From Source to Sea to Sustainability: Integrated Cycles in Wastewater and Nutrient Management

Complimentary Sourcebook for Teachers and Students, 2017

UNEP

GPA Global Programme of Action for the Protection of the Marine Environment from Land-based Activities

Global Partnership on Nutrient Management
GPNM

GLOBAL WASTEWATER INITIATIVE

Université Concordia University

FACULTY OF ARTS AND SCIENCE

Loyola Sustainability Research Centre

Note: this open access Sourcebook is intended for educational use only.

Preface

This Curriculum Sourcebook is intended to act as a guide for students, teachers, professionals, and lifelong learners to address the problems caused by two of the most pernicious water pollution sources of our time. It also aims to teach them how to they can begin to meet the challenges faced when establishing effective wastewater and nutrient management. It is increasingly evident that land-based sources of pollution are at least equally harmful to planetary health as sea-based sources such as intentional oil discharges and lost fishing gear. Indeed, the plague of microplastics in the oceans, a topic covered by another online course offered through United Nations Environment Programme (UN Environment) and the Open University of the Netherlands, is largely the result of litter from land-based sources. Two other major sources that we cannot ignore are the discharge of wastewater into aquatic ecosystems and nutrient runoff affecting waterways from agricultural and other sources. These discharges lead to eutrophication, algae blooms, and harm to many species and ecosystems, and can have a devastating impact on entire human communities.

While wastewater pollution and nutrient runoff are evident in freshwater and fluvial systems, the focus of this course is on impacts and solutions that pertain to coasts and oceans. Some of our case study material will refer to freshwater systems, however, so students should be prepared to tackle both of these scenarios.

The focus on oceans and coasts reflects the fact that the main catalyst driving the development of this course and sourcebook is the mandate of the **Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (the GPA for short)**. The GPA, hosted by UN Environment, is a global intergovernmental mechanism directly addressing the connectivity between terrestrial, freshwater, coastal and marine ecosystems. It aims to be a source of conceptual and practical guidance for national and regional authorities to devise and implement sustained action to prevent, reduce, control and/or eliminate marine degradation from land-based activities. Nutrient management, marine litter, and wastewater have been highlighted as priority source categories to address, giving UN Environment a strong mandate to continue its work on these issues. As part of its strategy to tackle these issues, the GPA Secretariat has established and is strengthening three global multi-stakeholder partnerships: the Global Partnership on Nutrient Management (GPNM), the Global Partnership on Marine Litter (GPML) and the Global Wastewater Initiative (GW^2I). These are in turn complemented by the Global Partnership on Waste Management (GPWM), which is hosted by the International Environmental Technology Centre (IETC) under the auspices of UN Environment.

Why take this course?

About one-fifth of the world lacks safe drinking water and almost half lack adequate sanitation. In developing countries, on average, about 90% of wastewater discharges directly into waterways, polluting the water that people use for drinking, bathing, and washing (Corcoran et al., 2010). Incidences of water-borne disease such as schistosomiasis and water-borne strains of tuberculosis are on the increase, accounting for 90% of infectious diseases in low-income countries. Added to that are the dangers of poisoning from toxic chemicals, pharmaceutical and personal care products, endocrine disruptors, and pesticides in waterways. The problem is not restricted only to low-income countries; even in the United

States, 40% of fresh water is considered “unfit” for drinking or recreational use because of biological and chemical factors (Pimentel et al., 2004). This is only the surface of a very deep problem that is leading to the degradation of vital ecosystems and the services they provide to all species.

Our intention is to demonstrate that people can manage the double threat of wastewater and nutrient runoff, given the right intentions, knowledge, institutional support, and other factors. Indeed, though the more egregious forms must be eliminated altogether, large levels of wastewater and nutrient runoff are inevitable in a densely populated world, and management should be viewed as an opportunity to utilize this waste as a resource with which we can pursue greater sustainability and community resilience. As the title of the course indicates, the complete cycle must be taken into account, from “Source to Sea” or “Ridge to Reef,” if we are to achieve sustainability in this vital area. The combination of these two environmental issues demands that we look at both urban and rural sources of pollution, and that we also take into consideration overarching ecological factors such as ecosystem services, the impact of climate change, and overexploitation of soil and marine resources.

This MOOC aims to share UN Environment’s knowledge base to global audiences in order to further awareness about the issue, build capacity at the local level, and empower policy makers, community organizers, students, and the general public to take meaningful action to protect their local communities and environment. Comprising eight modules, in addition to an advanced leadership track module, this course covers basic scientific information about hydrologic and nutrient cycles; the sources and impacts of wastewater and nutrient pollution; monitoring and assessment methods; innovative technologies and best field practices for management of this pollution; policy, governance, technology and institutional arrangements; financial and economic mechanisms to mitigate pollution and build long-lasting infrastructure; and case studies of effective wastewater and nutrient management from around the globe and at various scales. This multifaceted approach will help learners gain a holistic understanding of the importance of water in ecosystem health, human health, and its relation to important international agreements like the Sustainable Development Goals. All modules contain links to important websites, readings, and videos in order to enrich and deepen learning. This sourcebook provides complimentary reading material and will benefit both students and, where it is offered as a hybrid learning experience, teachers of the course.

Note: you may also be interested in the first MOOC developed by UN Environment and Concordia University, “Wicked Problems, Dynamic Solutions: the Ecosystem Approach and Systems Thinking”, available at: http://web.unep.org/ecosystems/resources/tools/wicked-problems-dynamic-solutions-ecosystem-approach-and-systems-thinking

The other MOOC developed between UN Environment and the Open University of the Netherlands, on Marine Litter can be accessed here: http://www.unep.org/gpa/gpml/MOOC.asp

The Advanced Leadership Certificate Track

Students will have the option of pursuing an “Advanced Leadership Certificate Track” after they complete the first eight modules of this course. This is designed not only for professionals who wish to try out their knowledge base on real-world problems, but also for students taking the course who want to go further with their studies. Professors and teachers offering the course as part of a "blended learning" package can also use the Advanced Leadership Certificate Track as a complement to classroom assignments that can be closely monitored and used to guide and encourage classroom discussions. For students taking the course entirely online, however, the grading system for the advanced certificate is based on peer-review: students will read and grade each other's papers/projects. We've provided a detailed outline of grading procedures in the online section of the course.

Funding

The development of the MOOC for Wastewater and Nutrients Management was jointly funded by the Governments of Norway and Sweden and the GEF-funded Global Nutrient Cycling Project. Concordia University has also contributed in-kind funding.

Authorship

The Loyola Sustainability Research Centre at Concordia University, Montreal, Canada, was commissioned to create a Massive Open Online Course (MOOC) in partnership with the GPNM and the GW^2I in 2016. The Centre worked with Montreal-based Knowledge One to compile the MOOC. This sourcebook has been lead authored and compiled by the Centre's former Director, Dr. Peter Stoett, a specialist in global environmental governance and human rights issues, with contributions from experts from the GPNM and the GW^2I, the Loyola Sustainability Research Centre, UN Environment, and its wider community of partners. Key contributors/reviewers include Christopher Cox, Noelia Gravotta, Birguy Lamizana, Nayereh Saborimanesh, Rebecca Tittler, Jillian Treadwell, Jaime Webbe, and Jerome Xu.

Summary Table of Contents

Module One: The "Source to Sea" Cycle: Land-Oceans Connections

Learning Objectives

After completing this module, students will:

1. Understand how the United Nations Sustainable Development Goals address fresh and marine water issues;
2. Be able to explain why there is a need for management of activities that pose pollution risk to freshwater and marine ecosystems;
3. Be able to evaluate the vulnerability of watershed and coastal zone fluvial systems to pollution;
4. Understand the basic concepts involved in the hydrologic, nitrogen, and phosphorus cycles, including the ways in which human activity interrupts or otherwise influences them.

1.1 Introduction: The universal importance of water

Students are taking this course at a vital crossroads in human and natural history as we struggle to cope with global anthropogenic demands and impacts on water sources. The 2015-2030 Sustainable Development Goals (SDGs) express international scientific and political consensus that the earth's oceans are in peril, and that there is an even more generalized problem with water sources. As we will see later in this module, we rely on the ecosystem services of the oceans and coasts for nothing less than our very survival.

Though one could plausibly argue that water is of such central significance for human survival it is relevant for all of them, there are two SDGs that pertain specifically to water resources. (The full list of the SDGs is available at: https://sustainabledevelopment.un.org/sdgs.) Goal Six is devoted to ensuring availability and the "sustainable management of water and sanitation for all." Its specific targets include:

6.1*: By 2030, achieve universal and equitable access to safe and affordable drinking water for all*

6.2*: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in*

vulnerable situations
6.3*: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials,* ***halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally***
6.4*: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity*
6.5*: By 2030****, implement integrated water resources management at all levels****, including through transboundary cooperation as appropriate*
6.6*: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*
6.6.a*: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes,* ***including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies***
6.6.b*:* ***Support and strengthen the participation of local communities in improving water and sanitation management***

As the bolded portions of this ambitious target list indicate, Goal Six is central to the educational mission of this course. Yet another SDG is focused on our primary water bodies, the oceans: SD Goal 14 calls on us to "conserve and sustainably use the oceans, seas and marine resources for sustainable development." Its target list, reflecting the input of experts, stakeholders, diplomats, and the public, is also an ambitious one:

14.1: *By 2025****, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution***
14.2*: By 2020,* ***sustainably manage and protect marine and coastal ecosystems*** *to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans*
14.3: *Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels*
14.4*: By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics*
14.5*: By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information*
14.6*: By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation*
14.7*: By 2030, increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism*
14.a*: Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and*

to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries
14.b*: Provide access for small-scale artisanal fishers to marine resources and markets*
14.c*:* ***Enhance the conservation and sustainable use of oceans and their resources by implementing international law*** *as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want.*

In addition to these two SDGs, water is embedded in other SDGs. Therefore, meeting the sustainable development targets in the SDG era without adequately addressing water-related SDG targets is highly unlikely, particularly in developing countries.

Taken together, SDG 6 and SDG 14 provide a clear mandate from the international community to deal with the ongoing problems of wastewater and nutrient runoff on a global scale in an integrated 'Source-to-Sea' or 'Ridge-to-Reef' approach within the next decade. This does not, however, imply this will be easy, since no two cases are the same. Rather, there are distinct sets of problems in different regions, which must be met with contextually pertinent, innovative, and unique solutions. The scope of these problems is indeed daunting, but the present moment of opportunity, and the widespread recognition that action must be taken in order to reverse the situation, should be inspirational for most students. In order to delve into more concrete issues, however, some background on oceans and coastal zones, the water and nutrient cycles, and general policy directions will be foundational.

1.2 Oceans and coasts

The National Oceanic and Atmospheric Administration (NOAA) of the United States puts it poetically enough: "The ocean is the lifeblood of Earth, driving weather, regulating temperature, and ultimately supporting all living organisms. Throughout history, the ocean has been a vital source of sustenance, transport, commerce, growth, and inspiration" (http://oceanservice.noaa.gov/facts/exploration.html). Oceans cover around 70% of the Earth's surface (Bollman et al., 2010) and contain 97% of the planet's water (NOAA, 2016), and despite the immense advances in oceanography that have been made in recent decades, more than 95% of the underwater world remains unexplored (NOAA, 2014). This is not surprising: the average depth of the ocean is about 3,688 meters and the deepest part of the ocean, named the "Challenger Deep" after the HMS *Challenger*, whose crew first sounded the depths of the trench in 1875, is almost 11km deep (NOAA, 2015)! However, as we will see, the parts of the ocean that are most affected by wastewater are the shallower coastal areas, along with the human communities that interact with the ocean on a daily basis, forming an ecosystem with a prominent human dimension, or what is commonly referred to as a **social-ecological system** (Berkes, Colding, Folke, 2003; Österblom, 2013).

It is difficult to overstate the importance of the oceans for human life. hey are a vital source of protein and many communities are highly dependent on ocean fishing for food and their economies. The astounding biodiversity found in oceans and especially in coral reef ecosystems contributes to our diet, our medicine and health care, and our cultures. But it is essential to understand the regulatory ecosystem services played by the oceans, since they can store much more carbon than the atmosphere and the terrestrial biosphere (plants and animals). You will learn about ecosystem services in Module One, but can access a very succint descritpion of them here: http://www.teebweb.org/resources/ecosystem-services/

As our greatest carbon reservoirs, oceans play an important role in the global carbon cycle. However, it takes centuries for carbon to reach the deep ocean because of the slow mixing rate of waters. Therefore, the current ocean's CO_2 uptake significantly lags behind its absorptive capacity through chemical processes. Unfortunately, anthropogenic CO_2 emissions are occurring at a faster rate than they can be absorbed by oceans, leading to ocean acidification and climate change.

Oceans are our primary carbon sinks – but marine ecosystems are also a **primary producer** of plant biomass, and roughly "half of the worldwide primary productivity is achieved by microscopically small plants, the phytoplankton, which grow and divide in the ocean" (Bollman et al., 2010:114). Various threats to phytoplankton, from acidification to warming temperatures to marine litter, threaten the entire food chain and therefore life on earth. We return to the essential role oceans play in the water and nutrient cycles below.

Coastal zones are also generally considered part of the ocean system: the ocean impacts the coast, and vice-versa, on a daily basis. This becomes especially clear when we look at land-based sources of marine pollution, and at the erosion of coastal land from waves. Indeed, many indigenous cultures, such as the Torres Strait Islanders in the south Pacific, do not make a clear distinction between land and sea but rather consider the land-sea interface as a continuum.

Since so many large urban zones are located on coasts, the link between humanity and oceans is a tight one. It should come as no surprise that coastal areas are among the most densely populated regions of the world. The populations in coastal zones are growing faster than in any other region on Earth, with coastal cities expanding accordingly. Experts estimate that over 40% of the world's population (i.e., more than 2.8 billion people) lives no more than 100 km from the sea, and this figure is likely to rise in the future (Cluster of Excellence "The Future Ocean," 2015). Thirteen out of twenty of the mega-cities with populations over ten million are located in coastal zones (yet another reason why the prospects of sea level rises associated with climate change are so troubling). In many regions, this human density is further boosted by the millions of domestic and international tourists who seek out the coasts for various forms of recreation, from bathing to fishing.

Around 90% of global fishery activity occurs in coastal waters. They are also the sites of important shipping routes and industrial facilities. Coastal areas contain important ecosystems and habitats that support biodiversity such as mangroves, coral reefs, seagrass meadows and salt marshes. Finally, they consolidate sediments flowing from rivers and influence many global processes in their role as a buffer between the land and sea. Mangroves (wetlands) are particularly important, containing tree species that can grow directly in seawater. Their roots are either permanently submerged or anchored in damp sediment. These are important buffers, protecting the inland from weather surges such as hurricanes or tsunamis, and are important habitats for fauna and fish, providing livelihood for coastal communities. Equally important are coral reef systems, usually found near shorelines, some of the most biologically diverse areas in the world. Approximately one quarter of all marine fish species inhabit tropical coral reefs, which makes them important areas for fisheries, but they also yield unique genetic material which can be useful for medical purposes.

Oceans and coasts provide multiple **ecosystem services** that contribute to human well-being and maintain conditions for life on earth. An overview is presented below:

- **Provisioning services**: fish and seafood, transportation, renewable energy, goods for jewellery or souvenirs, non-renewable resources, pharmaceutical ingredients and other biochemical substances, genetic resources. As mentioned above, over 90% of fishing activity takes place within coastal waters.
- **Supporting services**: water cycle, primary production, safeguarding biodiversity, nutrient cycle, maintenance of food web dynamics, maintenance of habitats.
- **Regulating services**: coastal protection by dunes, coral reefs and mangrove forests; maintenance of air quality through algal production of oxygen or ocean uptake of carbon dioxide; **maintenance of water purity by breaking down nutrients from wastewater and agriculture which enter the sea**; climate regulation through the transportation of heat by ocean currents and heat exchange between water and atmosphere; **maintenance of water purity by breaking down pollutants by means of dilution, chemical modification into harmless substances, or sinking and burial in the sediment.**
- **Cultural services**: Contribution to science and to natural history education, religious and spiritual value of marine landscapes and places near and in the sea, inspiration, recreation and tourism, aesthetic value, cultural heritage.

In short, oceans and coasts contribute to all dimensions of well-being. They provide material well-being to millions of people through services that offer food, employment, protection and a healthy environment. This course acknowledges this centrality and suggests ways we can work to make the relationship between human communities and coastal zones a more harmonious one, since oceans and coasts today must be conceived as threatened, complex adaptive systems. The multiplicity of threats to oceans and coasts are considered "**wicked problems**" (this is a term we define later in this text, but we cover this issue in more detail in the UN Environment-Concordia University online course on The Ecosystem Approach and Systems Thinking).

Oceans (and lakes) are continuously overexploited for resources such as fish, oil and natural gas reserves, sand, gravel, and rock, the extraction of genetic resources on the seafloor and coral reefs for the development of new pharmaceuticals. Future deep sea mining (such as ore mining on the seafloor) may further damage aquatic habitats, while aquaculture results in the release of marine litter, nutrient pollution, pharmaceuticals and pathogens.

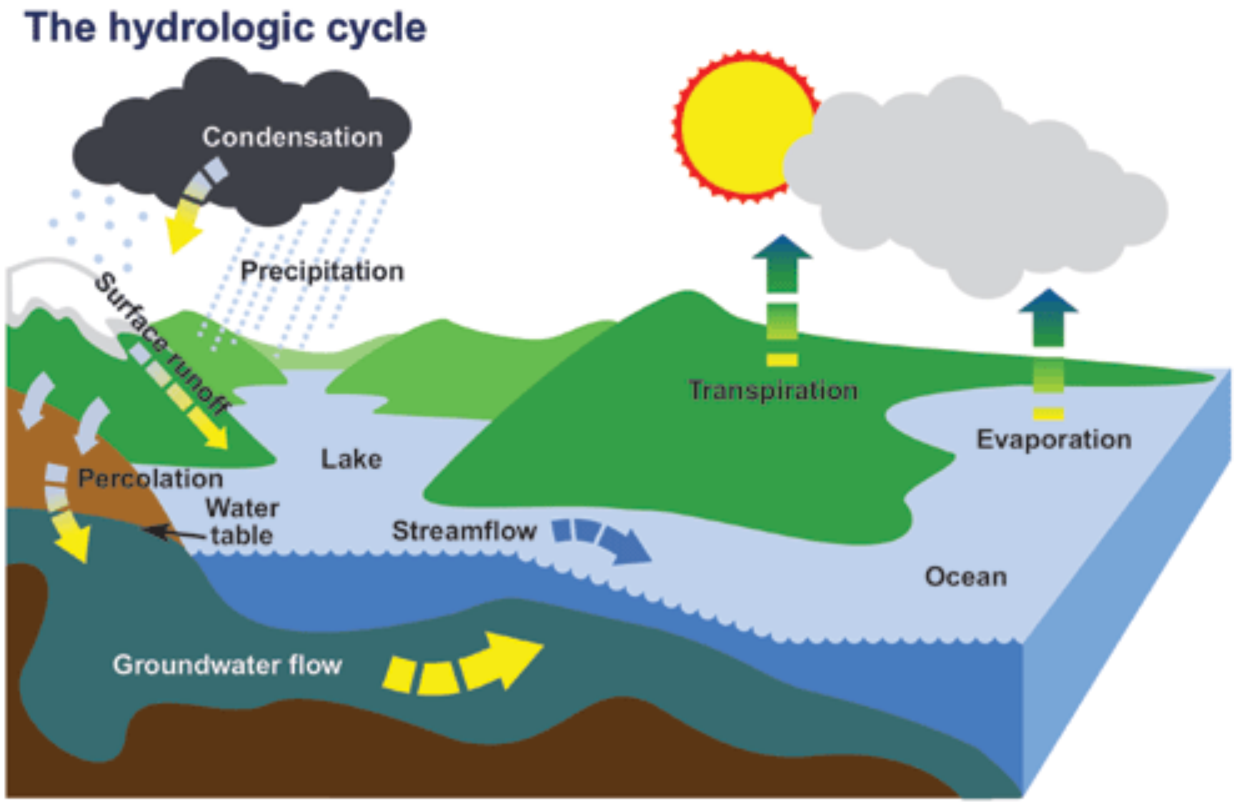
Habitat destruction results from many activities, including building projects and land reclamation; the clear-felling of mangrove forests for development or timber; the deliberate or incidental destruction of coral reefs as a result of coastal development, fishing, groundings of ferries, and tourism; and pollution of the seawater at the local level as a result of direct discharges of wastewater on the coast or from commercial vessels and cruise liners. The introduction of invasive species (sometimes via ballast water) remains an ongoing threat to biodiversity, as does underwater noise pollution and continued ocean acidification.

Equally important is the continued dispersal of marine litter (especially plastic, microplastic, and nanoplastic from land-based sources), wastewater (including emerging pollutants such as pharmaceuticals, personal care products, and endocrine disruptors), and nutrients (in particular phosphorus and nitrogen). These pollutants come from agricultural sources and untreated wastewater from domestic and industrial sources, resulting in the eutrophication of coastal waters. We expand on the drivers and impacts of this **point source** and **non-point source pollution** in the next module, but hasten to add here that wastewater and nutrient runoff remain primary threats to the environmental security and livelihoods of people living in coastal zones. Despite advances in technology, both of these problems are increasing as cities grow and agricultural and industrial production increase. In order to better understand these issues, we need to introduce some central concepts here, including the basic ideas behind the water and nutrient cycles that make our lives possible.

1.3 The water cycle

It is vital that we obtain a rudimentary understanding of the sources of water, the stages of the water (hydrologic) cycle, patterns of distribution, threats of scarcity, and the general, undeniable importance for human life of the hydrologic cycle. All wastewater management takes place within this broader context.

It may be hard to believe, but the water circulating on earth today, including the water that composes much of your own body, has been in a state of endless circulation since geological records indicate there was water on earth. Water circulates continuously between the land, water bodies, and the atmosphere. Some of it remains on land for extended periods of time in the cryosphere, the frozen parts of earth, in the form of ice. For the most part, however, the sun heats ocean water, causing evaporation, and thus water vapour rises to the clouds (some water also rises from transpiration from plants). The vapour condenses as it cools in the atmosphere, forming clouds which eventually release water in the form of rain, snow, or ice. When this water falls to the ground in the form of precipitation, it refills water bodies and feeds plants. Much of the fallen precipitation percolates into the underground water table, from where it enters groundflow and is either stored in aquifers or re-enters water sources. Some of it is stored as snow or ice in colder and higher regions; when it melts, it re-enters the cycle, permeating as groundwater or evaporating. When lakes, ditches, and other forms of water storage (including the absorption of soil and plants) overflow, this produces runoff (containing nutrients and pollutants) into water sources such as lakes and oceans. The image below neatly summarizes this ongoing process, so vital for human and other forms of life on earth. When we capture and use water for our own purposes, we are not removing it permanently from the hydrologic cycle. We are merely borrowing it, so to say, on a temporary basis. We create many problems if the habitual use of excessive nutrients in agriculture and other human systems intersect with the hydrologic cycle; we return to these issues in the next chapter.



SOURCE: Government of Canada, Environment and Climate Change Canada, Water Basics: The Hydrologic Cycle, accessed July 20 at: https://www.ec.gc.ca/eau-water/default.asp?lang=En&n=23CEC266-1

1.4 Biogeochemical nutrient cycles: nitrogen and phosphorus

Equally important to the water cycle are the various nutrient cycles, in particular the nitrogen and phosphorous cycles, which sustain life on earth. Though there are many nutrients necessary for effective agriculture (see the table below), it is generally recognized that nitrogen and phosphorus are the most important. These two nutrients are central to the growth process on which we rely for our food, timber, biofuel, and many other products essential for human survival. This is summarized nicely by Chris Jury in a treatise on coral reef sustainability (see the list of helpful websites at the end of this module):

Nitrogen is required to build a vast assortment of critical compounds within living things. It forms the amine group in amino acids, which are the subunits of proteins. Many proteins are used as structural compounds (e.g., muscles, organs, bones, etc.), especially in ***heterotrophic*** *organisms. Many enzymes and other biomolecules (e.g., chlorophyll) contain nitrogen.*

*Phosphorus is critical to cellular respiration in the form of adenosine triphosphate (**ATP**). It is also required in the structure of DNA, RNA, cellular membranes and other substances.*

Phosphorylation and dephosphorylation are also ubiquitous processes that control many activities essential for cellular survival.

Yet both these nutrients can have a negative effect when overused or underused, since overuse results in excess nutrients impacting water, and under-use causes “nutrient mining” leading to soil degradation.

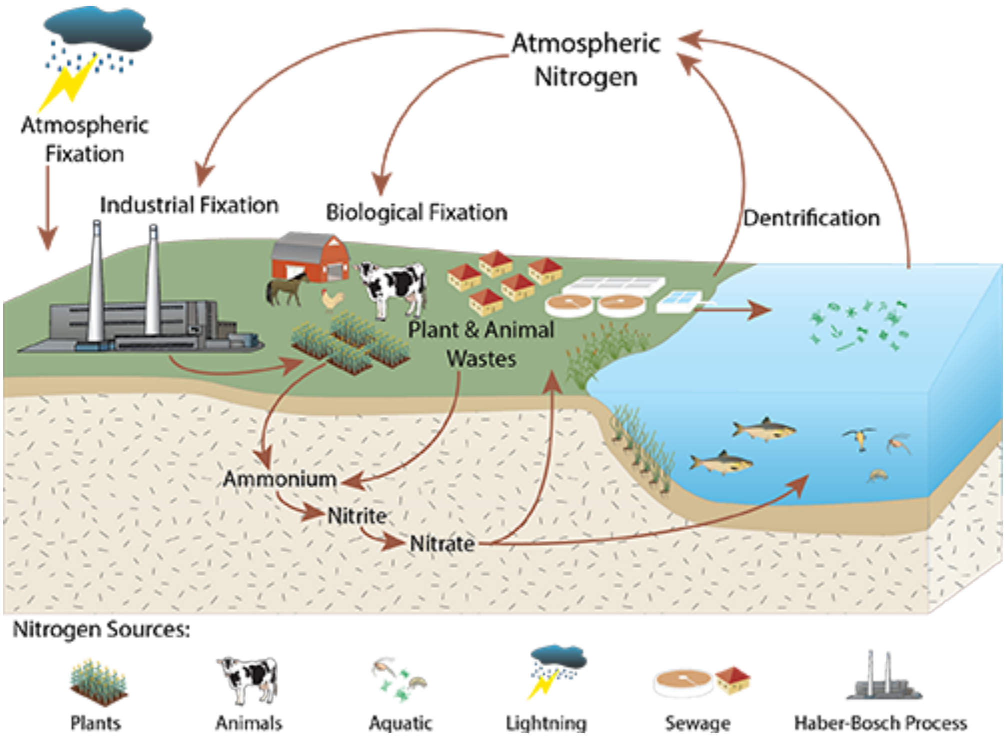
The Nutrient Table and Nutrients Needed for Agricultural Production

Nutrient	Where It Comes From	What It Does
Nitrogen (N)	The atmosphere	Essential in protein formation
Phosphorus (P)	Shallow rock deposits formed by decay of ancient sea life	Essential for photosynthesis and other cellular processes
Potassium (K)	Deep rock deposits left behind by evaporation of ancient seas	Helps produce higher quality crops
Calcium (Ca)	Found around the world in rocks such as limestone and dolomite	Strengthens plant structure
Magnesium (Mg)	China has replaced the United States as the largest supplier	Essential for chlorophyll formation
Sulfur (S)	Commercial deposits found in volcanic regions such as Japan, Indonesia, and Sicilly	Essential for production of amino acids
Boron (B)	Primary sources of borax ore are Turkey and the United States	Important for healthy cell growth and pollen formation
Chlorine (CI)	Salt deposits (sodium chloride) found around the world	Helps plants manage water stress
Copper (Cu)	Largest producers are Chile, the United States, Indonesia,	Important catalyst for chemical reactions within plant cells

	and Peru	
Iron (Fe)	Largest producers include China, Brazil, Australia, India, and Russia	Important catalyst for chemical reactions within plant cells
Manganese (Mn)	Most important sources are South Africa and Ukraine	Helps plants make chlorophyll and regulates several key enzymes
Molybdenum (Mb)	Keyproducers include the United States, Canada, Chile, Russia, and China	Helps plants use N and P more efficiently
Nickel (Ni)	Key producers include Canada and Siberia (Russia)	Helps plants regulate biochemical processes
Zinc (Zn)	Large deposits in Australia, Canada, and the United States	Helps plants form proteins, starches, and growth hormones

SOURCE: http://www.fertilizer101.org/science/?storyid=30

Much like water, nitrogen and phosphorus are continuously recycled through the atmosphere, land, and water. Nitrogen is the most common element in our atmosphere, and we all have trace amounts of phosphorus in our bodies. Humans also interfere with these cycles. For example, the chemical industry uses the **Haber-Bosch process** to combine dinitrogen gas with hydrogen to produce the reactive form of nitrogen called ammonia, which is then used for fertilisers. Today, "the chemical industry converts more atmospheric nitrogen into nutrient form than the combined action of all the nitrogen-fixing microbes over the entire globe" (Nuttle 2013). This ammonia is produced and used in order to ensure a stable and sufficient food production to support and feed the increasing world population.

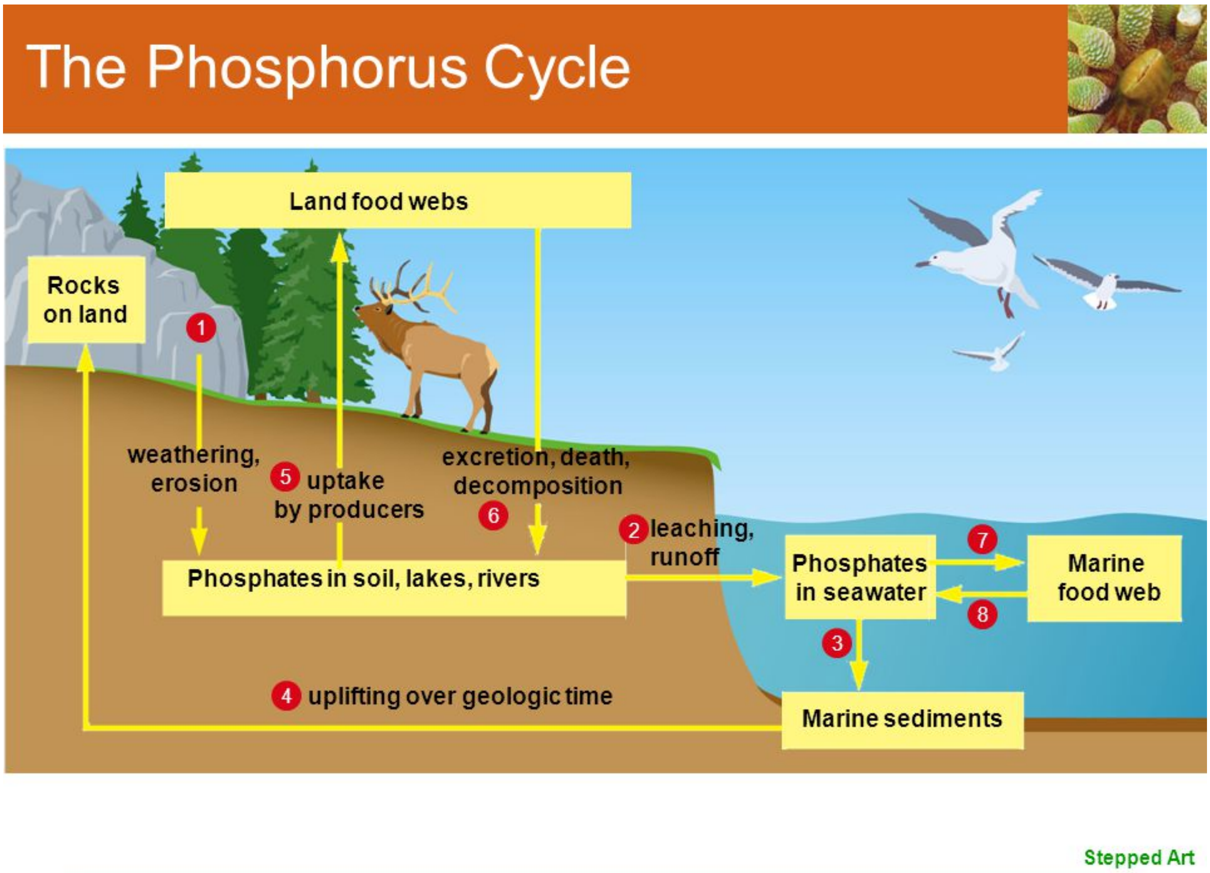


The Nitrogen Cycle

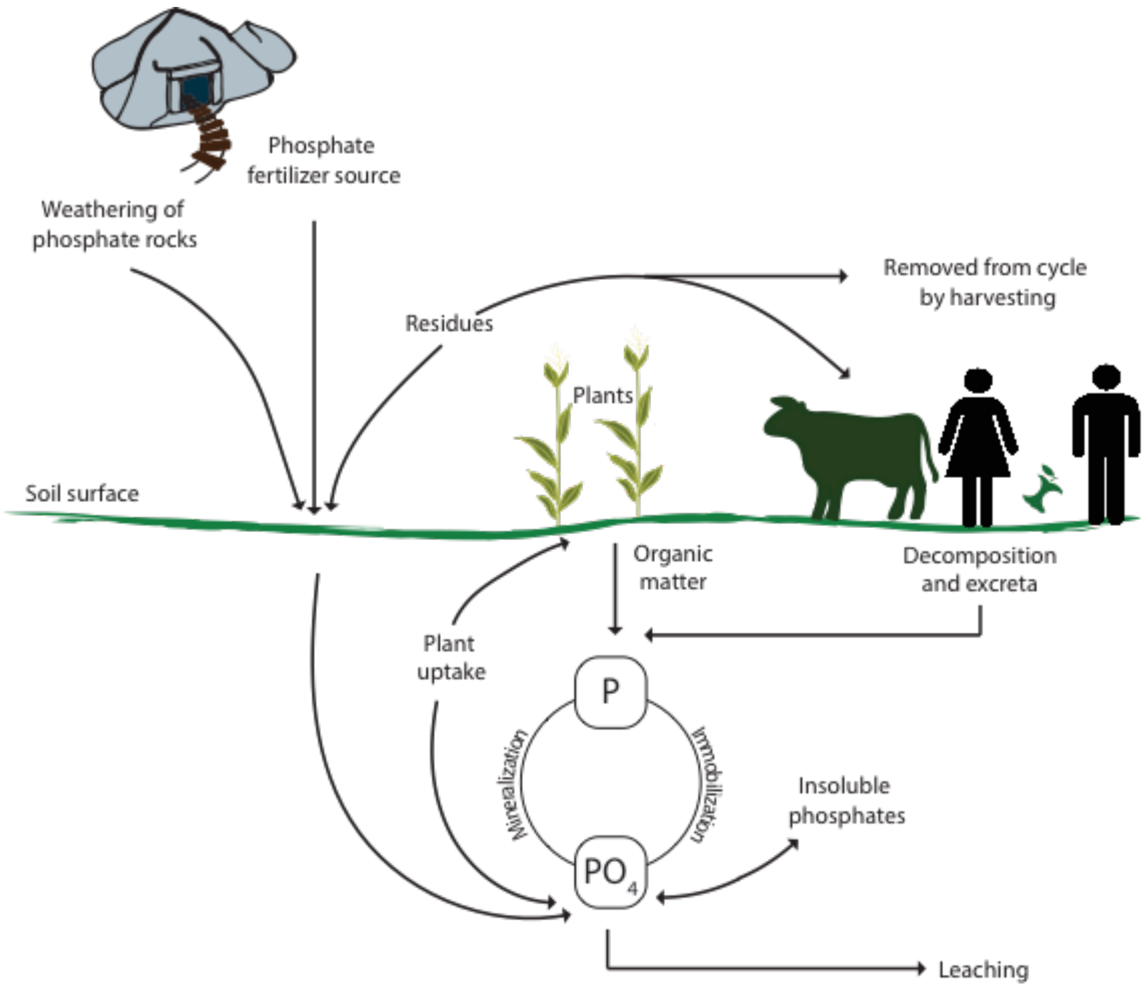
Source: William Nuttle, Integration and Application Network of the University of Maryland Center for Environmental Science. http://ian.umces.edu/blog/2013/04/26/celebrating-100-years-of-industrial-nitrogen-fixation/

The figure above offers a relatively clear image of the nitrogen cycle, as well as the human intervention that has taken place in order to optimize agricultural output. You can find much more detailed and scenario-based descriptions with a quick web search, and we have included helpful website URLs at the end of each module in this sourcebook and in the MOOC itself. A highly recommended source is the UNEP/GPNM report "Our Nutrient World" accessible at http://www.unep.org/gpa/documents/publications/ONW.pdf. Basically, we have doubled the amount of reactive nitrogen in terrestrial and aquatic ecosystems. This is yet another example of how we have effectively entered the **anthropocene**, fundamentally altering the life support systems on which humans have relied throughout their physical and social evolution. We will return to the unintended consequences of these developments in the next module.

With phosphorus, the cycle is quite distinct because there is no atmospheric component in the system. Instead, the cycle runs only through the **lithosphere**, **hydrosphere**, and **biosphere**. Because phosphorus derives in part from decomposition of organic material and in part from the dissolution of rock formations, its cycle involves a very long time-frame. Therefore, when it is found in deposits such as those in Northern Africa and can be used immediately, it is a highly attractive resource. Again, there are many representations of the phosphorus cycle available on the web, and students are encouraged to conduct a survey and compare them.



The Phosphorus Cycle Overview
From the textbook *The Unity and Diversity of Life*, by Cecie Starr, Ralph Taggart, Christine Evers, and Lisa Starr. 13th edition. 2013.



The Phosphorus Cycle in Depth
Image adapted from United States Environmental Protection Agency

Unlike nitrogen, we can only access significant quantities of this element through the environmentally-disruptive mining of phosphate rock, which is a finite resource. Phosphate mines are located in over 30 countries including China and the U.S., with the largest known reserves in Morocco. Some scientists posit the notion of "peak phosphorus," wherein easily-accessible reserves will run out by mid-century – either precipitating a global food crisis or forcing companies to turn to rock laden with impurities (some of these toxic in nature) or to mine offshore, thereby increasing the environmental impact of phosphate mining (Cordell, Dranger, and White 2008; also see Gilbert 2009). However, most experts argue that phosphorus availability is not an issue in the short- to medium-term. Data from the US Geological Survey (USGS) suggests that, at current consumption levels, existing reserves would last over 350 years. The International Fertilizer Development Center (IFDC) has reported higher reserves than were previously thought to exist, which means that along with improved extraction efficiency, reserves would last many hundreds of years at current consumption rates (Van Kauwenbergh 2010). These experts still note, however, that it is imperative to achieve sustainable use of phosphorus through increasing use efficiency, reducing phosphorus losses (for instance, runoff into the ocean), and improving phosphorus recycling from waste in order to be reused (Scholz and Wellmer 2015).

Much like nitrogen, this key nutrient is in oversupply in some regions, but severely undersupplied in others where agricultural development is lagging. For both nitrogen and phosphorus, a more even distribution of these key resources is necessary if we are to pursue regional food security on a global scale. Moreover, as we will see in the next module, excess runoff of phosphorus has serious ecological consequences. However, technologies to recover phosphorus from sewage and animal wastes have enormous potential to provide for the world's phosphorus needs and close the phosphorus cycle, as we shall see in subsequent modules.

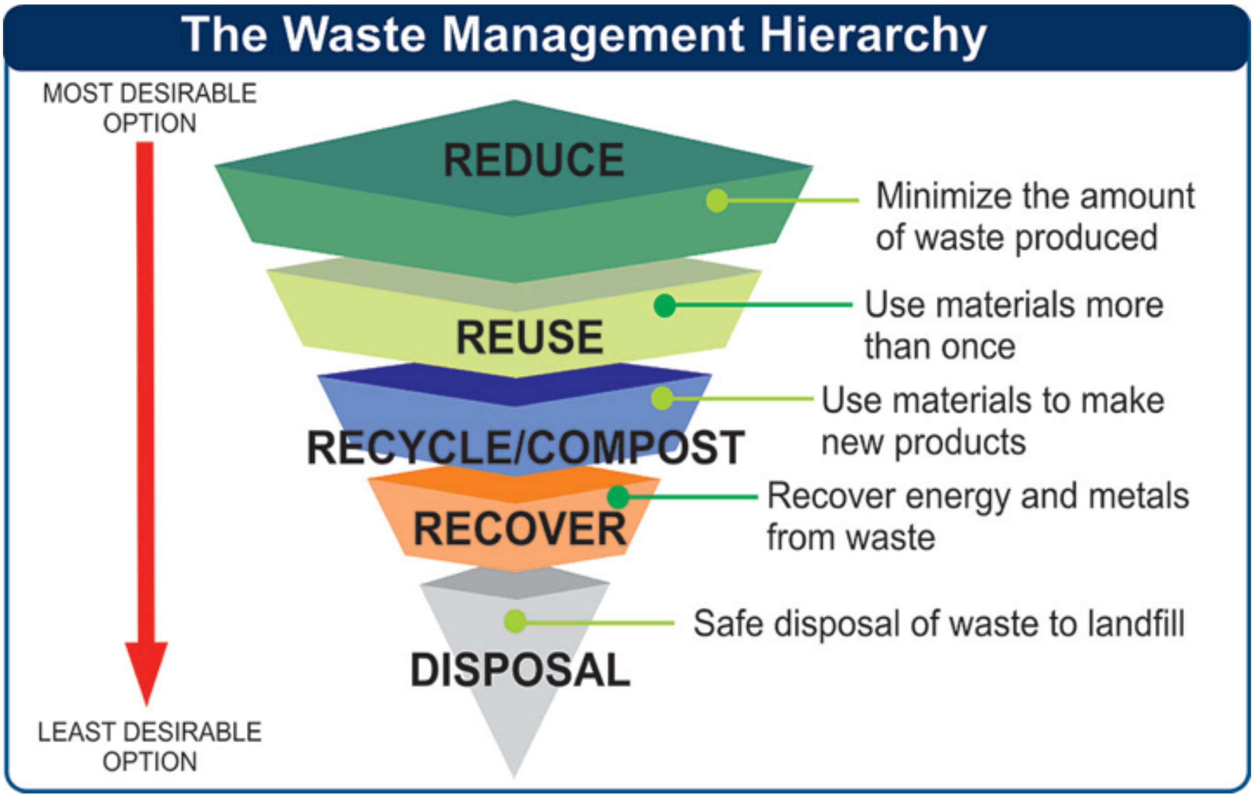
1.5 Holistic waste management

This course is based on the question of how the above biogeochemical cycles intersect with human activity, and how this dynamic influences the marine and coastal ecosystem services on which human communities rely for their own sustainability. How can we resolve the interrelated dilemmas that arise on a planet approaching a global population of 8 billion people? We will consider various technological and policy solutions throughout this course, but to begin, we must look at holistic waste management as one avenue toward managing this dilemma that tackles both wastewater and nutrient pollution.

Holistic waste management strives to take an integrated approach to waste management that looks at the waste cycle from start to finish, and addresses the generation, treatment, and recovery of waste, as well as the interactions between various waste and non-waste systems (Barr et al., 2013; Zotos et al., 2009). Conventional waste management programs are often "siloed", meaning that one sector takes care of the municipal solid waste, another deals with wastewater treatment, and others deal with stormwater management, industrial waste, air pollution, etc. Furthermore, conventional waste management is often disconnected from what are considered unrelated or outside sectors such as agriculture and energy departments.

While conventional waste management focuses primarily on short-term management and treatment of waste, holistic waste management uses a comprehensive approach to facilitate long-term, sustainable actions within the waste sector. By viewing the waste sector as part of a larger system, holistic waste management aims to avoid this "siloed" approach and often emphasises **circular economies** and zero waste structures. Holistic and integrated waste management systems consider how to prevent, reduce, recycle, and manage waste in ways that effectively protect the environment and human health.

These structures require compliance with a waste hierarchy that advocates first for waste prevention as the most desirable option followed by reuse, recycling, recovery, and finally disposal as the least desirable option (DEFRA UK, 2011). By reducing food waste and increasing the recycling of nutrients, this hierarchy allows us to reduce our demand on chemical fertilizers, which are generally mined (phosphorus) or produced through an energy-intensive process (nitrogen), and whose misuse pollutes our environment.



Source: https://www.durhamyorkwaste.ca/FAQ/FAQ.aspx

Beyond simply following a waste hierarchy, holistic waste management acknowledges that sustainable waste management fits into a larger system of resource use and recovery and considers some of the complex relationships between technology, policy, legislation, stakeholders, and waste management authorities.

Holistic waste management aims to reduce pollution and increase recycling and reuse. This means that beyond waste reduction, programs are in place that focus on converting waste material into valuable resources. This can be seen in the organic waste management sector where waste products from wastewater and solid waste are transformed into valuable, stable, and nutrient-rich end products such as struvite (a phosphorus-rich compound that can be precipitated from liquid waste streams and compost; see Childers, Corman, Edwards, & Elser, 2011; Elser & Bennett, 2011). These end products can then be reapplied to agricultural land thereby creating a circular loop for nutrients. Furthermore, some forms of organic waste management, such as anaerobic digestion, create biogas, which can be used as a substitute for fossil fuels. This interconnected process requires strong policies and communication between waste systems and other systems such as those surrounding food and energy.

Finally, holistic waste management acknowledges the unique variables associated with any particular location, and focuses on the development of plans that are most appropriate for that region. By doing all of this together, holistic waste management can help convert our discarded material into resources by maintaining some of their value, while also looking for ways to improve economic efficiency and social acceptability and reduce environmental burdens associated with waste generation and management.

We will return to the concept of holistic waste management throughout this course. It is a particularly challenging concept to apply to the source-to-sea context, but attempts have been made. For instance, below is a Swedish example of a holistic waste management and water provision system that has been put in place near Stockholm:

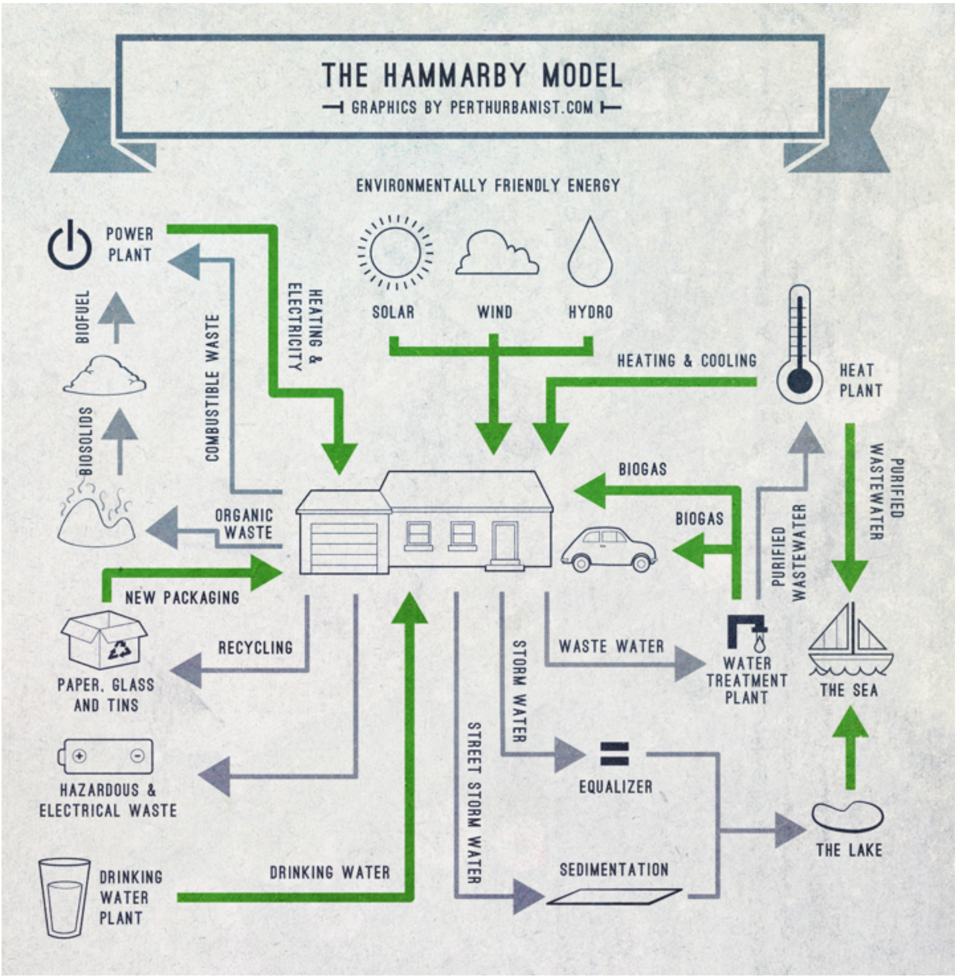


FIGURE REFERENCE: http://www.perthurbanist.com/images/hammarby.

Several things are apparent from this diagram. First of all, the system revolves around the common household, reflecting the residential area it is designed to service. Industrial or agricultural areas demand different designs – form follows function. Secondly, it is an intricate maze of interlinked systems, including at least two ecosystems, the lake and the sea. In fact it is even more complex than you can see here, since the hydrologic and nitrogen cycles are occurring as well. The system is designed for meeting some basic human needs, such as water and sanitation and energy, constantly proving its policy value to local politicians and planners. We will cover this example more in depth in Module Seven, when we examine case studies. A more generic conception of integrated or holistic waste management is provided below:

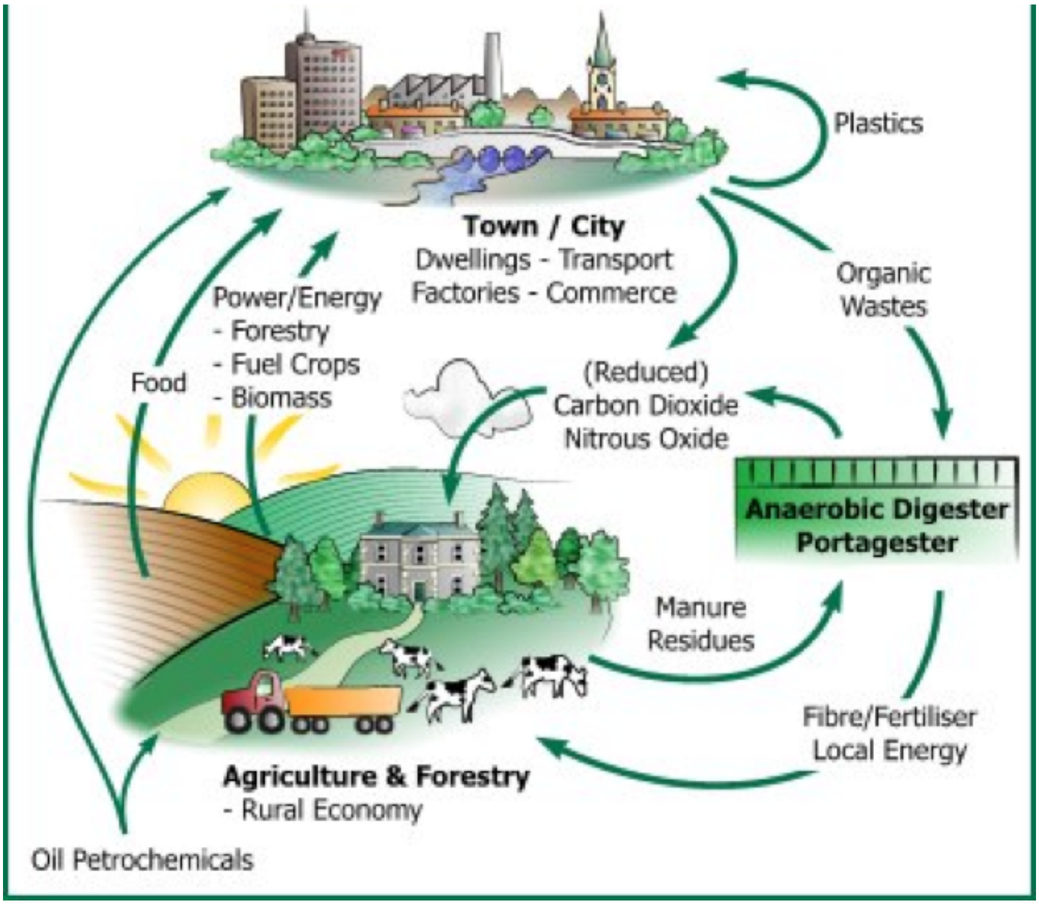


FIGURE REFERENCE: http://www.bioplex.co.uk/images/diagrams/CandN-Cycles.jpg

1.6 Conclusion

This introductory module stresses the importance of water and the ecosystems that support water provision and marine life, including the coastal regions that are so often adversely affected by wastewater and nutrient runoff. It also introduces the animating themes of the Sustainable Development Goals, the water, nitrogen, and phosphorus cycles, and the notion of holistic waste management. We turn next to a more detailed examination of the wastewater and nutrient management problems we face today.

Discussion Questions:

a) Of the important services provided by marine and coastal ecosystems, which ones affect your life most directly?
b) Do the Sustainable Development Goals related to water seem realistic to you?
c) What are the biggest problems related to wastewater management in your country, and what is your government doing to meet SDG 6.3 related to untreated wastewater?
d) . Discuss how fertilizer use benefits some stakeholders but at a cost to others.
e) What are the real (hidden) costs of our heavy reliance on nitrogen and phosphorus use?

Annotated Bibliography

Bollman, M., Bosch, T., Colijn, F., Ebinghaus, R., Froese, R., Güssow, K., et al. (2010). *World Ocean Review 2010: Living with the Oceans*. World Ocean Review: Living with the Oceans (Vols. 1-4, Vol. 1). Hamburg: Maribus, Future Ocean: Kiel Marine Sciences, International Ocean Institute, Mare. Retrieved from http://worldoceanreview.com/wp-content/downloads/wor1/WOR1_english.pdf. *This report provides a comprehensive, accessible and well-illustrated review of the complex state of the world's oceans and underline the urgent need for action. Important topics relevant to this module include the role of the ocean as a climate driver, the links between climate change and ocean chemistry, the uncertain future of the coasts, marine pollution and fisheries.*

Corcoran, E., C. Nellemann, E. Baker, R. Bos, D. Osborn, H. Savelli (eds). 2010. *Sick Water? The central role of wastewater management in sustainable development*. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. www.grida.no *This UN and UN-HABITAT assessment describes the current issues and trends affecting water globally.*

Steffen, W., Richardson, K., Rockström, J., Cornell, S., Fetzer, I., Bennett, E., Biggs, R., Carpenter, S. "Planetary Boundaries: Guiding human development on a changing planet." *Science* **2015**, *348*, 1217. *A landmark synopsis that covers the planetary boundaries approach, especially important for our examination here of the phosphorous cycle. This is an update to the original planetary boundaries paper published in the journal Nature in 2009, also worth reading:(http://www.nature.com/nature/journal/v461/n7263/full/461472a.html)*

Other Online Sources:

Introduction to wastewater pollution
https://www.youtube.com/watch?feature=player_embedded&v=itCOY7VviRU

Introduction to nutrient runoff:
https://www.youtube.com/watch?time_continue=130&v=nolsLLSpXeg

Transboundary Waters Assessment Programme (GEF TWAP): http://www.geftwap.org/. This project was a wide collaboration among many UNEP partners and has rich background resources...many good graphics and maps - lakes, rivers, large marine ecosystems, oceans.

Preventing Our Oceans from Becoming Dumps
https://www.youtube.com/watch?feature=player_embedded&v=uCXEHrmEYpM

National Science Foundation Water Cycle: https://www.youtube.com/watch?v=al-do-HGuIk

Michael Post explains the phosphorous cycle: https://www.youtube.com/watch?v=_IBx0zpNoEM

The phosphorous paradox: https://www.youtube.com/watch?v=qCZ89Tj5BRM

Chris Jury's well-written description of the nutrient dynamics of coral reefs and biogeochemical cycles, published in Reefkeeping: an Online Magazine for the Marine Aquarist: http://reefkeeping.com/issues/2006-08/cj/index.php

https://www.youtube.com/watch?v=D1xT2tevnIs *In this fascinating TED talk, biologist Mohamed Hijri brings to light a farming crisis no one is talking about: We are running out of phosphorus, an essential element that's a key component of DNA and the basis of cellular communication. All roads of this crisis lead back to how we farm -- with chemical fertilizers chock-full of the element, which plants are not efficient at absorbing. One solution? Perhaps ... a microscopic mushroom. (Filmed at TEDxUdeM.)*

http://www.thenatureofcities.com/2014/02/12/hammarby-sjostad-a-new-generation-of-sustainable-urban-eco-districts/ *A nice summary of the innovative and integrated city design implemented at Hammarby Lake City in Stockholm, Sweden.*

http://www.unep.org/gpa/ *The Global Programme of Action for the Protection of the Marine Environment from Land-based Sources website contains resources offering a variety of multimedia information and publications about both the Global Partnership on Nutrient Management (GPNM) and the Global Wastewater Initiative (GW^2I).*

http://www.geftwap.org/ *The Global Environmental Facility's Transboundary Waters Assessment Program (GEF-TWAP), with the goal of providing a global assessment program for groundwater, lakes and rivers, coastal areas, and the open ocean, similarly provides a wide array of resources.*

Module Two: The Problems: Wastewater and Nutrient Pollution

Learning Objectives

After completing this module, students will:

1. Understand and be able to describe the fundamental concepts behind the Drivers, Pressures, States, Impacts, and Responses (DPSIR) approach;
2. Be able to differentiate between point- source and non-point source pollution;
3. Recognize the human health impacts of wastewater and nutrient pollution.
4. Recognize and be able to categorize the drivers and impacts of wastewater and nutrient pollution;
5. Be able to formulate wastewater and nutrient management into fresh and coastal waters as both a public collective problem, and a collective opportunity to enhance sustainability;

2.1 Introduction: Wastewater and nutrient pollution as a problem and an opportunity

As the title of this course indicates, one of the keys to understanding a sophisticated approach to wastewater and nutrient management is that they can also be valuable sources of material for building sustainability. The $GW^2$1 website makes this clear:

*Properly managed wastewater is a **valuable resource** and a solution to more than one problem. It is a source of water and nutrients that can be used for crop production, reducing the need for scarce freshwater and fertilizers. Wastewater by-products can also be used to manufacture construction materials and to generate biogas and biofuel, thus providing opportunities for green jobs, sustainable development and social well-being.*

Nutrient recovery from wastewater is an excellent way to recover nutrients such as phosphorus and nitrogen which are essential to plant growth (including agricultural production) and are non-renewable (P) and energy intensive to produce synthetically (N). While P and N are essential for plant growth, they also present a distinct problem, which is that, when present in excess quantities, or in certain compounds they can lead to aquatic and atmospheric pollution. Effective recycling of nutrients from wastewater can allow us to recover valuable resources while limiting destructive pollution.

In this MOOC we are dealing with both **point source pollution** – where a discrete source of the pollution, such as a water treatment plant or an industrial discharge pipe, can be identified, and **non-point source pollution** (also known as diffuse pollution), which accumulates from diffuse sources that are difficult to precisely identify (see below).

What is non-point source pollution?

Non-point source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. Non-point source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. This pollution is caused by rainfall or snowmelt moving over and through the ground, excessive irrigation, and even wind gusts that blow elementally rich soil into water sources. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters.

Non-point source pollutants can include:

- Excess fertilizers, herbicides and insecticides from agricultural lands and residential areas
- Oil, grease and toxic chemicals from urban runoff and energy production
- Sediment from improperly managed construction sites, crop and forest lands, and eroding streambanks
- Salt from some irrigation practices and acid drainage from abandoned mines
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems
- Atmospheric deposition and hydro-modification

In the United States, state governments report that non-point source pollution is the leading cause of water quality problems. The effects of non-point source pollutants on specific waters vary and may not always be fully assessed. However, we know that these pollutants have harmful effects on drinking water supplies, recreation, fisheries and wildlife.
SOURCE: https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-sourcehttps://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-source

In developing countries, non-point source pollution is a growing issue as governments attempt to increase industrial and agricultural production. See Tonderski 1996, and: https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-source

https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/what-nonpoint-source

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2.2 The DPSIR Approach

Drivers, Pressures, State, Impact and Responses (DPSIR) is a framework employed by the European Environment Agency and others to articulate the interactions between the environment and society; the acronym stands for driving forces, pressures, states, impacts, and responses. This framework is based on the more commonly used PSR (pressure, state, response) model.

see: http://ia2dec.pbe.eea.europa.eu/knowledge_base/Frameworks/doc101182

It is not difficult to identify the primary causes of pollution today, though it is important that we avoid generalizations across regions and even between cities. But first, we need to distinguish between drivers, sources, and impacts. We are equally concerned about all three, but each leaves a different imprint along the cycle chain in pollution management. This is where the DPSIR approach comes in: it allows us to take a systems analysis view of the drivers, pressures, states, impacts, and responses when undertaking environmental analyses.

Drivers are economic sectors (such as the energy sector or the agricultural sector) and human activities (such as the use of water sources);

Pressures are the emissions and waste associated with those activities (such as the production of contaminated wastewater);

States are the current physical, chemical and biological condition of ecosystems;

Impacts are the influence pressures have on ecosystems, human health and capacity to engage in normal human activities, eventually leading to political responses such as prioritization, the development of indicators, and target setting;

(We discuss responses in subsequent modules, when we cover monitoring, policy responses, and financial mechanisms). See also Kristensen, 2004.

Impacts of Untreated Wastewater

By Magdalena Mis | September 1 2016

(Thomson Reuters Foundation) More than 300 million people in Asia, Africa and Latin America are at risk of life-threatening diseases like cholera and typhoid due to the increasing pollution of water in rivers and lakes, the United Nations Environment Programme (UN Environment) said.

Between 1990 and 2010, pollution caused by viruses, bacteria and other micro-organisms, and long-lasting toxic pollutants like fertilizer or petrol, increased in more than half of rivers across the three continents, while salinity levels rose in nearly a third, UN Environment said in a report on Tuesday.

Population growth, expansion of agriculture and an increased amount of raw sewage released into rivers and lakes were among the main reasons behind the increase of surface water pollution, putting some 323 million people at risk of infection, UN Environment said.

"The water quality problem at a global scale and the number of people affected by bad water quality are much more severe than we expected," Dietrich Borchardt, lead author of the report, told the Thomson Reuters Foundation.

However, a significant number of rivers remain in good condition and need to be protected, he said by phone from Germany.

About a quarter of rivers in Latin America, 10 percent to 25 percent in Africa and up to 50 percent in Asia were affected by severe pathogen pollution, largely caused by discharging untreated wastewater into rivers and lakes, the report said.

Some 3.4 million people die each year from diseases such as cholera, typhoid, polio or diarrhoea, which are associated with pathogens in water, UN Environment said.

It estimated that up to 164 million people in Africa, 134 million in Asia and 25 million in Latin America were at risk of infection from the diseases.

It said building more sewers was not enough to prevent infections and deaths, adding that the solution was to treat wastewater.

Organic pollution, which can cause water to be completely starved of oxygen, affects one kilometre (0.6 mile) out of seven kilometres (4.4 miles) of rivers in Latin America, Africa and Asia, threatening freshwater fisheries, UN Environment said.

Severe and moderate salinity levels, caused by the disposal of salty water from mines, irrigation systems and homes, affect one in 10 rivers on the three continents, making it harder for poor farmers to irrigate their crops, it said.

The trend of worsening water pollution was "critical", Borchardt said.

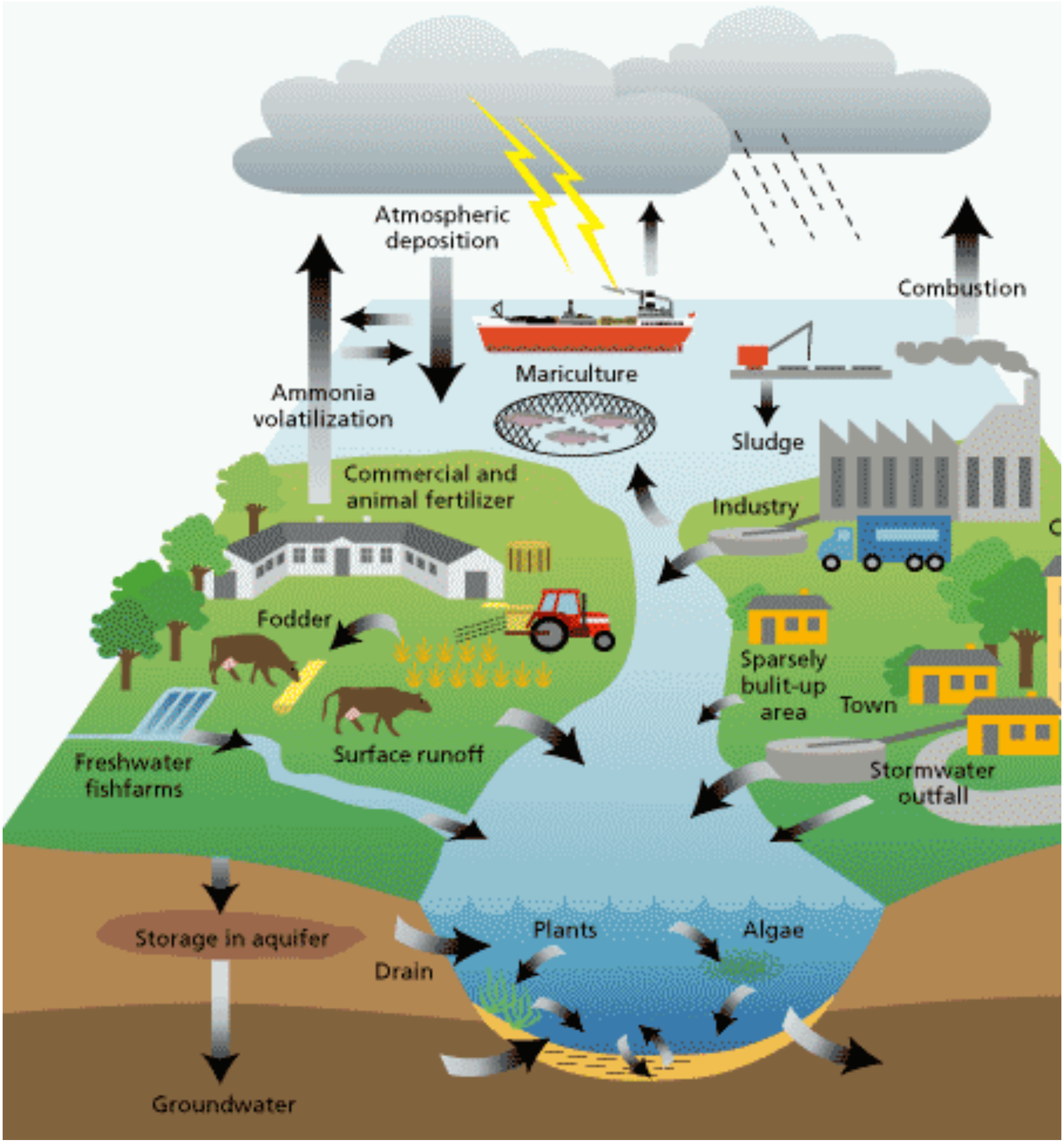
"It is much more expensive to clean up surface water from severe pollution than to implement proper management which includes prevention of pollution," he said. "Tools are available but the challenge is to implement them."

Source: http://sustainability.thomsonreuters.com/2016/09/01/more-than-300-million-at-risk-of-life-threatening-diseases-from-dirty-water-un/

According to the 2010 UN Environment /UN-HABITAT Sick Water Report, most untreated wastewater flows are generated in densely populated coastal areas, resulting in high levels of pollution of rivers, lakes, groundwater and coastal waters. The resulting de-oxygenated "dead zones," (caused by hypoxia or oxygen depletion through coastal eutrophication) are spreading, with impacts on fisheries, livelihoods and the food chain.

Wastewater produced from agriculture and livestock production constitutes a considerable challenge for downstream users, containing organic and inorganic contaminants originating from fertilizers, pesticides, human waste, livestock manure and nutrients. Similarly, the wastewater produced by mining and industry generates its own set of challenges resulting from water contamination by heavy metals, man-made organic pollutants, and micro-pollutants such as pharmaceutical products. Sick Water Report, UNEP/UN-Habitat, 2010, p. 31

The figure below is illustrative of some of the complex linkages between biogeochemical cycles and human activity; this one is based on an assessment of Danish sources of pollution and the nitrogen cycle, but would apply to many other countries. Note that the arrows represent flows of nitrogen through the system. The accumulation of pressures on the marine environment are quite overwhelming when viewed from this perspective.



Source: Danish Environmental Protection Agency and National Environmental Research Institute, "Nutrients and Eutrophication in Danish Marine Waters", accessed July 23 2016 at: http://www2.dmu.dk/1_viden/2_miljoe-tilstand/3_vand/4_eutrophication/causes.asphttp://www2.dmu.dk/1_viden/2_miljoe-tilstand/3_vand/4_eutrophication/causes.asp

2.3 Agriculture

We introduced the idea of nutrient availability in the previous module. A useful concept here is often referred to as **Liebig's Law of the Minimum**: the growth rate of a plant (or any other organism or population) will be limited by the least available resource. This applies to the nutrients necessary to sustain agricultural yields, and it is the main reason we have introduced such large amounts of nitrogen and phosphorus into the agricultural process with the application of fertilizer. However, not only agricultural crops are affected by fertilizer inputs -- due to the aforementioned non-point source pollution resulting from runoff and leaching, nearby aquatic ecosystems tend to receive excess nutrients from fertilizer application as well. This results in repercussions and feedback loops throughout the environment, one of which is described below.

2.4 Eutrophication and Algal Blooms

The process of eutrophication is a very good example of an unintended and harmful feedback loop. It is often associated with excessive nutrient use in agriculture, though there are other causes.

Let's imagine a lake that receives phosphorus (P) from agricultural runoff. The concentration of P in the water column will depend on two factors: (1) the amount of P flowing in and (2) the amount of P trapped in the lake's sediments.

If there is a low concentration of P in the sediments, then the sediments will absorb the P from the lake's water. When the water near the sediments has plenty of oxygen, P has a low solubility and will remain in the sediments. In such a case, agricultural runoff will cause an initial algae bloom in response to the arrival of nutrients. The water will become murky for a while until the P is absorbed in the sediments, after which the algae will die since there are no longer enough nutrients available and the water will become clear again. The lake ecosystem can cope with a certain amount of P and still maintain its basic function.

However, if over time P accumulates in the lake's sediments, the potential for a new regime will develop as the lake's resilience is eroded. In times of agricultural runoff, algae will proliferate, die and sink to the bottom of the lake where they will decompose. The decomposition of algae uses up the oxygen in the bottom of the lake – this is where a change in feedback occurs. The P trapped in the sediments will become very soluble and will be released back into the water column. This is referred to as *internal phosphorus loading*. The P will feed algae that will continue to grow and die and a positive feedback has been set in motion. Once the threshold is crossed, even if there are no more P inputs into the lake, it will not return to its clear water state. The P concentration in the water will remain sufficiently high to sustain algal growth, which in turn will keep the bottom water low in oxygen. The system is now regulated by a new set of feedback and is now firmly in a new, eutrophic and stable state.

Clearly, nitrogen and phosphorus both have serious impacts on ecosystem health and resilience. As Judith Weiss writes, *"Nutrient enrichment due to excessive amounts of nitrogen is the main cause of impaired coastal waters worldwide, while excessive phosphorus tends to be associated with enrichment in freshwaters… sewage, even after treatment, contains high levels of nutrients, while excess nitrogen flows from agricultural fields, suburban lawns and stockyards, entering freshwater and going down to estuaries along streams and rivers. It is also released from septic tanks and reaches water bodies through groundwater, and comes from the atmosphere in precipitation. These nutrients cause algal blooms and when the algae die and sink to the bottom, bacterial decay uses up oxygen, resulting in hypoxia (low oxygen) in deeper waters"* (Weiss, 2014:17).

The global spread of algal blooms has been well-documented for many years now and is set to continue. Researchers have predicted that average global lake warming over the next century will lead to a 20% increase in algal blooms and a 5% increase in toxic blooms over the next century (O'Reilly et al 2015). There are several types of harmful algal blooms, summarized by Hallegraeff as follows:

(1) Species which produce basically harmless water discolorations; however, under exceptional conditions in sheltered bays, blooms can grow so dense that they cause indiscriminate kills of fish and invertebrates due to oxygen depletion. Examples: dinoflagellates Gonyaulax polygramma Stein, Noctiluca scintillans (Macartney) Ehrenberg, Scrippsiella trochoidea (Stein) Loeblich III, cyanobacterium Trichodesmium erythraeum Ehrenberg.

(2) Species which produce potent toxins that can find their way through the food chain to humans, causing a variety of gastrointestinal and neurological illnesses, such as: - Paralytic Shellfish Poisoning (PSP), Diarrhetic Shellfish Poisoning (DSP), Amnesic Shellfish Poisoning (ASP), Ciguatera Fishfood Poisoning, Neurotoxic Shellfish Poisoning (NSP), Cyanobacterial Toxin Poisoning

(3) Species which are non-toxic to humans, but harmful to fish and invertebrates (especially in intensive aquaculture systems) by damaging or clogging their gills.

2.5 Industry

Most industrial processes require the use of water as a raw material, as a means of production, or as a coolant. According to the Organization of Economic Cooperation and Development (OECD) estimates, over 10% of total water withdrawal is used for industrial processes. When discharged, this water is often contaminated with hazardous chemicals or is discharged at high temperatures -- both of which disturb the ecosystems into which they enter. The rapid rate of industrialization in developing countries, along with a lack of requisite treatment measures and regulations means that untreated wastewater production is even higher in these countries.

Each industry sector produces specific types of pollutants, as seen in the table below. Note that BOD stands for biochemical oxygen demand, which indicates how much oxygen certain organic pollutants "demand" of their surrounding water environment in order to decompose. COD, which stands for chemical oxygen demand, indicates the oxygen that non-organic compounds require to oxidize. Both BOD and COD indicate how much oxygen depletion can be predicted to result from certain wastes. SS refers to suspended solids, which are particles that affect water clarity and can clog rivers as they settle.

Sector	Pollutant
Iron and steel	BOD, COD, oil, metals, acids, phenols, and cyanide
Textiles and leather	BOD, solids, sulfates and chromium
Pulp and paper	BOD, COD, solids, Chlorinated organic compounds
Petrochemicals and refineries	BOD, COD, mineral oils, phenols, and chromium
Chemicals	COD, organic chemicals, heavy metals, SS, and cyanide
Non-ferrous metals	Fluorine and SS
Microelectronics	COD and organic chemicals
Mining	SS, metals, acids and salts

Source for info + table: http://www.eolss.net/sample-chapters/c09/e4-11-02-02.pdf

Another issue centers around the plastics industry. The production of plastic begins with small beads called “nurdles” to which are added various chemicals which give this material different properties (rigidity or flexibility, different colors, etc). These nurdles can accidentally spill during transport or outflow from processing plants, contaminating waterways. The cosmetic and clothing industries also play important roles: small plastic particles called “microbeads” are often present in exfoliating products and toothpastes, while polyester threads from clothing are released during washing. These tiny particles are not caught by municipal water treatment plants and therefore also enter aquatic ecosystems. Finally, both negligence inappropriate waste disposal methods result in plastic litter thrown directly into waterways or entering the water through storm runoff.

Plastic pollution in freshwater and the ocean is a growing problem, given that plastic production is on the increase and its usage is becoming globally pervasive. A European Commission report suggested that approximately 10% of the global plastic manufactured each year (265 million tonnes) ends up in the oceans or other water systems (EC 2011). The durability of plastics means that some of this debris will persist for hundreds, if not thousands, of years.

The impacts of plastics in aquatic ecosystems are not fully known, but their presence is cause for alarm given that a wide variety of animals have been demonstrated to ingest it, from tiny microzooplankton to huge humpback whales. Along with carrying the chemicals added to them in the production process, plastics accumulate persistent organic pollutants (POPs) that can cause endocrine disruption, a decrease in fecundity, and cause be toxic for species eating them. At the zooplankton level, ingesting plastic as opposed to carbon-based matter could disrupt the crucial carbon cycling function that ocean ecosystems play.

The UNESCO-International Hydrological Programme broadly defines emerging pollutants as:

any synthetic or naturally-occurring chemical or any microorganism that is not commonly monitored or regulated in the environment with potentially known or suspected adverse ecological and human health effects. These contaminants comprise a wide variety of chemicals used in our daily lives, including pharmaceuticals, personal care products, pesticides, industrial and household chemicals, metals, surfactants, industrial additives and solvents. They are a source of concern since a wide variety of pharmaceuticals and household and industrial chemicals are used and released continuously into the environment even in very low quantities and some may cause chronic toxicity, endocrine disruption in humans and aquatic wildlife and the development of bacterial pathogen resistance. As a result, the medicines have become ineffective and infections persist in the body, increasing the risk of spread to others. In addition, new resistance mechanisms are emerging and spreading across the globe, threatening our ability to treat common infectious diseases, resulting in prolonged illness, disability, and death. Potential human health risks of emerging pollutants through the exposure via drinking water needs special attention and further scientific research because conventional water purification and wastewater treatment facilities are not effective in removing them. See: http://unesdoc.unesco.org/images/0023/002352/235241E.pdf

There are many other forms of pollution found in wastewater with deleterious impacts on ecological and human health, such as pesticides, pharmaceuticals, personal care products, estrogens, drugs such as antibiotics, steroids, antidepressants, narcotics, painkillers, tranquilizers as well as oral contraceptives, antiseptics, fragrances, shampoos, sunscreens, insect repellents, food supplements, caffeine, and nicotine, ash residue from coal scrubbers and hazardous compounds resulting from hydraulic fracturing and tar sands exploitation, and other contaminants found at low concentrations in water, sediments and organisms that are not removed from wastewater by sewage treatment plants. While the health benefits of medication are important for humans and livestock, the potential environmental risks of these substances to wildlife are just beginning to be clarified.

Nanomaterials or nanoparticles (<100nm) are another group of emerging contaminants, covering a variety of substances including organic carbon nanotubes and inorganic nanosilver materials, as well as nanoplastics (Bernhardt et al. 2010). These materials are used in cosmetics, electronics, drug delivery, manufacturing, paints and other products. They are released into the environment through runoff and sewage effluent and accumulate in depositional environments, including freshwater and coastal areas. The vast number of these products and their extremely small size gives them distinctive properties but also makes understanding their impacts on the environment and human health a major challenge (Schaumann et al. 2015; Canadian Council of Academies 2008).

It also important to note that, though it is logical to pursue sustainability through the re-use of wastewater, this also carries risks if it is not done carefully, as the UNESCO-IHP project mentioned above emphasizes:

Wastewater reuse is becoming an integral part of water resources management plans in many regions. Effects of these noxious chemicals found in diverse forms and various quantities in water resources and wastewater can have a serious effect on water-food-agriculture interdependencies. As wastewater is used to irrigate crops in many countries in water scarce areas, people in these regions are exposed to these contaminants via the agricultural produce they eat. The potential risk of emerging pollutants to human health through the use of insufficiently treated, or untreated, wastewater in agricultural irrigation requires particular consideration. Consequently, to provide significant additional water resources of satisfactory quality for agricultural irrigation and other purposes, safe reuse and reclamation of wastewater need to be promoted through water quality protection and appropriate wastewater management strategies. Source: http://unesdoc.unesco.org/images/0023/002352/235241E.pdf

2.6 Ecosystem, socio-ecological, and human health impacts of wastewater and nutrient pollution

Some of the diseases caused by untreated human sewage are cholera, typhoid fever, paratyphoid fever, salmonella, dysentery, gastroenteritis, leptospirosis, meningitis, hepatitis, and various parasitic diseases. According to the World Health Organisation, more than 840, 000 people are estimated to die each year from diarrhoea as a result of unsafe drinking-water, inadequate sanitation and poor hygiene.

Eutrophication presents very serious problems directly related to wastewater and nutrient runoff. The symptoms and impacts of eutrophication are:

· Increase in production and biomass of phytoplankton, attached algae, and macrophytes.

· Shift in habitat characteristics due to change in assemblage of aquatic plants.

· Replacement of desirable fish (e.g. salmonids in western countries) by less desirable species.

· Production of toxins by certain algae.

· Increasing operating expenses of public water supplies, including taste and odour problems, especially during periods of algal blooms.

· Deoxygenation of water, especially after collapse of algal blooms, usually resulting in fish kills.

· Infilling and clogging of irrigation canals with aquatic weeds (water hyacinth is a problem of introduction, not necessarily of eutrophication).

· Loss of recreational use of water due to slime, weed infestation, and noxious odour from decaying algae.

· Impediments to navigation due to dense weed growth.

· Economic loss due to change in fish species, fish kills, etc.

Source: FAO, http://www.fao.org/docrep/w2598e/w2598e06.htm

A recent survey of progress made toward the Sustainable Development Goals (see Module One) concluded that over 780 million people live in coastal regions at very high risk of eutrophication:

Coastal regions are particularly vulnerable to pollution. Since river basins, marine ecosystems and the atmosphere are all part of hydrological systems, the effects of pollution are often felt far from their source. In many coastal communities, pollution and eutrophication—excessive nutrients in water, frequently due to runoff from land, causing dense plant and algal growth and the death of animal life from lack of oxygen—have been key factors driving detrimental changes. According to the Transboundary Waters Assessment Programme global comparative assessment in 2016, the five large marine ecosystems most at risk from coastal eutrophication are the Bay of Bengal, East China Sea, Gulf of Mexico, North Brazil Shelf and South China Sea, areas which provided ecosystem services for coastal populations of 781 million in 2010. http://unstats.un.org/sdgs/report/2016/goal-14/

These heavily populated areas are only part of the problem, however: most coastal communities are at risk from wastewater and nutrient runoff impacts. This is especially so for coastal communities that rely on the ocean directly for food security and employment, which is often the case for small island states and countries with long coastlines. Every situation will be unique, of course, but in general, healthy aquatic ecosystems are vital for the survival of less affluent communities. (See https://www.mission-blue.org/2010/04/mission-blue-voyage/) It is thus vital that we conserve the natural ecosystems that help nature to clean and cycle water, such as mangroves (see below).

THE IMPORTANCE OF MANGROVES

One type of ecosystem that suffers great harm from excessive nutrient runoff is the mangrove; yet mangroves are more important than ever, as this excerpt from UN Environment's Global Environmental Outlook for the African Region (2016) makes clear:

Mangrove forests inhabit many of the saline and brackish coastal and marine areas of the continent's coastline ... Mangroves are essential ecosystems, providing multiple ecological services including fisheries, shoreline stabilization, nutrient and sediment trapping and high biodiversity. The economic value of 1 square kilometre of mangroves is estimated to range between USD 200 000 and USD 900 000 annually. Mangroves in western Central Africa are among the most carbon-rich ecosystems in the world, with estimates that 1 299 tonnes of carbon dioxide would be released per hectare of pristine mangrove if cleared. Mangroves are threatened by over harvesting for firewood, timber and charcoal; conversion to land for other uses including agriculture, aquaculture, infrastructure development, tourism and salt production; pollution, including from oil and gas exploration; increased sedimentation; and changing hydrology.

With projections of sea level rise along Africa's coastal zones by 2100 approximately 10 per cent higher than the global mean, the coastal wetlands of 37 countries will be vulnerable at various spatial and temporal scales. Densely populated low-lying coastal and estuarine zones, including small islands such as Seychelles, Comoros and Mauritius in the Western Indian Ocean, will be most affected. With a 1-metre sea level rise accompanied by 10 per cent intensification of storm surges, the mangrove areas of Gabon, Cameroon, Guinea, Guinea Bissau and Nigeria and the coastal lagoons of Angola and Ghana, in addition to low-lying coastal urban centres and ports, will be inundated.

Salinity is an environmental stress and limiting factor for agriculture. Salt prevents, limits or disturbs normal metabolism, and affects water quality and nutrient uptake of plants and soil biota. One of the main characteristics of salt-affected soils is their temporal variability. Prolonged rainfall can lead to a temporary leaching of salt from the surface layers. In many salt-affected areas, small ponds are dug to drain the saline water from the soil thus allowing limited agriculture on other parts of the land. The white deposits on the banks of the pond are evaporated salt crystals. Coastal zones are subject to natural erosion and sedimentation processes, including high wave energy and strong littoral transport, but these are intensified by human activities such as sand mining, river damming, port construction, dredging, and mangrove deforestation. Harbour construction has altered long-shore current transport of sediment leading to erosion and siltation…

As a study on the human health impacts of wastewater disposal in the Ikpoba River near Benin City in Nigeria concludes (Odige, 2014): Improper disposal of wastewater and the problems of addressing challenges from wastewater discharge into water bodies have led to an increase in agricultural runoffs, and wastewater from a car wash located close to the Ikpoba River have adverse effects on the water quality. High levels of pollutants in rivers cause an increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS). Toxic metals such as Cd, Cr, Ni and Pb make such water unsuitable for drinking, irrigation, aquatic life and even pose a great risk to human health. One of the worst consequences of excessive nitrate content in drinking water is commonly referred as "blue baby syndrome", described below.

Methaemoglobinemia According to the WHO

Methaemoglobinemia is caused by the decreased ability of blood to carry vital oxygen around the body. One of the most commonly alleged causes is nitrate in drinking water. It is most important in bottle fed infants and water from wells in rural areas is of special concern. Controlling nitrate levels in drinking water sources to below around 50mg/litre is thought to be an effective preventive measure.

The disease and how it affects people

Methaemoglobinemia is characterized by reduced levels of normal haemoglobin. Infants are most often affected, and may seem healthy, but show signs of blueness around the mouth, hands, and feet, hence the common name “blue baby syndrome”. These children may also have trouble breathing and may suffer from vomiting and diarrhoea. In extreme cases, there is marked lethargy, an increase in the production of saliva, loss of consciousness and seizures. Some cases may be fatal. In the body nitrates are converted to nitrites. The nitrites react with haemoglobin in the red blood cells to form methaemoglobin, affecting the blood's ability to carry enough oxygen to the cells of the body. Bottle-fed infants less than three months of age are particularly at risk. The haemoglobin of infants is more susceptible and the condition is made worse by gastrointestinal infection. Older people may also be at risk because of decreased gastric acid secretion.

Malnutrition and infection seem to increase the risk of methaemoglobinaemia. The general health of the infant as well as Vitamin C intake may determine whether or not the condition develops. Others at risk for developing methaemoglobinemia include: adults with a hereditary predisposition, people with peptic ulcers or chronic gastritis, as well as dialysis patients.

The cause

The most commonly cited cause of methaemoglobinemia is high levels of nitrates in drinking-water. High nitrate levels may be present in drinking-water due to the use of manure and fertilizers on agricultural land. The natural level of nitrites and nitrates from the environment is normally a few milligrams per litre, although high levels may occur naturally in some areas. Intense farming practices may increase this to more than 50 mg/litre.. Levels greater than 50 mg/litre are known to have been associated with methaemoglobinaemia in bottle fed infants. Nitrate is also found in vegetables.

Scope of the problem

Methaemoglobinaemia is now rare in most industrialized countries due to control of nitrate contamination in water supplies, although occasional cases continue to be reported from rural areas. It is a risk in developing countries, for example where the drinking water is from shallow wells in farming areas. There is no reliable estimate of the extent of the problem worldwide. WHO is presently collecting information in order to make such an estimate.

Interventions

Control of nitrate in drinking water is an effective preventive measure. WHO's Guideline Value for nitrate in drinking water is 50 mg /litre and for nitrite is 3 mg/litre. This is relatively readily achieved in centralised, piped, supplies, but is difficult in rural and small supplies. The group at greatest risk is bottle fed infants. Breastfeeding protects babies from methaemoglobinaemia. Boiling water does not remove nitrate.

Source: WHO website on water-related diseases: http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/ accessed Sept 10 2016.

2.7 Conclusion

This module has introduced the drivers, pressures, and impacts of wastewater and nutrient runoff. We've seen that there are many sources of both, from industrial to agricultural to domestic sewage and waste. And they both have serious implications in terms of ecosystems and human health concerns. We have strong scientific consensus about these problems: there is no credible denial of their extent. But how do we measure and follow changes in the actual extent of wastewater and nutrients in water sources and elsewhere? What techniques can we use to measure this, in order to craft appropriate policy responses? We turn to this question in the next module.

Discussion questions:

a) What are the main non-point source pollutants in your local area?
b) What are the main source pollution points in your local area?
c) Which of the drivers of eutrophication and algae blooms, do you think are the easiest to tackle from a policy perspective? Which may require technological advances to address??

d) How do you think that the main human health impacts of wastewater pollution will change over the next 20 years and how can future health impacts be managed in a fair and equitable manner?

e) Are there emerging water-related health threats that you think we need to focus on as we pursue the SDGs?

Annotated Bibliography:

Bouwman, A.F., et al. 2013. "Nutrient Dynamics, Transfer and Retention Along The Aquatic Continuum From Land To Ocean: Towards Integration of Ecological And Biogeochemical Models". *Biogeosciences* 10: 1–23. doi:10.5194/bg-10-1-2013. *Offers an overview of current understandings of river and land ecologies and pollution, and argues for the need to consider them as one continuous ecosystem. Only through this integrated approach can issues like wastewater and nutrient management be effectively addressed.*

Selendy, Janine, ed. 2011. *Water and Sanitation Related Diseases and the Environment.* London: Wiley-Blackwell. *Written by authorities from various related specialties, this book presents a comprehensive treatment of the conditions responsible for water- and sanitation-related diseases, the pathogens and their biology, morbidity and mortality resulting from lack of safe water and sanitation, distribution of these diseases, and the conditions that must be met to reduce or eradicate them. Preventive measures and solutions are presented throughout.*

Weiss, Judith. 2014. *Physiological, Developmental, and Behavioral Effects of Marine Pollution.* New York: Springer. *This extensive summary offers one of the most comprehensive and accessible texts covering a multitude of marine pollution sources (drivers, pressures, and impacts).*

Other Online Sources:

World Health Organization sites: http://www.who.int/water_sanitation_health/wastewater/en/ This site features links to guidlines for the safe use of wastewater, excreta, and grey water.

http://www.who.int/water_sanitation_health/diseases/methaemoglob/en/ This site covers blue baby syndrome and other health threats.

This UNESCO Project on "Emerging Pollutants in Wastewater Reuse in Developing Countries" is fully funded by the Swedish International Development Cooperation Agency (Sida) under the Programme Cooperation Agreement between UNESCO and Sweden for 2014-2017: http://en.unesco.org/emergingpollutants

United States Environmental Protection Agency's website on Nutrient Pollution and Human Health: https://www.epa.gov/nutrientpollution/effects-human-health

NITRATES, BLUE BABY SYNDROME, AND DRINKING WATER: A FACTSHEET FOR FAMILIES, helpful Q & A composed by the University of Washington's Pediatric Environmental Health Unit: http://depts.washington.edu/pehsu/sites/default/files/PEHSU%20nitrates%20NATIONAL%20NET%20Aug%2015%20final.pdf

Module Three: The Role of Monitoring and Modeling in Nonpoint Source Pollution Management

Learning Objectives

After completing this module, students will:

1. Understand the importance of a reliable and accurate monitoring system in any pollution abatement policy and programme;
2. Describe some of the standard measuring methodologies employed in the field;
3. Be able to summarize the principal challenges involved in establishing satisfactory monitoring systems;
4. Identify measurement techniques for nutrient use efficiency and its assessment;
5. Identify measurement techniques for the assessment of nutrient loading (surface, groundwater, coastal waters, deltas, coral reefs);
6. Understand the importance of nutrient and water use efficiency.

3.1 Introduction: Nonpoint source pollution management

In this module, we introduce monitoring and its important role at all stages such as contaminant assessment or the identification of effective and economic nonpoint source management strategies, and overview the standard measuring methodologies for estimating nutrient fluxes or pollution loading at the watershed coastal zone level. Some of the technical, economic, and political monitoring challenges are briefly discussed. Several real-world indicators and modelling approaches such as coastal eutrophication index and Global NEWS model and environmental reporting approaches are provided.

The protection and improvement of water resources, as a part of the Sustainable Development Goals (SDGs), demands international cooperation and shared responsibility, and the support of local communities for sanitation management and preserving/improving water resources (United Nations, 2016). In this regard, major changes in several areas including monitoring programs, data analysis, and system thinking are needed from local to international levels to achieve the SDGs. The implementation of such changes could prevent marine ecosystems from further pollution, promote the conservation and sustainable use of marine resources, and increase the economic benefits of such resources (United Nations, 2016). Figure 3.1 shows the reduction in the coastal nutrient contamination due to the implementation of sustainable practices. Further reduction (30%) in nutrient contamination of coastal zones is expected by 2025 (ICSU and ISSC, 2015).

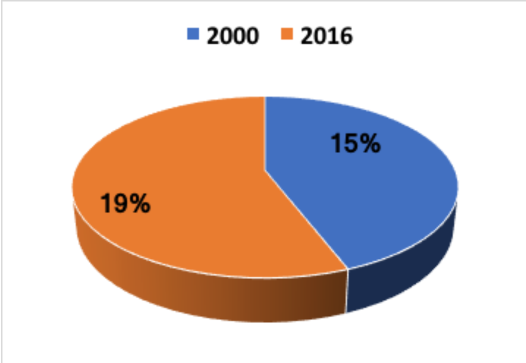


Figure 3.1. The worldwide increase in protection of marine biodiversity areas. (Adapted from United Nations, 2016).

Despite the worldwide improvement in protecting coastal marine waters, **eutrophication** (see the previous module for more information) of aquatic environments is still one of the most challenging environmental issues (United Nations, 2016). For example, the "Bay of Bengal, East China Sea, Gulf of Mexico, North Brazil Shelf and the South China Sea" ecosystems are at significant risk due to eutrophication causing by human activities (United Nations, 2016). Agricultural activities have become a major component of this problem globally (Ongley, 1996). This is due to the consumption of great amounts of freshwater and fertilizers/pesticides in agricultural activities (Ongley, 1996).
In fact, agricultural nonpoint source (NPS) pollution is the main source of water resources contamination and the primary pollutants include organic and inorganic nutrients (nitrogen (N) and phosphorous (P)), sediment, organic compounds and pathogens from animal waste, salts, and agricultural chemicals (Dressing et al., 2016a). Regardless of the source, nonpoint source contaminants are transported overland and through the soil by rainwater and melting snow and enter the groundwater, wetlands, rivers, lakes and oceans and caused major environmental, economic, and human health problems. Tables 3.1-3.3 summarize major water resource contamination and the physical, chemical, and microbiological contamination of surface and groundwater by nonpoint sources.

Table 3.1 Leading sources of water impairments (Adapted from Dressing et al., 2016b).

Rank	**Nonpoint sources**
1	Agriculture
2	Construction
3	Habitat alterations
4	Hydromodification
5	Recreational boating and marines
6	Resource extraction
7	Forestry
8	Unspecific nonpoint sources
9	Urban-related runoff/Stormwater

Table 3.2 Major nonpoint source contaminants (Adapted from Dressing et al., 2016a).

Contaminants	**Sources**
Fertilizers, herbicides, and insecticides	Agricultural lands and residential areas
Oil, grease and toxic chemicals	Urban runoff and energy production
Sediment	Improperly managed construction sites, crop and forest lands, and eroding streambanks
Salt	Irrigation practices and acid drainage from abandoned mines
Bacteria and nutrients	Livestock, pet wastes and faulty septic systems
Atmospheric deposition and hydromodification	-

Table 3.3 The impact of agricultural activities on water quality (Taken from Ongley, 1996).

Agricultural activity	**Impacts**	
	Surface water	**Groundwater**
Tillage/ploughing	• Sediment contamination with phosphorus and pesticides that are attached to soil particles and carried out to surface water • Water turbidity • Loss of aquatic habitat due to siltation of river beds	-
Fertilizing	Nutrient-based fertilizers carried out by runoff lead to: • Eutrophication, oxygen depletion leads to ecosystem degradation and fish kills • Taste and odour in drinking water resources	Public health impacts due to leaching of nitrate to groundwater
Manure spreading	• If spread on frozen ground it leads to contamination of receiving waters with pathogens and chemical (e.g., metals, phosphorus, and nitrogen) • Eutrophication	Groundwater contamination, especially by nitrogen

Pesticides	• Contamination of water and biota • Pesticides lead to dysfunction of ecological system because of growth inhibition and reproductive failure of top predators • Public health impacts caused by eating contaminated fish	Human health problems

3.2 Monitoring

Data collection, assessment, and the establishment of realistic management objectives are three main steps that need to be consistently considered to make effective management decisions for the control of adverse effects of agricultural nonpoint source pollutants on water quality.

Data collection through effective monitoring programs provides the basis to understand the impact of agricultural activities on water quality and ecosystems. In general, unsuccessful nutrients pollution management is the consequence of implementations of the management practices that are designed based on the unsystematic water quality monitoring data. However, in recent years the impact of systematic monitoring programs on nutrient pollution management have become evident. For example, it was known that further control of point source contaminants would not lead to water quality improvement without proper control of nonpoint sources where the nonpoint sources are the main water quality impairment. Systematic monitoring of water quality impairment by the point and nonpoint sources in the USA showed that nearly 65% of assessed rivers in the United States were impaired by nonpoint sources mainly by the agricultural activities (see Table 3.4). Moreover, a comprehensive monitoring study on the deterioration effects (e.g., algal bloom) of point and nonpoint source pollutants on Great Lakes basin (Canada) showed that the situation was caused by the excessive phosphorus entered to the Lakes from point and nonpoint sources which required the management of both contaminants sources (Ongley, 1996). Below, we introduce the GEMI global monitoring framework, with improved data collection and analysis that monitored different aspects of the management of water, wastewater and ecosystem resources.

Table 3.4 Main sources of water pollution in the United States (Taken from Ongley, 1996).

Rank	**Contamination of**		
	Rivers	**Lakes**	**Estuaries**
1	Agriculture	Agriculture	Municipal point sources
2	Municipal point sources	Urban runoff/storm sewers	Urban runoff/storm sewers
3	Urban runoff/storm sewers	Hydrologic/habitat modification	Agriculture
4	Resource extraction	Municipal point sources	Industrial point sources
5	Industrial point sources	On-site wastewater	Resource extraction

GEMI, "a coherent framework for global monitoring of sustainable development goal (SDG 6)",

Source: http://www.unwater.org/gemi/en/

Water and sanitation have significant roles in sustainable development. Therefore, providing reliable data through integrated monitoring programs is needed to plan management practices that support sustainable development. In this regard, GEMI, "a coherent framework for global monitoring of sustainable development goal (SDG 6)", has been developed to support water, wastewater, and ecosystem resources related issues. As an integral part of SDG 6 and complement to WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) and UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS), the framework goals are to:

- "Integrate and expand existing monitoring efforts, to ensure harmonized monitoring of the entire water cycle
- Provide Member States with a monitoring guide for SDG targets 6.3-6.6
- Engage Member States and enhance their capacity in water sector monitoring
- Report on global progress towards SDG targets 6.3-6.6"

Reliable water quality and quantity data will support sustainable development in several ways including raising public awareness and engagement, political commitment, and inform decision making which consequently leads to public health improvement and environment and economic benefits. For example, information about water resources availability through consistent monitoring programs will promote water savings and use efficiency.

3.2.1 Nonpoint source monitoring objectives

Water quality monitoring is conducted to evaluate the quality of aquatic environments and to find the trend of past, current, and future water quality changes. Monitoring is the first step of water quality management and if properly conducted it can provide useful information regarding:

- The quality of waterbodies
- The overall condition of aquatic life and ecosystems (e.g., "health of fisheries")
- The sources and impacts of water contaminants
- The effectiveness of management practices (Dressing et al., 2016b)

Through consistent water quality monitoring water impairment can be identified which then helps to design plans for addressing current and future problems (Dressing et al., 2016b). Therefore, the design of effective monitoring programs with clear objectives can lead to the development of realistic and effective nonpoint source monitoring plans (Dressing et al., 2016b).

Essential criteria that should be addressed when designing a monitoring program in a watershed level include:

- Critical water quality impairments
- Significant pollutants involved and their sources
- Methods of pollutants transportation
- The most important drivers of pollutant generation and delivery (Dressing et al., 2016b).

Table 3.5 summarizes the essential steps in designing a successful monitoring program.

Table 3.5 Essential steps in designing a monitoring program (Taken from USDA-NRCS 2003).

No.	Steps	No.	Steps
1	Identifying problems	7	Locating stations
2	Setting objectives	8	Determining sampling frequency
3	Designing experiments	9	Designing stations
4	Selecting scales	10	Defining collection/analysis methods
5	Selecting variables	11	Defining land use monitoring
6	Choosing sample type	12	Designing data management

3.2.2 Nonpoint source monitoring limitations

Poorly conducted monitoring programs not only cannot meet management objectives but also "create confusion, leave critical questions unanswered and waste time and money" (Dressing et al., 2016b). Ineffective monitoring program is a result of several factors including limited financial resources, extent of the monitoring project (e.g., assessment of several scenarios and alternatives at the same time), monitoring program or land treatment plans modifications due to socio-economic factors and logistical constraints (e.g., watershed size and topography), variability of resource water quality conditions (e.g., water flow rate is too high or low), effects of natural or human-based phenomenon such as flood, chemical spills and/or other physical changes, small achievement in magnitude of change expected to result from treatment, and short-term mentoring program.

Agricultural nonpoint source pollution management can be challenging due to two main reasons including the incompleteness of available data and because the relative proportion of point and nonpoint sources (NPSs) are not distinguishable by the conventional water quality monitoring programs. Studies showed that the environmental impacts of NPSs on water resources caused by agricultural activities cannot be separated from the non-agricultural activities thus it is necessary to develop and implement water resource monitoring systems with a prior definition of indicators, parameters, tolerance limits, frequency and sampling points, and combining this information with quantity data (Andreoli, 1993).

Insignificant improvement in water quality following implementation of best management practices (BMPs) in the watershed can be the consequences of lack of proper identification of pollutants sources, improper experimental design, natural constraints such as harsh weather, and unsuitable selection of BMPs and "lag time in water quality response to best management practices" (Meals et al., 2010; Meals and Dressing, 2016a). Studies conducted by Reid (2001) showed that "design problems/flaws and procedural problems" were the main reasons for insignificant achievement in the examined monitoring programs (Reid, 2001).

Design flaws in the monitoring plan lead to obtaining incorrect data which prevent answering fundamental questions or otherwise achieving the project goals (Meals and Dressing, 2016a). Design flaws can be due to lack of accurate problem identification/analysis such as inaccurate identification of the source of nonpoint pollutants. It is important to precisely determine the source of problematic contaminants because the errors introduced by one step may be added to by subsequent processing steps. For example, inability in the identification of the source of a contaminant such as E. coli bacteria which can originate from various sources including livestock, septic systems or wildlife can lead to the selection of inappropriate treatment methods (Meals and Dressing, 2016a). Similarly, inability in accurate identification of pollutants loads and transportation and delivery methods can lead to the implementation of ineffective treatment methods.

For example, if a contaminant such as nitrate ends up in groundwater, then monitoring of surface runoff would not result in the identification of the nitrate contamination in the system. Likewise, ineffective monitoring plan such as selection of wrong sampling station or time can lead to misleading results. Moreover, the monitoring program should consider the duration of intended treatment (known as "lag time"). For example, if a response to BMPs takes ten years to become evident, a three-year sampling would not be sufficient to reveal the effectiveness or failure of the BMP (see Table 3.6). The monitoring program must be in regard to program objectives to carefully present the actual conditions of the system (Meals and Dressing, 2016a).

One of the most important factors in the success or failure of a monitoring program in terms of meeting water quality improvement expectations is lag time. The lag time is a time between the implementation of nutrient reduction treatment and the first measurable improvement in water quality (Meals and Dressing, 2016a). Figure 3.2 present the lag time conceptual model.

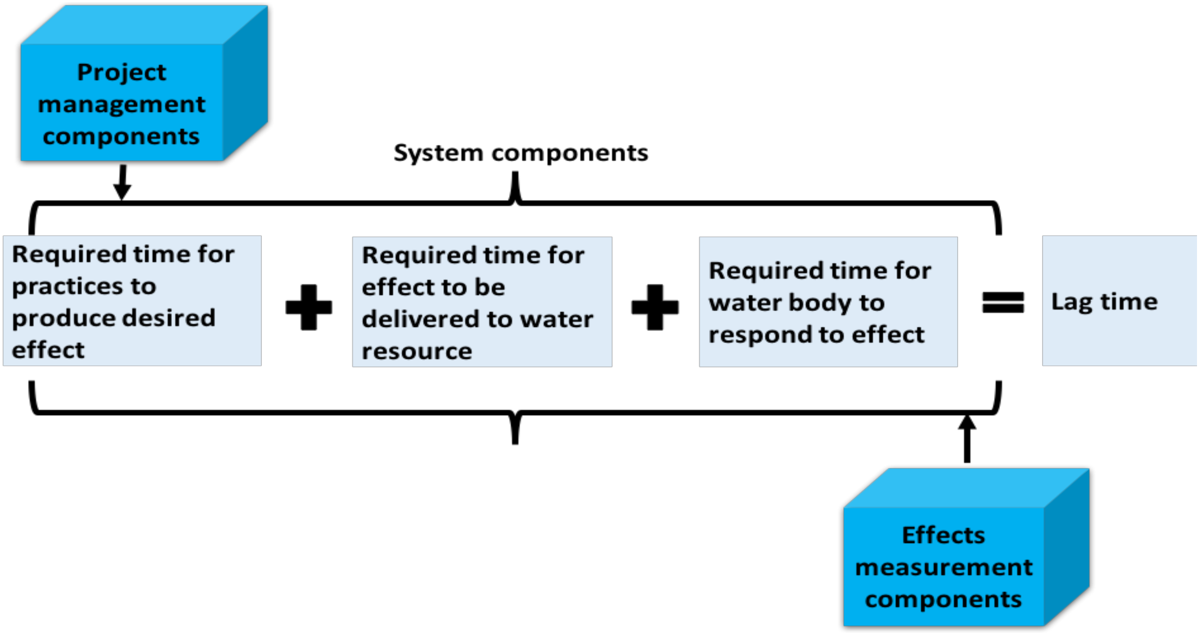


Figure 3.2 The lag time between treatment and response (Adapted from Meals and Dressing, 2016a).

Table 3.6 The lag time between implementation of environmental impact/treatment and water quality improvement (Adapted from Meals and Dressing, 2016a).

Parameters	Scale	Impact/Treatment	Response time	References
NO_3-N	Small watershed	Nitrogen fertilizer rates	> 30 year	(Tomer and Burkart, 2003)
NO_3-N	Large watershed	Nutrient management	≥ 5 year	(STAC, 2005)
Phosphorous	Lake	WWTP upgrade/agricultural BMPs	> 20 year	(LCBP, 2008)

Procedural problems can lead to the collection of wrong data because of numerous factors including:

(i) inadequate training or enthusiasm of field staff,
(ii) inadequate frequency and wrong location of sampling
(iii) unavailability of collateral information,
(iv) selection of wrong field or laboratory instruments and technologies
(v) infrequent data evaluation
(vi) inconsistent field monitoring methods or analytical methods, procedures, and protocol (Meals and Dressing, 2016a).

It is recommended to avoid poorly design monitoring program and instead limit the monitoring objectives and use modeling as an effective alternative, especially when several alternative scenarios must be considered. For example, water quality simulation models are used as an integral part of watershed-level monitoring for point and nonpoint source pollution assessments where preliminary data are not available or generating good quality data are limited. There are several modeling toolboxes and indices that can be used to assess the aquatic environments conditions. In the following sections, the common measuring techniques and modeling tools and indicators will be reviewed.

3.3 Standard measuring methodologies for estimating nutrient fluxes

As described in Module 2, eutrophication is one of the concerning issues caused by the excessive level of nutrients in aquatic environments with various environmental effects such as algal blooms and negative effects on aquatic ecosystems and water quality (e.g., oxygen depletion). As most nutrient contaminants eventually end up in marine environments thus evaluation of the environmental impacts of nutrients in marine environments is of important interest. The extent of eutrophication (see Table 3.7) in the coastal marine environments are assessed using "statistical techniques, simulation models and water quality indicators" (Karydis, 2009). The nutrient impacted coastal marine environments are classified into "oligotrophic, mesotrophic and eutrophic." This classification provides valuable information regarding the existing conditions of marine environments and management measures that must be taken to protect and conserve these ecosystems (Karydis, 2009).

Table 3.7 Eutrophication classifications (Adapted from Gray, 1992).

Classifications	Specifications	Impacts
Oligotrophic	Low nutrients level Low algal biomass (low productivity)	Slight increase of phytoplankton biomass Changes in community structure
Mesotrophic	Intermediate nutrients level Intermediate algal biomass (high productivity)	Decrease the water transparency Accumulation of organic matter
Eutrophic	High nutrients level High algal biomass (high productivity)	Hypoxia or anoxia

It is relatively easy to identify the involved parameters and variables in eutrophication but it is challenging to quantitatively determine such parameters (Karydis, 2001; Primpas and Karydis, 2010). Some of the reasons that make quantitative assessment difficult are:

- It is hard to separate naturally existing nutrients from nutrients from human activities in the marine environment.
- Indicator criteria (e.g., "nitrate, nitrite, ammonia, phosphate, chlorophyll, phytoplankton biomass, and water transparency") that are used to quantify the level of eutrophication are interrelated and influenced by chemical, physical, and biological factors (Primpas et al., 2008).

To resolve these problems, important ecological/biological and physical/environmental variables such as (i) nutrients (phosphates, nitrates, nitrite), (ii) chlorophyll-a, (iii) dissolved oxygen (vi) water transparency and (v) phytoplankton primary production and phytoplankton biomass have been used to classify the level of eutrophication and to determine or predict the aquatic system's health.

3.3.1 Variables

3.3.1.1 Nutrients

As with other water bodies, marine coastal environments are commonly classified with regards to their trophic state, a term that describes the health state of a coastal marine environment, based on the assessment of several criteria including nutrients levels in the water (Brown and Simpson, 2001). As direct measurement of algae biomass is not always practical due to the time and cost associated with its measurement, indirect measurements of variables, which their relationship with eutrophication have been known, is performed (Brown and Simpson, 2001). Based on indirect measurements the existing trophic state of water can be determined and by comparison of measurements at different time and locations a trend toward a less or more eutrophic state can be achieved (Brown and Simpson, 2001). Table 3.8 summarizes a eutrophication scaling that has been determined based on four nutrient concentrations including phosphates, nitrates, nitrites, and ammonia (Ignatiades et al., 1992). Nutrient values for assessing eutrophic levels may differ based on the method of threshold values calculation (e.g., annual means or seasonal means, see Table 3.9) (Karydis, 2009).

Table 3.8 Trophic state classification based on nutrients concentrations (Adapted from Ignatiades et al., 1992).

Eutrophication Level	$P\text{-}PO_4$ (mean values, µM)	$N\text{-}NO_3 + N\text{-}NO_2$ (mean values, µM)	$N\text{-}NH_4$ (mean values, µM)
Oligotrophic	0.02	0.21	0.36
Mesotrophic	0.09	0.33	0.84
Eutrophic	0.34	0.53	1.15

Table 3.9 Water quality classification based on nutrients (Adapted from Karydis, 2009).

Water Quality	$P\text{-}PO_4$ (µM)	$N\text{-}NO_3 + N\text{-}NO_2$ (µM)	$N\text{-}NH_4$ (µM)
High/Good	0.4	5	1
Good/ Moderate	0.8	10	2
Moderate/Poor	1.4	20	4
Poor/Bad	2.8	40	8

3.3.1.2 Chloropyll-a

Initial evaluation of the trophic state of coastal water quality (eutrophication state) and trends of water changes over time can be achieved by measuring the characteristics such as photosynthetic pigments (e.g. chlorophyll-a concentration) which are measured as an indicator of phytoplankton abundance (algal biomass). Measurement of chlorophyll-a is faster and less costly than measurement of algal biomass. Chlorophyll-a concentration increases as nutrient concentrations increase and reduces in the presence of filtering organisms such as clams, mussels, and oysters. High concentrations of chlorophyll-a in water imply an increase in the growth of algae ("overproduction of algae"). Overgrowth of algae leads to problems such as "surface scums, fish kills, noxious odors, low dissolved oxygen and decreased water clarity" (Ignatiades, 2005; US. EPA, 2006). Table 3.10 summarizes the levels of eutrophication categorized based on the chlorophyll-a concentrations and primary production rates (Ignatiades, 2005). Table 3.11 summarizes five levels of water quality based on chlorophyll-a concentrations (Karydis, 2009, 1999; Simboura et al., 2005).

Table 3.10 Trophic state classification based on Chlorophyll-a and primary production rates (Adapted from Ignatiades, 2005).

Eutrophication	**Chlorophyll-a (mean value, mg/m^3**	**Primary Production Rates (mg C/m ^{3}. h)**
Oligotrophic	<0.5	<1.5
Mesotrophic	0.5 – 1.0	1.5-3
Eutrophic	>1	>3

Table 3.11 Trophic state classification based on Chlorophyll-a (Adapted from Karydis, 2009, 1999; Simboura et al., 2005).

Water Quality	**Chlorophyll-a (mean value, µg/m^3)**
High	<0.1
Good	0.1-0.4
Moderate	0.4-0.6
Poor	0.6-2.21
Bad	>2.21

3.3.1.3 Phytoplankton Abundance

It has been found that the population of some species of plankton, more specifically diatoms, reduce as a response to nutrient enrichment while the population of nanoplankton (small or unicellular species) including flagellated and green plankton increase with an increase in nutrients (Oviatt et al., 1989). Phytoplankton cell numbers can be a useful variable in studying spatial trends of water quality (Kitsiou et al., 2002; Kitsiou and Karydis, 2001). Table 3.12 summarizes the relationship between levels of eutrophication and cell numbers (Karydis, 2009).

Table 3.12 Trophic state classification based on phytoplankton cell numbers (Adapted from Karydis, 2009).

Eutrophication	Phytoplankton cell numbers (cell/L)
Oligotrophic	6×10^3
Mesotrophic	6×10^3-1.5×10^5
Eutrophic	$>1.5 \times 10^5$

3.3.1.4 Water Transparency

Water clarity/transparency is one of the practical variables that is used to predict the water quality of coastal marine environments, especially offshore waters, using a simple device known as Secchi disk (see Figure 3.3, a Secchi disk is an 8-inch circle metal disk with alternating black and white quadrants attached to a cord) (Brown and Simpson, 2001; Ignatiades et al., 1995). Water transparency shows the amount of light that penetrates to water column (RMB, 2016). In the case of algal growth, the clarity of water and in turn the penetration of light is reduced thus the Secchi disk cannot be seen easily from the surface of water (RMB, 2016). That is, the higher the algal concentration and water productivity the lower the Secchi depth and consequently the lower the quality of water (RMB, 2016). Table 3.13 summarizes the water quality based on water clarity.

Table 3.13 Trophic state classification based on Secchi disk depth (Adapted from Ignatiades et al., 1995).

Eutrophication Level	Secchi disk depth (m)
Oligotrophic	20-40
Mesotrophic	10-20
Eutrophic	< 10

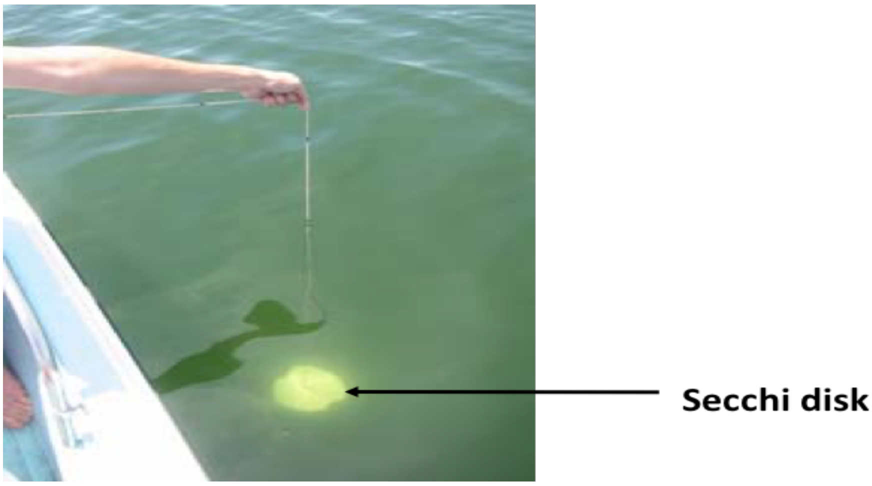


Figure 3.3 Using a Secchi disk to measure water clarity (Adapted from RMB Environmental Laboratories, Inc. available at http://rmbel.info/how-to-use-a-secchi-disk/).

3.3.1.5 Primary productivity

Primary productivity rates (PPRs) are the most commonly used nutrients flux measurement for assessing the level of eutrophication. The structure of phytoplankton communities varies as a response to water quality changes (Cloern, 2001; Gray, 1992). In order to determine the PPRs, the quantity of photosynthesis by organisms such as plants and algae are measured by the radiocarbon technique (Vollenweider et al., 1974). For example, ^{14}C labeled bicarbonate uptake by phytoplanktonic cells is measured (Cloern, 2001; Gray, 1992). Indices such as species richness, dominance, diversity, and resemblance are studied to determine the effects of nutrient contaminants on the marine environment (Danilov and Ekelund, 1999; Wilhm and Dorris, 1968). However, the level of sensitivity of such community indicators to contaminants and the relationship between such indicators with increasing levels of eutrophication are difficult to be determined (Karydis, 2009).

3.3.2 Nutrient loading assessment

Nutrient loading is a result of surface and subsurface transport of nutrients from the contributing landscape. Weather conditions, soil topography, and land activities play important roles in the nutrient loading phenomenon.

Models are developed to assess the impact of nutrient loads from current and future land activities on waterbodies considering the nutrient pollution limits. In general, nutrient modeling is an important part of the watershed assessment: through nutrient modeling flow pollutant loads can be calculated or estimated and the link between nutrient sources to their potential impacts can be determined. Furthermore, modeling can provide the opportunity to identify nutrient-rich aquatic environments. More importantly, practical management practices for nutrient pollutant reduction can be developed based on the modeling results. Likewise, more effective monitoring programs can be designed and the cost-effectiveness of alternatives can be analyzed through assessments using models.

However, modeling can be challenging in watershed projects. This is because some models require supporting data and information for model parameterization, calibration, and validation so that inadequate supporting data can negatively influence the obtained results by modeling. Moreover, lack of fundamental understanding of the involved parameters and their interactions would result in complex and sometimes incorrect interpretations (Meals and Dressing, 2016b). Therefore, attention must be given not to over or understating the results because failure to properly analyze the uncertainties associated with results obtained by models may threaten the credibility of the model. For example, a comparison between the monitoring data with the Chesapeake Bay model showed that the interpretation based on the model results led to overstating of the environmental achievements (GAO, 2005; Meals and Dressing, 2016b; Powledge, 2005). Despite the challenges, when direct nutrient measurements are not possible the application of watershed models can provide useful information regarding the nutrient loading in a watershed.

3.3.2.1 Ecological indicators

Several indicators have been used to describe the ecological or eutrophic state of marine waters (see Table 3.14). Ecological/biological indicators including algal biomass and community composition can effectively represent the trophic state of coastal waters than the nutrients or other physicochemical variables (e.g., water transparency) (Desrosiers et al., 2013). This is because, unlike the nutrients and physicochemical variables that may be influenced by physical and chemical conditions of water, biological variables are less influenced by the water chemistry but can show both qualitative/functional and quantitative/structural changes in the structure and function of biological communities (Desrosiers et al., 2013). That is, ecological indicators show biological community changes as a response to nutrient pollution and effectively indicate the relationship of ecological changes with the environmental conditions (Desrosiers et al., 2013). A practical bioindicator has characteristics including a short life span to integrate short-term environmental variability, high abundance and easy to sample, sessile in reflecting studied areas conditions and being response-specific to be able to clearly identify a particular impact on the ecosystem (Desrosiers et al., 2013).

Measured data from biological indicators are converted into multimetric and functional indices (Borja et al., 2009). The multimetric indices integrate quantitative information at the community level and are driven based on richness, abundance, and biomass while the functional indices emphasize on species composition (Borja et al., 2009; Borja et al., 2000; Carballo et al., 1996; Devlin et al., 2011, 2009; Green and Webber, 2003; Jaanus et al., 2009; Lopez Y Royo et al., 2011). The index calculation is based on two phenomena including "species sensitivities or tolerances to different parameters and the ecological strategies used by species in reaction to chemical or physical stress". The challenging problem associated with multimetric indices is that there should be a reference value to compare the final calculated value with it while for functional indices, there is no need to any reference value and the final calculated value provides a direct relationship of the ecological status of the study site, but it requires an important preliminary work to define species sensitivities (Desrosiers et al., 2013).

Table 3.14 Some of the bioindicators used for marine environment monitoring (Adapted from Desrosiers et al., 2013).

Organism	Timescale	Spatial scale	Characteristics
• Phytoplankton • Marine benthic diatoms	Days	Coastal and open sea	Detect nutrients input; seasonal variability
• Macroalgae • Foraminifers • Benthic invertebrates	Months	Coastal	• Detect nutrients and pollutants input • Detect nutrients • Detect organic enrichment
• Seagrass meadow • Sponges/tunicates • Coral reef	Year	• Shallow and non-turbid waters • Coastal • Tropical oligotrophic	• Detect nutrients input • Detect nutrients and MES inputs • Detect nutrients input, changes in temperature and MES input
Mangrove forest and associated sessile community	Varying	Tropical and sub-tropical	Detect metal contamination and soil pollution

3.3.2.2 Coastal eutrophication indices

Phytoplankton grows rapidly when nutrient concentrations increase in an aquatic system (Oviatt et al., 1989). As a result of their growth, the concentration of dissolved oxygen (DO) in eutrophic systems is significantly influenced by the activity of bacteria and animals that degrade phytoplankton biomass and organic compounds. The changes in the concentration of dissolved oxygen can be used as an indicator for assessing the trophic states. Based on the variations in the oxygen changes in water systems, two indicators based on physical variables including "Physically Sensitive Area" (PSA) and "OXYgen depletion RISK index" (OXYRISK) (EMIS, 2016a) have been developed. With the RSA index, vulnerable areas to oxygen deficiencies can be identified. This indicator considers a presumption including even distribution of the primary production and nutrients in the studied system (EMIS, 2016a). In the PSA calculation (see Eq. 3.1), the surface and bottom physics conditions are defined by three phenomena including advection, stratification, and bottom diffusivity (EMIS, 2016a). The advection has a major role in the dilution of a point source nutrient in the water via horizontal transportation and diffusion, while stratification represents the stable or unchanged conditions of the upper layer of the water column and the activities of phytoplankton cells in the highly available nutrients zones (EMIS, 2016a). The capacity of water to recover and generate oxygen reduced with increases in water depth but the bottom diffusivity plays an important role in the vertical mixing and providing oxygen for the benthic ecosystems to prevent severe oxygen deficiency.

$$PSA = (surface\ physics + Bottom\ physics)/2 \qquad \textbf{Eq. 3.1}$$

The OXYRISK index predicts the possibility of oxygen deficiency at the seabed in coastal areas as a result of the degradation of organic matter (EMIS, 2016b). This index calculation is based on two sets of data (i) "Satellite-derived optical radiometry data" and (ii) "numerical modelling" (EMIS, 2016b). The satellite-derived optical radiometry data assess "phytoplankton biomass and primary production" while the "numerical modelling" provides data on the "physical capacity of oxygen renewal near the seabed and the oxygen reserve below the mixed layer" (EMIS, 2016b). The calculation is based on two assumptions including (i) "phytoplankton is the main source of production and (ii) phytoplankton horizontally transfers the organic matter to the seabed in coastal and shelf areas (<100 m depth)" (EMIS, 2016b). Particulate organic matters (POM) flux can be calculated with this index considering the following steps. First, a monthly average advection (using a hydrodynamic model) and a "horizontal diffusive factor" are used to determine the horizontal transfer of organic matters produced in the upper layer and transferred to the mixed layer. Secondly, the vertical transfer of particulate organic matters is determined by a constant termed as "sinking velocity (Vs)". Finally, a "degradation rate (τ_{degrad}=0.075 per day)" is used to reflect the higher deposition rate of POM in shallower waters compared to deeper waters (EMIS, 2016b). In summary, the OXYRISK indicates the balance between the dissolved oxygen that is consumed for the degradation of organic matters and the dissolved oxygen that is either produced or reserved at the seabed.

3.3.2.3 Global NEWS (Nutrient Export from WaterSheds) model

Global NEWS is a "global, spatially explicit, multi-element and multi-form" model developed to investigate the correlation between dissolved and particulate nutrients contamination as a result of human-based activities on coastal nutrient enrichment (Global NEWS, 2008; Mayorga et al., 2010). Unlike previously developed global models, which focus on a single type of contaminant (e.g., nitrogen or phosphorous), this model investigates the impact of multiple contaminants (e.g., carbon, nitrogen, phosphorous and silica) at different forms including dissolved and particulate or organic and inorganic forms. A reason for developing a multi-element global model is the inability of single element models in predicting the distinct and inter-related influence of single element on ecosystem response because several factors and elements impact the natural processes. Therefore, the multi-element or multi-form approaches can increase our understanding regarding the effect of human activities on coastal ecosystem (Global NEWS, 2008).

Global model are used (i) to identify the areas prone to nutrient contamination (ii) to explain past, current, and future pattern of nutrient contamination, (iii) to predict and mitigate the environmental impacts of nutrient contamination, (iv) to identify the sources of nutrient contamination and their relative importance, (v) to evaluate the effect of national, regional, and global economic and policy decisions on the environment (Global NEWS, 2008).

3.3.2.4 Total maximum daily load (TMDL) modeling toolbox

Mathematical watershed models can provide useful information regarding the water quality, the causes/effects of water contamination and predict the future water quality trends. These models quantitatively link pollutants driven from land activities to waterbody response for TMDL development. The TMDLs modeling toolbox compose of several models (e.g., "The watershed loading/water quality model, Soil Water Assessment Tool (SWAT) developed by the United States Department of Agriculture-Agricultural Research Service (USDA–ARS)"(Arnold et al., 1998; Santhi et al., 2001)) to estimate the maximum loads of pollutants a waterbody can receive from point and nonpoint sources in a watershed and still maintain the specified standards (Wool, 2015). TMDLs projects are developed to set numeric targets for pollutant load reduction and connect point and nonpoint source pollutant control strategies and practices (Dressing et al., 2016b; Santhi et al., 2001). The TMDL Modeling Toolbox provides "steady-state/dynamic simulation of mass transport and water quality processes" in a verity of aquatic environments such as "overland flow, small creeks, rivers, lakes, estuaries, coastal embayment, and offshore areas". Table 3.15 provides a list of commonly used models and databases for TMDL development. A wide range of contaminants including pathogens, sediment, nutrients, dissolved oxygen, metals, temperature, and toxicants have been investigated using the Toolbox models either independently or collectively (US. EPA, 1999; Wool, 2015).

Table 3.7 TMDL Modeling Toolbox (Adapted from Wool, 2015).

Assessment Tools	Watershed Models	Receiving Water Models
• Water Resources Database (WRDB) • Watershed Characterization System (WCS) • WCS Sediment Tool • WCS Mercury Tool • WCS LSPC Tool	• Loading Simulation Program in C++ (LSPC) • Watershed Assessment Model (WAMView) • Storm Water Management Model (SWMM)	• A Dynamic One-Dimensional Model of Hydrodynamics and Water Quality (EPDRiv1) • Stream Water Quality Model (QUAL2K) • CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) • Environmental Fluid Dynamics Code (EFDC) • Water Quality Analysis Simulation Program (WASP)

3.3.2.5 Nitrogen Use Efficiency (NUE) indicator

It is well-known that nutrients and particularly nitrogen are essential to support food production but the efficient and effective use of nutrients is also critical (Norton et al., 2014). Nitrogen Use Efficiency (NUE) is a quantitative indicator which is utilized to evaluate the effectiveness of nutrient applications and management policies and farming practices effectiveness to not only improve food production but also to reduce/control the negative effects of excess use of nitrogen-based compounds from manufactured and animal waste fertilizers on the aquatic environment (Norton et al., 2014). In general, the NUE indicator is based on the differences between the amount of nitrogen-based fertilizers that is applied in the agricultural field and the amount of fertilizers that is removed from the field mainly through crops harvesting (see Figure 3.4) (Norton et al., 2014). Following the NUE calculation step, the results are interpreted in a simple and understandable way to help decision makers to plan management policies and practices. Table 3.16 is an example of the results and initial interpretation of NUE.

Table 3.8 NUE results and interpretation (Adapted from Norton et al., 2014).

NUE	Interpretation	Considerations
NUE < 1	More nitrogen is being applied than is	Risk of high nitrogen loss to the

	being removed	environment
NUE = 1	The amount of nitrogen removed equals the input of nitrogen	Balanced in-and outputs
NUE > 1	More nitrogen is being removed than is being supplied	Soil mining / depleting soil fertility

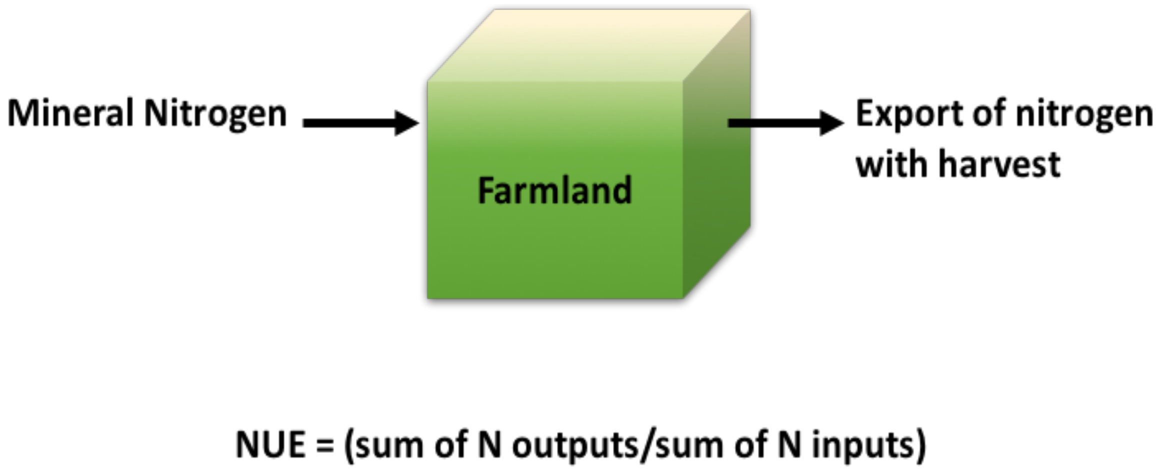


Figure 3.4 NUE calculation step (Adapted from Norton et al., 2014).

Despite some data limitations and uncertainties, one of the significant advantages of NUE is that the required data for the NUE calculation are usually available and when the site-specific data are not available it is possible to directly or indirectly calculate or estimate the concentrations of nitrogen from regional literature values (Norton et al., 2014). However, there are some challenges with this indicator. First, it is not possible to directly estimate the amount of nitrogen loss from the studied system and this indictor cannot explain pathways of internal nitrogen transformation (e.g., biochemical transformation of nitrogen to another forms) within the studied system. Secondly, the NUE is not capable of assessing agricultural sustainability and an additional interpretation scheme is needed for NUE interpretation (Norton et al., 2014). Therefore, some consideration muse be addressed during calculation to achieve reliable results. For example, the cycle rotation of whole crops must be considered in NUE calculation and not only the rotation cycle of the studied crops if more than one crop is grown in the field. This is because some crops (e.g., maize and soybeans) are rotated annually while longer and more complex crop rotations are employed for other types of crops. Moreover, biological nitrogen fixation (BNF) must be distinguished from total nitrogen removal by plant harvesting. For example, when calculating NUE, the input nitrogen should be estimated as total plant nitrogen times the fraction from BNF (Norton et al., 2014).

Moreover, in the calculation of NUE for mixed crop-livestock operations, the crop or animal products that are used within the farm must be distinguished from the crops that are not used on the farm. Therefore, outputs would include (i) some crop products that are exported and not used entirely on the farm for feed, (ii) the dairy or animal products, including any manure that might be exported to another farm and inputs would include fertilizers and feed supplements (Norton et al., 2014). In addition, attention must be given to NUE results when the NUE values of different crops are compared and interpreted. This is because different NUE values can be obtained for different crops which may influence the BMPs or do not properly present the success or failure of national and regional nutrient management practices. For example, the NUE value of wheat is higher than maize thus a relatively high NUE value is reported for wheat, which may indicate problem of the soil mining/depleting soil fertility in a farm or region that wheat is the main product. Additionally, it is recommended to provide interpretation based on long-term (several years instead of one year) NUE values to determine the progress (success or failure) of nutrient management practices. Moreover, in assessing progress to improved nutrient performance, both productivity (such as yield) and soil health (such as soil test values) should be considered (Norton et al., 2014).

3.3.2.6 Resource Value Mapping (REVAMP) tool

"Resource Value Mapping" is an initiative tool developed by the Stockholm Environment Institute (SEI) on Sustainable Sanitation. The main objective of developing this tool is to evaluate the possibility of reuse of water, energy, and mineral resources to decrease the negative effects of resource extraction and waste disposal on the environment and to promote sustainable development. The primary emphasize has been on the recovery of industrial resources but interest in the reuse or recovery of wastewater, sanitation, food and other organic waste streams is rising (Ddiba et al., 2016).

The REVAMP provides the opportunity to "estimate, visualize and value" the recoverable or reusable resources in various forms from a broad range of waste stream. For example, to estimate the potential use of wastewater sludge as plant nutrients and/or biogas or to quantitatively estimate the amount of recoverable resources and their potential revenues. This tool helps decision-makers including policy-makers, engineers, and investors in low and middle-income countries to effectively assess and manage the produced wastes and compare the reuse of resources regarding energy and nutrient content and potential revenues (Ddiba et al., 2016). One of the advantages of this tool in comparison to previous versions is its capability to evaluate multiple resources or waste streams from small (e.g., a specific project) to big levels (e.g., whole city) and can compare several reuse options and scenarios (e.g., the potential reuse of wastes at local market (Ddiba et al., 2016). Moreover, when sufficient local data are not available, this tool uses default values adapted from peer-reviewed literature to calculate and analyze resources and the potential for reuse products.

Case Study Example: Application of REVAMP in Kampala (Ugandan, 2016)

Kampala is the capital of Uganda with a population of 1.5 million. The majority (90%) of households in this city use on-site decentralized sanitation systems (mainly pit latrines and septic tanks) and the central business district is connected to the public sewer system (Ddiba et al., 2016).

The REVAMP tool was applied to investigate the potential reuse and recovery of fecal sludge, sewage sludge, and organic municipal solid waste as biogas or solid combustion fuels from waste resources as a substitute to valuable natural resources ("woody biomass") that were used for cooking purposes by 78% of the city's population. Moreover, the potential application of nutrients from the waste stream as a reliable source of fertilizer for agricultural activities was investigated (Ddiba et al., 2016). Two scenarios including (i) current solid waste collection (around 40% of what is generated) and (ii) 100% solid waste collection were evaluated. The assessment was conducted by calculating and comparing the financial revenues of recoverable materials and products with the currently used materials and products including “propane, fuel briquettes and sludge-based soil conditioner”. The environmental, economic, and social assessments revealed the significant benefits of recoverable products such as improvement in food production and public health, job creation, and environmental protection (Figure 3.5) (Ddiba et al., 2016).

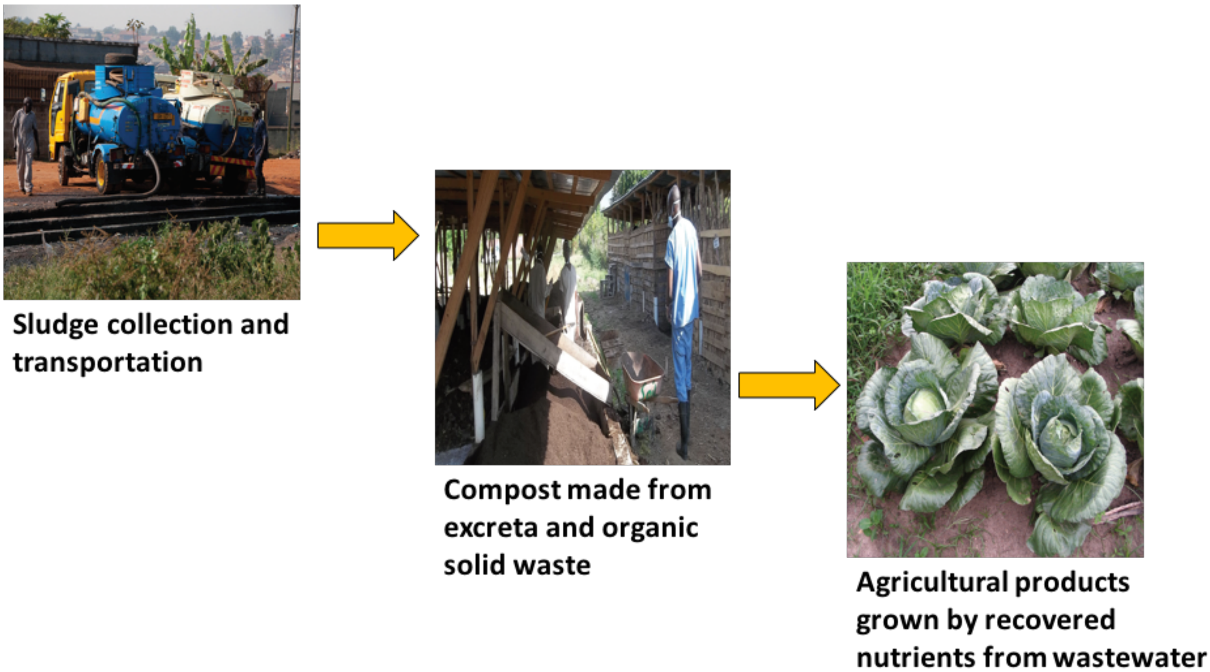


Figure 3.5 Resource recovery and reuse, Kampala, Ugandan (Adapted from Ddiba et al., 2016).

3.4 Environmental reporting

3.4.1 Environmental report methods and approaches

Public environmental reporting is a response to the public awareness that demands a move towards greater environmental practices. In general, environmental reports cover economic, social, and environmental issues and the actions that have been taken to address such issues in regard to sustainable development goals. This section discusses two of the common methods that were developed for effective communication to support nutrient management practices.

3.4.1.1 Environmental report cards

Monitoring programs and modeling toolboxes are developed to determine the aquatic water quality and ecosystem health. In one hand, adaptive management frameworks are established based on the monitoring results and on the other hand monitoring programs help to evaluate the effectiveness of adaptive management programs and assists in the development of further management practices (Connolly et al., 2013). One of the important factors in the successful achievement of environmental goals in an adaptive management framework is to effectively convey the monitoring findings to target audience including decision makers, communities, and industries which require to develop innovative methods to transfer the information (Connolly et al., 2013). The information can be conveyed by various methods and ecosystem health report cards are one of the effective tools used to clearly communicate the complicated scientific information in understandable ways to broad audiences. They are used to (i) provide information on the states or conditions of water bodies (ii) represent and track the effectiveness of protective and restorative management actions, and (iii) are an integral part of adaptive management cycle (Abal, n.d.). Report cards apply grades or scores to present the information and vary based on the type of ecosystems, scale of studied area, and the monitoring and management program goals (Connolly et al., 2013).

There are several steps that must be considered before establishing the environmental report cards. For example, clear objectives must be set and the objectives should be based on robust scientific information and be aligned with the management aims for the reporting location. Furthermore, the report card should be able to make strong links to all stakeholders and the implementation of objectives should be easy and flexible (Connolly et al., 2013).

Although report cards present the monitoring results and management practices of water quality and ecosystem health values, economic and social aspects of assessments still need to be included in any comprehensive, ethically responsible monitoring system. Moreover, as monitoring data are presented as score or grades, thus defining the scores/grades and comparing the presented values with guidelines would help in the clarity of report cards (Connolly et al., 2013). In addition, the reported zones in the report card should be a real representative of monitoring results and management actions and should clearly distinguish the significant effects of natural self-purification phenomenon from preservative management practices (Connolly et al., 2013). Figure 3.6 and Table 3.17 provide a Global Reporting Initiative (GRI) principles and some of the environmental report cards.

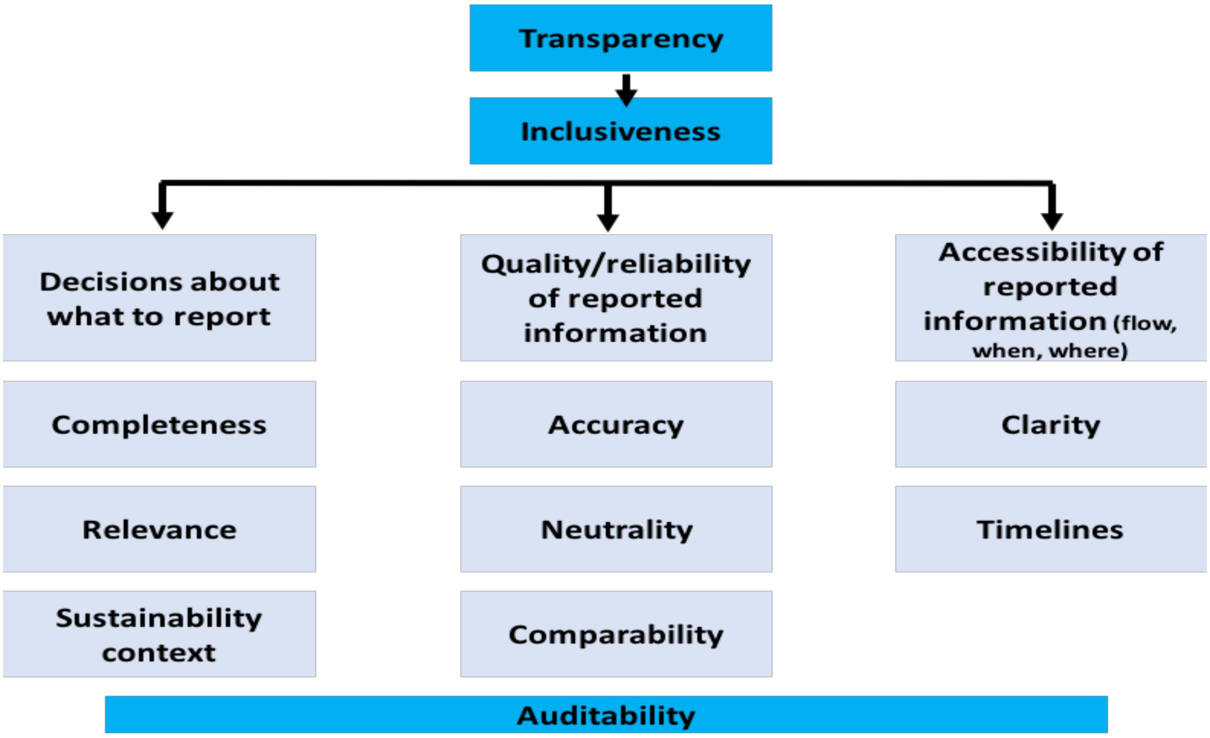


Figure 3.6 Global Reporting Initiative (GRI) principles (Adapted from DEAT, 2005).

Table 3.9 Some of the environmental report cards developed in the world (Adapted from Connolly et al., 2013).

Report Card Program	**Location/First Report Card**	**Abbreviation**	**Website**
South East Queensland Healthy Waterways-Marine	Australia: QLD/2000	EHMP Marine	www.ehmp.org
South East Queensland Healthy Waterways-Freshwater	Australia: QLD/2001	EHMP Freshwater	
Arctic Report Card	Multi-national Arctic/2006	Arctic	www.arctic.noaa.gov
Chesapeake Bay Report Card	USA/2007	Chesapeake	www.chesapeakebay.net
Ocean Health Index	171 countries and territorial regions/2012	OHI	www.oceanhealthindex.org

3.4.1.2 Transboundary Waters Assessment Programme (TWAP)

The "indicator-based Global Environment Facility Transboundary Waters Assessment Programme" was developed in response to ongoing contamination of transboundary water systems caused by human activities and natural processes. The main goal of the program is to identify and evaluate the trend of changes in the transboundary water systems and the resulting effects of such changes on human populations (TAWP, 2016).

The program was developed by establishing the proper methodologies for conducting a comparative global assessment through institutional partnerships. The program covers five types of transboundary water systems including groundwater, lakes/reservoirs, rivers, large marine ecosystems and open seas (see Figure 3.7). The assessment results will be used to set priorities for promoting conservation of transboundary water systems by developing regional and national strategies in regard to sustainable development goals (TAWP, 2016). The program aimed to:

- Conduct independent indicator-based assessment
- Link between such assessment (e.g., "socioeconomic and governance-related features").
- "Identify and classify water bodies at risk"
- Advise policy and decision makers
- "Encourage knowledge exchange"
- Increase public awareness (TAWP, 2016)

The indicators are identified and thematically categorized to "biophysical, socioeconomic, and governance" and five levels of risks including "lowest, low, moderate, high, and highest" were developed. The results can be amended to system and regional scale comparisons to support national monitoring and management practices to achieve sustainable development goals for the intended period (e.g., 2015 – 2030) (TAWP, 2016).

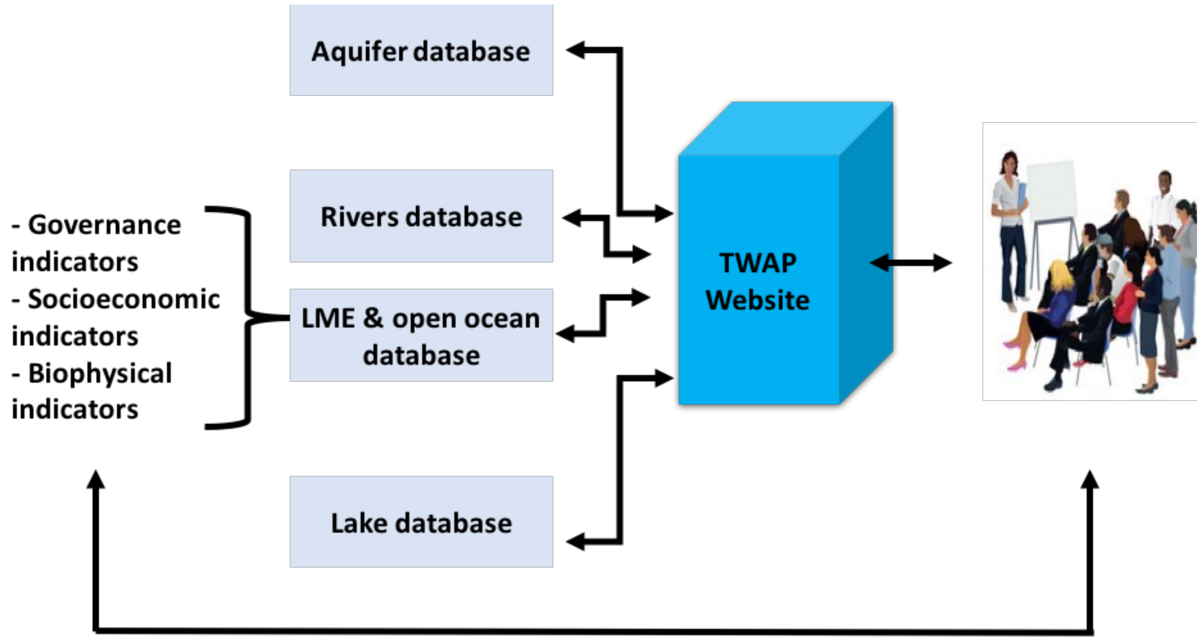


Figure 3.7 Development of GEF TWAP (Adapted from TAWP, 2016).

3.5 Conclusion

The effective control of nonpoint source nutrient contaminants is extremely challenging due to the diversity of the nutrient sources and complex and interrelated interactions of contaminants. Thus, it is critical to establish a systematic approach to effectively assess, plan, implement, and evaluate the nutrient pollutants.

In this module, we learned that monitoring plays an important role in determining the nonpoint sources and future nutrient management efforts. However, due to the complexity and interrelated interactions of contaminants it is not possible to apply a single approach to monitor nonpoint source nutrients. Therefore, robust measuring programs and effective monitoring design with clear objectives must be developed to provide reliable data for assessing the effectiveness of pollutant load estimation methods and best management practices.

Discussion Questions

a) What are the main challenges of effectively monitoring wastewater management and nutrient runoff? Are they technical or political in nature?
b) Are there ways we can improve monitoring systems so we can better assess progress towards our goals?
c) How can we best ensure transparency in reporting of contaminants, when incentives to make false claims are so strong?
d) Can you envision the application of the NUE approach in your community?

Annotated Bibliography

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Available at:
https://www.epa.gov/polluted-runoff-nonpoint-sourcepollution/monitoring-and-evaluating-nonpoint-source-watershed
This document provides information on the designing steps and technical and scientific challenges of a nonpoint source monitoring program, data analysis, pollutant load estimation methods, and quality assurance and control.

Karydis, M., 2009. Eutrophication Assessment of Coastal Waters Based on Indicators : a Literature Review. Global NEST Journal 11, 373–390.
Available at: http://journal.gnest.org/sites/default/files/Journal%20Papers/373-390_626_KARYDIS_11-4.pdf .
This paper provides useful information on practical methods developed for the quantitative assessment of eutrophication, statistical techniques, simulation models and water quality indicators for assessing water quality and coastal management.

Norton, R., Davidson, E., and Roberts, T. (2014). Nitrogen Use Efficiency and Nutrient Performance Indicators. Global Partnership on Nutrient Management.
Available at: http://unep.org/gpa/documents/publications/NUEandNPIGPNM2015.pdf
This paper provides information on Nitrogen Use Efficiency (NUE) indicator developed to assess the effectiveness of nutrient management strategies and farming practices.

Online Resources

Transboundary Waters Assessment Programme (TWAP)
http://www.geftwap.org/twap-project
This website provides an example of successful global-scale program aiming to assess the transboundary water systems to provide reliable knowledge for effective management efforts.

European Commission Environmental Marine Information System,
http://emis.jrc.ec.europa.eu/emis_2_2.php
This website provides information on eutrophication level of coastal marine environment by assessing the biological and physical variables using hydrodynamic models and satellite remote sensing.

Further Reading

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Module Four: Nutrient Removal Technologies and Best Field Practices

Learning Objectives

After completing this module, students will:

1. Grasp the axiomatic role that technological change has played in the evolution of wastewater management;
2. Understand the possible benefits of waste recycling, in both urban and agricultural settings;
3. Be able to describe some of the more prevalent waste recovery methods;
4. Be able to describe some small-scale, innovative recovery/re-use technologies;
5. Describe the non-point source pollution recovery techniques, including the capture of nutrient loads from fields

4.1 Introduction: The historical development of wastewater management

Technologies to recover nutrients such as nitrogen, phosphorous, and potassium from waste streams have undergone accelerated development in the past decade mainly due to stringent discharge limits on nutrients, as a result of their deleterious impact on environment, and rising fertilizer prices. In this module, the historical development of wastewater removal methods and technologies, traditional and modern wastewater minimization, separation, and reuse methods and technologies, small community wastewater management and finally nutrient pollution and controlling strategies will be reviewed.

One of the most interesting historical characterizations of ancient civilizations is how they managed their waste. Technological changes have been instrumental in the evolution of wastewater management and nutrient cycling, long before people had any solid idea of what, exactly, was in wastewater or nutrient runoff. It is a long complex history, especially in some regions where cities have existed for many centuries; for example, a history of sewage treatment in Britain (Stanbridgem, 1976) runs up to 12 volumes, and that only covers up until the early 1970s!

See Cooper (2001) for a quick review of some of the earliest forms of organized WWM. Interestingly, the ancient Greeks had discovered the potential of reusing wastewater well over 2000 years ago. As Cooper writes, they utilized "public latrines which drained into sewers which conveyed the sewage and stormwater to a collection basin outside the city. From there brick-lined conduits took the wastewater for irrigation and to fertilize crops and orchards"

(2001:12). Of course, wastewater management also had its perils before the development of water treatment. It would be nearly impossible to estimate the number of human deaths that were caused by the lack of proper sanitation in centuries previous to our own, and it continues to be a major cause of disease and death in many regions today. We often forget that rudimentary toilets were not invented until the mid-1500s in Britain, and were not perfected for popular distribution until the heroic efforts of none other than Thomas Crapper in 1861.

In general, wastewater management frameworks/strategies, regulations, and standards were established as responses to health and environmental concerns associated with the physical (e.g., colloidal, suspended and dissolved materials), chemical (e.g., biodegradable organics and nutrient compounds), and biological (e.g., pathogenic organisms) contaminants in raw/untreated wastewater (Metcalf & Eddy Inc. et al., 2003a). Table 4.1 summarizes some of the diseases associated with the presence of concerning bacteria in untreated wastewater.

Table 4.1 Some of diseases associated with untreated wastewater (adapted from WHO, 2006).

Diseases	**Pathogenic Bacteria**
Cholera	*Vibrio cholera*
Typhoid fever	*Salmonella typhi*
Gastroenteritis (possible long-term sequelae, e.g., arthritis)	*Campylobacter jejuni*
Gastroenteritis	*Escherichia coli*
Bloody diarrhea, hemolytic uremic syndrome	*E. coli O157:H7*
Abdominal pain, peptic ulcers, gastric cancer	*Helicobacter pylori*
Salmonellosis, gastroenteritis, diarrhea (possible long-term sequelae - e.g., arthritis)	*Salmonella spp.*
Dysentery (possible long-term sequelae – e.g., arthritis)	*Shigella spp.*

Unlike the earliest treatment methods of wastewater such as sewage farms that were capable of removing a few contaminants, modern treatment processes and technologies have been significantly advanced to the point that they can effectively remove major contaminants and produce high quality effluent that is frequently being used for urban, industrial, and agricultural purposes (Parker, 2011; U.S. EPA, 2012). This technological advancement is driven mainly by disposal or reuse regulations, which demand a more efficient removal of wastewater contaminants as part of new or refurbished WWM systems. These regulations stem from increased awareness of what, exactly, is in wastewater today, including relatively new contaminants such as biocides, pesticides, heavy metals, pharmaceuticals, and hormones (Kolpin et al., 2002; Singh et al., 2004; Wittmer et al., 2010). Therefore, innovative technologies are needed to not only effectively remove such contaminants from wastewater, but also to remove the contaminants in a sustainable manner and to reduce wastewater treatment costs (e.g., capital, maintenance, and operational costs) (Parker, 2011).

4.1.1 Land treatment (sewage farms)

The use of sewage as fertilizer has had various proponents over centuries (see Wolfe, 1999), including the famous German chemist Justus von Liebig (1803-1873), often considered the founder of organic chemistry (or, indeed, the "father of fertilizer") who championed the land treatment approach largely because he thought the spread of related phosphate content would be beneficial on farms. One of his most important contributions was the development of what has come to be known as the “Law of the Minimum,” or “Lieberg’s law”, which states that:

> *... if one of the nutritive elements [in soil] is deficient or lacking, plant growth will be poor even when all other elements are abundant. If the deficient element is supplied, growth will be increased up to the point where the supply of that element is no longer the limiting factor. Increasing the supply beyond this point is not helpful, as some other element would then be in minimum supply and becomes the limiting factor. A concept of the “law of the minimum” is still being used in nutrient management and crop production today. It has been modified as additional elements have proved to be essential in plant nutrition and has been extended to include other factors such as moisture, temperature, insect control, weed control, light, plant population and genetic capacities of plant varieties. In fact, modern advances of agriculture have consisted mainly of identifying successive limiting factors and correcting them. Thus, attainment of optimum yields involves a complex mix of nutrients in combination with other inputs.*
>
> *(Written by Travis P. Hignett, International Fertilizer Development Center. Adapted from “The Fertilizer Handbook,” 1982. http://www.fertilizer101.org/science/?storyid=10*

Of course, the fertilizer industry, aided by adaptive technologies that allowed us to procure more nitrogen, phosphorus, and potassium, would go on be a trillion-dollar enterprise that actively pushed its wares on farmers around the globe. Land treatment, despite fairly widespread usage in the late 1800s and into the 1900s, did not fare as well. It could waterlog farmland, and there were nagging hygienic issues. However, there are numerous movements to revisit its utility today and the use of human sewage as a fertilizer is still common practice in many regions, so it is well worth discussing it in more depth here.

Land treatment is a wastewater treatment method during which raw wastewater is distributed on the land. The large-scale agricultural application of land treatment/sewage farms dates back to about 150 years ago, when due to rapid expansion of cities in western Europe and North America public sewage collection systems were developed (National Research Council, 1996). The collected sewage was transferred to sewage farms for treatment and for its fertilizer value (e.g., the phosphorous content) (National Research Council, 1996). The method was quickly spread so that there were nearly 50 sewage farms across Europe by 1875 (National Research Council, 1996). This led to some improvements in the quality of receiving water bodies, but it caused different environmental problems including, “clogging of soil pores, waterlogging or saturation of soil with water, odors, and contamination of food crops” (National Research Council, 1996). These problems and the development of more efficient wastewater treatment methods that not only required smaller areas than that of the sewage farms but also were capable of producing higher quality effluent gradually put an end to the application of sewage farms (National Research Council, 1996).

4.1.2 Chemical treatment

Chemical treatment is a process during which chemicals such as lime are used. The main goals of chemical treatment of wastewater were to precipitate contaminants from sewage so that the sewage could be safely disposed of (Cooper, 2001; Wardle, 1893) and also produce artificial fertilizers (Cooper, 2001). Despite the removal of suspended contaminants from wastewater, the complete removal of pollutants was not possible with this method (Cooper, 2001). Moreover, the chemical treatment led to the generation of higher amounts of sludge, which was challenging to dispose of (Cooper, 2001). With the development of biological processes which can remove of both dissolved and suspended contaminants from wastewater, this method was abandoned in the 1800s (Cooper, 2001). However, this method is now used for phosphate removal from wastewater (Cooper, 2001; Culp and Culp, 1971).

4.1.3 Primary and secondary treatments

Up to 1900, land treatment was the first choice for treating wastewater. However, due to some challenges such as waterlogging and difficulty in finding lands near big cities, the land treatment method was substituted with less problematic methods.

Additionally, due to rapid population growth, diseases such as cholera were significantly increased and led to several epidemics. Investigations showed that the contamination of water supplies with pathogenic microorganisms in wastewater had a major role in such epidemics. This led to an enhanced demand for wastewater treatment. The search for effective wastewater treatment methods was further promoted with the passage of legislations such as "Royal Commission Standard" or "general standard" (UK, 1912) (Guest, 1987) that encouraged treatment of wastewater to the level/s that reduces the concentrations of suspended solids and biochemical oxygen demand (**BOD**) in the final effluent to 30 mg/L and 20 mg/L, respectively, (Sterritt and Lester, 1986).

Biological filtration of wastewater was found to be an effective treatment technique. This method was introduced by Sir Edward Frankland in 1870 and was developed further by others (e.g., Warington and William Dibdin) until 1914 (Cooper, 2001). In this method, wastewater was passed through coarse porous gravel. As clogging was one of the challenges of this method, more studies were conducted to resolve this problem. A series of field experiments showed that the filter clogging was minimal when the wastewater passed at a flow rate of 0.045 m^3/m^3 of bed per day. Moreover, at this flow rate, the filter generated an effluent with low concentrations of nitrogenous contaminants (Stanbridge, 1976). These were found to be due to the effect of microorganisms in wastewater degradation. The idea of separating sludge and using microorganisms to treat the wastewater was revolutionary at that time and led to the development of "artificial ground" and later to the development of "contact bed" and modern biological filters. The first artificial filter ("alternating layers of burnt clay and soil") was installed at UK (Merton, south of London). Soon, the first biological filters "trickling Filter" were installed in the US (Madison, Wisconsin, 1901) and the UK (Salford near Manchester, 1893)(Cooper, 2001).

Activated sludge ("a suspended-growth process") is another method that was used to treat wastewater since the 1880s. Dr. Angus Smit's work showed the effective oxidation of the organic compounds in the aeration tanks. This method was further studied by a number of investigators between 1914 to 1965 (Bitton, 2005a; Cooper, 2001; Metcalf & Eddy Inc. et al., 2003b). For example, several experiments were conducted during 1912-1913 at Lawrence Experiment Station (Massachusetts, USA) where significant wastewater degradation through aeration of wastewater was reported (Clark and Adams, 1914 in Metcalf and Eddy, 2003). Similar laboratory studies at the Manchester Sewage Works (UK) (Ardern and Lockett, 1914) confirmed the high degradation of wastewater in bottles cultivated by wastewater microorganisms. The process was named activated sludge because active microorganisms capable of aerobic degradation of organic compounds had major contributions in the removal of organic contaminants (Metcalf & Eddy Inc. et al., 2003b).

In an activated sludge process, raw wastewater is aerated for a period of time. This provides oxygen for aerobic microorganisms to oxidize the organic compounds in wastewater to non-pollutant forms (e.g., CO_2, H_2O, and NH_4) and produce new microbial cells. The treated liquid is allowed to settle (Bitton, 2005a). Then the supernatant (top liquid layer) is separated from the bottom layer, which is activated sludge or flocs formed by microbial cells (Bitton, 2005a; Cooper, 2001). This process was extensively used in the US, Denmark, Germany, Canada, the Netherlands, and India. However, the process did not receive popularity in the

UK, where the major cities had already adopted the biological filter processes. The activated sludge adaptation in the rest of Europe was also slow until about 1948 due to the Second World War and Russian War and occupation (Finland) and resumed when the search for more efficient methods was the main focus of the wastewater treatment industry (Cooper, 2001).

Up to 1965, the main reasons for wastewater treatment were public health protection and water supply improvement. However, in the later years (1965-2000), the focus shifted to "process refinement towards standards" for environmental protection (Cooper, 2001). For example, in this period, in addition to removal of organic compounds (BOD) and suspended solids (TSS), the efficient removal of nutrients such as ammonia, nitrate, and phosphate was also required. Moreover, more emphasis was given to the disinfection of effluent for further public health and environmental protection (Cooper, 2001). These led to the emerge of a new generation of biological treatment technologies, aimed mainly at the simultaneous removal of organic, nitrogenous, and phosphorous contaminants (Metcalf & Eddy Inc. et al., 2003b).

4.2 Wastewater minimization, separation, and reuse

4.2.1 Wastewater generation

Wastewater can be managed at three main levels including,

(i) minimal wastewater generation,

(ii) wastewater separation either at the source of generation or in the treatment facilities, and

(iii) wastewater recycling and reuse.

Minimal wastewater generation depends significantly on the efficient use of water, which benefits communities in two ways. First, it reduces the need for high quality water and secondly, it leads to the generation of a lower amount of wastewater. The emphasis is to reduce wastewater quantity (flow) and concentrations of contaminants or combinations of both. The environmental benefits include less fresh water consumption, especially in water-stressed areas. This, in turn, reduces the discharge of effluent to receiving water bodies. The economic benefit resulting from wastewater minimization includes the reduction in wastewater treatment costs (e.g., energy, chemicals) (Ferguson et al., 2003).

One of the important steps in wastewater minimization is to determine the amount of water needed for various activities at the source of wastewater generation and where possible, use efficient water-saving technologies (Table 4.2). For example, conventional flush toilets use 17 gal/cap/d of water, while low-volume flush toilets use 8 gal/cap/d of water or dry toilets use no water. The ECOSAN is a waterless toilet that is used in the water-stressed regions of Africa. The ECOSAN is a completely closed system with no need to pipe network and on-site or centralized sewage treatment facilities. Since no effluent is produced, it has minimum impact on the regional surface and groundwater. One of the advantages of this system is that the system is odorless and thus can be installed indoor as well as outdoor (EcoSan, n.d.).

In addition to efficient use of water, the choice of household products has a huge impact on the characteristics of the produced wastewater. This, in turn, impacts the operational efficiency of on-site or centralized treatment systems and consequently the quality of receiving water bodies. For example, the toxic compounds in the household products (e.g., heavy metals, surfactants in the detergents) negatively impact the activity of microorganisms in the biological treatments (e.g., in septic tanks, secondary treatment processes) (Ferguson et al., 2003). Therefore, the contaminants cannot be effectively removed from wastewater and eventually enter to surface and ground water.

Table 4.2 Technologies for lower wastewater generation (taken from Ferguson et al., 2003).

To reduce the volume of black water	To reduce the volume of gray water	To recycle and re-use water
• Low-volume flush toilets • vacuum toilets • Urine separating toilets • Composting toilets • Waterless urinals	• Low-flow shower heads • Low-volume washing machines • Aerated tap faucets • Controlled-flow tap valves • Pressure reducing valves	• Graywater recycling • Rainwater collection • Stormwater recovery

However, various water usages even in small quantities result in wastewater generation. Based on the source of generation, wastewater can be classified as

(i) **gray water**, which is the wastewater produced from baths, showers and kitchens and

(ii) **black water**, which is the wastewater generated from human wastes (e.g., urine).

The chemical and microbial characteristics of gray water and black water vary; gray water contains lower pathogens and organic contaminants and thus creates less public health and environmental problems and can be used for irrigation or discharged into water bodies with no or primary treatments (Paulo et al., 2013).

Water shortages, population growth, the contamination of water resources, and climate change have all forced communities to search for alternative water resources. Reclaimed water ("highly treated wastewater effluent") is one of the promising alternatives that has been used in many water-stressed areas for both potable and nonpotable purposes. Agricultural irrigation is the largest user of reclaimed water (Metcalf & Eddy Inc. et al., 2003c).
Table 4.3 summarizes some of the reclaimed water applications.

Table 4.3 Reclaimed water applications (taken from Metcalf & Eddy Inc. et al., 2003c).

Sector	Applications	Sector	Applications
Agricultural irrigation	Crop irrigation	Groundwater recharge	Groundwater replenishment
	Commercial nurseries		Saltwater intrusion control
Landscape irrigation	Parks	Recreational and Environmental uses	Marsh enhancement
	School yards		Fisheries
Industrial reuse	Cooling water	Potable and nonpotable urban uses	Blending in water supply reservoirs
	Boiler feed		Toilet flushing

4.2.2 Wastewater treatment processes and technologies

Wastewater is produced when fresh water is used in various activities by residences, businesses, industry, and agriculture. All discharges of wastewater to the environment or reuse of effluent regulated since the early 20th century to protect public health and the environment. Therefore, wastewater requires proper treatment before it can be discharged to the environment. Wastewater treatment is achieved through physical/mechanical, chemical, and biological processes to improve the quality of wastewater by reducing (i) suspended solids (ii) biodegradable organics (e.g., BOD), (iii) pathogenic organisms, and (iv) nutrients (Metcalf & Eddy Inc. et al., 2003a).

Unit operations are treatment methods that use physical or mechanical forces to remove contaminants. These include screening, sedimentation, filtration, or flotation. Unit processes use chemical and biological processes to remove contaminants from wastewater. The chemical units include disinfection, adsorption, or precipitation processes. The biological unit processes include processes that use microorganisms to remove organic and nutrients (nitrogen & phosphorous) from wastewater (Metcalf & Eddy Inc. et al., 2003a).

Wastewater treatment is classified as primary, secondary, and tertiary or advanced treatments. The level of contaminants is reduced in each step until a high quality effluent is produced (Figure 4.1) (Davis and Cornwell, 2014). A classification of secondary treatment systems is based on the presence and activity of the dominant microorganisms in the treatment systems. Treatment methods are grouped into aerobic and anaerobic systems. The common aerobic treatment systems include activated sludge systems, trickling filter, and oxidation ponds, and the anaerobic systems include septic tanks, Imhoff tank, and cesspool (Metcalf & Eddy Inc. et al., 2003e).

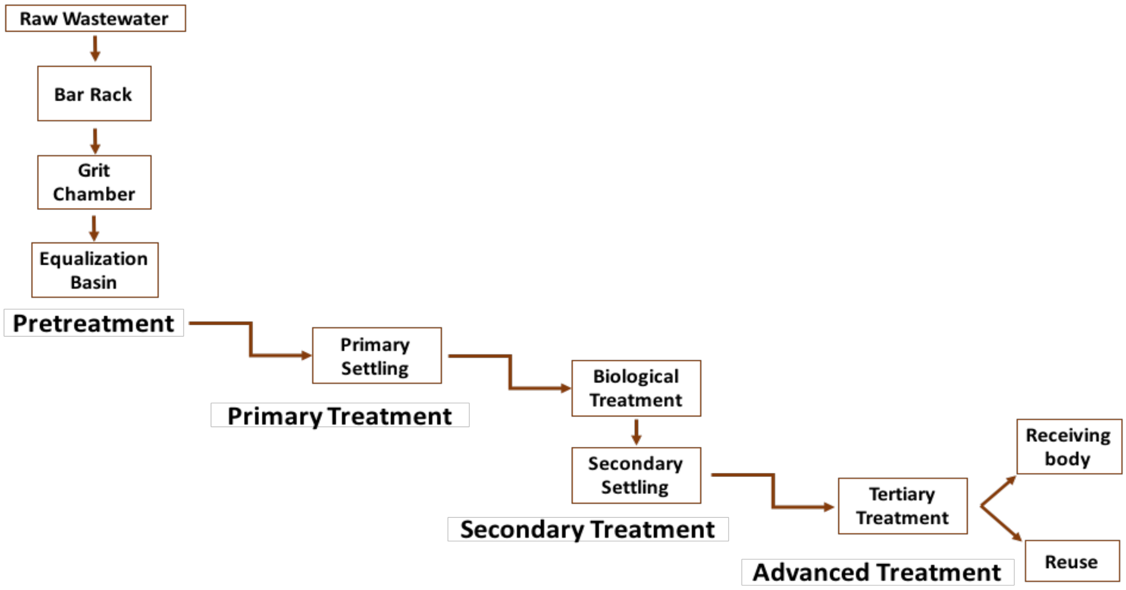

Figure 4.1 Wastewater treatment processes (Adapted from Davis and Cornwell, 2014).

Primary treatment is the first level of wastewater treatment (Davis and Cornwell, 2014). The primary treatment is used to remove solids (e.g., suspended and floating solids) from raw wastewater. The primary treatment includes screening and sedimentation. The big solid objects are removed at the screening step and suspended solids are removed at the sedimentation step (Metcalf & Eddy Inc. et al., 2003d). Nearly 60% of suspended solids and 20-35% of organic matters (BOD) of wastewater are removed by primary treatment (Davis and Cornwell, 2014). However, soluble constituents of wastewater are not removed in this step (Davis and Cornwell, 2014). The secondary treatment is used to further remove the remaining suspended solids and a major part of dissolved organic compounds (e.g., BOD). Unlike the primary treatment wherein the wastewater contaminants are removed physically or mechanically, the contaminants removal in the secondary treatment is achieved through the application of biological processes (e.g., trickling filters and activated sludge processes), in which the organic compounds are consumed by microorganisms. Nearly 85% of BOD can be removed by the biological treatment, but nutrients, pathogenic bacteria, and viruses are not completely removed in this stage (Davis and Cornwell, 2014).

In cases that the quality of produced effluent does not meet the discharge standards and regulations or the reuse specifications, the effluent goes under advanced treatment. These processes (mainly membrane filters) produce high quality effluent which is comparable to high quality water. The processes are typically similar with the processes that are used for drinking water treatment (Davis and Cornwell, 2014). The effluent then is disinfected (with chlorine or ultraviolet radiation) to improve the microbiological quality of effluent. The disinfected effluent is usually discharged to the water bodies or transferred to the end users (e.g., for irrigation or industrial uses).

Although most of the contaminants are removed by the primary, secondary, and advanced treatments, recent studies showed that some contaminants cannot be completely removed and some other compounds are changed to harmful or toxic contaminants (Kolpin et al., 2002; Singh et al., 2004; Wittmer et al., 2010). Moreover, the removed contaminants concentrate in the produced sludge, which makes careful and consistent sludge handling, treatment, and disposal a necessary part of WWM (Davis and Cornwell, 2014). In the following sections, two aerobic systems, including activated sludge and fixed film biological processes, are discussed.

4.2.2.1 Activated sludge process

A conventional activated sludge system includes an aeration tank and a sedimentation tank. The oxidation of organic compounds is carried out in the aeration tank. The separation of produced sludge (mainly microbial cells), which is produced in the aeration tank, from the effluent takes place in the sedimentation tank. In general, a portion of the activated sludge (e.g., 1500-200 mg/L of sludge, known as “return activated sludge” (RAS)) is returned from the sedimentation tank (clarifier) to the aeration tank to stimulate the oxidation of organic compounds in the aeration tank (Bitton, 2005a). The remaining sludge is transferred for further treatment by aerobic or anaerobic digesters (Bitton, 2005a). Figure 4.2 shows the conventional activated sludge system.

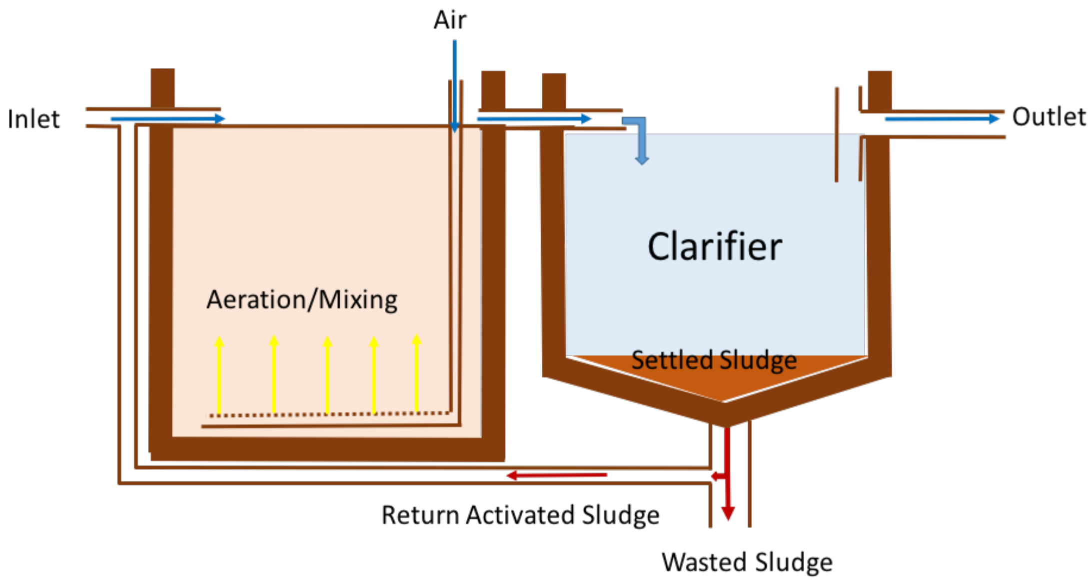

Figure 4.2 Activated sludge system (Adapted from Tilley et al., 2008).

To date, various configurations of the activated sludge process have been developed to increase the efficiency of the aeration and consequently the mixing in the system. Aeration typically is provided by mechanical surface aerators or by introducing air or pure oxygen through diffusers (Figure 4.2) into the aeration tank. Common configurations of the active sludge system are as follows;

- Conventional Activated Sludge
- Contact Stabilization
- Step Aeration
- Extended Aeration
- High-Rate Aeration
- Pure Oxygen
- Complete Mix
- Sequential Batch Reactors (SBRs)

Activated sludge systems can efficiently treat wastewater and are less sensitive to organic and hydraulic shock loads. Moreover, up to 99% of BOD and pathogens and a high percentage of nutrients can be removed by these systems. However, these systems require high energy (electricity) for aerators and generate relatively high amounts of sludge that needs further treatment. They have high capital, operation, and maintenance costs and require skilled operators (Tilley et al., 2008).

4.2.2.2 Fixed-Film biological processes

"Fixed-film biological processes" or biofilm reactors (Figure 4.3) use biological processes. Unlike the activated sludge systems where microorganisms are suspended in the aeration tank, in these systems, microorganisms are attached to a medium. The medium is built from either natural (e.g., sand, gravels, stones) or synthetic materials (e.g., plastic, activated carbon particles). The performance of the biofilm reactors depends on the flow rate and the type of selected medium. Trickling filters, rotating biological contactors (RBCs), and up-flow/down-flow submerged filters are common types of the biofilm reactors (U.S. EPA, 2000).
Trickling filters (TFs) are aerobic treatment systems that are used to remove organic compounds from wastewater (U.S. EPA, 2000). However, nutrients are also removed to some extent in these systems. A variety of microorganisms including "aerobic, anaerobic, and facultative bacteria, fungi, algae, and protozoa" attach to the medium and form a biological film or biofilm (U.S. EPA, 2000). The biofilm formation increases the availability of organic compounds in the wastewater to these microorganisms (U.S. EPA, 2000). In general, two types of microorganisms including aerobics and anaerobics are predominantly developed on the biofilm. The aerobic microorganisms usually develop on the surface of the biofilm (U.S. EPA, 2000). When the thickness of the biofilm increases as the result of microbial growth (or biomass), the underlying anaerobic layer is developed. The development of the anaerobic layer occurs because less oxygen penetrates the inner region of the biofilm (U.S. EPA, 2000). The growth of microorganisms on the biofilm is limited (U.S. EPA, 2000). This is because the microorganisms are washed out of the filter (U.S. EPA, 2000). This phenomenon is known as "sloughing". The sloughed biomass are transported to another tank (clarifier), where they are separated from the effluent (U.S. EPA, 2000).

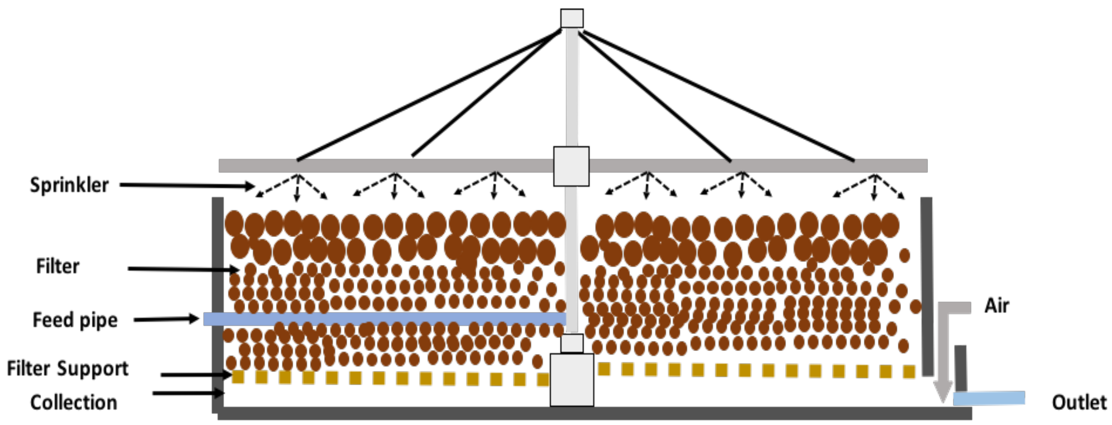

Figure 4.3 Trickling filter system (Adapted from Tilley et al., 2008).

4.2.2.3 Membrane filters

Several processes and technologies such as "granular filtration, membrane filtration, carbon adsorption, chemical and biological phosphorous removal, and nitrogen control" have been advanced for tertiary treatment of wastewater (Davis and Cornwell, 2014). Membranes are one of the proven technologies for the tertiary treatment of microbial, organic, and inorganic constituents of wastewater (Melin et al., 2006). In a membrane-based treatment, a low quality water (e.g., the secondary treated wastewater; known as "feed water") pass through a membrane, where the physical, chemical and microbial contaminants are retained based on their size and finally clean water (known as "permeable") pass through the membrane (Stephenson, 2000; U.S. EPA, 2006). Membranes are classified based on their abilities in separating the contaminants to;

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO) (Lenntech, 2016).

However, microfiltration is used more commonly in wastewater treatment (Davis and Cornwell, 2014). Nearly 75-90% of BOD and 95-98% of TSS can be removed by MF. However, membrane fouling (e.g., due to pore clogging) is one of the challenges of membrane technologies (Davis and Cornwell, 2014; Lim and Bai, 2003).

4.2.2.4 Microfiltration Membrane Bioreactors (MBRs)

Microfiltration Membrane Bioreactors are the combination of activated sludge process (for biological treatment) and membrane filtration (for solid removal). The technology was developed to overcome the limitations associated with the conventional wastewater treatments. For example, unlike the conventional methods, the enrichment of the right types of wastewater-treating microorganisms is promising and the technology is compact and does not need a big space because more concentrated biomass (flocs of microorganisms) can be formed by membrane filtration. The technology is being commonly used in the last 10 years especially for secondary treatment of municipal wastewater. The MBRs removal efficiency is very high and they can effectively remove nutrients (nitrogen, phosphorus), bacteria, organic contaminants (BOD), and total suspended solids (U.S. EPA, 2006).

Earlier applications of MBRs were limited to small systems because of the high capital, maintenance, and operational costs. Today, however, MBRs are increasingly used for the treatment of municipal wastewater in large cities (Gold Bar wastewater treatment plant, Edmonton, Canada). The technology produces high quality effluent that is being reused for environmental, urban, industrial, and agricultural activities (Melin et al., 2006; U.S. EPA, 2006). Table 4.4 summarizes the effluent produced by MBRs at Gold Bar Wastewater Treatment Plant.

Table 4.4 Effluent produced by MBRs (data taken from Gold Bar Waste Water Treatment Plant, 2014).

Parameter	Units	Effluent quality
Ammonia	mg N/L	0.6
Conductivity	mS/cm	984
E.coli	Count/100 mL	< 1
[1]COD	mg/L	25.9
[2]BOD	mg/L	< 2
Total Alkalinity	mg $CaCO_3$/L	141
pH	-	7.9
[3]TSS	mg/L	0.7
[4]TDS	mg/L	608
TP	mg P/L	0.303
[5]DOC	mg/L	8.1
Turbidity	NTU	0.29

[1]Chemical Oxygen Demand
[2]Biological Oxygen Demand
[3]Total Suspended Solids
[4]Total Dissolved Solids
[5]Dissolved Organic Carbon

4.2.3 Decentralized/ small community wastewater management

Many small and rural communities around the world do not have access to basic sanitation services and consequently proper wastewater treatment services. This is because such communities have limited access to financial resources, appropriate disposal or treatment technologies, and well-trained treatment system operators, or are located in isolated geographical areas or extreme climate which limits their access to proper services.
Decentralized wastewater treatment systems are receiving more attention since they are cost-effective and economic. Moreover, if they are properly constructed and maintained, they can effectively treat sewage and protect the environment and public health; however, these systems should be compatible with the local demands (Parkinson, 2003). That is, in the selection of treatment methods, the local environment (e.g., temperature, rainfall, topography), community culture, and resources should be considered. Efforts have been made to develop treatment systems to treat sewage at the source of generation rather than collecting and transporting the sewage to centralized (public wastewater treatment systems) treatment facilities. There are a variety of decentralized systems such as individual on-site septic systems and clusters systems that serve isolated or small communities (Massoud et al., 2009).

4.2.3.1 Conventional septic tank system

A septic tank system is constructed underground and uses natural methods (e.g., “soil filtration and microbiological processes”) to treat wastewater. The system comprises of two parts including a septic tank or container made of local/natural or synthetic materials (e.g., “concrete, fiberglass, or polyethylene”) and an effluent disposal site (“a drain field, or soil absorption field”) (Bitton, 2005b). Suspended and floatable matters separation and microbial degradation of wastewater occur in the septic tank (Figure 4.4) (Massoud et al., 2009). The settled sludge is called” septage” and the floating matters is called “scum” (Bitton, 2005b).

The effluent/liquid is then transferred from the septic tank to disposal site (Bitton, 2005b). The effluent slowly percolates into the soil and further removes pathogenic microorganisms (but not viruses) and nutrients. One of concerning issues with the septic systems is soil and water contamination, especially when the treatment capacity of soil is exceeded. Some alternative systems are being used to further reduce the levels of microbial and nutrient contaminants in the effluent. For example, the septic tank effluent is transferred to constructed wetlands or to the systems that evaporate wastewater or disinfect it (U.S. EPA, n.d.).

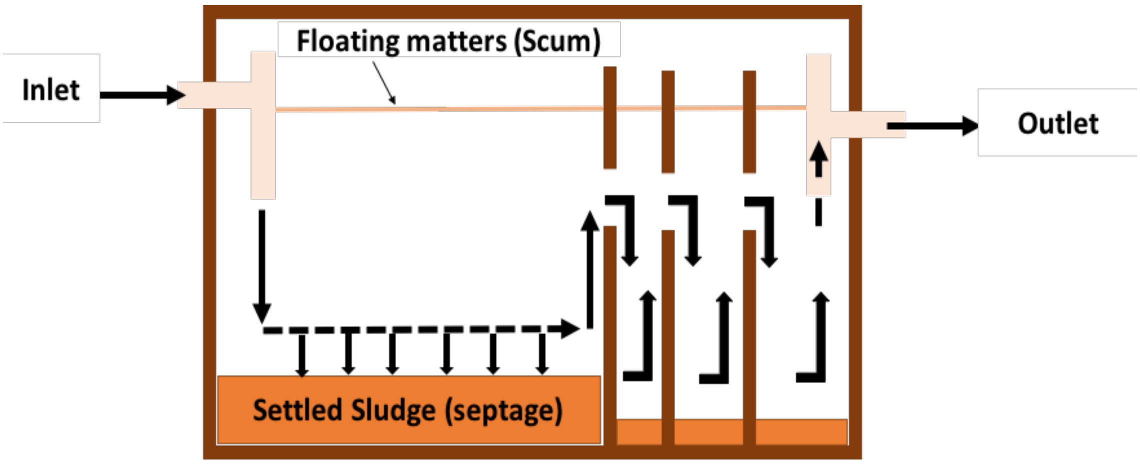

Figure 4.4 Schematic of a conventional septic tank (Adapted from Tilley et al., 2008).

4.2.3.2 Anaerobic Baffled Reactor (ABR)

An anaerobic baffled reactor is a modified type of conventional septic tank with a series of baffles. In this system the wastewater remains in the tank for longer times and is in more contact with sludge, thus the quality of effluent is improved (up to 90% BOD removal). (Tilley et al., 2008).

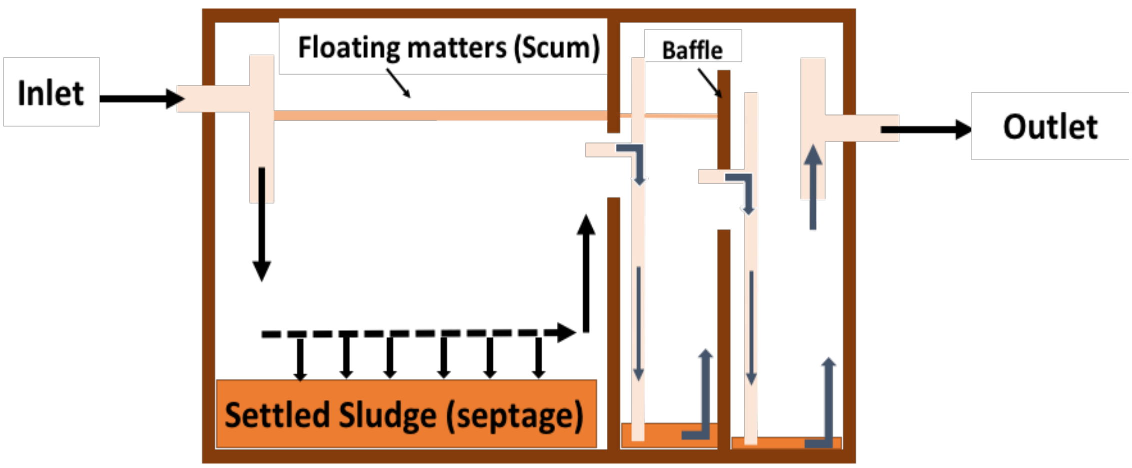

Figure 4.5 Schematic of an anaerobic baffled reactor (Adapted from Tilley et al., 2008).

4.3 Agricultural nutrient pollution and control

4.3.1 Nutrient management strategies

Nitrogen and phosphorus compounds from agricultural activities (e.g., fertilizers, manure), stormwater and discharge of wastewater effluent with high ammonia or nitrate concentrations can adversely impact receiving aquatic environments if nitrate and ammonia are not efficiently removed from the effluent. As discussed in Module 2, several environmental, economic, and public health problems were associated with these components. The known environmental problems are (i) toxicity of un-ionized ammonia to fish, (ii) oxygen depletion in receiving waters (since for oxidation of 1 mg of ammonia by nitrifiers (nitrogen-consuming bacteria), a 4.6 mg of oxygen (O_2) is required), and (iii) eutrophication (excessive growth of algae in water bodies) of surface waters. The economic problems are (i) the effect of ammonia on the chlorination efficiency, (ii) increase in water treatment costs and (iii) pipeline corrosion. Ammonia adversely impacts chlorination efficiency because ammonia and chlorine (which uses as a strong disinfectant) react and form chloramine, which has a less disinfection property. Thus, more chlorine must be used to maintain the desired chlorination efficiency. Additionally, corrosion of copper pipes occurs if the concentration of ammonia exceeds 1 mg/L. As most surface waters are used as the sources of drinking water, thus further treatment processes and or special technologies are required to remove nutrients from the drinking water resources, which consequently increase the overall drinking water treatment cost. One of the known adverse effects of nitrate on human health is methemoglobinemia or “blue baby” syndrome. This phenomenon usually occurs in infants but can also occur in adults with certain health problems. Methemoglobinemia leads to suffocation due to disruption of the molecular oxygen (O_2) transportation in the human body by nitrate. Moreover, higher rates of miscarriages in women were observed where the nitrate concentration in drinking water exceeds 19-26 mg/L (Bitton, 1980; Centers for Disease Control and Prevention, 1996; Dean and Lund., 1981; Fewtrel, 2004; Hammerschlag, 1986; U.S. EPA, 2016, 1975).

Aquatic nutrient pollution occurs due to release of excessive nitrogen and phosphorus into the water bodies. The sources of nutrient pollution are runoff from agricultural activities, stormwater contaminated with fertilizers, nutrient-rich wastewater effluent. However, nutrient-contaminated runoff from agricultural sources is the main way that nutrient pollutants such as nitrogen and phosphorous carry out to aquatic environments. Several agricultural management strategies have been developed to primarily prevent the delivery of nutrients to the aquatic environment and secondly to reduce the speed or quantity of nutrients into the water bodies. The preventive practices are (i) to avoid excessive application of fertilizers and animal manure, (ii) applying the fertilizers with a proper method and (iii) use of fertilizers at the right time of the year. Moreover, planting certain plants (e.g., grains) increases uptake of excess nutrients. Such practices can reduce the amount of nutrient in the receiving water bodies (Bosch et al., 2013; U.S. EPA, 2016).

Table 4.5 Some of the common nutrient reducing strategies, practices, and treatments (Adapted from PEI Agriculture and Forestry, 2014; U.S. EPA, 2016).

Management Strategies	**Management Practices**	**Agricultural Wastewater Treatment**

• To apply fertilizers in the proper amount • To apply fertilizers at the right time of year • To apply fertilizers with the right method • To reduce the frequency of tillage • To manage livestock waste • To prevent nutrient-rich agricultural runoff from entering the water	**Vegetative Filter Strips**: certain vegetation (e.g. grasses, grains or cloves) • To reduce nutrients levels before entering the water bodies by recycling excess nitrogen • To reduce soil erosion **Buffers:** planting trees, shrubs, and grass around fields • To absorb or filter out nutrients prior to entering the water bodies	**Natural and constructed wetlands** • To remove organic contaminants and nutrients (N, P) through natural processes such as microbial degradation and plant uptake **Bioreactors or constructed purifying system** • To remove nutrients from subsurface drainage waters from agricultural lands

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Nutrient run-off reduction: suggestions from the EPA

Source: US. EPA: https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture

"Farming operations can contribute to nutrient pollution when not properly managed. Fertilizers and animal manure, which are both rich in nitrogen and phosphorus, are the primary sources of nutrient pollution from agricultural sources. Excess nutrients can impact water quality when it rains or when water and soil containing nitrogen and phosphorus wash into nearby waters or leach into ground waters.
Fertilized soils and livestock can be significant sources of gaseous, nitrogen-based compounds like ammonia and nitrogen oxides. Ammonia can be harmful to aquatic life if large amounts are deposited to surface waters. Nitrous oxide is a potent greenhouse gas.
There are many ways that agricultural operations can reduce nutrient pollution, including:

- **Watershed efforts:** The collaboration of a wide range of people and organizations often across an entire watershed is vital to reducing nutrient pollution. State governments, farm organizations, conservation groups, educational institutions, non-profit organizations, and community groups all play a part in successful efforts to improve water quality.
- **Nutrient management:** Applying fertilizers in the proper amount, at the right time of year and with the right method can significantly reduce the potential for pollution (see Module Three).
- **Cover crops:** Planting certain grasses, grains or clovers can help keep nutrients out of the water by recycling excess nitrogen and reducing soil erosion.
- Buffers: Planting trees, shrubs and grass around fields, especially those that border water bodies, can help by absorbing or filtering out nutrients before they reach a water body.
- **Conservation tillage:** Reducing how often fields are tilled reduces erosion and soil compaction, builds soil organic matter, and reduces runoff.
- **Managing livestock waste:** Keeping animals and their waste out of streams, rivers and lakes keeps nitrogen and phosphorus out of the water and restores stream banks.
- **Drainage water management:** Reducing nutrient loadings that drain from agricultural fields helps prevent degradation of the water in local streams and lakes"

4.3.1.1 Buffers and vegetative filter strips

One of the potential solutions to manage nutrient-contaminated runoff from agricultural fields is “drainage water management”. The negative effects of nutrient runoff pollution can be controlled by vegetative (e.g., grass or plants) filter strips (VFSs) and buffers. The vegetative filter strips such as grass are used to slow down the runoff speed. Sediment-adsorbed nutrients and particulate organic are attached to sediments in the runoff. The VFSs reduce the speed of runoff and as a result, the pollutants are removed as the sediments are settled down (Franti, 1997; Zhou et al., 2014). Filter strips are installed around the fields, where the delivery of nutrients by runoff is a concern (Figure 4.6). They are also used along water bodies to prevent the nutrient-polluted runoff from entering the water (Figure 4.7). Several parameters including “type and durability of vegetation, soil characteristics, land slope, shape and area of the farmland” and climatic conditions impact the effectiveness of filter strips (Franti, 1997).

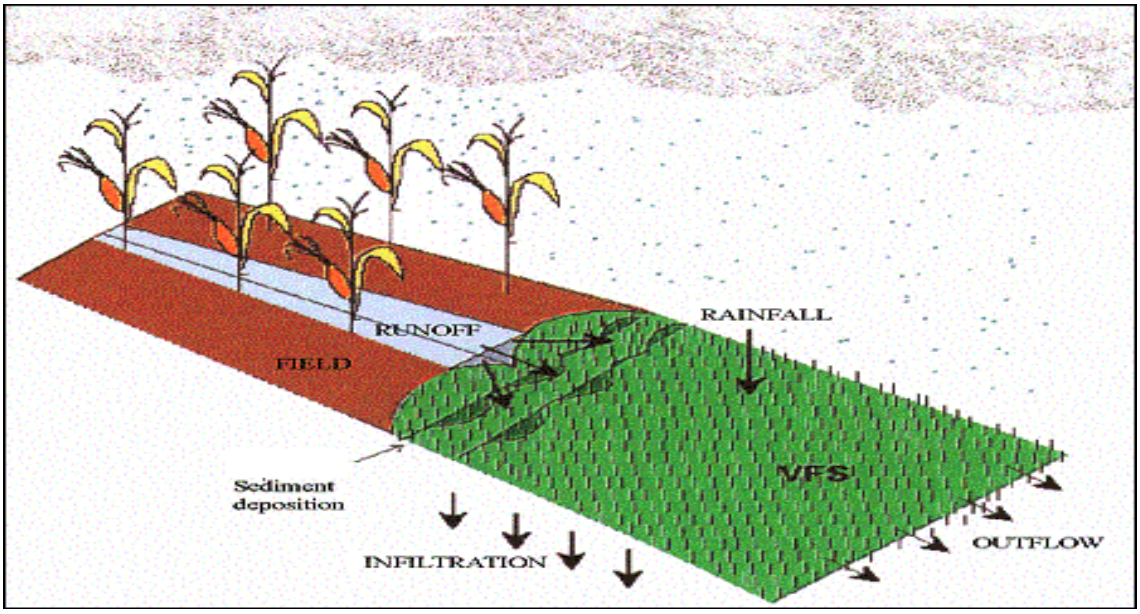


Figure 4.6 Schematic of a vegetated filter strip (taken from Carpena and Parsons, 2014).

Table 4.6 Some of the characteristics of VFSs (Adapted from Cahill et al., 2011).

Parameter	**Design**
Flow velocity	Not effective in handling runoff of high velocities
Minimum VFS length	The length of the filter strip depends on pollutant levels and local stream sensitivity. However, a min length of 10- to 15-foot is recommended
Vegetation type	The selected vegetation should be native to survive in the local climate conditions and grow with no need to fertilizers, herbicides or insecticides. Moreover, vegetation such as perennial flowers, ornamental grasses and shrubs with a minimum maintenance and watering are more desirable.

4.3.1.2 Wetlands

Wetlands (natural or constructed (Figure 4.7)) are also used for reduction of nutrients from municipal/agricultural wastewater. Constructed wetlands are known to improve receiving water quality. Wetlands remove organic contaminants and nutrients (N, P) through natural processes such as microbial degradation and plant uptake. Therefore, they can be cost-effective and suitable for low-income communities. Moreover, they require low energy and maintenance, and the construction of wetlands is also simple. The treatment efficiency is influenced by parameters such as construction design such as water depth and loading rate, and the area of coverage by aquatic plants (DeBoer and Linstedt, 1985).

The common types of constructed wetlands are free-water surface constructed wetlands and subsurface wetlands (Tilley et al., 2008). A free-water surface constructed wetland consists of a shallow basin. As wastewater effluent (e.g., from a septic tank or agricultural runoff) flows through the wetland basin, suspended solids settle and nutrients are consumed by plants and microorganisms (Tilley et al., 2008). The treated effluent gradually is discharged to waterbody or reuse. The removal of contaminants through biological processes mainly takes place in the root zone (or rhizosphere) of constructed wetlands.

Unlike the free-water surface constructed wetland, horizontal/vertical subsurface flow constructed wetlands are filled with gravel and sand and are planted with vegetation. As wastewater flows through the wetland, suspended particles are filtered and organic and nutrient contaminants are removed by microorganisms and plants (Tilley et al., 2008). This is in many respects an optimal nutrient management system, but there are serious concerns about its costs, both in term of the further environmental costs associated with constructing a wetland where one might not have existed previously, and the social and financial costs accrued to those who may need to be relocated at development ensues.

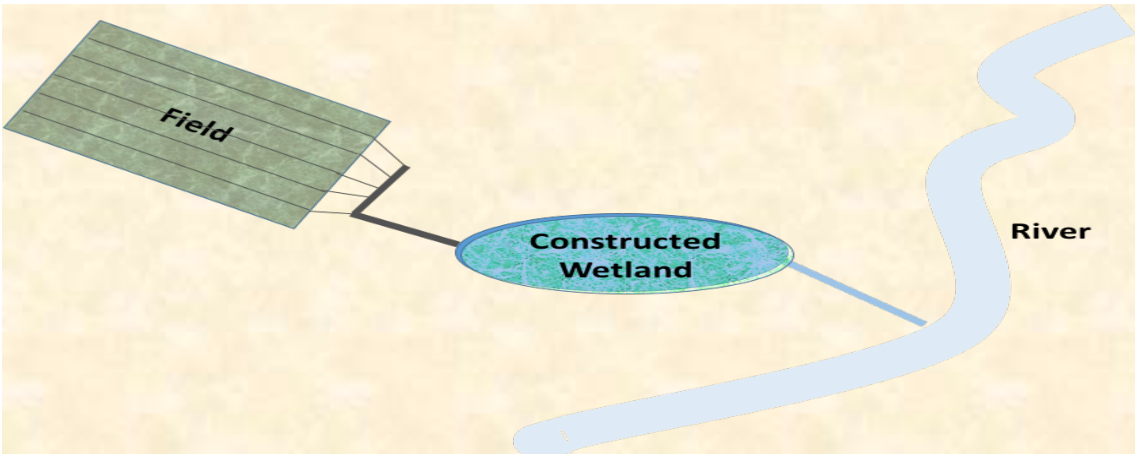


Figure 4.7 Nutrient pollution management using constructed wetland.

4.3.1.3 Bioreactors

A bioreactor is an agricultural wastewater treatment system that is built to removes the nutrients-rich water from agricultural fields by the microbial processes (PEI Agriculture and Forestry, 2014). Thus, the water contains less nutrients when it enters to surface or groundwater (PEI Agriculture and Forestry, 2014). The naturally occurring nitrifying bacteria are the dominant microorganisms in the bioreactors and convert nitrogenous compounds such as ammonia or nitrate to less harmful compounds such as nitrogen gas (Christianson et al., 2012). As the nitrifying bacteria need a source of energy to be able to grow, thus a source of carbon (e.g., “wood chips, tree bark, leaf litter, corn cobs”) should be added to the bioreactors (PEI Agriculture and Forestry, 2014). A bioreactor contains “an inlet pipe, an outlet pipe, and two control structures with stop logs to control the flow of influent and effluent water” (Christianson et al., 2012; PEI Agriculture and Forestry, 2014).

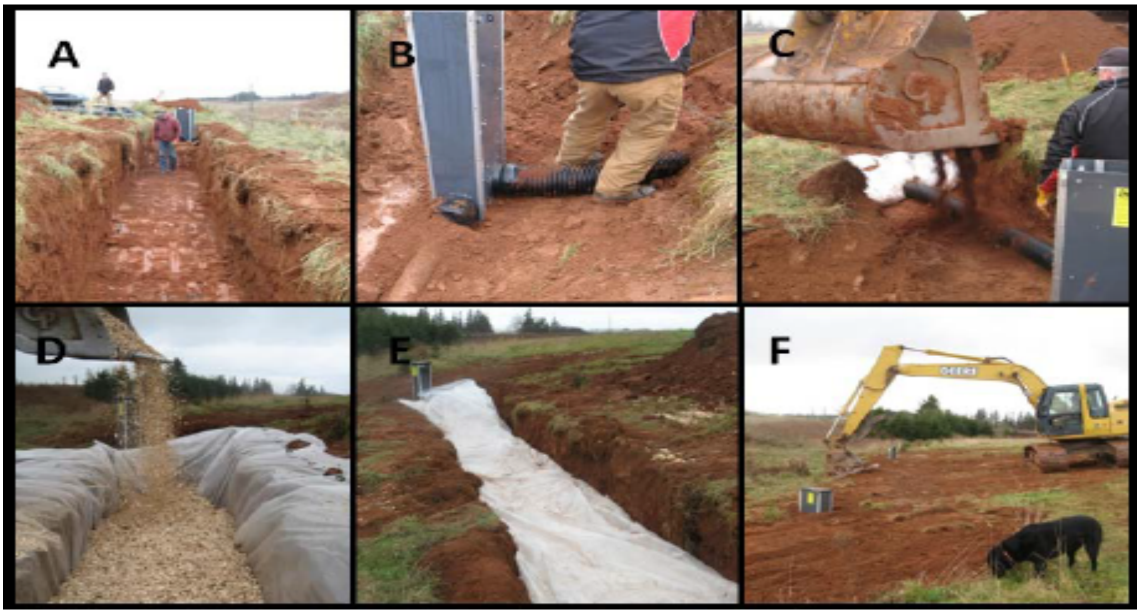


Figure 4.9 Bioreactor construction steps: “(A) trench construction, (B) flow control structures, (C) backfill pipes and control structures, (D and E) placing plastic liner and filling trench with woodchips, (F) final soil coverage” (taken from PEI Agriculture and Forestry (2014), available at http://www.knwsa.com/pdfs/Bioreactor_20140210.pdf).

The effectiveness of bioreactors in the removal of nitrogenous compounds such as nitrate significant depend on influent water volume, temperature, retention time or contact time between the nutrient-rich water with nitrifying bacteria. Investigation showed that bioreactors can remove 12 to > 99% of NO_3-N depending on the aforementioned factors. For example, bioreactors work better at a lower volume of influent water due to increasing the retention time (recommended retention time: 4-8 hours) which provides longer contact time between the nutrient-rich water and nitrifying bacteria. Moreover, as the main part of nutrients are removed by nitrifying bacteria and as these bacteria work better at higher temperature, thus the effectiveness of bioreactors is increased at higher temperature (Christianson, 2011; Christianson et al., 2012; Kult and Jones, 2011; PEI Agriculture and Forestry, 2014; Ranaivoson et al., 2012)

4.4. Conclusion

This module highlighted the historical development of municipal wastewater treatment methods. Moreover, the principles of some of the conventional and modern centralized and decentralized treatment processes and technologies were briefly overviewed. Of course, we have covered just some of the technologies and techniques that have been or are being deployed to reduce wastewater contamination and nutrient runoff in this module. There are, no doubt, many more innovations in development, and we will cover some of them in the

MOOC as well. Students are encouraged to think about what innovative solutions are available to them, in their geographic context. However, it is important to note that even the best technologies and systems are useless if they are not implemented with proper public policy efforts and financial mechanisms to pay for them, and the next two modules cover these challenges.

Discussion Questions

1. Name and discuss the merits of some of the technologies employed in your local area to combat wastewater and nutrient runoff. Are they sustainable?
2. Does the fertilizer industry induce farmers to use more fertilizer than they actually need today?
3. Organic farming may be a potential solution to nutrient issues. (or worded less strongly... like "what might be the benefits of organic versus conventional agriculture?")
4. Lieberg's law discusses a minimum of nutritional and other factors in plant growth. Do we need to develop a maximum threshold as well in order to regulate agriculture? Why or why not?
5. How can we encourage further technological development in these areas? If you are/were a civil engineer or scientist, what would incentivize you to pursue a career in WWM?

Annotated Bibliography

Benidickson, J. 2007. *The Culture of Flushing: A Social and Legal History of Sewage*. Vancouver: UBC Press. *Jamie Benidickson's examination of the social and legal history of sewage in Canada, the United States, and the United Kingdom demonstrates that the uncontroversial reputation of flushing is deceptive; particularly relevant in a time when community water quality can no longer be taken for granted.*

Bijker, W.E., T. Hughes, and T. Pinch, eds. 2012. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, Mass.: MIT Press. *This is the 25th Anniversary Edition of what has become a classic advanced text in the sociology of technology and its complex relationship to humankind and human agency. It does not deal directly with wastewater management but serves the broader purpose of helping us understand how we make technology and how it makes us.*

Bitton, G., 2005. *Wastewater Microbiology*. John Wiley & Sons, Inc., Hoboken, New Jersey. This book focuses on "*microbial contaminants found in wastewater, conventional and new methods of detection for these contaminants, and methods of cleansing water of microbial contamination*".

Brears, R.C., "How can cities reduce water-energy nexus pressures?" Accessed from http://blogs.worldbank.org/water/how-can-cities-reduce-water-energy-nexus-pressures?CID=WAT_TT_Water_EN_EXT. This article provides two successful examples regarding how innovative water-saving management strategies in the water-stressed regions helped these communities to not only understand the connection between water and energy, it also led to a significant reduction in water consumption.

Cooper, P.F. 2001. "Historical Aspects of Wastewater Treatment." In P. Lens, G. Zeeman, G. Kettingo, eds., Decentralised Sanitation and Reuse: Concepts, Systems, and Implementation (International Water Association), 11-38. *A concise summary of thousands of years of technological development.*

Lofrano, G., and J. Brown. 2010. "Wastewater Management Through the Ages: A History of Mankind." *Science of the Total Environment* 408:22, 5254-5264. *A comprehensive treatment of the evolution of wastewater management, stressing the links between it and the broader patterns of societal development.*

Metcalf & Eddy, 2003. Wastewater Engineering - Treatment and Reuse, McGraw-Hill. One of the fundamental book on wastewater treatment. *"It describes the characterization of wastewaters; unit operations and processes used for wastewater treatment, health and environmental impacts of wastewater constituents*; *advanced wastewater treatment; risk assessment for water reuse applications; effluent discharge and reuse regulations; sludge disposal and regulations"*.

Other Online Resources

https://www.youtube.com/watch?v=N7KH20F3lqc

Small Scale Innovative Solutions

http://www.pacificwater.org/userfiles/file/TR0288.pdf

http://www.cwn-rce.ca/project-library/project/small-scale-wastewater-management-initiative

Decentralized: https://www.epa.gov/sites/production/files/2015-06/documents/mou-intro-paper-081712-pdf-adobe-acrobat-pro.pdf

http://www.nesc.wvu.edu/pdf/WW/publications/pipline/PL_FA00.pdf

DEWATS (decentralized wastewater treatment system) - https://www.youtube.com/watch?v=uITzstXZtqo

https://www.epa.gov/nutrientpollution

Module Five: Policy, Governance and Institutional Arrangements

Learning Objectives

After completing this module, students will be able to:

1. Distinguish between principles, norms, and regulations;
2. Identify key actors in wastewater and nutrient management;
3. Understand the need for and difficulties associated with adaptive, holistic waste management cycling, including factors related to social justice;
4. See policy problems from various scaled perspectives, from local to national to regional to international;
5. Discuss the development of some new innovative policy approaches.

5.1 Introduction: Public policy and administration

The interplay between the technologies introduced in the previous chapter and the public policy and public administration of wastewater and nutrient management should not be underestimated: if we want to implement the best public infrastructure to reduce contamination, we need the social and policy infrastructure to enable actors to work unhindered by obstinate power games or corruption. We also need to take into consideration the buy-in of citizens, and the importance of ensuring inclusive and accessible infrastructure and policy. Thus, good governance, at many scales (from the local to the global in some cases), and public legitimacy are key factors in the recipe for success. In places where these variables are non-existent, capacity-building will be necessary as well. The provision of wastewater and nutrient management is a major project that is intrinsically linked to social issues of our day; it is what many observers refer to as a "wicked problem", a phrase we describe in more detail below. It would be a serious mistake to think that technological solutions on their own could suffice, just as it would be an error to believe that, in the age of the anthropocene (Zalasiewicz, Williams, Steffen, & Crutzen, 2010), nature will solve our problems for us.

The purpose of this module is not to convey an in-depth knowledge of public policy or public administration theory. Numerous sources which cover these topics are offered in the annotated bibliography. Our aim here is to discuss the main players and principles that should guide policy development, as well as the immense challenges we face when seeking to implement good policy under what are often unstable and uncertain conditions. Examples of policy development are sprinkled throughout the module, though we reserve the presentation of major case study material for the subsequent modules.

5.2 Policy interlinkages

It is vital to understand that policies do not materialize in a vacuum: they are developed under particular sets of circumstance, historical patterns, popular opinion, elite dominance, and other pertinent factors. Nor can we isolate a specific policy realm from all others today; they are linked in many ways, especially when dealing with the "wicked problems" framework we discuss below. For example, the issue of nutrient overload is not just about crop farming, but also about livestock production. This is made evident by the dynamics emerging in nutrient management problems overwhelming the Chesapeake Bay in the eastern United States: agriculture in the area is almost wholly devoted to livestock production. Feed is imported from the Midwest, meaning that the nutrient-rich animal waste is not being used productively to grow crops; meanwhile, the feed crops being grown far away rely on synthetic fertilizers. In both cases, nutrient overloads are produced rather than the two industries complementing each other. Thus, in policy-making it would be a colossal error to only focus on crop farming and not livestock production if we want to reduce nutrient pollution. This type of systems thinking is essential if we are to understand the enormity and depth of the challenges that policy makers face today.

In addition, we need to take into account the overarching issue of climate change, which will inform environmental impact assessments of projects and test the collaborative resolve of national and international water resource management institutions (see Earle 2015; Stoett and Temby 2017). Climate change and the wastewater ramifications are a concern for all countries. For instance, in this article (http://www.cbc.ca/news/politics/sewage-pollution-wastewater-cities-1.3889072), we can see that wastewater management in Canada -- one of the few counties with relatively large freshwater supplies -- remains an ongoing issue, which will only be worsened by increasing storm surges due to climate change.

Climate change is a troubling phenomenon not just to scientists and environmentalists: it demands a policy response from politicians who are often reluctant to commit the necessary funds to mitigate greenhouse gas emissions for fear that this will harm their economies (and, in some cases, politicians have refused to acknowledge climate change as a major issue, though this is a limited grouping at this point in time -- albeit a prevalent perspective in the United States, which is the world's second greatest emitter).

5.3 Principles, Norms and Regulations

A key distinction should be made between principles, norms and regulations in policy development. They are all significant, and reinforce each other; on occasion, they contradict each other as well.

Principles are ideas that are shared widely (though rarely universally), and help set the contours of specific actions. For example, the idea that wastewater management and sanitation cannot be divorced from the provision of basic human rights has, arguably, been an animating principle at least since the recommendations of Sir Edwin Chadwick (1800-1890) in his 1842 Report on the Sanitary Conditions of the Labouring Population of Great Britain, which included the provision of clean water to every home and the discharge of domestic wastewater directly into sewers rather than disease-generating cesspools.

Interestingly, Chadwick was also a proponent of the cycle-based approach advocated in this course, recommending that sewers should convey waste into agricultural areas "away from town where its manurial value could be utilized" (Cooper, 2001: 18) – though this recommendation would be scuttled for a "dilution solution" approach that would turn the River Thames into a moving cesspool for many decades. Chadwick's recommendations helped pave the way to the 1848 Public Health Act in Great Britain, and would be replicated in the United States, Brazil, and elsewhere.

Today, we are more likely to discuss access to potable water as a basic human right, especially after the United Nations General Assembly passed Resolution 64/292 on July 28th, 2010, explicitly recognizing the human right to water and sanitation. This is a principle that should inspire public policy development, as indeed it inspired the Sustainable Development Goals discussed in Module One of this course. An important precedent to this was set at the International Conference on Water and the Environment held in Dublin Ireland in 1992, where experts adopted the Dublin Principles, declaring that:

Principle No. 1 - Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.

Principle No. 2 - Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all level.

Principle No. 3 - Women play a central part in the provision, management and safeguarding of water.

Principle No. 4 - Water has an economic value in all its competing uses and should be recognized as an economic good.

Other important principles include the **principle of preventative action**, which

> requires action to be taken at an early stage and if possible before damage has actually occurred, requiring that an activity which does or will cause damage to the environment in violation of the standards established under the rules of environmental law to be prohibited. One obligation that flows from the concept of

> prevention is prior assessment of potentially harmful activities. Since the failure to exercise due diligence to prevent transboundary harm can lead to international responsibility, it may be considered that a properly conducted Environmental Impact Assessment might serve as a standard for determining whether or not due diligence was exercised. Preventive mechanisms also include monitoring, notification, and exchange of information, all of which are entrenched obligations under customary international water law, and are reflected in almost all recent environmental agreements. (UNEP 2015)

Yet another guiding principle at the international level is the **precautionary principle**, expressed in Principle 15 of the 1992 Rio Declaration, which provides that, “Where there are threats of irreversible damage, lack of full scientific certainty shall not be used as reason for postponing cost-effective measures to prevent environmental degradation.” This principle is key to many of the multilateral agreements that have emerged over recent decades, such as the Convention on Persistent Organic Pollutants, and played a key role in the formulation of the SDGs as well. The polluter pays principle (PPP), discussed at more length in the next module, is often heralded as a universal principle, though it is very difficult to apply to non-point source pollution cases.

While many observers would argue that the only true motivating principle in politics is self-preservation and/or promotion, it is generally accepted that within certain limits many of the principles that animate efforts to achieve the SDGs are based on the principles of fairness, equity, and humanitarian concern. When billions of people lack access to clean potable water and food security is challenged by an excess of nutrient use in some areas and a lack of it in others, the question of universal principles that address global inequality also arises. Regardless of the principles applied to individual contexts, however, the complexity of wastewater and nutrient management as a policy puzzle serves to qualify them as “wicked problems” that demand responses rooted in adaptive management.

5.4 Wicked Problems in Policy Development

A wicked problem is a problem that is difficult or impossible to solve because of incomplete or contradictory knowledge, changing requirements that are often difficult to recognize, the number of people and opinions involved, and the interconnected nature of these problems with other problems. Horst Rittel (1973), one of the first to formalize a theory of wicked problems, cites ten characteristics of these complicated social issues:

1. Wicked problems have no definitive formulation. The problem of poverty in Texas is grossly similar but discretely different from poverty in Nairobi, so no practical characteristics describe "poverty."

2. It's hard, maybe impossible, to measure or claim success with wicked problems because they bleed into one another, unlike the boundaries of traditional design problems that can be articulated or defined.

3. Solutions to wicked problems can be only good or bad, not true or false. There is no idealized end state to arrive at, and so approaches to wicked problems should be tractable ways to improve a situation rather than solve it.

4. There is no template to follow when tackling a wicked problem, although history may provide a guide. Teams that approach wicked problems must literally make things up as they go along.

5. There is always more than one explanation for a wicked problem, with the appropriateness of the explanation depending greatly on the individual perspective of the designer.

6. Every wicked problem is a symptom of another problem. The interconnected quality of socio-economic political systems illustrates how, for example, a change in education will cause new behavior in nutrition.

7. No mitigation strategy for a wicked problem has a definitive scientific test because humans invented wicked problems and science exists to understand natural phenomena.

8. Offering a "solution" to a wicked problem frequently is a "one shot" design effort because a significant intervention changes the design space enough to minimize the ability for trial and error.

9. Every wicked problem is unique.

10. Designers attempting to address a wicked problem must be fully responsible for their actions. (Source: Rittel, 1973)

While we might debate whether or not it is advantageous to label certain policy problems “wicked”, it has become a common refrain and some of the main attributes of wicked problems outlined about are certainly evident when it comes to solving the immense social challenge of fairly distributing clean water resources and striving for pollution-free oceans. The attributes can serve as warnings to those who seek simple solutions to inherently complex problems.

5.5 Who Are the Key Policy Actors in Wastewater and Nutrient Management?

The first question we usually face when analyzing a policy question is, who is involved? Who has a stake in the outcome of deliberations and policy implementation? There are many actors engaged in wastewater and nutrient management, at many levels. Indeed it is difficult to summarize them all here since each situation is inherently unique, but we can identify some central players that are commonly involved: politicians, industry leaders, city and coastal development planners, the media, community activists and environmentalists, and scientists (from various fields such as agronomy, biology, biochemistry, geochemistry, ichthyology, oceanography, climatology, and others). A partial list of stakeholders would include:

WASTEWATER:

Sewage industry

Water providers

Individual consumers

Factories and other heavy industry

The tourism industry

Hospitals

Schools

Fishing industry

NUTRIENTS:

Farmers and agri-business

Small-scale farms

Chemical and fertilizer industry

Fishing industry

Forestry and mining industries

Fluvial systems engineers

Irrigation suppliers

Again, these are but partial lists, and students can probably add or subtract from it according to their own particular political/policy context, but the idea remains: there are so many actors involved in policy development today, some of whom are not even in geographic proximity to the actual problem being addressed, that we need to be careful that we don’t exclude important groups while deciding on the scope of the stakeholders and people who are affected by decisions made by governments, corporations, international organizations, and other institutions.

5.6 Holistic Waste Management as a Wicked Problem and the Value of Adaptive Management

In the field of public policy, we often differentiate between simple and complex systems. The latter can lead to what are called wicked problems (see section 5.4 above) that have "no definitive formulation, no stopping rule, and no test for a solution," problems that cannot be separated from issues of values, equity and social justice (Berkes 2004:624) and are not subject to a solely technical solution. We should note that simple systems can fail due to the concurrence of various simple problems: once compounded, they become wicked problems themselves.

A simple, reductionist approach (which focuses on the individual components of a system only) will not work to solve a wicked problem. A **systems-thinking approach** (covered in the first Environment Academy MOOC) is necessary. For example, we can't help society cope with substance addiction without looking beyond the characteristics of the individual addict and substances (alcohol, prescription or illicit drugs) involved. There is a much broader constellation of factors, some at the societal level and some at the metabolic level, that lead to substance addiction, and how we see those factors will to some degree determine our attitudes toward various possible interventions.

Indeed, it is very important that we are aware of the added complexity of the human element when it comes to attempting to solve wicked problems. We are both blessed and burdened with the element of human perception, reflecting the complexity of our brains and influences from culture, science, philosophy and other conceptual inputs. We will always have an incomplete view of complex adaptive systems due to these contingencies, and though scientific consensus remains our most valuable tool in the advancement of our knowledge, it is also subject to political manipulation and cultural distortion.

Additionally, **adaptive management** is crucial to addressing wicked problems. Adaptive management is a systematic process for continually adjusting policies and practices by learning from the outcome of previously used policies and practices. Each management action is viewed as a scientific experiment designed to test hypotheses and probe the system as a way of learning about it (Holling 1973). The adaptive management cycle includes at least four stages:

(1) **planning**, which is obviously a crucial stage where input from various stakeholders must be taken seriously, and during which scientific expertise must be accumulated and considered;
(2) **implementation**, which cannot take place in a vacuum but must also involve the stakeholders, so that they feel they are part of the process and not just passive observers;

(3) **monitoring**, which in turn demands transparency, the engagement of both scientists doing the monitoring and citizens affected by projects contributing their own observations, and often involves external actors, including funding agencies and international organizations;

(4) **interpreting the results of the monitoring so that a new, hopefully more appropriate plan can be developed**. In other words, a feedback loop is established so that adjustments can be made. Learning from experience is key. Creating and maintaining space for this aspect of the process is crucial and often overlooked, since it might be assumed that democratic

governments will automatically ingest citizen feedback and make adjustments. Beyond the obvious fact that many of the governments we will deal with are not democratic, it would also be erroneous to assume that feedback will be taken seriously by politicians and administrators.

5.7 Why We Need Equitable Policy

When considering how best to structure policy, it is essential not to only include experts, industry leaders, and politicians, but also members and representatives of impacted communities -- and within that cohort, representatives of specific interest groups such as women, ethnic and religious minorities, indigenous groups, and others who have been marginalized from decision-making power in the past. This is not only reflective of the universal aim to achieve fairness in decision-making, but it is also sound pubic policy since many of the people who will live closest to the implementation process of new developments are from these groups and need to be consulted if we aim for success. .

Some critics may argue that this multitude of stakeholders hinders the efficiency and efficacy of policy-making and project implementation. However, this efficiency and efficacy is impossible without community participation, for a variety of reasons. For one, tackling wastewater and nutrient management issues often requires people to make some sort of change in their daily lives, whether that be changing their farming practices or paying a fee in their water bill devoted to financing a treatment plant. People may be unwilling to cooperate in an effective manner unless they understand the benefit of doing so, and they may be even more resentful of such changes if they had no part in planning them. A lack of cooperation and communal support can doom some projects in the long term, or even from the start. Secondly, without the input of stakeholder communities, policies and projects may misjudge the issue being addressed, its complexity, and the most suitable solutions.

Equitable policy requires consideration of socioeconomic status, gender, and other factors which affect people's perceptions, behavior, and practices; sensitivity to the specific needs of these particular groups; and an understanding of how the above factors determine the impact policy will have on different groups.

For instance, contamination of water sources through untreated effluent or nutrient runoff can present equity issues without well-made policy. Those most impacted in this case are often low income groups who must rely on the water resources and infrastructure already in place, and who lack the capacity and capital to change their practices (for instance, transitioning to integrated nutrient management). Wealthier people can usually afford to buy water if communal sources are contaminated, they can choose to live far away from waste disposal and treatment areas, and they often consume more water and thus contaminate more of it. Yet they tend to have a larger role in decision making about infrastructure and management projects. This creates a huge disparity between those who are most impacted by an issue and those who create or influence policy. To ensure equitable social and economic development, policy must do more than simply mandate change, it should also provide clear strategies to facilitate implementation.

Beyond environmental sustainability and basic human rights, access to clean water has immense significance for gender parity as well. Women spend a disproportionate amount of time searching for, collecting, and working with water. They're also prime caretakers, and must deal with the consequences of contaminated water on their families, particularly the elderly and children. Projects that are implemented to reuse wastewater will need to be clearly conveyed to those most affected, including women who are often left out of educative efforts. This also applies to girls, who in some regions are not exposed to engineering or other relevant sciences. Policy development should reflect these concerns and always bear in mind that every development project will affect different people differently.

As a final note, it is essential that policy makers take the initiative to identify and reach out to vulnerable or marginalized groups, as these groups may not have the capacity or willingness to address politicians but whose priorities, concerns, and also local knowledge and suggestions are highly valuable.

5.8 Communities of practice: the need for multi-level governance

There are a number of policy scales involved in wastewater and nutrient management, ranging from small-scale local operations to regional action plans that encompass multiple countries and international organizations. Policy networks develop across these scales, and communication amongst and between experts is invaluable; it is also essential that these communities of practice promote openness, transparency, and fairness. In some cases, these communities will even span national borders, since shared or transboundary water resources are quite common (see Earle 2015).

We can view a community of practice as a group of people who share significant meaningful communication about a specific societal need. As one of the originators of the term puts it, "…a focus on practice is not merely a functional perspective on human activities … [nor does it] address imply the mechanics of getting something done, individually or in groups; it is not a mechanical perspective. It includes not just bodies (or even coordinated bodies) and not just brains even coordinated ones), but moreover that which gives meaning to the motion of bodies and the working of brains" (Wenger, 1998).

It is a powerful concept that evokes images of empowerment. Water is central theme around which communities of practice can emerge, regardless of the specific society and/or political system in which they are located. Indeed, one can argue that the GPNM and the GW^2I are emerging communities of practice, and that the large crowd of diplomats, NGOs, and experts that converged at the UN headquarters on June 8^{th}, 2017 for World Ocean Day during a week-long oceans conference constituted such a community. The challenge is to get people to unite on projects and goals that do not prove divisive and unsustainable.

5.9 Conclusion: Emerging issues in policy development

As the international community strives to implement the Sustainable Development Goals, new issues will emerge in policy development. Many of these are related to the subject of the next Module on financial mechanisms, since paying for improvements and sophisticated applications of new technology will always be a major challenge. But as importantly, questions of fairness and community engagement will continue to animate debates over how and when policy is developed. Adaptive management will demand adjustments to programs related to economic crises, climate change, market fluctuations, population movements, resource availability, international relations, and other complicating factors.

Discussion Points

1. Who are the main policy actors in the wastewater or nutrient management fields in your particular geographic area?
2. What social justice issues permeate the discussion of water provision and treatment where you live? Are you involved in these debates?
3. Is it possible to manage waste effectively without multi-scale governance?
4. How do you think women can achieve greater participation in the discussions and decisions around WWNM? Why is this important?
5. How can policy, norms and regulations bolster sustainable wastewater and nutrient management?

Annotated Bibliography

Gray, J., C. Holley, R. Rayfuse. *Trans-jurisdictional Water Law and Governance* (London: Routledge 2016).
Focusing on the concept of trans-jurisdictional water governance, this book diagnoses barriers and identifies pathways to coherent and coordinated institutional arrangements between and across different bodies of laws at local, national, regional and international levels. It includes case studies from the European Union, Australia, New Zealand, South Africa, the United States and Southeast Asia

Earle, A., A-E Cascao, S. Hansson, A. Jagerskog, A. Swain, J. Ojendal. *Transboundary Water Management and the Climate Change Debate* (London: Routledge 2015).

Winner of the 2105 International Water Resources Book of the Year Award, this book charts approaches which have been taken over the past two decades to promote more effective water management institutions, covering issues of conflict, cooperation, power and law. A new framework for a better understanding of the interaction between transboundary water

management institutional resilience and global change is developed through analysis of the way these institutions respond to the climate change debate. This framework is applied to six river case studies from Africa, Asia and the Middle East (Ganges-Brahmaputra, Jordan, Mekong, Niger, Nile, Orange-Senqu).

UNEP/GPA: *Good Practices for Regulating Wastewater Treatment: Legislation, Policies and Standards*, jointly developed by UNEP/GPA and Waterlex on an in-depth study resulting in a 120-page e-book which details good practices in wastewater regulation around the world. See more at: http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

Kuai, P., and W. Li. "Evaluating the Effects of Land Use Planning for Non-Point Source Pollution Based on a System Dynamics Approach in China." PLoS One 10:8 (2015), found at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4534394/

This advanced paper compares seven planning scenarios of a case study area, namely Wulijie, China, from the perspective of NPS pollution. A System Dynamics (SD) model was built for the comparison to adequately capture the planning complexity.

Other Online Resources

Read this article by Elizabeth Grossman on the ENSIA website. She links the nutrient overload problem with meat production on a global scale. **http://ensia.com/features/weve-changed-a-life-giving-nutrient-into-a-deadly-pollutant-how-can-we-change-it-back/?utm_content=buffer6d2c4&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer**

Waterwise http://waterwise.org.uk/

A nonprofit non-governmental Organization dedicated to promoting the wise use of water.

WateReuse http://www.watereuse.org/?assoc&wra

A nonprofit Organization whose mission is to advance the beneficial and efficient use of water resources using reclamation, recycling, reuse, and desalination.

UNEP, Good Practises for Regulating Wastewater Treatment: Legislations, Policies, and Standards:
http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

Module Six: Financial and Economic Mechanisms for Innovation

Expected Learning Outcomes

After completing this module, students will:

- Understand basic fiscal policy and funding mechanisms related to wastewater and nutrient management;
- Understand the basic concepts behind the economic valuation of wastewater management methodologies;
- Grasp and consider the challenges of obtaining sufficient investments to implement new and effective wastewater and nutrient management projects and to move toward autonomous, sustainable funding solutions;
- Engage in creative thinking about innovative approaches to financing contemporary projects

6.1 Introduction: Fiscal policy and funding mechanisms

Everything comes at a price, and waste management is certainly expensive. So expensive, in fact, that it is often a seemingly unattainable goal for many communities around the world. How can we ensure that there is global equity in this area, despite the lack of easily available financial mechanisms? While the most basic and, many would say, responsible financing system would be based on the simple "polluter pays principle" (see the box below), this is not always possible to put into effect when dealing with nonpoint source pollution, or when considering the needs and capacity to pay of different segments of the population (see the previous module for a discussion of fairness and equity in policy development).

An effluent tax charged to polluters in proportion to the amount they pollute would, in theory, give them an incentive to reduce their pollution, and the money pooled in this manner could be directed towards better water treatment facilities. In reality, most waste management programmes are heavily subsidized by governments, which rely on general taxation and direct users fees (at the household level) to raise the necessary funding. Some projects are funded with external investment, either through the private sector or through official development assistance. In this module we explore these and other approaches to financing the type of infrastructure projects that can reduce wastewater effluent and nutrient discharge into marine resources such as rivers, lakes, and especially the oceans. Coupled with the sound public policy principles discussed in the previous module, financial mechanisms are essential if we are going to make progress.

The Polluter Pays Principle

In many countries, it is readily accepted that factories – such as this one in Sydney – should pay for the impact of any pollution they create. Photograph: Reuters

The *polluter pays principle* refers to the commonly accepted practice that those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment. For instance, a factory that produces a potentially poisonous substance as a by-product of its activities is usually held responsible for its safe disposal.

This principle underpins most of the regulation of pollution affecting land, water, and air. Pollution is defined, in United Kingdom law, as the contamination of the land, water or air by harmful or potentially harmful substances. Part of a set of broader principles to guide sustainable development worldwide (formally known as the 1992 Rio Declaration), the *polluter pays principle* has also been applied more specifically to emissions of greenhouse gases which cause climate change. (*Bob Ward and Naomi Hicks of the Grantham Research Institute at LSE in collaboration with the Guardian*; https://www.theguardian.com/environment/2012/jul/02/polluter-pays-climate-change).

With non-point source pollution it is often very difficult to apply the polluter-pays principle with any consistency. Careful measurement (see Module Three) of nutrient runoff might help us determine how much each farm should contribute to a fund designed to limit runoff, but it would be difficult to determine exactly how much runoff is originating from each farm without constant measurements under different types of weather in different growing seasons. Similarly, it is almost impossible to trace the wastewater emerging from a city sewer and thus hard to calculate how much each individual polluter should pay towards management.

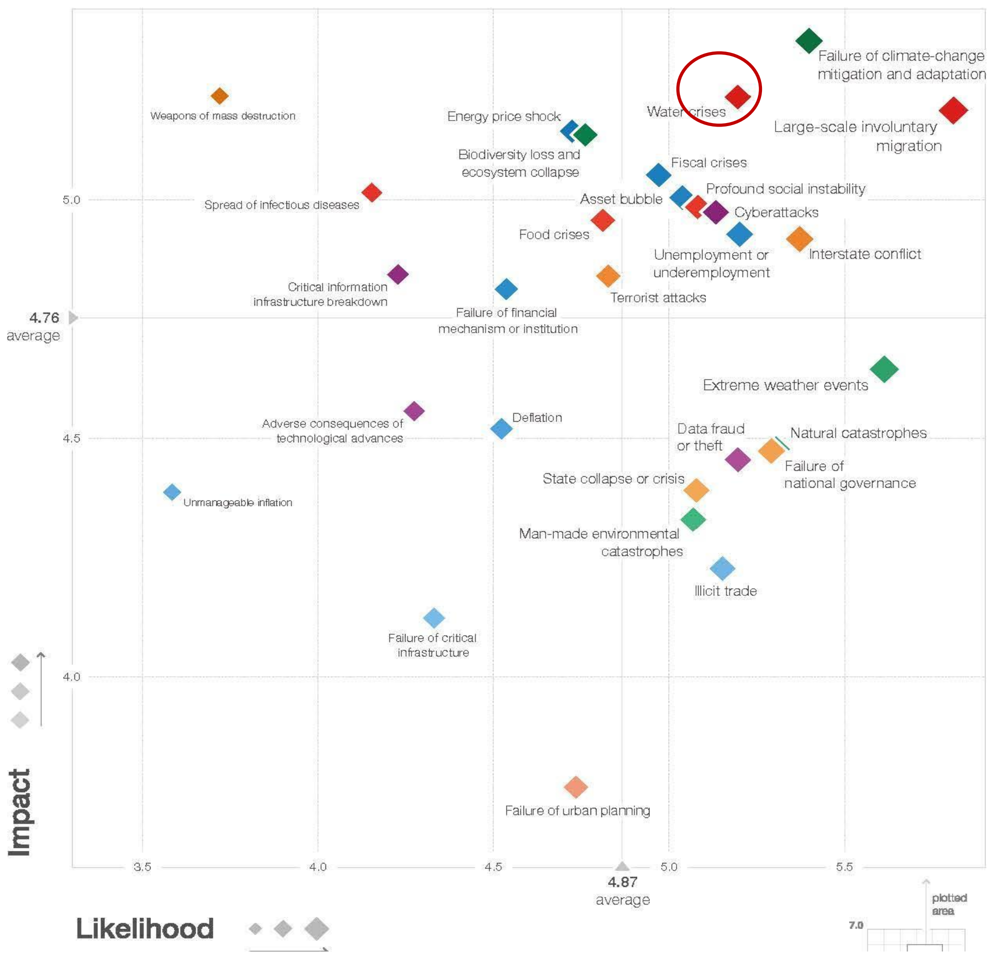
6.2 Economic valuation of wastewater management methodologies: Rationale for valuation, methodologies for assessment, how to align to mainstream national accounting?

According to The Global Risks Report 2016, 11th Edition published by the World Economic Forum, (see Figure 1) water crises have become a critical emerging risk. As this MOOC has already made clear, the world is facing a water quality crisis caused by increasing pollution loads from growing cities, unsustainable industrialization and food production practices, increased consumption and poor water and wastewater management strategies. Wastewater is both an asset and a problem in an urbanizing world (Drechsel et al., 2015a; UN-Water, 2015). Uncontrolled use of wastewater is an important source of pollution and a hazard for human health and ecosystems services.

The costs related to the pollution of water bodies can be significant: the Millennium Ecosystem Assessment report suggests the cost of degradation of ecosystem services in coastal waters is mostly associated with impacts on human health (MEA, 2005), while the overall economic value of the goods and services delivered by healthy coasts and oceans are worth trillions of dollars. Wastewater treatment and reuse involves significant environmental, social and health benefits. Valuation of these benefits is nevertheless necessary to justify suitable investments and financing mechanisms to sustain wastewater management.

By comparing the cost of taking actions versus the benefits lost by taking no action, we can decide if countries should invest in wastewater management systems.

Figure 1: The Global Risks Landscape 2016



(Source: The Global Risks Report 2016 11th Edition, World Economic Forum http://www3.weforum.org/docs/Media/TheGlobalRisksReport2016.pdf)

6.3 The costs of no action

Managing wastewater is obviously linked to the management of the entire water cycle. Inadequate wastewater management pollutes water bodies, which will seriously affect human health, environment quality, and productive activities. For example, reduced drinking water quality, bathing water quality, and increasing wastewater-irrigated areas will increase the risk of diseases and increase the financial burden on health care. Wastewater can also decrease biodiversity and degrade ecosystems. Land and water salinization induced by industrial wastewater discharges may have severe impacts on agricultural productivity if these waters are used for irrigation. It may also reduce the market value of harvested crops, fish and shellfish.

Wastewater management and treatment involves significant benefits (avoided costs). Therefore, the cost of no action may be interpreted as benefits not achieved due to the discharge of the wastewater with no or inadequate treatment. In other words, if untreated or inadequately treated wastewater is discharged directly into the environment, costs are generated or potential benefits are lost. The potential benefits associated with improving wastewater management can be grouped into two general categories: market and non-market benefits. Most environmental and health benefits have significant value, but — unlike most benefits from productivity — cannot be valued in monetary units as market prices do not exist.

Valuation methodologies mainly concern three valuing impacts: impacts on human health, the environment, and economic activities. The value of the adverse **health effects** (see Module 2) includes:

(i) direct medical expenditures, including medicines and physician's costs, for illness treatment. We need to identify the most significant wastewater-related diseases and the medical costs associated with it.

(ii) indirect costs resulting from illness, which includes the value of time lost from work, decreased human productivity, potential for demotion, money spent in caregiving and premature death (Calhoun and Bennett, 2003); and

(iii) pain and suffering associated with illness.

In relation to non-market values, the methods used to estimate the economic value of risk reductions are based on willingness to pay (WTP), described in the next section.

b) To value impacts on **the environment**, the traditional valuation techniques are based on the demand approach. Stated preference methods are the most common for valuing the environmental impacts (Bateman et al., 2006) using survey techniques to elicit for example individuals' WTP for the hypothetical provision of an environmental good (e.g. an improvement in water quality as the consequence of wastewater treatment). The values obtained are taken to represent the economic benefits or costs avoided of the proposed change in environmental quality. They can then be aggregated in a cost-benefit framework to obtain the social and environmental benefits of public policies aimed to improve wastewater management.

Unlike most commodities, the pollution of lakes, rivers, and streams is generally not traded in a market. Therefore, there is no market price for pollution or the lack of it. Among different approaches to the valuation of non-market goods, three that are most commonly used are:

> i) The travel cost method. Although people do not pay direct fees to visit an aquatic site, they do spend time and incur other costs, such as the cost of gasoline, to travel to the site. The opportunity cost of time plus other costs are their prices for access to clean water. Hence, "travel cost" can be used to elicit the value of clean water.
>
> ii) The hedonic method. This method recognizes that water quality affects housing prices. A house on a very clean lake or river is usually more expensive than one on a

polluted lake or river. Thus, the differences in the housing price reflect peoples' valuation of clean water.

iii) The contingent valuation (CV) method is not based on what people do, but what people say they will do under certain scenarios in a hypothetical market. This approach directly elicits the maximum WTP for better water quality in a survey.

Despite these three popular methods for water quality valuation, other (and probably cheaper) methods have been recently tested. One, for example, considers wastewater treatment as a productive process in which a desirable output (treated water) is obtained together with a series of undesirable outputs (suspended solids, heavy metals, nutrients, etc.) using inputs (labour, energy, etc.). This production perspective makes it possible to estimate the shadow prices of pollutants (Färe et al., 1993, 2001). A shadow price for these undesirable outputs would be the equivalent of the environmental damage avoided if these pollutants are removed or recovered. Therefore, they can be interpreted as an estimate of the environmental benefits gained from the treatment or recovery process.

The suitability of each method will depend upon several factors. The CV is a very flexible technique that can be applied to a great variety of non-market goods and to ex-ante and ex-post assessments.[1] However, it is very expensive to carry out. Shadow pricing, despite its limited scope, may be useful to quantify environmental impacts derived from production processes. It does present an advantage since obtaining the necessary information is more direct and cheaper (Färe et al., 2001).

3. To identify the market value of the impact on economic activities, we focus on the reduced production and loss of tourists. Tourism can be impacted because of the lack of clean water, the degraded landscape, limited recreation opportunities, bad odors and other environmental effects. The valuation could be very complex, so we may require the use of the methods which we use to value the impact on the environment. To value the impact on production, we can compare two similar productive systems in different locations where the only difference is the water quality. We can analyze the changes in production in terms of quality and quantity before and after polluted water is used for irrigation.

6.4 The cost of action

Implementing effective water recycling, safe reuse or disposal involves costs referred to as the cost of action. This assessment includes costs of investing, as well as operating and maintenance of the required facilities.

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[1] Ex-ante means before the event. Ex-ante assessment helps to give an idea of future movements in price or the future impact of a newly implemented policy. Ex-post stands for actual returns. Ex-post assessment centers on regression analysis to determine how much price change might be the result of market exposure.

The most common approach for developing cost function in the context of wastewater management is the statistical method. Steps ranging from the collection of the raw data to the generation of the cost functions are summarized in Figure 2

Figure 2:

(Source: Economic Valuation of Wastewater - The cost of action and the cost of no action, United Nations Environment Programme, 2015 http://unep.org/gpa/Documents/GWI/Wastewater%20Evaluation%20Report%20Mail.pdf)

1) Classify data according to process. For the cost functions of wastewater activities, sorting means first to distinguish each activity (sewer networks or wastewater treatment). Later, in each activity and based on its process, a classification is made (e.g. wastewater treatment based on extended aeration, membranes, etc.).

2) Choose a reference year. Due to the difficulty in obtaining economic data relating to the investment and the operation of wastewater activities, sometimes the reference year of all available information is not the same. In this case, the reference year is generally the year of analysis.

3) Select cost components. Usually, treatment capacity is the most important factor in determining cost. However, other factors such as contaminants removed or age may affect the operation of facilities.

4) Adjust available data regarding cost. Several statistical methods can be used to study the relationship between the independent variable (cost) and a series of variables (dependent ones) such as the capacity or the age of the facility. The most common is regression analysis (Gonzalez-Serrano et al., 2006; MARM, 2009), which can express the relationship between variables in a simple equation that connects a variable response, Y to one or more explanatory variables (X1 , X2 , ...Xk).

5) Check the significance of independent variables. Once the regression model has been developed, the next step is to check that all independent variables are significant. At its simplest, this involves checking that all the regression coefficients, β, have the expected sign. A further step is to carry out a statistical hypothesis test.

6) Evaluate through a quality of the adjustment. Quality can be assessed through the coefficient of determination. This coefficient measures the proportion of total variability of the dependent variable relative to its average, which is explained by the regression model. Its value is between 0 and 1. If the determination coefficient value is 1, the adjustment between actual and estimated data is perfect. If it takes the value of 0, there is no relationship between these variables.

6.5 Valuation cost methodologies

To value the cost of action, we need to evaluate internal costs and external costs. When we analyze internal costs, we particularly focus on capital expenditures and operational expenditure. Capital expenditures are those related to investment in assets that will last for many years (e.g. equipment). Operational Expenditure includes the expenses needed to operate and maintain the system assets. We can divide the process of wastewater treatment into many different parts and analyze the detailed cost of each part (Engineering methodology). We can also develop equations to identify relationships between costs and explanatory variables (Parametric methodology).

Contrary to the internal costs, external costs such as land pollution, emissions of greenhouse gases and noises, are usually much more difficult to monetize and quantify. The bearers of such costs can be either particular individuals or society at large. We commonly use a life-cycle assessment approach to forecast the project's impacts on the environment and ecological system under different development scenarios over its lifespan.

6.6 Comparison of cost of action and cost of no action

In order to compare the cost of action and cost of no action, we need to know the net present value (NPV) of the wastewater management project. We already know the first cost (or investment cost) at the very first stage of the life cycle, and using the method we explained above, we can identify the net value for each year. We also need to forecast the salvage value at the end of life of each facility. By discounting the net value of each year and the salvage value to today minus the initial investment, we can arrive at our project's net present value. If NPV>0, the intervention benefits outweigh the costs. If NPV<0, the costs exceed benefits, and the intervention is not economically feasible. An implementation may be justified by other factors, including social benefits, but not from an economic point of view.

One difficulty in calculating the present value of a project is the determination of an appropriate discount rate because the discount rate takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. The most used in the literature are 1 and 3 percent. We should keep in mind that if we only consider the market impacts, some projects' economic feasibility would be undermined. If we incorporate the external benefits, the economic feasibility analysis would provide positive results for all water reuse projects evaluated.

We can do a scenario analysis which will tell us under different scenarios (Basic, Worst, Best), how variable the net present value would be. We can also do a sensitivity analysis, which measures the impact of changing one or more key input values on the study result.

Based on the results of the empirical applications, we can conclude that in order to reverse current trends and prevent and address the negative consequences from untreated wastewater, many countries should invest in wastewater management systems, especially developing countries. Taking the cost of no action versus the cost of action approach into a decision-making process, it is obvious that wastewater management is a socially desirable and economically rewarding option. It provides many public benefits, including those related to health and the environment.

6.7 Valuing effective nutrient management: Rationale for valuation (looking at both nutrient excess and nutrient deficit considerations), methodologies for assessment, how to align to mainstream national accounting

The efficient and effective use of nutrients underpins food security and reduces the loss of valuable nutrients to the environment. With increasing demand for food, the contribution of synthetic nitrogen fertilizers has made over the past half century has been quite essential. When used at the wrong time, or the wrong rate, or in the wrong form and put in the wrong place, it can severely impact the whole environment.

Water and wastewater treatment has always been included in traditional national accounting as part of utilities or infrastructure spending by governments. But since the Environmental, Social and Governance (ESG) sector is getting more attention, we should account its contributions to economic activity. Therefore, we need to reclassify certain traditional economic activities in a different way than government statistical agencies usually do so as to avoid double counting. For example, the recent version of the System of Environmental-Economic Accounting (SEEA) marked a significant change from the previous version. The United Nations now only recognize two economic-environment activities: Environmental protection activities and resource management activities. In addition, the SEEA excludes activities related to natural resource use and the management/minimization of natural hazards. This would eliminate from the counting process activities involving the extraction, harvesting, and consumption of natural resources (e.g., mining, fishing, agriculture, etc.), but not necessarily technology innovations that support the efficient use of those resources.[2]

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[2] Getting a Handle on the Environmental Goods and Service Industry, Environment and Energy Bulletin, volume 6. http://www.bcbc.com/content/1440/EEBv6n6.pdf

6.8 Applying the Integrated Coastal Management (ICM) methodology to catalyse finance for coastal and ocean management

Coasts and oceans are being degraded at a rate that will have significant social and economic implications world-wide if allowed to continue unabated. Large Marine Ecosystems (LMEs) are relatively large areas of ocean space of approximately 200,000 km² or greater, adjacent to the continents in coastal waters where primary productivity is generally higher than in open ocean areas. The physical extent of an LME and its boundaries are based on four linked ecological, rather than political or economic, criteria: (i) bathymetry (depth), (ii) hydrography, (iii) productivity, and (iv) trophic relationships.

The world's LMEs produce about 80% of the world's annual marine fisheries catch and contribute an estimated $12.6 trillion in (non-market) goods and services annually to the world's economy. A majority of the world's 64 LMEs are shared ecosystems in that they are bordered by two or more countries, reaching as high as 28 countries in the Caribbean Sea LME.

However, continued over-fishing in the face of scientific warnings, fishing down food webs, destruction of coastal habitat, and accelerated pollution loading, especially nitrogen export, have resulted in significant degradation of LMEs adjacent to both developed and developing nations. Fragmentation among institutions, inter-national agencies, and disciplines, lack of cooperation among nations sharing marine ecosystems, and weak national policies, legislation, and enforcement all contribute to the need for a new imperative for adopting ecosystem-based approaches to changing human behavior in these systems in order to avoid serious social and economic disruption. To the loss of economic, environmental, and community security that accompanies the degradation and depletion of coastal and marine waters, climate change now adds even more complexity.

UNDP-GEF has successfully applied, refined and scaled up a 'bottom up' approach, working primarily at municipal and provincial scales, to strengthening ocean and coastal governance, **Integrated Coastal Management (ICM),** which, in combination with the negotiation, adoption and implementation of regional ocean strategies, creates a powerful, two-pronged tool for advancing sustainable use of marine ecosystems.

Over last two decades, UNDP-GEF has supported the creation, operation and institutionalisation of **PEMSEA**, Partnerships in Environmental Management for the Seas of East Asia, into the East Asian Seas region. Over this period, PEMSEA has developed, demonstrated and applied ICM programmes at various locations across the East Asian Region as a systematic approach to achieving sustainable development of coastal and marine environment and resources, specifically through on-the-ground implementation by local governments.

To govern its ICM programmes, PEMSEA utilises two important methodological frameworks developed during its first phase of GEF support Management of Marine Pollution in the East Asian Seas (**MPP-EAS**):

(1) the Framework for Sustainable Development of Coastal Areas (SDCA) and

(2) the ICM cycle.

Both serve as a conceptual map and an analytical/decision-making tool that enable how ICM is operationalised and institutionalised in the sites.

6.9 The Sustainable Development of Coastal Areas (SDCA) Framework

PEMSEA has developed and implemented a comprehensive, multi-faceted, ecosystem-based approach – the Framework for Sustainable Development of Coastal Areas (SDCA) – to provide as comprehensive a platform as possible by which to achieve sustainable development goals in coastal areas. The SDCA Framework is based upon initiatives in the East Asian Seas region in the last decade; it encapsulates the principal elements that contribute to sustainable ocean and coastal governance. The SDCA Framework ensures more focus and accountability in coastal governance.

The governance component of the SDCA Framework emphasises the integration of policies and strategies in developing actions as well as creating a policy environment for environmental financing, stakeholder participation, including scientific and expert advice, and capacity development. It also promotes institutional arrangements that facilitate interagency and multi-sectoral cooperation and collaboration, develops appropriate legislation to ensure policy and functional integration across sectors, and provides a legal basis for their enforcement. It is a strategic attempt to streamline and fast track government actions.

Embedded in the Framework is a call for action to create food security, sustainable livelihood and other programmes on coastal habitat protection, restoration and management; water use and supply management; pollution reduction and waste management; and natural and manmade hazard prevention and management. Thus, the frame-work emphasises the link that exists between governance of coastal and marine activities, the rehabilitation and sustainable management of ecosystem services, and the benefits and impacts to people.

Ideally, a harmonious, peaceful co-existence between these mutually linked (but oftentimes competing) concerns can be established. But pragmatically and given the increasing trend in coastal urbanisation, development of the ocean economy, and the pressure coming from climate variation and change, trade-offs and priorities need to be determined and agreed upon; local governments have to choose which coastal activity in which area is the main concern and is in need of the financing and investment portfolios that can better achieve the goals of sustainable development.

Two other important components of the SDCA Framework are the **State of Coasts Reporting System (SOC)** and the **ICM Code**. The SOC serves as a tool for assessing baseline conditions at a site (e.g., demographic; socio-economic; ecological) and for measuring changes and determining trends over time. The SOC provides local Chief Executives with a report card on the effectiveness and impact of ICM programmes, and gives direction for future actions. The ICM Code provides the rules of practice in an integrated coastal management system. The Code enables local governments to undertake an ICM programme following a standard planning and management framework and set of procedures, and for measuring progress toward and conformity with recognised international standards e.g., ISO 9001 (Quality Management System) and ISO 14001 (Environmental Management System).

6.10 The ICM Cycle

The SDCA Framework utilises the **integrated coastal management (ICM)** cycle comprised of mechanisms and processes that have matured over four decades as the principal driver to operationalise ICM. In other words, the ICM cycle provides a stepwise, iterative approach and the necessary innovative tools, which facilitate a systematic and integrated policymaking, planning and management approach.

The ICM cycle (Figure 3) has primarily taught us that a coastal governance policy must not exist separately from its implementation; that this is a long-term endeavor. And as an ICM programme matures, both the SDCA Framework and the ICM cycle provide robust, scaling-up platforms to accommodate increasing (and evolving) needs and aspirations in the coastal areas.

Figure 3:

(Source: PEMSEA (2011), Catalysing Ocean Finance, Volume II, 2012 United Nations Development Programme)

The **Preparing stage** focuses efforts on setting up the management and administrative aspects of the ICM site, which includes:

1) establishment of a project management office (PMO) to coordinate the implementation of identified activities and selection of project staff
2) establishment of an inter-agency, multi-sector coordinating body (normally in the form of project coordinating committee or PCC) that will coordinate diversified project activities and direct the programme
3) establishment of a technical working/advisory group to provide technical and scientific advice to the project
4) clarification of working relationships within the local government and among national government agencies and other stakeholders

It is also essential to prepare a work plan and arrange available financial and other administrative resources.

In the **Initiating stage**, environmental issues and concerns are identified and prioritised for management interventions.

To address the perceived issues, the **Developing stage** prioritises the action programmes within the coastal strategy for short-, medium- and long-term implementation. A coastal strategy implementation plan is developed as a collaborative planning exercise involving the lead agency and line agencies. It identifies goals, targets, measurable indicators of progress and outcomes for key management interventions, based on the coastal strategy. The implementation plan also specifies an indicative budget and financing strategy for each action programme. It enhances the coordination and integration of many diverse projects to ensure effective use of time, funding and resources.

Although financing is a critical need for the development and implementation of an ICM programme, it is not a limiting factor. An ICM programme can be initiated within the limits of existing financial resources using available line agency budgets. The key is the strong support and participation of the relevant agencies because benefits are accrued from such participation.

Other key outputs from the Developing stage are: 1) institutional arrangements and supporting sustainable financing mechanisms are established to ensure the programme's sustainability within existing social, political and legal structures; and 2) a coastal use zoning scheme and its implementing arrangements are set up to provide local governments with a mechanism for planning and managing development and human activities in coastal areas, as well as for establishing permits, user fees, etc. for access to/use of coastal and marine resources and services.

Adoption of the above plans and arrangements by the local government guarantees the integration of the plans into the development planning framework of the local government, allocation of budget, harmonisation of efforts, and institutionalisation of coordinating arrangements for implementation of the action plans. Involvement of the lawmakers and public to pass local laws in support of the proposed plans in the Adopting stage requires intensive public awareness and political will. Thus a target-oriented communication plan needs to be developed and started during the Initiating and Developing stages in order to prepare the concerned policy-makers and stakeholders for the Adopting stage.

The **Implementing stage** demands the availability of competent personnel, financial resources, as well as the political commitment to implement action plans. Training and development of competent personnel in the different line agencies and sectors involved in ICM implementation is also a key aspect at this stage. A critical mass of human resources must be available at the local level or available within reach of the local government. A successful ICM programme is built on the local capacity to plan and manage the coastal and marine areas.

During the **Refining and Consolidating stage**, a practical and efficient monitoring and evaluation (M&E) system, established at the onset (Preparing) facilitates the process of assessing ICM programme implementation and management. Updating the SOC report provides the local government and their stakeholders with an assessment of ICM achievements and resulting changes, and contributes to the planning for the next ICM cycle.

The next programme cycle begins when new action plans are being formulated and implemented, based on the experience and foundation established in the previous cycle. The new cycle can address the challenge of scaling up the ICM programme with regard to the following contexts:

1) geographic expansion of existing ICM programme and/or replication of ICM in other coastal areas;
2) functional expansion of ICM with regard to management issues, including the linking of coastal management and watershed and river basin management;
3) temporal considerations, as ICM needs to become an integral part of government programmes instead of being implemented as a separate project.

Results:

Since the adoption of the SDS-SEA in 2003, changes in coastal and ocean governance and management approaches have occurred in the East Asian Seas at the regional, national and local levels. Based on the survey of 2010, countries confirmed that ICM programmes now cover approximately 11% of the region's coastline.

ICM development and implementation has paved the way for environmental improvements and investments in the East Asian Seas region by putting in place the necessary enabling environment (national and local policies, legislation and institutions) for such investment. For example, in Xiamen, China, the local government invested more than $190 million in 7 sewage treatment facilities covering the entire municipality. The investments were in accordance with the policies and coastal strategies developed and adopted by the local governments under their respective ICM programmes. The project was able to substantially reduce total loadings of nutrients and oxygen-demanding substances discharging into their respective coastal waters. The Xiamen case study indicates that domestic sewage treatment rose from 28% of the population in 1995 to 85% in 2007. Improvements in water quality in sea areas around Xiamen have been documented, particularly in Yangdong Lagoon where the transition was from heavily polluted waters to fishable waters. Other sea areas around Xiamen have been able to maintain their water quality despite substantial increases in population and economic development. A major effort is currently underway to address nutrient pollution of Xiamen's coastal waters, as a consequence of river discharges from adjacent upstream cities.

In total, environmental investments leveraged through PEMSEA-facilitated ICM and sub-regional programme implementation have amounted to $369 million (Table 1), of which $78.65 million came from the private sector and the balance from the public sector. This underscores that the impacts of PEMSEA on coastal sustainability through upscaling of ICM are not just regional, but global.

Total GEF Grant Financing	$36.1 million
Total Programme Co-financing	$94.12 million
Catalysed Public and Private Sector Financing (through 2007)	$369.21 million

(Source: Catalysing Ocean Finance, Volume II, 2012 United Nations Development Programme)

6.10 Challenges of raising finance for investment

Despite its social, economic, and environmental promise and societal expectations, there are clearly some challenges to raising finance for dealing with wastewater and nutrient runoff. The difficulties arise because most projects have large scale and long term demands, and are often associated with high risk. For some projects, the financial institution involved did not participate in the early stage, so it is hard for them to identify the risk. Even for projects in which both governments and corporations share risks, when there are asymmetries in information, the investors cannot forecast stable cash flows and build models to predict profitability, discouraging participation.

Another concern is the credibility and sustainability of government finances. As the majority of the investments are likely to involve sub-national governments, whether they can manage current and future liabilities is a critical factor in taking sound investment decisions. This kind of problem is likely to be greater in developing countries. If the government lacks the desire or ability to commit to contractual obligations, it may eventually fail to honour contractual terms. This is even more serious than a firm's failure, since it affects future investment confidence.

Finally, regarding the wastewater treatment, common difficulties include the diversity of wastewater types and source at the city level and lack of infrastructure to gather wastewater flows from diverse areas to a single common point of proper treatment. As a result, only a small proportion of wastewater is treated, and the portion that is safely reused is significantly smaller. Multilateral development banks, bilateral donors, and other development agencies find it challenging to get policymakers and managers in national and local governments to develop policies to address wastewater management effectively.[3] The cost of investing in centralized wastewater treatment systems is typically high. Global investments in modern water and sewer systems have been estimated at some USD $30 billion per year, and by 2025 it may cost USD $75 billion per year, excluding costs for operation and maintenance. In centralized systems, wastewater transport and treatment facilities must be engineered to cope with these irregular extreme flows. For developing countries alone, it has been estimated that USD $103 billion per year are required to finance water, sanitation and wastewater treatment through 2015. Industrialized countries such as Brazil, China and India are all already committing considerable resources to develop their infrastructure.

Various financing options, from traditional approaches to more innovative solutions

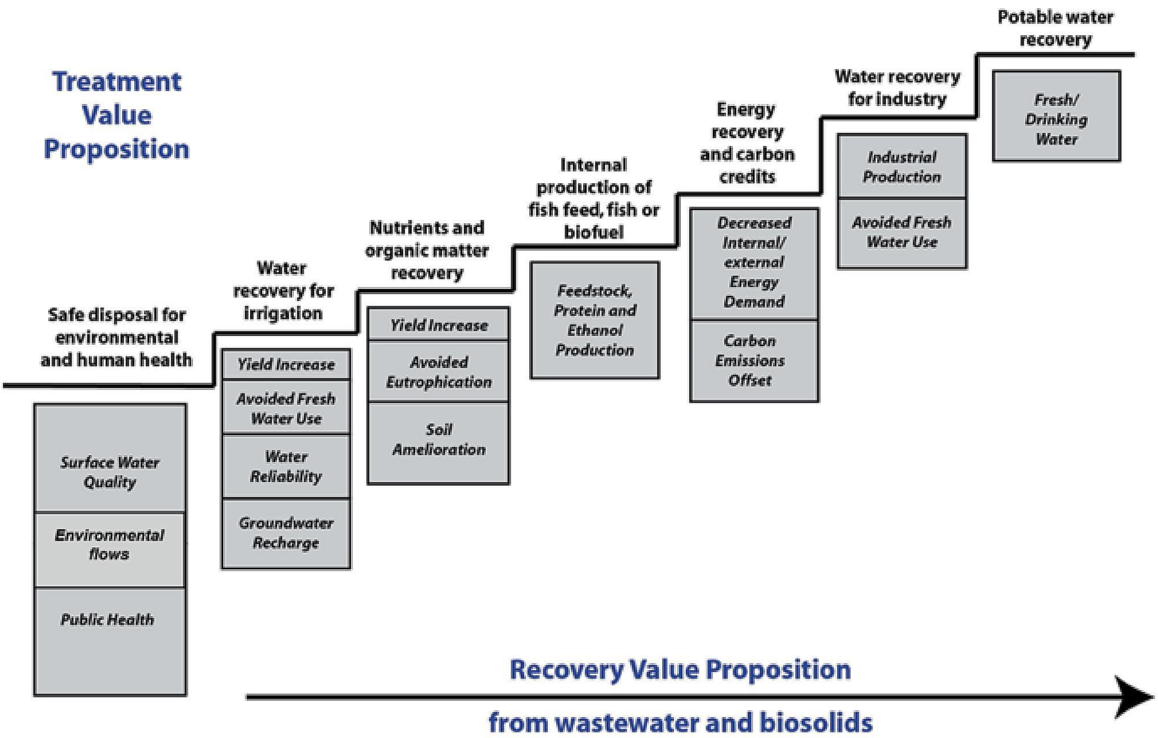

Figure 4: Ladder of increasing value propositions related to wastewater treatment based on increas–ing investments and cost recovery potential. (Source: IWMI, Wastewater: Economic Asset in an Urbanizing World. Pay Drechsel, Manzoor Qadir, Dennis Wichelns)

Traditionally, investments for wastewater management infrastructure have been met solely from public grants financing, foreign aid, or multilateral lending. The largest funding sources

[3] http://unep.org/gpa/Documents/GWI/Wastewater%20Evaluation%20Report%20Mail.pdf

are local, originating from governments (who obtain funds through various local and national fiscal flows), users (paying for their own on-site systems or paying bills to official service providers), and local banks and donors (including private voluntary contributions).

Taxation has played an important role in financing wastewater management. Wastewater taxes are defined as compulsory payments independent of any service received and apply to direct discharger, i.e. those entities which discharge directly into a recipient water, and possibly to the residual discharge from sewage treatment plants after treatment. The main function of wastewater taxes is to raise financial revenue and its secondary role is to regulate and control the polluter's wastewater emission behaviors. [4]

For example, in the Netherlands, the levy is imposed on all direct discharges to surface water as well as on all indirect discharges. The revenue from the state water levy has been recycled both for support of municipal sewage treatment plants and to support in-house pollution abatement in industry. In Germany, the tax affects only direct discharger, i.e. discharges from industries and municipal sewage outlets. Indirect dischargers are affected by the tax via the ordinary wastewater user fee. The revenue raised by the tax is spent by the Länder authorities on municipal sewage treatment and on Länder administration of water quality programmes. In Denmark, the tax applies to discharges of organic material (BOD - biological oxygen demand), nitrogen and phosphorous from direct dischargers, i.e. wastewater treatment plants, industries with direct discharges and dwellings not connected to the sewerage network. The revenue of the tax accrues to the national treasury. As part of the political compromise in parliament, a substantial sum was devoted to an independent Water Fund, the purpose of which is to finance projects which protect groundwater resources.[5]

However, it is clear that, to meet current challenges, existing funding sources and instruments are not sufficient. Unlocking additional funding and innovative mechanisms is important if progress is to be made in achieving sustainability in wastewater management. Local governments should play a key role in managing resources and societies. They are the primary party in the dialogue with the people and the local corporate community who are affected by government decisions

To increase **the local community-based sanitation initiatives**, the government needs to ensure the solidarity among different stakeholders and service levels. For an intervention to be successful, participation of beneficiaries in the planning and decision-making process is always essential. This increases the sense of responsibility among beneficiaries to pay wastewater bills once the service is operating. In addition, solutions selected by local users tend to be lower cost technologies. Many well-known case studies have shown that people's

[4] Environmental Taxation in China and Asia-Pacific: Achieving Environmental Sustainability through Fiscal Policy, Hope Ashiabor, Larry Kreiser, Julsuchada Sirisom, J E Milne
Edward Elgar Publishing, 2011

[5] Study on Environmental Taxes and Charges in the EU,
http://ec.europa.eu/environment/enveco/taxation/pdf/ch7_waste_water.pdf

willingness to pay for sanitation improvements is much higher than expected if they can select the type of system they prefer.

Public-private partnerships (PPP) have become increasingly popular in recent decades as indebted governments look for more private sector investment in public projects. Transferring part of the responsibility for infrastructure management to private partners (bringing in capital) spreading risk and gaining from typical private sector virtues in management and operation is a potentially promising solution. Water supply and sanitation projects can benefit from typical private company characteristics such as their professional managerial capacity, the fact that they are technically better qualified and equipped, and operate at high efficiency levels, all resulting in lower operating costs and more secure revenues. Besides, they offer potential for innovative solutions and risk sharing, and with their easy access to capital markets, they open up routes to alternative and additional forms of cheaper and long-term financing (Figuères, 2003).

One of the most common methods is **build-operate-transfer** (BOT). BOT is a form of project financing, wherein a private entity receives a concession from the private or public sector to finance, design, construct, and operate a facility stated in the concession contract.[6] At the end of this period, the private entity needs to transfer the facility to its owner for no cost. For example, if the host government wants to build a sewage treatment plant, it will delegate to a private sector entity the responsibility to design and build the plant and operate and maintain it for a certain period, usually 20 - 30 years. During this period, the private party needs to finance the project. However, it is entitled to keep all revenues generated by this sewage treatment plant and maintains property ownership. After the 20-year period, it has to transfer this plant and the property ownership to the host government without any cost. This approach especially works well for projects led by governments.

The advantages are obvious: this method encourages private investment and brings new foreign capital to the country. Because the private party has the responsibilities to raise the funds for the project, so it releases government's' burden on the public budget for infrastructure development. In addition, in order to recover the principal and generate profits, the private parties usually operate the project more efficiently with more advanced technology. However, due to the long-term nature of the arrangement, the private party has to face a substantial risk, including the risk of political changes that could leave the project in a hazardous predicament. There may be some technical risks if the construction is difficult to complete. Moreover, the financial risks are also high, including foreign exchange risk, interest risk, and market risk.

[6] https://en.wikipedia.org/wiki/Build%E2%80%93operate%E2%80%93transfer

Many countries are using the BOT approach to address this global change. For example, the AEPA International, an American company, became the first foreign company to gain the operating rights to a Beijing sewage harness project. The sewage harness factory will cover more than 20 hectares. By using BOT, AEPA International needs to invest ten million dollars and expects to recoup the investment in 20 years.[7]

Source: http://www.aepa.com/news.html

A similar approach is called **transfer-operate-transfer** (TOT), in which the private party buys the facility and the operational rights and receives the revenue generated by the facility within a concession period. At the end of such period, the private party needs to transfer the facility to its owner without costs. Compared to the BOT method, the risk for private parties is lower because the risk in the construction state and the production state has been consumed by its owner. Due to the lower risk, the method will attract a wider range of investors, such as financial institutes, monetary funds, and private institutes, but not limited to the financial syndicate or large banks. Moreover, the procedure is easier and simpler. However, the owner of the facility has to bear more risk. If the assessment is undervalued, the owner will suffer a loss, but if it is overvalued, the investors would be discouraged.

In 2004, Berlin Water Group acquired the Wangxiaoying wastewater treatment plant in Hefei, China for around 63 million dollars. It was the largest and the most influential TOT project in the wastewater treatment sector.[8]

A more creative way to finance is **securitization**. This is achieved by using asset-backed securities (ABS), which are securities whose income payments, and hence value, is derived from a collateralized (or "backed by") specified pool of underlying assets. The pool of assets is typically a group of small and illiquid assets whose owners are unable to sell individually. Often a separate institution, called a special purpose vehicle (SPV), is created to handle the securitization of asset-backed securities. The special purpose vehicle, which creates and sells the securities, uses the proceeds of the sale to pay back the bank that created, or originated, the underlying assets.[9] For example, the owner of the wastewater treatment facility could let SPV use its future revenues to create a pool and sell ABS to investors, then the owner could use the collecting funds to operate or even expand facilities. Finally, the owner gives a part of those revenues to SPV, and SPV uses those cash flows to repay investors' principal and interests. Obviously, this approach has many advantages. It turns these illiquid assets into financial instruments that can be bought and sold freely, and lenders are then free to write additional loans. Because ABS are backed up by SPV, they have a higher credit rating so the

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[7] https://issuu.com/beijingtoday/docs/2001-12-14 BEIJING TODAY
[8] Reform of China's Urban Water Sector, Tao Fu, Miao Chang, Lijin Zhong, Michael Sievers, Sven-Uwe Geissen, Movva Reddy
[9] https://en.wikipedia.org/wiki/Asset-backed_security

borrowing cost and transaction fees are lower. By creating tranches[10] of securities from this pool of assets, investors are able to select different offers to align with their risk tolerance and investing time horizons. In addition, ABS pay investors a yield premium when compared to the same credit rating traditional offerings. Of course, investors have to bear some risks, such as prepayments from the borrower, and if the owner of the wastewater treatment facility accelerates their payments, investors will receive lower returns. If interest rates are falling, the owner may decide to refinance their loans at more attractive rates. Lastly, in the worse case scenario, there may be no payments due to bankruptcy.

There is a more straightforward way called **divestiture.** Full divestiture pertains to a situation where utility has been fully privatized. Ownership of utility rests with private operator. Private operator is responsible for operation and maintenance, investments and tariff collection. Regulation (to safeguard public interest) in hands of Government, so completely separated from ownership and operation. This will improve incentives for efficient investment decisions and development of innovative technologies. Low transaction costs compared to costs of tendering and contract negotiations associated with models discussed above. However, possible conflict of interest may exist. For example, public sector responsible for regulation and company shareholder responsible for maximizing returns. This could lead to political interference and counteract private sector management advantages. No competition (as no tendering) can raise transparency and corruption concerns.

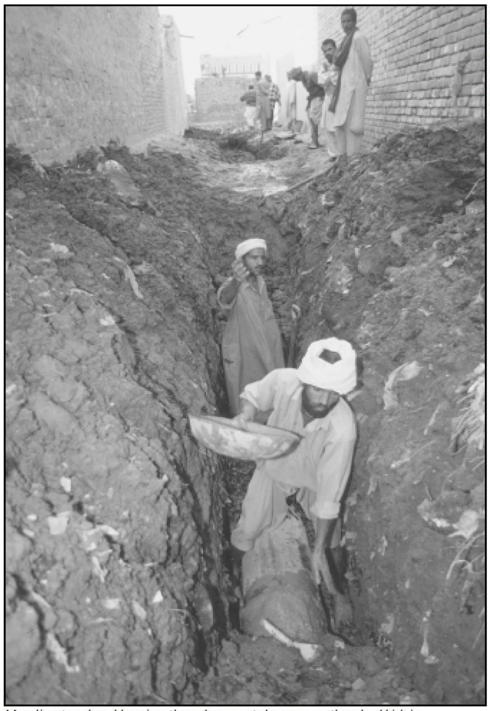
There are more alternative approaches to financing projects today, for instance, using bonds, taxation, or even lotteries. Each community should choose the most suitable approaches based on its own status.

For example, the Caribbean Regional Fund for Wastewater Management (CReW) pilots innovative financing mechanisms in Belize, Trinidad and Tobago and Guyana via revolving funds and in Jamaica, via a credit enhancement facility. The credit enhancement facility modeled by Jamaica uses CReW resources (US$ 3 million) as leverage financing for a further US$ 7 million to fund wastewater projects. The innovative model creates an incentive for allocating the resources garnered from the monthly collection of the K-factor funds (a portion of the water tariff) for debt servicing for larger commercial bank loans, rather than using the funds directly for capital investments in the sector. The CReW funds will be placed into a reserve account as a secondary assurance to commercial lenders to cater for any temporary unavailability of K-factor funds. Belize, Trinidad and Tobago use CReW resources (US$ 5 million and US$ 2 million respectively) to loan to the respective water utility to finance select wastewater projects. Replenishment of the revolving funds depend on income generated primarily through the tariff regime. The Guyana pilot offers an innovative mechanism of

[10] Tranches are pieces, portions or slices of debt or structured financing. Each portion, or tranche, is one of the several related securities offered at the same time but with different risks, rewards, and maturities. (source: http://www.investopedia.com/terms/t/tranches.asp)

financing various wastewater projects in the private sector via a revolving fund valued initially at US$ 3 million.[11] (To see more details in Module 7 - Case Study 8)

Case Studies



Men dig a trench and lay pipes through compacted sewage, earth and rubbish in Hassanpura, Faisalabad.

(Source: From the Lane to the CIty- The Impact of the Orangi Pilot Project's Low Cost Sanitation Model, A Water Aid report by Akbar Zaidi)

In the 1980s, the 600 000 residents of the Orangi, Karachi, Pakistan slum area had no access to the city's sewer system. A renowned community organiser then started with a small amount of core external funding to explore alternatives. Residents were asked about their needs and wishes and some community members participated in the construction of facilities, which included in-house sanitary latrines and house sewers on each plot and underground sewers in lanes and streets. Simple techniques and free labour reduced infrastructural costs to less than US$100 per household. Elected lane and neighbourhood managers maintained the sewers, and households pay for the costs, partly in kind. (Serageldin 1994). By April 2001, the project had benefited 92,184 families in 6,134 lanes, representing almost 90% of the entire settlement. There have also been 409 collector sewers built and collectively the community have invested Rs. 82.141 Million (£924,000) in their sewerage system.[12]

The Kinnegar Wastewater Treatment Project involves cooperation by Laganwater and Northern Ireland Water, and this contract for Northern Ireland Water was the first of its kind in Northern Ireland and set up under a Public-Private Partnership. The project included the design and construction of a treatment work catering for a population equivalent of 110,000. The site was an existing disposal work at Belfast Lough on the County Down coast. The works consisted of a new Inlet Treatment structure to screen incoming flows and remove inert material, two 9m diameter SwirlFlo tanks to provide primary treatment and four Sequential Batch Reactors (SBR) each of 7500 m^3 capacity for secondary treatment. The final effluent water is discharged into Belfast Lough via an outfall from the site's tidal ponds.

[11] Wastewater Innovative Wastewater Financing Mechanisms – Why the CReW is not only about Constructing Wastewater Treatment Plants (Important Considerations for Replication), Marlon Daniels. http://www.aidis.org.br/PDF/cwwa2015/CWWA%202015%20Paper%20Submission%20-%20Marlon%20Daniels%20-%20Innovative%20Financing%20Mechanisms%20-%20Why%20CReW%20is%20not%20only%20about%20Wastewater%20Treatment%20Plants.pdf

[12] From the Lane to the City: The Impact of the Orangi Pilot Project's Low Cost Sanitation Model, Akbar Zaidi.http://www.wateraid.org/~/media/Publications/from_the_lane_to_the_city.pdf

Discharges from the ponds occur twice daily high tide. The operational period of the contract is 25 years starting from April 1999.[13]

(source: https://www.laganwater.com/case_studies/kinnegar-wastewater-treatment-works-pfi/)

Discussion Questions

1. Which financing mechanisms are conducive to the greatest equity when applied in the southern hemisphere?
2. Do developed countries have an ethical obligation to finance or co-finance wastewater treatment infrastructure in less-developed countries? Why or why not?
3. Is it feasible to apply the polluter pays principle in the case of wastewater and nutrient runoff management?
4. How can investments be insured against losses?
5. What could be the cultural/perception barriers to reuse of treated water for home use?

Annotated Bibliography

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http://unep.org/gpa/Documents/GWI/Wastewater Evaluation Report Mail.pdf

Rob Norton, Eric Davidson, and Terry Roberts. "Nitrogen Use Efficiency and Nutrient Performance Indicators" This paper offers the technical basis and supporting research for using Nitrogen Use Efficiency (NUE) as a performance indicator to improve global food production and control the potentially harmful environmental impacts of excess nitrogen-based compounds from manufactured and animal waste fertilizers.

[13] https://www.laganwater.com/case_studies/kinnegar-wastewater-treatment-works-pfi/

http://www.unep.org/gpa/documents/publications/NUEandNPIGPNM2015.pdf

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http://www3.weforum.org/docs/Media/TheGlobalRisksReport2016.pdf

Study on Environmental Taxes and Charges in the EU, Chapter 7 – Waste Water. This chapter talks about the wastewater taxes in three countries and hence illustrate the range of options which may combine environmental effectiveness with economic and administrative feasibility. http://ec.europa.eu/environment/enveco/taxation/pdf/ch7_waste_water.pdf

Guidelines on Municipal Wastewater Management, UNEP/WHO/HABITAT/WSSCC. A practical guide for decision-makers and professionals on how to plan, design, and finance appropriate and environmentally sound municipal wastewater discharge systems.https://esa.un.org/iys/docs/san_lib_docs/guidelines_on_municipal_wastewater_english.pdfhttps://esa.un.org/iys/docs/san_lib_docs/guidelines_on_municipal_wastewater_english.pdf

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United Nations Environment Programme. “Catalysing Ocean Finance”, Volume II. This publication demonstrates that, far from being an intractable problem, sustainable ocean management could become a successful legacy of today’s generation of decision-makers. It shows how the challenges facing the ocean stem from widely understood market and policy failures - failures which can be addressed through the application of appropriate mixes of market and policy instruments.https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjrq__qzbrPAhUClB4KHf4kBZsQFggjMAE&url=http%3A%2F%2Fwww.undp.org%2Fcontent%2Fdam%2Fundp%2Flibrary%2FEnvironment%2520and%2520Energy%2FWater%2520and%2520Ocean%2520Governance%2FOceans%2520and%2520Coastal%2520Area%2520Governance%2FCatalysing-Ocean-Finance-Vol-II.pdf%3Fdownload&usg=AFQjCNFZAmhN9oglFMNM9ODLlpQ6569qmg&sig2=lm_V_ZdBmdAaiEUVBGa5aAhttps://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjrq__qzbrPAhUClB4KHf4kBZsQFggjMAE&url=http%3A%2F%2Fwww.undp.org%2Fcontent%2Fdam%2Fundp%2Flibrary%2FEnvironment%2520and%2520Energy%2FWater%2520and%2520Ocean%2520Governance%2FOceans%2520and%2520Coastal%2520Area%2520Governance%2FCatalysing-Ocean-Finance-Vol-II.pdf%3Fdownload&usg=AFQjCNFZAmhN9oglFMNM9ODLlpQ6569qmg&sig2=lm_V_ZdBmdAaiEUVBGa5aA

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Wastewater: Economic Asset in an Urbanizing World. Pay Drechsel, Manzoor Qadir, Dennis Wichelns. Springer Dordrecht Heidelberg New York London. Based on the most up to date information and data, this book showcases wastewater from on-site sanitation as well as sewered systems as an asset that can be valued financially and economically. By changing the paradigm of 'treatment for disposal' to 'treatment for reuse' a variety of value propositions for water, nutrient and energy recovery can support cost savings, cost recovery, or even profit generation, contingent upon management of possible health and environmental risks.

Wastewater: Innovative Wastewater Financing Mechanisms – Why the CReW is not only about Constructing Wastewater Treatment Plants (Important Considerations for Replication), Marlon Daniels. The Caribbean Regional Fund for Wastewater Management (CReW) pilots innovative financing mechanisms in Belize, Trinidad and Tobago and Guyana via revolving funds and in Jamaica, via a credit enhancement facility. This article will explore the unique challenges faced by each pilot during project implementation and the lessons learnt from the Guyana pilot point to the need for appropriate policy and institutional reform adjustments in order to use this mechanism in the private sector. http://www.aidis.org.br/PDF/cwwa2015/CWWA%202015%20Paper%20Submission%20-%20Marlon%20Daniels%20-%20Innovative%20Financing%20Mechanisms%20-%20Why%20CReW%20is%20not%20only%20about%20Wastewater%20Treatment%20Plants.pdf

Other Online Sources

There is an urgent need to accelerate the transition to a green economy by better aligning the financial system to the resilience and the long-term success of the real economy. The UNEP Inquiry is intended to support such actions by identifying best practice, and exploring financial market policy and regulatory innovations that would support the development of a green financial system.
http://web.unep.org/inquiryhttp://web.unep.org/inquiry
http://web.unep.org/inquiry

The Climate Registry is a non-profit organization governed by U.S. states and Canadian provinces and territories. We design and operate voluntary and compliance GHG reporting programs globally, and assist organizations in measuring, verifying and reporting the carbon in their operations so they can manage and reduce it.
https://www.theclimateregistry.org/https://www.theclimateregistry.org/
https://www.theclimateregistry.org/

GRI is an international independent organization that helps businesses, governments and other organizations understand and communicate the impact of business on critical sustainability issues such as climate change, human rights, corruption and many others.
https://www.globalreporting.org/Pages/default.aspxhttps://www.globalreporting.org/Pages/default.aspx
https://www.globalreporting.org/Pages/default.aspx

CDP is a not-for-profit that runs the global disclosure system for investors, companies, cities, states and regions to manage their environmental impacts. Over the past 15 years we have created a system that has resulted in unparalleled engagement on environmental issues worldwide.
https://www.cdp.net/enhttps://www.cdp.net/en
https://www.cdp.net/en

Established in 1997, Asia Research Centre (ARC) built on LSE's long engagement with Asia, China and India in particular. The Centre was multi-disciplinary; its primary purpose was to conduct and support research on issues concerning Asia both in-house as well as across teaching and research units of the School.
http://www.lse.ac.uk/asiaResearchCentre/about/Home.aspxhttp://www.lse.ac.uk/asiaResearchCentre/about/Home.aspx
http://www.lse.ac.uk/asiaResearchCentre/about/Home.aspx

The PRI is the world's leading proponent of responsible investment. It works to understand the investment implications of environmental, social and governance (ESG) factors and to support its international network of investor signatories in incorporating these factors into their investment and ownership decisions.
https://www.unpri.org/https://www.unpri.org/
https://www.unpri.org/

Module Seven: Case studies of effective wastewater management

The next two modules will present an array of case studies, both successful and unsuccessful, from which we can learn how to pursue best practices and avoid mistakes. In Module Seven we focus on wastewater management; in Module Eight we will turn to nutrient management. The case studies are taken from around the world and are an important component of the course, since they permit us to look closely at actual "on-the-ground" applications of some of the principles and policy points made in previous sections. We will move from local to global in scale. Note that some of these case studies are covered in the online course and others are not.

For all these case studies, there are organizations that can provide further information and even arrange visits to the sites in question. We encourage all those who are interested in pursuing the cases in more detail to conduct their own explorations!

Learning Objectives

After completing this module, students will:

1. Be able to relate the material they have covered in preceding modules to actual case studies;
2. Relate "best and worst practices" analysis to wastewater management

Case Studies:

1) Hammarby Sjöstad, Stockholm, Sweden
2) Tenorio Project, San Luis Potosí, Mexico
3) Bora Bora
4) The Msingini-Mtoni Wastewater Management Project, Pemba Island, Tanzania
5) Jordan
6) Singapore
7) Xi'an, China
8) The Caribbean Regional Fund for Wastewater Management
9) The Georgia Wastewater Project
10) The Global Wastewater Initiative

End of module discussion questions can be found at the end of this chapter.

Case Study One

Integrated waste management in practice: Hammarby Sjöstad, Stockholm, Sweden

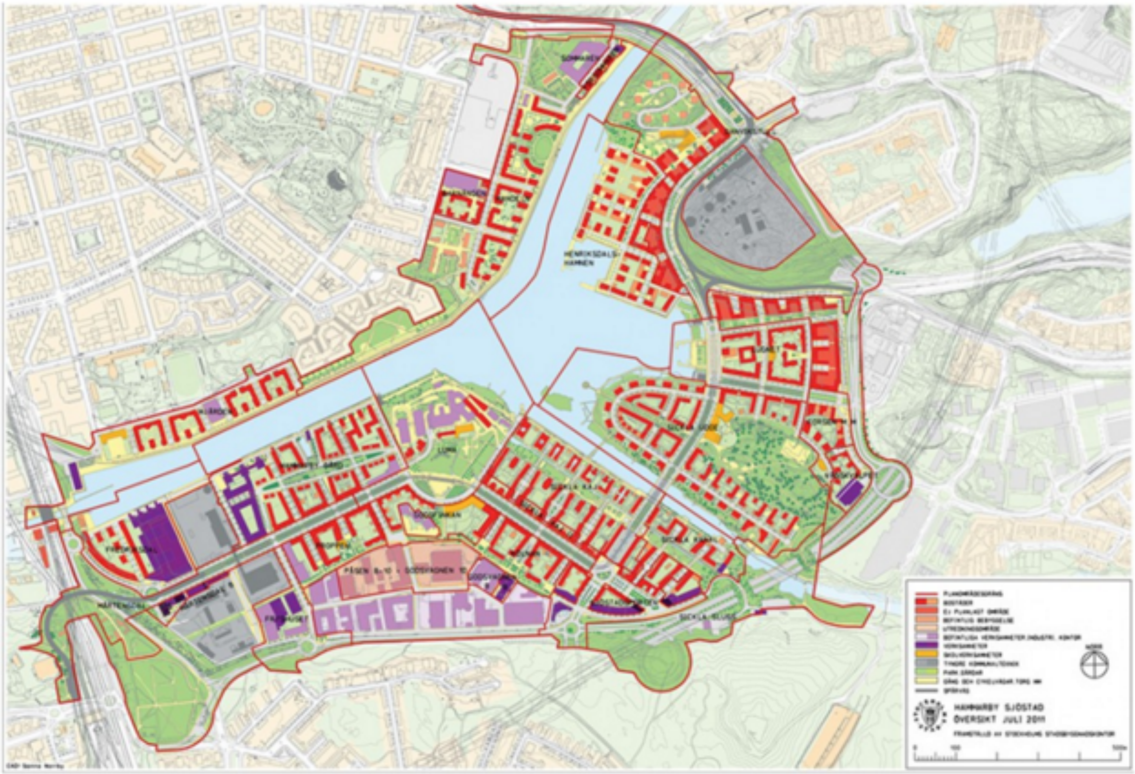
In several countries, water and sanitation companies are working towards becoming energy-neutral by generating energy from wastewater that equals the amount of energy consumed in their other operations. Many wastewater treatment plants have been able to generate biogas from wastewater or sludge and convert it to heat or electricity. In Stockholm, for example, public buses, waste collection trucks and taxis run on biogas produced from sewage treatment plants (Osterlin, 2012).

But it is perhaps the Hammarby Sjostad area more specifically that has become the most famous in Sweden for integrated waste management...

Figure reference: http://www.symbiocity.org/Global/Images/undersida/case_L_hammarbysjostad.jpg

Summary of the main problem faced

Before development began in the late 1990s, Hammarby Sjöstad was a **brownfield** site dominated by small-scale industries and heavily polluted soils (Foletta, 2014). Plans for the Hammarby Sjöstad development project were started in the early 1990s when there was a strong urban housing demand in Stockholm accompanied by a growing population. The project then gained traction when Sweden applied to be the site of the 2004 Olympics. Hammarby Sjöstad was originally intended to be an eco-village for the Olympic games, however when Sweden did not win the Olympic bid, the City of Stockholm continued forward with development plans for a sustainable residential neighbourhood (Brogen & Green, 2003).



Plan © Stockholm City Planning Administration

Figure reference: http://www.urbangreenbluegrids.com/projects/hammarby-sjostad-stockholm-sweden/

Actors involved

The primary actors involved in the project were the municipality of Stockholm, Stockholm City, Business Sweden (SymbioCity), local and national transportation agencies, the Stockholm business region, and private developers, architects, and consultants (Ecodistricts, 2013). Hammarby Sjöstad is well known for its integration between municipal departments including waste, transportation, and energy.

Summary of actions taken

Strict environmental requirements were set by the City of Stockholm for this development project – these applied to buildings, transportation infrastructure, and technical installations. The primary goal was to produce only 50% environmental impact compared to other developments undertaken in the 1990s, or to be “twice as good” (Olsson, n.d.). This ambitious environmental program was inspired by the United Nations Agenda 21 (declaration on environment and development) and the Bruntland report (Iverot & Brandt, 2011). The targets were surrounding land use, soil pollution, energy, water, wastewater and sewage, garbage, building material, transportation, noise, and green areas. A report published by Stockholm city stated that Hammerby Sjöstad should *“impose as little demand as possible upon resources, and be an environmentally well-adapted city district, whilst being at the* *forefront of international strivings towards sustainable development in densely populated urban areas''* (City of Stockholm 1996, p. 4).

This project implemented a holistic approach, which involved collaboration between all authorities and administrators involved in the development project (Iverot & Brandt, 2011; Sväne, 2008). Together, they created a plan and conceptual approach for the area that focused on sustainability. This allowed for integration between sectors, such that waste from one sector could be used as valuable resource in another sector while streamlining energy and resource use. GlashusEtt, an environmental center, was also set up by the city to integrate the public by providing citizens and tourists with information and education about sustainable urban planning and measures to increase sustainable lifestyles (Freudenthal, 2012). At the inception of the project, the land in the area was privately owned, however, Stockholm City eventually bought the land thus facilitating the development project (Mahzouni, 2015).

Figure reference: http://www.symbiocity.org/en/

Several strategies are in place to reduce water consumption such as education and awareness programs and the implementation of water-saving appliances. This includes water efficient toilets, information about contaminants found in detergents and other products, and optional monitoring programs where residents can follow their energy and water consumption patterns (Urban Green-Blue Grids, 2008).

Wastewater from the area is treated at a local wastewater treatment plant and several methods and processes are used to increase resource recovery within the system. For example, heat is extracted from the wastewater and used within the district heating system. Solids generated from the wastewater treatment plant are sent to an anaerobic digester, which collects the biogas created during processing. This biogas is then treated/purified and used as fuel for municipal vehicles and heating. Finally, treated biosolids (the output from the anaerobic digesters) are used as fertilizer for nearby farmland and forestry land (Urban Green-Blue Grids, 2008).

Results so far

In 2016, Hammarby Sjöstad housed 25,000 people in 11,000 apartments. The development project is scheduled to be completed in 2017.

As of 2009, environmental impacts had been cut by 30-40% in most sectors compared to other developments from the 1990s. Some sectors, such as aquatic pollution and eutrophication, have achieved the target of 50% impact reduction (Olsson, n.d.).

Conclusions: Hammarby Model

The Hammarby model recognized for its holistic management structure and integration of sectors has broad implications for other regions. This type of holistic approach can be used to manage wastewater while reducing overall environmental impacts and increasing social and economic sustainability through community building and resource use efficiency.

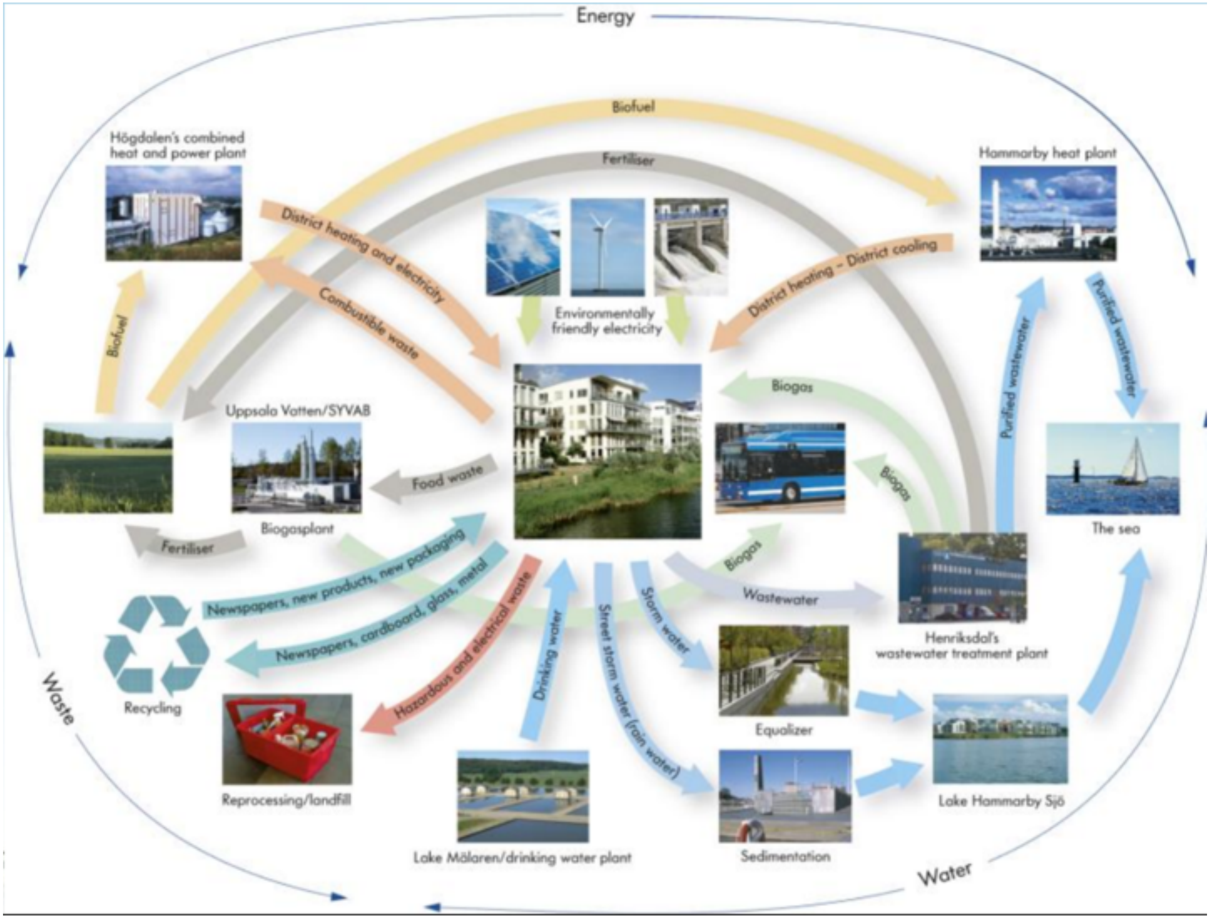


Figure reference: *http://www.oecd.org/science/inno/49521826.pdf*

Further lessons can also be learned through this project such as the needs for citizen engagement early in the process, prioritization of goals, and continued monitoring and follow-up (Mahzouni, 2015; Iverot & Brandt, 2011).

Videos

View of city (no words): https://www.youtube.com/watch?v=QE1mYP0URDA

Good background on the project: https://www.youtube.com/watch?v=TpITgSmk6rY

Stockholm as a sustainable city: https://www.youtube.com/watch?v=yuMuMnvcYvA

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Case Study Two

Multipurpose and Sustainable Water Reuse in a Semi-Arid Region: The Tenorio Project

Location: San Luis Potosí City, San Luis Potosí, Mexico

Figure reference: http://www.map-of-mexico.co.uk/images/sanluispotosienglish.gif

Summary of main problem faced

The city of San Luis Potosí is a densely populated metropolitan area with more than 1.3 million inhabitants, and is located in a semi-arid climate which receives less than 400mm of rainfall annually. Due to the scarcity of water, the development of the city has been restricted to a certain extent by water availability and conservation efforts (Equihua & Rojas, 2012).

However, during the 1980s and 1990s, industry developed rapidly in the city. The main source of water for the residents, industry, and agriculture in the area was the San Luis Potosí aquifer, which, by the year 2000 was being overdrafted by approximately 50% of the natural recharge rate. The city is located within the interior basin of San Luis watershed, but sits on the edge of both the Rio Verde watershed and the Rio Lerma watershed which flow to the oceans on either side of Mexico (Rivers Network, 2016). Until 2005, wastewater treatment covered only 32% of the city, and the majority of raw wastewater ended up in storm basins, degraded wetlands, or the Tenorio reservoir (Equihua & Rojas, 2012).

Actors involved

Degrémont – Owner/operator of plant
Government of Luis Potosí
Water State Commission
Villa de Reyes Power Plant
(additional stakeholders include industry and farmers)

Summary of actions taken

In the late 1990s, the Government of San Luis Potosí implemented an *Integral Plan for Sanitation and Water Reuse*. This plan was aimed at increasing water recycling thereby reducing the groundwater withdrawal rate (Lazarova et al., 2014). The project involved the construction of a municipal wastewater treatment facility with a capacity of over 90,000 m3/day along with sewage collectors, and distribution and irrigations systems to allow for effluent reuse. It is the first project of its kind in Mexico that "combines industrial water reuse, agricultural reuse, aquifer recovery, and the recovery and development of an ecosystem that could be considered as an artificial wetland" (Equihua & Rojas, 2012). The water for industrial use is treated through several steps and processes including secondary treatment with activated sludge and nitrogen removal processes, followed by tertiary treatment with lime, filtration and final chlorination step. This water is used in the cooling towers of the Villa de Reyes power plant. (Figure X; Equihua & Rojas, 2012).

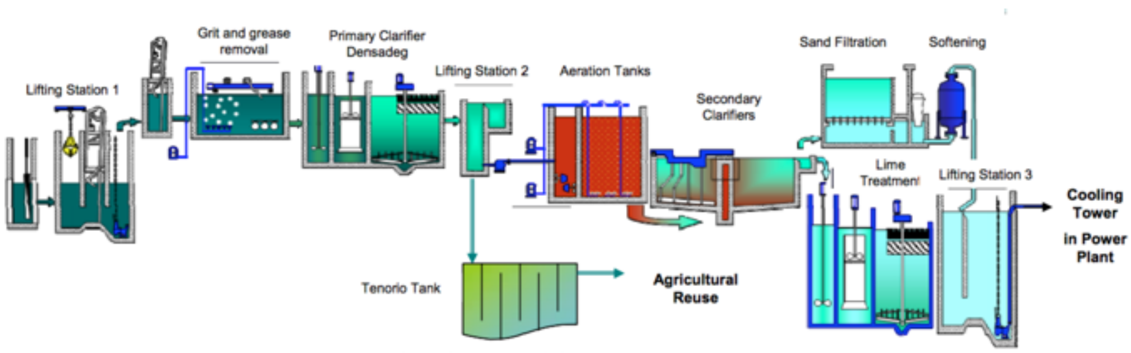

Figure Reference: (Lazarova et al., 2014)

Figure Reference: http://www.emag.suez-environnement.com/en/wp-content/gallery/the-treatment-and-reuse-of-wastewater-throughout-the-world/mexique.jpg

Results so far

Presently, the facility treats approximately 80,000 m^3 of wastewater daily. Approximately 60% of this water is used for agricultural purposes while the other 40% undergoes secondary and tertiary treatment before it is used at the Reyes power plant (in cooling towers, for instance) (SUEZ, 2013). Table X shows a summary of water quality before and after treatment at the Tenorio facility in 2012. Additionally the water sent for reuse at the power plant has directly replaced nearly 40 million m^3 of potable groundwater that would have otherwise been withdrawn from the aquifer. Given the primary treatment of all wastewater, and restoration of the Tenorio reservoir, this area acts as an artificial wetland and has seen a return of native flora and bird species.

Table 1. Characteristics of raw sewage and recycled water with different quality for agricultural irrigation and industrial uses by the power plant (January 2007- April 2012)

Parameter	Raw wastewater*	Primary effluent*	Tenorio Tank effluent to reuse in agriculture**	Reclaimed water to Power Plant*
TSS mg/L	188.96 (±72.78)	33.18 (± 20.82)	25.83 (±10.73)	3.30 (±2.71)
BOD_5 mg/L	286.49 (±93.73)	36.8 (±21.85)	31.4 (±13.96)	2.96 (±2.1.83)
COD mg/L	524.1 (±226.46)	99.7 (±51.81)	81.2 (±28.9)	16.2 (±13.07)
P_{TOTAL} mg/L	8.5 (±3.38)	6.2 (±1.91)	6.2 (±1.20)	1.2 (±0.8)
TKN mg/L	34 (±8.91)	26.8 (±8.94)	22.3 (±5.1)	1.6 (±3.59)
Fecal Coli /100 mL	4.57 $x10^9$(±1.33 $x10^2$)	8.72$x10^2$ (±2.21$x10^{2)}$	240 (±189)	18.56 (±16.6)
Total hardness mg/L	115 (±29.86)	Not measured	Not measured	109.3 (±23.42)
Silica mg/L	104.3 (±20.69)	Not measured	Not measured	64.5 (±7.82)

*Average (minimum-maximum) from 1945 daily composite samples,
**Average from 54 monthly composite sample3

(table from Lazarova et al., 2014)

Conclusions

This project shows how the use of appropriate technology can not only reduce pollution, but can also help to conserve valuable freshwater resources and recycle important nutrients from wastewater back to agricultural land. One might wonder, however, whether treated water that includes wastewater from industrial sources and thus, possibly, heavy metals, poses a threat when used for the irrigation of food crops.

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Case Study Three:

Urban and Commercial Applications of Reclaimed Water: Bora Bora Island

Bora Bora island (Figure 1) is a small island in French Polynesia which lies to the northwest of Tahiti (Tahiti Tourisme, 2016).

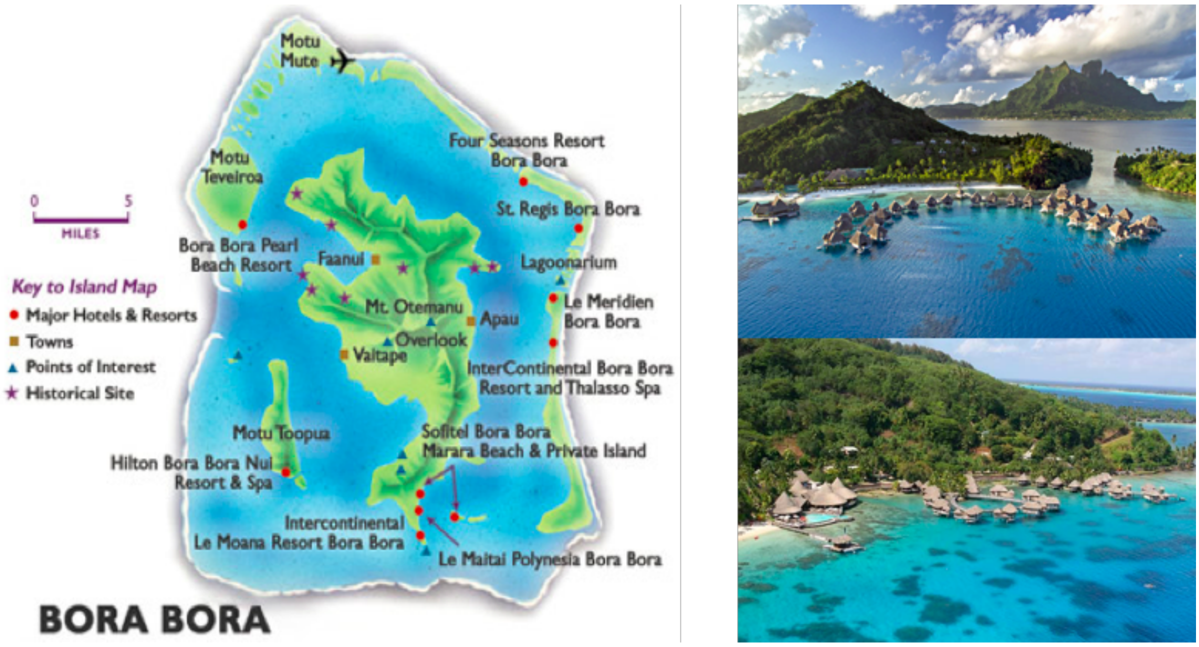

Figure 1. Bora Bora Island (taken from http://www.tahiti.com/island/bora-bora and http://www.tahiti-tourisme.com/islands/borabora/bora-bora-map.asp)

Summary of the main problem faced

Tourist-based activities are the main factors in the economic development of Bora Bora island. Such activities have led to rapid population growth and further development of tourist-based activities, which in turn, led to increasing freshwater consumption and pollution of the aquatic environment (Lazarova et al., 2012).

In the last decade, water shortage as the result of climate change (e.g., decreasing rainfall and frequent droughts) have compounded the increased demand for high-quality water needed for hotel development and local populations. In addition, preserving and restoring local aquatic environments which are central for local livelihoods as well as the tourism industry have been a major concern for the community (Lazarova et al., 2012).

Summary of actions taken

In this regard, reclaimed water (highly treated wastewater) was selected to be used (1) to protect and restore water resources and the local ecosystem in sustainable manners, (2) to further increase the tourism related activities, and (3) to improve "social wellbeing and full employment" (Lazarova et al., 2012). A reclamation facility was built through a public-private partnership, with reclaimed water generated through conventional activated sludge (for carbonaceous and nitrogenous contaminants removal) followed by "ultrafiltration organic submerged membranes Zenon" (known as Zeeweed 500) for removal of concerning pathogenic microorganisms including protozoa, cysts, bacteria and viruses, and a final disinfection through chlorination prior to distribution of the produced water (Lazarova et al., 2012).

Reclaimed water was initially used for hotel landscape irrigation and subsequently for cleaning, boat washing, and firefighting purposes (Lazarova et al., 2012). Furthermore, the sludge produced at the reclamation plants was used as fertilizer for "hotel's landscapes, public areas and private gardens" (Lazarova et al., 2012).

However, various challenges had been overcome prior to the use of reclaimed water. One of the challenges was "public acceptance," mainly due to concerns over the possible health risks associated with the reclaimed water. Several actions were taken to control this problem. For example, a water quality monitoring program at the reclamation plant and also distribution system was established. Furthermore, the local communities were educated about the quality of the produced reclaimed water. Finally, a close cooperation between "local authorities, water professionals and stakeholders" works to resolve ongoing issues and challenges, and identifies the potential economic, social, technical, and environmental opportunities in the project (Lazarova et al., 2012). Moreover, Initial technical challenges such as operational failures due to leakage or membrane fouling were resolved by upgrading the treatment facility and proper membrane cleaning, respectively (Lazarova et al., 2012).

Results so far

The proper selection and operation of the reclamation technology led to providing reliable high-quality recycled water which further increased public acceptance of reclaimed water. The implementation of reclaimed water resulted in major environmental, economic, and social benefits including;

· Aquatic environments protection: this was because due to reuse of wastewater less wastewater was discharged to the local water bodies. Moreover, the discharged wastewater was properly treated before it is discharged which led to the reduction of the lagoon's algal growth and restoration of white-sand beaches.

· Less freshwater was withdrawn which led to a saving of 10% of drinking water for domestic potable uses.

· Reclaimed water provided an uninterrupted and reliable source of water for the local communities which not only costs less expensive than potable water (e.g., 2.5 to 3 times), it also avoided economic losses during drought periods which consequently attracted more small and large end users.

· The ability to provide high quality water with the properly selected technology and effective water quality control and monitoring program increased the social acceptance of water reuse.

· The acceptable pricing of water ensured the economic viability of water reuse (in that it "covered the operating and maintenance costs of tertiary treatment, pumping and distribution network").

· International recognition (receiving "Blue Flag of Europe" award for 10 consecutive years)

Factors involved

Public education and public/political involvement were the main factors in the success of the water reuse project. Moreover, effective reclaimed water management (e.g., the high quality of produced water, accessibility, reliability, and practical pricing) further encouraged the water reuse by the local communities.

Conclusions

This project showed that reclaimed water can be considered as one of the reliable options in water management in water stress areas if the main concerns over health risks and water quality specifications are effectively managed through proper selection of reclamation technologies such as membranes.

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Case Study Four: The Msingini-Mtoni Wastewater Management Project: A Case for Constructed Wetlands

A UNEP Case Report

Location: Chake Chake Municipality, Pemba Island, Tanzania

Figure reference: http://www.africaguide.com/country/zanzibar/

Summary of the main problems faced

The Chake Chake Municipality is located in the central region of Tanzania's Pemba Island where almost all the administrative offices and commercial activities are located. The main activities located here include Clove Oil Distillery, Public Health Laboratory, Power Plant operation and distribution, etc. The town has an estimated population of about 20,000 people, covers about 3.5 square km, and is situated along the coast in the western region of the island. The town is located on a hilly area with slopes ranging between 30 to 70 degrees and the average altitude is 40m above sea level. Due to the presence of steep slopes, stormwater (including wastewater flow) easily flows directly to the sea. Wastewater and stormwater from Chake Chake town and surrounding areas flow directly to the Chake Chake Bay through a mangrove-fringed creek.

Wastewater from Chake Chake Bay then contributes to the flow of wastewater reaching Misali Island, a Marine Protected Area (MPA) located just west of Chake Chake. Both the MPA and the Pemba Channel are of great ecological and economic importance. For example, the coral reef system found around Misali Island is second to none in Zanzibar in terms of richness of species and beauty and as such is an important tourist destination. The Msingini and Mtoni wards of Chake Town have a population of about 4,000 (650 households). The area has elongated natural drainage channels (approx. 1700m), which carry stormwater and wastewater from Msingini-Mtoni and the surrounding areas. However, the drainage channels are interrupted by unplanned settlements. Although the area looks planned in the forefront of the channel, it has tremendous wastewater mismanagement implications. Most of the septic tanks and soak-pits used in the area are leaking, causing serious pollution and human health risks. The area concerned is largely residential with some small businesses, and the total flow of wastewater from the area is estimated at 300 to 400 m^3 per day.

The pollution of the coastal and marine environment in Pemba can only be managed effectively if the wastewater is controlled and treated before it is discharged into the sea. This project aims at controlling the discharge of wastewater including raw sewage into the coastal/marine environment through development of proper channelling and treatment using constructed wetlands.

Actors involved

Government of Tanzania
Ministry of Agriculture
Ministry of Water, Construction, Energy & Lands
Ministry of Health and Social Welfare
Ministry of Communication & Transport
Local Authorities (Chake Chake District Chake Chake Town Council Msingini, Chanjaani and Kichungwani Shehias and Wards)
UNEP WIO-LaB
Marine and Coastal Environmental Management Program (MACEMP)
Sustainable Management of Lands & Environment (SMOLE)
Chief Minister's Office Tanzania
Community Development & Environmental Conservation Zanzibar (CODECOZ)
Faith Based Organization (Mosque Committee)
Commercial Business group
Hoteliers

General Public
Mtoni Community
Msingini Community

Summary of actions taken

The sanitary facilities that are currently used in the project area include pit latrines, septic tanks and in some areas, septic tanks followed by soak-way pits. In order to maximize the collection of the sewage from the project area, a shallow sewage system was constructed in order to allow lateral sewers from households to connect to one of the chambers constructed close to the houses. The sewer network collects discharge wastewater in an anaerobic pond after which the water moves through a subsurface flow constructed wetland (See Module 4).

Suspended solids are removed from the water in the anaerobic pond through sedimentation as they accumulate at the base of the pond. The accumulated sludge in the pond is then digested through natural anaerobic bacterial processes. When the sludge in anaerobic pond reaches 75% capacity, wastewater will be redirected to a second anaerobic pond. The sludge from the first pond will then be left to dry for three years, after which it will be removed and may be used for agricultural activities or as soil conditioning. This process is repeated when the second anaerobic pond is filled.

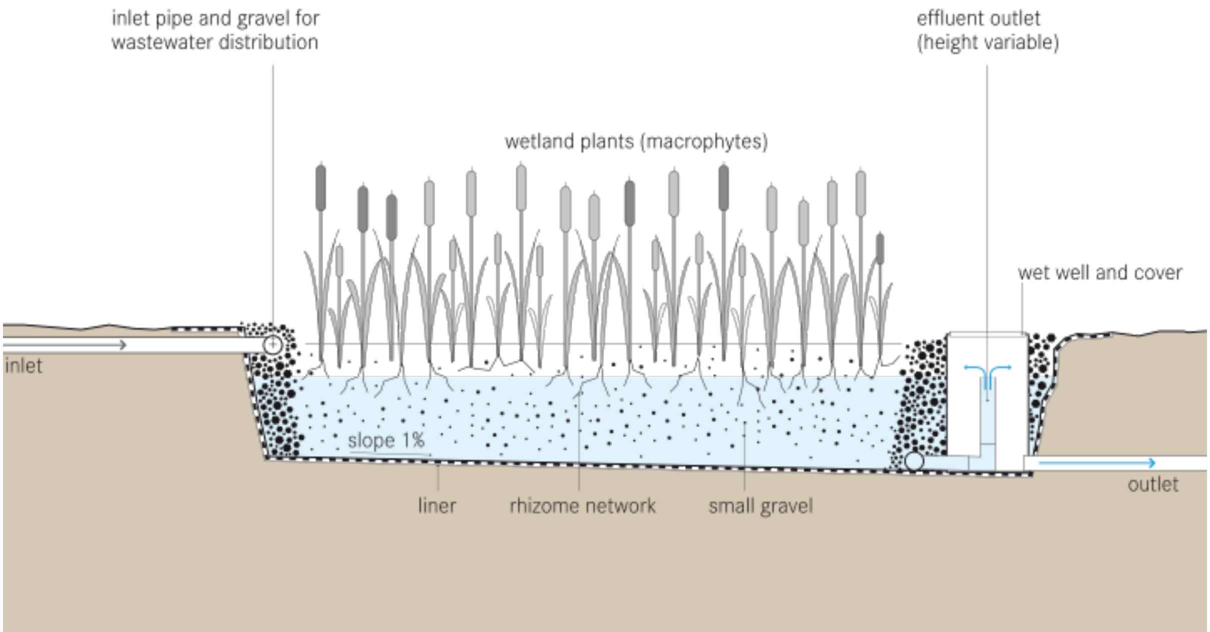

Figure reference: http://ecompendium.sswm.info/sanitation-systems/system-7

After this primary treatment, the effluent from the anaerobic pond will be discharged into subsurface flow constructed wetland for secondary treatment of wastewater (Figure X). The constructed wetland is planted with macrophytes that are locally available in the area. Such constructed wetlands are low cost, efficient, and easy to maintain. When the wetlands are fully stabilized, effluent treatment efficiencies greater than 90% can be realized. After treatment, effluent from the wetland is finally discharged into the stormwater drain leading to an ocean.

Results

The upgrading of the stormwater channels improved drainage in the area and reduced flooding and contamination of the freshwater and marine resources. The project also demonstrated methods for separation of household wastewater and stormwater. Several activities have occurred after project closure including the construction of a stormwater drain of about 1200 metres at the Kichungwani Shehia. The channel is connected to the main stormwater channel, which sends water to the sea. Similarly, 8 houses and 2 institutions have been connected to the sewage system after project completion at their own cost. Future projects will focus on neighbouring shehias of Madungu and Chanjaani, which need materials for their own sewage systems. The project will also be replicated to other nearby towns such as Wete and Mkoiani.

Construction of the wetland relied on labour provided by the local community. Furthermore, nearly $60,000 USD were attributed in cash co-financing from community development funds, which demonstrates a clear sign of local ownership and engagement.

Conclusions

The outcomes of the project are invaluable, not only in Zanzibar but also in other countries in Eastern Africa where wastewater treatment systems are hard to come by, despite the increasing incidences of waterborne diseases.

The self-purification ability of constructed wetlands has found wide application as a wastewater treatment method in several developing countries such as China, Philippines, Burma, India, Thailand and Tanzania, Kenya. Through the intermediate activities of bacteria, algae and plankton, nutrients such as nitrogen and phosphorus are made available and metabolized by the fish. Constructed wetlands can serve the same small communities as natural wetlands and can be incorporated into the treatment systems for larger communities as well. Wetlands can also be constructed to treat agricultural runoff or other non-point sources of pollution. They have most commonly been used in wastewater treatment for controlling organic matter; nutrients, such as nitrogen and phosphorus; and suspended sediments. The wetlands process may also be suitable for controlling trace metals, and other toxic materials. Demonstration projects implemented elsewhere have shown that wetlands are effective at removing both organic and inorganic contaminants. The relatively inexpensive nature of this type of treatment makes it a potentially cost-effective option for remediation.

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Primary source: UNEP Report
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Video for constructed wetlands:
(1) https://www.youtube.com/watch?v=pXaXjzbccPo
(2) https://www.youtube.com/watch?v=wxxleTPZbGQ

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(NB: These are more general references for constructed wetland)

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Case Study Five

Water-Responsible Economic Growth: Singapore

Singapore (officially the Republic of Singapore) is a city-state located in Southeast Asia, at the southern tip of the Malaysian peninsula. Since independence from the United Kingdom in 1963 and from Malaysia in 1965, its rapid and successful economic development led to it being known as one of the original four “Asian Tigers” in the 1980s. Today, it is a well-known hub for financial services, trade and manufacturing, transport and logistics, including ship-repair services; its port being the second largest worldwide in terms of exports.

Over the past 50 years, the country’s territory, composed of a main island and about 60 islets, expanded through land reclamation by almost one fifth, reaching a current total of 718 km². With a population of 5.5 million, Singapore has the second highest density in the world (7,713 inhabitants per km²).

The case of Singapore illustrates the fact that high economic growth rates do not have to go hand in hand with wastewater problems. Singapore has invested heavily in the production of water from wastewater treatment, installing some of the world’s first plants for large scale indirect potable reuse. Water pollution here has been treated as a political priority, leading amongst other things to the development of discharge standards, pre-treatment requirements, the unification of pollution control, sewerage, drainage and environmental health under one ministry, the separation of rainwater used water collection systems, and the introduction of regular water-quality monitoring.

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Summary of the main problems

The country's tropical rainforest climate is hot (between 22 and 35°C) and humid (84% humidity on average), with little seasonal variations. Despite its tropical climate, Singapore is a small city-state with limited catchment area to store rainfall and no natural aquifers or lakes. The country is therefore classified as being water scarce and ranks 170th out of 190 countries in terms of freshwater availability.

With the second highest population density worldwide and in view of growing population and GDP (3-fold and 30-fold increase respectively since 1965), this water-scarce country has managed over the past five decades to overcome water shortages, by developing a strategy based on the "Four National Taps".

Actors Involved

Ministry of the Environment and Water Resources
Public Utilities Board (National Water Agency)
National Environment Agency

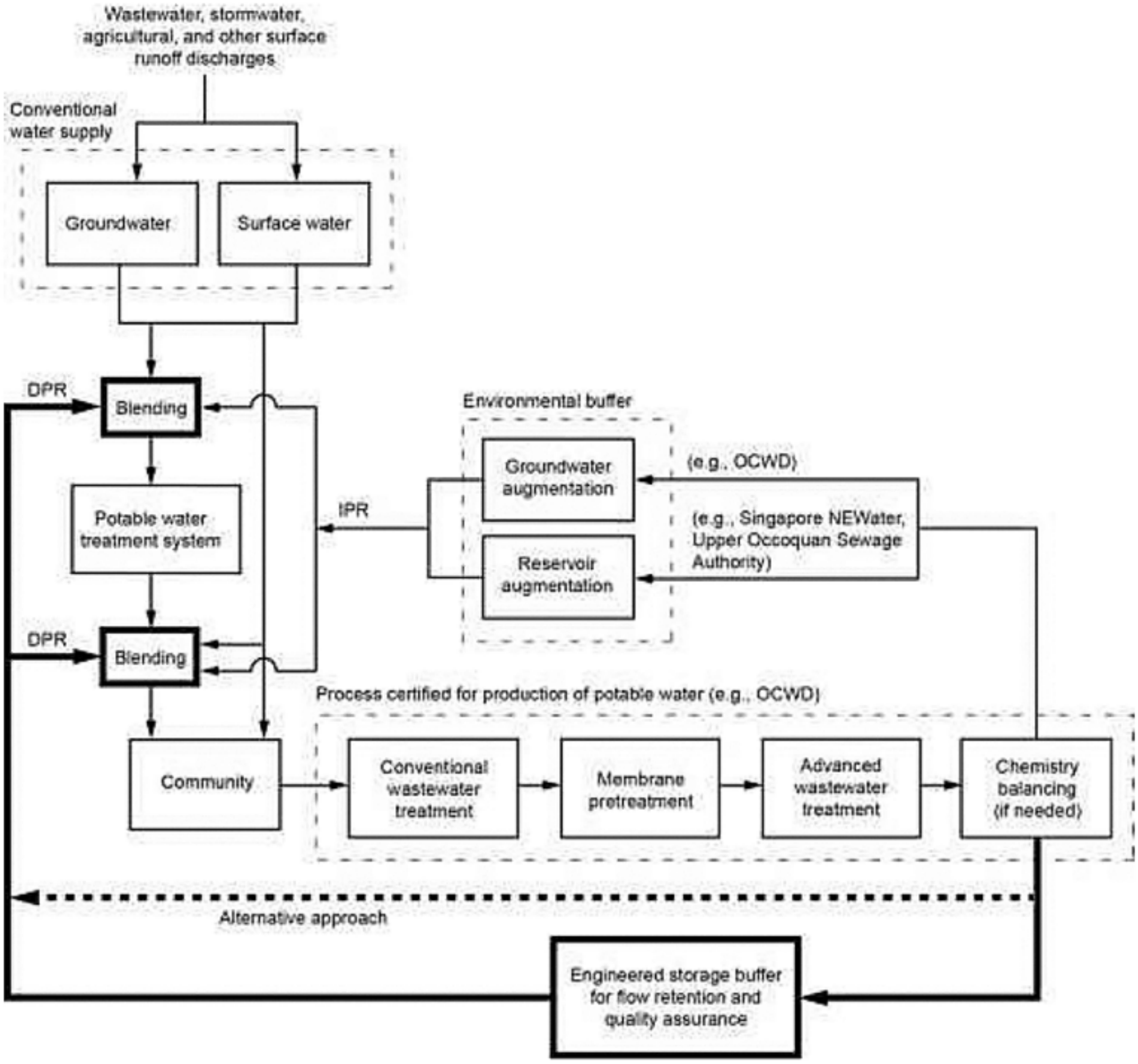
Summary of Actions Taken

The Public Utility Board oversees a closed-loop water cycle through a program called "The Four National Taps." These taps are: water imports from neighbouring Malaysia, local catchments (such as rainfall storage), seawater desalination, and the world's first large-scale wastewater reuse system for potable water production, operating since 2003, called NEWater (Irvine et al., 2014).

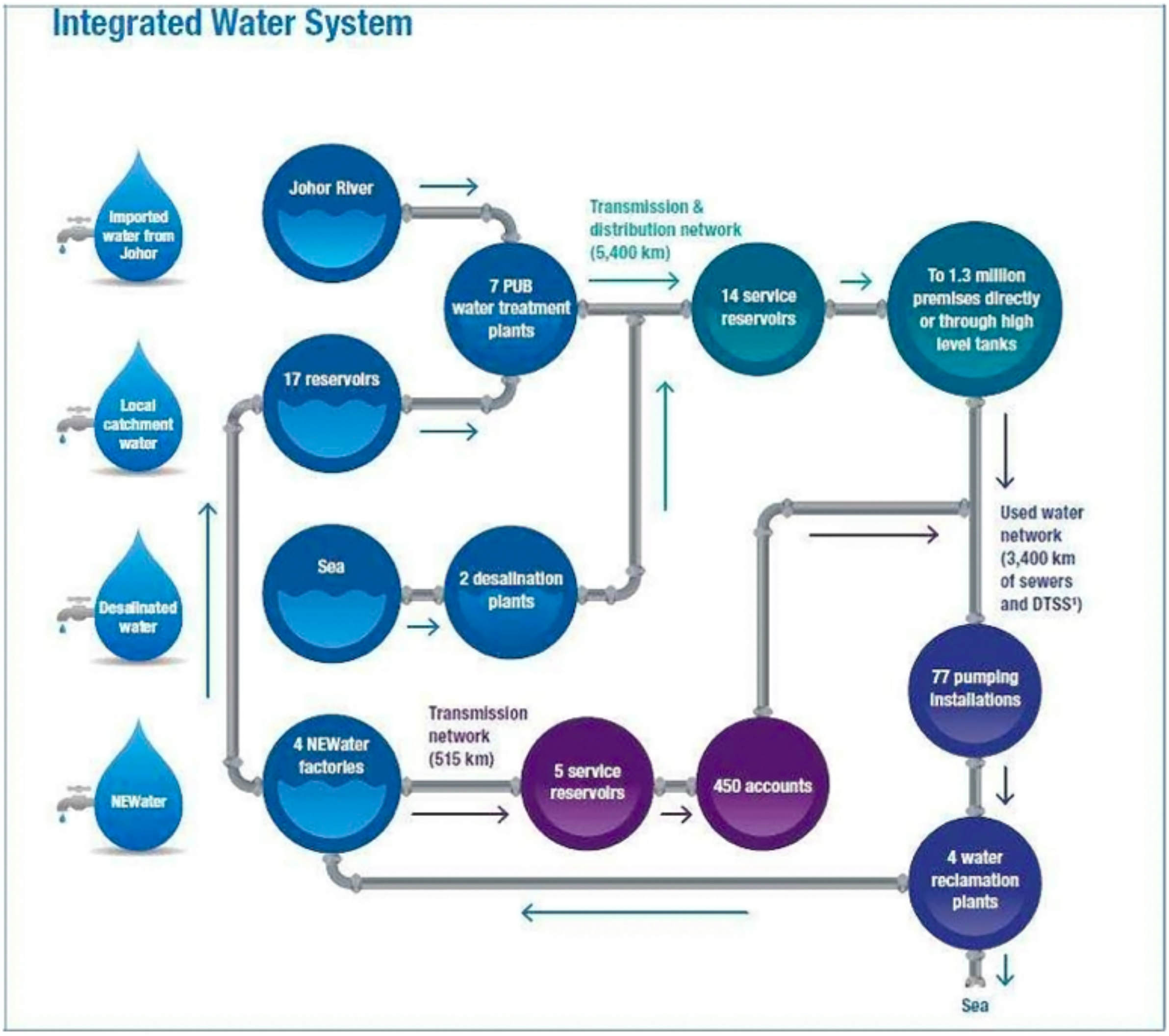
A strong and stable political will and vision helped orchestrate what is now frequently recognised as a unique holistic approach to water resources management since water was identified as a national priority in 1971. This strategic approach combines several ingredients:

Policy axis: long-term planning and integrated public policies (from public housing and urban management to industrial regulation) keeping in mind the overall economic development of the country; water pricing to cover full production and supply costs; technological research to develop very high quality treated wastewater; and public education and involvement to develop ownership and gain support for water conservation.
Legislation axis: strict laws (regularly amended and enacted according to needs); regular monitoring and enforcement.
Institutional axis: restructured and coordinated institutions allowing for an integrated management of the whole water loop (in particular, the Public Utilities Board which is in charge of all water and wastewater-related services, controls and administrations; and the National Environment Agency, which oversees the implementation of environmental policies. Both are housed under the Ministry of the Environment and Water Resources).

Definition of planned indirect and direct potable reuse (IPR/DPR)



(Source: Tchobanoglous G., 2012 NWRI Clarke Prize Conference Research and Innovations in Urban Water Sustainability)



(Source: PUB (2013) Our Water, Our Future: p.6)

Results so far

Today, Singapore has its own brand of recycled water: NEWater. Four plants currently produce 547,200 m3/day of reclaimed water, covering 30% of the country's freshwater needs. The ambition is to increase this figure to 55% by 2060 to achieve water independence from neighbouring Malaysia, by building new recycling plants with bigger capacity and by increasing seawater desalination (two reverse osmosis desalination plants have a capacity of producing 454,500 m3/day of water). Currently, the reclaimed water is mainly used for industrial purposes, and, in a small proportion, for indirect potable reuse (re-injected into reservoirs, it is treated and used as tap water, suitable for drinking purposes, as it surpasses World Health Organization requirements).

Over the past few years, the Public Utilities Board has received more than 20 international awards – including the 2014 UN-Water "Water for Life" Best Practices Award, the 2013 Global Water Awards and the 2007 Stockholm Industry Water Award- recognising its outstanding performance in water and wastewater management. Singapore is on its way to becoming the "City of Gardens and Water" it envisions (Allaoui et al., 2015).

References and Resources

Allaoui, M. et al. 2015. Good Practices for Regulating Wastewater Treatment: Legislations, Policies and Standards. *United Nations Environment Programme*. http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

Irvine, K., L. Chua and H.S. Eikass. 2014. "The Four National Taps of Singapore: A Holistic Approach to Water Resources Management from Drainage to Drinking Water." *Journal of Water Management Modeling* C375. doi: 10.14796/JWMM.C375

PUB Singapore (2016). *Our Water, Our Future.* Accessed at https://www.pub.gov.sg/Documents/PUBOurWaterOurFuture.pdf.

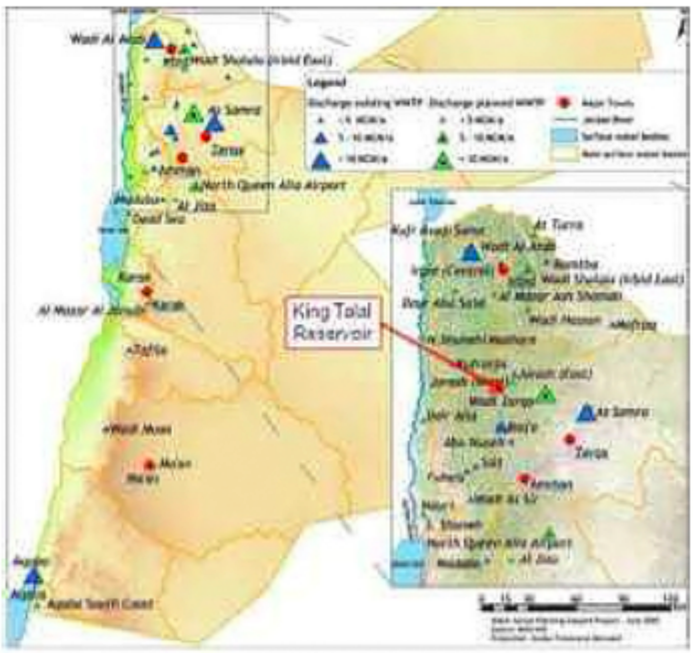
A valuable document created by Singapore's Public Utility Board which outlines the various ways in which the government has approached its water quality and water conservation goals.

Tchobanoglous G., 2012. "The Importance of Decentralized Wastewater Management in the Twenty-first Century." NWRI Clarke Prize Conference: Research and Innovations in Urban Water Sustainability.

Case Study Six:

An Example of Policy Effectiveness: Jordan

In Jordan, operational practices, driven by very high levels of water scarcity, have resulted in exceptionally high performance in wastewater treatment and effluent reuse. In addition, the country boasts some of the highest rates of connection to wastewater systems in the Middle East and well-developed, demand-driven standards for wastewater treatment linked to reuse for irrigation.



Water consumption for irrigation, in Jordan

Region	Total irrigated area (dunum)	Water resources	Quantities of consumed water (MCM/ Year)
North JV	89,836	KAC (freshwater)	38
Middle-south JV	212,525	KTR, Kafrain, and Shu'aeb dams (reclaimed water)	120
		Wells (brackish water)	62
Southern Ghors	56,580	Surface (freshwater)	37
Highland	701,814	Wells (freshwater)	245
Total	**1,060,754**		**502**

(Source: JVA and MoA, 2010)

Summary of the main problems

Jordan is one of the 10 countries most affected by water scarcity worldwide. The available renewable water resources are dropping drastically to an annual per capita share of around 130 m^3 in recent years, compared to 3,600 m^3 per capita in 1946. At the same time, the country has one of the highest average growth rates in the world, among other causes due to successive waves of immigrants and refugees (Palestinians, Iraqis and Syrians). In addition, its population is highly urbanised: about 73% of Jordanians currently live in urban areas concentrated in the northern and middle parts of Jordan.

Actors involved

The Ministry of Water and Irrigation (MWI)
The Water Authority of Jordan (WAJ)
The Jordan Valley Authority (JVA)
Public water companies: Miyahuna, Aqaba Water Company, Yarmouk Water company

Summary of actions taken

What specifically characterizes Jordan is its well-designed and effective policy meeting the specific challenges of the country. By the early 1980's and during the International Drinking Water and Sanitation Decade (1980-1990), the Jordanian Authorities have been conducting comprehensive plans with regard to the different issues of wastewater management: sanitation utilities improvement, a better addressing of public health concerns, and strengthening pollution control of water resources. Then in 1998, the Government initiated a Wastewater Management Policy as a global strategy for the wastewater sector articulated around 4 key issues, adding to those already targeted by the previous plan, consideration of treated effluents as a source for irrigation reuse and the improvement of the socioeconomic conditions in the areas to be served by the proposed systems. This exhaustive policy includes 67 points regarding the future use and management of wastewater covering several aspects such as legislation, standards, financing and investment, pricing, research and development...etc. The key point of this policy is that treated effluent has to be considered as a water resource and not separated in policy from other water resources.

This was followed by the National Water Strategy for water and sanitation for the period (2008-2022) "Water for Life Strategy" with its main priority "to achieve national water security and to serve the overall development objectives" and paying particular attention to the development of land and water resources in the Jordan Rift Valley, among other things by increasing the use of treated wastewater in agriculture. This strategy contains a chapter around wastewater and among the goals set in this strategy we have:

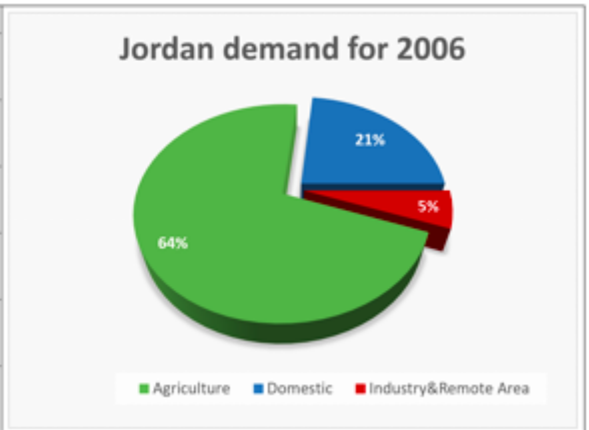
· All the major cities and small towns in Jordan are provided with adequate wastewater collection and treatment facilities,
· Public health and the environment, in particular groundwater aquifers, are protected from contaminated wastewater in the areas surrounding wastewater treatment plants; treated wastewater is used for activities that provide the highest return to the economy,
· The quality of treated wastewater from all municipal and industrial wastewater treatment plants meets national standards and is monitored regularly,
· Tariffs for wastewater collection are rationalized,
· All treatment plants are operated according to international standards

Additionally, Jordan has set up multi-level institutions capable of putting into practice this policy. In particular, the Ministry of Water and Irrigation, the Water Authority of Jordan, the Jordan Valley Authority and 3 major public water utilities work together across policy scales. This has been accomplished without omitting the role played by international cooperation (especially with US and Germany), civil society and private sector in the implementation of these objectives, and the impetus given by the Performance Management Unit (Part of the Water Authority of Jordan), responsible of promotion, monitoring and auditing private sector participation in water sector.

Results so far

All these strategies and the effective cooperation between the different stakeholders have led to the construction and renovation of 28 wastewater treatment plants across the country (in the 1960's there was only one plant.) These plants are currently treating 98% of the collected wastewater and providing secondary high quality reclaimed water with about 90 % reused in agriculture. This is in addition to one of the highest sanitation rates in the region; indeed, 98% of Jordanians have access to improved sanitation facilities with no significant differences between urban and rural areas.

	[M m^3]
Water supply	925
Domestic	290
Industry & Remote Areas	46
Agriculture	589
Water Demand	1512
Deficit	-587



References

Case study from: Allaoui, M. et al. 2015. Good Practices for Regulating Wastewater Treatment: Legislations, Policies and Standards. *United Nations Environment Programme*. http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

Case Study Seven:

Application of Reclaimed Water in Housing Development: City of Xi'an, Northwestern China

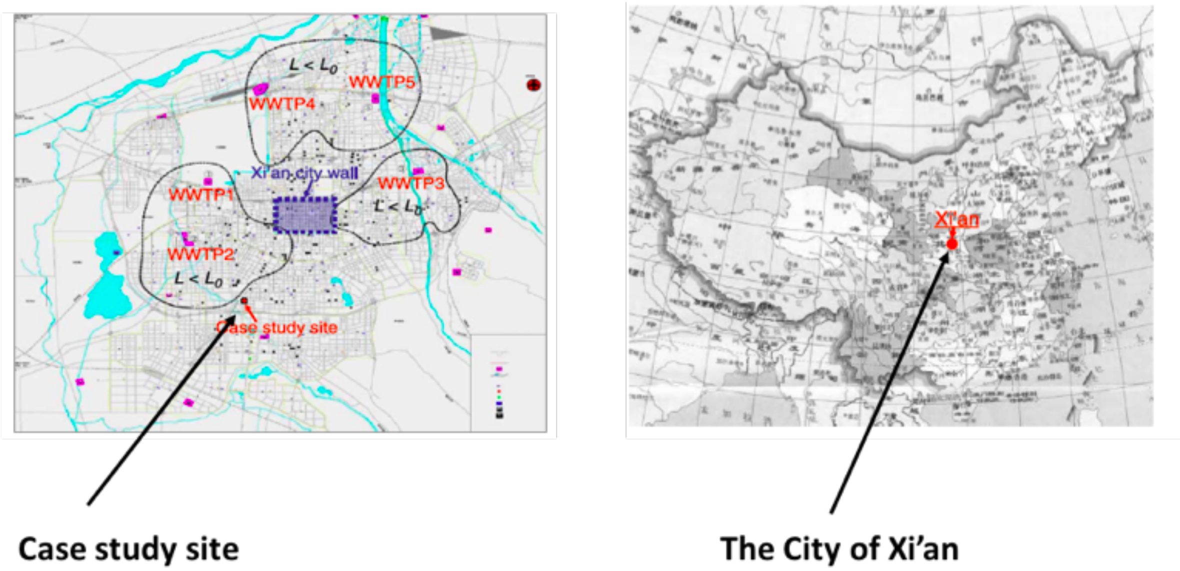


Figure 1. Location of the residential area in the city of Xi'an (China) that uses treated water from an on-site decentralized wastewater treatment (taken from Wang et al., (2008)).

Summary of the main problem faced

Rapid population growth, urbanization, and economic development demanded a high amount of water in the city of Xi'an. Since the city was located in an arid area, further withdrawal of local freshwater was virtually impossible for newly developed residential areas (Wang et al., 2008).

Actors involved

Government at several levels
Local citizens and residents

Summary of actions taken

A pilot study was conducted to determine the possible application of alternative water sources for newly developed residential areas located in the suburbs. One of the proposed options for resolving this problem was to reuse treated wastewater either from centralized or decentralized wastewater treatment facilities mainly for the following purposes;

- Replenishment of artificial ponds
- Greenbelt

- Gardening
- Car washing

Analysis of demand and supply for reclaimed water showed that the reuse of reclaimed water from on-site decentralized wastewater treatment systems for use in residential area (contained 6 residential buildings, population: 1600 residents) seem promising due to the following reasons;

- It was cost efficient (e.g., required less capital, maintenance, and operational costs)
- It eliminated needs for construction of an 8 km pipeline from the nearest centralized reclaimed water system to the site.
- It was more accessible (produced on-site and did not need to be delivered from the centralized facilities).

Two management strategies were adapted to protect public health. First, a dual-piping sewer collection system was installed in order to separate blackwater and greywater at the source of generation. The source separation reduces the contamination of graywater (generated from water usage in kitchens) by black water (generated from water usage in toilets). Therefore, the gray water can be reused by minimum treatment since it contains less pathogenic microorganisms. Secondly, a part of the water from the artificial pond was returned to the on-site wastewater treatment plant to prevent it from stagnating and maintain proper water quality.

The black water was treated by a septic tank system. The greywater treatment system was installed on the site ("in the basement of one building next to the underground parking") and the graywater was treated through "a fluidized pellet bed bioreactor and ozone-enhanced flotation". The fluidized pellet bed bioreactor performed "chemical coagulation, biodegradation, particle pelletization, and separation in one unit". The ozone-enhanced flotation performs "coagulation, ozonation, and flotation in an integrated unit"(Wang, 2007; Wang et al., 2008).

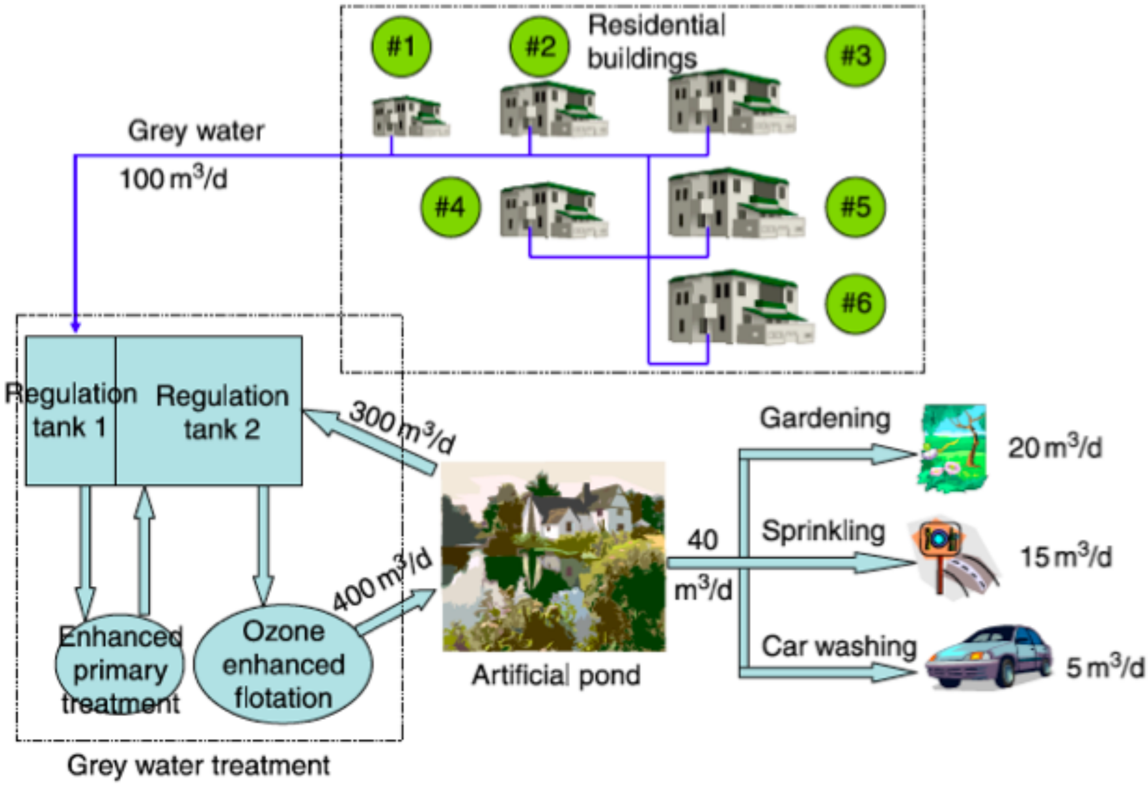


Figure 2. The decentralized wastewater treatment system in the newly developed residential area in the city of Xi'an (taken from Wang et al. (2008)).

Factors involved

Water shortage and increasing needs for a high quality water due to population growth, urbanization, and economic development are the main drivers for reuse of treated wastewater for the development of residential areas in the city of Xi'an. The main reason in the selection of decentralized wastewater treatment system over the centralized system was the cost efficiency of the project.

Results so far

The cost analysis showed that the total construction cost of decentralized treatment system was less than that of constructing of the pipeline from the project site to the nearest centralized reclaimed water system. Moreover, the operation and maintenance costs of the decentralized system are also much lower than the current rate of reclaimed water from the centralized system.

Conclusions

This project showed that the decentralized reclaimed water can be considered as one of the most reliable options for urban water management in the water stressed areas, especially where the residential areas are not close to the existing centralized wastewater treatment systems.

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Wang, X.C., Chen, R., Zhang, Q.H., Li, K., 2008. Optimized plan of centralized and decentralized wastewater reuse systems for housing development in the urban area of Xi'an, China. Water Science and Technology 58, 969–975. doi:10.2166/wst.2008.456

Case Study Eight

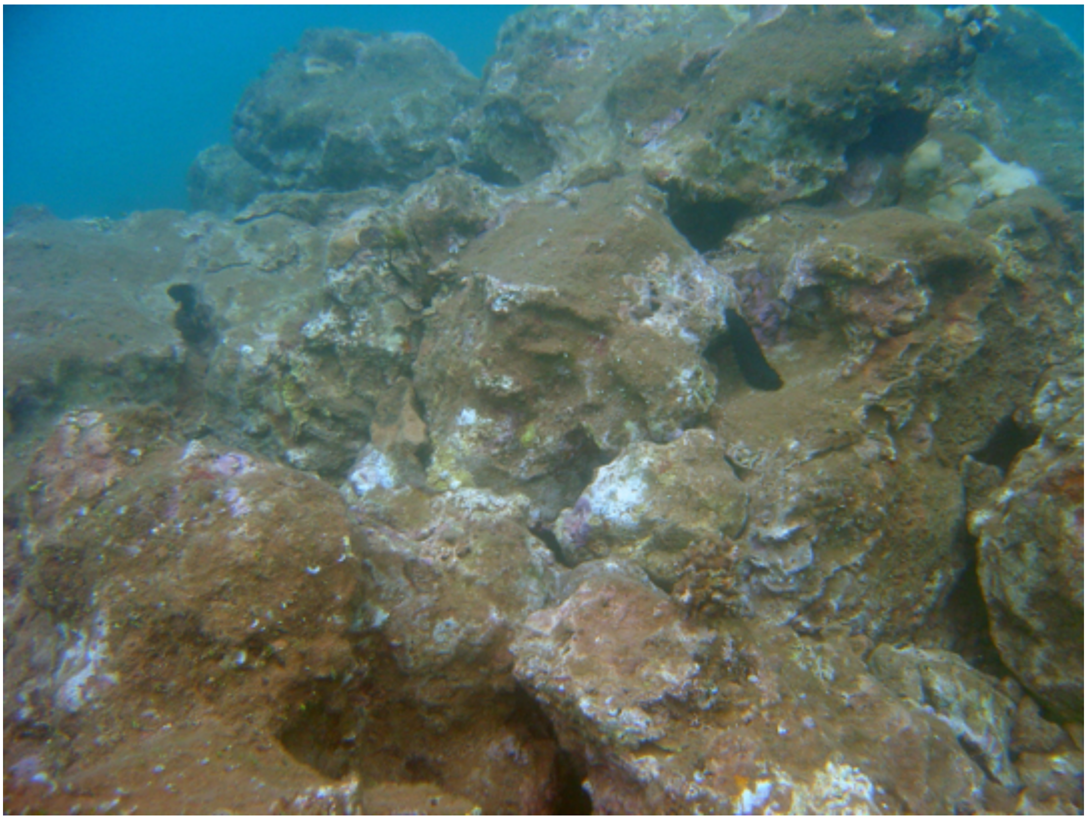
A Successful Regional Fund to Facilitate Wastewater Management: The Global Environmental Facility's Caribbean Regional Fund for Wastewater Management Projects (GEF CReW)

Location

Headquarters in Kingston, Jamaica. The nine GEF CReW participating countries in the Caribbean are Antigua and Barbuda, Barbados, Belize, Jamaica, Guyana, Saint Lucia, Saint Vincent and the Grenadines, Suriname, and Trinidad and Tobago.

Summary of the main problem faced

In general, Caribbean nations lack sufficient wastewater treatment plants and those that exist are poorly functioning or non-functioning. The combined impact of industrial growth, high urbanization rates (mostly occurring within 2 km of the coast), and expansion and increase of coastal resorts, has put great pressure on coastal ecosystems and on islands' water resources. 85% of wastewater entering the Caribbean Sea remains untreated, 51.5 % of households lack sewer connections, and only 17% of households are connected to acceptable collection and treatment systems. Most collection and treatment facilities dispose their effluent and wastes directly into the marine environment, mainly on the shoreline or in lagoons or streams, resulting in high coliform concentrations and low dissolved oxygen levels in coastal waters. Standing pools of contaminated sewage water and agricultural pesticides run-off loaded with fertilizers result in outbreaks of disease such as gastroenteritis, various cancers, birth defects, and more. The 2007 Caribbean Sea Ecosystem Assessment (CARSEA) found that sewage – much of it black water – was one of the key factors causing approximately 80% of living coral in the Caribbean to be lost in the previous twenty years, along with increases in waterborne disease and deterioration of beaches and the marine environment. As the health of coastal ecosystems deteriorates, they are less able to withstand extreme weather events (such as hurricanes and floods) as well as rising sea levels caused by climate change. The damage wrought by pollution and environmental degradation is estimated to cost the wider Caribbean between USD $350 million and $870 million per year by 2050.



Erosion due to deforestation and inappropriate agricultural methods, along with the run-off from rapid development and untreated wastewater, can all contribute to sedimentation on the ocean floor which chokes and kills coral reefs.

Image source: David Burdick, National Oceanographic and Atmospheric Administration

Some of these Caribbean countries are water-scarce and reliant on expensive desalination systems, as well as food importation because of lack of water availability for agriculture. Despite this, few Caribbean countries reuse wastewater, and those that do, do so mainly during the dry season.

The majority of states in the Wider Caribbean Region (WCR) have ratified the Cartagena Convention, a legally binding regional agreement for the protection and development of the Caribbean Sea. The Protocol on the Control of Land Based Sources of Marine Pollution (LBS Protocol) forms part of the Convention and recognizes the need for shared responses to the threats which land-based sources of pollution pose to population health, economic welfare and the marine environment. The LBS Protocol mandates parties to establish measures to prevent, reduce and control pollution from land-based sources and activities, using the best practicable means at their disposal in accordance with their capabilities, including the use of the most appropriate technology and management approaches.

However, Caribbean governments have identified major constraints to enacting the LBS Protocol, including a lack of financing for the expansion and maintenance of wastewater treatment facilities, as well as a lack of capacity to assess and operate facilities and to enforce policies and regulatory measures. For this reason, the Caribbean Regional Fund for Wastewater Management (CReW) Project was established in 2011 as a four-year program to provide sustainable financing and capacity-building with regards to legal, institutional, and policy frameworks for the wastewater sector. Interestingly, GEF CreW drew on some elements of Jordan's water policy in terms of best practices and partnerships.

Actors involved

Funded by the Global Environment Facility (GEF) and implemented by the Inter-American Development Bank (IDB) and the United Nations Environment Programme (via the Secretariat of the Cartagena Convention, a UNEP Regional Coordinating Unit), water and wastewater utilities of participating countries, various Ministries in participating countries (such as Environment, Finance, Health, Fisheries, Agriculture, and Tourism), and local communities.

Summary of actions taken

Initial actions included conducting a baseline study of wastewater management policies, legislation, regulations, and enforcement capacities in participating countries which resulted in a publicly-available "toolkit" with information on the key issues of wastewater management policy targeting managers, technocrats, and policy officers. Various other capacity-building activities have been conducted in each participating country, including: conferences and working groups to help develop tools to improve and strengthen the legislative framework for wastewater management in order to implement the LBS Protocol; training and facilitation in wastewater technologies; establishing partnerships with regional universities for professional development training; public education and outreach; development and application of a resource valuation methodology for use in wastewater management.

One of the most important actions the GEF CReW has undertaken has been piloting sustainable financing programs for the wastewater sectors with the creation of Wastewater Revolving Funds (WRF) in Belize, Guyana, Trinidad and Tobago, as well as a Credit Enhancement Facility in Jamaica. CReW resources are being used to capitalize these four pilot financing mechanisms (PFMs), to provide technical assistance, and to ensure that the projects to be financed satisfy the technical, financial, socio-economic and environmental requirements of the CReW and local governments.

Results so far

The impact of the GEF CReW program varies between the participating countries. In general, awareness of the wastewater issue has been increased – especially its relation to water availability in general – and therefore more governments are placing it at a higher priority than before. As of 2016, 50% of participating countries have initiated national wastewater planning activities and National Action Plans have so far been developed and approved in three countries.

Jamaica's implementation of a small surcharge on water consumption capitalizing a special account for water and wastewater investment projects is considered a best practice example by UNEP. It has led to the successful establishment of a revolving fund mechanism (the new Credit Enhancement Facility), which enabled the National Water Corporation to acquire its first private sector loan, without a sovereign guarantee, that quadrupled the pool of investment resources. This fund is currently being used for eight projects, including the rebuilding or rehabilitation of some wastewater treatment plants and the connection of some areas to the central sewer system.

Source: Global Environmental Facility

In Guyana, the priority was to partner with the private sector, as resorts and industries were the main generators of wastewater. However, there were many difficulties in securing private-sector partners, party due to the regulatory weaknesses in the country that did not incentivize the private sector to implement environmental regulations. The revolving fund established in Guyana did eventually partner with a resort located along the Demerara River to ensure proper treatment of water before discharging, but national agencies have also identified the need to strengthen the enabling environment through policy and institutional reform as well as raise awareness about wastewater management in Guyana.

In Belize, an ambitious project to service the Placencia Peninsula encountered many obstacles and so the focus was then placed on various smaller projects, one of them being the upgrade of the Belmopan Wastewater Treatment Plant and the consolidation and expansion of the city's existing sewerage network.

In Trinidad and Tobago, the initial project was to expand the sewerage network and wastewater treatment plant in Scarborough in order to bring the area into compliance with the LBS Protocol. However, various misunderstandings about the exact nature of the CReW meant significant delays and the project is moving slowly.

Conclusions

As outlined by UNEP, a great deal was learned about issues surrounding the implementation of sustainable financing mechanisms (SFMs). On one hand, the fact that more affordable financing is being made available for wastewater management projects is seen as a sign that wastewater management is a national priority. On the other hand, existing weaknesses in the enabling environment (lack of policies, legislation and regulations) mean that there has been little incentive for the private sector to put systems in place to treat or properly dispose of the wastewater that they were generating, or in some cases, collecting. The Project Management Unit therefore identified a broader need to raise public awareness of issues surrounding wastewater management, especially around the links between wastewater and human health. The establishment of the GWRF provided an opportunity to turn the spotlight on wastewater issues, particularly for decision-makers. Increasing visibility of the GWRF and education of the private sector in concert with strengthening of the enabling environment were both seen as necessary for change in order to improve the quality of effluent produced by their processes.

Since public-private investment partnerships for wastewater management are a relatively new and unique option for local development financing, agencies that coordinate and manage these types of investment partnerships need access to targeted training in order to develop the necessary technical and operating skills to effectively manage these partnerships. The Jamaica experience has demonstrated this successfully; while the Belize experience has highlighted the importance of involving local stakeholders early on in the process to address local concerns which in turn helped avoid delays in project implementation; the Guyana experience underscored the importance of identifying champions early on and focusing on public outreach to build awareness and demand from the private sector.

The GEF CReW program has reached its end, but because of the important work still needed, CReW+ has been proposed to continue working on institutional and policy frameworks around water and wastewater management; the expansion of financing options; the implementation of national and community-based integrated and innovative solutions; and advocacy especially around the importance of wastewater management to achieve the SDGs.

Videos

- The K-Factor & Jamaica's Quest for Better Wastewater Management by CEPUNEP. https://www.youtube.com/watch?v=wDy6c4LF5dA
- Wastewater Policy: A Caribbean Priority by CEPUNEP. https://www.youtube.com/watch?v=SYpooYnlhEQ

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Cashman, Adrian. “Water Security and Services in the Caribbean.” *Water* 6.5 (2014): 1187-1203. doi:10.3390/w6051187

“GEF Caribbean Regional Fund for Wastewater Management Project (GEF CReW) Regional Wastewater Management Policy Template and Toolkit.” Revised January 2015. Accessed October 18, 2016. <http://iwlearn.net/iw-projects/3766/technical-reports/gef-crew-regional-wastewater-management-policy-template-and-toolkit-2015>

“Charting a New Course for Wastewater Management in the Wider Caribbean Region: GEF CReW’s Journey.” May 2016. <http://gefcrew.org/images/media_items/Learning_4_Better_web.pdf>

Peters, E.J. “Wastewater reuse in the Eastern Caribbean: A Case Study.” *Water Management* 168 (2014): 232-242. http://dx.doi.org/10.1680/wama.14.00059

Readings

Peters, E.J. and L. Goberdhan. “Potential Consumers’ Perception of Treated Wastewater Reuse in Trinidad.” *The West Indian Journal of Engineering* 38.2 (2016): 33-43.

> This paper gives an insightful perspective as to the importance of public perceptions surrounding wastewater treatment and reuse for the success of projects such as GEF CReW. It highlights the importance of public awareness and education campaigns, as well as participatory approaches to development projects that involve the impacted community.

UNEP-CAR/RCU (2014). *Case Studies, Lessons Learnt, and Recommendations in the Development, Implementation and Management of GEF Projects in the Wider Caribbean Region (WCR).* United Nations Environment Programme CEP Technical Report 59. Retrieved from: http://cep.unep.org/meetings/documents/191a7500d80f4e1ac40f121b8d5614fc

Provides a broad overview of the different projects and programs developed by the GEF in the Caribbean, including IWCAM, REPCAR, CLME, IW: LEARN. It outlines best practices for solid and liquid waste management, improving water conservation and quality, improved land conservation practices and environmental monitoring systems. It includes discussions on the creation of an enabling policy and legislative environment, participatory approaches in development projects, and economic mechanisms to enable local capacity-building and training.

CASE STUDY 9

Addressing Regional Pollution: The Georgia Wastewater Project

INTRODUCTION

Georgia is a country of four-and-half million people in the Caucasus region of Eurasia. It is bounded to the west by the Black Sea, to the north by Russia, to the south by Turkey and Armenia and to the east by Azerbaijan. The coastline of Georgia is 310 km. One of the major problems of the coastal areas of the Black Sea is the discharge of insufficiently treated sewage waters, which results in microbiological contamination as well as eutrophication and poses a threat to public health. Since the 1980s, the Black Sea pollution has also greatly harmed Georgia's touristic industry. An estimated 70 per cent of surface water contains pathogenic bacteria to which Georgia's high rate of intestinal disease is attributed. Solving Georgia's environmental problems has not been a high priority of the national government in the post-soviet years.

Figure 1: Location of Project

Summary of the main problem faced

The pollution of the river Khobi that adjoins river Rioni near the town Poti poses a big threat to the Colchis lowland swamps which provide water resources and also habitat to migratory birds. Illnesses related to bad hygiene and water quality, such as diarrhea and hepatitis A, are widespread in the area. All together 11 villages are located alongside river Khobi with the population of 22 000 inhabitants. The target villages Khorga with 1,320 inhabitants and Chaladidi with 1,245 inhabitants are located in Khobi Municipality, Samegrelo Zemo-Svaneti Region.

The predominant sanitation system is pit-latrines; most of the pit latrine toilets are located nearby river Khobi. Drinking water in these villages is often obtained from shallow wells, which are polluted with microbes and nitrates. Untreated human and animal waste and chemical fertilizer seeps into the land and permeates the water system. Raw sewage flows into the river and is carried downstream to the already highly polluted Black Sea. The awareness of hygiene, water and sanitation-related diseases affecting women and children most as well as of safe and affordable solutions for improved water supply and sanitation is generally low.

Figure 2: Unsafe disposal of waste and sludge dumping

Figure 3: Pit latrines in the project area

Actors involved

- UNEP (United Nations Environment)/ Global Programme of Action for the protection of marine environment from land based activities (GPA)
- The Global Wastewater Initiative (GW^2I) under GPA,
- The Women in Europe for a Common Future (WECF)
- The Rural Communities Development Agency (RCDA)

Khamiskuri Water, Resource Centre Supported trainings and public meetings and supported replication of demonstration facilities. Other Stakeholders included Children and their teachers/ citizens/ local authorities (100 children + 8 teachers + 15 local/regional authorities), Citizens, Farmers, Local working groups, Decision makers (authorities) (at least 10), Experts at local and regional level (at least 10), National and international authorities and Media.

Actions taken

The project addressed in a holistic and gender sensitive approach the problem of water contamination, caused by widely used pit-latrines, poor management of water resources, uncontrolled animal grazing, intensive use of chemical fertilizers, open and unsafe disposal of waste, including animal manure. The project identified appropriate simple, affordable decentralized sanitation systems, such as urine diverting dry toilets (UDDT) and promoted their adaptation.

The activities were divided into three blocks:

1. **Increasing public participation and awareness raising**: This was done through organizing public meetings and establishment of community based working groups (gender balanced), Disseminating project information and results via local, regional and national media and disseminating project results at international level.

2. **Development and dissemination of information**: through fliers, brochures, leaflets and press releases.

3. **Practical training, implementation of demonstration objects and workshops:** Participants were selected according to their interest, background and their capacity, gender balance was considered. Some modules targeted all citizens, others farmers, others teachers and others local authorities.

Figure 4: Building local capacities in waste management through training (RDCA Director here)

Results so far

Increased understanding of the target groups in rural communities on the impact of human activities on the quality of the environment and water sources: 12,000 citizens and 40 authorities have access to information to improve their environment, in particular on wastewater management, 320 citizens of the target villages are actively involved in the project, 7 informative flyers/brochures; of each flyer 1000 printed, 3 manuals: of each manual 200 printed, 16 public meetings, 2 community based working groups and 10 press releases – 3 websites updated.

The target groups are enabled to practice sustainable wastewater management, sanitation approaches, and to protect their environment /water resources: 320 citizens, 12 authorities are trained on sustainable management, 3000 citizens have access to demonstration objects and 200 citizens of the target villages practice sustainable water and sanitation approaches.

Provision of information, recommendations at regional, national and international meetings and conferences 15 regional, 25 regional and 100 international policy makers and experts are informed about the project approach and results, and aware of the developed recommendations for a safe and sustainable water, wastewater and waste management approach.

Figure 5: Construction of demonstration objects like UDDT toilet in Khorga

Figure 6: Greywater filters in households and the kindergarten in Khobi

Conclusions

The implementation of the project started in May 2014. From the very beginning the activities strived to ensure broad public participation and increased awareness about the existing problem of water contamination caused by widely used pit-latrines, poor management of water resources, uncontrolled animal grazing, intensive use of chemical fertilizers, open and unsafe disposal of waste, including animal manure.

Understanding on the importance of safe water, sanitation, human and animal waste disposal and to prevent pollution of the Black Sea, was fostered by an exposure visit that was organized to the Khamiskuri Water and Sanitation Resource Center for members of village initiative groups, local authorities, local CBOs/NGOs and school teachers. During these visits the participants got acquainted with the technologies of safe use of human and animal excreta for fertilization and protecting the environment as well as the water bodies against pollution.

Cooperation between UN Environment, RCDA and WECF is excellent, weekly contact by mail, Skype and personal with the WECF regional coordinator took place. The manual on principles, construction and operation of UDDTs revised and adapted to Georgian conditions; Technical University of Hamburg gave its input.

On the flip side, the schools in Khorga and Chaladidi municipalities were not interested in carrying out Water Safety Plans activities. RCDA conducted discussions with schools from neighboring villages which express their willingness to conduct a WSP, and proposed to implement this activity there. Further, sanitation awareness on the relationship between safe water, hygienic practices, wastes disposal and health remains low in the area. The construction of excreta management, and disposal facilities at household; institutions (schools, health facilities, offices etc.); and public places (markets, eating places, parks etc.) is not accorded the deserved priority, often considered an additional expense. The project contributed to raising awareness and addresses this flip side.

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http://www.wecf.eu/english/articles/2014/06/kickoff-wastewatermanagement.php

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http://www.wecf.eu/english/articles/2014/09/water-testing.php

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2 Articles on the Khobi website:

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5 flyers on the WECF website:

http://www.wecf.eu/download/2015/June/UDT_ENG.pdf

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http://www.wecf.eu/download/2015/June/WECF_Kompostflyer_ENG.pdf

All project publications and news are now also available at the WECF Georgia website:

http://www.wecf.ge/new/8/

Case Study Ten

The Success of Global Cooperation: The Global Wastewater Initiative

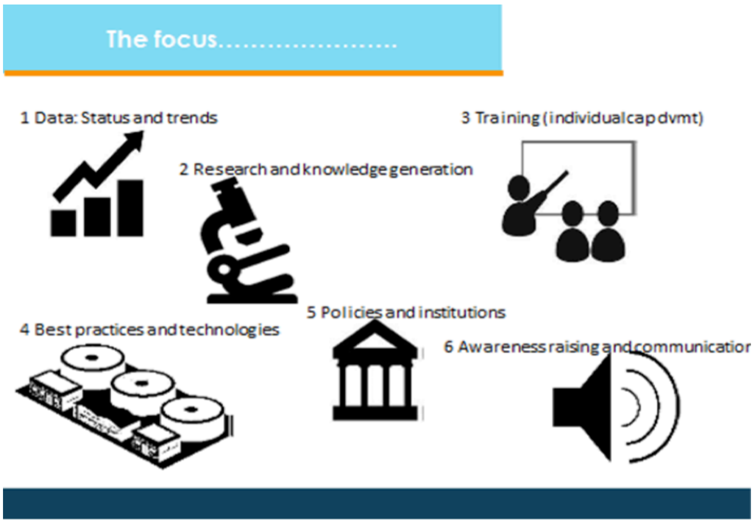
Introduction

The Global Wastewater Initiative (GW^2I), a multi-stakeholder platform, was launched by the United Nations Environment Programme in 2013, in response to the Manila Declaration to address wastewater-related issues, prompt coordinated action and encourage new investments in wastewater management. The GW^2I intends to bring about a paradigm shift in world water politics to prevent further pollution and highlight the fact that wastewater is a valuable resource for future water security. It is a voluntary network of stakeholders with an international Steering Committee and a Secretariat provided by UN environment in line with the mandate received in the "Manila Declaration on Furthering the Implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities" (GPA). Finally, it is a space to work under thematic groups or focal areas on major wastewater issues and challenges as well as potential opportunities and benefits such as wastewater reuse, nutrient removal and biogas production.

Summary of the main problem faced

The adverse effects of wastewater on human health and the ecosystem can no longer be disregarded, and response by adoption of wastewater management practices has become one of the top most agenda for most Governments and the International organizations. This is evident from the recently adopted Sustainable Development Goals 2015, specifically goal 6 which intends to 'Ensure access to water and sanitation for all'. Also, empirical studies show a direct link between wastewater management practices to sustainable development by contributing to environmental, social and economic development aspects. Sustainable wastewater management is one of the primary drivers for the green growth agenda, poverty alleviation, education, public health, gender equity and many more. The GW^2I is committed to contribute to reverse the trend, addressing the threats posed by wastewater, and to the implementation of Goal 6 of the 2030 SDGs.

Focal Areas and expected outputs

 	1. Responding to data and trends 2. Research & knowledge generation 3. Capacity development and training 4. Promotion of best practices and technologies 5. Policies & institutions 6. Awareness raising & communication

Actors involved

Results so far

At the global and regional levels, GW^{2}I generates knowledge by developing tools and guidance documents and sharing information to improve the management of wastewater. The GW^{2}I provides a flexible framework to assist countries in fulfilling their duty in accordance with international law to preserve and protect the marine environment from sewage, physical alterations and destruction of habitats, persistent organic pollutants etc. In this regards, the GW^{2}I has supported the development of a Global Enhanced Monitoring Initiative (GEMI) for wastewater and water-related SDG indicators, with the financial support of the Swiss Development Cooperation agency, to help countries comply with their obligations in implementing the 2030 SDG agenda.

Working with partners, the partnership is engaged in several demonstration projects on the ground. Joint initiatives have been developed to apply the knowledge generated in order to reverse the trend of wastewater challenges. Pilot projects implemented by countries have aimed at demonstrating sustainable management approaches, testing of new technology (e.g. use of constructed wetlands for wastewater management), stimulating multi-agency cooperation and developing partnership between State and non-State actors to address land-based sources of coastal and marine pollution.

Conclusions

A number of workshops have been held in the involved countries where experiences have been shared and the lessons learnt have contributed to their capacity development with regard to sustainable wastewater management. Knowledge has also been generated raising awareness on the importance of sustainable wastewater management, looking at in in a more holistic way and with the circular economic approach in mind. The tools and Guidance documents developed are helping to build the basis for an enabling environment in member states for better wastewater management and reuse, considering it as a resource.

In conclusion, more innovation, more research, and more investment is needed in wastewater management, while the current accomplishments are contributing to a global knowledge base that will enable progress. Wastewater is a resource that is too valuable to throw away, especially in an increasingly water-scarce world therefore engaging dynamic stakeholders facilitates sharing of best practices and provides opportunities for collaboration.

Links + Readings

Key publications:

1. Wastewater Analytical Brief (2015)

http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/UN-Water_Analytical_Brief_Wastewater_Management.pdf

2. Sick Water Report (2010)

http://www.unep.org/pdf/SickWater_screen.pdf

3. Economic Valuation of Wastewater (2015)

http://web.unep.org/ourplanet/december-2015/unep-publications/economic-valuation-wastewater-cost-action-and-cost-no-action

4. Good Practices for regulating Wastewater Treatment (2015)

http://unep.org/gpa/documents/publications/GoodPracticesforRegulatingWastewater.pdf

5. Wastewater Technology Matrix (2015)

https://www.dropbox.com/sh/vepn18zln7vmgkp/AABM-nYNwzFWK3oLIuQFphNra?dl=0

6. Sanitation, Wastewater Management and Sustainability - From waste disposal to resource recovery. (2016)

https://wedocs.unep.org/rest/bitstreams/14147/retrieve

7. The GW^2I wastewater video by Jim Toomey

http://unep.org/gpa/news/JimToomeyWastewater.asp

End of Module Discussion questions

1. Can you think of other examples that demonstrate best or worst case approaches?
2. Are any of the cases discussed in this module similar to problems and/or solutions in your geographic area? Develop.
3. What could be the cultural and individual barriers to reuse of treated water for industrial, commercial, and home use? What are some of the strategies to overcome these barriers? Take a close look at the Irvine et al. reading as well as the Peters and Goberdhan reading to give you some ideas about public perception and policy.
4. Choose one of the case studies above and discuss what decisions were well-made, and what could have been done better. Take into account economic, social, and environmental factors when conducting your assessment.

Module Eight: Case studies of effective nutrient management

Learning Objectives

After completing this module, students will:

1. Be able to relate the material they have covered in preceding modules to actual case studies;
2. Relate "best and worst practices" analysis to integrated cycles of nutrient runoff management

Case Studies

1) Chesapeake Bay, United States
2) Lake Erie
3) Black Sea/Danube
4) Manila Bay
5) Nepal
6) China
7) EU Nitrate Directive
8) Global Partnership on Nutrient Management (multinational scale)

End of module discussion questions can be found at the end of this chapter.

Case Study One: Chesapeake Bay, United States

Location: New York, Pennsylvania, Delaware, Maryland, Virginia and West Virginia, and the District of Columbia.

Summary of the main problem faced

At over 320 km long from north to south, with a watershed shared between six states, the Chesapeake Bay is the largest estuary in the United States, with over 150 major rivers and streams flowing into its basin. The watershed that affects and is affected by the Bay, however, is far larger, covering about 165,760 square km that includes forests, farms, cities, suburbs, industries, and wildlife habitats.

Pressure from agriculture, industry, and growing population has led to a decline in the health of the Bay noted since the 1970s. Agricultural runoff is the largest source of pollution, contributing about 40% of nitrogen runoff. In fact, over 300 pounds of nitrogen enter the Chesapeake Bay annually, an estimated six times more than during the Bay's peak health in the 1600s. However, agricultural factors have been mitigated by various programs since the 1980s and have not increased the amount of their contribution to nitrogen pollution – it is in fact *stormwater runoff* that is increasing. Development and population growth in the area have led to an increase of paved surfaces by 34% since 1990.

Algal blooms, water-borne diseases, sedimentation, pesticide and nutrient runoff have all led to significant health, economic, and environmental impacts in the Bay area. In fact, Chesapeake Bay contained one of the earliest recorded "dead zones" due to oxygen depletion in the waters. According to the CBF, the Bay has lost 98% of its oysters, about 80% of grasses, and almost 50% of forest and wetland buffers. The US Environmental Protection Agency (EPA) has placed the Chesapeake Bay on its "dirty waters" list, along with several rivers that flow into the Bay.

Oysters have historically been critical revenue source for fishermen in the Bay, and they also provide crucial water filtration services. Yet they are estimated to be at 1-2% of historic population levels. With their loss and the loss of other fish species due to pollution, overharvesting, and water-borne disease, many Bay area fishermen have lost their livelihoods.

Image source: Chesapeake Bay Program

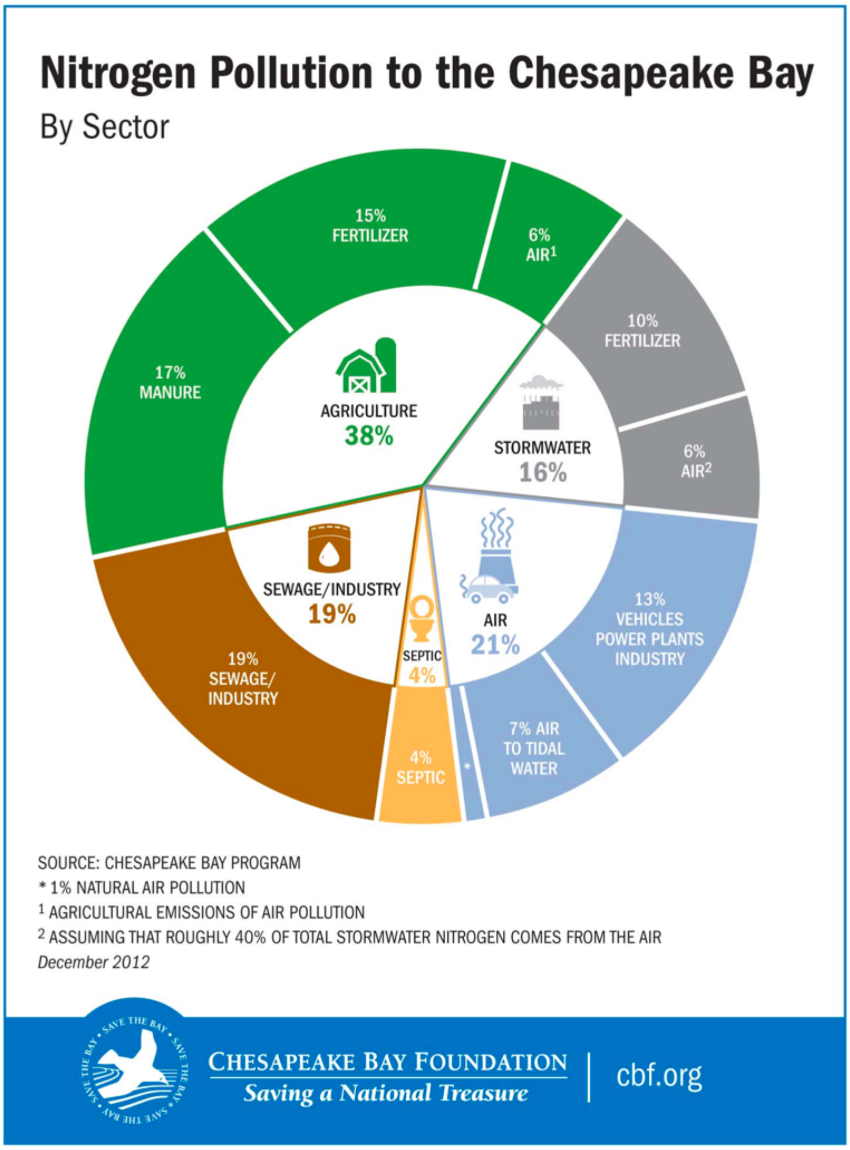


Image source: Chesapeake Bay Foundation

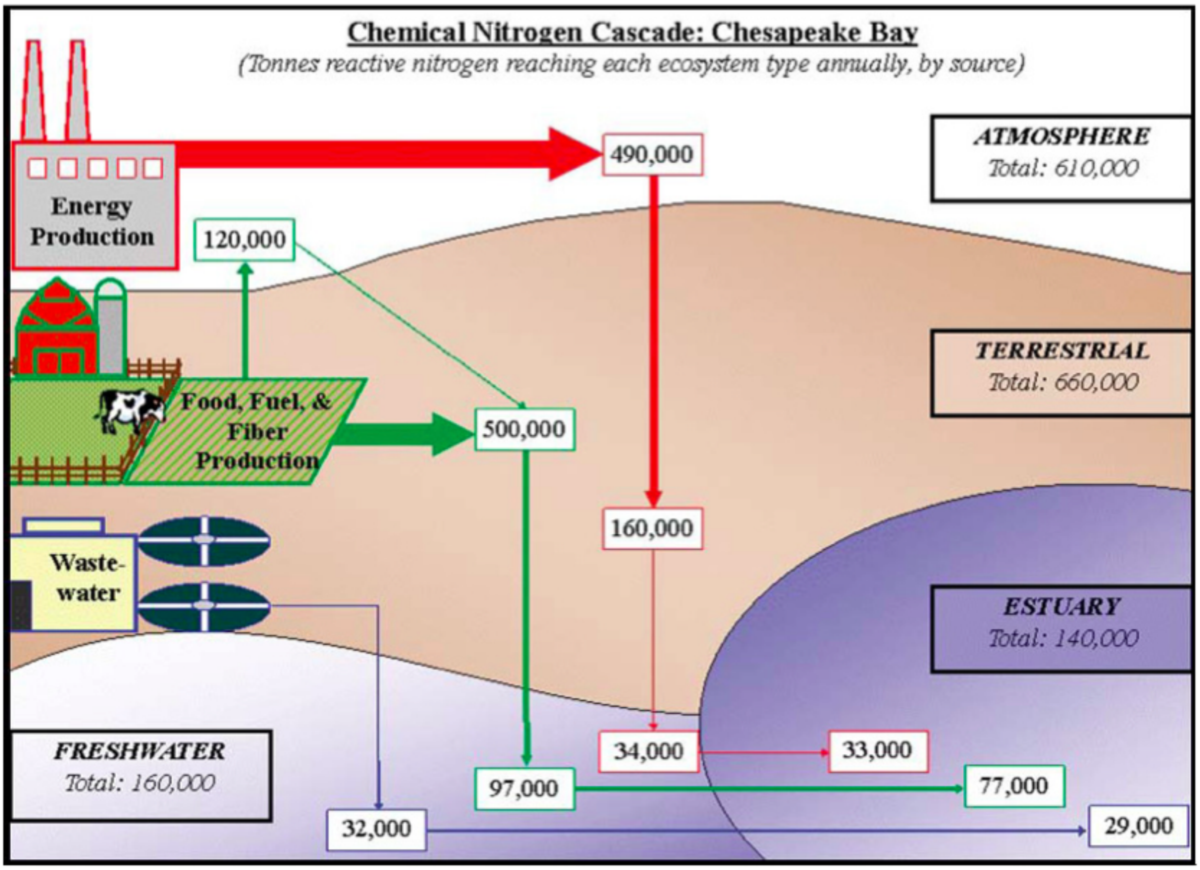
Actors involved

State and Federal Departments related to Conservation, Recreation, Wildlife, Agriculture, and Environment, including the NOAA
Academic partners such as universities, the Academy of Natural Sciences, etc
Non-governmental organizations such as The Chesapeake Bay Foundation, Alliance for the Chesapeake Bay, Low Impact Development Center, etc

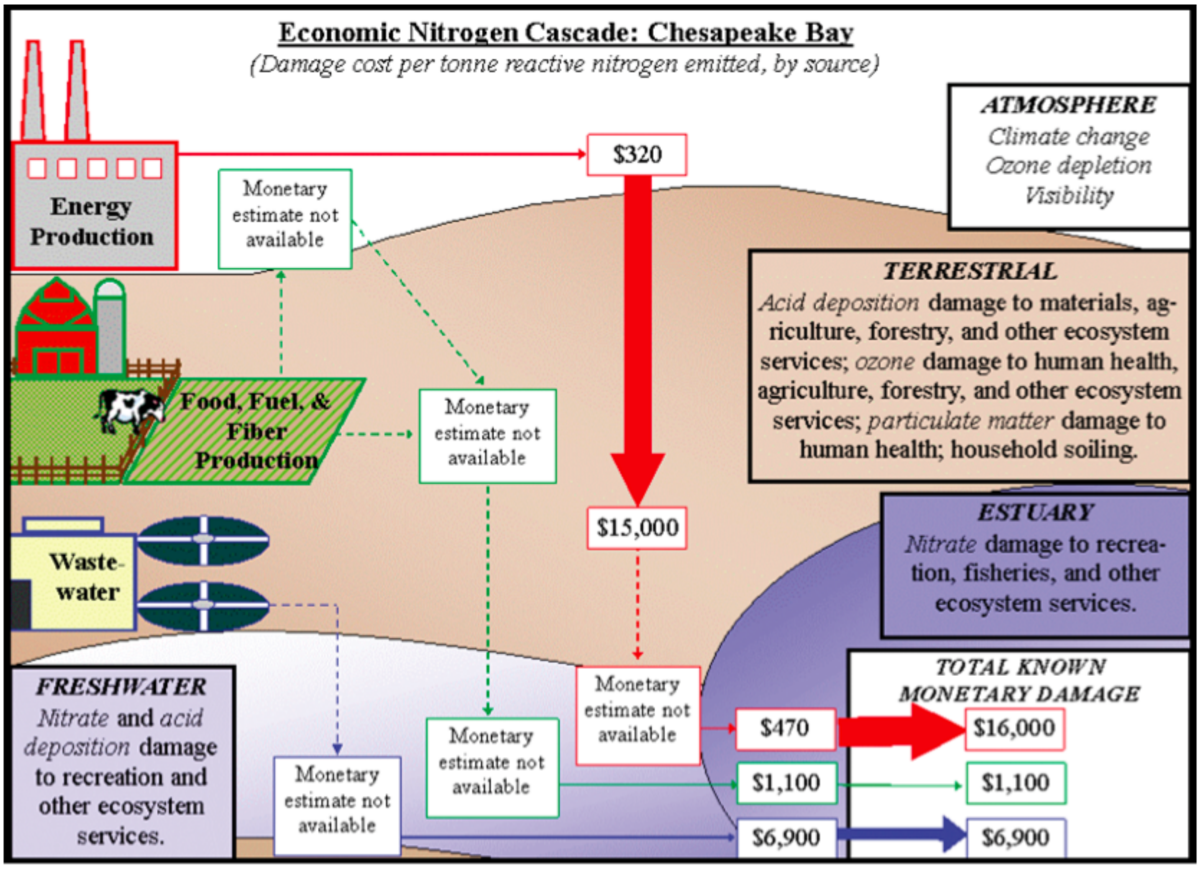
Summary of actions taken

The alarming state of the Bay led to a the formation in 1983 of a regional partnership called the Chesapeake Bay Program which involves local, state, federal and non-governmental organizations to develop and coordinate policy. Some major agreements resulting from the partnership include the 1987 Chesapeake Bay Agreement establishing the goal of reducing nitrogen and phosphorus pollution by 40% by 2000 – although this goal has not been met, it remains the goal for Bay organizations working on pollution reduction. In 2000, the Program adopted Chesapeake 2000 which outlined specific actions to restore the Bay, including the protection of its living resources, restoration of vital habitats, improvement in water quality, better planning of land use, and engagement of the community. However, by the end of the decade, many restoration goals were still not met. President Obama signed an Executive Order directing the federal government to renew restoration and protection efforts of the Chesapeake Bay, involving federal organizations like the NOAA. Subsequently, the US Environmental Protection Agency (EPA) sought to enforce the Clean Water Act by releasing legal pollution limits for nitrogen, phosphorus, and sediment pollution in the bay. This prompted surrounding states to develop plans and targets to meet the USEPA's limits by 2025, together called the Chesapeake Clean Water Blueprint. The Blueprint aims to ensure coordination of and shared responsibility for cleanup efforts, and additionally sets two-year incremental pollution reduction goals that are legally enforceable.

The Chesapeake Bay has undergone one of the more thorough economic analyses in order to assess economic costs of pollution to the watershed and thus gain a better understanding of the economic benefits of clean up. One of the more prominent analyses conducted was an "economic nitrogen cascade" that estimated the economic impacts of nitrogen inputs by aggregating the costs of different stages of nitrogen as it "cascades" through ecosystems. The results further galvanized action to mitigate and minimize nutrient pollution in the Bay.



Chemical nitrogen cascade depicting tons of nitrogen flowing through the ecosystem annually from various sources. (Source: Building Foundations for Sustainable Nutrient Management, GPNM).



Economic nitrogen cascade depicting costs to the human and natural environment caused by excess nitrogen inputs. (Source: Building Foundations for Sustainable Nutrient Management, GPNM).

A large focus of restoration efforts has been on the agricultural sector by introducing nutrient management plans and other best management practices such as stream buffers, cover crops, and fencing livestock out of streams. These measures are considered the most cost-effective mechanisms for pollution mitigation in the Chesapeake Bay, according to the CBF. "In fact, scientists estimate that we could achieve almost two-thirds of the nitrogen and phosphorus reductions necessary to restore the Chesapeake Bay, at only 13 percent of the total cost of Bay restoration, by implementing them." (CBF) There are a variety of restoration-focused organizations that exist multiple levels of governance such as local soil and water conservation district offices and state departments of conservation, forestry, game and fisheries. Within these governments, there are funding bodies such as the conservation portion of the federal Farm Bill and specialized programs such as Virginia's Conservation Reserve Enhancement Program (CREP) who provide financial incentives and cost-share rental payments to farmers who aid in riparian and wetland restoration efforts.

Funding and capacity-building is also available through non-governmental organizations such as the Chesapeake Bay Foundation, which also acts as a lobby group to pressure the state and federal governments to increase conservation funding to the Bay and litigates to protect pollution limits and spur enforcement efforts. Overall, efforts have shown great improvement: nitrogen and phosphorus inputs have decreased by 25% since the 1980s. In addition – and quite unintentionally – air pollution controls have also helped reduce nitrogen inputs in the water by 10% since 1985, via reducing the nitrogen oxides created as a byproduct of fossil fuel combustion. Lobbying on the part of groups like the CBF has resulted in the establishment of a Chesapeake Bay Fund in Maryland which is financing efforts such as upgrading sewer plants to an Enhanced Nutrient Removal (ENR) standard and on-site septic systems to improve wastewater treatment. This has resulted in 646,000 fewer pounds of nitrogen entering water streams.

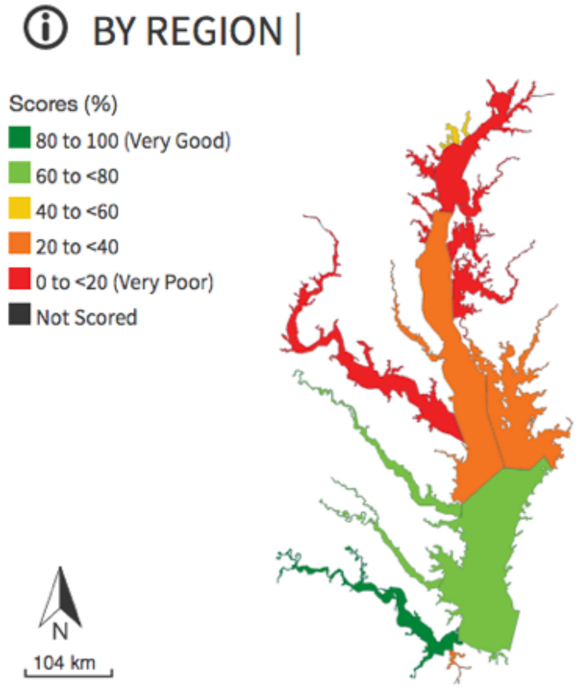
However, improvements in the situation of the Bay have slowed down. Part of the reason, as previously mentioned, is increased development in the watershed. In addition, there is a structural problem related to conventional agriculture and the economics of environmental pollution. Penn State professor Douglas Beegle has pointed out is that modern farming practices almost inevitably lead to nutrient overloading because of specialization. That is, traditional agriculture practiced in the area recycled nutrients: farmers grew a significant amount of crops to feed their animals using the manure the animals produced, ensuring that the nutrient-rich manure went back into the soil.

With the advent of fertilizers, farmers in the Midwest US focused on producing large amounts of crops and farmers in the Chesapeake Bay area found it made more economic sense to buy these crops for feed and devote more of their land to livestock. Therefore, the nutrient cycling of traditional farming was disrupted and more animal waste tended to run off into waterways – another environmental pressure added to the existing land degradation due to livestock grazing and the resultant reduction of vegetation along waterbanks. Some academics have suggested going beyond only applying nutrient management plans on farms: we must also create policy or mechanisms to internalize the environmental harm wrought by this nutrient runoff (for instance, labelling food produced on farms with good nutrient management practices in a manner much like organic food products, or providing economic incentives to better managing manure and implementing nutrient cycling). However, little action has been taken to address this structural issue so far.

Other efforts in the Bay have focused on wastewater management, urban planning, as well as oyster restoration. The latter are a key economic resource but also providing essential ecosystem services by filtering pollutants, sediment, and algae thereby increasing water quality. Oyster populations have seen a slow rebound, increasing about 350% from 2007 to 2015, though populations remain low. Progress in wastewater management and land use planning has been patchy, with some municipalities such as Lancaster County investing heavily in updating and expanding wastewater services and aiming to reduce impacts from developed land.

Results so far

Nitrogen levels in the Chesapeake Bay and major rivers in 2000:



Nitrogen levels in the Chesapeake Bay and major rivers in 2015:

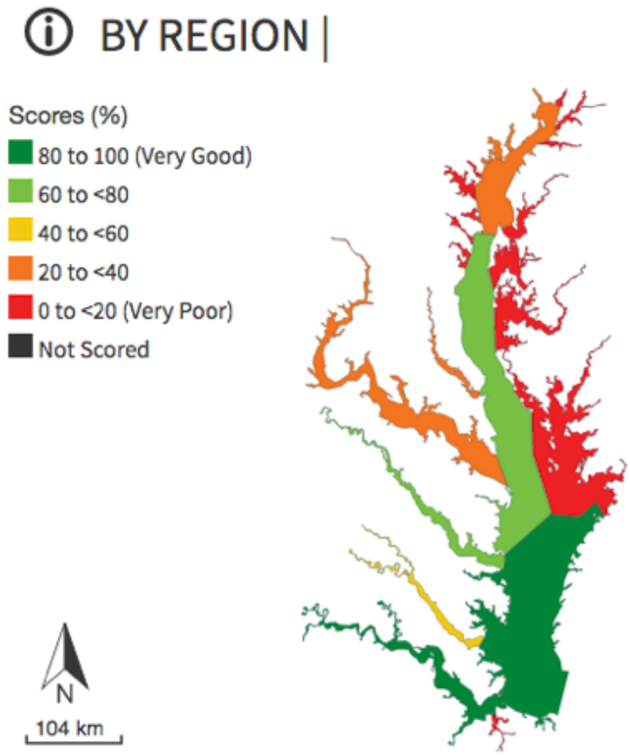


Image source: University of Maryland Center for Environmental Science

Pollution reduction progress

Nitrogen Loads to the Bay *(million lbs/year)*	Phosphorus Loads to the Bay *(million lbs/year)*	Sediment Loads to the Bay *(million lbs/year)*
1985–369.78	**1985**–25.62	**1985**–10.80
2009–282.66	**2009**–19.23	**2009**– 8.68
2012–264.14	**2012**–17.97	**2012**– 8.24
2017–219.04	**2017**–16.42	**2017**– 7.87
2025–191.57	**2025**–14.55	**2025**– 7.34

Table source: Chesapeake Bay Program
(Note: future years are based on predictive modelling from current data)

While there have been significant improvements in terms of nutrient inputs, almost 75% of the Bay's waters contain high levels of chemical contaminants such as pesticides, pharmaceuticals, and heavy metals. There have not been significant reductions in this area.

Conclusions

The Chesapeake Bay problem illustrates the difficulties inherent in managing a large watershed area due to the complexity of measuring, regulating, and enforcing a large array of pollution sources that include agriculture, industry, and urban/suburban development.

These difficulties often mean that achieving targets is a very long-term project in which enabling conditions must be created, and several plans of actions are implemented with increasingly strict regulations. Financial investments and capacity-building must be ongoing and ambitious. Only with these factors can the transition to more sustainable development occur. Mature ecosystem-based programs like the Chesapeake Bay Program demonstrate that progress towards set goals through incremental phases. As each incremental goal is attained, the program gains public credibility as well as political and financial support. This enables more issues and goals to be addressed over time while sustaining the achievements already made. Furthermore, when economic analyses like the economic nitrogen cascade are undertaken, stakeholders gain a better grasp of the advantage of addressing nutrient pollution.

http://www.cbf.org/about-the-bay/state-of-the-bay-report-2014

Readings:

Chesapeake Bay Foundation (2014) *State of the Bay Report.* http://www.cbf.org/about-the-bay/state-of-the-bay-report-2014

> The annual "State of the Bay Report" presents information on water quality, habitat health, population of key species, and nutrient levels in different areas of the Bay. The overall health of the Bay has been found to be quite low, with a grade of "D+".

"Polluted Runoff: How Investing in Runoff Pollution Control Systems Improves the Chesapeake Bay Region's Ecology, Economy, and Health." 2014. *Chesapeake Bay*

Foundation. Report. Retrieved from: < http://www.cbf.org/features-publications/reports/polluted-runoff-report-2014>.

> This report outlines the increasing impacts of runoff from developed areas, strategies to control runoff, economic reasons for doing so, and the current policy environment on the Bay issue.

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> This paper uses the case of the Chesapeake Bay to address a wider question: how can we develop economic pollution-control mechanisms with low initial costs of compliance in order to ensure that it is actually feasible for targets to be met?

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Case Study Two: Lake Erie 4R Nutrient Stewardship Certification Program

Location: Western Lake Erie Watershed, Ohio-Indiana-Michigan, United States of America

Summary of the main issue faced

In Lake Erie, one of the five Great Lakes of North America, water quality and phosphorus loading have been connected for decades. Programs put in place in the 1970s and 1980s were successful in reducing total phosphorus loadings per year from over 25,000 tonnes in 1969 to 11,000 tonnes by the early 1980s (Figure 1; Maccoux et al., 2016). While the majority of these loading reductions were achieved through controls on point sources such as sewage treatment plants, increases in the use of conservation tillage practices on agricultural cropland are among the practices considered to have contributed to load reductions by 1995 (Richards et al., 2002).

Starting in the early 2000s, however, the western basin of Lake Erie began showing a resurgence of algal blooms similar to those that were frequent in the late 1960s to the early 1970s. By 2011, during which an algal bloom of unprecedented scale was documented by satellite monitoring, it became apparent that the increasing trend in bloom severity and extent paralleled an increase in loadings and concentrations of dissolved phosphate in the tributaries. The tributaries drain a large area of productive cropland in northwestern Ohio and parts of Indiana and Michigan (Figure 2). Lake Erie provides drinking water for millions of people, produces more than half the fish in the Great Lakes, and attracts many tourists. The blooms threaten drinking water quality, beach quality, and coastal recreation. In addition, the nutrient loadings and algal blooms connect to a bottom water hypoxia issue in the Central Basin of the lake (IJC, 2014).

Reasons for the increased phosphate in the tributaries are not fully understood, but it is recognized that several causes are probable. One major cause is changes in weather patterns, with increased frequency of intense rain in late fall and early winter, and increased river flows. Non - point sources are estimated to contribute 71% of the dissolved and 89% of the total annual phosphorus load in the western Lake Erie watershed (Maccoux et al., 2016). Agriculture is considered a large source since it occupies over three quarters of the land area. Crop yields have increased; however phosphorus application rates have not increased substantially during this period. As a result the cropland phosphorus balance is changing from a small surplus to a small deficit (Jarvie et al, 2017). Aggregated soil sampling data indicates that the levels of phosphorus in the watershed's soils have not increased and in fact the frequency of soils deficient in phosphorus has increased. In fact, Ohio soils are lower in available phosphorus than the soils of other states and provinces in the vicinity (Bruulsema, 2016). Practices such as tile drainage, conservation tillage, and broadcast application are possible contributors to the trend in increased losses, but there are no consistent datasets on the frequency of these practices across the watershed over the time period.

Much of the western Lake Erie watershed drains into the western basin of Lake Erie, which experienced increasing algal blooms from the mid-1990s to 2015. Source: http://4rcertified.org/about/

The stakeholders involved

<u>Agricultural Fertilizer Retailers</u>
The Andersons, Morral Companies, LLC, Legacy Farmers Cooperative, Farmers Elevator Grain and Feed Association, and others
<u>Industry Associations</u>
Ohio Agri Business Association, The Fertilizer Institute, International Plant Nutrition Institute, Ohio Farm Bureau Federation, Ohio Soybean Council
<u>Government Agencies</u>
Ohio Department of Agriculture, Ohio Environmental Protection Agency, United States Department of Agriculture - Natural Resources Conservation Service
<u>Educational Institutions</u>
Heidelberg University, The Ohio State University
<u>Environmental Organizations</u>
The Nature Conservancy, Ohio Federation of Soil & Water Conservation Districts, Environmental Defense Fund

Actions taken

By 2010, researchers from Heidelberg University had been reporting increases in loads and concentration of phosphate in the Sandusky and Maumee rivers, two of the major tributaries monitored in their water quality sampling program. The Andersons, a large agricultural retail business headquartered in Maumee, Ohio, began discussions with these scientists to better understand the issues. Recognizing that a large part of their business was located in the watershed, they became engaged, even to the extent of financially supporting the program monitoring the river phosphorus loads. Around the same time, the North American fertilizer industry was developing the concept of 4R Nutrient Stewardship—the application of the right source of nutrients at the right rate, right time, and right place. Working with the Nature Conservancy, The Andersons invited other local agricultural retailers, fertilizer industry associations, government agencies and environmental organizations to come together, with the aim of developing a specific implementation of 4R Nutrient Stewardship to change and document nutrient application practices toward reducing phosphorus losses. Following multiple engagement sessions, the stakeholders developed and agreed to support a voluntary program which became known as the Western Lake Erie Basin 4R Nutrient Stewardship Certification Program.

The program is directed at agri-retailers, and provides guidelines with criteria regarding the training of their staff, record-keeping, on-farm recommendations and provided application services. Each participating retail location is audited to ensure consistency with the 41 criteria in the program. Regarding nutrient recommendations and applications, criteria include all plant nutrients, but are focused on practices relevant to reducing phosphorus losses. The criteria relate to source, rate, time and place of nutrient application. On source, they encourage utilization of all nutrient sources available to the producer, including manure, and appropriately considering the amounts of phosphorus available in these sources. Rates are based on soil testing and crop yield potential, and are not to exceed the recognized recommendations of the land grant university, unless the producer has documented results from on-farm adaptive research justifying a difference. Regarding timing, the criteria assure that nutrients (including fertilizers, manures and other sources) are not applied on soils that are frozen or snow-covered, and that surface broadcast applications are not made when large rainfall events are in the weather forecast. On placement, the criteria encourage injecting or banding phosphorus sources below the soil surface, and using variable rate applications accounting for within-field variability in soil phosphorus availability and expected removal of phosphorus by the crop.

It was recognized that while most of the practices listed above have been shown to reduce phosphorus losses while maintaining the opportunity to continue increasing crop yields, the knowledge base was insufficient to quantify the total reduction of phosphorus loss expected at the watershed scale, nor the amount contributed by each practice. Thus the industry simultaneously agreed to support, through a 4R Nutrient Stewardship Research Fund, a project aimed at assessing the changes in practices and the resulting impacts on water quality.

Results so far

Since the program has only been in place for two years, it is too early to see direct impacts on water quality in Lake Erie. The approach, however, has demonstrated actual and potential benefits to participating stakeholders.

The 4R certification program was launched in March 2014, though educational outreach to retailers had been underway since 2012. In its first two years, 30 retailers were certified. Through their producer customers, the reach of the certified retailers extends to over two million acres of cropland, including almost 40% of the agricultural land in the watershed (Vollmer-Sanders et al., 2016). Weather events in 2013 and 2015 featured unusually large amounts of rain in June and July, resulting in increased phosphorus loads and concentrations in the tributaries, and large algal bloom events. Against the backdrop of large weather effects, it is not possible to say as yet whether practice changes have been or will be effective in achieving the 40% load reduction agreed to by the collaborating federal, state and provincial governments of the entire Lake Erie watershed (USEPA, 2016). Edge-of-field research on farm fields, however, is beginning to document efficacy of rate, time, and place practices in reducing losses. The research, initiated in 2014 and funded to continue through 2019, has documented the importance of losses through subsurface tile drains, and the connectivity to surface-placed phosphorus inputs by macropore flow through the soils.

Agri-retailers are experimentally introducing equipment that places the commonly used granular forms of phosphorus fertilizer in the soil while retaining residue cover on the soil – combining the benefits of conservation tillage in limiting losses of particulate phosphorus while using placement that limits loss of the dissolved form. This equipment can also apply at variable rates within the field, matching the phosphorus supply to crop need (Reese, 2014).

Conclusions

The value of the program was demonstrated during a widely publicized "do not drink" advisory issued for the City of Toledo's water supply in August of 2014. While the program was not yet at a stage to have impacted phosphorus losses or algal blooms, the many stakeholders involved were able to provide consistent messages about the efforts being made to address the issue. Subsequent public pressure for action resulted in the state of Ohio passing two legislative bills that made some aspects of the voluntary 4R program mandatory for all producers. Collaboration in developing the guidelines nevertheless provided benefits for all involved. Government agencies were able to get better buy-in to the regulations since they had been developed with stakeholder input. Retailers were well positioned and informed, enabling them to support their producer customers with assurance of regulatory compliance.

Issues remaining include: 1) uncertainty with regard to conservation tillage. Incorporation or sub-surface injection of applied phosphorus is known to reduce loss risks for dissolved phosphorus, but the soil disturbance entailed may increase losses of particulate phosphorus through erosion. 2) Owing to the large influence of weather on annual loads of phosphorus in the tributaries, many years may be required to detect the effect of this and other programs being implemented to reduce phosphorus loading from nonpoint sources.

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Case Study Three: The Black Sea/Danube Recovery

Location: The Black Sea is an isolated sea located between Southeastern Europe and Western Asia (ICPDR, 2016a). The Danube, Dnjestr, and Dnjepr rivers are the major supplying rivers that feed the Black Sea and connect it to the Atlantic Ocean via the Mediterranean (ICPDR, 2016a). Figure 1 shows a map of Black Sea basin (Philippe Rekacewicz, 2006).

Figure 1. The Black Sea basin (taken from Philippe Rekacewicz (2006))

Summary of the main problem faced

The Black Sea has an inflow of both river water with a salinity of 17 ppt (parts per thousand) and high saline Mediterranean Seawater (34 ppt). As the result of the differences in the salinities of these two sources, two layers or zones of water with different densities are formed. These two layers cannot naturally be mixed by the action of wind. Therefore, an **anoxic** (with low amounts of dissolved oxygen, DO) zone was formed between 80 and 150 m below the surface water, while the surface held a high level of dissolved oxygen. This led to two phenomena including water stratification and the formation of hydrogen sulfide (H_2S) in the lower zone (ICPDR, 2016b).

In addition to the natural stratification phenomenon, the environmental conditions and ecosystems of the sea have been adversely impacted as the result of industrial, agricultural, and tourism related activities in the coastal area and the supplying rivers (e.g., the Danube River Basin which is shared among 19 countries (ICPDR-ICPBS, 1999; ICPDR, 2016a)).

High levels of nutrients such as nitrogen and phosphorous compounds, organic pesticides, heavy metals like lead and copper, and petroleum/hydrocarbons as the result of accidental oil spills have continuously been entering the sea.

Summary of actions taken

As the Black Sea is shared among many countries, close and sustained cooperation with a focus on nutrient reduction was established between the United Nations Development Programme (UNDP), Global Environmental Facility (GEF), International Commission for the Protection of the Danube River (ICPDR), European Union (EU), the Danube countries, and NGOs. Several frameworks were developed to address the deleterious effects of agricultural, industrial, and tourism activities on the Black Sea through the implementation of numerous "programs, institutions, and legal agreements, and concrete environmental progress".

For example, the the Danube River Protection Convention (DRPC) recommended the following strategies aiming to:

1. Protect and improve the Danube River basin conditions by rational use of water resources.

2. Implement "protective measures" in order to control the accidental contamination of the water by floods and hazardous materials.

3. Determine the source of contaminants and prevent the contaminants from reaching the Black Sea.

To achieve such goals, several local and national-scale projects have been carried out to find sustainable solutions for the existing problems and to raise public awareness and encourage the public to contribute to environmental decisions and solutions.

In a regional pilot project conducted in the northeast of Vojvodina in the Falesti District of Moldova, "nine NGO's, 90 farmers, national and international experts and local governments" were actively involved in reduction of nutrient and toxic pollutants from farm runoff to the Prut River, one of the rivers in the Danube River basin. In this project, several nutrient management strategies were effectively practiced targeting both the public and municipalities aiming to encourage best agricultural practices. For example, four organic demonstration gardens ("chemical-free demonstration gardens") were built to show the innovative agricultural practices and to train local farmers to use less chemical fertilizers and pesticides on their farms. Moreover, public awareness was raised through community-wide activities including radio and TV programs promoting the substitution of inappropriate agricultural practices with more "earth-friendly or organic farming". Moreover, municipalities were involved through "a contest to identify the cleanest and greenest areas of the Prut River Basin", which resulted in significant achievements. For example, illegal waste disposals in the region were identified. Moreover, "water-loving native plants" were planted to reduce the runoff from the farms and control soil erosion, and the local springs were cleaned up (ICPDR, 2016c).

Results so far

The following are some of the outcomes of the planning, development, and implementation of practical nutrient management strategies in the Black Sea.

- Initial recovery in both the Danube and the Black Sea ecosystems (GEF, 2005)
- Reduction in the nitrogen input into the Black Sea (ICPDR, 2016c)
- Increase in the dissolved oxygen level in the lowest zones of the Black Sea (GEF, 2005)
- The occurrence of fewer and less intense algal blooms in the sea (GEF, 2005; ICPDR, 2016c)
- Increase in the total fish population in the sea (ICPDR, 2016c)

"Strategic partnership, joint action programs, providing technical and financial assistance for environmental improvements, adopting and implementing nutrient and toxics reduction policies and regulatory measures, public involvement & communication" are the major factors that strongly influenced the effective implementation of nutrient management strategies in the Danube River basin and the Black Sea Basin (GEF, 2005; ICPDR, 2016c).

Conclusions

This case study shows how cooperative efforts, public involvement in environmental problems and solutions, and applicable strategies have resulted in a demonstrable effect on improvement of the Black Sea environmental conditions and ecosystems (GEF, 2005).

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Case Study Four: Manila Bay Environmental Management Project, Philippines

image source: http://wild-about-travel.com/2010/08/ghosts-philippines/

Location: Manila Bay, Philippines

image source: http://dil.bosai.go.jp/disaster/2009philippine/images/10-1e.jpg

Summary of main problem faced

Manila Bay (the Bay) is a semi-enclosed estuary facing the South China Sea. The Bay is about 1,800km^2, is bordered by five coastal cities (including the densely populated Metro Manila), and has a watershed of over 19,000 km^2. The Bay's major tributaries are the Pasig and Pampanga Rrivers. There are an additional 11 non-coastal cities located within the watershed. The Bay area is a major fishing ground, the nation's largest shipping port, and the financial centre of the country. It is estimated that the Bay area contributes to approximately 55% of the country's domestic production and 30% of the national population lives within the watershed (GPNM, n.d; Sotto et al. 2015).

In recent years, a growing population combined with agriculture, aquaculture, and industry have lead to an increase in organic and nutrient loading to the Bay. This is primarily due to untreated domestic wastewater, agricultural waste, and industries within the Bay's watershed. Nitrogen and phosphorus loading are of particular concern and the enhanced levels of nutrients have lead to episodes of hypoxic conditions in the Bay and an increased incidence of algal blooms (Jacinto et al., 2006). Combined with increased organic loading, this has also increased the amount of suspended material in the water column. As the coastal population continues to grow, this places ever-increasing pressure on the Bay which serves as a source of food and livelihood for many people (Jacinto et al., 2006). This increasing pressure combined with reduced water quality pose a significant risk to both the human and ecosystem health in the area.

Actors involved

Philippines Department of Environment and Natural Resources (DENR)
Laguna Lake Development Authority Pasig River Rehabilitation Commission
Department of Agriculture
MetroManila Waterworks and Sewerage System
Government of the Philippines (Supreme Court)
University of the Philippines – Marine Science Institute
PEMSEA (Partnerships in Environmental Management for the Seas of East Asia)
Global Partnership on Nutrient Management - Global Nutrient Cycle (UNEP, UNDP, & GEF Global Environment Facility)
The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA)

Summary of actions taken

Several steps have been taken to improve conditions in Manila Bay. The Manila Bay Environmental Management Project began in 2000 and was a coordinated effort, lead by the Department of Environment and Natural Resources with funding and support from PEMSEA, GEF, UNDP, and the UNEP.

In 2001, the Manila Bay Environmental Management Project (MBEMP) released the Manila Bay Coastal Strategy – this strategy described the historical, social, economic, and ecological value of the region and provided a detailed inventory of the risks and challenges facing Manila Bay (PEMSEA, 2015). The Strategy was developed in partnership with several stakeholders including national, regional, and local government agencies, academia, the public, the private sector, and religious organizations. The objectives set within the Strategy targeted a broad range of goals that required ambitious actions and institutional, political, technical, economic, social and environmental reforms (PEMSEA, 2015).

Subsequently, the MBEMP released the Operational Plan for the Manila Bay Coastal Strategy in 2005. The aim of the Operational Plan was to translate the strategies and action programs that were outlined in the Manila Bay Coastal Strategy into action plans. The action plans fell into three broad categories: Partnership and Governance; Water Pollution; and Over-exploitation of Resources and Degradation of Habitats and Historical, Cultural, Religious, Archeological and Unique Geological Sites. The action plans within the Coastal

Strategy set measurable targets, timeframes, budgetary requirements, and implementing arrangements (responsible agency/ sector/partner, and enabling policies and laws). Additionally, the Coastal Strategy included financing strategies, monitoring and evaluation procedures, and communication, information dissemination, and education strategies (PEMSEA, 2015).

Underpinning this project is a specific legal requirement from the Philippines Supreme Court that the Philippine government agencies and other bodies should work together in restoring the water quality of the Bay and its coastal area, addressing in so doing the root causes of the current degradation, including the problems of nutrient over-enrichment (UNEP, 2011).

Manila Bay is considered a pilot project for the Global Partnership on Nutrient Management and is designed to strengthen information and reporting on nutrient issues in Manila Bay watershed and establish foundations for nutrient reduction strategies in the watershed and beyond based on source-impact modeling and best practices (GPA, 2014). The UNEP/GEF Global Nutrient Cycling Project is providing resources to support necessary technical and advisory service to DENR and other agencies for updating management systems and coastal reports as an input for prioritization of environmental concerns through risk assessment, systematic development of measures, mobilization of stakeholders, and putting in place necessary institutional arrangements to effectively implement and sustain plans and programmes (GPNM, n.d.).

Results so far

This project has strengthened information and decision support systems on nutrient issues for the Manila Bay watershed as part of an integrated approach to overall water quality. Government agencies and relevant stakeholders in the Manila Bay area have developed and agreed upon nutrient reduction strategies to be implemented, including their effective insertion into integrated national water quality planning for the Bay area (UNEP, 2011). Furthermore, as a GPMN pilot study, this project has included the development and integration of indicators, best management practices, source-impact models, and reporting on nutrient issues in the Manila Bay for the creation of ecosystem health cards that may later be applied to additional case studies (UNEP, 2011).

This project is still in relatively early stages, however the MBEMP aims to achieve a balance between economic development and environmental management of land and sea based practices and activities that threaten the health of the Manila Bay area (GPNM, n.d.). At this stage several reports and workshops have been conducted, stakeholder engagement has been ongoing, and strategies and models have been developed, however, little implementation of nutrient reduction practices has occurred (PEMSEA, UNEP, 2011)

Conclusions

A practical effect and implication of this project is the degree of cooperation and stakeholder engagement required among the relevant agencies in addressing the range of contaminants (including nutrient over-enrichment) threatening Manila Bay. In so doing they will need to address the root causes of pollution by looking at the Manila Bay watershed as a whole and implement integrated plans. This fits with the integrated coastal management and stakeholder approach supported by the project partners. It also lends itself to the application of the integrated modeling and tool box approach developed under this project, the essence of which is to provide a mechanism to help policy makers weigh the environmental and cost effectiveness of various measures in a co-ordinated and integrated manner and make investments accordingly (UNEP, 2011).

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Videos:
https://www.youtube.com/watch?v=YlTy8C5lco0

Case Study Five: Nepal Opening of Urine Bank in Siddhipur, Nepal

Location: Siddhipur, Nepal

Summary of the main problems faced

Urine is mostly water, mixed in with nutrients that plants can quickly and easily absorb. It can be compared to the nitrogen-rich fertilizer urea, except that it's liquid and free. [1] In Siddhipur about 100 Ecosan toilets have been installed by various NGOs; most of these are of a type that allows for separation of urine from faecal matter. Therefore, approximately 35000 litres of urine are available for use as plant fertiliser annually. Various studies found however that a large percentage of the source-separated urine was never used, but leached into the ground instead. For this there were various reasons, the most important of which is that a lot of people don't have fields close to their house, so they cannot very easily use the urine.

Actors involved

United Nations Human Settlements Programme (UN-Habitat)
Swiss Federal Institute of Aquatic Science and Technology (EAWAG)
Local population/citizens

Summary of actions taken

On Monday 17th of May 2010 the "Urine Bank" in Siddhipur, Nepal was inaugurated. The urine bank, which is a spin-off from the STruvite recovery from Urine in Nepal (STUN), is a pilot project aimed at increasing the re-use of nutrients from human urine. Source-separated urine is collected from households which don't have a use for it and is sold for 1 Nepalese Rupee per litre to farmers who use it to fertilise their crops. In a bid to increase the re-use of nutrients the STUN project was set up in a collaboration between UN-HABITAT and EAWAG from Switzerland (www.eawag.ch/stun). The aim of the project is to precipitate Struvite (a phosphorus fertiliser) from the urine and then either use the effluent in drip irrigation or treat it so that it can be leached without causing ground or surface water pollution.

The project found that though the precipitation process is simple and robust it could not be operated profitably if the urine has to be collected from many households. The main reason is that the process needs a magnesium source for the precipitation to happen, but currently there is no market for magnesium in Nepal and thus the price of the magnesium is too high locally. Further experiments with Struvite precipitation will be done at a school in Kathmandu where large amounts of urine are available in one spot.

During the project an increasing number of farmers in Siddhipur have started using urine as a fertiliser, because it yields good growth results while the crops require noticeably less chemical pesticides. As a result, there is enough demand in the village for the urine and all of it will be used as long as it can be bought from a central point. In order to facilitate this a central collection tank has been installed, and a user committee has been established. For the collection the user committee employs one person equipped with a bicycle, and this collector is paid 50% of the revenue from the sales of the fertiliser. The remaining half is used to set up a maintenance fund.

Conclusion

As a result of the work of number of enthusiastic pioneering farmers and the effort of various NGOs, Siddhipur now sets an example of how to increase farm productivity and combat environmental degradation through a new view on human "waste".

(Source: https://sanitationupdates.wordpress.com/2010/05/31/nepal-opening-of-urine-bank-in-siddhipur/)

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[1] http://scitechdaily.com/urine-used-as-fertilizer-to-boost-crop-yields/

Case Study Six: Managing fertilizer phosphorus by soil test level improves food production and environmental performance in China

Summary of the main problems faced

China is a country with a very large population and limited land resources. To ensure food security and sustained increases in crop production, China has paid strong attention over the past 60 years to building up soil fertility.

With a history of several thousand years of reliance on soil organic matter and recycling of crop residues as nutrient sources for maintaining soil fertility, by the early 1950s most arable land in China was low in fertility and had low crop productivity. Since then, use of N fertilizer became a common practice and crop yield increased, removing more P and other nutrients from the soil. Since a large portion of crop-absorbed P is in the harvested part (about 80% for grain crops), soil P was quickly depleted, and low soil P became a severe yield-limiting factor for crop production. By the 1980s, based on the results of the second national soil fertility survey, about 48% of the arable land was very low in Olsen P (below 5 mg/kg), and another 30% was considered low (below 10 mg/kg).

Given that soil P condition, and with the national objective to ensure food security and to build up soil fertility, P fertilizers became an important part of the national fertilization program throughout China, starting from the south and gradually spreading to the north. It has been estimated that from 1981 to 2000, a total of about 133 million metric t of P_2O_5 has been applied to arable lands in China as chemical fertilizers. Assuming the accumulated utilization rate (recovery efficiency) of that applied P was 50%, about 480 kg/ha P_2O_5 accumulated in the soil, on average. If organic P sources were taken into consideration, the P accumulation in the soil would be even greater (Li, 2003).

The overall soil P balance (i.e. P input – P output) changed quickly after the extended period of large negative balances that continued from the 1950s into the 1960s and 1970s. By the 1980s, the P balance in arable lands became positive and P began to accumulate in soils. It has been estimated that soils in China received a P surplus of about 79 kg P_2O_5/ha in 2005. With this high P balance in soil-crop systems, it was expected that available soil P would build up gradually and that soil P fertility would be improved. Although there is no direct national survey data to verify this, it is now generally believed that the percentage of total arable land with P deficiency (i.e. Olsen P level below 10 mg/kg) has declined to less than 50%. The results of P analyses performed by the CAAS-IPNI Soil and Plant Analysis Laboratory on 43,156 soil samples collected from 1991 to 2007 also showed that 48% of soils tested were deficient in P.

Actors involved

Chinese farmers
Government officials and scientists

Summary of actions taken

In recent history, the high rate of P fertilization helped China to increase crop production and to build up soil P fertility. However, at the same time, with the increased accumulation of P in the soil, the risk of P losses from crop land and its effect on the environment cannot be ignored. Although there is only limited information available about the contribution of P losses from crop land to surface water pollution, it has been reported that 14% to 68% of the total P in selected lakes came from agricultural lands (Li, 2003).

With these changes in soil P fertility levels in China, for both economic and environment benefits, the following points were considered when strategy for P fertilization was developed:

1. Application strategy for P should be according to soil test. Apply enough to build soil P levels when the Olsen soil test is below 20 mg/kg for most crops. Replenish crop removal on soils above this level, and apply no P on soils with very high levels of soil test P.
2. For all conditions, attention is needed to control soil P losses through soil erosion.

3. A P fertilizer program should be developed for the entire crop rotation with attention to increasing overall P fertilizer use efficiency. Pay attention to long-term accumulated P recovery efficiency for different cropping systems.
4. Realize that different crops (i.e. vegetables vs. grain crops) have different requirement for soil P levels. Different critical levels of soil test P for different yield levels may also need to be identified.

Results so far/conclusion

The change of fertilizer efficiency in China followed the Law of Minimum and other related principles in plant nutrition. Before the 1950s, Chinese farmers mainly used organic manures to maintain the nutrient balance in soil/crop systems with relatively low production capacity. After the 1950s, with increase of crop yield and increased use of N and P, higher crop removal of K resulted in depletion of available K in the soil and negative balances for K in soil/crop systems. Based on the study and nutrient balance estimated by Li Jiakang in 2003, the input-output balance of N and P in the soil/crop system turned from negative to positive in the mid 1980s, but the balance for K was still negative in 2000.

(Source: Plant Nutrition- Nutrient Management Planning, http://www.ipni.net/publication/4rmanual.nsf/0/5D751ABF7818737985257CE0006BEE14/$FILE/4RMANUAL-Case%20Study%209.1-4.pdf)

Case Study Seven: The EU Nitrate Directive

The "Nitrates Directive" was adopted by the European Union (EU) member states in 1991. The main goal of this Directive is to improve water resources quality across EU. As a result, significant efforts have been made to reduce nutrients pollution from agricultural sources (European Commission, 2010; Monteny, 2001).

Summary of the main problem faced

The European water resources have been significantly impacted by improper agricultural practices such as the excessive use of nitrogen-based fertilizers (Figure 1) which eventually ended up in the aquatic environments (European Commission, 2010). Nitrogenous compounds not only are harmful to aquatic environments (Figure 2) but also can be dangerous to human health if the nitrogen-contaminated water is used as a drinking water supply (see Module 2). As agriculture was the main source of water resources pollution, the Nitrate Directive was adopted by the EU countries to control the further pollution of water resources by planning, developing, and practicing effective and innovative management strategies to improve the water quality of polluted resources (European

Commission, 2010; Monteny, 2001).

Figure 1. Application of fertilizers

Figure 2. Surface water contamination

Source: http://ec.europa.eu/environment/water/water-nitrates/index_en.html

Summary of actions taken

The EU Nitrate Directive sought:

- To identify the existing nitrate-polluted water resources (e.g., containing nitrate above 50 mg/L of nitrate) or water resources at risk of pollution through expanding the water quality monitoring networks across the European countries and reporting every four years (European Commission, 2010; Monteny, 2001)
- To establish “Codes of voluntary good agricultural practices” (European Commission, 2010; Monteny, 2001)
- To designate “Nitrate-vulnerable zones” where the nitrate concentration in groundwater resources are above 50 mg/L (European Commission, 2010; Monteny, 2001).
- To plan, develop, and implement “specific action programs” to control the agricultural activities in the Nitrate-vulnerable Zones (Figure 3) (European Commission, 2010; Monteny, 2001). Moreover, to include measures in the action programs to (i) decrease the fertilizers use, (ii) manage livestock (e.g., “minimize storage capacity for livestock manure”), and (iii) control the application of nutrients near water resources (Table 1) (European Commission, 2010; Monteny, 2001).
- To develop innovative nutrient control technologies for manure management (European Commission, 2010; Monteny, 2001)
- Innovative feeding techniques such as low nitrogen diets were practiced to “improve feed conversion efficiency” and lower the “nutrient excretion” (European Commission, 2010; Monteny, 2001)

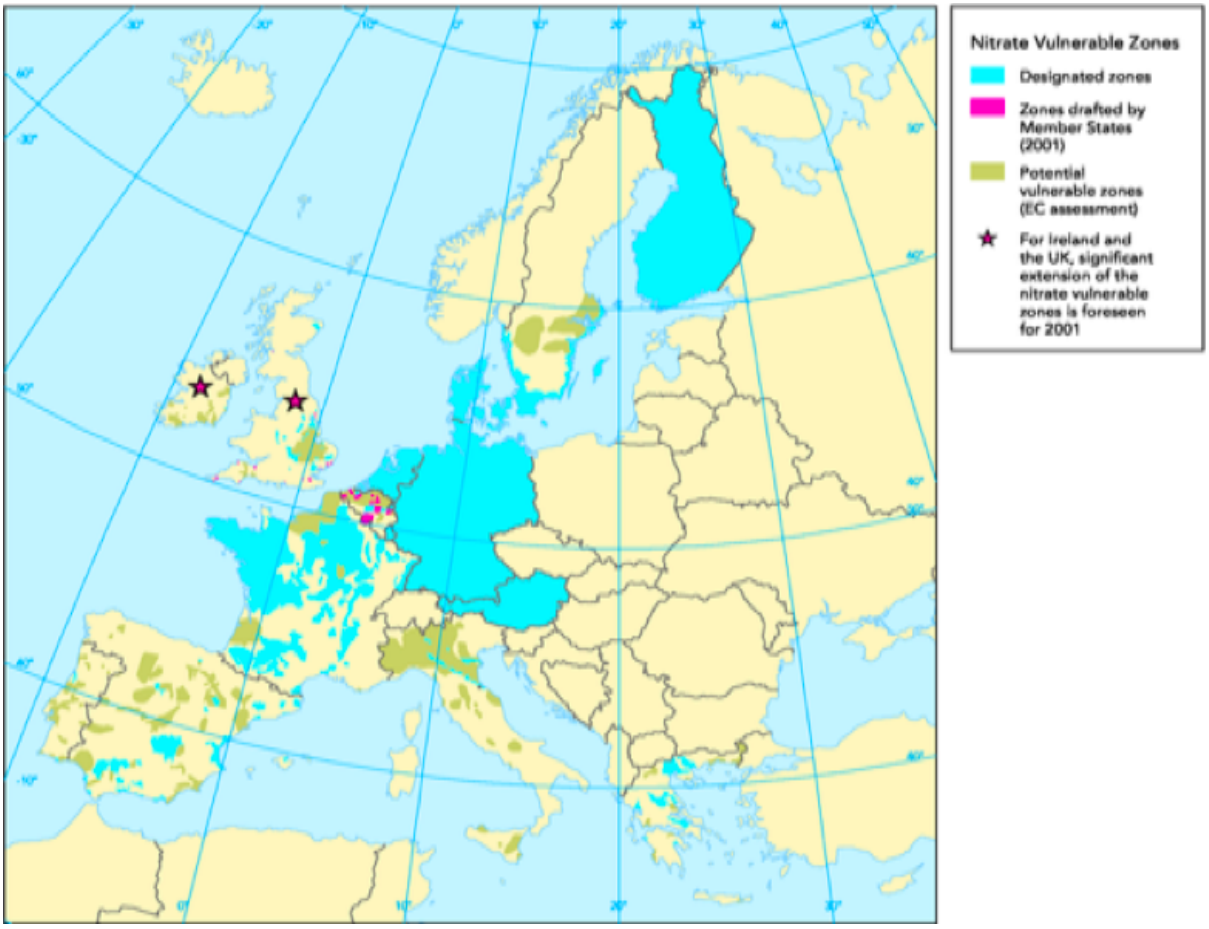

Figure 3. Nitrate vulnerable zones (Source: http://amaltea.co/es/proyectos/directiva-nitratos/)

Table 1. Some of the "Action Programme Measures" adopted by the EU countries to support the Nitrate Directive (taken from (Monteny, 2001))

Measure	**Example**
Periods when the application of fertilizers is not appropriate	From 1 October to 1 March
Fertilizers are not allowed on sloped soils if	slope > 6%
Application of fertilizers is not appropriate on	snow-covered, soaked, frozen soils
Fertilizers are not allowed near water bodies (including buffer strips)	5-10 m when slope < 6%
	10-20 m when slope > 6%
Effluent storage works	Sufficient storage capacity
Capacity of manure storage	6-10 months
Land use management such as crop rotation, permanent crop maintenance	Winter crops

Fertilization plans, spreading records	Soil analysis

Results so far

Although tremendous efforts are needed to restore the water resources across EU, the implementations of sustainable practices have shown promising results (European Commission, 2010). Some of the noticeable effects of the EU Nitrates Directive are as follows:

- Nitrate (NO_3) concentrations in surface water either remained unchanged (e.g., below 50 mg/L) or significantly reduced (at "70% of monitored sites, between 2004 and 2007") (European Commission, 2010; Monteny, 2001).
- The quality of groundwater was either stable (e.g., below 50 mg/L) or considerably improved ("at 66% monitoring points") (European Commission, 2010; Monteny, 2001).

The following elements were the main factors that had significant effects on the successful implementation of EU Nitrate Directive.

- Financial and scientific supports to expand monitoring networks for assessment of the quality of water resources
- Substitution of existing agricultural practices with innovative and environmentally friendly techniques
- Raising of public (farmers) awareness regarding the effect of their activities on the water resources

Conclusions

This case study showed an international level success in nutrient management, albeit within the specific and unique policy context of the EU. Effective and sustained communication between scientists, governments, and public/farmers not only secured economic benefits of agricultural activities but also led to less contamination of water resources.

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Case Study Eight: The Global Partnership on Nutrient Management

Summary of the main problem faced

The use of nitrogen and phosphorus, along with other nutrients, are essential to growing crops and ensure food security for a growing population. However, we have seen time and time again that in many regions of the world, increased access to fertilizer and the spread of intensive agriculture has tremendous negative impacts on the environment and human health. The issue is how to reconcile the need for food without undermining the very resource base upon which we all depend.

The Global Partnership on Nutrient Management (GPNM) was launched at the UN Commission on Sustainable Development in 2009 in response to this 'nutrient challenge' facing every part of the globe: how to reduce the amount of excess nutrients in the global environment consistent with global development, poverty reduction and food security? The GPNM reflects a need for strategic, and coordinated international advocacy to trigger governments and stakeholders in moving towards lower nitrogen and phosphorus inputs to human activities. It provides a platform for governments, UN agencies, scientists and the private sector to forge a common agenda, build capacity, share and mainstream best practices and integrated assessments, so that policy making and investments are effectively 'nutrient proofed'. The GPNM also provides a space where countries and other stakeholders can forge more co-operative work across the variety of international and regional fora and agencies dealing with nutrients, including the importance of assessment work.

Summary of actions taken

Initially, the GPNM focused on awareness raising, consensus building, synthesizing existing information, and identifying assessment gaps in certain regions (particularly Africa), and supporting stakeholders as necessary. As of 2014, the GPNM has focused on organization of and participation in global, regional, and national meetings to raise awareness of the issues and mobilize action.

Furthermore, the GPNM has facilitated the creation of outreach material, covering issues such as nutrient pollution, eutrophication and ocean acidification, case studies on efficient nitrogen use, the innovative reuse of urea in wastewater as fertilizer, and the negative impacts of mariculture.

The GPNM Secretariat, in collaboration with its partners, has also implemented a UNEP/GEF project entitled "Global foundations for reducing nutrient enrichment and oxygen depletion from land based pollution, in support of Global Nutrient Cycle (GNC)". The core objective of the project is "to provide the foundations (including partnerships, information, tools and policy mechanisms) for governments and other stakeholders to initiate comprehensive, effective and sustained programmes addressing nutrient over-enrichment and oxygen depletion from land based pollution of coastal waters in Large Marine Ecosystems". This approach has been applied to the Manila Bay watershed in the Philippines (as seen in case study four) and Chilika Lake in India.

Results so far

The Steering Committee of the GPNM meets regularly and the Programme is now a key deliverable under the UNEP Programme of Work for 2014-2015. The GPNM has also launched regional platforms in Asia and the Caribbean. Specific Task Teams, led by governments or industry representatives, each focus on policy issues; the development of an investment decisions toolbox; definitions of, indicators and targets for nutrient use efficiency; or mobilization of support for the GPNM.

Mobilization and advocacy efforts have led to nutrient management being placed on the agenda of several governments. Academics and policy-makers have been spurred to promote this initiative; for instance, a professor from China Agriculture University (a member of the GPNM) is leading an effort to integrate a collaborative global approach to phosphorus sustainability. It is possible this would be integrated in UNEP's 2050 Sustainable Development Plan. With the publication of its 2013 report "Our Nutrient World," the GPNM catapulted the nutrients issue from a fairly restricted scientific viewership into broader academic discussion (300 articles published worldwide on the subject) as well as mainstream discourse (such as extremely high viewership in news media such as *The Independent* and *The Guardian* in the UK). It has also influenced discussion and agenda-setting around the post-2015 SDGs targets.

OUR NUTRIENT WORLD

"Our Nutrient World" put forward the notion that **fullchain nutrient use efficiency** (NUE) should be an indicator of successful nutrient management plans. Fullchain NUE "means the ratio of nutrients in final products used by society (food crops eaten by people, animal products eaten by people, other durable nutrient products, etc.) to the original nutrient inputs (e.g. mineral fertilizers, biological nitrogen fixation, etc.). This approach gives countries the maximum flexibility to see how they can improve. In many cases this will be by improving technical efficiency, but could equally be by considering choices between societal consumption patterns of different efficiency."

"Our Nutrient World identified a list of 10 key actions for change (Fig. 1). Based centrally around the idea of improving NUE, these include technical measures in crop and livestock agriculture and for better use of animal manures (Actions 1–3). They cover measures for the transport and industry sectors (Actions 4–5) and in waste water treatment sector (Actions 6–7), in both cases emphasizing the need to improve recycling of existing nitrogen and phosphorus sources (including from nitrogen oxide emissions and from wastewaters). Each of these actions focus on challenges for different production sectors in society. As regards citizens choices, humans can improve NUE and reduce emissions substantially by energy and transport saving – both aligning well with air pollution and climate policies – and by reducing our consumption of animal protein (Actions 8–9). Finally, the tenth key action considers the opportunities for integration and optimization leading to overall improvements in NUE. This includes both temporal and spatial aspects, such as more closely linking crop and livestock farming systems, so as to make better use of manures (Billen et al., 2013). Contrary to the drive to scale-up crop and livestock agriculture in different regions, there is thus substantial potential for localization to improve nutrient use efficiency and reduce pollution levels."

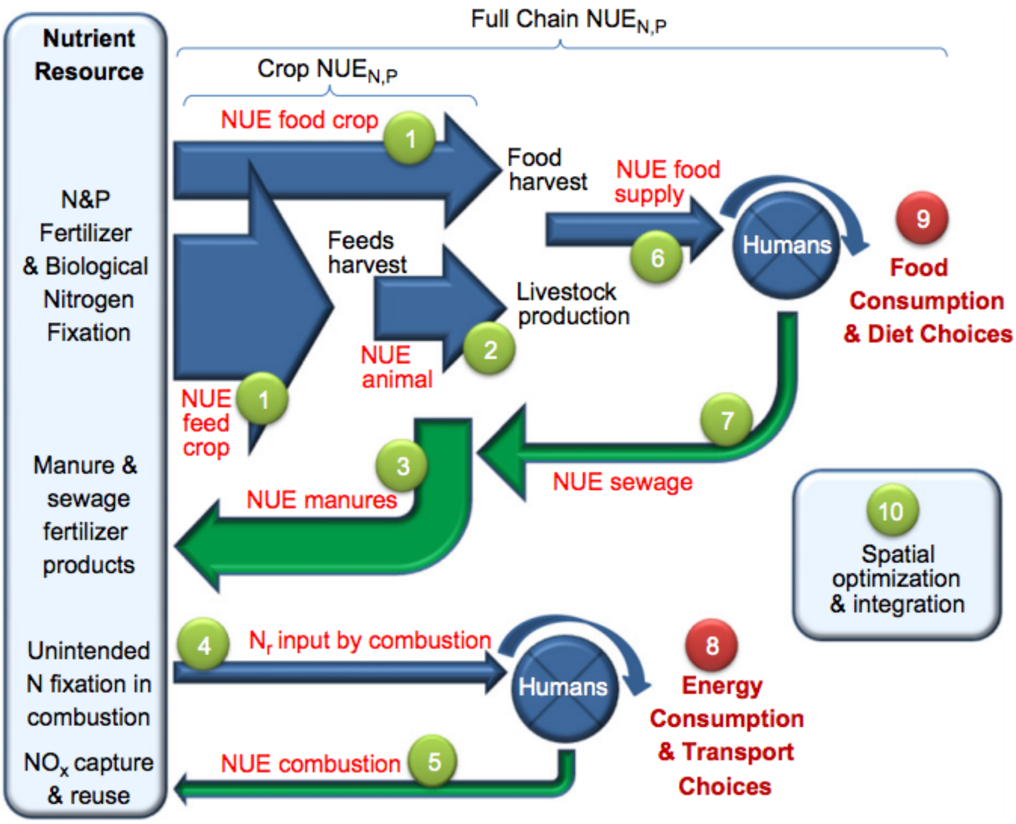

Fig. 1. Summary of major global nutrient flows highlighting the potential to improve nutrient use efficiency (NUE) for nitrogen (N) and phosphorus (P) through 10 numbered key actions (for details see text).

Source: Sutton, M.A., et al., The Global Nutrient Challenge: From Science to Public Engagement (2013). http://dx.doi.org/10.1016/j.envdev.2013.03.003

The GNC project has developed a searchable global toolbox of practices, policies, and case studies and an ecosystem health report card to assess nutrient impacts for policymakers (which has impacted the Chilika Lake Management Plan, for instance). It has also promoted and supported organizations developing quantitative nutrient modelling, in which nutrient loading can be correlated with effects such as hypoxia and eutrophication, as well as with economic costs (including analyses like the economic nitrogen cascade we have seen in the Chesapeake Bay). The GPNM is now holding capacity- and knowledge-building workshops in order to assess lessons learned from its pilot projects and devise replication strategies.

Conclusions

The development of the GPNM demonstrates the need for multi-level governance and a diversity of stakeholders to come together to address this global issue. The nutrient challenge requires consensus-building and coordinated agenda-setting, information-sharing, policy-making, and financing.

The GPNM has made major strides in raising awareness and developing tools that can be used by governments to implement their national nutrient programs, but remaining challenges include increased population pressure and market forces that are demanding the intensification of agriculture on a globally unprecedented scale.

Links + Readings

The Global Partnership on Nutrient Management official website: http://www.nutrientchallenge.org/

The GPNM Toolbox to search for BMP, policies, case studies, reports, and calculator tools: http://nutrientchallenge.org/toolbox2/gpnm-toolbox

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End of Module Discussion Questions

1. Can you think of other examples that demonstrate best or worst case approaches?
2. Are any of the cases discussed in this module reminiscent of problems and solutions in your geographic area?
3. Which case study introduced in this Module do you find the most demonstrative of the issues we have discussed in the course so far, and why?
4. Choose one of the case studies above and discuss what decisions were well-made, and what could have been done better. Take into account economic, social, and environmental factors when conducting your assessment.

Module Nine: Advanced Leadership Certificate Track

Students who wish to continue with the Advanced Leadership Certificate Track will need to commit themselves to at least another twenty hours of work for this course, and to delve deeply into a realizable project plan that they can describe in a written assignment or video presentation. They can do this on their own, or in teams of 2-3 students. In cases where the course is taught as a blended course, professors/teachers will conduct this aspect of the course in-class and grade the assignments. For students taking the course purely online, their assignments will be peer-graded (i.e., a group of students will grade each assignment and an average grade will be distributed).

Students could be assigned to work in teams of 2-3 students, or they could do the assignment on their own. Better to allow for flexibility here.

Scenarios for this assignment:

a) Develop and describe a wastewater/nutrient management plan for your local community.
b) Propose a strategy for financing using an innovative financial mechanism wastewater/nutrient management in your country.
c) Compose an essay on one of the pressing problems inherent in contemporary wastewater/nutrient management. Please include a word-count; the essay should not exceed 5,000 words.
d) Analyze the utility of a recent technological advance in wastewater management or nutrient management.

Again, for students taking the course online only, they will peer evaluate each other's work. This in itself is a considerable assignment, since each student generally reads 2-3 other papers and follows a marking key to arrive at a grade. Details can be found on the online MOOC.

Common Bibliography

NOTE: this bibliography lists references from all of the modules detailed in this sourcebook, though there may be additional sources within the modules and the case studies which are not found here. Our apologies for any discrepancies. Please see the "Annotated Bibliography" and suggested readings at the end of each module for further reading, and the sources referenced at the end of each case study in Modules 7 and 8.

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Glossary

NOTE: there is also a glossary in the actual MOOC content of the course.

Anoxic: an adjective applied to water with low oxygen content.

Anthropocene: a term used to describe the current human-dominated geological epoch. First coined by Nobel-prize-winning atmospheric chemist Paul Crutzen, the epoch was first said to have begun in the late 18th century, when analysis of air bubbles trapped in polar ice shows the beginning on increases in atmospheric carbon dioxide and methane (Crutzen, 2002), but there has since been controversy about when exactly it can be said to have begun.

ATP (Adenosine Triphosphate): the basic unit of cellular energy, produced through cellular respiration and photosynthesis.

Biochemical Oxygen Demand (BOD): the amount of dissolved oxygen used by aerobic bacteria to consume or degrade organic matters (usually carbonaceous (CBOD) and nitrogenous (NBOD)) in wastewater. The BOD value is typically measured from the difference between the initial dissolved oxygen in a sample of water/wastewater and the dissolved oxygen after a period of time (usually 5 days e.g., five-day BOD or BOD_5) and it is reported as milligrams per liter (mg/L) (Davis and Cornwell, 2014).

Bioavailable: refers to a nutrient being in a form that is capable of being accessed by living organisms

Biosphere: the layer of the Earth where life exists. It ranges from the depths of the ocean to about 10 km above sea level. It can also be defined as the sum of all ecosystems on Earth. Finally, in general terms, it can be used to define closed, self-regulating ecosystems.

Build-operate-transfer (BOT): a form of project financing wherein a private entity receives a concession from the private or public sector to finance, design, construct, and operate a facility for a period of time stated in the concession contract. At the end of this period, the private entity is required to transfer the facility to its owner for no cost.

Brownfield site: "a former industrial or commercial site where future use is affected by real or perceived environmental contamination" (Dictionary.com, 2017). "Brownfields are often abandoned, closed or under-used industrial or commercial facilities, such as an abandoned factory in a town's former industrial section or a closed commercial building or warehouse in a suburban setting. Brownfields, however, can be located anywhere and can be quite small. For instance, many dry cleaning establishments and gas stations produced high levels of subsurface contaminants during their operation. A second growth forest or a vacant lot may contain contaminated fill or be the site of the illegal dumping of pollutants. According to the EPA there are presently over half a million brownfields in the United States, but this number only includes sites for which an ESA has been conducted. The actual number of brownfields is certainly many times greater." (Brownfield Action, 2017).

Brundtland Report: a report published by the United Nations World Commission on Environmental and Development (UNWCED) in 1987 officially entitled *Our Common Future.* This report put the concept of sustainable development firmly in the global political sphere and laid the groundwork for the Earth Summit in Rio de Janeiro in 1992.

Capital Expenditure (CapEx): funds used by a company to acquire or upgrade physical assets such as property, industrial buildings or equipment. It is often used to undertake new projects or investments by the firm. This type of outlay is also made by companies to maintain or increase the scope of their operations. These expenditures can include everything from repairing a roof to building, to purchasing a piece of equipment, or building a brand new factory (Investopedia, 2017).

Centralized Wastewater Treatment Systems: facilities that receive raw sewage from public sewer collection systems.

Circular economy: a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer *et al,* 2017).

Chemical Oxygen Demand (COD): the amount of oxygen used for oxidizing of organic matter in wastewater by a strong chemical oxidizing agent (e.g., potassium dichromate). It is reported as milligrams per liter (mg/L) (Davis and Cornwell, 2014).

Cultural services: the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (MEA Board, 2005).

Decentralized Wastewater Treatment Systems: on-site individual or clusters of treatment systems that treat private and small communities' sewage.

Discounted Cash Flow (DCF): a valuation method used to estimate the attractiveness of an investment opportunity. DCF analysis uses future free cash flow projections and discounts them to arrive at a present value estimate, which is used to evaluate the potential for investment. If the value arrived at through DCF analysis is higher than the current cost of the investment, the opportunity may be a good one (Investopedia, 2017).

Discount Rate: the rate to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate (Investopedia, 2017).

Divestiture: The partial or full disposal of a business unit through sale, exchange, closure or bankruptcy (Investopedia, 2017).

Ecosystem services: the benefits that humans derive from ecosystems. The Millennium Ecosystem Assessment developed in the early 2000s categorized these into **supporting**

services, **provisioning services**, **regulatory services**, and **cultural services** (see entries for each of these).

Eutrophication: a phenomenon that occurs due to the excessive influx of nutrients into a water body, often, although not always due to agricultural runoff or discharge of nutrient-rich wastewater effluent. This influx results in excessive growth of aquatic plants such as algae (algal blooms) due to the availability of high concentrations of nitrogen and phosphorous compounds (mainly PO_4). This phenomenon leads to the extensive depletion of oxygen and consequently has adverse effects on fish and other aquatic life and reduces the quality of water for drinking and recreational activities. Note that this phenomenon can occur naturally, but generally over a much longer time-scale than when it is human-induced.

Free Cash Flow: a measure of a company's financial performance, calculated as operating cash flow minus capital expenditures. FCF represents the cash that a company is able to generate after spending the money required to maintain or expand its asset base. FCF is important because it allows a company to pursue opportunities that enhance shareholder value (Investopedia, 2017).

Full chain nutrient use efficiency: the ratio of nutrients in final products used by society (food crops eaten by people, animal products eaten by people, other durable nutrient products, etc.) to the original nutrient inputs (e.g. mineral fertilizers, biological nitrogen fixation, etc.) (Sutton *et al.,* 2013).

Haber-Bosch process: a method of directly synthesizing ammonia from hydrogen and nitrogen that involves combining nitrogen from the air with hydrogen under extremely high pressure and moderately high temperature (Encyclopaedia Britannica, 2017).

Heterotrophic: an organism that gets its carbon (necessary for growth) from the consumption of other organisms (organic carbon) as opposed to fixing carbon from non-organic sources as autotrophs like plants do.

Hydrosphere: the liquid water component of the Earth, including oceans, seas, rivers, lakes, etc.

Lithosphere: the hard crust and upper mantle of the Earth, made up of tectonic plates.

Nitrogen cycle: the process through which nitrogen is cycled through the biosphere, atmosphere, and geosphere. This process consists of five main steps:

(1) **Nitrogen fixation:** the process by which N_2 is converted to ammonium (NH_4^+), generally by nitrogen-fixing bacteria or by burning fossil fuels but also occasionally by lightning, forest fires, and lava flows
(2) **Nitrogen uptake:** the process through which ammonium is taken up by living organisms and incorporated into organic molecules such as DNA.
(3) **Nitrogen mineralization**: the conversion of organic nitrogen back into ammonium when organisms die, decompose, and are consumed.

(4) **Nitrification**: the conversion of ammonium to nitrate (NO_3^-) by bacteria in oxygen-rich environments. Note that, due to its negative charge, nitrate is easily washed out of soils, leading to decreased soil fertility and increased nitrate concentrations in downstream surface and groundwater.

(5) **Denitrification:** the conversion of nitrate and nitrite to dinitrogen (N_2) and nitrous oxide gas (NO_2) by denitrifying bacteria. Both dinitrogen and nitrous oxide are gaseous, and are therefore released into the atmosphere. To return to organic form, this gas must be converted to ammonium via nitrogen fixation. Note that nitrous oxide is a greenhouse gas, and therefore contributes to climate change.

Non-point source pollution: pollution resulting from many diffuse sources, in direct contrast to point source pollution which results from a single source. Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrological modification (rainfall or snowmelt) where tracing the pollution back to a single source is difficult (US Environmental Protection Agency, 2017).

Overdrafting: **"**The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin" (Office of Water Programs, 2017). Overdrafting can result in a variety of social and ecological issues, including the depletion of a water source.

Social-ecological system: An ecosystem with a prominent human dimension, in which human communities have important mutual interactions with an ecological system. The notion of a social-ecological system arises from the need to analyze human and natural environments in an interdisciplinary manner in order to understand the ways that human activity and natural ecosystems influence and impact each other. The social-ecological system is a complex, adaptive system in which humans and "nature" are constantly interacting (Zurlini, 2008).

Supporting services: services that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation (MEA Board 2005).

Sustainable Development Goals (SDGs): a framework of 17 goals and 169 targets across social, economic, and environmental areas of sustainable development to be met by 2030. The SDGs form part of the 2030 Agenda for Sustainable Development adopted in 2015 by the Members of the United Nations.

Transfer-operate-transfer (TOT) is a private investor buys the property and operational rights of a facility, and receives his returns through normal business operations for a period of time stated in the concession contract. At the end of this period, the private entity needs to transfer the facility to its owner for no cost.

Phosphorus cycle: the process by which phosphorus cycles through living and non-living matter. Phosphorus may be contained in rock, soil, water, and living organisms. Weathering causes rock to release inorganic phosphate ions into soil and water. Living organisms take up these ions and incorporate them into organic molecules such as DNA, rendering them organic, and, eventually releasing the phosphate back to the soil when they die. Through the process of **mineralization**, bacteria in the soil then break down the organic phosphate into inorganic phosphate so that is it once again available for uptake by other living organisms, or it can end in sediments that are eventually incorporated into rocks once more (Science Learning Hub, 2013).

Point source pollution: "any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack" (Hill, 1997).

Pollution: the introduction of contaminants into the natural environment that cause adverse change. Pollution can take the form of chemical substances or energy, such as noise, heat or light. **Pollutants**, the components of pollution, can be either foreign substances, energies or naturally occurring contaminants (Pollution, 2017).

Primary production: the synthesis of organic compounds from atmospheric or aqueous carbon dioxide. It principally occurs through the process of photosynthesis, which uses light as its source of energy, but it also occurs through chemosynthesis, which uses the oxidation or reduction of inorganic chemical compounds as its source of energy. Almost all life on Earth relies directly or indirectly on primary production. The organisms responsible for primary production are known as ***primary producers*** or autotrophs, and form the base of the food chain (Primary production, 2017).

Provisioning services: the products people obtain from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources (MEA Board, 2005).

Regulating services: the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification (MEA Board, 2005).

Securitization: the process of taking an illiquid asset, or group of assets, and through financial engineering, transforming them into a security (Investopedia, 2017).

Shadow prices: the avoided costs resulting from removing pollutants during wastewater treatment.

Systems Thinking: an approach to problem solving that takes the entire system into account, rather than just examining the component parts of a system.

UN Agenda 21: a comprehensive plan of action and development adopted by more than 178 governments at the United Nations Conference on Environment and Development in Rio, Brazil, in 1992. The plan outlines actions to be taken globally, nationally and locally by organizations of the United Nations system, governments, and major groups in every area in which human impacts on the environment (United Nations Department of Economic and Social Affairs, 2016).

Wastewater: a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture ef uent, either dissolved or as suspended matter.

Water stratification: a process by which water bodies form distinct layers of different properties that do not mix. These water layers may differ in salinity, temperature, oxygen content, or density. This may lead to a lack of oxygen in lower layers, for example.

Wicked Problems: a problem that is difficult or impossible to solve because of incomplete or contradictory knowledge, changing requirements that are often difficult to recognize, the number of people and opinions involved, and the interconnected nature of these problems with other problems. For more detail and a discussion on the ten characteristics of a wicked problem, see module 5.

Willingness to pay (WTP): the maximum amount an individual is willing to sacrifice to procure a good or avoid something undesirable (Willingness to pay, 2017). The average willingness to pay is a tool often used to assess the economic value of ecosystem services.

Zero Waste: a philosophy that encourages the redesign of resource life cycles so that all products are reused. No trash is sent to landfills or incinerators. The process recommended is one similar to the way that resources are reused in nature (Zero waste, 2017)

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