though groundwater is susceptible to contamination from septic tanks, complete decommissioning of septic tanks in the islands may not be possible without a suitable alternative for sewage management.

In contrast, sewer systems have a much lower impact on groundwater pollution compared to non-sewered systems given proper management, operation and maintenance of the system are conducted. It's believed that conventional separate gravity sewer systems are the industry gold standard to reach in sanitation. However, the capital infrastructure and operation and maintenance costs of a conventional gravity sewer system are quite high compared to septic tank systems. Further, the full environmental and health benefits of such systems can only be achieved with proper wastewater treatment facilities being available at the end of the system. Sewer systems have not yet been installed in many islands, and the community continues to rely on septic tanks for sewage disposal. Many islands that are equipped with sewerage systems do not currently have functioning wastewater treatment plants. Such systems, even though reduces the contamination of the groundwater, may be an environmental hazard due to the discharge of untreated effluent into the ocean .

The government has a plan to provide sewer systems in all the inhabited islands covering the entire population of the country within the next 5-years. Even though the implementation of sewer systems will reduce the adverse negative impact on groundwater quality, proper management and maintenance are paramount during system operation. In general, it is not recommended to install septic tanks in islands where sewer systems are already built or in areas where new sewer systems are feasible. In the case of either onsite or offsite sanitation

systems, proactive sewerage management disposal plans and methods are required at every stage of the sanitation service chain to conserve groundwater resources and protect human health.

CHAPTER 2:

Hard-standing and road drainage storm run-off collection and disposal

2.1 Introduction

As described in detail in Part I of this guide, stormwater is the main cause of flooding in the islands and should be removed effectively from the road surfaces of urban and less developed areas, to reduce the risks of flooding. Emphasis was given on Part I of this guide on the importance of infiltrating rainwater for recharging the groundwater lens of the islands rather than discharging it to the sea. Stormwater can play a crucial role in contaminating groundwater. Hence, it is equally important to ensure that the stormwater infiltrated is free of pollution and environmentally harmful substances. This chapter is focused on the water quality aspects of storm run-off generated on hard surfaces such as roadways and hard standings. It's recommended to supplement this chapter with Chapter 2 of Part I of this guide.

Due to urbanisation, ongoing developments in urban areas leads to an increase in the number of impermeable surfaces. Developments lead to an increasing number of pollutants accumulated on road surfaces due to human activities, for example, from the increase in the number of vehicles on the streets. Storm run-off generated on hard-standings and road surfaces in the islands of Maldives carry a significant number of pollutants hence, where possible treatment options (especially natural) should be employed, to reduce groundwater pollution.

This chapter is a guide on the sources and reduction of pollution of groundwater resulting from stormwater. It starts with a brief description of storm runoff generation on road surfaces and describes the sources of stormwater pollutants, their impact on groundwater quality. The next section describes the importance of rainwater harvesting to reduce storm runoff the following section discussed the importance of collection and disposal of stormwater using stormwater drainage systems. Then, a discussion of sustainable drainage methods for stormwater runoff reduction and treatment have been presented. A conclusion has been drawn at the end of the chapter.

2.2 Storm Run-off Generation in the Islands

Storm run-off is generated by impervious surfaces on islands that prevents the infiltration of rainwater into the ground. Hence, storm run-off generation is increased in urban areas as opposed to less developed (grassy) areas. Stormwater, which is the water derived from rainfall accumulates on these impermeable surfaces during heavy rainfall creating excess water causing

flooding (see Figure 2.1). One of the most significant impervious surfaces in a developing urban area is the roadways and hard standings.



Figure 2.1: Mobile pumps are used occasionally to drain stormwater from the streets of Male' city after a heavy rain shower. (Source: psmnews.mv/en/40417)

There are mainly two types of roads in the Maldives; sandy unpaved roads and paved roads (made of asphalt or interlocking paver blocks). Roads are used by vehicles for transportation of people and goods and need to be designed to accommodate high traffic loading (see Figure 2.2 & Figure 2.3). Hard-standings are paved areas for parking vehicles such as parking lots (see Figure 2.4). These surfaces are usually constructed using hard impervious material. Surfaces with no capability to pond or infiltrate water will produce runoff. Therefore, roads and hard-standings generate a significant amount of storm run-off.



Figure 2.2. A paved road in Male' where vehicles are parked on the left side and catch pits are installed for drainage. This setup is different for a less-developed island in the Maldives – (Source: Authors)

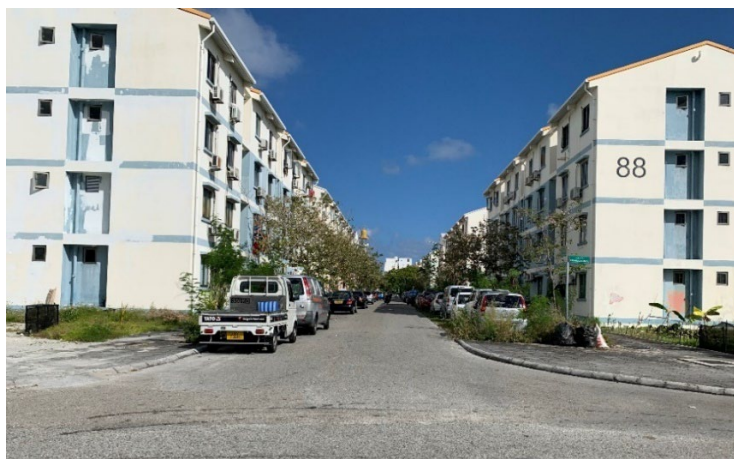


Figure 2.3. An asphalt paved road in Hulhumale'. Asphalt roads are becoming increasingly popular in all the islands – (Source: Authors)



Figure 2.4: A motorbike parking zone in Male' where paved using interlocking paver blocks – (Source: Authors)

Rain falling directly onto the road surfaces and building roofs get contaminated by mixing with pollutants. Storm runoff picks up numerous pollutants accumulated on the surfaces of road pavements and hard-standings and drains them along with the water through storm drain inlets (see Figure 2.5) (in areas where there are stormwater drainage systems). Stormwater drainage systems usually discharge untreated storm runoff directly into water bodies (sea in the case of Maldives). Hence, polluted runoff may not only get introduced into the groundwater but also into the receiving waters.



Figure 2.5: A stormwater catch pit located on the roadside of Male' city, seen filled debris and trash – (Source: Authors)

2.3 Sources of Stormwater Pollutants and its Constituents

Harmful physical, chemical and microbial pollutants are introduced onto land surfaces from natural processes as well as from anthropogenic activities. They may include garbage, debris, oil, grease, chemicals and sediments (see Figure 2.6). A study conducted by US-EPA for 28 NURP (National Urban Runoff Program) projects which included 81 specific sites and more than 2,300 separate storm events gives an idea of the expected quality parameters of stormwater (USEPA, 1999) (see Figure 2.7). Concentrations of selected water quality parameters in urban runoff are comparable to that found in untreated domestic wastewater (USEPA, 1999) (see Figure 2.8).

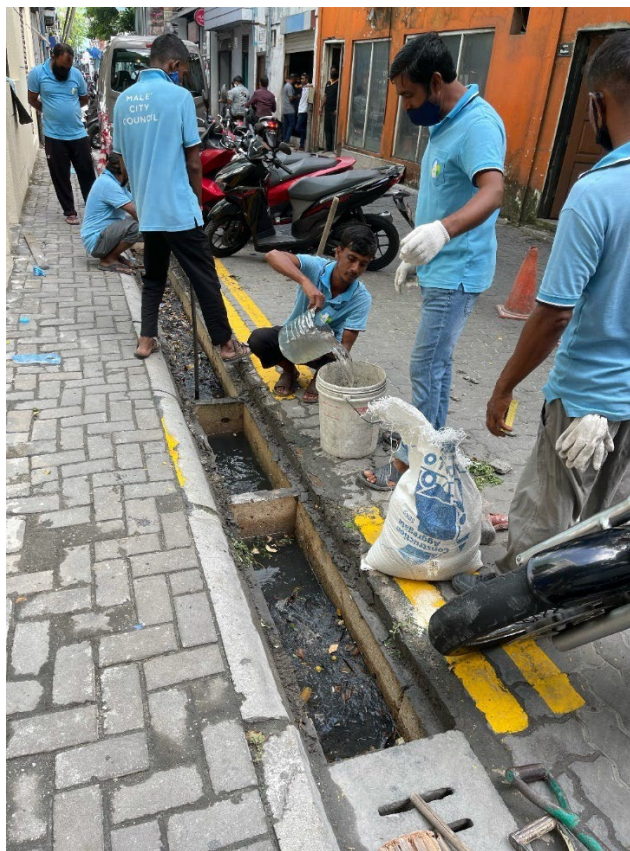


Figure 2.6. A street gutter in Male' which has been blocked with waste material is being cleaned by the workers (regular cleaning and maintenance is important to prevent infiltration of pollutants into the groundwater) – (Source: Authors)

Pollutant	Units	Residential		Mixed		Commercial		Open/ Non-Urban	
		Median	COV	Median	COV	Median	COV	Median	COV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	--	--
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	µg/l	33	0.99	27	1.32	29	0.81	--	--
Total Zinc	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	µg/l	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

COV: Coefficient of variation

Source: Nationwide Urban Runoff Program (US EPA 1983)

Figure 2.7. Median Event Mean Concentrations for Urban Land Uses (USEPA, 1999)

Constituent	Urban Runoff		Domestic Wastewater		
	Separate Sewers		Before Treatment		After Secondary
	Range	Typical	Range	Typical	Typical
COD	200-275	75	250-1,000	500	80
TSS	20-2,890	150	100-350	200	20
Total P	0.02-4.30	0.36	4-15	8	2
Total N	0.4-20.0	2	20-85	40	30
Lead	0.01-1.20	0.18	0.02-0.94	0.10	0.05
Copper	0.01-0.40	0.05	0.03-1.19	0.22	0.03
Zinc	0.01-2.90	0.02	0.02-7.68	0.28	0.08
Fecal Coliform per 100 ml	400-50,000		10 ⁶ -10 ⁸		200

Source: Bastian, 1997

Figure 2.8. Comparison of water quality parameters between urban runoff with wastewater (USEPA, 1999)

Among the various sources of pollutants on roads, vehicular transportation or motor vehicles is of major concern in roadways and hard standings in the Maldives. Pollution sources attributed to vehicular transportation have been identified as; vehicle operation, vehicle washing and road abrasion (Müller, et al., 2020). Pollutants sources from vehicular traffic are; oil, grease, lubricants, abrasive products and heavy metals etc. which accumulate on the road surfaces (see Figure 2.9). There is a high tendency that vehicles may introduce many pollutants to the environment. Hence, it is important to reduce the number of vehicles and regulate the condition of the vehicles, to reduce the introduction of these pollutants into the groundwater. This is particularly relevant for high-traffic urban environments like that of Male' and Hulhumale and can become problematic in other larger islands.

A related, more substantial issue in the Maldives is the pollution by seafaring traffic like boats. Spilling of oil, illegal dumping of solid waste, sewage and contaminants from these vessels contaminate the sea. Servicing of these is done at the harbours of islands making it also possible to contaminate groundwater from service activities and boatyards.

An important aspect of the pollution potential of roads and hardstandings is the accidental (and sometimes illegal) directing of stormwater to the sewer pipes. As was mentioned in the previous section, these can cause sewers to overflow and contaminate the groundwater.

Another related issue is the flooding caused by improper drainage of roads and hardstandings. Flood water can enter sewer pipes (through manholes), septic tanks and solid-waste dumps making it possible for contaminants to mix with stormwater and pollute the groundwater. This can be avoided by (a) using Sustainable Drainage Systems to manage stormwater at or around the source and (b) efficiently removing the excess water using drainage systems to the sea or (preferably) managed aquifer recharge systems.

Specific source	Pollutants released
Vehicle operation Exhaust gases and particles	Hydrocarbons, PAHs, NOx, Ni, BTEX
Catalytic converters	Rh, Pd, Pt
Vehicle wear Tires	TSS, Cd, Cu, Zn, PAHs, microplastics
Tire studs Brakes	W TSS, Cd, Cu, Ni, Pb, Sb, Zn, PAHs
Engine and vehicle body wear Body paint Wheel balance weights	Cr, Ni Pb Pb, Fe (steel), Zn
Vehicle washing Commercial car washing facilities	Pb, Cd, Cr, Zn Phthalates, NPs, NPEOs
Road abrasion Abrasion by tires (non-studded and studded)	TSS PAHs Microplastics

Figure 2.9. Sources of pollutants released by vehicular traffic (Müller, et al., 2020)

2.4 Preventing Overflow to Public Roads by Harvesting Rainwater from Roofs

Rainwater can either be collected before it turns into stormwater or treated before infiltrating into the ground. In addition to the main water security benefit, rainwater harvesting can also reduce the overflow of rainwater into roadways and hard standings, wherever practicable. One way to achieve this is by harvesting rainwater falling on roofs of households and institutions by using RWH systems (see Figure 2.10).



Figure 2.10: PVC pipes and a PE tank are connected to the roof to collect rainwater in a rainwater harvesting system installed on an island. (Source: www.bluepeacemaldives.org/blog/2009/03)

Island communities should be encouraged and advocated to utilize roofs of households and community buildings for rainwater harvesting as much as possible. Public awareness and education programs on simple rainwater harvesting or methods should be conducted that can be implemented at the household level. Rainwater harvesting is discussed in detail in Chapter 2 of Part 1 of this guide. It is also possible to innovatively combine RWH facilities with simple groundwater recharge solutions (e.g. infiltration pits) to enhance the stormwater reduction aspects.

2.5 Stormwater Drainage Systems for the Collection and Disposal of Storm Run-off

Stormwater drainage systems are used to collect and dispose of excess water accumulated on hard surfaces into water bodies. It's important to discharge the polluted run-off away from groundwater and prevent contamination utilizing open channels or underground pipes. However, the water collected and conveyed to the sea is lost to the FWL. Excessive removal of stormwater as a result of buildings and other impervious surfaces can result in deteriorated

There are two types of storm sewer systems; separated and combined sewer systems. Nowadays separated sewer systems are preferred and only separated stormwater drainage systems are installed in Maldives islands (see Figure 2.11). Unlike sewerage systems, these systems are quite new to the Maldives and have become popular only recently. A detailed

description of stormwater drainage systems and their design aspects have been discussed in Part I of this guideline.



Figure 2.11: A catch pit of the stormwater drainage system installed on an unpaved sandy road of S.Feydhoo island. These systems can be clogged with waste and may carry other pollutants on road surfaces with them – (Source: Authors)

The design of stormwater drainage systems should not only aim to address flooding issues but also pollution control measures by using filtration components for oil, grease and other harmful substances. Untreated storm-runoff should not be allowed to be discharged into the watercourses as it is, without some form of filtration as it may potentially deteriorate the quality and harm aquatic habitat. These systems should also be constructed completely leak-proof so as not to allow polluted rainwater to be soaked into the groundwater. Other methods that can complement stormwater drainage systems are SuDS components that allow infiltration of rainwater instead of disposing of water to watercourses.

2.6 Sustainable Drainage Components as Roads Drainage for Treatment and Reduction of Storm Run-off

Approach to managing surface water that takes account of water quantity (flooding), water quality (pollution) biodiversity and amenity are collectively referred to as Sustainable Drainage Systems (SuDS). SuDs are ‘green’ solutions that can slow down runoff and treat stormwater

before it is allowed to soak into the ground. This method of stormwater drainage reduces the amount of water discharged into the sea and allows for groundwater recharge at the same time. These methods mimic the working of the natural catchments by increasing retention, attenuation and infiltration of water. It can be used together with rainwater harvesting systems or road drainage systems. Most of these components are special drainage components with trees and vegetation that helps in filtering out pollutants before allowing water to infiltrate into the ground. Hence, in areas where pollution is likely, components that are specifically designed to filter out and treat pollutants should be used. Some of these components have already been used in the Maldives for drainage, for example in Hulhumale' (see Figure 2.12).



Figure 2.12: Bioretention systems or bioswales located on either side of the roadways in Hulhumale' allows drainage and filtration of rainwater before it infiltrates into the ground. (Source: Authors)

Given below is a list of suitable SuDS components that can be used to treat stormwater before allowing it to infiltrate into the ground;

- a) Filter Strips
- b) Filter Drains
- c) Bio-retention systems
- d) Swales
- e) Infiltration Basins
- f) Retention Basins

g) Trees

Further details on the suitable type of components that can be adopted for road drainage are found in Part 1, Chapter 2 of this guide.

2.7 SuDS and Groundwater Quality

Stormwater associated with man-made structures like roads, industries carries a level of pollutants. Therefore, the seemingly obvious and straightforward solution is to safely convey the stormwater away from the source and safely discharge it. However, in the context of the small islands like those of the Maldives, this does not necessarily lead to better groundwater quality outcomes. Draining stormwater into the sea deprives freshwater lens of water. The reduction of recharge of the freshwater lens causes two water quality challenges: First, due to reduced recharge rate, the thickness of the FWL is reduced and the salinity of groundwater is increased. Secondly, in an already contaminating environment (e.g. due to wastewater) the reduction of recharge of (relatively) clean water would increase the concentration of contaminants in the FWL. Therefore, where possible, SuDS components should be included in the drainage system design. Further, relatively cleaner water sources (e.g. roof runoff excess of RWH) should be used as sources of SuDS instead of letting them be combined with polluted water sources (e.g. Road drainage). Finally, there are many SuDS solutions (e.g. Vegetated Swales) that can perform a significant amount of pollution trapping and treatment. Such systems can be used in conjunction with road drainage.

2.8 Conclusions and Recommendations

The increase in the number of impervious road surfaces and hard-standings that prevents the infiltration of rainwater into the ground causes an increase in storm run-off. Storm run-off collects various pollutants from road surfaces and carries them with it. Furthermore, the increasing number of motor vehicles will exacerbate the number of pollutants deposited on road surfaces.

Several pollution prevention strategies can be utilized to prevent groundwater contamination by stormwater. One way is to maximize the harvesting of rainwater from building roofs to reduce stormwater run-off in the islands. In the case of capturing and disposing of road runoff using stormwater drainage systems, various considerations need to be taken during the

construction, operation and maintenance of these systems. These systems should be leak-proof and stormwater should not be allowed to infiltrate into the groundwater untreated, as it carries pollutants with it. Methods of managing stormwater largely on or close to the sources known as SuDS, have recently become popular around the world and is expected to increase in the Maldives. Such approaches, collectively known as SuDS, provide additional benefits, among which is groundwater recharge. Directly relatively cleaner stormwater sources (e.g. roof runoff excess of rainwater harvesting) to appropriately designed SuDS should be an important part of the stormwater management strategy. Carefully designed and implemented, SuDS can also handle somewhat polluted stormwater by utilizing their ability to trap and (naturally) treat contaminants.

In highly urbanized environments (e.g. Male and Hulhumale) it is also important to regulate the number and quality of motor vehicles to manage pollution. It is important to consider water quality aspects and to filter out the pollutants when designing stormwater drainage components to prevent pollution of groundwater.

CHAPTER 3:
Desalination Plant Brine Disposal

3.1 Introduction

Drinking water for potable purposes should be treated to a certain standard of quality before consumption. There is a shortage of fresh water in some islands due to the lack of rainfall during dry periods and due to the contaminated groundwater in the islands. Further, many of the inhabited islands are highly populated, making their water demand too high for the natural systems to easily cater for. Therefore, islands need to establish alternative methods of water supply to their residents. There are several methods of water treatment technologies available including ultra-filtration, nanofiltration, Reverse Osmosis (RO) etc. In the Maldives, a common method of producing water supply is desalination. Membrane-based RO technology is the most popular method used in the Maldives and can remove pathogens, dissolved solids and heavy metals etc., in addition to desalination. Desalination began in Male' in the year 1985 with a 200m³/day capacity RO plant (MEE, 2017). Today, there are several desalination plants in capital Male', and there is a growing need for supply water in the islands. All tourist resorts use desalinated water as the main water supply (NBS, 2018). Nowadays, there are private operators in the Maldives supplying bottled drinking water produced from RO plants. The government has pledged to supply piped water to the entire population. It is expected that most of the inhabited islands in the Maldives will soon be equipped with a water supply network attached to a seawater desalination plant (size based on water demand and population).

RO plants operate by running pressurized saline water (feedwater) to a membrane assembly. The membrane allows water molecules to pass easily while preventing the salt and pollutants from passing, resulting in a freshwater product stream and a concentrated brine reject stream. (Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water.) The reject, also known as brine, needs to be safely discharged to the sea. Brine from desalination processes could have a detrimental impact on the subsurface groundwater if allowed to mix with it. Hence, groundwater should be protected from pollution by brine discharge from desalination processes in the Maldives.

This chapter guides how to reduce potential groundwater pollution caused by brine discharge from desalination processes in the Maldives. It starts with an overview and a brief description of desalination in the Maldives. The next section describes the characteristics of brine discharge

from outfall systems. Then, a discussion of ways to control pollution from brine discharge has been presented. A conclusion has been drawn at the end of the chapter.

3.2 Seawater Desalination in the Maldives

Drinking water in Male' is treated using the process of desalination and is supplied to the household taps via a network of sub-surface pipes. Feedwater goes through several stages of treatment starting from abstraction in which dissolved impurities are removed leaving behind freshwater permeate and brine as reject. In this method, high pressure is applied through semi-permeable membranes in the RO plant after it has been abstracted from deep boreholes. Sea Water Reverse Osmosis (SWRO) membranes are used for water filtration (see Figure 3.1). Maldives has adopted the Integrated Water Resource Management (IWRM) model for environmental and financial long-term sustainability. In the IWRM model, RO water and rainwater are often mixed before supplying to the consumers to reduce cost (see Figure 3.2).



Figure 3.1: A desalination plant established on an island. (Source: kuredu.com)

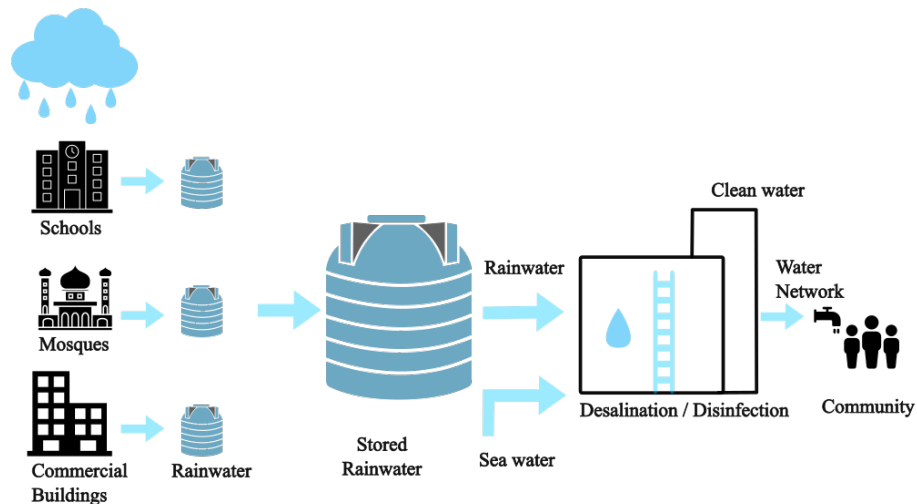


Figure 3.2: IWRM model of water supply in the Maldives. (Source: kuredu.com)

A water distribution system consists of several components forming a complete system that supplies water to the consumers with enough quantity, quality and pressure. Major components of a typical water network, including the RO plant are explained below (Figure 3.3 & Figure 3.4).

1. House Connections: A lateral line from the main pressure pipeline from the RO plant for connecting to the houses to which a water meter and internal plumbing are connected.
2. Distribution Network: An HDPE pressure pipe network laid from the RO plant throughout the island.
3. Storage Tank: A reservoir containing the treated water for supplying to the consumers. RTP tanks are commonly used in the Maldives.
4. Filtration: In the treatment process, filter units consisting of filter media or other methods such as carbon filters are used as pre-treatment before passing through RO modules.
5. Disinfection: Final stage of water treatment in which, chlorine dosing, ozonisation, UV radiation methods etc. are used for disinfection before releasing the water into the distribution network from the reservoir.
6. Pumps: Submersible pumps are installed within the borehole for water extraction and dry mounted pumps are used to pass the water pass through the membranes and to pump through the distribution network.

7. Borehole: A long, deep underground well drilled (typically to a depth of 30m) for abstracting feed water.
8. Brine outfall: Marine outfall from the desalination plant laid to transfer reject from the desalination process to the sea.

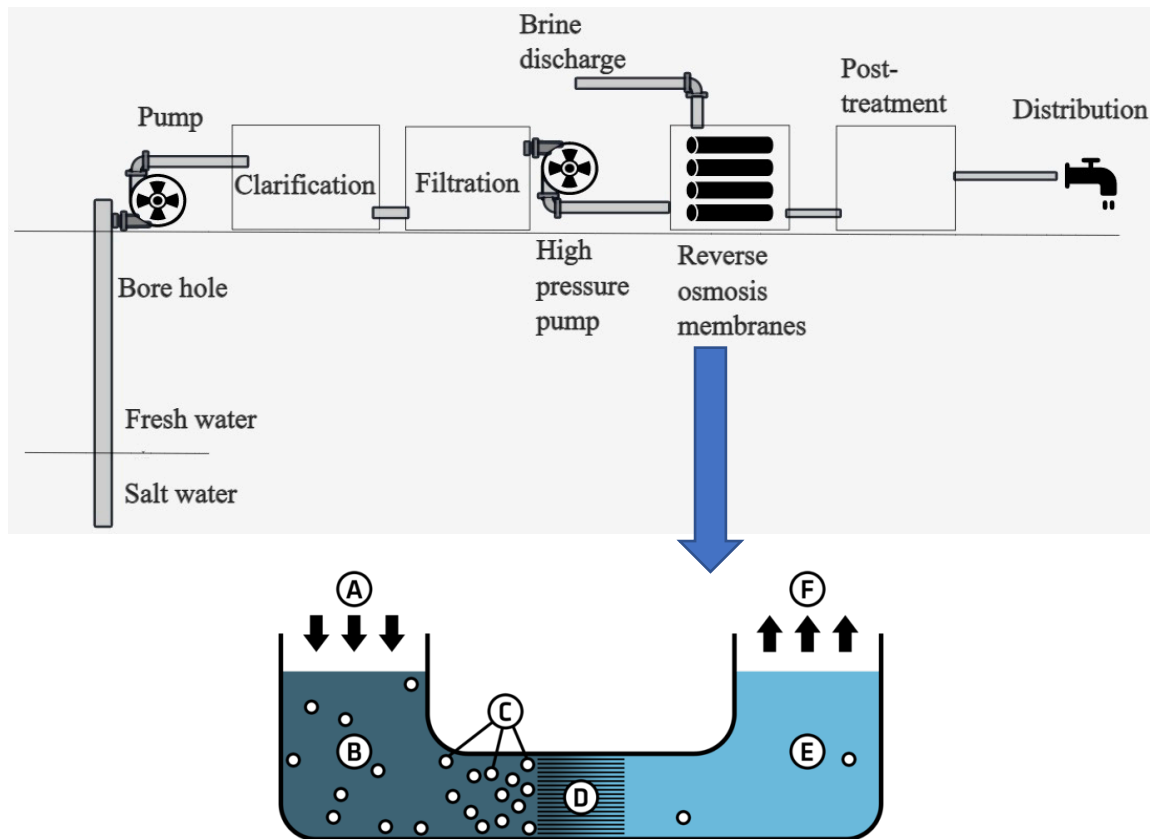


Figure 3.3: Schematic of a simple Reverse osmosis plant. (1) Water intake, (In the Maldives, deep bore-wells that reach beyond the fresh-saltwater interface to abstract saltwater without overly impacting the freshwater lens) (2) Pre-treatment, (3) Reverse Osmosis process, (4) Discharge of brine and (5) Post-treatment and distribution. High pressure (A) forces water (B) through the semipermeable reverse osmosis membrane elements (D). RO membranes are made of thick polyamide film that contains tiny pores through which water molecules can flow. The pores are small enough to restrict salt molecules and other pollutants like organic compounds (C), but allow water to pass through. Only a very small portion of the pollutants will pass through (E) allowing clean water to be collected (F) (Top image: Authors, Bottom image: MediaWiki commons)

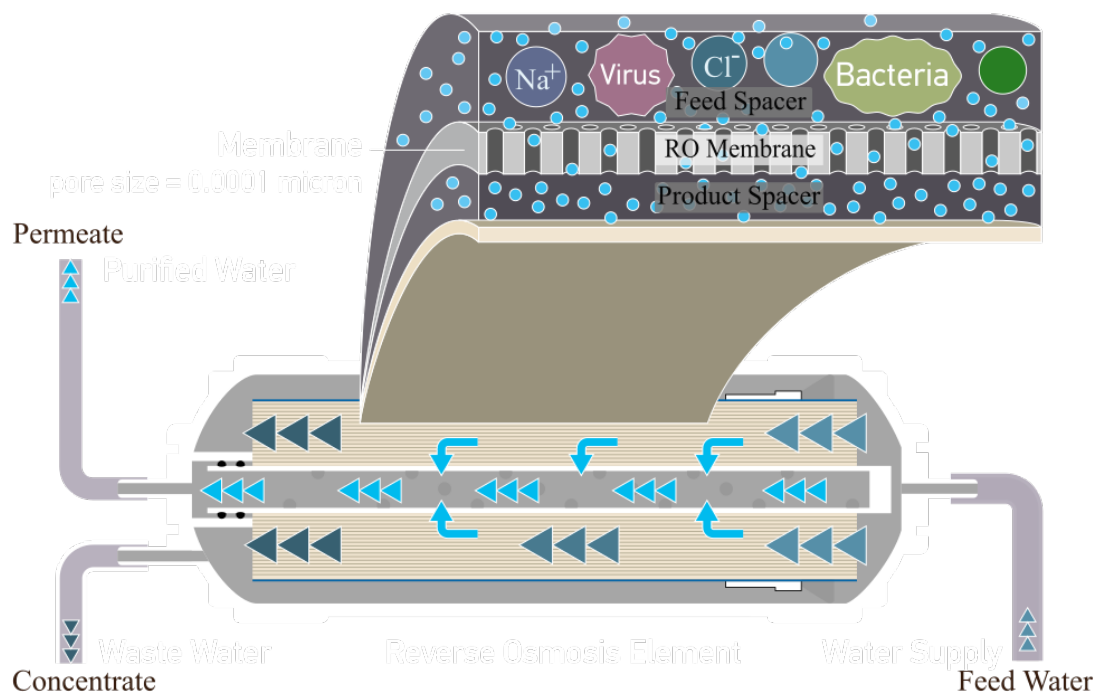


Figure 3.4: Schematic of a RO membrane (Adopted from yokogawa.com). Feed spacer has raw water under high pressure overcoming the osmotic pressure, causing water molecules to pass through the membrane. Larger contaminants and salt (in the form of Na^+ and Cl^- ions¹) will not pass through the membrane easily. Therefore the product water would have a much smaller concentration of contaminants and salt.

Among these components, brine outfall or saline effluent tends to cause groundwater pollution (see Figure 3.5). Therefore, it is important to ensure that the reject from desalination processes is disposed of safely into the sea.

¹ Na^+ and Cl^- ions themselves are smaller than a water molecule. However, in saltwater these ions form hydrogen bonds with surrounding water molecules forming what is known as a sphere of hydration, whose size is much bigger than individual water molecules. This effective size is what prevents salt (Na^+ and Cl^- ions) from passing through the membrane. (See: https://en.wikipedia.org/wiki/Solvation_shell and <https://opened.cuny.edu/courseware/module/609/student/?task=6> for details)



Figure 3.5: A brine outlet discharging to sea in Male' southern side harbour basin (Land and Marine Environmental Resources Group, 2010)

3.3 Characteristics of Brine Discharge

Discharge brine or waste by-product of the desalination process consists of high levels of salt and other minerals which could have an impact on marine organisms. According to the local desalination plant regulation, brine outfall should not be discharged to the house reef and should be placed 10m away from it. Given below is the chemical concentration of reject from a study conducted on a brine outfall located in Skhira, Tunisia, which indicates the characteristics of brine discharge (Figure 3.6). Similar results can be seen from tests conducted on water produced from a RO plant in Male' in which a high level of conductivity and total dissolved solids are evident in the brine reject (see Figure 3.7). The resulting brine has a high concentration of salt (and traces of other pollutants) any groundwater that comes in contact with brine discharge will be polluted due to high levels of salt concentration.

Designation	Units	Raw water	Permeate	Concentrate
Temperature	°C	30	30	30
pH	...	7.2	7.2	7.2
Conductivity	µs/cm	12500	300	33000
Ca ²⁺	mg/L	720	10	2.08 × 10 ³
Mg ²⁺	mg/L	335	5	0.77 × 10 ³
Na ⁺	mg/L	1950	40	5.12 × 10 ³
Cl ⁻	mg/L	3550	100	14.17 × 10 ³
SO ₄ ²⁻	mg/L	2250	25	5.92 × 10 ³
Fe ³⁺	mg/L	0.2	0.01	...
Ba ²⁺	ppb	10
Sr ²⁺	mg/L	13
HCO ₃ ⁻	mg/L	135	5	...
TDS	mg/L	9000	185	28000

Figure 3.6. Comparison of the chemical composition of raw water, permeate and concentrate from an RO plant (Hajbi, et al., 2010)

Parameter	Analysis result				Test method	Guideline for drinking water		Unit
	Feed	Product	Reject	Sea		WHO guideline	EPA guideline	
pH	7.64	6.68	7.43	8.11	EM	6.5-8.5	6.5-8.5	NA
Conductivity	51500	448	70900	53300	EM	<1500	<1500	µS/cm
Total Dissolved Solids	25600	226	35400	26600	EM	<1000	<500	mg/l
Total Suspended Solids	0	0	0	0	EM	NA	NA	mg/l
Chloride	21500	131	31500	23300	TM	<250	<250	mg/l
Salinity	36.6	0.2	51.4	36.3	EM	NA	NA	mg/l
Turbidity	0.101	0.057	0.371	0.331	PM	<5	<5	NTU
Iron	0.17		0.1		Photometry	<0.3	<0.3	mg/l
Manganese	0.2		0.1		Photometry	<0.4	<0.1	mg/l

Figure 3.7. Chemical parameters of the feed, product, reject of an RO plant in Male' (together with values of seawater) compared with parameters from WHO and EPA guidelines (Land and Marine Environmental Resources Group, 2010)

3.4 Control of Groundwater Pollution caused by Brine Discharge

The design and operation of brine discharge points in the sea need several considerations like discharging to a location with sufficient turbulence to allow efficient dispersion and mixing and not to discharge in locations with concentrated flora and fauna (e.g. reefs). Many guidance and publications cover this topic (e.g. El-Naas, 2011, Sola, et al., 2020, among others). However, the scope of this section is limited to the potential and prevention of groundwater pollution due to RO brine reject.

The RO brine discharge has to travel overland (sometimes under high pressure) before it reaches the sea. Maintaining this discharge system is of utmost importance to avoid brine mixing with groundwater.

Brine discharge outfalls from desalination plants and the transmission pipes should be constructed and maintained with care to control and minimize the pollution of groundwater caused by desalination processes. If the pipe joints are not properly sealed or are cracked, brine outfalls can cause environmental pollution. This includes the risk of groundwater contamination from leaking brine outfall pipes buried below ground.

It is important to ensure that the pipes are of suitable material and that they are properly joined together. It is a requirement for the outfall pipeline to be of HDPE material with a minimum class of PN16 with a 't-head diffuser' installed at the termination point of the outfall according to EPA design criteria. Individual pipes should be properly joined together using an appropriate method before laying the pipes (see Figure 3.8). A proper leak testing of the pipelines should be conducted after laying the pipelines to ensure that it does not leak into the surroundings. There are various methods for leak testing of pressure pipes (using air or water) and the most appropriate method should be adopted. Furthermore, warning tapes should be placed above the pipe so that there are no accidental breakages that could leak brine into the surrounding groundwater during excavations. In case of leakages, no detrimental harm should be caused to the groundwater. Hence, monitoring of the quality of receiving waters at the discharge point should be conducted during operation to ensure that brine discharge is within the limits acceptable by EPA.



Figure 3.8: An ongoing operation to join HDPE pipes together by butt fusion welding. (Source: mwsc.com.mv)

Another important risk of groundwater pollution occurs during routine maintenance and repair of the RO systems. Quantities of (a) Concentrated brine and (b) intake saline water can be spilt and therefore mixed with groundwater during these activities. Care must be taken to minimize the spillage of saltwater during operation, maintenance and repair activities.

3.5 Conclusions and Recommendations

Seawater desalination is the main method of supply water treatment in the Maldives. Desalination processes produce a by-product known as brine which is discharged back into the ocean. If not properly constructed or maintained, brine outfall pipelines that are buried below ground has a high tendency of causing groundwater pollution due to their chemical constituents. Hence, it is important to properly design, construct and maintain brine outfall systems to control the potential contamination of groundwater caused by brine discharge from desalination plants. Furthermore, frequent monitoring of the discharge is important to ensure that the quality of discharge is within acceptable limits set by local authorities.

Following are important points to pay attention to:

1. Brine discharge pipes that run overland should be constructed with material that can withstand pressure and environmental conditions (e.g. heat, UV radiation from sunlight)
2. Regular inspection of brine discharge pipes for joint leakage, cracks etc. Inspection of brine discharge point in the sea (as blockage there can cause pressure build-up).
3. Care should be taken when constructions are done and heavy machinery operated next to the brine discharge pipes.
4. Operators should minimize the possibility of spilling brine or raw saline water into the environment during operation, maintenance and repair activities.

CHAPTER 4:
Construction De-watering

4.1 Introduction

Construction is one of the largest economic sectors in the Maldives and is growing rapidly at a fast pace. Many new buildings are being built each year for residential and other purposes. It is permitted to build up to 15 story buildings in the capital Male' which requires deep foundations and often the designs may include basements. Most of the building foundations in Male' are constructed up to the plot boundary right next to existing buildings. Deep foundations and trenches require excavations into water-bearing soil as Male', as well as other islands, have a shallow groundwater table. Therefore groundwater control is an inherent process of construction that is required during excavation and laying of foundations. Hence, the construction industry in the Maldives pumps a huge amount of water extracted from the freshwater lens, into the sea (MEE, 2017). Pipes for groundwater control in excavations are laid in the sidewalks and streets of Male' directly from construction sites to the sea.

Groundwater control techniques can be accomplished using two methods; exclusion techniques (where water is prevented from entering into the excavation by using walls such as sheet piles) and dewatering or pumping techniques. Groundwater removed and discharged to the sea from construction dewatering processes in the Maldives should be free of pollution and as much water as possible should be infiltrated back into the aquifer.

This chapter is a guide on ways to control groundwater pollution resulting from dewatering processes used for groundwater control in construction sites. It starts with a brief description and an overview of the practice of dewatering in the Maldives followed by a discussion of pollutants in the water removed. Then, the next section discusses groundwater pollution control measures that can be adopted. Conclusions and recommendations are given at the end of the chapter.

4.2 Construction De-watering in the Maldives

Construction dewatering is the removal of groundwater and surface water from excavations and trenches for the construction of sub-surface structures (see Figure 4.1). It helps to lower the groundwater table for a dry and stable working environment and prevent the collapse of excavation slopes (loss of material from the excavations). Groundwater emerges from the bottom of excavations and sides of slopes due to hydrostatic pressure and seepage. Therefore,

lack of dewatering may cause piping, heaving and generally reduce the stability of the slopes and increase soil erosion in construction sites. It is the responsibility of the contractor to provide groundwater control systems before laying the foundations. This has to be done before constructing building foundations and for laying pipelines for utility pipe networks. Once the foundation is concreted and backfilled, dewatering is stopped and will no longer be necessary.

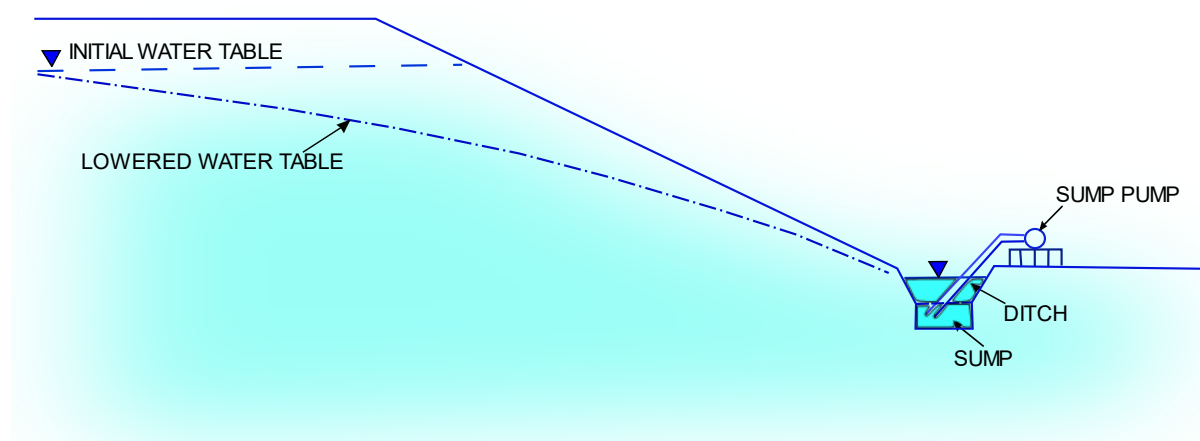


Figure 4.1: The water table is lowered from the existing level through sump pumping. (After Hossain, 2012))

There are various dewatering methods and procedures available which includes; open sump pumping, wellpoint systems and deep well construction etc. Method of dewatering is chosen based on several factors including the size, depth and type of excavation. Too much dewatering causes drawdown which may affect the well water in the surrounding households. Well-discharge capacity is determined based on empirical methods in which several hydraulic parameters are evaluated.

Since there are no stormwater inlets to connect the outlets of dewatering pipes in Male', water is pumped directly to the sea. The current practice is to use mobile pumps to discharge groundwater via PVC pipes laid directly from the property to the sea (see Figure 4.2). The sump pump method is the most common method of dewatering in the Maldives. A small sump is provided well below the excavations and submersible pumps are placed within the sump to pump out the water (see Figure 4.1). As groundwater seeps into the sump, it is constantly pumped out using submersible pumps by ensuring that groundwater is kept about half a meter below the deepest excavation. There is adequate open space in the outer islands for infiltration

of water to the ground, however, this is not the case in Male'. It was permitted previously to discharge groundwater to catch pits connected to a sewer network. However, this is no longer allowed and pipes are laid on the road surfaces or the sidewalks next to each other (or sometimes above) which can often cause a nuisance to vehicles and pedestrians (see Figure 4.3).



Figure 4.2: Discharge end of dewatering discharge pipes laid over the southwestern quay wall of Male'. (Source: Authors)



Figure 4.3: PVC pipes laid on a road surface in Male' for pumping groundwater away from construction sites to the designated discharge point. (Source: Authors)

The current local regulation on de-watering mandates applying for a permit from EPA before starting the dewatering process. Hence, it is important to follow the de-watering guideline from EPA. Furthermore, it is required to test the quality of groundwater as per EPA regulations and provide a water quality test report considering the below parameters, before allowing the removal of groundwater from the site;

- pH
- Temperature
- TDS
- Dissolved Oxygen (DO)
- Electric Conductivity (EC)
- Turbidity (NTU)
- Salinity
- Ammonia Concentration
- Faecal Coliform
- H₂S
- Nitrates
- Phosphate

4.3 Pollution caused by Dewatering Processes

Even though there is no specific requirement for filtering groundwater when discharging, contaminated water is not allowed to be discharged to the sea as per local regulations. The water removed from construction sites can be contaminated with oil, grease and chemicals due to leakages and runoff from construction activities. This may also include cement and concrete and fines from excavations. Hence, fines, silts and debris in the construction site are also discharged directly into the sea when groundwater is pumped into the ocean without adequate filtration of silts and sediments (see Figure 4.4).



Figure 4.4: Northeastern harbour basin of Male' where groundwater from construction sites is discharged is often seen contaminated with dirty water. (Source: Authors)

4.4 Control of Pollution caused by De-watering Processes

Contaminated groundwater at the construction sites from various sources should be prevented from infiltrating into the groundwater. Therefore, information about groundwater of the dewatering site should be collected during the site investigation phase. If joints of the pipelines are not properly sealed and if there are cracks in the pipeline, there is the risk of groundwater contamination in case the dewatering site is polluted. Therefore, pipelines that are laid to the sea should not have any cracks in them and no leakages from the pipes should be allowed. It is important to use a filter to prevent the migration of fine soil particles from construction sites even if the groundwater is not contaminated (see Figure 4.5). Sediment control and silt traps can be used to settle the silt before discharging the water to the sea (see Figure 4.6). There are several possible designs to slit traps (Figure 4.7) In addition, it is also important to construct a stormwater drainage system with sub-surface pipes that can accommodate the dewatering from construction sites. Proper monitoring is also required to ensure the quality of discharged water does not have any impact on the quality of groundwater.

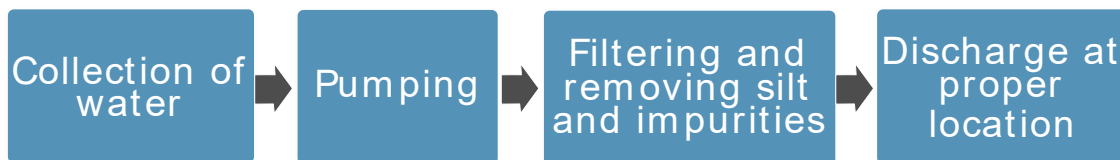


Figure 4.5: Phases of dewatering



Figure 4.6: Silt traps acting as filters that can be used to clean water before discharging (Source: drainagepipe.co.uk/soakaways-and-membranes/what-is-a-silt-trap-and-why-should-i-have-one/)





Figure 4.7: A settlement unit used for separating sediments from dewatering. Source: h-dewatering.ca (top). Dewatering bag is a solution that can be used to release dewatering output to the land (in case of less saline water) (bottom) source: <https://spillcontainment.com/>

4.5 Conclusions and Recommendations

Dewatering is a requirement when constructing sub-surface structures such as deep foundations. Although water can be infiltrated to the ground in the islands, the current practice of dewatering in the country is not effective and creates a nuisance to the public because of the pipelines laid on the road surfaces. Groundwater removed from excavations is susceptible to contamination from various sources thus, a mechanism or a filtering arrangement should be established before pumping water out to the sea. A stormwater drainage system with a sub-surface pipeline is ideal to cater for both stormwater management as well as construction dewatering. Furthermore, it is most beneficial to the environment if there is a mechanism to infiltrate most of the water back into the ground to replenish the groundwater.

Following are important points to pay attention to:

1. EPA guidelines for dewatering water testing should be followed.
2. Dewatering output can contain significant amounts of sediment and many pollutants like grease, oils and chemicals. These should be trapped before releasing the water into the environment.
3. Care should be taken when laying dewatering lines over pedestrian and vehicle traffic areas. They should not be a nuisance or a risk to the users of the facilities.
4. Dewatering lines should be inspected regularly and maintained so that they do not leak (saline, polluted) water to the groundwater system.
5. Where possible, low saline water should be released back to the islands to minimize the impact on the freshwater lens. However, proper care should be taken to desilt and decontaminate as well as monitor the quality of the water in this case.

GLOSSARY

Aquifer: Underground rocks and sediments that are saturated with groundwater.

Combined Sewer Overflows (CSO): The discharge of a mixture of sewage and stormwater from a combined sewer system that is caused by stormwater runoff.

Combined Sewer: Sewer systems that collect stormwater runoff, domestic sewage, and industrial wastewater in the same pipe and bring it to the wastewater treatment facility.

Effluent (Wastewater treatment): Sewage that has been treated in a septic tank or sewage treatment plant.

Foul Water Sewer: A sanitary sewer network

Freshwater lens: A convex-shaped layer of fresh groundwater that floats above the denser saltwater, usually found on small coral or limestone islands and atolls (like those of the Maldives).

Gravity sewer: A conduit utilizing the energy resulting from an elevation difference to remove unwanted water.

Groundwater: Water that is below the surface of the ground in the saturation zone.

Impervious Surface: A surface that cannot be penetrated by water and thereby prevents infiltration and generates runoff.

Infiltration (to the ground): The passage of surface water into the ground

IWRM System: (In the context of the Maldives) a water supply system that sources fresh water not only from reverse-osmosis membrane filtration but from other sources like harvested rainwater and sustainable extraction of fresh groundwater.

Onsite Sanitation: A sanitation system in which excreta and wastewater are collected and stored or treated on the plot where they are generated.

Outfall: The point of discharge from the sea, pipe, drain, etc. to a receiving body of water.

Peak Discharge: The greatest rate of flow of streamflow occurring during a storm event.

Primary Treatment: A treatment process that uses settling and anaerobic processes to reduce solids and organics, for example by a Septic Tank.

Rain Water Harvesting: A technique of collection and storage of rainwater into reservoirs or tanks for different uses.

Recharge: The process by which water moves downward through the soil layer from surface water to groundwater.

Reverse Osmosis Membrane Filtration: Reverse osmosis (RO) is a water purification process that uses a partially permeable membrane to separate ions, unwanted molecules and larger particles from drinking water. A high feed pressure is used to overcome the osmotic pressure of water molecules, making it possible for the osmosis to happen from lower water concentration (feed water) towards higher (product water).

Runoff: Water from rainfall or other sources that flows across the ground surface instead of infiltrating into the ground.

Rural: Less built-up areas with an adequate number of pervious surfaces that allow rainwater to infiltrate into the ground.

Sanitation service chain: The combination of (1) the experience of the user, (2) excreta and wastewater collection methods, (3) transporting and treatment of waste, and (4) reuse or disposal.

Septic Tank: An underground chamber made of concrete, fibreglass, or plastic through which domestic wastewater (sewage) flows for basic (primary) treatment.

Sewage: A type of wastewater that is produced by a community of people, typically transported through a sewer system. It consists of wastewater discharged from residences and from commercial, institutional and public facilities that exist in the locality.

Shit Flow Diagram: A tool to understand and communicate how excreta physically flows through a city or town.

Soakaway (septic tank): The drainage system is used to discharge wastewater from a private sewage system like a septic tank or domestic treatment plant, by infiltration to the soil.

Stormwater Management: The effort to reduce runoff of rainwater into streets, lawns and other sites and the improvement of water quality.

Stormwater: Water derived from a storm event or water conveyed through a stormwater drainage system.

Sustainable Drainage Systems (SuDS): Approaches to managing surface water that takes account of water quantity (flooding), water quality (pollution) biodiversity (wildlife and plants) and amenity.

Urban: A city or town with a significant number of pervious surfaces that do not allow infiltration of water into the ground.

Vacuum tanker: A tank truck that has a pump and a tank, to pneumatically suck liquids, sludges, slurries, or the like from a location (e.g. household septic tanks) into the tank of the truck to be transported for treatment and disposal.

Watershed: The land area, or catchment that contributes water to a specific waterbody.

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