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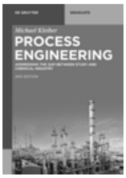

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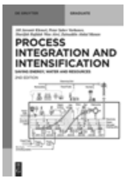

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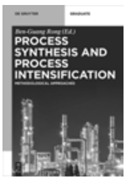

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Water Resources Management

Innovative and Green Solutions

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Chapter 1
Introduction

Abstract: As the century progresses, the water sector is facing increasing pressure from a wide range of climatic and non-climatic trends that challenge its ability to provide sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future. Traditionally, the water sector has been typically slow to evolve and incorporate new innovative solutions into existing systems in response to various challenges due to a number of barriers. Nonetheless, failure to implement innovations in water management will expose the water sector to a variety of risks. This book provides new research on innovative water management technologies that have been applied by leaders in the water sector to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.

Keywords: Water Sector, Climate Change, Water Infrastructure, Innovation

As the century progresses, the water sector is facing increasing pressure from a wide range of climatic and non-climatic trends that challenge its ability to provide sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.[1] Climate change will impact water resources in many ways, including increasing demand for scarce water while water supplies become limited, or variable, increasing the magnitude and frequency of storms and flooding, and increasing illnesses from poor water quality. Rapid population growth will increase the number of people living in water-scarce regions of the world while at the same time exposing a greater number of people to floods. Urbanisation is increasing demand for scarce water resources while at the same time impacting water quality in source watersheds. Rapid economic growth is placing significant demand on water for manufacturing and industrial processes. Furthermore, water scarcity is arising from growing water-energy and water-food nexus pressures. Ageing infrastructure is not only resulting in significant water losses from leakage but also deteriorating water quality. At the same time, the providing of water and wastewater-related services is contributing to rising greenhouse gas emissions. Meanwhile land-use change is impacting waterways, leading to biodiversity loss. Finally, customer expectations are rising with regards to the types of services they expect from water utilities, including greater emphasis on environmental sustainability.

The term 'water sector' is divided by the UN World Water Assessment Programme (WWAP) into three main functional categories: water resources management, which includes integrated water resources management and ecosystem restoration and

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remediation and is aimed at ensuring the protection, sustainable use, and regeneration of water resources by protecting ecosystems, rivers, lakes, and wetlands, and building the necessary infrastructure, such as dams and aqueducts, to store water and regulate its flow; water infrastructure, which includes the construction, operation, and maintenance of water-related infrastructure, both human and natural, for the management of the resource as well as for the provision of water-related services, including the management of floods and droughts; and water services, which comprises the provision of services such as water supply, sanitation and hygiene, and wastewater management for domestic use as well as water-related services for economic use, for example, in energy, agriculture, and industrial sectors.[2]

Traditionally, the water sector has been typically slow to evolve and incorporate new innovative solutions into existing systems in response to various challenges due to a number of barriers.[3] Nonetheless, a failure to implement innovations in water management will expose the water sector to a variety of risks including environmental degradation, public health risks from poor quality water, damage to people and infrastructure from extreme weather events, and reductions in the level of service customers have come to expect.[4,5]

This book provides new research on innovative water management technologies that have been applied by leaders in the water sector to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future. In particular, the book provides readers with knowledge of how leaders in the water sector are implementing innovative technologies to conserve and recycle and reuse water, produce renewable energy and recover valuable nutrients from wastewater, protect and restore water quality at various scales, and improve the overall management of water resources. It also provides knowledge on the various innovative financial instruments and approaches available to meet water resources management challenges globally.

The synopsis of the book is as follows:

Chapter 2 discusses the various climatic and non-climatic challenges to the water sector before defining innovation. It will then discuss the various barriers to innovation before providing an overview of the strategies to overcome barriers to innovation.

Chapter 3 discusses how demand management utilises existing water supplies before plans are made to further increase supply before discussing water recycling and reuse innovations.

Chapter 4 discusses how wastewater treatment plants are water resource recovery facilities that produce clean water, reduce dependence on fossil fuels through the use and production of renewable energy, and recover nutrients.

Chapter 5 discusses the various green infrastructure solutions available to manage stormwater while utilising natural processes to improve water quality.

Chapter 6 provides an understanding of how river basin planning can protect and restore water quality before discussing how permit systems, best management practices, and source water protection can improve water quality.

Chapter 7 will first discuss the concept of smart digital water management followed by its components before discussing managing customers of the future.

Chapter 8 provides an overview of the various innovative financial instruments and approaches available to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.

Chapter 9 provides an overview of best practices followed by the conclusion.

Notes

1 UKWIR, "Research and Innovation Mapping Study for the UK Water Research and Innovation Framework.," (2011), https://www.theukwaterpartnership.org/research-and-innovation-mapping-study-for-the-uk-water-research-and-innovation-framework/.
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Chapter 2
Innovative water management

Abstract: The water sector is faced with multiple challenges in ensuring sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future. This chapter will first discuss the various challenges to the water sector before defining innovation and the multiple benefits of change to the water sector. The chapter will then survey the numerous barriers to innovation before providing an overview of the strategies the water sector can employ to overcome obstacles to change.

Keywords: Water Sector, Climate change, Water-Energy, Water-Food, Environmental Degradation, Innovation

Introduction

The water sector is faced with multiple challenges in ensuring sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future. This chapter will first discuss the various challenges to the water sector before defining innovation and the multiple benefits of change to the water sector. The chapter will then survey the numerous barriers to innovation before providing an overview of the strategies the water sector can employ to overcome obstacles to change.

2.1 Multiple challenges to the water sector

The water sector is faced with multiple challenges in ensuring sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future, including the following.

2.1.1 Climate change

Climate change is projected to reduce renewable surface water and groundwater significantly. For each degree of global warming, around seven percent of the world's population is expected to be exposed to a decrease in renewable water resources of at least 20 percent. Climate change is likely to increase the frequency of meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) in presently dry regions. The result is an increased frequency of short hydrological

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droughts (less surface water and groundwater). Meanwhile, by the end of the century, around three times as many people will be exposed annually to the equivalent of a 20^{th}-century 100-year river flood under a high emissions scenario (Representative Concentration Pathway 8.5 (RCP8.5)) than for a low emissions scenario (RCP2.6).[1] Climate change will impact water resources in many ways, including:

- *Increased demand for scarce water*: In many areas, climate change is likely to increase demand for water, while water supplies become limited, or variable. The result is water managers will need to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, energy producers, and manufacturers. In some areas, increased precipitation events and flooding will become more frequent, impacting the quality of water, and potentially leading to damage of infrastructure used to transport and deliver water
- *Increased storms and flooding*: More frequent and intense storms will overwhelm stormwater management systems, causing localised flooding and increasing runoff of contaminants, such as rubbish, nutrients, sediment, or bacteria, into local waterways. In urban centres with combined stormwater and wastewater drainage systems, more frequent and intense downpours can lead to combined sewer overflows into waterways, reducing water quality and making it difficult for cities to meet water quality standards
- *Increased illnesses from poor water quality*: Increased stormwater runoff into surface water bodies, indicated by increased turbidity from suspended solid particles eroded from the landscape, are associated with elevated levels of bacteria and other microorganisms. Small increases in the turbidity of drinking water have been linked to increased occurrence of acute gastrointestinal illnesses among children and the elderly
- *Eutrophication and algal blooms*: In lakes and reservoirs, there will be more intense eutrophication and algal blooms at higher temperatures, or shorter hydraulic retention times. During a harmful algal bloom, people can get exposed to toxins from fish they catch and eat, swimming in or drinking the water, and from the air they breathe. Depending on the type of algae, harmful algal blooms can cause serious health effects and even death, for example, eating seafood contaminated by toxins from algae called *Alexandrium* can lead to paralytic shellfish poisoning
- *Saltwater intrusion*: Sea level rise, together with increased groundwater pumping, can increase saltwater intrusion in groundwater aquifers. This can increase treatment costs for drinking water facilities or render groundwater wells unusable. Regarding surface water, sea-level rise may result in the ‘salt front’ (location of the freshwater-saltwater line) progressing further upstream. Saltwater intrusion of this nature can result in increased water treatment, relocation of water intakes, or the development of alternative sources of freshwater. Also, water infrastructure in coastal cities, including sewer systems and wastewater treatment facilities, are at risk from rising sea levels and the damaging impacts of storm surges[2–9]

2.1.2 Rapid population growth

The world's population is expected to increase from 7.7 billion currently to 9.7 billion in 2050, and potentially nearly 11 billion by 2100. The world's population will increase, but at varying rates globally. Nine countries will make up more than half the projected growth of the global population between now and 2050: India, Nigeria, Pakistan, the Democratic Republic of Congo, Ethiopia, the United Republic of Tanzania, Indonesia, Egypt, and the United States of America (in descending order of the expected increase). Regionally, the population of sub-Saharan Africa is estimated to more than double by 2050 (a 99 percent increase), while other regions will experience slower population growth: Oceania, excluding Australia/New Zealand (56 percent), Northern Africa and Western Asia (46 percent), Australia/New Zealand (28 percent), Central and Southern Asia (25 percent), Latin America and the Caribbean (18 percent), Eastern and South-eastern Asia (three percent), and Europe and Northern America (two percent).[10]

Already, around 3.6 billion people live in areas that experience water shortages for at least one month per year. By 2050, this could reach nearly six billion. Global demand for water has been increasing by around one percent per annum since the 1980s. Global demand for water is expected to continue rising at a similar rate until mid-century, accounting for an increase of 20 to 30 percent above the current level of water use, mainly due to increasing demand for water from the industrial and domestic sectors. At the same time, the number of people exposed to floods is expected to increase from 1.2 billion today to 1.6 billion in 2050.[11,12]

2.1.3 Urbanisation

Currently, 55 percent of the world's population reside in urban areas. By 2050, it is estimated that this will increase to 68 percent. Urbanisation is increasing in all regions of the world, but with a variation. Latin America and the Caribbean and North America are heavily urbanised, with over 80 percent of their population estimated to live in urban areas, rising to nearly 90 percent in 2050. Almost 75 percent of Europe's population is urban, and this is expected to rise to 85 percent by mid-century. Africa and Asia are urbanising more rapidly, with the percentage of Africa's and Asia's urban population likely to increase from approximately 40 percent and 50 percent respectively in 2018 to 59 percent and 66 percent in 2050.

While nearly an additional one billion persons will be added to today's urban population by 2030, more than half of the world's urban population will still be living in urban settlements with less than one million inhabitants, growing from 2.4 to 2.8 billion. The numbers of people living in medium-sized cities (1–5 million inhabitants) are expected to increase by 28 percent between now and 2030, growing from 926 million to 1.2 billion. Meanwhile, the number of megacities (cities with more than 10 million inhabitants) currently stands at 18. By 2030, the world is projected to have 43 megacities.[13]

Urbanisation is increasing demand for water resources with large cities estimated to obtain around 78 percent of their water from surface sources, some of which are far away. Cumulatively, large cities move 504 billion litres a day a distance of 27,000 ± 3,800 kilometres, and the upstream contributing area of urban water sources is 41 percent of the global land surface. Despite this infrastructure, one in four cities, containing $4.8 ± 0.7 trillion in economic activity, remain water stressed due to geographical and financial constraints.[14] Meanwhile, urbanisation is having an impact on water quality in urban source watersheds, with 90 percent of these watersheds having some level of degradation, with the average pollutant yield of municipal source watersheds increasing by 40 percent for sediment, 47 percent for phosphorus, and 119 percent for nitrogen. It is estimated that the degradation of watersheds has impacted treatment costs for 29 percent of cities globally, with operation and maintenance costs for affected cities increasing on average by around 53 percent and replacement capital costs rising by about 44 percent.[15]

2.1.4 Economic growth and resource use

Population growth, along with rising income levels, will drive a substantial increase in global demand for goods and services. Gross domestic product (GDP) is projected to quadruple between 2011 and 2060. By 2060, the global average per capita income is estimated to reach the current OECD level of around $40,000. Global materials use is projected to more than double from 79 gigatonnes (Gt) in 2011 to 167 Gt in 2060.[16] Between now and 2050, global demand for water is expected to increase for all major water use sectors: manufacturing (400 percent), thermal electricity generation (140 percent), and domestic use (130 percent). The most significant proportion of this growth in water demand is expected to occur in countries with developing or emerging economies, for example, in Africa water demand for industry will increase by 800 percent. In comparison, it will increase by 250 percent in Asia.[17,18] A failure to secure adequate and reliable supplies of water will result in the loss or disappearance of jobs. It is estimated that more than 1.4 billion jobs, or 42 percent of the world's total active workforce, are heavily dependent on water. Furthermore, it is estimated that 1.2 billion jobs, or 36 percent of the world's entire active workforce, are moderately water dependent. Overall, 78 percent of all jobs globally are dependent on water.[19]

2.1.5 Rising demand for energy

Energy is vital for a range of water processes, including water distribution, wastewater treatment, and desalination. Meanwhile, water is essential for all phases of energy production, including fossil fuels, biofuels, and power generation. In 2014, around four percent of global electricity consumption was used to extract, distribute, and treat water and wastewater, along with 50 million tonnes of oil equivalent of thermal energy, mostly diesel, used for irrigation pumps and gas in desalination plants. By 2040, the amount of energy used in the water sector is projected to more than double. The most substantial increase will come from desalination, followed by large-scale water transfer, and increasing demand for wastewater treatment and higher levels of treatment. For example, following a business-as-usual approach to centralised wastewater management, electricity consumption for urban municipal wastewater treatment could increase by over 600 terawatt-hours over the period to 2030.[20] Globally, the energy sector accounts for around 10 percent of total water withdrawals (the amount of water withdrawn from a source) and three percent of total water consumption (the volume of water withdrawn but not returned to the source). By 2040, it is projected that water withdrawals from the energy sector will increase by two percent to reach over 400 billion cubic metres (bcm). At the same time, the amount of water consumed is projected to increase by almost 60 percent to over 75 bcm, mainly due to a switch to advanced cooling technologies in the power sector that withdraw less water but consume more.[21]

2.1.6 Rising demand for food

Agriculture accounts for 70 percent of global freshwater withdrawals (surface and groundwater). Forty percent of irrigation uses groundwater sources, some of them non-renewable at the human time scale. It is estimated that food production will need to increase by 60 percent by 2050 to feed a population of over nine billion. Increased demand for food will result in irrigated food production growing by more than 50 percent by 2050. However, the amount of water withdrawn by agriculture can only increase by 10 percent, provided irrigation practices improve and yields rise. Furthermore, rising incomes and economic development are increasing demand for meat, fish, and dairy products, in addition to coarse grains and protein meals, impacting water resources with beef and dairy products being more water-intensive than cereals.[22,23]

The use of nitrogen and phosphorous, along with insecticides, herbicides, fungicides, and bactericides, in agricultural production is the leading cause of inland and coastal eutrophication. The result is algal blooms, loss of habitat and biodiversity, and long-term reduction or loss of fish catches. The runoff of farm and agro-processing chemicals into waterways and their seepage into aquifers poses risks to human health and the environment. Pollution reduces the availability of water for beneficial use and increases the cost of water treatment. Polluted water also has a high cost to human health with one-tenth of global disease attributed to water. Other pollution costs include clean-up and damage to fisheries, ecosystems, and recreation.[24] Furthermore, the current food production system relies on constant inputs of phosphorus to meet the growing demand for food. Phosphate rock, which is the dominant source of phosphorus for phosphate fertilisers, is a limited resource with current world reserves estimated to last between 30 and 300 years.[25]

2.1.7 Ageing infrastructure and deteriorating water quality

In many cities around the world, a large portion of the water infrastructure is approaching or has already reached the end of its useful life, with ageing infrastructure often resulting in high water loss from physical leakage.[26] In an earlier World Bank study, it was estimated that around 32 billion cubic metres of treated water physically leaks from urban water supply systems around the world each year.[27] Also, sewage, as well as contaminated groundwater surrounding pipes, can enter leaking pipes and travel throughout the water distribution network causing public health concerns, for example, outbreaks of gastrointestinal illness.[28,29] The required investment to rebuild these networks has to come on top of other water investment needs, including investments needed to comply with standards for drinking water quality. In the United States, it is estimated that repairing and expanding the country’s drinking water infrastructure would top $1 trillion over 25 years and with increasing capital needs and potential funding shortfalls, many water utilities are increasing their rates they charge for water services in the immediate future.[30] However, there is evidence that customers’ willingness to pay for any infrastructure upgrade is negatively affected by the cost of the proposed improvement.[31]

2.1.8 Greenhouse gas emissions

Water utilities are faced with climate change leading to increased water scarcity, lower water quality, and flooding challenges. At the same time, water utilities contribute to global emissions from energy consumption as well as nitrous oxide emissions and methane emissions from wastewater management. Water utilities collectively influence up to 12 percent of regional total primary energy consumption, with energy mainly used for water heating. Urban water utilities themselves typically account for one to two percent of aggregate global primary energy use and at times up to six percent of regional electricity use. The result is that the amount of regional greenhouse gas emissions contributed by urban water management is up to 17 percent.[32] It is estimated that 58 percent of emissions from urban water utilities comes from energy use while 40 percent is attributed to treatment processes and two percent from chemical use.[33]

2.1.9 Environmental degradation and biodiversity loss

Around the world, nature has been significantly altered by multiple human drivers with most indicators of ecosystems and biodiversity showing a rapid decline. Seventy-five percent of the land surface is changed substantially, 66 percent of the ocean is experiencing cumulative impacts, and over 85 percent of wetland areas have been lost. The average abundance of native species in most major terrestrial habitats have declined by at least 20 percent. Human actions threaten more species with global extinction now than ever before, with around 25 percent of species in the assessed animal and plant groups threatened. In total, approximately one million species are already facing extinction within decades unless action is taken to reduce the intensity of drivers of biodiversity loss. The main drivers of terrestrial and freshwater ecosystem degradation have been land-use change followed by the overexploitation of animals, plants, and other organisms mainly via harvesting, logging, hunting, and fishing.[34] The impacts of land-use change on water quantity and water quality include increased groundwater use from expanding human settlements; lower streamflow from land restoration activities; increased runoff resulting in increased sediment yield and higher nutrient loading of waterways from agricultural activities; increased total runoff and peak flow and a decrease in the baseflow; and evapotranspiration as a result of deforestation activities.[35–37]

2.1.10 High customer expectations

Water utilities are under increasing pressure to show customers the value for the rates paid and to enhance customer engagement and participation in various programmes.[38] The result is end-users of water services transitioning from being captive consumers of a uniform product delivered under fixed circumstances to end users that demand they be able to choose different products and services, for example, purchasing rainwater harvesting systems. Customers then turn from being consumers into co-constructors of new water infrastructure, helping to support water innovations while at the same time demanding these systems to be delivered and subsidised by the water utility or municipal agencies. Furthermore, water users are demanding that global water-using practices become more sustainable, which in turn provides support to water conservation initiatives developed by their local providers.[39]

2.2 Innovative water management

With challenges to the water sector increasing over the course of the century, there is an expectation that demand for innovative water management solutions will increase, in particular, solutions that enable the more efficient use of available water resources, enhance the quality of water for humans and nature, improve water resource planning to balance rising demand with limited, and often variable, supplies of water, and enhance resilience to extreme weather events.[40,41]

2.2.1 Innovation in the water sector

In the context of the water sector, innovation can be defined as "*the creation, development and implementation of a new product, technology, service, tariff design or process of production with the aim of improving efficiency, effectiveness or competitive advantage. It includes new ways of acquiring or deploying inputs, such as financial resources. The change may be incremental or fundamental*."[42] It should be noted that the definition includes the following:

- It deals with both products and processes
- It refers to the creation, development, implementation of a new product/process developed either in-house or by other companies and sectors
- All products and processes to be new or novel
- The aim must be to improve efficiency, effectiveness or increase competitive advantage[43]

2.2.1.1 Degree of novelty

A vital aspect of the definition of innovation is that it must contain a degree of novelty, specifically one or more of the following:

- *New to the firm*: The innovation must be new to the firm. Other firms may have already implemented a product, process, marketing method or organisational method, but if it is new to the firm (or in the context of products and processes it is significantly improved), then it is an innovation for that firm
- *New to the market*: Innovations are new to the market when the firm is the first to introduce the innovation to the market, where a market is defined as the firm and its competitors, and it can include a geographic region or product line
- *New to the country*: An innovation is new to the country when the firm is the first to introduce the innovation for all domestic markets and industries
- *New to the world*: An innovation is new to the world when the firm is the first to introduce the innovation for all markets and industries internationally[44]

2.2.2 Innovative water management technologies

The term 'technology' is comprised of hardware, software, and orgware. Hardware includes physical infrastructure and technical equipment while software includes approaches, processes, and methodologies, for example, planning and decision support systems, models, knowledge transfer mechanisms, and capacity building. Orgware includes organisational and institutional arrangements as well as ownership models. There are four main categories of innovative water management technologies available to water managers in response to water sector challenges:

- *Supply enhancement*: Traditionally, water managers have met rising demand for water by increasing supply. However, with significant economic and environmental costs associated with supply-side management, water managers are increasingly focussing on innovations that create more drought-resilient water supplies, such as recycled water. Water managers are also focussing on decentralised systems such as rainwater and stormwater harvesting and on-site potable reuse systems. Furthermore, they are focusing on technologies that reduce energy use, such as extracting energy from wastewater, which in turn reduces water-energy nexus pressures
- *Demand management*: As water managers transition towards demand management, the focus will be increasingly on innovations that encourage or enable water conservation or water efficiency. Such innovations can decrease demand for new water supplies, increase water reliability, and decrease the costs and pollution associated with wastewater disposal. Innovations range from smart irrigation controllers to smart meters that encourage behaviour change
- *Green infrastructure*: Water managers can utilise natural processes to improve water quality and manage water quantity by restoring the hydrologic function of the landscape. Specifically, water managers can implement green infrastructure solutions at various scales to manage water quality and water quantity. Green infrastructure is defined as a strategically planned network of high-quality natural and semi-natural areas with other environmental features, which, in addition to managing water, is designed and managed to deliver a wide range of ecosystem services and protect biodiversity
- *Governance improvements*: Innovations can improve overall water governance, which is essential to securing access to reliable water supply and reducing demand. A wide range of innovations are available at various scales to reduce inefficiencies in the governance system, for example, smart grids can enable water utilities to quickly identify leaks in the distribution system while monitoring customer demand through smart meters can improve resource planning and management.[45–48]

2.2.3 Stakeholder contributions to innovative water management technologies

In addition to government entities at the local, state, and national level, many stakeholders within the water sector contribute to an innovative ecosystem including private sector companies and entrepreneurs, foundations, research centres, and trade associations. Through a variety of models, these actors can make progress towards developing and commercialising innovative water management technologies. The models include:

- *Public-private partnerships*: Partnerships with the private sector are an underutilised tool in the water sector for meeting regulatory demands, making system improvements, and bringing new efficiencies and technologies to system operations. Public-private partnerships (PPP) can take many forms, including:
  - *Civil works and service contracts*: Utilities commonly source goods and services from private sector third parties, whether to purchase spare parts or to procure public works such as laying pipes. Utilities may also contract out a service, such as customer service. The utility will often purchase goods based on the provider's standard terms and conditions
  - *Management and operation and maintenance contracts*: These contracts govern the type of PPP agreement, which can range from technical assistance contracts to full-scale operation and maintenance agreements. Typically, the awarding authority engages the contractor to manage a range of activities for a relatively short period
  - *Build-Operate-Transfer (BOT) and Design-Build-Operate (DBO) projects*: A BOT project is typically used to develop a discrete asset rather than a whole network and is generally entirely new, or greenfield in nature, with the project company or operator obtaining its revenue through a fee charged to the utility/government. In a DBO project, the public sector owns and finances the construction of new assets while the private sector designs, builds, and operates the assets to meet certain agreed outputs
- *Public programmes*: At various levels of government, policymakers regularly reshape institutions to meet interests, such as enhancing community wellbeing. Governmental actors may develop public policies to promote innovation to advance these interests, such as subsidising research and development, designing innovation prizes and challenges, creating publicly funded research laboratories, or providing marketplaces to foster strong collaborations and active networks
- *Regional collaboration*: Creating regional-wide water system collaborations can help provide the economies of scale and the technical, managerial, and financial capacity necessary for the development and adoption of water innovations. To reduce the fragmentation in the water sector and accelerate the adoption of innovative technologies, regional collaboration can be fostered by aligning technical experts, research institutions, and innovators regionally through non-profit organisations in the water sector that promote innovation through research, workshops, and collaboration as well as developing regional water clusters that connect water utilities with private partners and entrepreneurs.[49–51]

2.2.4 Barriers to innovative water management technologies

While water innovation provides many tangible benefits, including creating efficiencies, helping water systems meet regulatory requirements, and enabling better adaption to emerging pressures, there are many barriers to innovative water management technologies being developed, including:

- *Economic*: Water pricing is often not reflective of the costs of obtaining and transporting water. In many locations, water users are either charged a flat rate for water usage regardless of the volume used or a volumetric rate where the amount users pay is strictly based on the volume of water consumed, with neither pricing structure reflecting the rising costs of delivering higher amounts of water. The result is that revenue is often insufficient to cover the costs of infrastructure maintenance as well as investments in new water management technologies. Furthermore, water prices seldom reflect the costs of environmental damage
- *Financial*: The mainly public nature of the water sector is an initial barrier to available capital. Public entities commonly rely on bonds, issued at low-interest rates, to fund new projects. They are typically paid back using new revenue generated from the project or tapping into existing funds. However, rising operational and maintenance costs, as well as declining revenue from reduced demand from conservation efforts as well as leaks and inefficiencies in the water delivery system, threaten these funding sources. They can even affect bond ratings, further increasing the costs of new projects. This is particularly challenging for locations considering new technologies that might already present riskier rates of return than established technologies
- *Cultural and perception*: Change in regulations does not necessarily equate to innovation if other practices, norms, or cultural perceptions are not aligned. Substantial social and cultural barriers can inhibit current, proven technologies from being adopted, such as recycled water for direct potable reuse. Furthermore, the water sector is perceived to be less innovative than other sectors, resulting in less research and development investments being made as compared to other sectors
- *Institutional*: Institutions are broadly defined as the rules, norms, and practices that govern decision-making. This definition can include formal institutions, such as laws and regulations, as well as factors that shape water systems such as behaviour and cultural factors. Institutions may be a barrier to the uptake and utilisation of new technologies, for instance, there is often a reluctance to support unique/novel ‘soft’, sustainable technologies over traditional hard-engineering grey approaches
- *Infrastructure*: A lack of appropriate infrastructure can impede the development of innovations with current infrastructure being unable to support alternative practices. Often this is due to relying on conservative, highly visible infrastructure solutions rather than attempting to do new things. In addition,

new technology may not fit well into the existing system. In particular, new technologies may require complementary technologies that may not be available or are expensive or difficult to use
- *Lack of knowledge*: It is difficult for policymakers to keep up with science and technology relating to water management as the breadth and depth of water sector science and technology is significant. Furthermore, there are increasing research demands on limited available funds. Therefore, there is a lack of time and funds for policy and decision-makers to be familiar with the latest research findings and technology advancements
- *Risks adverse*: Water utilities are naturally risk-averse. As a water provider, the most considerable risk of applying new, innovative methods or technologies is creating an inadvertent disruption to the treatment or distribution of water. For example, with government agencies regulating the quality of water by setting baseline standards, violation of those standards will result in penalties from environmental agencies. Therefore, utilities are reluctant to try new approaches to treatment unless they are confident that the new technology will achieve the desired goals
- *Regulations*: Regulatory barriers are commonly cited as being one of the main barriers to water innovation, locking organisations into existing technologies. Regulatory regimes often develop around existing technologies and may clash with the characteristics of innovations. At times, manufacturers of existing technologies or other vested interests may use regulations as a market barrier. New technologies often face administrative costs stemming from the need for permits or other forms of regulatory approval that existing technologies do not face
- *Fragmentation*: In many countries, water management, infrastructure funding, and regulatory policies can differ within states and even within the same region or county. The result is a disjointed network that frequently prevents companies from establishing or spreading a new innovative technology. Also, with water utilities often operating autonomously, without an overarching and unifying body, any innovation must be independently tailored for each utility. For example, in the United States there are 3,200 electric utilities compared to 7,450 stormwater systems, over 16,000 publicly owned wastewater treatment systems, and more than 50,300 community water systems: therefore, achieving widespread adoption of any innovation in the water sector is a challenging task
- *Political*: Institutions often create barriers to the uptake of innovations due to lack of leadership or political will to initiate and sustain a transition towards new technology. For instance, water utility managers may lack significant support from superiors to initiate water conservation technology programmes with customers. Lack of political leadership or political will is often due to the lack of defined responsibility for decision-making or leadership lacking quality (skill set), integrity, transparency and accountability, coordination/interaction between government bodies, or capacity (financial and technical).[52–67]

2.2.5 Overcoming barriers

To overcome these barriers to innovation, the water sector's various actors can promote:

- *Cultural change*: Innovation is about creating a culture and environment that allows changes to take hold and work in practice. It can also apply to the application of existing methods or technologies, in new ways or to new fields
- *Collaboration*: Collaboration is essential for inspiring new ideas and applications, allowing for insights to develop, which in turn, spurs innovation. As well as collaborating with external stakeholders, water sector actors can collaborate within their organisations, with other organisations, and with partners outside of the sector
- *Technology*: Technology, when paired with the right culture, processes, and people, is a powerful enabler of innovation. In addition to technology, such as smart meters and water-efficient appliances giving more control to water users over their consumption levels, technology can be applied to help water managers understand their systems and networks, helping them prevent interruptions to services and respond to and recover from service delivery challenges
- *Innovative regulatory frameworks*: Regulatory frameworks can be designed to challenge various actors in the water sector to improve innovation for the benefit of customers, the environment, and broader society. Regulatory frameworks can encourage innovation by:
  - Reconciling regulations that are inconsistent between government agencies and levels of government
  - Coordinating regulations across sectors, for example, water and wastewater and water and energy, to ensure consistent treatment of new technologies and to reduce obstacles to the development and adoption of new technologies
  - Shaping regulations to encourage utilities and various regulated water sector actors to meet performance standards, rather than force them to adopt fixed technology mandates
  - Creating markets and competition in the water sector that encourages innovation through water trading, greater third-party involvement in large projects, and markets for ecosystem services
  - Developing market-based instruments to recover the full cost of providing water and related services and encourage research and development in innovative projects in areas including water efficiency, resource recovery, and protection of ecosystems[68,69]

Notes

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Chapter 3
Conserving and recycling and reusing water

Abstract: Traditionally, water managers facing increased demand and variable levels of supply have relied on large-scale, supply-side infrastructural projects to meet increased demand for water. However, these projects are costly in both environmental and economic terms. Also, since most water resources are transboundary, supply-side projects can create political tensions. In contrast, demand management involves the better use of existing water supplies before plans are made to increase supply further. Meanwhile, water recycling and reuse water can increase supplies, which reduces the economic and environmental costs related to establishing new water supplies.

Keywords: Demand Management, Water Pricing, Water Metering, Water Restrictions, Water Recycling

Introduction

Traditionally, water managers facing increased demand and variable levels of supply have relied on large-scale, supply-side infrastructural projects, such as dams and reservoirs, to meet increased demand for water (supply-side management). However, these projects are costly in both environmental and economic terms. Environmental costs include disruptions of waterways that support aquatic ecosystems. Economic costs stem from a reliance on more distant water supplies, often of inferior quality, which increases not only the costs of transportation but also the cost of treatment. Also, since the vast majority of water resources are transboundary, supply-side projects can create political tensions because they rely on water crossing both intra- and inter-state administrative and political boundaries. In contrast, demand management involves the better use of existing water supplies before plans are made to increase supply further. Meanwhile, water recycling and reuse can increase supplies, which reduces the economic and environmental costs related to establishing new water supplies. This chapter provides an overview of the numerous innovative demand management technologies available before discussing water recycling and reuse.

3.1 Demand management

Demand management promotes water conservation, during times of both normal conditions and uncertainty, through changes in practices, cultures, and people's

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attitudes towards water resources. In addition to the environmental benefits of preserving ecosystems and their habitats, demand management is cost-effective compared to supply-side management because it allows the better allocation of scarce financial resources, which would otherwise be required to build expensive dams, water transfer schemes from one river basin to another, and desalination plants. Overall, demand management aims to:
- Reduce loss and misuse in various water sectors (intra-sector efficiency),
- Optimise water use by ensuring reasonable allocation between various users (cross-sectoral efficiency) while considering the supply needs of downstream ecosystems and other water users and uses
- Facilitate significant financial and infrastructural savings by minimising the need to meet increasing demand with new water supplies
- Reduce the stress on water resources by reducing or halting unsustainable exploitation of water resources

Demand management also involves developing alternative water supplies, which, in addition to conserving groundwater and surface resources, decreases diversion of freshwater from sensitive ecosystems, decreases discharge to sensitive water bodies, and saves energy.[1–3]

3.1.1 Demand management strategies

Demand management involves communicating ideas, norms, and innovations for water conservation across individuals and society, the purpose being to change people's culture, attitudes, and practices towards water resources and reduce consumption patterns. Water managers can use two types of demand management strategies to modify attitudes and behaviour towards water:
- Antecedent strategies attempt to influence the determinants of target behaviour before the performance of the behaviour
- Consequential strategies attempt to influence the determinants of target behaviour after the performance of the behaviour. This assumes that feedback, both positive and negative, of the consequences of that behaviour, will influence the likelihood of the behaviour happening or not happening in the future

3.2 Water pricing

A water tariff is a price assigned to water supplied by a public or private utility through a piped network to its customers. Water pricing is a long-used economic instrument to promote water conservation by creating disincentives for overuse. Economic theory suggests that water demand should behave like any other goods: as price increases, water use decreases. By serving as an incentive function, water pricing addresses water scarcity problems by promoting conservation as well as encourages investments in innovative, less water-intensive technologies. Also, water pricing can be used for cost recovery, with the water pricing scheme recovering direct costs (water supply and infrastructure costs) and indirect costs (environmental, social, and opportunity costs). There are two approaches to cost recovery: Supply cost recovery is the recovery of financial (internal) costs of water supply, including investments in infrastructure, operations and maintenance, and administrative costs. Full cost recovery is the recovery of financial as well as water use-related environmental, social, and opportunity costs. Overall, the meaning and level of cost recovery depend on what is considered to be part of the 'price' of providing and using water.

3.2.1 Common tariff structures

Frequently, a flat rate is charged for water usage regardless of the volume used, where typically the size of the charge is related to the customer's property value. In contrast, a volumetric rate is a charge based on the volume of water used at a constant rate. An increasing block tariff rate contains different prices for two or more pre-specified quantities (blocks) of water, with the price increasing with each successive block. A two-part tariff system involves a fixed and variable component. In the fixed component, water users pay one amount independent of consumption, which usually covers the administrative and infrastructural costs of supplying the water. Meanwhile, the variable amount is based on the quantity of water consumed and covers the costs of providing water as well as encouraging conservation.[4,5]

3.2.2 Irrigation tariff structures

Irrigation services can be charged for in many ways (Table 3.1). Each type of tariff provides different levels of incentive to irrigators to reduce consumption and different structures of income to the service provider.[6]

Case 3.1: Irish Water's new business charges

Ireland's Commission for Regulation of Utilities held consultations on its proposed decision on future water tariffs for business customers. The final decision was published on July 3rd, 2019 and set out a national set of charges that will be transparent, cost-effective, and equitable for all businesses countrywide. Previously, there was over 44 different business charging regimes with over 500 different price levels across the country. As a result, customers with similar water services paid vastly different amounts depending on their location. Irish Water's new business charges will apply to both business customers and mixed-use customers who use water services for both business and non-domestic purposes, with the new charges reflecting the actual costs of providing water services to the business sector. The new tariff classes and new metered tariff rates are listed in Table 3.2.[7]

Table 3.1: Irrigation Water Tariffs.

Type	Description
Area-based	A fixed rate per hectare of a farm, where the rate is not related to the area irrigated, the crop grown, or the volume of water received. It is usually part of a 'two-part' tariff designed to cover the fixed costs of the service. Different tariffs may be used for gravity and pumped supplies
	A fixed rate per hectare irrigated. The charge is not related to farm size, type of crop grown, or actual volume of water received (except that a larger irrigated area implies a greater volume of irrigation water)
Crop-based	A variable-rate per irrigated hectare of the crop, i.e. different charges for different crops, where the charge is not related to the actual volume of water received, although the type of crop and area irrigated serve as proxies for the volume of water received
Volumetric	A fixed rate per unit water received, where the charge is related directly to, and proportional to, the volume of water received
	A variable-rate per unit of water received, where the service charge is related directly to the quantity of water received, but not proportionately (e.g. a certain amount of water per hectare may be provided at a low unit cost, a further defined quantity at a higher unit cost, and additional water above this further quantity at a very high unit cost). This method is referred to as a rising block tariff
Tradeable water rights	The entitlements of users in an irrigation project, or more widely, other users, are specified in accordance with the available water supply. Rights holders can buy or sell rights in accordance with specified rules designed primarily to protect the rights of third parties. Sales require authorisation by a licensing authority or may require court approval without reference to any specified authority

Table 3.2: Irish Water's New Metered Business Charges.

Metered Tariffs	Water Service Charge	
	Standing charge (€/year)	Volumetric charge (€/m^3)
Band 1 class (<1,000 m^3)	43.76	1.87
Band 2 class (1,000–19,999 m^3)	113.31	1.30
Band 3 class (20,000–249,999 m^3)	1,872.98	1.21
Band 4 class (>250,000 m^3)	21,771.46	1.05

Case 3.2: San Diego County Water Authority's Special Agricultural Water Rate
The San Diego County Water Authority's (SDCWA) Board has approved a new and permanent Special Agriculture Water Rate programme structure that offers lower water rates to farmers in exchange for lower water supply reliability. The new programme, which will take effect on January 1st, 2021, will involve farmers and growers to receive a lower level of water service during water shortages or emergencies, allowing SDCWA to reallocate those supplies to commercial and industrial customers, who pay for full reliability benefits. In exchange, participating farmers are exempt from fixed water shortage and supply reliability charges. Currently, a temporary programme is in place with participants paying $1,231 per acre-foot for treated water, while municipal and industrial users pay $1,686 per acre-foot.[8]

3.3 Water metering

Automated Meter Reading (AMR) involves the automated transfer of recorded water consumption data via public or private radio to servers for the storage and subsequent processing of data by the utility and/or a third party. This usually involves the manipulation of existing manual meters, resulting in smart enabled meters. However, while AMR improves timeliness and accuracy of data, it does not significantly increase data density, for example, one read per month, although higher frequencies are possible. Advanced Metering Infrastructure (AMI) allows for two-way communication between the smart meter and the utility or other third party via the data logger as well as higher data density. AMI creates a data stream that enables real-time monitoring and analysis with high-resolution consumption data sent to the customer. This data can be used to raise awareness of water consumption and allow customers to develop their strategies to reduce water usage. From the water utility perspective, AMI meters provide multiple benefits including leak detection, energy reduction, demand forecasting, enhanced awareness campaigns, promotion of water-efficient appliances, and performance indicators. From the customer's perspective, smart meters provide information on when/where water is being used, comparisons of their water use against other customers, and quick leak detection. Water utilities can develop smart apps for customers to:
– Compare their water usage with neighbours in the same street or suburb
– Compare their consumption with standard profiles, such as consumers with the same socio-demographic factors
– Compare their water consumption with the most efficient users in the city
– Forecast their next water bill[9,10]

Case 3.3: Yorkshire Water's smart meter water leakage trial
Yorkshire Water is conducting a smart meter water leakage trial in Sheffield that could potentially save up to 250,000 litres of water per burst. The smart meters will remotely send 15-minute water flow information back to Yorkshire Water every 12 hours. The utility will then be able to use this data to identify when increases in demand are due to leakage and respond quickly. The two-year pilot project is located in Sheffield for geographical reasons: the hills in the city will test the capability of the wireless

solution for transferring flow data and the elevation and closeness to the Peak District means the area faces harsh winters and the associated challenges with leakage during freeze-thaw events. Overall, the trial is part of a broader project to create smart water networks in Sheffield and Hebden Bridge, which will aim to reduce leakage and supply interruptions while improving water quality.[11]

3.4 Leak detection and water distribution network rehabilitation

In many distribution systems, up to half of the water supplied by the water treatment plant is lost to leakage. A significant part of the leaks occurring in a water distribution network does not reach the ground surface. These leaks can be detected by applying a range of active leakage control strategies, including

- Analysing changes in night inlet volume over time
- Setting flat-line alarm levels at crucial monitoring locations in a water distribution network, allowing near real-time identification of, usually, large bursts
- Using hydraulic sensor technology with utilities deploying many pressure and flow devices, with data coming from such devices. When used in combination with predictions of the water distribution network behaviour by hydraulic modelling, it has the potential to enable fast detection and location of pipe bursts

A water utility can improve the management and rehabilitation of its water distribution network with a well-planned maintenance programme based on sound knowledge of the distribution network. This knowledge is usually embodied in a distribution system database that includes the following data:

- An inventory of the characteristics of the system components, including information on their location, size, age, and the construction material(s) used in the network
- A record of regular inspections of the network including the condition of the mains and degree of corrosion
- An inventory of soil conditions and types, including the chemical characteristics of the soils
- A record of the quality of the product water in the system
- A record of any high- or low-pressure problems in the network
- Operating records, such as pump and valve operations, failures, leaks, and of maintenance and rehabilitation costs
- A file of customer complaints
- Metering data[12–14]

By monitoring these records, advanced warning of possible problems can be achieved. For example, numerous complaints could be a warning sign of an impending breakdown in the system. This system should also include a regular programme of preventative maintenance to minimise the possibility of system failures.[15]

Overall, leak detection and water distribution network rehabilitation programmes provide multiple benefits in addition to reducing water loss including:
- Increased revenue
- Reduced stress on the area's water resources
- Reduced energy consumption for abstraction, treatment, and distribution
- Improved water quality due to optimised water distribution as chlorine content in the distributed water will be better controlled and the risk of pollution related to bursts and periods with low pressure or vacuum will be reduced.[16]

Case 3.4: Anglian Water trialling fibre-optic cables to detect leaks
Anglian Water has an active leak detection policy, with the company reporting half as much leakage per kilometre of pipeline as any other water company in the United Kingdom. Over the past five years, the company has invested £120 million to reduce leakage, with the aim of a further reduction of over 15 percent by 2025. To achieve this goal, Anglian Water has begun trialling the use of fibre optic cables to detect leaks in its water pipe network. The trial is testing the endurance and capability of the fibre optics and allows the engineers to hone their skills in installing and removing the fibre optics from the pipeline. Once the fibre optic sensor cable is fed into water pipes, the technology can enable engineers to continually monitor the pipeline for leaks and other events in the network by creating thousands of virtual sensors along the sections of the pipeline being monitored. This information enables the company to see in real-time where new leaks are or the start of events of interest. If the trial is successful, Anglian Water may consider progressing to full-scale operational trials in the live water network.[17]

3.5 Water restrictions

There are two types of water restrictions as follows:
- *Temporary water conservation ordinances and regulations*: These restrict certain types of water use during specified times and/or restrict the level of water use to a specified amount. Examples of water-use regulations include:
  - Restrictions on non-essential water uses, for example, watering lawns, washing cars, filling swimming pools, and washing driveways
  - Restrictions on commercial use, for example, car washes, hotels, and other large consumers of water
  - Bans on using water of drinking quality for cooling purposes
- *Permanent water conservation ordinances and regulations*: These include amendments to building codes or ordinances requiring the installation of water meters and water-saving devices, for example:
  - Plumbing codes ensuring that all new homes and offices meet the maximum water-use standards for plumbing fixtures such as toilets, urinals, faucets, and showers
  - The requirement that low-flow toilets, showerheads, and faucets are installed in all newly constructed or renovated homes and offices[18]

Case 3.5: Sydney's water restrictions
On December 10th, 2019, the State of New South Wales applied Level 2 water restrictions to Sydney and the wider region. With the area experiencing one of the most severe droughts on record, implementing Level 2 restrictions would save 78.5 gigalitres of water per year. This follows the implementation of Level 1 restrictions on June 1st, 2019. The fines for not adhering to government-mandated water restrictions are $220 for individuals and $550 for businesses. The Level 2 restrictions are summarised in Table 3.3.[19]

Table 3.3: Sydney's Water Restrictions.

	Level 1	Level 2
Garden	– Hose must have a trigger nozzle – No sprinklers or irrigation systems – No watering between 10 am and 4 pm	– Water cans and buckets only – No sprinklers or irrigation systems – No watering between 10 am and 4 pm
Cars	– Hose must have a trigger nozzle – High-pressure cleaning equipment is okay	– Buckets only – Commercial car wash okay
Paths	No hosing of paths or driveways	No hosing of paths or driveways
Pools	Permit for filling of new or renovated pools	– Permit for filling new or renovated pools – Maximum 15 minutes per day for topping – Trigger nozzle must be used

3.6 Water efficiency labelling

Water managers can promote water efficiency product labelling schemes that cover water-using devices such as taps, showers, and toilets. The labelling of household appliances according to their degree of water efficiency is essential in reducing household water consumption by eliminating unsustainable products from the market, provided the labelling scheme is clear and comprehensible and identifies both the private and public benefits of conserving water. There are two main types of labelling schemes:

- *Endorsement labels*: The label indicates that a product has met a certain minimum standard
- *Rating labels*: The label indicates the level of efficiency by rating the product on a performance scale and/or by stating the product's actual water consumption or flow rate figures

Endorsement labels provide an easy tool for consumers to identify environmentally friendly or water-efficient products while rating labels provide a greater incentive for manufacturers to develop more efficient products and enable consumers to make more informed purchasing decisions. Both types can be either voluntary or mandatory and are often based on performance requirements and/or technical standards.[20,21]

Case 3.6: Australia's Water Efficiency Labelling and Standards scheme
Australia's Water Efficiency Labelling and Standards (WELS) scheme is an urban water savings scheme. Managed and regulated by the Department of Agriculture and Water Resources, the WELS scheme aims to reduce demand for high-quality drinking water by informing consumers about water efficiency at the point of sale.

By 2030, the WELS scheme has the potential to save more than $2 billion with 65 percent of savings from reduced electricity and gas costs from avoided water heating and 35 percent from reduced water bills. The WELS scheme's purpose is to conserve water supplies by reducing water consumption, promote the adoption of efficient and effective water-using and water-saving technologies, and provide information for purchasers of water-using and water-saving products. Products that are regulated under the WELS scheme are plumbing products (taps, showers, flow controllers, toilets, and urinals) and white goods (clothes washing machines and dishwashers). All products regulated under the WELS scheme must be registered with the administrator and labelled with the correct water rating information. This includes displaying a water rating label or text advice with products in-store and online. The label is comprised of a:

– *Star rating*: This allows consumers to quickly compare the water efficiency of different products (the more stars, the more water-efficient the product is)
– *Rate of water consumption*: This can include flow rate, litres per flush or litres per wash, enabling consumers to estimate how much water the product will use
– *Registration and product details*: This includes licence number and registration number and for washing machines and dishwashers the model name and cycle used for testing

WELS is reviewed and evaluated every five years by an independent reviewer as required by the Water Efficiency Labelling and Standards Act 2005.[22]

3.7 Education and awareness

Education and awareness tools aim to change behaviour through public awareness campaigns around the need to conserve scarce water resources. Water utilities can promote water conservation in schools to increase young people's knowledge of the water cycle and encourage the wise use of scarce water resources. Water utilities can use a variety of strategies, including school presentations and distribution of water conservation information and materials that can be used in the school curriculum. Meanwhile, water utilities can use public education to persuade individuals and communities to conserve water resources. Water utilities can influence an individual's attitudes and behaviours towards water resources by increasing their knowledge and awareness of environmental problems associated with water scarcity. There are multiple tools and formats that water utilities can use to increase environmental awareness and water conservation, including:

– Public information such as television commercials, newspaper articles and advertisements

- Internet and social media campaigns
- Public events such as conservation workshops, public exhibitions
- Information included in water utility bills, such as leaflets on water conservation tips

Education and awareness campaigns can also involve the distribution of water conservation kits and providing of rebates to encourage physical water savings. Overall, a variety of best practices can be followed to ensure education and awareness campaigns are successful:
- Campaigns are most effective when they use a well-targeted range of media
- The use of existing networks can lower the cost of campaigns and increase their impact
- The provision of information needs careful management to ensure it is relevant and credible
- The impact of a water campaign can be magnified if it is followed by tangible action[23–28]

Case 3.7: San Diego County Water Authority's outreach and education programme
SDCWA offers a wide array of programmes to help the community learn about and understand the county's water supplies, infrastructure, and related issues. Programmes available include:
- *Speaker's Bureau*: This is a free service to the community and covers topics including water reliability, water transfers, legislation, and construction projects. Examples of organisations the SDCWA has made presentations to include Rotary clubs, Chambers of Commerce, Community college classes, and professional associations
- *Community fairs and expos*: Informing the community about the issues that affect their water supply, as well as important projects and programmes, helps fulfil the mission of providing a safe and reliable water supply to the region. SDCWA provides a calendar of events where it will be presenting to the community. Event organisers can request the SDCWA's participation in an upcoming event by contacting the designated utility representative. If the SDCWA is not able to attend, handout materials and other resources can be provided to the organisation hosting the event
- *Education*: The SDCWA teaches children about local water resources, instilling knowledge and appreciation of the resource while fostering an understanding of the need to protect the environment and use water wisely. Education programmes offered by the SDCWA include:
  - *Theatrical assemblies for elementary schools*: The assembly programme comprises:
    - *H2O, Where Did You Go?*: This musical-style performance focuses on the journey of water and why it is a natural resource that should be protected. While emphasising water conservation, the show intertwines comedy and music to teach students about the water cycle, states of matter, and other water facts
    - *Waterology*: Waterology is an energetic musical show about water science, water runoff, and water conservation for grades K-6. The show also educates students about aquifers, water pollution caused by runoff into storm drains, and the value of water
    - *Hydro Game Show*: This is a fast-paced, interactive assembly programme about water sources, water science, and conservation for grades K-6. The team-based format coupled with comical "commercials" and a high-energy host makes this one-person

show a memorable experience for students. The show also educates students about desalination, reservoirs, and the value of water

- *Splash Science Mobile Lab through the County Office of Education*: This field trip comes to schools and involves Students in grades 4 to 8 investigating how water pollution affects the environment and wildlife and learning why it is essential to conserve water. The Splash Lab is an entirely self-contained mobile lab that provides students with hands-on science experience at the school and includes:
  - A new watershed/storm drain model
  - State-of-the-art GIS computer stations
  - A water conservation station
  - A San Diego estuary station
  - Microscopes with video projection
  - Chemistry experiments
  - Cooperative learning skills[29]

3.8 Demonstration projects

Demonstration projects illustrate the feasibility and commercial viability of water conservation and water efficiency initiatives. They can also showcase the various economic, environmental, and social benefits to the community, including water utility customers, private building owners, and developers. Furthermore, demonstration projects can pilot new policies for municipal or regional governments and build local and institutional capacity and confidence.[30]

Case 3.8: Helix Water District's demonstration landscape

Helix Water District's new demonstration landscape located at its administration office in La Mesa beautifies the neighbourhood and inspires the community to install WaterSmart landscaping. The demonstration landscape includes three unique water-wise gardens on the streets around the building, including a Mediterranean garden, a desert landscape, and a California native landscape. Each garden is full of flowers, colours, and textures. The plants in all three gardens are adapted to San Diego's climate and need half to a fifth of the water that traditional lawns need. In addition to requiring less water, WaterSmart landscapes also require less maintenance and provide habitat for local wildlife, including bees, birds, and butterflies. The demonstration gardens show customers that water-efficient landscaping is not just one style, with homeowners able to choose plants that complement the home and personal taste. Plant markers provide the name of each plant and a QR code, which, when scanned with a smartphone, provides each plant's name, sun and water needs, mature size, and photo. The District has also created an interactive webpage where customers can make a list of their favourite plants and download each garden's design plan. Information on efficient irrigation and rebate programmes are also available. Overall, the District's new demonstration gardens encourages people to upgrade to WaterSmart landscapes by showing that water-wise plants are not only sustainable but beautiful too.[31]

3.9 Water recycling and reuse

Water recycling is the use of harvested water for the same or a different function, after treatment, where treatment can be tailored to meet the water quality requirements of planned use. In contrast, water reuse is the direct use of harvested water for the same or a different function, without treatment. Water recycling and water reuse systems can provide a reliable, climate-resilient, and economically sound source of water for non-potable and potable uses.[32,33]

3.9.1 Non-potable use

Water recycling and water reuse systems can be developed for a variety of non-potable projects. The water is usually of a lower quality than potable systems, and the level of treatment varies depending on the end-use.[34]

3.9.1.1 Industrial

Industrial water can be reused or recycled within a business itself or between several businesses. A business can directly reuse wastewater that is clean enough for the purpose for which it is being reused. Process water is produced by industrial processes such as cooling and heating and usually contains few contaminants, often making it suitable for reuse. Cooling towers are one of the most common water technologies in use by industry and the water is frequently reused for washing processes. Industrial process water and cooling tower water can be treated to meet fit-for-purpose specifications for a particular next use. Meanwhile, water recycling or reuse systems can be implemented for use between businesses, with the exchange of waste product for the mutual benefit of two or more businesses known as ‘industrial symbiosis’.

3.9.1.2 Agricultural

The increased availability of treated (secondary-treated wastewater) and recycled water (tertiary-treated), along with increased competition for water supplies, provides an opportunity to develop this resource for agricultural production particularly during times of drought when regular water supplies are limited or non-existent. The use of treated and recycled water for irrigated crop production is controlled by regulations that govern the treated water quality, with lesser standards required for forage crops compared with those for food crops.[35]

3.9.1.3 Urban

In urban areas, a variety of onsite non-potable reuse and recycling systems are utilised to meet non-potable needs:

- *Greywater*: Greywater is reusable wastewater from residential, commercial, and industrial bathroom sinks, bathtub shower drains, and clothes washing equipment drains. Greywater is reused onsite, usually for toilet flushing and irrigation. Greywater systems vary significantly in their complexity and size, ranging from small systems with simple treatment processes to large systems with complex treatment processes. Nevertheless, most have standard features including a tank for storing the treated water, a pump, a distribution system for transporting the treated water to where it is needed, and some sort of (basic) treatment, such as filtering, settlement of solids, chemical or UV disinfection etc.
- *Blackwater*: Blackwater, or sewage, is the wastewater from toilets. In blackwater recycling systems, all the blackwater is routed to an initial tank via gravity, from which it settles, and a primary colony of bacteria eats at the waste. The blackwater then goes through an aeration stage and a sludge settling stage, before it is chlorinated and used as irrigation water (watering lawns or non-food gardens)
- *Rainwater harvesting*: Rainwater harvesting systems collect and store rainfall for later use. When designed appropriately, they slow down and reduce runoff and provide a source of water. There are two main types of rainwater harvesting systems:
  - *Passive harvesting systems*: They are typically small volume (50–100 gallon) systems designed to capture rooftop runoff. Rain barrels are usually used in residential applications where the flow from rain gutter downspouts is easily captured for outdoor use, for example, garden and landscape irrigation or car washing
  - *Active harvesting systems*: They are larger volume (typically 1,000–100,000-gallon) systems, for example, cisterns, which capture runoff from roofs or other suitable surfaces. Rainwater collected in active systems is typically used for irrigation or indoor non-potable water replacement, for example, toilet flushing, clothes washing, evaporative cooling, etc.[36]

Case 3.9: The HAMBURG WATER Cycle® in the Jenfelder Au Quarter

The Jenfelder Au quarter is a new residential area in the Wandsbek district of Hamburg, built on the former Lettow-Vorbeck military barracks. The HAMBURG WATER Cycle® (HWC) will be implemented in over 800 newly constructed housing units and entails the separation of the material flows of wastewater. In conventional systems, all domestic wastewater streams are combined and discharged together into the sewer system. In contrast, the HWC decouples the wastewater flows. Blackwater, greywater, and stormwater are separately collected and then separately treated:

- *Blackwater*: Blackwater is less dilute and therefore facilitates material and energy recovery as well as reduces the energy required to treat it. To further concentrate the blackwater, water-saving toilets are used. The vacuum toilet consumes only about one litre of water per flush,

saving around five to nine litres of water per flush when compared with conventional toilets. The concentrated blackwater is then combined with other biomass sources such as organic waste in anaerobic digesters. Biogas is then formed which is converted into electricity and heat from a combined heat and power process
– *Greywater*: In the HWC, greywater is separated from blackwater and is transported to a specially designed facility before it is introduced into the local waters. They greywater can also be used as process water for household activities such as watering the garden or toilet flushing
– *Stormwater*: The HWC aims to manage stormwater on-site and as natural as possible. The stormwater can be used for watering lawns or managed using decentralised methods, such as retention ponds, where water is able to either evaporate or join nearby waters, improving the local climate or recharging groundwater[37]

Case 3.10: Hunter Water's recycled water service
Hunter Water in Australia is using recycled water as one approach to ensuring the reliable delivery of water to the Lower Hunter Region while ensuring confidence in public health and environmental protection. Over the period 2017–18, the water utility recycled 6,454 million litres of wastewater. Hunter Water's recycled water scheme can be divided into four categories:
– *Open space*: Recycled water is used for open space irrigation across the Hunter, including several golf courses and an educational college. These schemes use around 500 million litres of recycled water per year for landscape irrigation
– *Residential*: Hunter Water operates two dual reticulation schemes that provide recycled water for garden and toilet flushing in several housing estates. The water utility is also investigating dual reticulation schemes for other new residential developments
– *Industrial use*: Industrial reuse customers such as Eraring Power Station and the Oceanic Coal Washery use around 1,600 million litres of recycled water per year
– *Agriculture use*: This includes local farmers in the Clarence Town Irrigation Scheme which is an integral part of the Clarence Town Wastewater Treatment Works, which is designed to recycle all the product effluent in dry years. The final recycled water product is then stored in a 34 million litre dam before being pumped to the reuse area. The reuse area consists of 18 hectares of pasture irrigated by a system of irrigators. Commercial fodder crops are cultivated on the irrigated area[38]

3.9.2 Potable reuse

Potable water reuse involves the use of a community's wastewater as a source of drinking water. Two forms of planned potable reuse exist, which are indirect potable reuse (IPR) and direct potable reuse (DPR).

3.9.2.1 Indirect potable reuse

IPR can be defined as the reclamation and treatment of water from wastewater (often sewage effluent) and the eventual returning of it into the current/natural water cycle well upstream of the drinking water treatment plant. Planned IPR means there is an intent to reuse the water for potable use. The point of return could be either into a major water supply reservoir; a stream feeding a reservoir; or into a water supply aquifer (managed aquifer recharge). The natural processes of filtration and dilution of the water with natural flows aim to reduce real or perceived risks associated with eventual potable reuse. IPR (unplanned) is defined as treated wastewater entering the natural water (creeks, rivers, lakes, aquifers), which is eventually extracted from the natural system for drinking water: usually with no awareness that the natural system contains treated wastewater.[39]

Case 3.11: Orange County's Groundwater Replenishment System
Orange County's Groundwater Replenishment System (GWRS), a joint project between the Orange County Water District and the Orange County Sanitation District (OCSD), provides enough new water for nearly 850,000 residents and has become an essential local water supply. The GWRS is the world's most extensive advanced water purification system for IPR. OCSD treats the wastewater and produces water clean enough to undergo purification at the GWRS. The water is purified at the GWRS using a three-step advanced process of microfiltration, reverse osmosis, and ultraviolet light with hydrogen peroxide. The purified water is then injected into a seawater barrier and pumped to recharge basins where it percolates into the Orange County Groundwater Basin and supplements Orange County's drinking water supplies. Operational since 2008, the GWRS originally produced 70 million gallons a day (MGD) of purified water. In 2015, the project was expanded to produce 100 MGD. The GWRS' total capacity is projected to reach 130 MGD after the infrastructure is built to increase wastewater flows from OCSD to the GWRS, with the final expansion expected to be completed in 2023.[40]

3.9.2.2 Direct potable reuse

DPR can be defined as either the injection of recycled water directly into the potable water supply distribution system downstream of the water treatment plant or into the raw water supply immediately upstream of the water treatment plant (injection could be either directly into the water pipeline or a service reservoir). This means water used by consumers could contain either undiluted or slightly diluted recycled water. The key distinction with IPR is that there is no temporal or spatial separation between the recycled water introduction and its distribution to consumers.[41–43]

Case 3.12: Windhoek's direct potable reuse system
Windhoek, Namibia, is the first city in the world to produce drinking water directly from the municipal wastewater. For over 50 years, the city has been producing DPR with the first plant commissioned in 1968 and the second in 2001. Each day, 21,000 cubic metres of potable water is produced for direct reuse. There are five main aspects of the project:

1. *Multi-barrier approach*: A multi-barrier approach is taken to treat the water with the fundamental processes being powdered activated carbon dosing, pre-oxidation and pre-ozonation, flash mixing, enhanced coagulation and flocculation, dissolved air flotation, dual media rapid gravity sand filtration, ozonation, biological activated carbon filtration, granular activated carbon filtration, ultrafiltration, and disinfection and stabilisation
2. *Guaranteed water quality values*: The water produced must adhere to 'guaranteed values' based on World Health Organization Guidelines, Rand Water Potable Water Quality Criteria, and the

Namibian Guidelines for Group A water. Water samples are taken every four hours at various points throughout the plant and analysed for basic quality control purposes
3. *Blending of recycled and freshwater*: Blending the recycled water with treated surface water and/or groundwater provides an additional level of safety. The maximum portion of recycled water fed into the distribution system is 50 percent in times of water scarcity and low water demand
4. *Operation and maintenance agreement*: The plant is operated and maintained under a twenty-year operation and maintenance contract between the City of Windhoek and a consortium of three international water treatment contractors
5. *Public awareness campaign*: Persistent, well designed, and targeted marketing has meant the people of Windhoek generally take pride that they are the only city in the world where DPR is practised[44,45]

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Chapter 4
Generating renewable energy and recovering resources from wastewater

Abstract: Wastewater production is expected to increase significantly as the century progresses. This chapter will discuss how wastewater treatment plants should not be viewed as waste disposal facilities, but rather as water resource recovery facilities that produce clean water, reduce dependence on fossil fuels through the use and production of renewable energy, and recover nutrients.

Keywords: Wastewater, Water Resource Recovery, Renewable Energy, Nutrient Recovery

Introduction

Currently, it is estimated that the world produces 380 billion cubic metres of wastewater per annum. Globally, wastewater production is expected to increase by 24 percent by 2030 and 51 percent by 2050. It is estimated that energy embedded in wastewater would be enough to provide electricity to 158 million households. Among major nutrients, 16.6 million metric tonnes (Tg) of nitrogen is estimated to be embedded in wastewater produced per annum while phosphorous stands at 3.0 Tg and potassium at 6.3 Tg. The full nutrient recovery from wastewater would offset 13.4 percent of the global demand for these nutrients in agriculture.[1] This chapter will discuss how wastewater treatment plants should not be viewed as waste disposal facilities, but rather as water resource recovery facilities that produce clean water, reduce dependence on fossil fuels through the use and production of renewable energy, and recover nutrients.[2,3]

4.1 Renewable energy generation technologies at wastewater treatment facilities

Electricity is the main energy source required in wastewater treatment plants, accounting for around 25–50 percent of the operating costs of traditional activated sludge plants.[4] Energy derived from wastewater treatment is a renewable energy resource. It can include:

- Electrical energy, heat, or biofuels from the utilisation of digester gas (biogas that consists mainly of methane and carbon dioxide)
- Electrical energy and heat from thermal conversion of biomass (biosolids)

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– Heating or cooling energy using plant influent or effluent as a heat source or sink for a heat pump[5]

4.1.1 Biogas from anaerobic digestion

Anaerobic digestion is a proven technology for sewage sludge treatment and allows the generation of renewable energy from the same process. During anaerobic digestion, microorganisms break down the organic matter contained in the sludge and convert it into biogas which can be used for electricity, heat, and biofuel production. Specifically, the sludge is pumped into anaerobic continuously stirred tank reactors where digestion takes place, usually at mesophilic temperatures (35–39 degrees Celsius). During a retention time, usually around 20 days, microorganisms break down part of the organic matter that is contained in the sludge and produce biogas, which is composed of methane, carbon dioxide, and trace gases. The raw biogas is dried, and hydrogen sulphide and other trace substances removed to obtain a good combustible gas and avoid corrosion or unwanted deposition in the combustion equipment. After cleaning, the biogas can be upgraded to biomethane, or it can be combusted in a combined heat and power (CHP) plant to generate electricity and heat simultaneously.[6]

4.1.2 Biomethane

Biogas is primarily composed of methane (40–70 volume percent) and carbon dioxide and smaller traces of acidic gases and impurities such as hydrogen sulphide, nitrogen, water vapour, and traces of other volatile organic gases. Biomethane is produced via biogas upgrading, which is the removal of carbon dioxide before the biogas can be used as a vehicle fuel or injected into the natural gas grid, as the large volume of carbon dioxide reduces its heating value. Biogas can be upgraded using the following technologies:

– *Cryogenic separation*: This involves cooling the acid gases to a very low temperature so that the carbon dioxide can be liquefied and separated
– *Membrane separation*: This technique uses polymeric membranes to separate the carbon dioxide from the methane in biogas while under high pressure
– *Organic physical scrubbing*: Carbon dioxide is more soluble than methane. Raw biogas flows through a counter flow of a liquid in a column. The liquid absorbs the carbon dioxide, leaving biogas with a high content of methane
– *Pressure swing adsorption*: In this process, biogas is compressed to a pressure between 4–10 bar and is fed to a vessel (column) where it is put in contact with a material (adsorbent) that will selectively retain carbon dioxide
– *Amine scrubbing and water wash (or water scrubbing)*: Amine systems and water scrubbing are similar in that they are both 'wet' upgrading systems and involve

separating the carbon dioxide from the methane by solubilising the carbon dioxide in a liquid solution while allowing the methane to pass[7–9]

Case 4.1: Stockholm's wastewater treatment plants producing biogas for buses
In Stockholm, the two sewage treatment plants, Henriksdal and Bromma, serve more than one million people and industries in the city plus surrounding municipalities. During the sewage treatment process, the organic material is separated in the form of sludge from the water. In total, the two plants produce around a million tonnes of sludge per year. When the sludge is digested biogas is formed, providing a steady stream of vehicle fuel: currently, around 17 million cubic metres of crude gas is produced which is sold to Scandinavian Biogas, who then transform the raw gas into vehicle gas. The gas that is not converted to vehicle gas is used for heating and electricity generation. Most of the gas produced at Henriksdal is used by SL's inner-city buses. Meanwhile, vehicle gas from Bromma is sold, partly from a tank outside the plant and partly at other filling stations in the city, for use in taxis, private cars, buses, and waste trucks. Overall, the biogas mitigates more than 22,000 tonnes of carbon dioxide emissions annually.[10]

4.1.3 Combined heat and power

CHP is the most prevalent means of utilising biogas. As the process of anaerobic digestion requires some heat, it is suited to CHP. The ratio of heat to power varies depending on the scale and technology but typically 35–40 percent is converted to electricity, 40–45 percent to heat and the balance lost as inefficiencies in the various stages of the process. This equates to over 2 kWh electricity and 2.5 kWh heat per cubic metre, at 60 percent methane.[11] CHP offers a variety of benefits, including:
- *Efficiency*: CHP requires less fuel than separate heat and power generation systems to produce a given energy output. CHP also avoids transmission and distribution losses that occur when electricity travels over power lines from central generating units
- *Reliability*: CHP can provide high-quality electricity and thermal energy to a site regardless of what happens on the power grid, decreasing the impacts of outages and improving power quality for sensitive equipment
- *Environmental*: Because less fuel is burned to produce each unit of energy output, CHP reduces greenhouse gases and other air pollutants
- *Economic*: CHP lowers a facility's energy bill considerably due to its high efficiency, and it can provide a hedge against unstable energy costs[12]

Case 4.2: Charlotte Water's biogas CHP system
Charlotte Water operates seven wastewater treatment plants, with the largest being the McAlpine Creek Wastewater Management Facility located in Pineville, near Charlotte, North Carolina. In 2017, McAlpine Creek became the first wastewater treatment plant in North Carolina to utilise anaerobic digester gas to power a 1-megawatt (MW) CHP system. The CHP system generates electricity while also providing process heat for anaerobic digestion. The project was supported by a 20-year zero-

interest loan from North Carolina's Clean Water Revolving Fund. Also, the Southeast Combined Heat and Power Technical Assistance Partnership provided technical support to the utility during the planning phases of the project by conducting a CHP qualification screening and a feasibility analysis. By installing the CHP system, the previously-flared methane fuels a system that provides heat for the digesters and generates electricity that is sold to Duke Energy under a Power Purchase Agreement, with the revenue generated offsetting a significant portion of the cost to operate the plant.[13]

4.1.4 Anaerobic co-digestion

In addition to sewage sludge, some wastewater treatment plants include other organic feedstock in the anaerobic reaction. Known as anaerobic co-digestion, it can lead to a significant increase in gas production as most co-substrates have higher methane production per tonne of fresh matter than sewage sludge. This is due to lower water content and high contents of energy-rich substances, including:

– Lipid wastes including fats, oils, and greases (known as FOG)
– Simple carbohydrate wastes, including bakery waste, brewery waste, and sugar-based solutions such as soft drinks
– Complex carbohydrate wastes, including fruits and vegetables as well as mixed organics, including the organic fraction of a municipal solid waste stream
– Protein wastes, including meat, poultry, and dairy waste products
– Other waste organic feedstocks, including glycerine from biosolid fuel production[14,15]

Case 4.3: Hong Kong's co-digestion trial scheme

Food waste pre-treatment facilities for anaerobic co-digestion will be constructed at the existing Tai Po Sewage Treatment Works. The site will provide a maximum of 50 tonnes per day of pre-treated food waste to the sewage treatment works for anaerobic co-digestion. The scheme is collaboratively administered and run by the Environmental Protection Department (EPD) and Drainage Services Department (DSD). Under the scheme, EPD will be responsible for food waste sourcing, food waste pre-treatment, and delivery of pre-treated food waste to a designated anaerobic co-digester at the sewage treatment works. At the same time, DSD will be responsible for the co-digestion operation and making use of the biogas generated for electricity generation to supplement the sewage treatment facilities' internal power consumption.[16]

4.1.5 Thermal conversion of biosolids

Thermal oxidation (incineration), which is the complete oxidation of organics (biomass) to carbon dioxide and water in the presence of excess air, is a well-established technology. The benefits of thermal conversion include the reduction in biosolids mass, generation of heat for use in heating or electricity generation, reduction in the facility's overall carbon footprint, lowering of the reliance on fossil fuels, generation of ash for use in building materials, and generation of additional revenue to utilities.[17]

Case 4.4: Hunter Water studying the feasibility of biosolids for renewable energy
Hunter Water in Australia is undertaking a comprehensive study to help determine the feasibility of generating renewable energy from the utility's biosolids. Hunter Water's 19 wastewater treatment plants produce almost 8,000 dry tonnes of biosolids each year as a by-product of the sewage treatment process. The biosolids are currently used for pasture improvement, land rehabilitation, and other purposes in the farming and mining sectors. An initial estimate is that the use of biosolids for energy generation could reduce Hunter Water's emissions from energy consumption by around 10 percent. The study will also explore new commercial opportunities around renewable energy from other organic waste streams.[18]

4.1.6 Thermal energy recovery from wastewater

Thermal energy can be recovered from raw wastewater or effluent by exploiting the significant temperature differential between wastewater and ambient conditions. This temperature difference can be recovered for use in heating and cooling systems, which is often used for buildings at the facility and in buildings of areas surrounding the facility.[19]

4.1.6.1 District heating and cooling

District heating and cooling (DHC) is considered more efficient than the individual, distributed systems for heating and cooling as DHC solutions can utilise locally available, low-cost energy sources. Wastewater heat recovery applications based on heat pumps are becoming more widespread in energy-saving applications for both heating and cooling. Heat recovery can be performed inside the buildings (domestic-scale), from sewerage lines (urban-scale), and from wastewater treatment plants (municipal-scale). In densely populated areas, heat recovery from sewage has immense potential, particularly when Geographic Information System-based analysis is used to match the availability of sewage and heat demand.[20]

Case 4.5: Scottish Water Horizons' Stirling Low Carbon Heat Project
Scottish Water Horizons is recovering heat from wastewater in the sewer network for several large-scale heat from waste schemes across Scotland, including the Stirling Low Carbon Heat Project. The project, a partnership between Scottish Water Horizons and Stirling Council, will use heat from wastewater technology alongside a CHP to deliver low-carbon heat to a city community through the District Heat Network. The project will see Scottish Water Horizons owning and operating an energy centre at the existing Stirling Wastewater Treatment Works in Forthside. A CHP unit will be used to deliver renewable electricity to power the waste treatment site and be combined with technology designed to recover heat from Scottish Water's wastewater system to provide low carbon heat to the District Heating Network in the form of hot water. Scottish Water Horizons will sell the heat to

Stirling Council at an agreed rate and volume, which the Council will then sell on to users via their District Heat Network. The District Heat Network delivers heat and hot water to a number of buildings, including a leisure centre, high school, and office complex.[21,22]

4.2 Renewable energy activities on buildings and surrounding lands

Water utilities can implement renewable energy activities on facility-owned buildings and surrounding lands, including the following.

4.2.1 Solar energy

Wastewater treatment plants require many aeration tanks when treating sewage. These require a lot of space in the plant area, providing opportunities to utilise this space with solar photovoltaic (PV) systems to drive equipment or provide heat. These systems, which can produce electricity even in the absence of strong sunlight, can generate significant quantities of electricity depending on a variety of factors including quality of the sunlight and the system's mounted pitch. In addition to lowering energy costs, solar PV systems can improve air quality by reducing pollution caused by using fossil fuels in wastewater treatment plants.[23]

4.2.1.1 Floating photovoltaic installations

Floating PV installations are similar to that of land-based PV systems, other than the fact that the PV arrays, and often their inverters, are mounted on a floating platform. They can be installed on reservoirs as well as ponds and lakes. In a floating PV installation, the direct current electricity generated by PV modules is gathered by combiner boxes and converted to alternating current by inverters. For small-scale floating plants close to shore, the inverters can be placed on land a short distance from the array. For larger-scale floating plants, central or string inverters are placed on specially designed floats. The potential benefits of floating solar include:

- Reduced evaporation from water reservoirs, as the solar panels provide shade and limit the evaporative effects of wind
- Improvements in water quality through decreased algae growth
- Reduction or elimination of the shading of panels by their surroundings
- Elimination of the need for major site preparation, such as levelling or the laying of foundations, which are required for land-based installations
- Easy installation and deployment in sites with low anchoring and mooring requirements, with a high level of modularity, leading to faster installations[24]

Case 4.6: Watercare's floating solar array
Watercare in Auckland, New Zealand has commissioned the country's largest and only floating solar array at its Rosedale Wastewater Treatment Plant in Albany. The one-megawatt array covers one hectare and consists of more than 2,700 solar panels and 4,000 floating pontoons. It floats on a treated wastewater pond next to the Northern motorway and will generate over 1,400 MWh per annum: enough to supply 25 percent of the total energy needed at the treatment plant. The array will also reduce carbon emissions by 145 tonnes per annum.[25]

4.2.2 Wind power

Wind energy, which is captured on-site using wind turbines, can be very cost effective in areas with adequate wind resources. As opposed to large utility-scale wind farm turbines, which can have capacities as high as 3 MW, small wind turbines are often better suited for local facilities. These small wind turbines are most often installed in non-urban areas because installations typically require at least one acre of land and wind speeds averaging around 24 kilometres per hour at 50 metres above the ground.[26]

Case 4.7: Germany's hybrid sewage power plant
In Germany, the Bottrop sewage treatment plant serves a population of 1.34 million and currently self-generates 70–80 percent of its energy requirement. Through the project 'Vom Klärwerk zum Kraftwerk' ('From sewage treatment to power generation'), the plant's operators are aiming to self-generate 100 percent of the plant's total demand on-site (32 million kilowatt-hours of electrical energy per year), reducing its carbon emissions by 70,000 tonnes per year. This will be met through individual, decentralised renewable energy systems. To date, the plant's renewable energy is generated by a sewage gas CHP unit and a sludge incineration system. To meet the goal of 100 percent self-generation, the plant will install:
- A wind turbine (3.1 MW)
- Four new CHP modules (each with a capacity of around 1.2 MW)
- A solar PV system on a roof surface
- A hydrodynamic screw as part of the sewage treatment plant (around 80 kilowatts of power)
- A new steam turbine as part of the existing sludge incineration
- A thermo-sludge drying facility, which uses the sun's energy to extract the water from the excessively liquid sewage sludge so that it can be burned more easily, making the use of coal for sludge conditioning unnecessary[27]

4.2.3 Hydropower energy recovery

Hydropower energy recovery is defined as "*hydropower built using an existing, pressurized, manmade water conveyance that is already diverting water from a natural waterway for the distribution of water for agricultural, municipal, or industrial* *consumption and not primarily for the generation of electricity*". Recovering energy from the flow of wastewater entering or leaving a treatment plant using microhydropower turbines is also a viable method of energy savings at plants with large flows rates. Hydropower energy recovery is cost-effective because it is constructed utilising existing infrastructure. The main driver for this type of hydropower is the opportunity for water utilities to lower operational costs by offsetting energy use costs with on-site hydropower generation.[28,29]

Case 4.8: Sydney Water's hydro power generation from wastewater
Sydney Water generates 21 percent of its total energy needs through its renewable energy projects with the aim of keeping the amount of electricity used below pre-1998 levels, even with an increasing population and higher processing standards. One source of renewable energy utilised is hydro power generation. The utility has installed hydro power generation at its North Head Wastewater Treatment Plant, at its Prospect Water Filtration Plant, on the Warragamba pipeline, and on a pipeline from Woronora Dam. At the wastewater treatment plant, treated wastewater passes down a long drop shaft on its way to a deep ocean outfall. This energy is captured from a hydro-electric generator. The energy produced is enough to power 1,000 homes and will be used to power around 40 percent of the plant.[30,31]

4.3 Energy efficiency

There are various opportunities for improving energy efficiency in wastewater facilities through equipment upgrades (replacing items with more efficient ones), operational modifications (reducing the amount of energy required to perform specific functions), and modifications to facility buildings (reducing the amount of energy consumed by facility buildings themselves). In the wastewater collection and treatment process, there are opportunities to increase energy efficiency, including:

- Improving efficiency of aeration equipment and anaerobic digestion
- Implementing cogeneration and other onsite renewable power options
- Implementing lighting, HVAC improvements
- Fixing leaks
- Installing software
- Using efficient pumping systems (pumps, motors, variable frequency drives)
- Recycling water

In the treated wastewater discharge process, there are opportunities to:

- Use efficient pumping systems (pumps, motors, variable frequency drives)
- Capture energy from water moving downhill[32,33]

Case 4.9: Thames Water identifying energy savings at its wastewater treatment plant
Thames Water evaluated its wastewater treatment plant in Beckton to find potential energy savings. Already, the plant generates more than 50 percent of its energy from renewable sources, including wind and biogas. However, the plant still had an energy bill of more than £9 million per annum in electricity from the National Grid. The newer aeration lanes in activated plant four (ASP4) was found to have the greatest potential for energy savings. Savings was achieved in a few areas, including the doubling of the number of dissolved oxygen (DO) monitors to ASP4 and improving the efficiency of the blower that pumps air into the tanks. Cost savings were achieved by continuously measuring DO to ensure the right conditions for maximum efficiency as well as efficient blower control. This real-time control equipment constantly monitors and adjusts the process to ensure it runs under optimal conditions, using only the minimum amount of energy.[34]

4.4 Benefits of renewable energy and energy efficiency

Some of the benefits of implementing renewable energy schemes and improving energy efficiency include:

- *Reducing air pollution and greenhouse gas emissions*: Increasing the use of renewable energy and improving energy efficiency can help reduce greenhouse gas emissions and air pollutants by decreasing consumption of fossil fuel-based energy. Fossil fuel combustion also generates sulphur dioxide and nitrogen oxide emissions. These pollutants can lead to smog, acid rain, and airborne particulate matter that can cause respiratory health problems for many people
- *Reducing energy costs*: Local governments can achieve significant cost savings by generating their own electricity and heat from renewable energy systems and increasing their efficiency of wastewater treatment plants
- *Supporting economic growth through job creation and market development*: Investing in renewable energy systems and energy efficiency can stimulate the local economy and spur development of renewable energy system service and energy efficiency markets. Many of these jobs are performed locally by workers from relatively small local companies as they typically involve installation or maintenance of equipment
- *Demonstrating leadership*: Investing in renewable energy systems and energy efficiency demonstrates not only responsible government stewardship of tax revenue but also the environmental co-benefits that are obtained from reducing energy usage. The implementation of renewable energy systems and energy efficiency measures may facilitate broader adoption of these technologies and strategies by the private sector
- *Improving energy and water security*: Improving energy efficiency at wastewater treatment plants reduces electricity demand, avoiding the risk of brownouts or blackouts during high energy demand periods and helping avoid the need to

build new power plants, which in turn lowers water requirements to generate electricity
- *Extending the life of infrastructure/equipment*: Energy-efficient equipment often has a longer service life and requires less maintenance than older, less efficient technologies
- *Protecting public health*: The deployment of renewable energy systems and improvements in energy efficiency at wastewater treatment plants can reduce air and water pollution from the power plants that supply electricity to those facilities. Equipment upgrades may also allow facilities to increase their capacity for treating wastewater or improving the performance of treatment processes, reducing the risk of waterborne illness[35–37]

4.5 Recovering resources

Numerous resources can be recovered from wastewater, including the following.

4.5.1 Nitrogen and phosphorus

Most wastewaters are relatively diluted, yet their high volumes provide opportunities to recover a sizeable amount of nutrients.[38]

4.5.1.1 Nitrogen

Nitrogenous materials present in the sewage can be removed from sewage effluent and converted into biomass through activated secondary treatment processes. Fertiliser grade ammonium sulphate can be produced from the high ammonia-nitrogen concentration sidestreams from sludge digestion processes by stripping and absorption. The stripping of ammonia can be done by steam (steam is blown through the water, and after condensation, a concentrated ammonia solution is produced) or air (air is bubbled through wastewater and takes up the gaseous ammonia). Zeolites and other minerals such as clay can be used to absorb ammonium.[39,40]

4.5.1.2 Phosphorus

Resource recovery technologies applied to wastewater are generally focused on phosphorus recovery from the biosolids accumulated after the treatment of the main process stream or on sidestreams that have enriched phosphorus because of biological accumulation. The simplest form of beneficial reuse of the recovered phosphorus from sewage treatment is through the land application of biosolids, which can take the form of composted biosolids, alkaline stabilised biosolids, heat-dried pellets, char, or ashes.[41]

4.5.1.3 Struvite recovery

Struvite is mainly known as a scale deposit that naturally occurs under the specific condition of pH and mixing energy in specific areas of wastewater treatment plants, for example, pipes and heat exchanges, when concentrations of magnesium phosphate and ammonia approach an equimolar ratio 1:1:1. However, rather than struvite being a concern to wastewater treatment plants (pipeline blockages and higher plant-wide nutrient load), it can be recovered to reduce phosphorus levels in effluents while simultaneously generating a valuable by-product such as a slow-release fertiliser or raw material for the chemical industry.[42,43]

Case 4.10: Welsh Water maximising biosolids on farms

Welsh Water provides cost-effective and sustainable biosolids to farmers from the utility's advanced anaerobic digestion facilities – Port Talbot, Cardiff, Hereford, and Wrexham. The utility provides a variety of services to farmers to help agricultural customers fully utilise the potential for biosolids (Table 4.1). In addition to biosolids enhancing the water holding capacity of the soil, the recycling of biosolids uses less energy than intensive mineral fertiliser production, providing an alternative that reduces carbon footprint.[44]

Table 4.1: Welsh Water's Biosolids Services to Agriculture.

Service	Description
Soil testing	Before spreading every field must be tested. Every five years the land is tested for pH, Phosphate, Potassium and Magnesium. Every 10 years the soil is also tested for Cadmium, Chromium, Copper, Mercury, Nickel, Lead, Zinc, Fluoride, Arsenic, Selenium, and Molybdenum, ensuring fields are suitable for using Biosolids
Guidance on utilising biosolids in the farm system	The utility advises on the suitability and timings regarding incorporation into cropping and grazing systems to ensure compliance with regulations outlined by regulators
Agronomic Advisory Service	Welsh Water has in-house Fertiliser Advisor Certification and Training Scheme (FACTS) qualified advisors and offers free no-obligation advice on incorporating biosolids into a farm's nutrient management plan
Year-round availability	Welsh Water's biosolids are available all year round, delivered to farm
Stockpiling	Where direct spreading is not suitable, it may be possible for farmers to have biosolids delivered and stockpiled on-farm in preparation for when they are ready to spread
Ongoing support	Welsh Water will continually work with farmers to make sure everything is going as planned and offer advice where needed to get the best out of biosolids

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4.5.2 Cellulose

Toilet paper often ends as fibrous particles in the wastewater treatment plant. By using fine-mesh sieves, the cellulose fibres can be successfully removed. The cellulose materials that are recovered can be used:
- To dewater the wastewater treatment plant sewage sludge
- In the production of asphalt
- As a raw material for insulation material[45]

Case 4.11: The cellulose recovery initiative in the Netherlands
The Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants (SMART-Plant) project in Europe is aiming to prove the feasibility of circular management of urban wastewater and environmental sustainability of the systems and co-benefits of scaling-up water solutions through Life Cycle Assessment and Life Cycle Costing approaches. The project's cellulose recovery initiative consists of innovative integration of dynamic fine-sieving and in-situ post-processing that has been developed and is currently validated in the municipal wastewater treatment plant of Geestmerambacht in the Netherlands. Filter systems have been installed, separating cellulose fibres from toilet paper in the wastewater. The result is marketable cellulose that has been cleaned, dried, and disinfected while the sludge is sent for post-processing inside the treatment plant.[46]

4.5.3 Bioplastic

One of the most non-traditional technologies under development is the production of biodegradable plastic using polymers isolated from biosolids. Polymers contain carbon, hydrogen, oxygen, and nitrogen, and therefore biological wastewater can be used to make polymers. Polymers called polyhydroxyalkanoates (PHA) can be produced by anaerobic bacteria by metabolising renewable organic carbon sources. PHA polymers are biodegradable thermoplastics and can be used as a substitute for conventional petroleum-based plastics.[47]

Case 4.12: World's first kilogram of PHA from wastewater in the Netherlands
In 2015, three Dutch water authorities, Brabantse Delta, De Dommel, and Wetterskip Fryslân, in collaboration with STOWA (Dutch Foundation for Applied Water Research), sludge treatment plant SNB, and two commercial parties, Veolia and KNN, produced the world's first kilogram of PHA. It was produced by bacteria from a wastewater treatment facility in the Dutch province of Zeeland. While the capacity of the project is small – a few kilograms a week – the aim is to scale this up to include the total treated wastewater volume and ultimately result in production capacity of 2,000 metric tonnes/year.[48]

4.5.4 Bricks and tiles

Sewage sludge ash is the by-product from the combustion of dewatered sewage sludge in an incinerator. The ash is primarily a silty material with some sand-sized particles. The size range and properties of the ash depend on the type of incineration system and the chemical additives used in the wastewater treatment process. The ash can be used in the brick and tile industry.[49]

Case 4.13: Thames Water helping create energy-efficient bricks from sewage ash
Thames Water has signed a deal with a private-sector contractor to create energy-efficient bricks from sewage ash. Each day, wastewater enters Europe's largest sewage works in Beckton with the leftover solids used in the utility's waste-to-energy incinerator. Until now the leftover ash was disposed of in a landfill. Thames Water will now provide a contractor with the dried residue ash needed to create the bricks with the ash to be reacted and mixed with carbon dioxide, water, sand, and a small quantity of cement to form aggregate for 17-kilogram blocks. Overall, Thames Water will supply ash to make 18,000 tonnes of the aggregate, enough to create 2.3 million heavy-duty bricks.[50]

4.5.5 Mining wastewater for metals

Metals can be potentially mined from wastewater, for instance, silver and cadmium is increasingly being found in wastewater and is expensive enough to potentially warrant recovery.[51]

Case 4.14: The ZERO BRINE project in the Netherlands
The ZERO BRINE project in the Netherlands aims to prove that minerals can be recovered from industrial processes for reuse in other industries. The Demineralized Water Plant, in the Botlek area owned by EVIDES, is a large-scale demonstration of the ZERO BRINE project that uses a combination of ion exchanges and membrane technology: dissolved air flotation, reverse osmosis, and mixed bed ion exchange. Waste heat and wastewater streams will be combined in a multi-company site environment:

– Eliminating brine effluent (target: zero liquid discharge) of the industrial water supplier
– Recovering high purity magnesium products (target: magnesium purity >90 percent), sodium chloride solution, and sulphate salts
– Recycling streams within the site (target: >70 percent internal recycling of materials recovered) [52]

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Chapter 5
Greening of grey water infrastructure

Abstract: Traditionally, stormwater systems are designed to remove stormwater from sites as quickly as possible to reduce on-site flooding. Many cities have implemented these systems as part of a larger sewer system that also regulates domestic and industrial wastewater. The downside of this traditional system is increased peak flows and total discharges from storm events, enhanced delivery of nutrients, and combined sewer overflows during wet conditions. In contrast, various green infrastructure solutions are available to manage stormwater while utilising natural processes to improve water quality.

Keywords: Stormwater, Green Infrastructure, Green Roofs, Blue Roofs, Green Streets

Introduction

Traditionally, stormwater systems, which comprise of stormwater drainpipes, kerb inlets, access holes, culverts and so forth, are designed to remove stormwater from sites as quickly as possible to a main river channel or nearest body of water to reduce on-site flooding. Many cities have implemented these systems as part of a larger sewer system that also regulates domestic and industrial wastewater. Combined sewer systems are the most common where stormwater and wastewater is collected in one pipe network, with the mixed water transported to a wastewater treatment plant for cleaning before being discharged into a river or large body of water. The downside of this traditional system is increased peak flows and total discharges from storm events, enhanced delivery of nutrients degrading aquatic habitats in waterways, and combined sewer overflows during wet conditions. Also, sealed surfaces in urban areas are increasing peak flows, increasing downstream flooding risks and lowering groundwater recharge rates.[1] This chapter will discuss the various green infrastructure solutions available to manage stormwater while utilising natural processes to improve water quality.

5.1 Rainwater harvesting

Rainwater harvesting systems comprise three elements: a collection area, a conveyance system, and storage facilities. The collection area is typically the roof of a house or building. A conveyance system usually consists of gutter systems or pipes that deliver rainfall falling on the rooftop to cisterns or other storage vessels. It is recommended that both drainpipes and roof surfaces be constructed of chemically

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inert materials such as wood, plastic, aluminium, or fibreglass to avoid adverse effects. The water is stored in a storage tank or cistern, which should be constructed of inert material such as reinforced concrete, fibreglass, or stainless steel. The storage tank can be constructed as part of the building or built as a separate unit to the building.

Rainwater is considered naturally clean; however, the collecting surface always introduces contaminants such as sediments, pathogens, metals, organic matter, and volatile organic compounds. The quality of harvested rainwater also depends on the surrounding environment as well as the level of maintenance of the system and storage time. As such, rainwater is usually harvested for a variety of non-potable needs such as irrigation, laundry, and toilet flushing. The following guidelines should be considered when maintaining rainwater harvesting systems:

- A procedure to eliminate 'foul flush' after a long period of dry weather should be considered to remove undesirable materials that have accumulated on the roof and other surfaces between rainfalls
- The storage tank should be checked and cleaned periodically with chlorine solution recommended for cleaning, followed by thorough rinsing
- Care should be taken to keep rainfall collection surfaces covered to reduce the likelihood of mosquitoes using the cistern as a breeding ground
- Gutters and downpipes should be periodically inspected and cleaned
- Community systems require the creation of a community organisation to maintain them effectively[2–5]

Rainwater harvesting systems are suitable in all areas as a means of augmenting the amount of water available. The main benefits are:

- Rainwater harvesting provides a source of water at the point where it is needed. It is owner-operated and managed
- In addition to providing an alternative source of water, rainwater harvesting systems can be used as a stormwater control system to reduce localised flooding
- It provides an essential reserve in times of emergency and/or breakdown of public water supply systems, particularly during natural disasters
- The construction of a rooftop rainwater catchment system is simple, and the community can be easily trained to build one, minimising its cost
- The technology is flexible. The systems can be built to meet almost any requirements
- It can improve the engineering of building foundations when cisterns are built as part of the substructure of the buildings, as in the case of mandatory cisterns
- The physical and chemical properties of rainwater may be superior to those of groundwater or surface waters that may have been subjected to pollution, sometimes from unknown sources
- Running costs are low, and construction, operation, and maintenance are not labour-intensive[6,7]

Case 5.1: City of Tucson's rainwater harvesting rebate

Tucson Water in Arizona is providing rebates for qualifying rainwater harvesting systems up to $2,000 per property to encourage the capture, diversion, and storage of rainwater for plant irrigation. To qualify, applicants must be Tucson Water customers and attend an approved Rainwater Harvesting Incentives Program Workshop that covers topics including:

– What rainwater harvesting is
– Best methods to conserve potable water by utilising rainwater harvesting systems
– How to develop a rainwater harvesting project plan

There are two incentives available with applicants able to apply for both, provided the total does not exceed $2,000 for the combination per property:

1. *Simple/passive rain gardens*: Applicants can receive 50 percent off the costs of eligible materials and labour up to $500. Passive earthworks include:
   a. Directing and retaining water in landscapes
   b. Using site-appropriate practices including basins, berms, terraces, swales, infiltration trenches, and kerb cuts
2. *Complex/active rain tanks*: Applicants can receive a rebate covering the cost of the system based on the gallon per capacity of the tank up to $2,000[8]

5.2 Rain gardens

Rain gardens are planted basins which have several functions including increasing infiltration of runoff into the ground, improving water quality by removing pollutants from the runoff, and reducing the volume of stormwater entering the stormwater management system. Rain gardens are different to regular gardens in that they usually are bowl- or saucer-shaped and are specially designed to collect runoff and hold it for one or two days as the water infiltrates into the surrounding soil. Rain gardens are often used to promote absorption and infiltration of stormwater runoff. Generally, rain gardens are most effective on a small-scale, receiving runoff from an area of no more than one-two acres: this is to avoid high volume flows which would erode plant materials. Generally, rain gardens should be between 10 and 20 percent of the square footage of the area of impervious surface that they are receiving runoff from. Rain gardens can incorporate a variety of plants including perennials, shrubs, wildflowers, and/or grasses.

Rain gardens are often placed in areas that receive runoff from a roof or paved area such as car parking lot islands, residential developments, commercial developments, and campuses. A typical rain garden includes a ponding area and inflow and outflow structures. The ponding area can be a natural or artificial ground depression, constructed by soil excavation, which, in the sloping ground, can be combined with building an earth berm at the downslope side using the excavation material. A mulch layer usually covers the ponding area's bottom before topsoil is added. If the water infiltration rate is low, a gravel layer can be constructed, or a perforated underdrain pipe installed. Inflow structures are used to convey rainwater from downspouts or adjacent impermeable areas, such as streets and footpaths, to the ponding area. The construction of overflow structures allows water to exit the rain garden when the ponding area is full, with water usually directed to the sewer network.[9,10]

Rain garden maintenance is similar to that of a typical garden, including weeding and re-establishing plants where necessary. Periodically removing sediment may be required to ensure the proper functioning of these systems. Runoff can be pre-treated via swales and/or filter strips before entering the rain garden to avoid sediment accumulation. Plants should be selected to reduce maintenance needs and to tolerate various weather conditions.[11]

In addition to managing excess runoff and improving water quality, rain gardens provide a wide range of co-benefits, for instance, they can:

- Improve the aesthetics of a property and provide a natural habitat for birds, butterflies, and beneficial insects
- Contribute to climate change adaptation by improving adaptation to more intense rainfall events that are expected to increase with climate change
- Regulate urban temperatures, reducing energy demand for cooling buildings
- Contribute to groundwater recharge
- Provide educational opportunities for schools teaching classes on sustainability and the water cycle[12–15]

Case 5.2: The Rain Guardians of San Francisco

Over the next 20 years, the San Francisco Public Utilities Commission (SFPUC) will implement green infrastructure along with the grey infrastructure to manage stormwater across the City's eight urban watersheds and ensure a sustainable sewer system for future generations. This is part of the Urban Watershed Assessment which will identify green infrastructure (rain gardens, permeable pavement, and bioswales) and grey infrastructure (pipes, tunnels, and pump stations) solutions to the City's sewer system challenges. In addition to public input, SFPUC will ensure the projects are of maximum value using a Triple Bottom Line analysis tool that will assess each project's community, environmental, and economic benefits. Some immediate benefits identified from implementing green infrastructure include improving streets for cyclists and pedestrians, creating open public spaces, and beautifying neighbourhoods. SFPUC has launched the Rain Guardians Program to maximise the benefits of its green infrastructure, foster community engagement, and ensure they are effectively managed. Like the utility's Adopt-a-Drain Program, the Rain Guardians Program enables San Francisco residents or businesses to become 'guardians' of SFPUC's new rain gardens. Rain gardens are a green infrastructure solution that uses the natural processes of soils and plants to slow down and purify stormwater as well as keep it from overwhelming the City's sewer system. Rain gardens are typically depressed below the street level so stormwater can easily flow in and be treated by the plants and soils. With rain gardens often becoming a depository for rubbish year-round, Rain Guardians will regularly remove the rubbish and report any other issues.[16]

5.3 Bioswales

Bioswales are strips of vegetated areas that redirect and filter stormwater. A typical bioswale is a long, linear strip in an urban setting used to collect runoff from large impermeable surfaces such as roads and car parks. Bioswales have an inlet and outlet. When it rains, the inlet lets the water flowing down the street into the bioswale. The outlet is the kerb-cut closest to the catch basin. During heavy rain events, the bioswale may fill to its capacity, with the outlet letting excess water flow out of the bioswale so that it can flow into the catchment basin. Beneath the bioswale is layers that include sandy soils and stones that store stormwater and allow it to seep into the ground gradually. The trees and plants also absorb the stormwater and release it through evapotranspiration.

Bioswales are mainly constructed just upstream of the catch basins so that by design they can partially collect the stormwater flowing down the street and footpath before it goes into the catch basin and then into the sewer system. By partially catching stormwater in the bioswale first, the water can be used as a resource to help trees and plants grow, rather than overwhelm the sewer system. There are two types of bioswales commonly used:

- *Dry bioswales*: These provide both quantity (volume) and quality control by facilitating stormwater infiltration
- *Wet bioswales*: These use residence time and natural growth to reduce peak discharge and provide water quality treatment. A wet bioswale typically has water-tolerant vegetation permanently growing in the body of water[17–19]

In addition to managing excess stormwater runoff, bioswales provide a range of co-benefits including:

- Limiting the flow of water into centralised wastewater systems, therefore, reducing energy consumption and carbon emissions in wastewater treatment plants
- Increasing biodiversity in urban areas with the vegetation providing a diversity of flora that serves as a habitat for fauna
- Promoting the use of locally available construction materials
- Reducing the urban heat island effect
- Improving groundwater recharge
- Removing contaminants from stormwater
- Helping avoid polluted water from entering groundwater[20–22]

5.3.1 Maintenance of bioswales

The five main categories of care to ensure bioswales operate as they are intended are listed in Table 5.1.[23]

Table 5.1: Maintaining Bioswales.

Maintenance Category	Description
Communicate	The difference between bioswales and regular tree pits should be communicated to residents. There should be an explanation of what they are and how they work. The more people are informed about bioswales, the better care they will take of them and the greater the acceptance of future green infrastructure systems
Remove rubbish	Bioswales can quickly accumulate debris and litter with rubbish easily washing in from the street, blown in from the wind, or thrown in by people. This rubbish can clog the inlets and outlets and prevent the bioswale from collecting water properly
Inspect the soil and plants	The soil and plants are specifically chosen to help bioswales manage stormwater. They should be inspected to make sure they are working in the way they are supposed to. Signs of soil erosion should be checked for following storms and vegetative health assessed with healthy bioswales containing healthy and dense plants
Weed often	Frequently weeding is essential for keeping the plants healthy. Weeds are not only unsightly, but they crowd the plants, making it hard for them to absorb water and grow strong. Weeding should be done at least once a month during the growing season
Sufficient water for when it is hot or dry	Even though bioswales are designed to collect rainwater, they may need additional water during hot and dry periods. Watering is necessary for the plant root systems to become established and grow

Case 5.3: Network of bioswales in Kallang River @ Bishan-Ang Mo Kio Park, Singapore
Kallang River at Bishan-Ang Mo Kio Park is a collaboration between the Public Utilities Board (PUB) and the National Parks Board to turn a concrete canal into a picturesque river teeming with life. Under the Active, Beautiful, Clean Waters Programme, a combination of plants, natural materials, and civil engineering techniques were introduced to soften the edges of the waterway, give it a natural appearance, and prevent soil erosion. With the river renaturalised, wildlife has been attracted to the area. The river channel itself was designed based on a flood plain concept and is linked to a network of drains in the City. During dry weather, the flow of water is confined to a narrow stream in the middle of the river. During a storm event, the adjacent park area doubles up as a conveyance channel, carrying the rainwater downstream gradually. In the open lawn area of the park, there is a network of bioswales that are used to reduce surface runoff as well as filter contaminants.[24]

5.4 Floodwater detention and retention basins

A basin is an area that has been designed and designated for the temporary or permanent retention of floodwaters during a rain or storm event. There are two types of basins, the main difference being the presence or absence of a permanent pool of water, or pond:

– *Detention, or dry, basins*: These retain water only during storm events, releasing the water later at a controlled rate until the basin is empty. The basin remains dry between rain events
– *Retention, or wet, basins*: These retain a permanent pool of water, like a pond, irrespective of storm events and so they are wet year-round. They provide additional storage capacity above the permanent pool for the temporary storage of runoff. The depth of a wet basin is often based on water quality considerations, and so wet basins also act as water treatment devices[25]

In most cases, detention and retention basins have outlet openings that remain fixed; called static control, with the discharge rate varying according to water height but is not controlled otherwise. This static operation can be changed to a dynamic operation by controlling, in real-time, the opening of the outlet gate. The discharge rate, as well as the filling and emptying rates and volumes, can be controlled in real-time according to pre-established rules and weather and/or hydraulic conditions. Real-time control can delay the peak flow and discharge the water at times when the environment receiving the runoff has a better capacity to do so. Real-time control can also be predictive when seeking optimal solutions for discharge rates. For example, using rainfall forecasts generated by weather radars and hydrological/hydraulic models allows the system to anticipate the volume of water generated by the next rainfall event and empty the basin at the appropriate time.[26]

In addition to managing excess stormwater, detention and retention basins can improve water quality with treatment processes available including filtration, sedimentation, irradiation (UV/sun exposure), biological treatment, and plant uptake depending on the design components included in these basins.[27]

Case 5.4: City of Toronto's Earl Bales Stormwater Management Pond
The Earl Bales Stormwater Management Pond is one of the largest stormwater management ponds in Canada, covering 3.2 hectares with a depth of around three metres. It has the capacity to manage and treat 90 percent of total annual stormwater runoff from a 550-hectare catchment area that includes residential and industrial development. The pond helps prevent erosion along 2.5 kilometres of ravine system, protecting the urban forest and sewer infrastructure. The pond's water also provides recreational benefits with it being used for irrigation of a golf course in the summer and snowmaking on the Earl Bales ski hill in the winter, reducing demand for water from the West Don River.[28]

5.5 Green roofs

Green roofs consist of a layer of vegetation that covers an otherwise conventional flat or moderately pitched roof. Green roofs are composed of multiple layers which can include a waterproofing roof protection layer, moisture interception layer, drainage layer, leak detection layer, engineered planting medium, and specialised plants. By appropriately selecting materials, green roofs can effectively reduce both flow peak and volume in urban drainage networks.[29] Green roofs can be used on a variety of roofs including on terraces and high-rise building roofs. Generally, any roof that has a pitch up to 16.7 percent can accommodate green roofs without special slope stabilisation provisions. There are two types of green roofs:

- *Extensive green roofs*: These are thin (usually less than six inches), lightweight systems that are mainly planted with succulents, drought-tolerant ground covering plants, and grass
- *Intensive green roofs*: These are deeper (usually greater than six inches), heavier systems that are designed to sustain complex landscapes

The typical components of green roofs include:

- *Inlet control component*: Green roofs that receive direct rainfall do not have inlet controls. For green roofs that receive runoff from roof directly connected impervious area, inlet control systems may convey and control the flow of stormwater from the contributing catchment area to the green roof
- *Storage area component*: Green roof storage areas temporarily hold stormwater before it can either be used by plants through evapotranspiration or be released downstream. Storage areas for green roofs are usually composed of:
  - *Growing medium*: This supports plant growth and provides for storage of stormwater within voids. The storage capacity is a function of medium depth, surface area, and total void space
  - *Filter or separation fabric or geotextile*: This prevents migration of soil into the underlying drainage layer of the green roof
  - *Drainage layer*: This can incorporate measures to intercept and retain percolated rainfall as it moves through the green roof storage area
  - *Moisture interception layers/roof barriers*: These are impermeable liners that protect the underlying roof deck from moisture and plant root intrusion
  - *Underlying roofing system*: This typically consists of a structural deck, its supporting structures, and a traditional overlaying waterproofing system
- *Vegetation component*: Green roof plant material take up much of the water that falls on the roof during a storm event. It mitigates wind and water erosion, transpires captured moisture back into the atmosphere, and provides evaporative cooling. Plant materials also collect particulate matter and create oxygen. Some green roofs may have an irrigation system to support plant growth during dry periods
- *Outlet control component*: Outlet controls can include risers, edge drains, scuppers, gutters, or impervious liners

- *Inspection and maintenance access component*: Safe and comfortable inspection of all major components within a green roof is critical to ensuring its long-term performance. Depending on the roof height and slope, access components may consist of permanent or temporary safety monitoring systems, guardrails and safety net systems, warning line systems, and/or personal fall arrest systems. There may also be a long-term leak detection system for locating and managing leaks

In addition to managing excess stormwater runoff, green roofs provide a wide variety of co-benefits, including:
- Enhanced building aesthetics and market value
- Regulated building temperature in both the summer and winter, therefore reducing cooling and heating costs
- Reduced urban heat island effect by providing evaporative cooling
- Improved air quality by filtering particulate matter
- Extended service life of roofs by protecting the underlying roof membrane from mechanical damage, shielding it from UV radiation, and buffering temperature extremes
- Increased recreational space
- Opportunities for food production
- A wildlife habitat
- Educational resource[30–36]

5.6 Blue roofs

Blue roofs are detention systems that provide temporary storage and slow release of rainwater on a rooftop. Blue roofs can effectively control runoff from buildings with flat or mildly sloping roof surfaces. Typically, water is temporarily detained on the roof surface using rooftop check dams or rain drain restrictors. The outflow is controlled and is usually directed to the building's storm drains, scuppers or downspouts. The typical components of a blue roof include:
- *Inlet control component*: Blue roofs that only receive direct rainfall do not have inlet controls. For blue roofs that receive runoff from adjacent roof directly connected impervious area, including additional roof levels, inlet control systems convey and control the flow of stormwater from the contributing catchment area to the blue roof
- *Storage area component*: Blue roofs temporarily hold stormwater until it can either evaporate or be released downstream at a controlled rate
  - The area dedicated to storage is dependent on the chosen blue roof system type:
    - *Storage in roof drain restrictor systems*: Storage is determined by the roof slope and geometry relative to the height of both the restrictors and

parapets. The bulk volume occupied by all building mechanical systems and so on need to be factored into the storage volume calculations
    - *Storage in roof check dam systems*: Storage is determined by the roof slope and associated area dedicated to ponding behind the dams. The bulk volume occupied by all building mechanical systems and so on needs to be factored into the storage volume calculations
  - In all types of blue roofs, a waterproofing membrane underlies blue roof areas with numerous types of systems existing including modified bitumen roofing, synthetic rubber membranes, thermoplastic membranes and so forth
- *Outlet control component*: Outlet controls within a blue roof system can provide a range of functions including meeting drain downtime requirements, controlling the rate of discharge and limiting water surface elevations during various storm events, and bypassing of flows from large storm events
- *Inspection and maintenance access component*: Depending on roof height and slope, blue roof inspection and maintenance access components may consist of permanent or temporary safety monitoring systems, guardrail and safety net systems, warning line systems, and/or personal fall arrest systems. There may also be a long-term leak detection system for locating and managing leaks[37]

Case 5.5: Amsterdam's blue-green roofs
With European Union-Urban Innovative Action funding, Amsterdam's Project RESILIO aims to realise 10,000 square metres of blue-green roofs in four city districts, with at least 8,000 square metres sited on social housing rooftops. The consortium of both public and private partners aims to build an interconnected network of smart roofs, in which sensors and state-of-the-art equipment enable micro-water management on rooftops. Specifically, in the first phase of the project, singular blue-green roofs will be built with smart flow controls that anticipate heavy rain or drought, releasing or retaining water accordingly. In the second phase, the project will build a smart grid of blue-green roofs enabling real-time data exchange for dynamic water levels, allowing remote regulation of rooftop water levels based on weather forecasts and water management settings. In addition to reducing the impacts of heavy rain, the blue-green roofs will reduce the urban heat island effect, mitigate droughts, improve building insulation, and enhance biodiversity and quality of life.[38]

5.7 Permeable pavements

Permeable pavements are a stormwater practice designed to manage stormwater runoff. Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where the runoff is temporarily stored or infiltrated. These systems eliminate the need for construction of side drainage for collecting the stormwater. Permeable pavements also improve runoff quality as well as minimise the discharge of harmful pollutants to surface water bodies. Permeable pavements are usually limited to parking lots, basic access streets, and recreation areas which carry light vehicles or slow-moving traffic. There are four main types of categories of permeable pavement, as listed below, while Table 5.2 lists the components underneath the permeable pavement surface:

1. *Porous pavement*: This includes one or more layers of porous asphalt underlain by a choke-stone layer or treated base layer and aggregate base/sub-base reservoir. The layer depth is based on structural load, stormwater requirements, and frost depth requirements. The porous asphalt surface void space usually ranges from 18–25 percent, and surface permeability ranges from 170 to 500 inches/hour
2. *Pervious concrete*: This consists of a hydraulic cementitious binding system combined with an open-graded aggregate to produce a rigid, durable pavement. Pervious concrete pavement typically has 15–25 percent interconnected void space and a surface permeability of 300 to 2,000 inches/hour
3. *Permeable interlocking concrete pavement (PICP)*: This consists of manufactured concrete units that form permeable voids and joints when assembled into a laying pattern. The joints allow stormwater to flow into a crushed stone aggregate bedding layer and base/sub-base reservoir that support the pavers. The joints usually comprise 5–15 percent of the paver surface area and maintain surface permeability of 400–600 inches/hour
4. *Others (such as grid pavement systems)*: Grid pavements are composed of concrete or plastic open-celled paving units. The cells or openings penetrate the full thickness so they can accommodate aggregate, topsoil or grass. Surface void space ranges from 20–75 percent. Surface permeability depends on the fill material and ranges from 30 to 40 inches/hour for sand, 200 to 400 inches/hour for aggregate, and one to two inches/hour for grass fill

Table 5.2: Components Below Permeable Pavement Surfaces.

Component	Description
Bedding layer	Used for pavers so they can be laid flat
Choker layer	A layer of small rock to prevent fine material from migrating into the reservoir layer
Reservoir layer	Stone to hold excess water until it infiltrates
Underdrain	Conveys excess water into the drainage system when the reservoir fills
Filter layer/geotextile	A layer of stone or permeable geotextile to separate the reservoir layer from the soil below and prevent migration of fines into the reservoir layer
Impermeable liner	Prevents infiltration into subgrade or adjacent roadway structural section
Uncompacted subgrade	Existing soil into which stormwater infiltrates

Permeable pavements provide a range of environmental benefits, including:
- Reduced flows to storm sewer systems and streams
- Increased groundwater recharge
- Decreased and delayed peak discharge
- Reduced pollutants and improved water quality
- Reduced urban heat island effect[39–42]

Case 5.6: The largest permeable pavement retrofit in North America
In 2015–2016, the City of Atlanta, Georgia, Department of Watershed Management partnered with a private sector partner to install over four miles of PICP, the largest permeable pavement retrofit project in North America. With $16 million of funding, the Department of Watershed Management excavated streets upstream of flood-prone areas to use permeable pavers and the water storage capacity of deep aggregate reservoirs beneath them to provide downpipe capacity relief. The four miles of permeable pavers provide four million gallons of capacity relief. The permeable pavers chosen are designed to withstand vehicular travel in high-traffic areas and provide long-term durability in harsh climates, particularly those with extreme freeze/thaw cycles.[43]

5.8 Green streets

Green streets use green infrastructure practices installed within the public right-of-way to manage stormwater while preserving the primary function of a street as a conduit for vehicles, pedestrians, cyclists, and transit riders. Green streets also reduce contaminants from entering local waterways, improving water quality. The various types of green infrastructure commonly used in transitways, boulevards, main neighbourhood streets, commercial and residential shared streets, green alleys, industrial streets, and so forth, are listed below. At the same time, Table 5.3 provides a summary of the multiple benefits green streets provide.

5.8.1 Stormwater planters

A stormwater planter is a specialised, landscaped planter installed in the footpath area and are designed to manage stormwater runoff. Runoff is routed to the planter by setting the top of the planting media in the planter lower than the street's gutter elevation and connecting the planter to one or more inlets, allowing stormwater runoff from the street to flow into the planter. Runoff from the adjacent footpath can flow directly into the stormwater planter from the surface. Plantings are incorporated within the system to provide uptake of water and pollutants.

Table 5.3: Benefits of Green Streets.

Street User	Green Street Benefit
People walking	– Make the walking environment more inviting and pleasant by reducing the temperature, attenuating noise, and improving air quality – Calm traffic and improve safety conditions – High-quality public gathering spaces with natural features improve mental health and create opportunities for community development and social cohesion
People using transit	– Green infrastructure can be integrated into transit facilities, including traffic islands to improve natural drainage near transit stops – Transit shelters and facility roofs can incorporate green infrastructure – Green infrastructure can be incorporated alongside cycleways to improve drainage and increase cycling comfort and access during and after storms – Permeable pavement can be implemented on cycle lanes and raised cycle tracks to reduce the time required for the pavement to dry – Planters or vegetation may be incorporated into protected cycleway buffer elements to increase ride comfort and reduce stress
People driving motor vehicles	– Green infrastructure can capture runoff and reduce flooding and ponding, promoting safer driving conditions – Green infrastructure can be implemented with geometric changes that reduce vehicle speed and improve visibility
People conducting business	– Success and viability of commercial districts and neighbourhood shops depends on the ability of people to access and use streets comfortably – Economic performance is tied to the comfort and attractiveness of streets, with environments with green infrastructure performing better – Green infrastructure can increase property value

5.8.2 Stormwater bump-outs

A stormwater bump-out is a landscape kerb extension that extends the existing kerb line into the cartway. It is designed to manage stormwater runoff by setting the top of the planting media in the bump-out lower than the street's gutter elevation and connecting the bump-out to one or more inlets, allowing stormwater runoff from the street to flow into the bump-outs. Runoff from the adjacent footpath can flow directly into the stormwater bump-out from the surface. Stormwater bump-outs capture, slow, and infiltrate stormwater within a planted area or subsurface stone bed. Plantings take up some of the stormwater through their root systems, and the remaining stormwater is temporarily stored within the kerb extension until it either infiltrates or drains back to the sewer.

5.8.3 Stormwater tree

A stormwater tree is a street tree planted in a specialised tree pit installed in the footpath area. It is designed to manage stormwater runoff by placing the top of the planting media in the tree pit lower than the street's gutter elevation and connecting the tree pit to an inlet, allowing stormwater runoff from the street to flow into the tree pit. Runoff from the adjacent footpath can flow directly into the tree pit from the footpath surface. If the stormwater tree pit reaches capacity, runoff can bypass the inlet and enter other downstream green infrastructure or a storm drain.

5.8.4 Stormwater tree trench

A stormwater tree trench is a subsurface trench installed in the footpath area that includes a series of trees along a section or the total length of the subsurface trench. It manages stormwater runoff by connecting the subsurface trench to one or more inlets, allowing runoff from the street and footpath to flow into the subsurface trench. The runoff is stored in the empty spaces between the stones or other storage media in the trench, watering the trees and slowly infiltrating through the trench bottom.

5.8.5 Green car parking lots

Green car parking lots incorporate a variety of green infrastructure design elements, including trees, dispersion areas, bioinfiltration, and permeable pavement. These strategies use natural processes to reduce the volume of runoff, peak flow, and pollutants. In particular:

– *Trees*: Trees intercept water on leaves, slowly delivering it to mulch and soils, absorbing it through root systems, and transpiring it as water vapour directly back to the atmosphere
– *Dispersion areas*: Dispersion areas disconnect impervious areas from directly running to the storm drainage system. Dispersion areas use the natural functions of plants, mulch, and soils to slow stormwater runoff and remove pollutants. This strategy uses storage, sediment capture, and biological processes to clean the water
– *Bioinfiltration*: Bioinfiltration facilities are vegetated surface water systems that filter water through vegetation and soil or bioinfiltration soil media before discharge to the storm drain system. They also use shallow depressions to provide storage and evapotranspiration[44–52]

Case 5.7: The Toronto Green Streets Technical Guidelines

The Toronto Green Streets Technical Guidelines, generated after a consultation process involving various City departments, the utility and service providers, and the City of Toronto Complete Streets team, provide new standards for the development of green streets that manage stormwater while providing significant benefits, including:

- Relieving urban pressures on ecological systems
- Improving air quality
- Achieving energy efficiency
- Enhancing water quality while ensuring the City's streets remain efficient conduits for vital infrastructure and beautiful
- Functional corridors for pedestrians, transportation, and transit[53]

5.9 Multifunctional spaces

Multifunctional spaces, including streets, parking spaces, green spaces, sports grounds, and playgrounds can be used for short-term retention and/or transportation of runoff peaks during extreme precipitation events. These multifunctional spaces provide numerous benefits, including:

- Reductions in impervious areas
- Infiltration of runoff from paved areas and rooftops
- Public education opportunities
- Provision of shade when trees are used
- Improved habitat for wildlife
- Creation of a more welcoming environment
- Creation of park-like areas[54,55]

Case 5.8: Flood Water Retention for the City of Winterthur, Switzerland

The City of Winterthur is at risk of floodwater from the Eulach river. To mitigate the risk of flooding in the city centre, a new retention area will provide protection from one-in-30-year floods. As the Eulach reaches a critical level, some of the water will be diverted via an underground diversion structure onto the land of the gliding airfield and the Hegmatten football facilities where it will be held back with a 10.5-kilometres-long embankment that is up to 10 metres high in some places. The underground diversion structure with its supply channel to the retention area will be built in the middle of a residential area. The underground diversion structure will be as wide as a four-lane motorway and 100 metres-long, while the supply channel will be five metres-wide and nearly 400 metres-long.[56]

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Chapter 6
Protecting and restoring water quality in river basins

Abstract: River basins are geographic features that include all surface and groundwater, soils, vegetation, animals, and human activities and do not reflect local political boundaries. In most cases, river basins cross political and administrative boundaries and so by cooperating, communities within river basins can plan for the future of the river basin. River basin management focuses on the relationship between land use and land cover, the movement and storage of water, and water quality. This chapter will discuss how river basin planning can protect and restore water quality before discussing how permit systems, best management practices, and source water protection can protect and restore water quality.

Keywords: River Basin Management, Tradable Permits, Water Quality, Best Management Practices

Introduction

River basins are geographic features that include all surface and groundwater, soils, vegetation, animals, and human activities and do not reflect local political boundaries. In most cases, river basins cross political and administrative boundaries and so by cooperating, communities within river basins can plan for the future of the river basin. River basin management focuses on the relationship between land use and land cover, the movement and storage of water, and water quality. This chapter will discuss how river basin planning can protect and restore water quality before discussing how permit systems, best management practices, and source water protection can protect and restore water quality.

6.1 River basin planning to protect and restore water quality

A successful river basin plan to protect and restore water quality should clearly identify why the river basin plan is needed, where the existing problems, threats, and opportunities are located, what actions and projects are recommended to address the problems and threats and to take advantage of the opportunities, when the recommendations will be advanced, who will take the lead in making it happen, and how much will it cost to implement the plan. The river basin plan will have a variety of goals and strategies that it seeks to maintain or achieve. A successful

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river basin plan is informed by available data and driven by consensus. The plan characterises the physical aspects of the river basin and assesses municipal controls to ensure future water quality. The plan will also recommend corrective and preventive actions to protect and restore water quality as well as other ecosystem services.

6.1.1 Developing and implementing a successful river basin management plan

There are a variety of recommended activities that should take place to ensure the success of a river basin management plan as follows.

6.1.1.1 Planning for community involvement

River basin planning is only successful when the people that live and work in the river basin realise that they are a crucial part of their river basin. They recognise that their actions have an impact on the health of the river basin and participate in protecting and restoring their river basin for the benefit of the entire community and future generations. Community involvement is required in every stage of protecting and restoring the river basin. Community participation can take many forms, but it is generally designed to:
- Foster an appreciation of the river basin
- Introduce local leaders and community residents to the river basin planning process
- Generate a community consensus about the vision for the future of the river basin
- Develop a strategy to address the most critical river basin issues

6.1.1.2 Identifying the key stakeholders

A stakeholder is a person or group who has something to gain or lose based on the outcomes of the river basin plan. It is essential to involve those individuals and groups, which include elected officials, business and civic leaders, neighbourhood and environmental groups, and educational institutions, who have a direct stake in the future of the river basin. The setting and prioritising of goals are where stakeholders become critical players in identifying strategies and designing the actual river basin management plan. A strategy needs to be formed that effectively involves these stakeholders. The strategy needs to identify how to approach each stakeholder and what they can contribute, for instance:
- Do they need to be informed?
- Are the stakeholders required for funding?
- Are they to participate on a committee?

Throughout the river basin plan's implementation, stakeholders and other community members may be involved in a variety of ways, for example, creating a river basin advisory committee, creating specific issue-orientated subcommittees, establishing partnerships, encouraging partnerships, encouraging participating in visioning and planning workshops, or participating in volunteer work parties. At the same time, the entire community needs to be informed on what is going on with regular progress reports provided and how they can participate.

6.1.1.3 Organising a river basin advisory committee

In the early stages of the planning process, most communities establish an advisory committee that helps focus efforts, streamlines the planning process, and see the plan through to implementation. Responsibilities of advisory committees usually include:

- Managing the river basin planning process or advising staff on managing the process
- Providing input on river basin issues and conditions
- Holding regular meetings related to planning and project implementation
- Informing the community about the planning process and ways they can be involved
- Organising and participating in focus groups, workshops, and public hearings
- Keeping elected officials and municipal officials informed about the planning process

Members of the advisory committee should include representatives from groups including local governments, such as elected officials, staff, and members of planning, zoning and other boards of all municipalities in the river basin, neighbourhood and community organisations, local and regional non-profit organisations, property owners, representatives from the business community, water suppliers, and the academic community.

6.1.1.4 Establishing partnerships

In addition to advisory committees bringing together all the stakeholders in a river basin, partnerships need to be formed with these stakeholders. Partnerships are required when pursuing goals that affect other people and organisations, more resources, whether financial, political, or human, are required to accomplish goals, and a strong coalition is required to show that interests of various stakeholders are in agreement. Success in river basin planning requires partnerships that contain the right blend of stakeholders. They will come from the private sector, all levels of government, and from the community to form a partnership with the common goal of achieving a shared vision. There are a variety of critical potential partners, including local government, adjacent municipalities, regional planning or resource conservation organisations, state government partners, academic institutions, representatives of businesses and industries in the surrounding area, property owners in the surrounding area, residents in the surrounding area, community and neighbourhood groups, and non-profit organisation in the community and river basin.

6.1.1.5 Charting the course

It is essential to chart the course for the protection and restoration of the river basin by developing a step-by-step strategy to guide the completion and implementation of the river basin plan. To chart the course, the following needs to be specified:

- The tasks to be performed
- The technique to be used
- The roles of the people involved and their areas of responsibility
- The time frame for action

6.1.1.6 Implementing goals and strategies and monitoring

To fit their river basin's needs, stakeholders and decision-makers may customise the tools that exist for putting river basin management plans into practice. Several of those tools are permits, best management practices (BMPs), and source water protection. Each river basin management plan will have site-specific needs requiring different combinations of these tools. Measuring progress towards achieving river basin management plans and water quality goals can be done through increased and more efficient monitoring and other data gathering.[1–5]

Case 6.1: The Danube River Basin's TransNational Monitoring Network

The International Commission for the Protection of the Danube River (ICPDR) oversees the TransNational Monitoring Network (TNMN), which monitors physical, chemical, and biological conditions in the Danube and its tributaries, and provides in TNMN Yearbooks an annual overview of pollution levels as well as long term trends for water quality in the basin. TNMN was established to support the implementation of the Danube River Protection Convention in the field of monitoring and assessment utilising monitoring data assessed at national level. The TNMN consists of four elements: surveillance monitoring I (monitoring of surface water status); surveillance monitoring II (monitoring of specific pressures); operational monitoring; and investigative monitoring. The TNMN monitoring network is derived from national surface water monitoring networks and includes 101 monitoring stations with up to three sampling points across the Danube and its main tributaries. The minimum sampling frequency is 12 times per year for chemical determinands and twice a year for biological parameters.[6,7]

6.2 Permits

The goal of environmental permitting is to protect human health and the environment by defining, in a transparent, accountable manner, legally binding requirements for individual sources of significant environmental impact. Single-medium permitting, which is the traditional regulatory approach, is based on addressing specific environmental problems such as water protection. Specifically, under this type of regime, the limit for environmental impacts of installations are set to protect the environmental medium (for example, water). Meanwhile, integrated permitting means that emissions to air, water, and land, as well as other environmental effects, must all be considered together. This means that regulators set permit conditions to achieve a high level of protection for the environment overall. In the context of managing water quality, regulatory permits are mainly used to control point sources, including wastewater treatment discharges, industrial waste discharges, and stormwater collection systems. The permits are typically issued by the government and specify discharge levels for pollutants. Point sources may not exceed these permitted levels.[8,9] There are a series of fundamental principles in establishing a permitting system:

- *Permitting of all stationary sources of significant pollution*: All stationary pollution sources with significant environmental impact should have an environmental permit as a precondition for their operation. The provision of environmental permits to industrial installations is a fundamental element of the regulatory process addressing pollution. A coherent permitting system is also necessary to ensure economic competition remains fair under environmental regulations and that economic development proceeds in a sustainable way
- *Differentiation of regulatory regimes for major and minor pollution sources*: Major pollution sources should be subject to integrated environmental permitting on a case-by-case basis, where all environmental aspects are considered simultaneously, and that the environment is a disposal route of last resort. Small and medium-sized enterprises should be subject to simplified regulatory regimes as these businesses pose a lower environmental risk and case-by-case permitting would pose a disproportionately heavy burden on them as well as on the regulators
- *Appropriate permitting authority*: There should be a 'one-stop-shop' system where applicants deal with one designated authority that ensures coordination with all other stakeholders. This increases the consistency and predictability of the permitting process and reduces the administrative burden on both government and industry
- *Public participation and access to information*: The public should be allowed to comment on permit applications before the authority reaches its decision and have access to permit-related information after the permit has been awarded. Regarding consulting the public, it is appropriate to maintain a permit register accessible to the public, where applications and permits are placed, subject to commercial confidentiality

- *Extensive stakeholder involvement*: Permitting requires a transparent process for involving all institutional stakeholders. Stakeholder consultations should be part of both the development of the regulatory framework for permitting (procedures, rules, and guidance) and the permit determination process itself. The permitting authority should also consult other authorities with related responsibilities or interests. Permit registers and interagency electronic networks should be developed to facilitate such coordination
- *Outreach to the regulated community*: Environmental authorities should make substantial effort through trade associations, environmental and industry publications, industry seminars etc. to ensure operators are aware of its obligations under the environmental law. The environmental permitting authority may hold pre-application discussions with the operator before it submits a formal application to clarify relevant requirements
- *Close interaction with Environmental Assessment (EA)*: Both EA and environmental permitting follow legally binding procedures for identifying and analysing significant environmental impacts and making decisions related to economic activity. However, EA applies at an earlier stage of project planning and considers a wide range of alternatives and mitigation measures. As such, EA and permitting should be applied to maximise their effectiveness and avoid overlap. This should be achieved through using EA findings in preparing and evaluating permit applications and include EA recommendations on mitigation measures in permit conditions
- *Clear and enforceable permit requirements*: A permit must contain conditions that are unambiguous and enforceable. The key to simple, effective, and consistent permitting is to base permit conditions on statutory requirements and technical guidance that have been developed in cooperation with all stakeholders and are available to all, including the public[10]

6.2.1 Tradable permits

Tradable permits are market-based instruments that provide allowance or permission to engage in an activity. These permits are mainly used to allocate pollution rights, and they can be issued under a trading system. There are two main types of trading systems: cap-and-trade systems and baseline-and-credit systems. In a cap-and-trade system, an upper limit on permits is fixed, and the permits are either auctioned or distributed for free according to specific criteria. Under a baseline-and-credit system, there is no fixed limit on pollution, but polluters that reduce their emissions more than they have to earn credits that they sell to others who need them to comply with

regulations that they are subject to. Overall, the use of tradable permits has been made on the following grounds:
- Incentives for abatement cost equalisation
- Positive technological innovation and diffusion impacts
- A high degree of environmental certainty
- Relatively low administrative costs
- Flexibility to address distributional concerns[11–13]

In the case of water resources, tradable water pollution rights are where the water management authority establishes the maximum amount of emissions according to the carrying capacity of the ecosystem in question. The total amount of emissions is subdivided into a fixed number of permits or rights to pollute, that can be initially allocated according to past levels of pollution (grandfathering) or by auction. The holders can trade the rights in a secondary permit market.[14] For tradable water pollution rights to be successful, there need to be secure property rights, water rights must be enforceable, and an efficient administrative system must exist to ensure market operation. Overall, tradable water pollution rights systems can provide greater flexibility on the timing and level of technology a facility might install, reduce overall compliance costs, and encourage the voluntary participation of non-point sources within a river basin. Furthermore, trading can provide additional environmental benefits, including carbon sinks, flood retention, riparian improvement, and habitat.[15,16] There are a variety of trading scenarios possible for tradable water pollution rights systems, including:

6.2.1.1 Point source-point source trading

Trading between point sources is the most basic form of water quality trading. It is relatively straight forward, easily measurable, and directly enforceable. It is usually the most accessible type of trading to implement, measure reductions from, and ensure compliance and enforcement with because all sources have a permit, the effectiveness of removal technologies is relatively known, and monitoring protocols are in place. Several trading scenarios exist for point source-point source trading, which is summarised in Table 6.1.

6.2.1.2 Point source-non-point source trading

Trading between point source buyers and non-point source sellers provides another opportunity to meet water quality standards. In successful point source-non-point source trading schemes, point sources benefit by purchasing credits for required reductions at a lower cost than technology upgrades. Non-point sources benefit by gaining income from better resource management, and water quality improves. Several types of trading scenarios exist for point source-non-point source trading, which is summarised in Table 6.2.[17]

Table 6.1: Point Source-Point Source Trading Scenarios.

Scenario	Description
Trading between two point sources	– Generally, it involves a trade agreement between two point sources – One point source is the credit generator, and the other is the credit purchaser – A single permit can be issued that incorporates or references the trade agreement and includes both point sources as co-permittees. Alternatively, each discharger can be issued an individual permit with trading provisions placed in each permit
Multiple facility point-source trading/No exchange	– Involves a group of point sources operating under a single trade agreement – The agreement can establish ground rules for trading to allow point sources to trade among themselves – The agreement can precisely identify the point sources that may participate in water quality trading, or it can identify a geographic boundary (typically a river basin) or a type of discharger, or both, and allow qualifying point sources to participate in trading as desired or appropriate – An over-all limit or cap set by the permit regulates all trades
Point source credit exchanges	– Point sources purchase credits from a central exchange to comply with individual effluent limitations – The credit exchange is likely to be either operated by or approved and overseen by a state regulatory agency – Credits in the exchange are generated by point sources that control their discharges – The trade agreement can specify how credits may be generated and purchased, how trade ratios are calculated, and individual and group responsibilities for meeting effluent limitations and overall pollutant loading caps

Table 6.2: Point Source-Non-point Source Trading Scenarios.

Scenario	Description
Single point source-non-point source trades	– This is a trade agreement between a single point source and one or more non-point sources – Under this trade, the non-point source(s) reduce(s) pollutant loads below the established baseline to generate credits, and the point source purchases these credits

Table 6.2 (continued)

Scenario	Description
Non-point source credit exchange	– A credit exchange programme is established to buy credits from multiple non-point sources to sell to point sources – The exchange could be managed by the state, a conservation district, a private entity, or another third party – A broker can be used to identify trading partners and facilitate trades – There are two main types of exchanges: 1. A broker-facilitated exchange where the broker brings parties together to trade directly with each 2. A central exchange where the point sources are not required to deal directly with non-point sources – For the second type of exchange, the credit sellers (non-point sources) generate pollutant load reductions using a variety of approved BMPs and sell the credits to the credit exchange. Point sources may then purchase credits from the credit exchange rather than directly from the non-point sources

Case 6.2: Ohio River Basin Water Quality Trading Project

The Ohio River Basin Water Quality Trading Project is the world's most extensive water quality credit programme. The non-profit organisation Electric Power Research Institute led the development of the programme along with the collaboration of companies, farmers, state and federal agencies, and environmental groups. Working with local farmers and private landowners in Ohio, Indiana, and Kentucky, the programme funds agricultural conservation practices that reduce nutrient loading of waterways and ecosystems. Each credit equals one pound of nutrient (nitrogen or phosphorous) that, through voluntary action, is prevented from discharging into the water. Every credit is associated with a specific vintage year. For buyers interested in a more generalised water quality credit that is not specific to nitrogen or phosphorous, credits can be purchased as a 'bundle' of benefits including nitrogen and phosphorous reductions as well as any associated ancillary benefits (qualitative) such as pollinator habitat, habitat enhancement, and social benefits to farmers. Credits can be generated through the installation of conservation practices with private landowners in the river basin. Projects are intended to improve water quality while maintaining crop yields. Typical practices include cover crops, reduced fertiliser application, riparian buffer strips, cattle exclusion fencing, and manure wetland treatment systems. The contracts with farmers range from five years for seasonal practices, such as cover crops, to 40 years for tree planting. The Environment Registry runs the credit registry from IHS Markit. The registry ensures that each credit is created and used as approved under the trading plan. In one location, information about each farm project is captured, agricultural agencies verify that BMPs have been implemented on the ground, permitting authorities certify that a credit is acceptable for regulatory compliance, credit buyers can search for credits available to purchase, and stakeholders can view public information on projects. The registry utilises the WARMF watershed model so buyers can understand the load reductions of their credits at specific sites located significantly downstream from the location where the original credit was generated. The registry also assigns a unique serial number for each pound of nutrient reduction and allows for the tracking of the credit through its lifecycle.[18]

6.3 Best management practices

River basin management strategies generally involve controlling non-point source pollution by implementing various BMPs.[19]

6.3.1 Agricultural best management practices for water quality protection

There are a variety of agricultural BMPs that can protect water quality, including the following.

6.3.1.1 Conservation tillage

Low-till agriculture also known as conservation or reduced till consists of a combination of a crop harvest that leaves at least 30 percent of the soil surface covered after planting. This slows water movement, which reduces the amount of soil erosion and potentially leads to greater infiltration. Meanwhile, no-till farming is a type of conservation tillage that seeks to minimise soil disruption and entails leaving crop residue on the fields after harvest. The residue acts as a mulch to stabilise and protect the soil from wind and water erosion. Leaving crop residues on the soil surface can also increase water infiltration by helping slow and capture runoff, which in turn helps conserve water and enhances the utilisation of applied fertilisers and pesticides. By reducing the amount of surface runoff, conservation tillage can help reduce contamination of nearby water bodies by reducing the transport of sediment, fertilisers, and pesticides.[20–22]

6.3.1.2 Crop nutrient management

To successfully grow and produce crops, plants must receive sufficient and proper nutrients at correct times and in appropriate amounts. The practice of nutrient management involves effectively managing the amount, source, placement, form, and timing of the application of plant nutrients and soil amendments. Nutrient management not only helps retain optimum production levels but can also protect water quality and reduce input costs. By carefully managing nutrients and preventing overapplication of fertilisers and manure, the amount of excess nutrients lost to runoff can be reduced, which in turn reduces the amount of non-point source pollution from cropland.[23]

6.3.1.3 Riparian buffers

Riparian buffers are areas of trees or other vegetation located adjacent to a water body and are managed to reduce the negative impact of nearby land use. They have a variety of roles including separating the crop field from the stream, filtering runoff to remove sediment, nutrients, pesticides, and microorganisms, increasing water infiltration, taking up nitrate from shallow groundwater, and stabilising streambanks. Riparian buffers reduce nitrogen loading into the stream by filtering and sedimentation of organic and other particulate-bound nitrogen. In particular, riparian buffers increase infiltration, increase nitrogen uptake, especially if there is subsurface flow through the root zone, and increase denitrification, with denitrification relatively high with mature riparian forest, intermediate with a grass buffer, and least with cropland.[24–26]

6.3.1.4 Irrigation water management

Irrigation scheduling involves the application of irrigation water based on systematic monitoring of crop soil-moisture requirements. It should be based on the daily water use of the crop, the water-holding capacity of the soil, the lower limit of soil moisture for the crop, and the volume of water applied to the field. Irrigation water should be applied in a way that ensures efficient use and distribution, and that minimises runoff, deep percolation, and soil erosion. When chemigation, or the application of fertilisers, pesticides, or other chemicals through irrigation water, is implemented, precautions should be taken to prevent chemigated water from contaminating surface or groundwater. Irrigation practices that can minimise surface and groundwater contamination include:

- Knowing the water-holding capacity of all soils in the field
- Monitoring soil water content to determine how much water has been removed and to evaluate the effectiveness of current irrigation management practices
- Recording how much water is being delivered to the field
- Recording precipitation and estimating how much enters the crop root zone
- Estimating crop water use for each crop
- Calculating a soil water balance based on stored soil water, crop water use, and water applied via precipitation or irrigation[27,28]

Case 6.3: Saskatchewan's Farm Stewardship Program

The Farm Stewardship Program provides Saskatchewan producers funding to implement BMPs in three priority areas: water, climate change, and biodiversity. The Program focuses on the four outcomes of demonstrated improvements in water quality, demonstrated reductions in greenhouse gas emissions, enhanced resilience of the agricultural sector, and biodiversity maintained. To achieve these outcomes, the Program provides rebates for a variety of agricultural BMPs, including the following:

- *Drainage Stewardship BMP*: Existing agricultural drainage works impact downstream water quality and quantity. This BMP helps producers to address the impacts of existing private drainage networks. Eligible funding is available for implementing approved drainage stewardship practices, including installation of water control and erosion control structures. Funding is available to implement the BMP with eligible producers able to receive a rebate of 50 percent of eligible costs to a maximum of $20,000 on water and erosion controls with pre-approval required to qualify for this BMP
- *Variable Rate Mapping BMP*: The Variable Rate Mapping BMP assists producers to obtain zone maps for variable rate fertiliser and variable rate irrigation application. Through this BMP, producers can reduce their environmental impacts to soil and water resources and decrease

greenhouse gas emissions. Funding is available to implement the BMP with eligible producers able to receive a rebate of 30 percent to a maximum of $2,000 with the maximum eligible cost for variable rate mapping set at $8 per acre, with no pre-approval required[29]

6.3.2 Industrial best management practices for water quality protection

A variety of BMPs can be designed to prevent or reduce the effects of pollutants on waterways and habitat health from industrial stormwater discharges:

6.3.2.1 Best management practices to treat total suspended solids

Total suspended solids (TSS) is inorganic (for example, sand, metals) and organic (for example, vegetative and animal waste) particles and debris that are washed off surfaces into surface waters. TSS smothers fish eggs and larvae, causes turbidity that impairs sight-feeding fish, increases drinking water treatment costs, and acts as a vehicle to transport other pollutants such as nutrients and metals to surface waters. Control of TSS can be achieved by avoiding or minimising land disturbance such as clearing and grading as well as reducing stormwater runoff from construction, mining, and logging sites. BMPs that reduce TSS include:

- Implementing a frequent outdoor sweeping schedule
- Using grassed or vegetated areas to catch sediment particles in flowing stormwater, for example, adding rock filters upstream of existing grassed areas to slow down water velocity and adding fibre or synthetic mats on eroded areas or bare, non-vegetation areas
- Developing detention ponds[30]

6.3.2.2 Best management practices to manage availability of oxygen

The availability of oxygen for aquatic life is impacted by substances in water which use oxygen to break down materials washed into the water. Biological oxygen demand (BOD) is the amount of oxygen needed by aerobic biological organisms in a body of water to break down the organic material present. Chemical oxygen demand (COD) measures the oxygen required to decompose organic and inorganic materials, metals, and nutrients present in water by chemical reaction. The higher the BOD or COD, the less oxygen is available in the water for fish and other aquatic life. A variety of BMPs can be used to manage BOD and COD, including:

- Erosion control
- Litter prevention/management
- Stormwater detention ponds
- Constructed wetlands

– Filtration devices
– Infiltration devices[31]

6.3.2.3 Best management practices to manage nutrients

Excessive amounts of some nutrients can lead to algal blooms or other conditions toxic to aquatic life and detrimental to human health:

High amounts of phosphorus can create algal blooms and excessive plant growth which results in oxygen depletion and accelerated sediment filling of lakes when the algae die. Phosphorus sources include chemicals and fertilisers, animal wastes and by-products, food/energy processing wastes, wood processing wastes, and cleaning agents. BMPs used to treat phosphorus include:

– Properly storing materials
– Cleaning up materials from impervious surfaces
– Covering raw material, waste piles, and transfer processes
– Storing materials indoors or covering with a roof or tarp
– Capturing and treating high-strength waste streams separately
– Slowing down water to allow nutrient attenuation by grasses/vegetation before runoff occurs

Nitrates and nitrogen-containing substances can affect both surface water and groundwater with large concentrations of nitrates presenting a health hazard in groundwater and drinking water. Nitrate/nitrogen sources include fertiliser manufacturing, mining, food manufacturing, leather tanning, and fabricated metal manufacturing activities. BMPs used to treat nitrates/nitrogen include:

– Source control by implementing fertiliser application limits
– Minimising, or eliminating exposure before discharge
– Housekeeping such as sweeping spilt solid materials, and detention ponds[32]

6.3.2.4 Best management practices to manage metals

Metals originate from galvanising, chrome plating, and other industrial operations. As metals corrode, dissolve, or settle out in the air, small amounts are carried away by the wind or water and can concentrate in stormwater runoff. Many of these metals become attached to sediment particles and are carried with it to receiving waters. When these sediments settle out, the attached metals accumulate over time to concentrations that are harmful to sediment-dwelling and other aquatic life. BMPs used to treat metals include:

– Source control by limiting metal exposure to stormwater
– Modifying processes, storage, or handling
– Minimising or eliminating the usage of metal-containing product processes
– Replacing or painting galvanised surfaces
– Implementing vegetative buffer strips to capture sediment particles

– Adding recycling to recover and recycle specific metals from the production processes[33]

Case 6.4: City of Guelph's Stormwater Service Credits for large properties

The City of Guelph, Canada, is providing Stormwater Service Credits for industrial, commercial, institutional, and multi-residential properties of six units or more to reduce stormwater runoff from properties. The objective of the programme is to recognise and reward property owners who have implemented stormwater and/or pollution prevention BMPs and green infrastructure to reduce impacts to the City's stormwater infrastructure by controlling runoff quantity and quality discharged from their property. The specific goals of the programme include:

– Reducing the quantity of water entering the storm servicing infrastructure to reduce operational and future capital costs and mitigate potential flooding in areas with insufficient capacity
– Improving water quality by reducing pollutant loads to the storm system
– Improving overall environmental conditions through reduced pollutant loadings and the introduction of landscaping that will filter pollutants (for example, rain gardens, bio-filters, etc.)
– Encouraging infiltration measures to reduce overall runoff volumes, while still protecting groundwater quality, particularly considering existing Source Water Protection Policies
– Encouraging practices by individuals to reduce runoff and protect water quality at the source

Stormwater credits are available in each of four categories which align with the overall objectives of the City's stormwater programme (Table 6.3). The credit is performance-based, meaning credits are awarded based on how well a BMP achieves the defined performance criteria as established by the City. This encourages creativity, provides flexibility, and enables property owners to pursue technologies best suited for their properties and needs, as permitted by existing by-laws, codes, and regulations.[34]

Table 6.3: Stormwater Credit Categories and Rates.

Credit Category	Description/Basis for Charge Reduction	Maximum Credit
Peak flow reduction	Facilities that control peak flow of stormwater discharged from the property, based on the outlet rate in comparison to natural hydrologic conditions	15 percent
Runoff volume reduction	Facilities that control the amount of stormwater retained on the property, based on retention volume resulting from increased infiltration, evapotranspiration, or reuse	40 percent
Water quality treatment	Facilities that control the quality of stormwater discharged from the property, based on treatment type, pollutant load reduction, or Ontario Ministry of Environment and Climate Change level of protection	15 percent
Operations and activities	Non-structural measures including education programmes and pollution prevention/risk management practices	15 percent
Maximum credit available: Capped at 50 percent		

6.3.3 Urban best management practices for water quality protection

In urban settings, surfaces are subject to the deposit of contaminants, which are then subject to wash-off by rainfall or snowmelt. The typical contributors to pollutants in runoff include vehicular traffic, lawn care, pets, eroded sediments, and vegetative litter. The major urban non-point source pollutants include sediment, nutrients, oxygen-demanding substances, toxic chemicals, chloride, bacteria and viruses, and temperature changes. Stormwater BMPs aim to prevent or reduce the movement of sediment, nutrients, pollutants, or debris from land to surface or ground waters. There are a variety of structural and non-structure BMPs available that are summarised in Table 6.4.[35–37]

Table 6.4: Structural and Non-Structural Stormwater Best Management Practices.

Type	Best Management Practice	Description
Structural	Wet extended detention ponds	These are a combination of permanent pool storage and extended detention storage above the permanent pool to provide additional water quality or rate control
	Dry ponds	These have no permanent pool. Instead, they rely on extended detention storage for treatment. They are best combined with other BMPs such as filtration or infiltration
	Stormwater wetlands (constructed wetlands)	Stormwater wetlands are constructed management practices. They are similar in design to stormwater ponds; however, they differ by varying water depths and associated vegetation. They are typically installed at the downstream end of the treatment train
	Infiltration basins	These basins capture and temporarily store stormwater runoff while allowing it to infiltrate into subsurface soils
	Underground infiltration devices	These capture stormwater underground in pipes or tanks and allow stormwater to infiltrate into subsurface soils through open bottoms or perforations. They are typically installed where space is limited
	Filtration systems	These systems are a diverse group of techniques for treating stormwater runoff. Options can range from a simple sand filter or vegetative filter system through to complex engineered systems. The commonality is that each type utilises one or more forms of media, such as sand, gravel, peat, grass, soil or compost or synthetic media to filter stormwater pollutants

Table 6.4 (continued)

Type	Best Management Practice	Description
Non-structural	Information and education	Erosion control information, fertiliser and pesticide application guides, illicit dumping and littering information, landscaping information to reduce runoff, information on the correct disposal of hazardous waste and used motor oils
	Ordinances and regulations	Erosion-control ordinances, comprehensive management plans for developments, elimination of illegal connections, fertiliser and pesticide licensing, land-use controls, landscaping requirements to reduce runoff, special commercial or industrial requirements
	Source controls by the City	Limiting infiltration to storm sewers, effective use of de-icing chemicals, management of hazardous waste and used motor oils, monitoring programmes, spill response and prevention, street cleaning, storm sewer maintenance

Case 6.5: Melbourne Water's Water Smart City Model

Melbourne Water has developed the Water Smart City Model using Lego to raise awareness of the benefits of BMPs in managing stormwater quality and surface runoff. The model is an educational activity suitable for all ages that can be used at community events and festivals. The activity involves the audience building a model city with roads and buildings made from Lego building blocks. Food dye, representing pollutants, is placed on the City and rainfall is simulated over the model, carrying the pollution over the impervious surfaces and into the 'bay'. A variety of features including rain gardens, rainwater tanks, swales, and green roofs are then added. Pollution is again added to the model and rain simulated. The amount of surface runoff is significantly decreased due to the retention capabilities of the new features, reducing risks of flooding. Pollution is also captured in the features, so the water flowing into the 'bay' is cleaner.[38]

6.4 Source water protection

Source water refers to sources of water, such as rivers, streams, lakes, reservoirs, springs, and groundwater, that provide water to public drinking water supplies and private wells. Protecting the source can reduce risks by preventing exposures to contaminated water. Protecting source water from contamination also helps reduce treatment costs and may avoid or defer the need for complex treatment. Source water protection includes a variety of actions and activities that aim to safeguard, maintain, or improve the quality and/or quantity of sources for drinking water and their contributing areas. Examples of source water protection include:

- Riparian zone restoration
- Streambank stabilisation
- Land protection/conservation easements
- BMPs for agriculture and forestry activities or stormwater control
- Local ordinances to limit certain activities in source water or wellhead protection areas
- Developing emergency response plans
- Educating local industry, businesses, and communities on pollution prevention and source water protection[39–42]

Case 6.6: New York City's watershed protection programme

In 2017, the New York City Department of Environmental Protection (NYC DEP) was issued a 10-year waiver to continue delivering unfiltered drinking water from its Catskill and Delaware water supply systems. The system is the largest unfiltered water supply in the United States and delivers around 90 percent of New York City's water on a typical day. The waiver, known as a Filtration Avoidance Determination (FAD), was issued by the New York State Department of Health. Over the period, the NYC DEP will commit an estimated $1 billion to comply with FAD by administering programmes that protect the upstate reservoirs and the watershed lands that surround them. Including the new FAD, the City has committed more than $2.7 billion towards its watershed protection programmes since 1993. NYC DEPs source water protection initiatives include the following:

- Administering a land acquisition programme that has preserved more than 14,000 acres of land through fee-simple purchases or conservation easements. These lands are purchased at fair market value and only from willing sellers
- The non-profit Watershed Agricultural Council, which is one of the City's watershed partners, has completed more than 450 'whole farm' plans that incorporate pollution prevention into the business operations of local farms. These plans have included the installation of more than 7,400 BMPs to control runoff from farms
- NYC DEP administers a regulatory programme to review and approve new development proposals in the watershed. All proposals must comply with standards designed to protect watershed streams and reservoirs, especially as they relate to wastewater and stormwater[43]

Notes

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Chapter 7
Smart digital water management and managing customers of the future

Abstract: Smart digital water management is the use of Information and Communication Technology to provide real-time, automated data for use in resolving water challenges across a range of scales and differing contexts. Smart digital water management enables water utilities and customers to integrate smart principles into their strategies. Meanwhile, water utilities need to move away from viewing customers as recipients of services and instead view them as active participants in the delivery of those services. At the same time, there are growing customer expectations of the level of service delivered by water utilities.

Keywords: Smart Digital Water Management, Smart Water Grids, Smart Water Meters, Social Media

Introduction

Smart digital water management is the use of Information and Communication Technology (ICT) to provide real-time, automated data for use in resolving water challenges across a range of scales and differing contexts. Smart digital water management enables water utilities to integrate smart principles into urban, regional, and national strategies. Meanwhile, customers are not just passive consumers of water services, but instead, they are in the middle of the water chain, with customer behaviour demanding clean water, which affects the volume of water taken from the environment, treated, and transported for use. At the same time, it is the customer's behaviour that drives demand for how much wastewater needs to be removed, treated, and returned to the environment. Furthermore, customers are becoming active participants in the delivery of water resources while expecting higher levels of service.[1] This chapter will first discuss the concept of smart digital water management, followed by its components before discussing managing customers of the future.

7.1 Smart digital water management

There are many applications for smart digital water management including water quality monitoring, water efficiency improvement, efficient irrigation, leak detection, pressure and flow management, and floods and drought monitoring.[2,3] Smart

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digital water management allows conventional water and wastewater systems to become:

- *Instrumented*: The ability to detect, sense, measure, and record data
- *Interconnected*: The ability to communicate and interact with operators and people who manage the systems
- *Intelligent*: The ability to analyse the situation, enable quick responses, and optimise troubleshooting solutions

Smart systems allow informed and systematic decision making for water utilities, based on accurate and timely information. There are a few benefits that can be realised by implementing smart digital water management, examples of which are summarised in Table 7.1.[4,5]

Table 7.1: Benefits of Smart Digital Water Management.

Benefit	Description
Social	– Improved access to clean water and sanitation through water treatment and monitoring – Health improvements through access to clean, safe water – Improved livelihoods through job creation, higher productivity, and educational opportunities – Greater collaboration with community through increased engagement and knowledge-sharing – Increased gender equality through increased opportunities for capacity building and further education
Economic	– Increased efficiency in water and wastewater treatment systems – Reduced waste through lower leakage levels – Job creation through project research, design, development, and implementation – Reduction in future infrastructure costs by improving capacity and efficiency, resulting in less need for additional infrastructure
Environmental	– Improved water quality through reduced pollution and contamination of waterways – Improved ecosystem health and protection through improved water quality and water quantity – Increased groundwater protection – Lower carbon emissions from reduced energy consumption and increased energy efficiency – Lower water consumption through leak detection and reduced demand

7.1.1 Categories of smart digital water management technologies

Smart digital water management technologies can be divided into three categories depending on who is using or adopting the technology:

- *Type 1 institutional user*: Technologies are aimed at major institutional users such as water suppliers, water managers, and water treatment plants. Users adopt the technologies in a straightforward manner due to incentives, for example, improved efficiency, environmental benefits or because of regulations or targets introduced by government agencies
- *Type 2 individual user*: Technologies are aimed at many individual users. The implementation of technologies is more complex as it requires individuals to change what they are doing. Individuals are less likely to respond to economic incentives because of perceived inconveniences of taking up the new technology. However, the total impact is large and therefore social benefit is high
- *Type 3 institutional and individuals combined*: This is where an institution develops and implements a technology, but the success relies on the individual user, and therefore this approach requires some engagement[6]

7.1.2 Smart digital water management system components

Smart digital water management system components can be divided into digital output instruments (meters and sensors), Supervisory Control and Data Acquisition (SCADA) systems, Geographic Information Systems (GIS), and software for a wide range of purposes.

7.1.2.1 Digital output instruments

Digital output instruments are used to collect and transmit information in real-time for a variety of applications including water quality monitoring, real time leak detection, and pressure management:

- *Water quality monitoring*: Water quality is impacted by non-point and point sources and includes sewage discharge, discharge from industries, runoff from agricultural fields, and urban runoff from impervious surfaces. Other sources of contamination include floods and droughts. Water quality monitoring is the collection of information at set locations at regular intervals that provide data that can be used to determine current conditions and establish trends. The main objectives of online water quality monitoring include measurement of key water quality parameters including microbial, physical, and chemical properties as to identify deviations in parameters and provide early warning of hazards. Also, real-time monitoring can inform stakeholders of activities impacting water quality

- *Real-time leak detection*: Meters are usually read by manual meter reading which is an expensive and highly labour-intensive job. Water leaks can go undetected for long periods using manual meters, resulting in mounting damage, and wasted water. Smart water meters can monitor and detect leaks based on abnormal flow patterns, especially continuous water flow. Water utilities can install smart meters to detect and quantify the water losses in District Metered Areas (DMA). The water supplied to a DMA can be compared to the consumption volumes during a defined period and a water balance developed
- *Pressure management*: Pressure management is the practice of managing water distribution network pressures to the optimum levels of service, ensuring a sufficient and efficient supply of water to customers. It is one of the most cost-effective ways of reducing leakage in water distribution networks. The objectives of pressure management for reducing leakage is reducing background leakage, which is acoustically undetectable seeps at pipe joints and small cracks and are uneconomical to be repaired on an individual basis, reducing the rate of new leaks and breaks, which occur on mains and service connections, and reducing the flow rate from any leaks and breaks[7–12]

Case 7.1: New York City's water quality monitoring systems
New York City's Department of Environmental Protection (NYC DEP) uses multiparameter water quality monitoring systems to ensure early warning detection of issues in its reservoirs. Monitoring buoys are equipped with sondes that measure dissolved oxygen, conductivity, temperature, pH, and depth and are installed at different depths below the buoy, helping NYC DEP understand the dynamics of the reservoirs from top to bottom. Each buoy is equipped with a data acquisition system and a spread spectrum radio transceiver and has rechargeable batteries and solar panels. The data loggers convert the digital outputs of the sondes to outputs that can be sent from the logger through spread spectrum radio to the SCADA system, where an operator can view and archive the information. The sondes take readings every 15 minutes, and real-time information is downloaded and analysed, providing water quality managers with limnological data needed to assess conditions and make the best operational decisions.[13]

Case 7.2: Yorkshire Water's Internet of Things approach to real-time leak detection
Yorkshire Water is undertaking a data-led Internet of Things (IoT) approach that will enable the water company to obtain real-time information and understand trends about its water and sewerage operations. Intelligence on the condition of the water pipes will enable the company to adopt a 'predict and prevent' approach to the maintenance of its 31,000 kilometres of water mains. To help predict where and when things will happen on its network, 15,000 'acoustic ear' devices will be installed into the pipes to listen to the noise flowing water makes. Data generated from this technology will be analysed by a new team of data scientists based at the company's control room. The data can be analysed to help control the flow of water and prevent pipe bursts and leaks happening. It will also enable the water company to repair any issues within three hours, rather than the current average of three days. To encourage innovation in the water sector, Yorkshire Water has partnered with the Open Data Institute and the Datamill North as a data repository to host this data, which includes pollution data, consumption data, water resource data, leakage data, and bioresource data.[14]

Case 7.3: United Utilities' pressure management system

During the 1990s, the introduction of pressure management valves helped United Utilities reduce leakage levels by 50 percent. As such, pressure reduction stabilises the network and is a proven way to control leakage. To optimise pressure management, United Utilities has awarded contracts for the supply of pressure management valve controllers and associated data systems. Currently, the water company has a centralised command and control function for the water network, which is managed through an Integrated Control Centre. Automation and control of the pressure management valves are needed to optimise water pressure across the network. Currently, there are around 4,000 pressure management valves in place across the network and, via the use of the controllers, automation and control will be achieved through the installation of remote control of pressure management valves and pumping stations.[15,16]

7.1.2.2 SCADA systems

A water distribution network is made up of different operational components, including sensors, meters, pumps, and control valves. Components can be monitored or controlled onsite or from a central location. In the past, these operations were usually done using onsite instrument or control panels. In recent times, water utilities have transitioned to SCADA systems which measure, acquire information, and control over a distance. SCADA systems can process information and remotely operate and optimise systems and processes for a variety of uses. SCADA systems are used for accomplishing remote monitoring and control of water distribution facilities. The SCADA system's data acquisition function can be used for a variety of uses including monitoring storage tank levels, residual chlorine levels, pH levels, pressures, flows, pump status points (i.e. on/off), chemical feed station operation, and energy consumption. The SCADA system's control function can be used to optimise distribution system operations; for example, storage tank operating levels can be set based on real-time demand.[17,18]

Case 7.4: Yarra Valley Water's upgraded SCADA system

Yarra Valley Water has a substantial water network covering over 4,000 square kilometres, including over 9,000 kilometres of water and 18,000 kilometres of sewer mains. Development in Melbourne's growth corridor is increasing pressure on the utility to deliver sustainable water solutions. Yarra Valley Water's 30,000-point SCADA system monitors around 550 sites including 11 treatment plants, 67 water pump stations, over 100 sewer relief facilities, nearly 100 sewer pump stations, and 102 sewer flow control facilities. The system had received minimal updates in functionality since it was installed in 2001 with no graphical interface for mimics and relied on text and tabular displays to show alarms and status, with basic graphical trending capability for historical analysis. The system was mainly used as an alarm system, from which the control room generated work requests for the field crews. Following an upgrade to the system in 2014, staff now have a modern SCADA system that allows them to monitor the distributed assets and perform predictive and reactive maintenance and be better able to respond to incidents, such as environmental spills, promptly. Reported faults have been reduced by 66 percent, and there has been an 80 percent reduction in external support costs. The new user interface and open database tools allow real-time and historical information to be made available to operations and strategic planning staff for informed decision-making.[19]

7.1.2.3 GIS

A GIS serves as a repository of location information and asset details, based on a web map with layers corresponding to various systems that can be updated and shared in real-time with field crews. In water resources management, GIS is used to monitor water objects while checking the frequency and mapping of the quality of water sources. GIS can be applied in a variety of ways, including the following:

- *Asset management*: GIS enables water utilities to know in detail their assets, what their conditions are, what maintenance is required or the necessary budget, for example, it enables water utilities to determine whether the pipes that break the most often have a certain diameter or material
- *Disaster forecasting*: Flood reduction and drought monitoring programmes use GIS technology for forecasting. GIS determines the range of disaster events including magnitudes, frequencies, depth, and velocities
- *GIS in surface water and groundwater management*: Surface water risk management is determined by GIS, with data collected able to predict rainfall, determine the risk to aquatic habitat from surrounding areas, and assess pollution levels. GIS can be used to help measure the depth of groundwater as well as its quality. The groundwater source can be studied before drilling or developing a water source to reduce the risk of contamination[20–22]

Case 7.5: GIS transforming Thames Water's business processes enterprise-wide

Thames Water replaced all its previous, disparate systems with the ArcGIS platform. One of the water company's new GIS developments is the integration of ArcGIS into the organisation's SAP customer relationship management (CRM) system. Now, when customers contact Thames Water, call centre agents can locate the caller, identify assets concerning that customer address, and see any outstanding maintenance activities there. This information makes diagnosing customer issues easier. The ArcGIS platform also enables the water company to exchange accurate asset and location information with its mobile engineers, surveyors, and field workers. When they launch their laptops, ArcGIS Mobile automatically opens at that location and enables them to enter information about the job in hand. Any asset updates recorded in the field are automatically audited and transferred to the central asset database, where they are visible to everyone in the company. Overall, ArcGIS provides Thames Water with an accurate and up-to-date record of all its assets and makes this business information available to employees across the business, helping staff make better decisions, work more efficiently, and deliver a high level of customer service. In the customer contact centre, employees use ArcGIS to help them respond more quickly and appropriately to customer queries and issues. In the field, employees are more productive as they can be directed to the right place straight away and can instantly see the locations of Thames Water's assets and the property of other utilities such as buried cables. This enables the workers to speed up repairs and minimise public inconvenience. Meanwhile, the asset management teams can use ArcGIS to gain a deeper understanding of the condition of the company's assets then analyse asset performance and make informed decisions about which assets need replacing first and where investments should be directed. Overall, this ensures a better return on capital.[23]

7.1.2.4 Software

Software is used to store, use, and report data. It can be used for modelling of infrastructure and environmental systems, decision-making, and risk management. Software is usually integrated with SCADA and/or GIS to manage water networks, control pressure, and monitor leakage. Software is also used for smart metering, billing and collections, hydrological modelling for water security, and cloud-based management and hosting options. For instance, online portals can be developed that provide customers with household consumption data at the yearly, monthly, daily, and even hourly level as well as historical consumption patterns, leak information, and water use comparisons with similar households, all in an interactive, web-based format. Customers who sign into these portals are often provided access to customisable leak detection alerts and notifications. Customers that set up automated leak alerts typically have them delivered to their smartphones when the system detects a leak on their property at a specified scale.[24,25]

Case 7.6: DC Water's high usage alerts

The District of Columbia Water and Sewer Authority's (DC Water) customers can sign up for high water usage alerts (HUNA) to get notified if their water usage is higher than average. If there is a broken pipe or leaking toilet, HUNA may be the customer's first indication. This may help them determine the source of the problem and avoid high water bills. Customers that are already registered for My DC Water are automatically registered for the alerts via email. The service is linked to a tool that tracks how much water a customer uses on a daily, monthly, and yearly basis. Once the utility has tracked the customer's water usage for a full year, it can let the customer know when their water usage is significantly higher for four consecutive days with a spike in water usage potentially due to a leaking toilet, unattended hose or an internal plumbing issue or leaky faucet.[26]

7.1.3 Smart water grids and smart water meters

A smart water grid integrates ICT into the management of the water distribution system. Sensors, meters, digital controls, and analytic tools are used to automate, monitor, and control the transmission and distribution of water. Smart water grids aim to ensure water is efficiently delivered only when and where it is needed and that the water is of good quality. Smart water grids provide a wide range of benefits, including:

– *Real-time monitoring of asset condition and preventative maintenance*: With advanced sensors, data can be gathered on pipeline conditions and used to develop a risk-based model for pipe replacement projects. This enables utilities to better plan and schedule mains replacements and rehabilitation programmes
– *Real-time pressure and water quality monitoring*: Real-time sensor and meter data allow water utilities to quickly detect leaks to minimise water losses as well as detect stress in pipes early to mitigate the risk of pipe bursts. Water utilities can also use this technology to continuously monitor water quality in the distribution pipelines, providing early warning of potential contamination

– *Real-time water consumption information to help customers conserve water*: Smart water grids and smart water meter technology enables water utilities to provide customers with real-time feedback on water, as well as energy, usage. This helps customers make informed choices with regards to water consumption. Also, usage data from smart meters enable more accurate demand prediction for optimising water pumping schedules and the volume of water required to treat and pump[27,28]

Case 7.7: SA Water's Smart Water Network

In 2017, SA Water implemented a Smart Water Network in Adelaide's Central Business District. The network is comprised of 100 smart meters at 70 business customer sites and over 300 sensors – measuring flow, pressure, and water quality as well as acoustic leak detection – to provide near real-time information about what is occurring in the water network 24/7. This helps the utility identify and proactively fix leaks before they impact customers and commuters. The immediate benefits are less water loss and fewer water service interruptions and commuter delays. Since then, the Smart Water Network has been expanded across metro and regional South Australia. SA Water has also installed 88 flow and level sensors and one weather station in various parts of the Adelaide foothills suburbs to provide real-time information on the movement of sewage through pipes, aiming to find blockages before they can result in overflows. The water utility has also installed 88 odour sensors and three weather stations at Gawler, north of Adelaide, where detectable sewer odour levels in some areas of the town have been consistently above average.[29,30]

7.1.4 Artificial intelligence and machine learning

Artificial intelligence (AI) is intelligence exhibited by machines or computers, allowing them to perform tasks such as understanding, learning, reasoning, planning, and more. In its current application, AI systems can rationally solve complex problems, predict outcomes, and act in real-world situations to achieve goals. The spectrum of AI is expanding and includes:

– Automated intelligence systems that take repeated, labour-intensive tasks requiring intelligence, and automatically completes them
– Assisted intelligence systems review and reveal patterns in historical data and help people perform tasks more quickly and better use the information collected
– Augmented intelligence systems that use AI to help people understand and predict an uncertain future
– Autonomous intelligence systems that automate decision-making without human intervention

In the context of water resources management, a wide variety of IoT sensors and other data-driven technologies can continuously collect data on different phases in the water supply and demand. As such, AI can be used in a variety of contexts as summarised in Table 7.2.[31–33]

Table 7.2: Contexts that AI Can be Used in Water Resources Management.

Context	Example
Water supply	– Water supply monitoring and management – Water quality simulation and data alerts – Asset management on critical water and wastewater expenditures
Catchment control	– Harmful algal blooms detection and monitoring – Streamflow forecasting – Automated flood-centred infrastructure
Water efficiency	– Residential water use monitoring and management – Optimisation of industrial water use – Predictive maintenance of water plants – An early-warning system for water infrastructure – Detect underground leaks in potable water supply systems – Smart meters in homes
Adequate sanitation	– Drones and AI for real-time monitoring of river quality – Ensuring adequate sanitation of water reserves – Real-time monitoring and management of household water supply
Drought planning	– Drought prediction – Simulations for drought planning – Drought-impact assessments

7.1.4.1 Machine learning

Machine learning (ML) is a subset of AI that helps derive meaning from data generated by people, devices, and smart systems etc. Increasingly, the volume of data collected is surpassing the ability of humans to make sense of it and use it efficiently. ML uses this data to create predictions or answer questions. Specifically, a predictive model is trained using data to create predictions or answer questions, with the more data gathered, the more the model can be refined, and new predictive models developed.[34]

Case 7.8: Melbourne Water's AI programme saving energy

Melbourne Water's Winneke Treatment plant is one of the utility's primary water treatment sites for Melbourne's potable drinking water. Each day, around 350 million litres of water moves through the plant before being distributed to millions of homes and businesses across the City. The plant has a daily targeted flow rate for water production to ensure the City always has the right amount of water. This rate varies each day, and so different pumps run at different speeds. Melbourne Water is trialling a customised, in-house built, AI programme that mines historical pump operational data to 'learn' the most efficient pump configuration for any time of the day or week, ensuring the utility's pumps operate at maximum efficiency while ensuring the required flow rate. It is estimated that the project will reduce Melbourne Water's pump station energy costs at the site by around 20 percent per annum.[35]

7.2 Managing customers of the future

Water utilities need to move away from viewing customers as recipients of services and instead view them as active participants in the delivery of those services.

Customers and communities also have knowledge, skills, and creativity that can solve problems and help find ways to innovate. At the same time, there are growing customer expectations of the level of service delivered by water utilities.[36,37]

7.2.1 Customer participation

Ofwat defines customer participation as "*the active involvement of customers in the design, production, delivery, consumption, disposal and enjoyment of water, water services and the water environment in the home, at work and in the community*". There are different levels of customer engagement and involvement that water utilities can incorporate in their strategies to enhance customer participation, including:
- *Level 1: Listening and understanding*: Understanding what is important about water in the lives of different customer groups
- *Level 2: Listening and acting*: Listening to different customer groups and acting on what is heard to achieve business objectives
- *Level 3: Engaging and involving*: Involving customers or their representatives by making it easy for them to propose specific ideas or solutions to achieve change
- *Level 4: Customer participation*: Increasing active customer participation to bring these ideas to life

There is a range of benefits that customers can receive through participation including influencing the future, protecting lifestyles, improving local environments, improving customer service, saving money, saving water, avoiding the risk of flooding, avoiding the risk of sewer flooding, and feeling in control.[38]

7.2.1.1 Strategic framework to increase customer participation

Ofwat has proposed a strategic framework (Table 7.3) that water utilities can follow when aiming to increase customer participation. The framework allows a water utility to achieve a variety of ambitions, including:
- Co-imaging the future with their customers
- Co-creating the future with their customers
- Engaging customers to adopt actions or behaviours at scale to achieve real change
- Engaging citizens to own improvements to water resilience in their communities
- Giving customers more control over water in their homes
- Giving customers more control over their service experience[39]

Table 7.3: Strategic Framework to Increase Customer Participation.

Area	Aim	Benefits
Futures: Customer participation in the sector's future	Enhancing customer participation to improve the current and future sustainability of water in the lives of customers	– Increased customer support for plans – Improvements to customer satisfaction and customer trust – Innovative ideas from customers to help achieve sector goals – Active engagement to create a resilient future for water
Action: Increasing customer action to improve resilience	Increasing customer behaviour change actions, including saving water	– Increases the opportunity for financial benefits – Reduces costs – Improves sector resilience
Community: Increasing community ownership and participation	People acting together in local areas can make improvements to their local water environment	– A feeling of shared ownership in local communities – Increased understanding of the importance of water – Peer group persuasion
Experience: Increasing participation in the customer experience	Increasing customer control of water in their home or of the customer service experience	– Customer satisfaction increasing following contact – Reduced repeat calls on customer service issues – Product and service improvement ideas from customers

7.2.1.2 Strategies and tools to increase customer participation

A variety of strategies and tools can be implemented by water utilities to increase customer participation, including the following:
- *Personalisation*: Customer participation strategies need to make the customer feel special which promotes loyalty, which in turn makes the customer become an ambassador of the brand
- *Exclusivity*: Customer participation can reward loyal customers with access, information, and exclusive offers. Making a customer feel like a VIP enhances the connection between the customer and the brand, which increases the likelihood of the customer promoting the brand inside their social environment online and offline
- *Smartphone apps*: Smartphone apps provide customers with new ways of managing, calculating, communicating, and evaluating environmental information, potentially empowering customers to play an important role in the promotion of sustainable consumption
- *Gamification*: Gamification is the use of game designs in non-game contexts. Gamification encourages customers to adopt the behaviour associated with the

game. Specifically, gamification can guide and motivate customers to change their behaviours and achieve meaningful long-term objectives. Customers can also share their game results with friends, increasing the social network influence of the brand[40–42]

Case 7.9: Personalisation: Austin's Green Business Leaders saving water

The City of Austin runs the Austin Green Business Leaders programme which offers official recognition for businesses that take actions to protect the local environment while at the same time saving money and attracting new customers. Regarding water, Austin Green Business Leaders can participate in the 3C Business Challenge. To receive the 3C Business Challenge Certificate, businesses must:

– Sign and submit a completed form and checklist
– Identify and fix any leaks and adjust existing water-using equipment so that they are operating efficiently and without waste
– Make sure plumbing fixtures and water using equipment comply with existing codes and ordinances
– Evaluate the replacement or retrofit of equipment to more efficient models using Austin Water rebate opportunities or successfully participate in the utility's audit rebate programme

Overall, businesses that excel in the Austin Green Business Leaders programme are formally recognised as Silver, Gold, or Platinum Green Business leaders, have their business featured on the City's website and can place the programme logo on the storefront window and company website, and join the network of Austin's top sustainable companies, enabling them to make new connections, share best practices, and learn from peers at members-only events.[43]

Case 7.10: Exclusivity: Ventura Water's Capture Conservation contest

Over the summer period of 2016, Ventura Water in California ran its Capture Conservation contest which aimed to highlight the community's response to the call to water conservation. As part of Ventura Water's annual summer awareness campaign, residents were invited to share photos of how the drought has inspired them to save water. Contestants took a photo that captured their water conservation story and posted the photo to Instagram, Facebook, or Twitter with the hashtag #keepsavingventura. The winners went above and beyond the call of duty to minimise their water footprint. Contest winners were awarded the following prizes:

– Five Deluxe car washes compliments of Final Details
– Four Golf N' Stuff tickets
– 40 percent off coupon to Patagonia
– Two tickets to Santa Cruz Island
– $100 gift card to Green Thumb Nursery[44]

Case 7.11: Smartphone apps: The City of San Diego's 'Waste No Water' smartphone app

The City of San Diego's 'Waste No Water' smartphone app discourages wasteful use of water. The app, available for iPhone and Android, enables users to report sightings of violations of the City's water restrictions. The basis of the app is that addressing and correcting waste serves as a valuable conservation tool and helps educate the public on what restrictions are currently in place. The app allows users to report water waste immediately by photographing the issue and obtaining the offending address through the app's GPS, then submitting the information to the City's Conservation Department. A complaint file number is generated for staff to address. To use the app, users can either sign in under their profile or as a guest. However, only users with a profile can track the complaint submitted. App users signed in under their profile can, in addition to submitting trackable complaints, receive important notifications such as changes in watering restrictions and changes in time-of-day watering. They can also request a water survey of their residence or business to help optimise water use, connect with Waste No Water's social media accounts, and access the City's water rebate programs.[45]

Case 7.12: Gamification: The SmartH2O project

The SmartH2O project was funded by the European Union's Seventh Framework Program for Research and Innovation. The programme aimed to create a communication channel and a continuous feedback loop between water users and utility companies, providing customers with information on their consumption in near real-time while enabling water utilities to plan and implement strategies to reduce or reallocate water consumption. Specifically, the project involved:

– Creating an ICT platform to capture and store near real-time, high-resolution residential water usage data measured with smart meters
– Inferring the main determinants of residential water uses and building customer behaviour models
– Predicting how customer behaviour can be influenced by various water demand management strategies, ranging from dynamic water pricing schemes to social awareness campaigns

To encourage water savings, a gamified social game was created where consumers were encouraged to save water in return for points, badges, and prizes based on their actions. Leaderboards and weekly/monthly competitions provided a social dimension to the game and increased engagement and motivation to participate by creating a sense of community. Users of the game were encouraged to provide detailed profile information about their demographics and their household configuration.[46,47]

7.2.1.3 Social media strategies to increase customer participation

Water utilities are utilising a range of social media channels, including Twitter, Facebook, Instagram, and YouTube among others, to engage with customers, build brand visibility and popularity, inform customers of products, and offer customer services. Social media strategies that aim to increase customer participation can include the following:

1. *Build consumer connections*: Most often a water utility's social media practice revolves around outage notifications and communication, with water utilities using social media channels to proactively inform customers about a planned outage and quickly respond to a large base of customers regarding an outage, breakdown or disruption due to natural calamities. Water utilities can integrate their social media communication with their CRM function with social media communications going out in a few seconds of an outage, followed by calls, emails, and physical customer care visits within hours of the outage
2. *Create customer awareness*: Water utilities can use social media to educate their customers on topics such as water conservation, advantages of smart meters, and industry trends. Social media can also be utilised to generate user-specific awareness regarding changes in pricing or billing. Smart meter customer awareness

revolves around increasing awareness on issues such as 'what are the benefits for customers', 'how can the consumer manage consumption', 'how can the consumer be impacted during installation'

3. *Create brand awareness*: Customers are increasingly using social media to build or destroy the reputation of their service providers. Social media provides water utilities with the opportunity to manage brand perception and map customer sentiments towards the brand. Brands can also use their social media presence to manage customer satisfaction effectively
4. *Offer water advice and tips*: Social media can be used to educate customers about water conservation and water efficiency technologies. Water utilities can use social media to reach out to customers rather than adopting the expensive traditional ways of creating and managing audio-visual campaigns. This mode can be used to promote web-based tools to help consumers analyse their monthly usage and work towards a lower bill. Many water utilities are pursuing two-way discussions with customers on ways to save water, as well as energy, and the importance of water conservation. Real-time communication with customers across multiple platforms tends to increase engagement and allow 'virtual' conversations with the customer[48]

Case 7.13: Summary of social media strategies to engage customers
A few water utilities have initiated a range of social media strategies on Twitter to engage customers, examples of which are provided in Table 7.4.[49]

Table 7.4: Examples of Social Media Strategies on Twitter to Engage Customers.

Water Utility	**Social Media Strategy**
San Antonio Water System	San Antonio Water System's Twitter feed includes educational information, for example, what to flush/what not to flush/where to take the things you should not flush, community cheerleading, for example, 'go, go high schoolers', and talk on food, in particular on good tacos
Northumbrian Water	Northumbrian Water's Twitter feed includes shots of the region's waterways and protection efforts, strangest things to find in pipes, along with a mix of serious and humorous tweets
San Jose Water	San Jose Water tweets almost exclusively about customer desires, from outages to meet-and-greets. They sometimes provide a recipe that can be made with San Jose water
Yarra Valley Water	Yarra Valley Water informs its customers daily on issues along with tweets to encourage the use of reusable bottles and to 'Be Smart. Choose Tap'
Southern Water	Southern Water provides educational polls, heartfelt videos, and detailed snapshots of daily life inside the utility

With regards to measuring customer participation across social media, there are three main metrics available that can be followed up:

– *Commitment metrics*: Commitment metrics are based on the percentage of customers committed, which is determined by basics such as site traffic, fans, followers, likes, and shares etc.
– *Customer metrics*: Customer metrics can be used to focus on enhancing customers' loyalty, for example, net promoter score is the percentage of customers rating their likelihood of recommending a company, a product, or a service to a friend or colleague
– *Financial impact*: Financial impact involves identifying customer profiles and then conducting targeted campaigns such as contests and promotions to determine a return on investment[50]

7.2.2 Enhancing customer experiences across the water distribution network

There are a variety of strategies water utilities can implement to enhance customer experiences across the water distribution network, including the following summarised in Table 7.5.[51,52]

Table 7.5: Strategies to Enhance Customer Experiences.

Strategy	Description	Examples
Analytics	Predictive analytics and modelling can pre-empt issues and encourage proactive action by customers	– Postcode-driven early warning messages can inform customers of planned works that will reduce water pressure – Integrating weather and temperature data can help customers take preventative action to avoid frozen pipes or anticipate the risk of flooding
Automation	Automation can deliver service improvements with new technologies such as robots and sensors able to detect problems in the water network before they affect customers	– Robots can detect leaks in the distribution system – Sensors can detect water quality issues in reservoirs and water pipelines
Influencing behaviour change	Smartphone apps and digital devices can deliver timely and targeted prompts to help people to keep track of the water they are using	– A higher than normal bill could trigger water-saving advice along with examples of how much water can be saved on the next bill via Internet portals or app channels

Table 7.5 (continued)

Strategy	Description	Examples
Community engagement	Customer engagement can extend beyond functional customer service contact and problem resolution. Utilities can run schemes that help local communities	– Online community platforms make it easier for customers to engage with utilities on issues – AI can deliver bespoke flooding information to customers, making sure they know how to respond when problems occur – Interactive maps can be used to enable customers to report leaks
Self-service	Self-service allows customers to forgo call centres. This means water utilities are more accessible and responsive to customers 24/7. Developments in conversational technology including chatbots, voice interfaces, and conversational search are helping customers find the information they need more easily	– Apps that allow customers to make payments, submit meter readings, and view payment history – Report leaks

Case 7.14: Analytics: Hamburg's online, real-time heavy rain map

Hamburg Wasser has created an online heavy rain map that provides residents with information on rainfall intuitively and transparently. The tool lets users see how much precipitation has occurred, making it easier for people to classify and compare rainfall. The heavy rain is divided into 12 levels – from moderate to extreme. The colour representation in the index ranges from green to yellow, orange to red and to violet. Very rarely is the threshold for heavy rain reached with 90 percent of all rain in Germany not considered to be heavy. The online tool shows in real-time whether, where, and to what extent it is raining in Hamburg and the metropolitan region. For this purpose, radar data from the German Weather Service and rain data from Hamburg Wasser's own measuring points are combined. The information is assigned to fields with a size of 500x500 metres on a map of the metropolitan region, totalling around 24,000 fields. This gives a very precise picture of the current rainfall on a site. The online map is updated every five minutes, and users can set the time period up to a maximum of three days back. The fields are coloured according to the amount of rain: light rain in shades of blue and heavy rain from green to violet. When zooming in, rain levels and heavy rain indices are also displayed as a value. This information enables Hamburg residents to become sensitive to the effects of climate change. It encourages property owners to become aware of green infrastructure solutions to heavy rainfall events, such as permeable car parks. The City itself is also preparing to become a 'sponge city' with the aim of relieving the sewage system by temporarily storing the rainwater and then slowly releasing it again by unsealing areas, creating more green roofs or turning parks, squares or streets into temporary water storage areas.[53]

Case 7.15: Automation: Singapore's robotic swans testing water quality

Singapore's Public Utilities Board (PUB) has created the Smart Water Assessment Network (SWAN) robot to monitor water quality in the five reservoirs of Marina, Punggol, Serangoon, Pandan, and Kranji. In the past, water sampling was conducted manually and through stationary online water quality profiler stations that continuously monitored basic water quality. SWAN complements this process by automating the process of monitoring raw water quality in real-time and in hard-to-reach locations, with each SWAN collecting pH, conductivity, chlorophyll levels, and turbidity. To ensure the robot does not disturb the natural environment while collecting the data, designers from PUB and the National University of Singapore's Environmental Research Institute and Tropical Marine Science Institute came up with the swan design. Each SWAN is fitted with a water quality sampler and water quality profiler to monitor water in real-time with data sent back to PUB live. The SWANs also have an inbuilt camera to capture photos of the water surface. With this range of technology, the robots can work autonomously only requiring basic monitoring and operational maintenance, freeing up resources to perform other tasks.[54]

Case 7.16: Influencing behaviour change: Singapore's smart water meter trial

PUB is rolling out the first phase of its Smart Water Meter Programme. This will involve the installation of 300,000 smart water meters in new and existing residential, commercial, and industrial premises by 2023. By leveraging digital technologies, PUB aims to encourage behavioural change towards water conservation, optimise water demand management, and achieve greater operational efficiencies. Two trials have been undertaken to date in 2016 and 2018, where a total of 800 households reported average water savings of five percent due to early leak detection and adoption of water-saving habits. As part of the trial, households were given a smart meter that registers and transmits water usage readings wirelessly to PUB. A smartphone app for trial participants to download allowed them to access their daily water consumption data. By viewing the daily usage trend in the app, the participants were able to monitor their water usage and make water-saving adjustments as needed.[55]

Case 7.17: Community engagement: Essex and Suffolk Water's leaks in your area map

Essex and Suffolk Water have developed an online water leak map where customers can inform the water company about a leak in their area and track the water company's progress in solving the issue. The leaks the company knows about are marked with an icon with customers able to click on it to find out more information. If there is no icon on the map for a leak, then the water company does not know about it, and so customers can fill out an online form to update the map. When customers report a leak, the following steps are taken:

– *Step 1*: The information about the leak is recorded, and the water company will send a leakage technician to the leak location within 1–5 days, depending on the severity and location of the leak. If the leak is on the water company's pipes, the company will schedule a repair
– *Step 2*: If the leak is on a private pipe work, the company will advise the owner and agree to a date that the leak should be repaired by
– *Step 3*: Because the water pipes run under roads and footpaths, the water company often requires permission from local councils before it can start digging. To ensure the safety of road users, pedestrians, and the water company's crews, there may be the need for temporary traffic lights or diversion of traffic. If this is the case, the council will carry out an assessment, and if they feel there is too much work already going on in the area they will provide a date for which the water company can return to fix the leak, which may be up to 21 days later

– *Step 4*: A water company repair crew will visit the site, dig up the road or footpath to repair the leak followed by reinstatement of the area
– *Step 5*: A permanent repair to the hole in the road or footpath will be made[56]

Case 7.18: Self service: **Southern Water's report a leak service**
Customers of Southern Water can report a leak using an online form. First, customers can use the postcode checker to see whether the leak is located within the water company's region. If it is, customers can tell the company about the leak by answering the following questions:

1. How bad is the leak? Running water or trickling?
2. Is the water clear? Yes or no
3. Where is the leak? Images included in the report can help the water company make better assessments and fix leaks quicker. If possible, customers can attach a photo of the leak and the surrounding area. The specific questions customers are to answer are:
   a. Location (nearest landmark, for example, shop, door number, building)
   b. What is the Street, Town, and Postcode?
   c. Where is the leak coming from?
      i. Through the ground
      ii. From a cover
      iii. Other
4. Contact details (name, contact number, email, and whether the customer wishes to be kept up to date with the leak via a call or text)[57]

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Chapter 8
Innovative financial instruments and approaches for water projects

Abstract: Global demand for water is increasing due to population growth, urbanisation, economic development, and changing consumption patterns. Climate change will increase the numbers of people exposed to both flooding and droughts. Meanwhile, various climatic and non-climatic trends will reduce water quality in waterways, affecting both humans and nature. However, there is significant underinvestment in water resources management, including nature-based solutions, to meet these challenges globally. Nonetheless, there are various innovative financial instruments and approaches available to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.

Keywords: Water Financing, Economic and Financial Instruments, Tradable Permits, Payment for Ecosystem Services, Green Bonds, Public-Private Partnerships

Introduction

Global demand for water is increasing due to population growth, urbanisation, economic development, and changing consumption patterns. Climate change will increase the numbers of people exposed to both flooding and droughts. Meanwhile, various climatic and non-climatic trends will reduce water quality in waterways, affecting both humans and nature. However, there is significant underinvestment in water resources management, including nature-based solutions, to meet these challenges globally.[1–3] This chapter first discusses the initial lack of financing available for water projects before discussing the various innovative financial instruments and approaches available to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.

8.1 Overcoming barriers to water financing

Globally, there needs to be an additional investment of $1.7 trillion to ensure universal and equitable access to safe and affordable drinking water for all, which is around three times the current investment levels. Meanwhile, the scale of investments in water security needs to increase significantly, with estimates ranging from $6.7 trillion by 2030 to $22.6 trillion by 2050. Nonetheless, there are a few

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barriers that create a gap between current financing and future needs, including the following:
- Water is generally an under-valued resource, not properly accounted for by investors that depend on or affect its availability in other sectors such as urban development, agriculture, and energy etc.
- Water services are often under-priced, resulting in low cost-recovery for water investments
- Water infrastructure is generally capital intensive, with high sunk costs and long pay-back periods
- Water management provides both public and private benefits, many of which cannot be easily monetised. This reduces potential revenue flows
- Water projects are often too small or too context-specific, raising transaction costs and making innovative financing models difficult to scale-up
- Business models often fail to support operation and maintenance efficiency, hampering the ability to sustain service at least cost over time[4–7]

To overcome these barriers, the High Level Panel on Water has defined a range of principles that should be followed to help finance investments, enhance water services, mitigate water-related risks, and contribute to sustainable growth:
- *Maximise the value of existing assets for water-related investments*: Service providers can reduce overall investment needs and improve capital efficiency through improving the operational efficiency and effectiveness of existing infrastructure. Improvements can result from good operation and maintenance of infrastructure and demand management
- *Design investment pathways that maximise water-related benefits over the long-term*: The multiple benefits that water-related investments generate depend on how investments are designed and sequenced to meet strategic goals, including climate change adaptation. This means projects should be designed to be scalable and adjustable to changing conditions
- *Ensure synergies and complementarities with investments in other sectors*: Policies outside of the water sector should be encouraged to factor in water risks, which in turn stimulates water-wise investments
- *Attract more financing by improving the risk-return profile of water investments*: Governments can employ a range of fiscal policy instruments to recover the costs of investments from beneficiaries, improve the financial viability of utilities, and provide a revenue stream to improve the risk-return profile of water-related investments[8]

8.1.1 Economic and financial instruments

Economic instruments enable environmental or social costs to be incorporated into the price of goods, services or activities that give rise to them. This sends a price signal to users or consumers to reduce inefficient and wasteful use of resources and foster their optimal allocation. Economic instruments can be used to promote eco-efficient economic activities, therefore promoting innovation and competitiveness. Regarding pollution, economic instruments enable the implementation of the polluter-pays principle, making the polluter instead of society as a whole pay for the damage they cause. At the same time, ensuring the provision of sustainable, reliable, resilient, and affordable water and water-related services will require significant investments and therefore financing.[9,10]

8.2 Water prices

Water prices have the primary goal of financing water supply infrastructure. The price of water should be set at a level that ensures the recovery of costs for each sector (agriculture, households, and industry) and the allocation of costs to each sector (avoiding cross-subsidies). Water prices should relate to three types of cost:

- *Direct economic costs*: Full recovery of the economic costs of the water services requires the water price to include:
  - Operational and maintenance costs of water infrastructure
  - Capital costs for the construction of this water infrastructure
  - Reserves for future investments in water infrastructure
- *Social costs*: The social costs, direct and indirect, of providing water services varies mainly with respect to specific contextual settings. As such, calculating and comparing these costs across different settings is generally not feasible
- *Environmental costs*: The environmental costs of economic activities are generally not reflected in the prices established in the market but appear as externalities. The principle of full cost recovery requires that these costs be taken into consideration

Overall, water prices which represent full costs (economic and environmental costs) provide price signals to water users to be more efficient while generating the means for ensuring sustainable water infrastructure.[11,12]

Case 8.1: City of Toronto's water and wastewater consumption rate increase

The City of Toronto Water and Wastewater Program is currently fully funded on a 'pay-as-you-go' basis through a combined water and wastewater rate. The providing of water and wastewater services does not rely on property taxes or borrowing/debenture financing. Based on the updated water consumption forecast and the city's Capital Plan, the City Council has recommended a three percent increase in water and wastewater consumption rates, effective January 1st, 2020. The rate increase applies to both residential (Block 1) and industrial customers (Block 2 water rate) (Table 8.1). The three percent increase will raise an additional $37.17 million in revenue for the Program. The recommended rate increase will result in the average household, consuming 230 cubic metres/year, paying an extra $27 over the calendar year while the impact of the increase on a commercial customer at the Block 1 rate and an industrial consumer at the Block 2 rate with annual consumption of 100,000 cubic metres will be $11,860 and $8,478 respectively (the latter reflecting a 30 percent discount over the Block 1 rate for eligible industrial consumers with the City's Industrial Water Rate Program). Meanwhile, the impact on a large industrial consumer of 1,000,000 cubic metres eligible for the Block 2 rate will be $83,178.

The Industrial Water Rate Program offers a discounted water rate to manufacturers in Toronto to help support economic growth and encourage water conservation (known as the Block 2 water rate). The Program is open to manufactures that:

- Use more than 5,000 cubic metres of water annually
- Fall within the industrial property tax class
- Are in full compliance with Toronto's Sewers By-law
- Submit a comprehensive water conservation plan to the satisfaction of the General Manager, Toronto Water[13]

Table 8.1: Toronto Water's Water and Wastewater Rate Increase.

Annual Consumption	**Paid on or before the due date, $\$/m^3$**	**Paid after the due date, $\$/m^3$**
Block 1 water rate: All consumers of water, including the first 5,000 cubic metres per year consumed by Industrial users	4.0735	4.2878
Block 2 water rate: Industrial water consumption is over 5,000 cubic metres per year, representing a 30 percent reduction from the Block 1 water rate	2.8514	3.0014

8.3 Stormwater fee discounts

Cities can incentivise developers and property owners to manage stormwater as well as preserve open space and protect or plant trees by offering stormwater fee discounts. Stormwater fee discounts aim to reduce the required capacity and cost of stormwater treatment practices. They allow property owners to reduce the amount of stormwater fees they pay by decreasing impervious surfaces or by using green infrastructure techniques that reduce the amount of stormwater runoff. Before setting the discount, the agency in charge should set appropriate management goals and determine how to credit private property owners for the action being incentivised. It is common for cities to provide a percent discount for the level of performance. This discount is usually given for stormwater quantity reductions. Discounts can also be offered for impervious surface reductions or for implementing specific green infrastructure practices.[14–16]

Case 8.2: City of Guelph's stormwater service credits for businesses
The City of Guelph, Canada, provides a stormwater service credits programme where industrial, commercial, institutional, and multi-residential properties of six units or more may qualify for a credit on their stormwater bill of up to 50 percent. Reducing runoff in the city prevents floods, protects Guelph's water supply and wildlife habitat, and reduces costs for property owners and the City of Guelph. Stormwater credits are available in four categories, which align with the city's overall goals of its stormwater management programme (Table 8.2).[17]

Table 8.2: City of Guelph's Stormwater Credit Categories.

Credit Category	Description	Maximum Credit (capped at 50 percent)
Peak flow reduction	Facilities that control the peak flow of stormwater discharged from the property based on the outlet rate in comparison to natural hydrologic conditions	15 percent
Runoff volume reduction	Facilities that control the amount of stormwater retained on the property, based on retention volume resulting from increased infiltration, evapotranspiration, or reuse	40 percent
Water quality treatment	Facilities that control the quality of stormwater discharged from the property, based on treatment type, pollutant load reduction, or Ministry of the Environment and Climate Change Resources level of protection	15 percent
Operations and activities	Non-structural measures including education programmes and pollution prevention/risk management practices	15 percent

8.4 Stormwater volume credit trading

Stormwater volume credit trading provides an onsite compliance option for property developers or owners who are subject to stormwater management regulations. In many cases, regulations include onsite retention or detention requirements for new developments or redevelopment projects over a certain size. A credit trading programme enables developers or property owners subject to these regulations to meet all or a portion of their requirements offsite by buying volume-based stormwater credits. These credits are generated from the installation and maintenance of green infrastructure projects located offsite. Specifically, credits can be generated by:

– Developers or property owners who voluntarily implement green infrastructure retrofit projects on properties that are not subject to post-construction green infrastructure requirements
– Developers or property owners who are subject to green infrastructure requirements but build green infrastructure projects that exceed minimum stormwater requirements

A trading programme requires a local entity to oversee and manage the trading marketplace and ensure that the green infrastructure projects that generate the credits are properly maintained over time. This function is usually provided by a stormwater agency, but an independent entity can be created to administer the programme.

Some of the main benefits of a stormwater volume credit programme include the following:

– It allows flexibility for developers and property owners as they can choose the cheaper option. In some cases, it will be cheaper to buy credits from an offsite provider than managing stormwater onsite
– Buying credits can allow developers or property owners to make use of additional buildable areas onsite, including rooftop or underground areas
– Overall water quality in a city or watershed can improve as a trading programme allows for a greater number of small green infrastructure installations across an area in comparison to a smaller number of larger green infrastructure practices, all onsite[18]

Case 8.3: Washington, DC's Stormwater Retention Credit Trading Program

Washington, DC's Department of Energy and Environment (DOEE) runs the Stormwater Retention Credit (SRC) Trading Program that enables property owners and developers to earn revenue for projects that reduce stormwater runoff by installing green infrastructure or by removing impervious surfaces. Sellers of SRCs can lock in a sale price by selling to DOEE through the SRC Price Lock Program as well as through the open market to properties that have regulatory requirements for managing stormwater. The SRC Price Lock Program enables SRC generators to sell SRCs to DOEE at fixed prices, creating a price floor in the SRC market and offering certainty about the revenue from an SRC-generating project. If participants sell to another buyer, DOEE also pays a portion of the purchase price on behalf of the buyer. Furthermore, DOEE offers SRC Aggregator Startup Grants of up to $75,000 to support SRC-generating businesses. The grant can be used for the businesses to evaluate sites for the feasibility of green infrastructure retrofits, with the funds able to be used to support technical and outreach work to identify and aggregate SRCs from green infrastructure projects in the Municipal Separate Storm Sewer System, typically across multiple sites. Through the technical and outreach work funded by the grant, businesses can identify a pool of projects that are suitable to generate SRCs and participate in the SRC Price Lock Program. It is expected that the SRC Price Lock Program and the SRC Aggregator Startup Grants will make it easier to generate SRCs on land owned by non-profits, such as churches, cemeteries, schools, and similar institutions with DOEE prioritising funding for these projects.[19]

8.5 Environmental taxes

According to the OECD, environmental taxes directly address the market failure that causes markets to ignore environmental impacts. A well-designed environmental tax increases the price of a good or activity to reflect the cost of the environmental harm that it imposes on others. The harm to others, an externality, is internalised into market prices. This ensures that economic actors, including consumers and firms, take these costs into account in their decision-making. Environmental taxes provide other benefits including an ongoing incentive to abate (they provide a continuous incentive for the abatement of pollution), improving the competitiveness of environmentally-friendly alternative technologies (helping make alternatives more viable without the need for direct subsidies), and providing a strong incentive to innovate (taxes increase the cost to a polluter of generating pollution, providing firms with an incentive to develop innovations and adopt existing ones). Meanwhile, an alternative to environmental taxes is the providing of tax incentives to subsidise environmentally beneficial goods or actions. In the context of water resources management, environmental taxes are compulsory payments to fiscal authorities for behaviours that lead to the degradation of the water environment, with the objective being to encourage alternative behaviour to the one targeted by the tax, for example, the use of less polluting techniques and products. Overall, environmental taxes should:

- Be designed to target the pollutant or polluting behaviour with few exceptions
- Be as broad as the scope of the environmental damage
- Be commensurate with the environmental damage
- Be credible and its rate predictable to motivate environmental improvements
- Assist fiscal consolidation or help reduce other taxes
- Be clearly communicated to ensure public acceptance[20,21]

Case 8.4: Denmark's pesticide tax

Denmark's pesticide tax is closely related to the aim of reducing the pesticide load indicator. Effective from July 1st, 2013, the tax paid on pesticides is based on how large the impacts from the pesticides are on health, nature, and groundwater. The tax is a sales tax per unit litre or kilogram of an agent, with the tax for each product determined based on:

1. Health load (Charge: DKK 107 per litre or kilogram of medium per load unit)
2. Environmental impact load (Tax: DKK 107 per kilogram or litre of medium per load unit)
3. Environmental behavioural load (Fee: DKK 107 per kilogram or litre of medium per load unit)
4. Active substance concentration/basic charge (Charge: DKK 50 per kilogram or litre of active substance[22])

8.6 Subsidies

The OECD defines subsidies as "*government interventions through direct and indirect pay amends, price regulations, and protective measures to support actions that favour environmentally unfriendly choices over environmentally friendly ones*". Nonetheless, subsidies are economic instruments that can be used as an incentive to stimulate change in user behaviour towards environmentally friendly conduct or encourage investments in environmentally friendly production techniques, mitigating or eliminating adverse effects.[23] The following principles should be followed to ensure subsidies promote environmentally friendly conduct or technologies:

- *Subsidies should achieve the intended policy outcome*: Subsidies require a smart design and clarity about what the policy objectives and short- and long-term objectives are
- *Subsidies should reach the intended target groups*: They require clarity on who is the intended target group and how they can best be reached. It also requires rigorous monitoring to track how subsidies are reaching the intended groups
- *Subsidies should be financially sustainable*: A thorough understanding of the potential costs of the programme is required. Costs include both upfront capital costs and long-term operational and maintenance costs
- *Subsidies should integrate local peoples' needs*: To guarantee the sustainability of the subsidised environmental technology, it is of prime importance to facilitate the integration and participation of the local beneficiaries and to develop a sense of ownership towards the new infrastructure
- *Subsidies should be implemented clearly and transparently*: As subsidies involve public funds, subsidy programmes need to be clear and transparent, enabling eligible households or communities to access them and providing clear recourse mechanisms in cases where there is a suggestion of impropriety[24]

Case 8.5: Flanders' subsidies for environmentally friendly investments

Flanders, Belgium provides investment grants to encourage environmentally friendly green investments. Flanders Innovation and Entrepreneurship (VLAIO) provides two types of subsidies for green investments:

- *Ecology Premium-Plus (EP-Plus)*: The EP-Plus is granted to investments in technologies that feature on a limitative technology list (LTL). The list contains around 40 technologies divided into the five categories of cooling, transport, lighting, water, and diverse. The subsidy amount is dependent on the size of the company, the performance of the technology, and type of technology. The support for small and medium-sized enterprises (SMEs) can be as much as 55 percent (45 percent for large enterprises). The total amount available is limited to a maximum of €1 million every three years
- *Strategic Ecology Support (STRES)*: STRES is available for companies using technologies that, due to their exceptional and unique character, are not on the LTL list. This subsidy is intended for strategic environmental projects that contribute to global solutions (environmental or energy issues), focus on closed circuits (renewable energy, sustainable use of material,

recovery of material), and provide integrated solutions. The investment must be at least €3 million, with the size of the subsidy dependent on the type of investment, the performance of the technology, and size of the company. The support for SMEs can be as much as 40 percent (30 percent for large enterprises). The total amount available is limited to a maximum of €1 million every three years. To be eligible, a feasibility study must be conducted[25]

8.7 Tradable permits

With a variety of climatic and non-climatic trends resulting in water scarcity and pollution, a range of locations have implemented market mechanisms based on consumption rights and pollution in the management of water resources. Specifically, tradable permits are one of the most efficient market-based instruments for allocating water resources and for mitigating pollution of water resources.[26] There are two main tradable permit systems: Tradable water abstraction rights and tradable water pollution rights.

8.7.1 Tradable water abstraction rights

These rights are for quantitative water resource management with water rights being either permanent and unlimited (property rights to the water resource) or temporary and limited (transferable rights to use water without right of abuse). In a tradable water abstraction rights regime, the water authority sets a water consumption cap, which is the maximum amount of water that can be abstracted. It allocates the abstraction rights among the basin users, who then can exchange them based on their present and/or future expected water consumption demand. Water users are encouraged to use water efficiently for two reasons. First, it reduces the need to purchase costly abstraction rights and second, they can gain revenue from selling excess water rights once they reduce their water consumption.

8.7.2 Tradable water pollution rights

Tradable water pollution rights are used for the protection and management of water quality. The water management authority establishes the maximum amount of emissions according to the carrying capacity of the ecosystem that is focussed on. The total amount of emissions is divided into a fixed number of permits or rights to pollute, which can be initially allocated to economic actors according to their past levels of pollution, known as grandfathering, or via auction. The holders can then trade the rights purchased in a secondary permit market. This means a polluting point source, which has low abatement costs, can sell permits to sources with high clean-up costs. The result is the total cost of reducing pollution is minimised as pollution-reduction efforts are carried out by economic actors who can do it at the lowest cost.[27,28]

Case 8.6: Tradable water abstraction rights: Fox Canyon Water Market

Ventura County, California, generates $2.1 billion from agriculture. At the same time, there is significant population pressure with around 450 people per square mile: around five times the average population density of the United States. With groundwater being a critical resource, the state passed the Sustainable Groundwater Management Act (SGMA) in 2014 to ensure the future sustainability of groundwater supplies. Following the passage of SGMA, The Nature Conservancy (TNC) applied for a Conservation Innovation Grant from the U.S. Department of Agriculture (USDA) to develop the Fox Canyon Water Market. The grant enabled TNC to provide support to the Fox Canyon Groundwater Management Agency and project partner California Lutheran University in their effort to establish a market-driven, producer-led approach to reducing groundwater pumping. Under a cap-and-trade-like system, agricultural producers in the Fox Canyon area are subject to fixed groundwater allocations based on historical use. Producers can then purchase or sell their unused allocation. The market is online, anonymous, and uses an algorithm-driven matching platform, resulting in a level playing field and a fairer deal for farming operations of all sizes. After years of development, the market exchange opened in March 2020. Still in its pilot phase, the market has already seen 58-acre feet of pumping allocations change hands. The successful launch of the pilot is due to a variety of factors including:

- *Water scarcity*: Water scarcity requires innovative solutions
- *Fixed allocations*: Participating producers voluntarily agreed to a fixed allocation of groundwater
- *Agricultural stakeholder support*: From the beginning, the project has been collaborative, and producer-driven
- *Market design expertise*: The project leveraged the experience of TNC and partners in designing environmental markets, including robust pilot testing
- *Capacity and funding*: TNC provided robust planning and oversaw stakeholder engagement efforts to provide expertise and gain support from the USDA[29]

Case 8.7: Tradable water pollution rights: Ohio River Basin Trading Project

The Ohio River Basin Trading Project is the United States' first interstate trading plan signed by Ohio, Indiana, and Kentucky in 2012, making it the world's largest water quality trading programme. The project, which has been extended through 2020, achieves water quality goals by allowing permitted dischargers to purchase nutrient reductions from another source. The cost of reducing nutrient discharges can differ from one emitter to another, and water quality trading provides an option for meeting discharge requirements in a cost-effective manner. The project is voluntary with the incentive to participate based on credit sellers receiving attractive financial benefits from the selling of credits and the permitted dischargers having the flexibility to cost-effectively meet their environmental permit requirements. Measures of success during the pilot include:

- Identifying and overcoming barriers to successful full-scale roll-out
- Implementing trading mechanisms that are ecologically effective and acceptable to participants and other stakeholders
- Promoting early, voluntary participation
- Measuring the extent to which the broader ecosystem services can be supported through the project
- Establishing the full suite of systems and protocols needed for a complete and compliant programme[30]

8.8 Payment for watershed ecosystem services

A Payment for Ecosystem Services (PES) scheme is defined as a voluntary, conditional agreement between at least one seller and one buyer over a well-defined ecosystem service, or land use that is assumed to produce that service. Globally, there are hundreds of PES initiatives that provide direct payments to landowners for undertaking specific land-use practices that can increase the provision of biodiversity conservation, prevent erosion, enhance carbon sequestration, and improve scenic beauty, as well as provide other ecosystem services that are of interest, directly or indirectly, to humans. PES initiatives must achieve the same level of environmental benefits at a lower cost than other possible policies to be effective.[31,32] Payment for Watershed Ecosystem Services (PWES) have been widely implemented in both developed and developing countries at different scales to resolve upstream-downstream conflicts, with the most common focus being on water quality, water quantity, and flow regulation.[33] For PES and PWES schemes to be both environmentally beneficial and cost-effective, the OECD recommends a set of 12 criteria to be followed when these schemes are developed:

1. *Remove perverse incentives*: For a scheme to be clear and effective, there should be no conflicting market distortions, such as environmentally harmful subsidies available
2. *Clearly define property rights*: The individual or community whose land-use decisions affect the provision of ecosystem services must have clearly defined and enforceable property rights over the land
3. *Clearly define goals and objectives*: The scheme should have clear goals to help guide the design of the programme, enhance transparency, and avoid political influence
4. *Develop a robust monitoring and reporting framework*: The monitoring and reporting of biodiversity and ecosystem services is fundamental, enabling the assessment of the programme's performance and improvements over time
5. *Identify buyers and ensure sufficient long-term financing*: There must be sufficient and sustainable financing of the scheme to ensure its objectives can be achieved
6. *Identify sellers and target ecosystem service benefits*: Payments should be prioritised to areas that provide the highest benefits
7. *Establish baselines and target payments to ecosystem services that are at risk of loss, or to enhance their provision*: The programmes should only make payments for ecosystem services that are additional to the business-as-usual baseline, in other words in the absence of the programme
8. *Differentiate payments based on the opportunity costs of ecosystem service provision*: Programmes that reflect ecosystem providers' opportunity costs via differentiated payments can achieve greater aggregate ecosystem service provision per unit cost

9. *Consider bundling or layering multiple ecosystem services*: Joint provision of multiple services can increase the benefits of the programme while reducing transaction costs, especially if finance for multiple benefits is available
10. *Address leakage*: Leakage occurs when the provision of ecosystem services in one location increases pressure for conversion in another. If leakage is potentially high, the monitoring and accounting framework can be expanded to enable assessment of potential leakage so measures can be implemented to address it
11. *Ensure permanence*: Events, such as disasters, may undermine the ability of a landowner to provide an ecosystem service as stipulated in the agreement. If the risks are high, this will impede the effective functioning of the market, and so insurance mechanisms need to be considered
12. *Deliver performance-based payments and ensure adequate enforcement*: Payments should be ex-post, conditional on ecosystem performance. If this is not possible, effort-based payments, for example, improvements in management practices, are a suitable alternative. There should also be disincentives for breaching the agreement which is enforced[34]

Case 8.8: Milwaukee River Pay-for-Performance Project

Over the period 2013–2017, the Milwaukee River Pay-for-Performance Project, funded by the Great Lakes Protection Fund, rewarded farmers for improving water quality by reducing phosphorous loss from agricultural land in the West Branch of the Milwaukee River, a 58 square-mile Wisconsin watershed. Farmers were rewarded according to science-based outcomes where the environmental impacts of farmer-selected conservation practices were tracked, and payments made based on verified environmental improvements. A pay-for-performance approach was taken as it is data-driven and science-based, results in measurable water quality improvements, is cost-effective for farmers and conservation programmes, provides flexibility and allows for farmer innovation, and expands market opportunities for water quality trading. The project had five steps:

1. Farmers implement the most appropriate and cost-effective strategies for their farm
2. Science-based models predict less phosphorous entering the stream
3. Farmers are paid based on modelled farm-level results
4. Water quality improvements are monitored and verified
5. Farmers are paid based on monitored watershed-level results

The farmers were paid by wastewater treatment plants or other downstream entities that needed to meet water quality obligations as well as conservation programmes that wished to show measurable water quality outcomes. Overall, by changing field management practices, participating farmers reduced phosphorous losses by as much as 40 percent.[35,36]

8.9 Green bonds

Green bonds can help mobilise resources from domestic and international capital markets for climate adaptation and other climate and environmentally friendly projects. They are like conventional bonds, but the proceeds are invested in projects that generate climate and environmental benefits such as sustainable land use, biodiversity, and clean water.[37] To ensure green bonds genuinely contribute to climate and environmental targets, the following initiatives have been developed.

8.9.1 The Green Bond Principles

The Green Bond Principles (GBP), established by the International Capital Market Association, are voluntary process guidelines that recommend transparency and disclosure and promote integrity in the development of the green bond market by clarifying the approach for issuance of a green bond. The GBP recognises several categories of eligible green projects that contribute to the climate and environment, including climate change mitigation, climate change adaptation, natural resource conservation, biodiversity conservation, and pollution prevention and control. With regards to water management, the GBP provides an overview of eligible projects including sustainable infrastructure for clean drinking water, wastewater treatment, sustainable urban drainage systems, and river training and other forms of flood mitigation.[38]

8.9.2 Labelling scheme for green bonds

The Climate Bonds Initiative's Climate Bonds Standard and Certification Scheme is a labelling scheme for bonds. The scheme uses a rigorous scientific criterion to ensure the green bonds are consistent with the Paris Agreement and is used by bond issuers, governments, investors, and financial markets to prioritise investments that make genuine contributions to addressing climate change. The new Water Infrastructure Criteria has been developed that lays out the requirements that water infrastructure assets and/or projects must meet to be eligible for inclusion as a Certified Climate Bond, as summarised in Table 8.3.[39]

Table 8.3: The Water Infrastructure Criteria.

Step		Description
1.	Comply with mitigation component	Greenhouse gas emissions from water projects are not to increase. Instead, they are to comply with business-as-usual baselines or aim for emission reduction over the operational lifetime of the water asset or project

Table 8.3 (continued)

Step	Description	
2. Comply with adaptation and resilience component	The water infrastructure and its surrounding ecosystem are resilient to climate change and have sufficient adaptation to address climate change risks. To demonstrate this, the issuers should complete a scorecard made up of five sections:	1. *Allocation*: Addressing how water is shared by users within a given basin or aquifer 2. *Governance*: Addressing how/whether water will be formally shared, negotiated, and governed 3. *Technical diagnostic*: How/whether changes to the hydrologic system are addressed over time 4. *Nature-based solutions*: For nature-based and hybrid infrastructure, the issuers need to have sufficient understanding of ecological impacts at/beyond project site with ongoing monitoring and management capacity 5. *Assessment of the adaptation plan*: There needs to be a check of how complete the coping mechanisms are to identify climate vulnerabilities

Case 8.9: DC Water's green bonds

In 2014, the District of Columbia Water and Sewer Authority (DC Water) issued its inaugural green bond to finance a portion of the DC Clean Rivers Project. The $350 million issuance was the first certified green bond in the US debt capital markets with an independent second party sustainability opinion. It was also the first municipal century bond issued by a water utility in the United States. The proceeds of the green bond are used to construct green infrastructure practices to improve water quality by remediating combined sewer overflows, promote climate resilience through flood mitigation, and improve quality of life by protecting biodiversity and restoring waterfronts. By the end of 2019, DC Water's total green bond issuance was $650 million.[40]

8.10 Public-private partnerships

Public-private partnerships (PPP) are long-term, contractual agreements between a public entity and a private operator/company (or a consortium), under which a service is provided. PPPs involve a process where private operators bid for a contract to design, finance, and manage the risks involved in delivering public services or assets. In return, the private contractor receives fees from the public body and/or user charges for the long-term operation and maintenance of the asset. There are two types of green PPP projects:

– *Greenfield projects*: These projects develop new infrastructure, such as a new wastewater treatment plant
– *Brownfield projects*: In these projects, the private sector participates (as investors and operators) in existing infrastructure facilities[41]

For PPPs to be successful, a range of conditions need to be met:

– *Effective partnerships*: Effective partnerships are crucial to the success of PPPs. Unlike traditional procurement for assets or services, which use short-term contracts to acquire or renovate public assets, a PPP is a global contract that may last anywhere from 15 to sometimes more than 90 years. As such, establishing a real partnership based on cooperation, expertise, and credible commitment is essential. Also, the public body must acquire internal knowledge and expertise necessary to define the terms of the agreement
– *Interaction and negotiation*: Interaction and negotiation with an operator or operators during the call for bidders' phase can clarify objectives of the partnership and provide innovative technological solutions not yet envisioned by the public body. This is helpful for PPPs negotiated in an uncertain environment with complex technologies that vary in speed of obsolescence. For this phase to be successful, the public body needs to invest in gaining expertise and generating enough competition to challenge private operators
– *Clear environmental objectives*: Clear environmental objectives and their weights in the procedure to award PPP projects need to drive effective environmental-related PPPs. The addition of green requirements to the project specification after PPP design will be costly and likely incompatible with technological choices put in place. Also, environmental targets need to be measurable and clearly defined, with agreed-upon approaches for *ex-post* monitoring
– *Flexibility*: Flexibility is a crucial element of PPPs. Discussion with private operators for a PPP should focus on efficient and flexible solutions that allow for a quick response to changing requirements and new technologies. Also, the contract should describe and anticipate how the relationships evolve over time as soon as unanticipated events occur[42]

Case 8.10: The largest public-private partnership for wastewater operations in the United States
The City of Wilmington, Delaware, has selected an international engineering firm to operate and manage its wastewater treatment plant, combined sewer overflow facilities, and its Renewable Energy Biosolids Facility. The city is Delaware's largest with a wastewater operation serving more than 400,000 residents. The agreement, which combines the operations and maintenance of all facilities under the engineering company's management, has provisions for additional engineering studies and design-build projects to renew existing structures and develop value-added projects. The City estimates the base contract is valued at $20 million per year for an initial 20-year term, with options for two additional two-year extensions, for a possible contract term of 24 years. With the wastewater treatment plant having a maximum design flow of 168 million gallons per day (MGD) and up to 320 MGD in wet weather, the contract is one of the largest PPPs for wastewater operations in the United States. As part of the contract, the engineering company will improve the plant's performance and ensure it becomes a net-zero energy facility that reduces greenhouse gas emissions.[43]

8.10.1 Public-private partnerships for ecosystem restoration

Existing financial, legal, and policy mechanisms of PPPs are suitable for major ecosystem restoration initiatives, including protecting and restoring the health of rivers, improving water quality, restoring and enhancing significant areas of habitat, and sequestering significant quantities of carbon dioxide. PPPs are suitable for major ecosystem restoration initiatives as they provide a suitable framework for:

- Sharing costs and benefits between governments, investors, businesses, and the environment
- Leveraging private sector skills, capacity, and capital with strategically directed public funds
- Generating new models of achieving ecosystem restoration outcomes and improving cost effectiveness of ecosystem restoration programmes
- Combining public and private sector knowledge, skills, land, and capital in ways that could result in landscape-wide benefits
- Turning large scale landscape change into business opportunities, creating new asset classes

For the PPPs in ecosystem restoration to be successful, there needs to be:

- Measurable performance standards developed
- Government payments that flow to projects sequentially when they meet specified environmental service standards
- A relatively long-term commitment with the term depending on the nature of the project
- Either a dedicated party responsible for contracting with multiple providers or a government agency contracting directly to multiple providers

- Risk allocation defined at the contracting phase
- Outcomes monitored to determine the delivery of the specified ecosystem services and accompanying payment
- Where possible, project costings will be determined by competitive tendering processes or equivalent[44]

Case 8.11: The United Kingdom's Natural Environment Impact Fund partnering with the private sector
The Government of the United Kingdom's 25 Year Environmental Plan has made clear that while the public sector will continue to be an essential source of funding for the natural environment, this must be alongside private sector investment to protect and enhance the environment. In support, the government has committed £10 million in the Budget, from 2021, to support natural environment projects that attract private sector investment through the Natural Environmental Impact Fund. As part of this, the Department for Environment, Food and Rural Affairs (Defra), Esmée Fairbairn Foundation (EFF), and Triodos Bank UK have formed a collaborative partnership to encourage private sector investment in environmental projects that help tackle climate change and restore nature. Four projects that protect and restore valuable habitat have been selected to receive funding in a pilot scheme to encourage sustainable private sector investment in the natural environment. The projects, having been sourced and evaluated by Triodos Bank UK, will receive grant funding from Defra, the EA, and EFF to support their development, complete business plans to attract private sector investment, and deliver long-term environmental benefits and sustainable financial returns. The four projects are:

- *Devon Wildlife Trust's restoration of the Caen wetlands*: The wetlands site is one of the UK's most important sites for wetland birds but is under pressure from human impacts, climate change, and rising sea levels. The project is a bold and innovative proposal to create a stunning habitat and visitor resource in northern Devon. Alongside the restoration of the habitat, the development of the site for ecotourism through a visitor centre and other facilities will provide a source of income, with the seed funding being used by Devon Wildlife Trust to develop a business case for investment in this project
- *Rivers Trust's work on natural flood management in the Wyre catchment in Lancashire*: Hard engineering alone will not address future flood risk challenges, and natural solutions must supplement them. The seed funding will allow The Rivers Trust to work with the Wyre Rivers Trust, Environment Agency, United Utilities, Triodos Bank UK, Co-op Insurance, and Flood Re, to develop a financial instrument that would allow upfront investment from the private sector to be reimbursed by the beneficiaries of a healthier environment
- *National Farmers Union's (NFU) work to reduce nitrate pollution in Poole Harbour*: One of the largest natural harbours in the world, Poole Harbour in Dorset is of international importance to wildlife. However, it is under pressure, with nutrients such as nitrate from agriculture in its catchment flowing down into the harbour and leading to a rapid growth of algae which smothers the estuarine habitat and reduces the amount of food available for birds. Through the Poole Harbour Nutrient Management Scheme, the NFU is aiming to work with and support the farmer-led collaboration in the catchment, equipping them with tools to reduce their use of nitrates. The proposed innovative, industry-led model is designed to offer both environmental benefits and productivity gains for farming businesses while the local community, water companies, and local government will all see benefits from the improved water quality
- *Moors for the Future Partnership's restoration and conservation of peatlands in the Pennines*: Peatlands have a vital part to play in tackling climate change, storing more carbon than all other types of vegetation in the world combined, and damage to peatlands is a significant source of

carbon emissions. The Moors for the Future Partnership is already working to restore and conserve peatland in the area but needs to attract greater investment to carry out this work on a larger scale to protect more of this vital habitat. It is hoped this project will be successful in developing a range of returns, including financial, for investors[45]

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Chapter 9
Best practices and conclusion

Abstract: To ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future, water managers will need to implement innovative water management technologies to conserve and recycle and reuse water, produce renewable energy and recover valuable nutrients from wastewater, protect and restore water quality at various scales, and improve the overall management of water resources. The financing of these technologies can be implemented through a variety of innovative financial instruments and approaches.

Keywords: Water conservation, Water Recycling, Renewable Energy, Nutrient Recovery, Green Infrastructure, Water Quality, Smart Meters, Economic Instruments, Finance Instruments

Introduction

Based on the case studies, the following best practices have been identified for other regions of the world implementing innovative water management technologies that ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future.

9.1 Conserving and recycling and reusing water

From the case studies of locations conserving and recycling and reusing water, a variety of best practices have been identified for other locations to implement:

- *Uniform water rates for equitability*: Uniform water tariffs across regions promote transparency, cost-effectiveness, and equitability for all water users
- *Water rates based on reliability of supply*: Water rates can be lowered for farmers in exchange for lower water supply reliability during water shortages or emergencies, allowing the water to be reallocated to commercial and industrial customers, who pay for full reliability benefits
- *Smart meters and leak detection*: Smart meters can send high-resolution water flow information back to water utilities, enabling the quick identification of leaks in the system
- *Real-time leak detection*: Fibre optic cables can be used to detect, in real-time, leaks in water pipe networks. The technology enables engineers to continually

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monitor the pipeline for leaks and other events in the network by creating thousands of virtual sensors along the sections of the pipeline being monitored
- *Enforcement fines during drought restrictions*: During times of droughts, water restrictions can include the use of fines for non-compliance
- *Water efficiency labelling schemes*: Water efficiency labelling schemes reduce the demand for high-quality drinking water by informing consumers about water efficiency at the point of sale. Effective labels are those that allow consumers to quickly compare the water efficiency of different products as well as see the product's rate of water consumption
- *Water conservation education programmes*: Water utilities can offer a range of programmes to help communities learn about water conservation and related issues. A variety of formats can be used including:
  - Utility representatives speaking at community events on request
  - Conducting musical plays for children to learn about the importance of saving water
  - Creating mobile water labs for students to learn about water pollution as well as the importance of conserving water
- *Demonstration projects*: Water utilities can create demonstration landscape gardens to show customers that water-wise plants are not only sustainable but beautiful as well. The gardens can have interactive features, including each plant having a unique QR code for information on watering requirements. An interactive website can be established for customers to make lists of their favourite plants and download garden design plans
- *Decoupling wastewater flows*: Newly constructed housing can decouple wastewater flows, with blackwater, greywater, and stormwater separated and then treated separately:
  - Water-saving toilets concentrate blackwater for later biogas production
  - Greywater can be used for watering the garden or toilet flushing
  - Stormwater can be used to improve the local climate and recharge groundwater
- *Recycled water for non-potable use*: Wastewater treatment plants can produce recycled water for non-potable municipal use such as irrigation of sporting fields, industrial use in powerplants and mining activities, and agriculture use in irrigation systems
- *Indirect potable reuse systems*: These systems enable reclaimed water to be pumped into recharge basins for eventual use in drinking water supplies
- *Direct potable reuse systems*: These systems can be developed that meet the World Health Organization Guidelines
- *Recycled water blended with drinking water supplies*: Recycled water can be blended with treated surface water and/or groundwater to provide an additional level of safety

9.2 Generating renewable energy and recovering resources from wastewater

From the case studies of locations generating renewable energy and recovering resources from wastewater, a variety of best practices have been identified for other locations to implement:

- *Biogas for vehicle fuel use*: Sewage treatment plants can produce biogas for use as a vehicle fuel with additional biogas used for heating and electricity generation
- *Anaerobic digester gas*: Anaerobic digester gas can power combined heat and power (CHP) systems, with the electricity sold to energy utilities and the revenue generated used to offset the costs of operating the plant
- *Co-digesting of food waste and sewage sludge*: Food waste and sewage sludge can be co-digested with the biogas used to generate electricity to supplement the sewage treatment facilities' internal power consumption
- *Renewable energy from biosolids*: Wastewater utilities that currently provide biosolids for pasture improvement can also assess the feasibility of generating renewable energy from the biosolids along with other commercial opportunities for generating renewable energy from other organic waste streams
- *District heating networks*: Water utilities can use CHP units to provide low-carbon heat to district heating networks in the form of hot water
- *Floating solar panels*: Large-scale floating solar panels can be deployed on treated wastewater ponds
- *Decentralised renewable energy systems*: Wastewater treatment plants can meet their total energy demand through individual, decentralised renewable energy systems, including wind turbines, CHP units, and solar photovoltaic systems
- *Hydropower energy recovery*: Water utilities can install hydro-electric generators at wastewater treatment plants to capture energy from wastewater passing down drop shafts to ocean outfalls
- *Energy efficiency*: Water utilities can upgrade their wastewater treatment plants to reduce energy consumption, including the use of real-time control equipment to constantly monitor processes to ensure optimal conditions are maintained, using only the minimum amount of energy
- *Biosolids for farmers*: Water utilities can provide biosolids to farmers and offer a variety of services to help farmers maximise the potential of biosolids while complying with regulations
- *Recovery of resources from wastewater*: A variety of resources can be recovered from wastewater, including:
  - *Cellulose*: Wastewater treatment plants can use filters to separate cellulose fibres from toilet paper to produce commercial cellulose that has been cleaned, dried, and disinfected
  - *Bioplastic*: Bacteria can produce PHA plastic from wastewater treatment facilities

- *Sewage ash for brick production*: Water utilities can deliver leftover ash from waste-to-energy incinerators to brick producers for the manufacturing of energy-efficient, heavy-duty bricks for the construction industry
- *Minerals*: A variety of minerals can be recovered from industrial wastewater for reuse in other industries

9.3 Greening of grey water infrastructure

From the case studies of locations implementing green infrastructure solutions to manage stormwater and improve water quality, a variety of best practices have been identified for other locations to implement:

- *Rebates for rainwater harvesting systems*: Water utilities can provide rebates for the installation of rainwater harvesting systems. The application can require property owners to attend a workshop to learn about best management practices (BMPs), and how to develop a rainwater harvesting project plan
- *Green infrastructure community adoption*: Water utilities can create green infrastructure community adoption projects to foster community engagement and ensure they are managed effectively with the regular removing of rubbish and reporting of any issues
- *Renaturalising waterways*: Cities can renaturalise concrete canals, turning them into picturesque rivers that foster wildlife, while green infrastructure solutions can be installed on adjacent parkland to store excess stormwater while also filtering contaminants
- *Multipurpose stormwater management ponds*: Cities can create stormwater management ponds that, in addition to managing excess stormwater, provide water conservation opportunities with the pond's water used for irrigation during the summer months
- *Smart blue-green roofs*: Public-private partnerships can be formed to build interconnected networks of smart blue-green roofs in cities. Each roof can have smart flow controls that anticipate heavy rain or drought, releasing or retaining water accordingly. The blue-green roofs can be connected in a smart grid, enabling real-time data exchange for dynamic water level management
- *Retrofit of streets with permeable pavement*: City departments can partner with the private sector to retrofit streets upstream of flood-prone areas with durable, permeable pavers
- *Green street technical guidelines*: Cities can develop green street technical guidelines that provide standards for the development of streets with green infrastructure solutions that manage stormwater runoff as well as yield significant environmental benefits

- *Multifunctional flood retention areas*: Water authorities can build new multifunctional flood retention areas to protect urban locations with sporting fields, public facilities as well as farmland used as temporary flood storage areas

9.4 Protecting and restoring water quality in river basins

From the case studies of locations implementing river basin planning and other initiatives to protect and restore water quality, a variety of best practices have been identified for other locations to implement:

- *Monitoring networks*: River basin authorities can establish monitoring networks that monitor physical, chemical, and biological conditions in the river and its tributaries. Yearbooks can be published that provide an annual overview of pollution levels as well as long term trends for water quality in the basin
- *River basin water quality trading programmes*: These programmes can be established to fund agricultural practices that either solely focus on reducing nutrient loading of waterways and ecosystems, or improve water quality while achieving a range of secondary benefits, such as habitat enhancement and increased social benefits to farmers
- *Funding Agricultural Best Management Practices*: Farm stewardship programmes can be developed to provide agriculture producers with funding to implement BMPs that improve water quality, reduce greenhouse gas emissions, enhance the resilience of the agricultural sector, and maintain biodiversity
- *Stormwater credit programmes*: Cities can create stormwater credits that are performance-based to encourage creativity, provide flexibility, and enable property owners to pursue technologies best suited for their properties and needs, as permitted by existing by-laws, codes, and regulations
- *Public demonstrations*: Water utilities can use small-scale, hands-on models that demonstrate at public events how green infrastructure can reduce stormwater flooding and improve water quality in bays and other waterbodies
- *Land acquisition programmes*: Water utilities can implement land acquisition programmes to protect drinking water reservoirs and the watershed lands that surround them
- *Partnerships*: Water utilities can partner with non-profits to help farmers implement BMPs to control runoff
- *Cooperation with regulatory agencies*: Water utilities can work with regulatory agencies to review new developments in watersheds to ensure streams and reservoirs are protected

9.5 Smart digital water management and managing customers of the future

From the case studies of locations implementing smart digital water management initiatives, a variety of best practices have been identified for other locations to implement:

- *Water quality monitoring systems*: Water utilities can use water quality monitoring systems to ensure early warning detection of issues in their reservoirs. Monitoring buoys can send water quality data to operators to download and analyse, ensuring the best operational decisions are made
- *Predicting and preventing leaks*: Water utilities can take a data-led 'Internet of Things' approach towards predicting and preventing leaks in the water distribution network. Data generated from acoustic devices can be analysed to help control the flow of water and prevent pipe bursts and leaks happening. It also enables water utilities to repair any issues rapidly, minimising disruptions to customers
- *Optimising water pressure*: Water utilities can combine pressure management valve controllers with data systems to optimise water pressure across the network, which in turn reduces leakage
- *Real-time monitoring of distributed assets*: Upgraded SCADA systems allow water utilities to monitor distributed assets and perform predictive and reactive maintenance and are better able to respond to incidents, such as environmental spills promptly. Real-time and historical information can be made available to operations and strategic planning staff for informed decision-making
- *GIS platforms facilitating rapid repairs*: GIS platforms enable:
  - Employees to instantly see the locations of the water utility's assets and the property of other utilities, enabling the workers to speed up repairs and minimise public inconvenience
  - Asset management teams to assess the condition of the company's assets then analyse asset performance and make informed decisions about which assets need replacing first and where investments should be directed
- *High water usage alerts*: Water utilities can offer customers high water usage alerts when water usage is higher than average. The alert can be delivered via email or text message etc. The alert system can be provided in tandem with high-resolution data that enables customers to see their water consumption on a daily, monthly, and yearly basis
- *Smart networks*: Water utilities can install smart networks in city centres that provide near real-time information about what is occurring in the water network 24/7, helping utilities to identify and proactively fix leaks before they impact customers and commuters

- *Artificial intelligence*: Artificial intelligence programmes at water treatment plants enable water utilities to mine historical pump operational data and learn the most efficient pump configuration for any time of the day or week, reducing pump-related energy costs significantly

From the case studies of locations managing customers of the future, a variety of best practices have been identified for other locations to implement:
- *Green business challenges*: Cities and water utilities can create green business challenges that recognise businesses that take actions to protect the local environment while saving money and attracting new customers. Challenges can include water conservation with participants:
  - Fixing leaks
  - Ensuring water-using fixtures and equipment comply with existing codes and ordinances
  - Replacing or retrofitting water-using equipment
- *Water conservation contests*: These can be developed that encourage residential customers to show on social media how they are conserving water, with a range of prizes available for category winners
- *Smartphone apps*: Apps can be developed that enable users to report sightings of violations of water restrictions, with users able to photograph the water waste and then submit it to the water utility for further action
- *Real-time consumption data*: Water utilities can provide customers with their consumption data in near real-time. In addition to promoting water conservation, it enables utilities to plan and implement strategies to reduce or reallocate water consumption
- *Gamification*: Gamified social games can be created where consumers are encouraged to save water in return for points, badges, and prizes based on their actions
- *Social media*: Water utilities can use social media to engage customers on water conservation and protecting the environment in a light-hearted manner, including on the topics of how to save water, what should not be flushed down the toilets, and use of reusable bottles and drinking of tap water
- *Enhancing customers' experience*: Water utilities can enhance customers' experience across the water distribution network by:
  - *Providing real-time maps*: Providing online, real-time maps of rainfall events to encourage property owners to become aware of green infrastructure solutions
  - *Automatically detecting water quality issues*: Utilising robotic technologies to automatically detect any water quality issues that may arise in the water distribution system
  - *Installing smart meters*: Distributing smart meters to all new and existing domestic and non-domestic customers to encourage behavioural change towards

water conservation, optimise water demand management, and achieve greater operational efficiencies
- *Providing online leak detection maps*: Developing online water leak maps where customers can inform the water utility about a leak in their area and track the water company's progress in fixing it
- *Providing online customer forms*: Providing online forms for customers to report leaks, with a questionnaire so the water utility gains as much insight as possible before sending out a repair crew

9.6 Innovative financial instruments and approaches for water projects

From the case studies of locations implementing various innovative financial instruments and approaches to ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future, a variety of best practices have been identified for other locations to implement:

- *Increasing water and wastewater rates*: Water utilities can increase water and wastewater rates for both residential and industrial customers to raise additional revenue for capital expenditures
- *Water rate discounts*: Industrial water users can be offered discounted water rates if they implement water conservation initiatives
- *Stormwater fee credits*: Water utilities can provide stormwater fee credits for property owners that reduce runoff by implementing green infrastructure BMPs. The discount on the stormwater component of the water bill not only saves customers money but the utility too, all the while protecting and enhancing nature
- *Stormwater credit trading*: Water utilities can develop stormwater credit trading programmes where property owners and developers can earn revenue from installing green infrastructure on their properties. Grants can be provided to non-profits, including schools and institutes, to help them generate stormwater credits from their land
- *Pesticide taxes*: Pesticide taxes can be developed to reduce loadings of waterways, with the tax paid based on how much of an impact the pesticide has on health, nature, and groundwater
- *Subsidies for water technologies*: Governments, including water utilities, can provide subsidies for investments in pre-approved green technologies, including those that are water related, as well as subsidies for investments in bespoke green technologies, including water-related technologies, that promote circular economy thinking
- *Tradable water abstraction rights programmes*: These programmes can be developed by partners across the public, private, and non-profit sectors to encourage

agricultural producers to use their water efficiently and enable reallocation of water resources to those that value it the most

- *Tradable water pollution rights programmes*: These programmes can be developed by partners across the public, private, and non-profit sectors to enable permitted dischargers to meet their environmental permit requirements cost-effectively
- *Pay-for-performance projects*: These projects can be developed to reward farmers for improving water quality by implementing agricultural verified BMPs, with payments made by wastewater treatment plants or other downstream entities that need to meet water quality obligations
- *Green bonds*: Water utilities can issue green bonds with the proceeds used to construct green infrastructure practices to:
  - Improve water quality by remediating combined sewer overflows
  - Promote climate resilience through flood mitigation
  - Improve quality of life by protecting biodiversity and restoring waterways
- *Public-private partnerships*: There are a variety of ways public-private partnerships (PPP) can be implemented, including the following:
  - Municipalities can implement PPPs for the operation and maintenance of wastewater treatment plants, with contracts stipulating upgrades in operational efficiency and the meeting of renewable energy goals
  - Government agencies can financially support natural environment projects that attract private sector investment by developing dedicated natural environmental impacts funds. Collaborative partnerships encourage private sector investment in environmental projects that help tackle climate change and restore nature, including developing natural flood management schemes and working with farmers to improve water quality

Conclusion

In conclusion, as the century progresses, the water sector is facing increasing pressure from a wide range of climatic and non-climatic trends that challenge its ability to provide sustainable, reliable, resilient, and affordable water and water-related services that meets customers' expectations in the future. Traditionally, the water sector has been typically slow to evolve and incorporate new innovative solutions into existing systems in response to various challenges due to a number of barriers. Nonetheless, a failure to implement innovations in water management will expose the water sector to a variety of risks to human health, the environment, and infrastructure as well as reductions in the level of service customers have come to expect. To ensure the provision of sustainable, reliable, resilient, and affordable water and water-related services that meet customers' expectations in the future, water managers will need to implement innovative water management technologies to conserve and recycle and reuse water, produce renewable energy and recover valuable nutrients from wastewater, protect and restore water quality at various scales, and improve the overall management of water resources. The financing of these technologies can be implemented through a variety of innovative financial instruments and approaches.

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