OCEAN SEWAGE ALLIANCE

A Practitioner's Guide For

OCEAN WASTEWATER POLLUTION

#REIMAGINEYOURWASTE

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It's time to look at your pee and poo with fresh new eyes

EXECUTIVE SUMMARY

Ocean wastewater pollution is serious, pervasive, and overlooked. Ignoring ocean wastewater pollution has consequences which threaten local and national economies, public health, fisheries, and coastal security, and can even amplify the impacts of climate change. Efforts to improve ocean health have most recently focused on establishing marine protected areas, improving fisheries management, and restoring coastal habitats. However, all this work is dependent on good water quality in order to succeed. By continuing to ignore the threat of ocean wastewater pollution, we put our past and future investments at risk. While there is significant interest from conservation practitioners to address this threat—because the problem has been neglected—there is minimal guidance on how to proceed. This report synthesizes what we know about the impacts of ocean wastewater pollution, provides a primer for those unfamiliar with management of human waste and the water, sanitation, and hygiene sector (WASH), and points to opportunities to address the threat so both people and oceans benefit.

The perfect treatment solution does not yet exist. There is no silver bullet or prescription for every place. We understand the problem, and, in most instances, we have the knowledge and technology to solve it. The greatest challenge is to foster better understanding and buy-in so that we can mobilize the public, industry, and government to take action to address this threat. Additionally, by employing solutions that treat human waste not as trash, but as a valuable resource, far greater benefits can be achieved than just eliminating wastewater pollution. The potential to provide energy, water, fertilizer, jobs, climate solutions, and opportunities for some of the poorest and most marginalized populations is substantial and makes the case for addressing this threat all the more compelling.

Meeting the challenge is, in essence, the reason this report was created. If you are someone working in ocean conservation and/or natural resource management, and if these are all new topics to you, then you are the audience for this document. This document is meant to be an overview for people unfamiliar with management of human waste and its impacts on marine environments and to help in becoming fluent in terminology around wastewater treatment and management. When addressing any aspect of sanitation and wastewater pollution, decision-makers need a reference to give them a fundamental understanding of the problem, the impacts, the solutions, and the individuals and entities that are major players in the world of ocean wastewater pollution.

Because this threat has been largely ignored, there are limited resources and guides available to help address these local problems. This report, and other associated resources, are aiming to change that. We outline a few of the initiatives and resources under development at the time of publication. We will update as needed.

The Our Shared Seas portal now has an Ocean Sewage Pollution Hub, that includes a primer, expert interviews, and research digests, and will continue to be updated. This resource focuses on donor and NGO audiences to educate and encourage engagement on important ocean health topics.

The Reef Resilience Network recently created a Wastewater Pollution Toolkit that presents resources and curriculum designed for a conservation practitioner audience. They currently host a webinar series on ocean sewage pollution and share information, including case studies and literature summaries. In the near feature, they will be sharing audience-specific topic briefs and an organization and project database. There also will be a web-based guide and supplemental resources for sanitation managers interested in using natural solutions, such as constructed wetlands. The Reef Resilience Network is currently working to develop a searchable directory to support organizations around a specific expertise or geography. Existing case studies can be found on their Case Studies site. Please contact us if you have a case study to share.

Finally, the Ocean Sewage Alliance officially launched in June 2021. The Alliance is a collaborative partnership of academic researchers and organizations from wide-ranging sectors, including conservation, WASH, technology, public health, and development. From this partnership, we expect collaboration around problem solving, fundraising, scientific research, project implementation, communications, and outreach. An awareness campaign was one of the first products of the Alliance, with implementation beginning in 2021 and continuing through 2022. The Ocean Sewage Alliance welcomes all parties interested in solving this difficult challenge using the most sustainable and beneficial methods possible. Please reach out to us at info@oceansewagealliance.org for more information.

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INTRODUCTION

Wastewater pollution is a serious threat to ocean health and, in turn, to the health of the planet and its inhabitants. Wastewater pollution and lack of proper sanitation in general is also a threat to human health and well-being. Yet how human waste is managed and disposed of is not well regulated at the municipal, national, or international scale. It has been a largely invisible problem. It becomes visible when people begin to get sick, fisheries become impaired, beaches have to close, and toxic algal blooms wreak havoc and start making the news. But right now, there is a great opportunity to solve this problem once and for all. This report synthesizes what we know about the impacts of ocean wastewater pollution, provides a primer for those new to the sanitation space, and points to opportunities to address the threat so both people and oceans benefit.

The conservation sector has multiple roles to play to address ocean wastewater pollution. First, conservation practitioners serve as a voice for the ocean. This voice is critical given that it is currently lacking in places where plans and designs are underway, technology is being developed, and decisions are being made. Natural resource management and conservation professionals share deep knowledge about how vulnerable ecosystems function, how they are impacted, and what steps need to be taken to avoid damage to those ecosystems. Conservation practitioners can provide insight into how to best use nature as a solution and where it is possible to maximize ecosystem services. Finally, the conservation sector not only has an interest in ensuring that we are not polluting the environment, but it can also advocate for solutions that create multiple environmental benefits, including recycling of important resources such as clean water, fertilizer, and clean energy.

This report translates the specialized technical detail and processes of sewered and non-sewered sanitation systems into plain language for a lay audience. If you are someone working in ocean conservation and/or natural resource management, and if these are all new topics to you, then you are the audience for this document. This document is meant to be an overview for people unfamiliar with the impacts of wastewater on marine environments and how human waste is managed, to help in becoming fluent in terminology around the treatment and management of wastewater. This guide is particularly useful to those involved in policy-making that need to build the case for addressing wastewater pollution and provides an introduction to the solution space in order to structure those early conversations with decision-makers.

Objectives

This document provides an overview of topics related to ocean wastewater pollution, including the impacts on ocean health, the connection to the global sanitation crisis, how human waste is currently managed and treated, solutions and technology already in use or on the horizon, and the status of related policy initiatives. We are constantly learning more about the impacts of and solutions to this threat to ocean and human health. Consequently, this guide will be updated as we learn.

The main objective of this document is to provide conservation practitioners and policymakers with a foundation in the problem of ocean wastewater pollution, so that they are well prepared to dive into what may be new content and unfamiliar concepts. More specifically, this document aims to provide:

- A comprehensive view of causes and impacts of wastewater pollution at the global scale, including information about specific effects on ocean organisms, as well as the magnitude of the threat.
- A reference guide for conservation practitioners to learn about wastewater treatment technology, increase fluency in terminology and technology, and prepare to engage in cross-sector collaboration/problem solving.
- A range of ocean-friendly solutions that are already in use, or in development.
- Examples of efforts to mitigate wastewater pollution in coastal areas both as a reference and a point of inspiration.

Human Waste & Taboo

Often called the silent crisis, the global sanitation crisis is wrought with taboo, we avoide mentioning the toilet, using words for human excrement, sharing a toilet or even having a toilet.

There has been great progress in the last two decades to break down these taboos. A pioneer in the space, Jack Sim (aka Mr. Toilet), a man who dared to discuss toilets publicly, founded the World Toilet Organization, and even started World Toilet Day in 2001 (November 19th) – he has been breaking taboo and "making sanitation sexy" ever since. The United Nations officially recognized World Toilet Day in 2017, and the attention around this issue (and the humor) has continued to grow. In 2018, Bill Gates addressed the audience at the Reinvented Toilet Expo in China with a jar of human feces next to him on the lectern, in a bid to inspire inventors and philanthropists to get involved in creating new off-grid toilet solutions. In this act, Gates, one of the world's leading philanthropists, and co-founder of The Bill and Melinda Gates Foundation signaled an end to the polite taboos that have kept the global wastewater pollution and sanitation crisis from being effectively addressed. While this is great progress, taboo still exists. The more we talk about it, the more the power of taboo is diminished. This report aims to contribute to breaking taboo as a critical part of solving the problem of ocean wastewater pollution. As Mr. Toilet says, "what we don't discuss, we can't improve."

A Note About Terminology

We speak about human waste differently, depending on our cultures, nationalities, and even fields of work, so it is important to know these distinctions when engaged in cross-sector collaboration. Colloquially, the general use of the term *sewage* means any human excrement and household grey and/or black water, regardless of where or how it has been stored and transported. Technically, the term *sewage* refers to human excrement that has been conveyed through a conduit using water – typically where plumbing and centralized sewer systems are in place. Instead, sanitation practitioners use the term *wastewater* to refer to discharged human waste, regardless of origin. When we talk about *wastewater effluent,* we must also remember it also includes household wastes like phosphates and a host of chemicals of emerging concern, as well as urban run-off and associated pollutants. Additionally, human waste includes endocrine disruptors, pharmaceuticals, recreational drugs, petrochemicals, pathogens, and more. All of these contaminants pose a threat to ocean and human health and are part of *wastewater* pollution.

UNDERSTANDING THE PROBLEM

- → Pollution as a Matter of Practice
- → Scale of Wastewater Pollution
- → Wastewater Impacts on Oceans
- → Wastewater Impacts on People
- → Climate Change and Wastewater

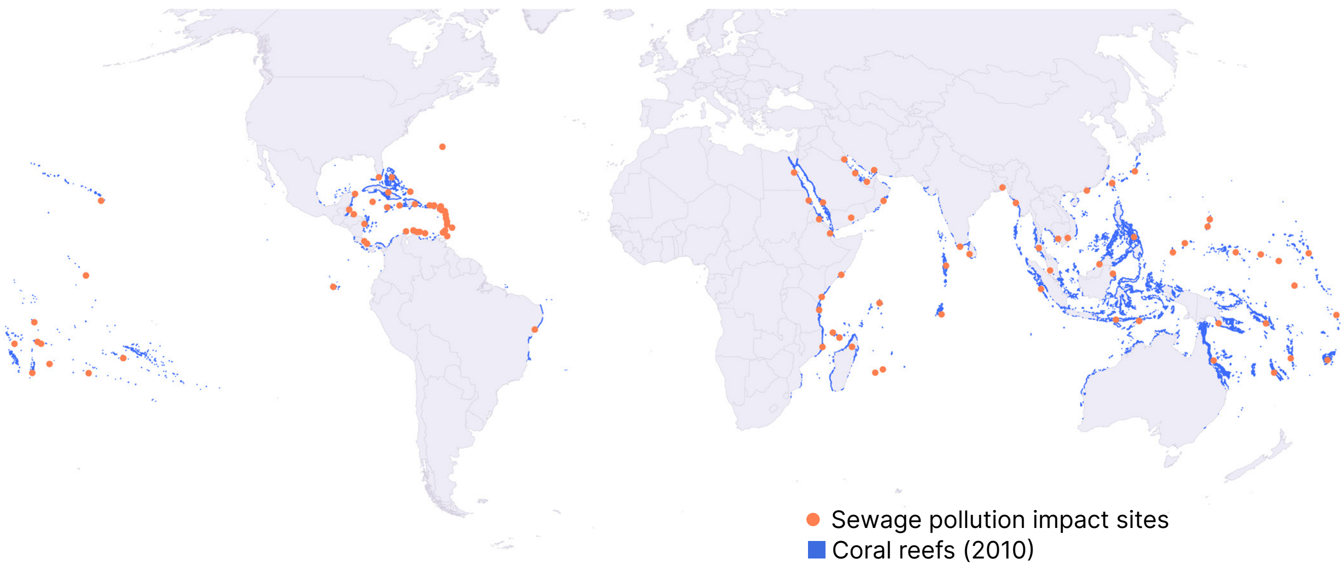


Figure 1
Global map of coral reef geographies with coastal wastewater pollution problems

Source: Wear & Vega Thurber, 2015

Pollution as a Matter of Practice

For too long, the ocean has been viewed as the solution for waste disposal. The practice of collecting and disposing of human waste is what has allowed people to live closely together in densely packed cities, without being hit again and again by devastating epidemics of infectious disease. But in many regions of the world, wastewater management is nonexistent or inadequate, with tremendous consequences to ocean health and human health.

For hundreds if not thousands of years, people have mistakenly assumed that the ocean is vast enough to absorb and dilute human waste without consequence. Historically, scientists have mostly ignored the impacts of human waste, by instead focusing on the role of agriculture and other land-use change in degrading water quality. Consequently, the impacts have not been well documented, and leave us in need of high-quality data.

More recently, scientists have begun documenting wastewater pollution's role in the decline of coastal ecosystems, including coral reefs, sea grasses, salt marshes, mangroves, and shellfish beds. Scientists have demonstrated how wastewater triggers harmful algal blooms that coat everything in slime, poison the water with invisible neurotoxins, create deoxygenated dead zones that are uninhabitable for fish and other marine life, and shift the ocean's nitrogen cycle into a low-oxygen mode, which produces nitrous oxide (N_2O) — a potent greenhouse gas 300 times more powerful than carbon dioxide (Breitburg et al., 2018).

Scale of Wastewater Pollution

Wastewater is ubiquitous – it pollutes coastal waters from the temperate zones to the tropics—and its threat reaches beyond underdeveloped countries. In fact, very few places have managed to avoid discharge of untreated wastewater into surface waters. A recent review of wastewater pollution impacts on coral reefs found that of the 108 coral reef geographies with human populations, 104 had a documented wastewater pollution problem (Wear & Vega Thurber, 2015). Approximately 31% of the world's salt marshes are exposed to high levels of wastewater pollution (Wear et al., 2021).

Wherever you have people, you are likely to have some sort of wastewater problem. Approximately 80% of the world's wastewater is discharged untreated into surface waters (UNESCO, 2017) with some places having even higher discharge rates (e.g., the Caribbean, with 85%; Diez et al., 2019). In New York City, even a light rain triggers a combined sewer overflow system, which discharges an average of 27 billion gallons of wastewater and stormwater directly into New York Harbor annually (NYSDEC, 2008). In Hawaii, more than 88,000 cesspools discharge an estimated 53 million gallons of untreated wastewater into the groundwater each day (Hawaii DHEM, 2018). This does not include leaky septic tanks or sewage spills from inadequately managed treatment facilities. In total, the U.S. discharges about 1.2 trillion gallons of untreated wastewater into coastal waters annually (EPA, 2001). This problem is only getting bigger as the population grows, and people move to coastal cities. Already about 40% of the world's population lives within 100 kilometers of a coast.

Wastewater Pollution Impacts on Oceans

The tremendous volume of wastewater produced and disposed of in the ocean is killing marine life, degrading critical habitats, harming the ecosystems on which people depend, and seriously threatening human health. Typical components of human waste include freshwater, nutrients, organic matter, bacteria, viruses, parasites, endocrine disruptors, suspended solids, sediments, and heavy metals — each of which have an array of negative impacts on marine ecosystems and likely work synergistically to weaken the chances of survival for many marine species (Wear & Vega Thurber, 2015). Below, we illustrate how common components of wastewater can impact marine organisms and ocean habitats.

Nutrients

Growth of algae and bacteria in the ocean — whether it is phytoplankton, leafy macroalgae or turf algae — is often limited by the amount of nutrients available in the water. The nutrients that limit growth of marine plants are most often nitrogen, including inorganic nitrogen (e.g., nitrates and ammonium), organic nitrogen (e.g., urea), and inorganic phosphorus (e.g., phosphate), and sometimes iron in various forms. Wastewater discharge often has high concentrations of these nutrients. At low levels, these extra nutrients can enrich food webs, but at high levels, which occur in many places, algal blooms and other impacts have dire consequences for marine life.

As algae outcompete grasses and corals for light, the direct impact of these algal blooms is overgrowth and death of many habitats, including seagrass beds and coral reefs. The indirect impacts are more varied, but just as lethal. As massive amounts of algae naturally die back and sink to the bottom, large dead zones lacking oxygen can form. These dead zones destroy habitat in shallow and deep water, in temperate and tropical regions, on coral and oyster reefs; in kelp forests and seagrass beds, and over extensive areas of coastal plains — in some cases, the width of these areas stretching for kilometers.

Nutrient pollution from wastewater not only increases algal growth, but also shifts the composition of algae. On coral reefs, it shifts the dominant algae from slow-growing, coralline algae, to leafy, fast-growing algae. In the water column, the consequences of species swaps have been shown to be particularly toxic, as increased nutrients shift the dominant phytoplankton from ones palatable to most filter feeders to others that are loaded with chemical defenses. These blooms of toxic algae, called harmful algal blooms (HABs), can create extensive areas of surface waters that have lethal concentrations of plant chemicals. HABs can kill most macro-marine life, including shellfish, finfish, marine mammals, and seagrasses; sometimes, causing massive fish kills. When HABs occur near beaches, they can make people sick and result in beach closures. HABs have been found to contribute to illnesses such as respiratory and neurodegenerative diseases in people. Nutrients can also fuel growth of pathogenic algae that can attack marine life, including corals and fish. In the case of coral, for instance, nutrients are known to increase prevalence of coral disease, which then increases susceptibility to bleaching.

Besides causing decreased growth of ocean habitats by fueling algal growth and algal species changes, increased nutrients, if concentrations of ammonium levels are high enough, can directly decrease growth of habitat-forming grasses. For corals, high levels of nitrate and ammonium are toxic and can slow growth, or kill coral polyps directly.

Pharmaceuticals

Even after treatment, wastewater can contain pharmaceuticals, such as antibiotics, caffeine, nicotine, painkillers, antidepressants, and synthetic hormones (Meador et al., 2016; WHO, 2011). Recent field studies by Pusceddu and colleagues (2018) have shown that wastewater contaminated with pharmaceuticals can increase concentrations of antibiotics and painkillers in marine animal tissue and lead to subsequent declines in their health. Their studies demonstrated that sewage outflow off the coast of Brazil drastically increased concentrations of pharmaceuticals, including painkillers, resulting in higher concentrations of these same chemicals in filter-feeding clams and urchins. Their follow-up studies showed occurrence of these drugs in the tissues of young clams and urchins, which decreased their growth rates and altered their development. Similarly, antibiotics found in wastewater can impede coral growth by disrupting their microbiome, which plays a critical role in helping guard against disease (Glasl et al., 2016). Given the findings that pharmaceuticals found in wastewater suppress growth, development, and microbiomes of taxonomically diverse corals, clams, and urchins, it is very likely that these effects on marine organisms are more common than previously thought.

Pathogens

It is well known that pathogens, such as SARS-CoV-2 (COVID-19), *Vibrio spp*., *Salmonella spp*., *Shigella spp*., *E. coli*, *Streptococcus spp*. and *Giardia spp*., are found in wastewater (Bogler et al., 2020; Chahal et al., 2016). Since many of these pathogens can infect animal species besides humans, researchers are now investigating whether wastewater containing these pathogens can affect habitat-forming species on coral reefs. One recent study has experimentally confirmed that this can occur. Researchers in the Florida Keys found that increased occurrence of white pox disease in elkhorn coral — a dominant habitat-forming species in the region — was associated with wastewater exposure. A sampling of coral tissue infected with the disease revealed high concentrations of the opportunistic human-associated pathogen *Serratia marcescens*, while subsequent experiments using Koch's postulates determined that *S. marcescens* does cause white pox disease in elkhorn coral (Patterson et al., 2002; Sutherland et al., 2011). Since a severe die-off event of elkhorn coral in the Florida Keys was attributed to white pox disease, poor wastewater management has been implicated as an important driver of coral loss in the region. Yet for such a significant event, there is little awareness or acknowledgement of wastewater pollution as a potential driver of this loss. As this field of study expands, it is likely that more research will show that pathogens in wastewater can infect and kill marine organisms.

Endocrine Disruptors

Both natural and synthetic endocrine disruptors occur in wastewater, including estrogen, PCBs, plasticizers, parabens, phthalates, detergents, and pesticides. These chemicals disrupt organisms' natural endocrine (hormone) systems, altering key functions such as reproduction, tissue growth, and immune response. Most of the research on impacts of endocrine disruptors focuses on effects on marine animals and shows that a diverse group can be impacted; from corals, to fish, to oysters, to worms (Depledge & Billinghurst, 1999; Matthiessen et al., 2017; Tarrant et al., 2004). Corals, oysters, and mussels are the marine habitat-forming species that are most susceptible. In these species, endocrine disruptors can reduce the size and number of egg and sperm bundles and reduce growth rates (Wear & Vega Thurber, 2015). Additionally, some studies suggest that endocrine-disrupting compounds may have a negative impact on human health, with exposures at early stages of development presenting greater risks (Kabir et al., 2015).

Wastewater Impacts on People

Health

Human health and well-being are intimately tied to ocean health, which is especially apparent in communities that have polluted coastal waters (Landrigan et al., 2020). The well-established water, sanitation and hygiene (WASH) sector is devoted to addressing and preventing illness associated with contaminated water and lack of safe sanitation.

The statistics are usually reported as number of deaths and Disability Adjusted Life Years lost (DALYs) due to diarrheal disease associated with lack of sanitation. Although the number of deaths is going down, from an estimated 2.4 million in 2008 (Prüss-Ustün et al., 2008) to 829,000 in 2016 (Prüss-Ustün et al., 2019), with more than a third occurring in children under five, numbers of deaths are still too high, representing only a portion of the burden of disease associated with wastewater pollution. Because wastewater is ubiquitous and moves easily throughout the environment, it contributes to a wide range of illness in human populations. Diseases caused by wastewater exposure include cholera, schistosomiasis, and hookworm disease, as well as illnesses related to nitrate exposure (Mara et al., 2010). The estimated DALYs lost to infectious disease, disability, and death contracted through exposure to wastewater in the ocean is estimated at 3 million years annually (Shuval, 2003). In places where wastewater pollution results in contaminated seafood (see examples below), food security is also at risk. An estimated 180 million cases of upper respiratory disease and gastroenteritis each year are attributed to ingesting contaminated seafood or bathing in polluted ocean waters (Shuval, 2003; WHO, 2015). The following examples illustrate the patterns of illness associated with wastewater pollution.

Table 1 Lack of Access to Sanitation, by Region[1]

1 UNICEF & WHO, 2019

Region	Number of People without Access to Sanitation
Southern Asia	953 million
Sub-Saharan Africa	695 million
Eastern Asia	337 million
South Eastern Asia	176 million
Latin America and the Caribbean	106 million
Other areas	98 million

Swimming Exposure

As recognition of the risks of swimming in polluted waters grows, so does the body of evidence to support better monitoring and management of water quality. Yet most places remain unmonitored or have poor notification systems in place to protect swimmers. (Check out the safety of your beach with the Swim Guide app.) Studies like the "Beach Bum Survey" which looks at the impacts of water quality on the surfing community in different parts of the world, work to highlight this need. The survey found that surfers in the U.K. are three times more likely to be colonized by antibiotic-resistant bacteria like *E. coli* — because of increased exposure — than are swimmers and other recreational water users (Leonard et al., 2018). Antibiotic-resistant strains of bacteria are becoming more common for a host of reasons, including poor hygiene and sanitation. In addition to gastrointestinal infections, swimmers exposed to polluted waters are at risk for chest, ear, eye, and skin infections, as well as hepatitis.

Karenia brevis, the marine dinoflagellate that causes red tides, a type of harmful algal bloom, produces brevetoxins that can aerosolize. These toxins have been associated with increased incidence of asthma, and a 40% increase in emergency room admissions for gastrointestinal disease during red tide events (Fleming et al., 2007; Kirkpatrick et al., 2010).

Contaminated Seafood

Shellfish are just one example of seafood that present potential health risks. Illnesses associated with shellfish include hepatitis, cholera, and amnesic shellfish poisoning (ASP). ASP results from an accumulation of domoic acid, produced by algae in some harmful algal blooms (HABs). Domoic acid has been found in seaweed, crabs, mussels, clams, scallops, anchovies, sardines, albacore, halibut, and mackerel, with shellfish accumulating some of the highest levels (Bejarano et al., 2008). Although foodborne illness is hard to track and is often mistaken as the stomach flu, 4 million people a year contract hepatitis A and E from eating wastewater-contaminated seafood, with roughly 40,000 deaths and another 40,000 cases of long-term disability from chronic liver damage (Shuval, 2003). In a recent study along the coast of Myanmar, Littman and colleagues (2020) identified 5,459 bacterial pathogens in oyster tissue, marine sediments, and seawater, as well as 78 types of microdebris — mostly microplastics but also oils, polymers, and milk powder. They reported that 51% of the pathogens found in the oyster samples were known to be detrimental and of emerging concern to human health. In examining 150 **contaminants of emerging concern** (CECs) in the environment, a Puget Sound study found 81 CECs in **effluent** from wastewater treatment plants (treated effluent) and 42 CECs in the tissue of juvenile salmon and sculpin — concentrations high enough to adversely affect growth, reproduction, and behavior (Meador et al., 2016).

Contaminated Drinking Water

It can be difficult to find direct linkages between illness and wastewater-polluted waters, but a study looking at emergency room visits for gastrointestinal illness did just that. Over a four-year period, scientists compared hospital records in parts of Massachusetts with and without **combined sewer overflow** (CSO) systems (Jagai et al., 2015). The authors found that only people living in areas with CSOs that discharge to drinking water sources (i.e., people who could have been exposed to wastewater-polluted waters) were at elevated risk for gastrointestinal illness up to 8 days after heavy or extreme precipitation.

In addition to pathogens, nitrates are common components of wastewater, even when treated, that find their way into drinking water. Elevated nitrate levels are known to cause methemoglobinemia, commonly known as blue baby syndrome (Greer & Shannon, 2005), and recent studies have linked nitrates in drinking water to colon, ovarian, thyroid, kidney, and bladder cancer in adults (Ward et al., 2018). In fact, numerous studies have shown that increased risk of cancer occurs with nitrates at levels below the U.S. standard of 10 parts per million. (Temkin et al., 2019; Ward et al., 2018). A Danish study reported increased risk of colon cancer with nitrate levels above 3.87 parts per million (Schullehner et al., 2018).

Antimicrobial Resistance

The increase in antibiotic-resistant pathogens, or "superbugs," is probably the most concerning human health impact we face related to wastewater pollution. Antimicrobial resistance is responsible for 700,000 deaths annually, a number that is growing because of poor antibiotic stewardship (i.e., over-prescribing antibiotics), lack of sanitation, insufficient wastewater treatment, and discharge into the environment (O'Neill, 2016). Superbugs originate with illness that is treated — often liberally — with antibiotics. These antibiotics make it into wastewater, where they mingle with microbes. The antibiotics kill many microbes, while other microbes that have the genetics to resist lower doses of antibiotics, are selected for and increase in relative abundance. If not properly treated, these new superbugs make their way into the environment. It is a dangerous feedback loop of disease, antibiotics, commingling, and exposure. There is a growing realization that wastewater treatment plants are a breeding ground for superbugs (Naquin et al., 2015; Rodríguez-Molina et al., 2019). Improving sanitation and wastewater treatment is a critical component of addressing this threat to human health.

Reducing pollution and the prevalence of superbugs also benefits ocean health. With the COVID-19 pandemic, the importance of public health in even distant places has never been more appreciated. Local or regional wastewater pollution challenges have the potential to create global health crises. Taneja and Sharma (2019) document an excellent example of the severity of this situation in India. Throughout the country, there has been liberal and injudicious use of antibiotics to treat many illnesses. This practice has led to one of the highest rates of resistance to antimicrobial agents used to treat humans and food animals, and to one of the highest concentrations of drug-resistant microbes in natural water bodies. Their findings are a warning to the rest of the global community, while the containment plans now being put in place (reduction in antibiotic use and ban of wastewater sludge application to agricultural fields) serve as a model of how to abate the issue.

Gender Equity and Environmental Justice

Wastewater pollution is ubiquitous, but there are big differences in who is impacted — and how severely. Wastewater pollution, whether marine, freshwater, or terrestrial, disproportionately impacts women and girls, communities of color, and the poorest among us. These inequities are directly tied to inadequate sanitation and the persistent relocating of pollution to communities that lack a voice or are grossly underrepresented in planning, decision-making and problem-solving processes. While much attention has been focused on developing countries, where millions of people lack the most basic sanitation, challenges faced by communities of color in places like the Southern U.S. and parts of Australia have attracted significantly less attention (Carrera & Flowers, 2018; Leker & Gibson, 2018; Yashadhana et al., 2020). The fact is that examples of systemic racism feeding the cycle of poverty through lack of safe sanitation can be found around the world in both developed and developing countries (Winkler & Flowers, 2017). The implications are generational, impeding the ability of people to improve their lives, educate themselves, contribute to their communities, and ultimately, contribute to the health of the planet.

The impact is felt disproportionately by women and girls, because of their unique needs and the roles they play in their families and communities (Kayser et al., 2019). Lack of sanitation leads to girls dropping out of school when they begin menstruating; this leads to missed educational and income opportunities not only as individuals and for their families, but also for their communities. This gender inequality in access to safe sanitation extends to disproportionate impacts of wastewater pollution. When family members exposed to wastewater pollution get sick, women and girls are more likely to be the ones to stay home to care for them, again missing out on opportunities. By addressing gender equity in access to safe water and sanitation, we increase the ability of women to contribute to solutions in their communities. In fact, Project Drawdown, an effort to identify the top 100 climate solutions, has found that empowering women and educating girls can make the biggest contribution to drawing down greenhouse gas emissions. Addressing these inequities is not only the right thing to do for women and girls, but also the smart thing to do to help us address a range of environmental and social challenges.

Economic Implications

The impacts of ocean wastewater pollution are predominantly felt by coastal communities, but the interconnectedness of public health, the marine environment, and our global economy means the ramifications of local pollution can be felt around the world. Marine pollution more broadly reduces the value of the goods and services that oceans provide (World Bank, 2019), including coastal protection, fisheries and tourism. A 2019 World Bank report on global water quality called polluted waters “the invisible water crisis,” that drastically reduces gross domestic product in many countries. “Clean water is a key factor for economic growth. Deteriorating water quality is stalling economic growth, worsening health conditions, reducing food production, and exacerbating poverty in many countries,” wrote World Bank Group President David Malpass. More specifically, the report shows that when biological oxygen demand (i.e., the amount of oxygen consumed by bacteria in water during decomposition of organic matter) reaches a certain threshold, GDP drops by as much as one third. For example, the Caribbean loses an estimated $70 million to $175 million annually, owing to land-based pollution (Diez et al., 2019). Globally, the direct impacts of ocean wastewater pollution on people alone cost an estimated $16.4 billion (2018 USD) in annual economic losses (Shuval, 2003). The World Bank recommends countries act now to improve water quality, update water treatment infrastructure, accurately monitor water quality, and update and enforce quality standards (Diez et al., 2019).

Climate Change and Wastewater

As with most environmental problems, climate change makes things worse. In this case, wastewater treatment and pollution actually contribute to, and accelerate, climate change. Climate change, in turn, makes properly managing and treating wastewater more difficult.

Wastewater and Greenhouse Gases

The relationships between wastewater pollution, wastewater treatment, and greenhouse gas emissions are complex, and overwhelmingly negative. While the energy consumption of wastewater treatment plants is considerable, the bigger issue is their contribution to greenhouse gases from the compounds emitted by microbes as they process the waste in wastewater; roughly 3% of global annual emissions (Tseng et al., 2016). **Aerobic wastewater** treatment processes emit carbon dioxide (CO_2), nitrification-denitrification processes emit nitrous oxide (N_2O, a greenhouse gas 300 times more potent than CO_2), and **anaerobic wastewater** treatment processes emit methane (34 times more potent than CO_2). Carbon dioxide, methane, and nitrous oxide are the big three greenhouse gases.

In fact, methane produced by wastewater treatment plants represents anywhere from 3% to 19% of global anthropogenic methane emissions (Yang et al., 2017). These numbers will only grow if we work to treat all wastewater, as only 20% of the world's wastewater is currently treated (UNESCO, 2017).

Another significant contributor to greenhouse gas emissions is the hypoxic, or low-oxygen zones, created by harmful algal blooms (HABs) that can occur when wastewater is discharged in freshwater and marine systems (see Nutrients). In freshwater systems like lakes, the anaerobic decomposition of the algae produces carbon dioxide, nitrous oxide, and methane. In marine systems, such decomposition emits mainly carbon dioxide and nitrous oxide, the latter at levels that are 10,000 times higher than in nonhypoxic zones (Codispoti, 2010). Given that climate change is creating favorable conditions (warmer waters, more carbon dioxide, higher salinities) for HABs and that HABs release significant amount of greenhouses gases, a climate change feedback loop is likely possible.

In addition to contributing to greenhouse gas emissions, discharging wastewater pollution into the ocean is compromising our ability to draw down carbon in the atmosphere. Coastal habitats that are known to be carbon sinks, such as salt marshes and seagrass beds, store carbon in soil and plant material (Bulseco et al., 2019). But the high concentrations of nitrogen found in wastewater and other types of coastal pollution increase microbial decomposition rates of organic material in the soil, thereby releasing more carbon than the habitats can store. In other words, wastewater pollution has the potential to convert these coastal habitats from carbon sinks to carbon sources.

Wastewater treatment plants hold a key to reducing emissions. It is possible to capture methane and potentially nitrous oxide, and transform emissions from wastewater treatment into usable energy, fertilizer and water (see Resource Recovery). Strategies include developing on-site carbon sequestration technology that runs on renewable energy. There is great potential to transform a whole industry from being a massive consumer of energy and contributor to climate change to one that provides energy and is carbon neutral — or even carbon negative.

Climate Change Impacts on Wastewater Treatment

So much of climate change is about the distribution and redistribution of water: sea-level, rainfall patterns, frequency and intensity of storms, and accumulation —or not — of snow (OECD, 2013; Singh & Tiwari, 2019). When snow fails to form or melts earlier, river flows are altered, and both drought and flooding are more likely. Such changes impact wastewater systems in a number of ways.

Wastewater treatment plants are designed to handle a certain volume of water on a daily basis. When a plant receives too much stormwater too quickly, it releases wastewater into the environment untreated to avoid overwhelming the system. As climate change brings about more frequent rainstorms, more high-volume days will likely mean more frequent discharges of untreated wastewater.

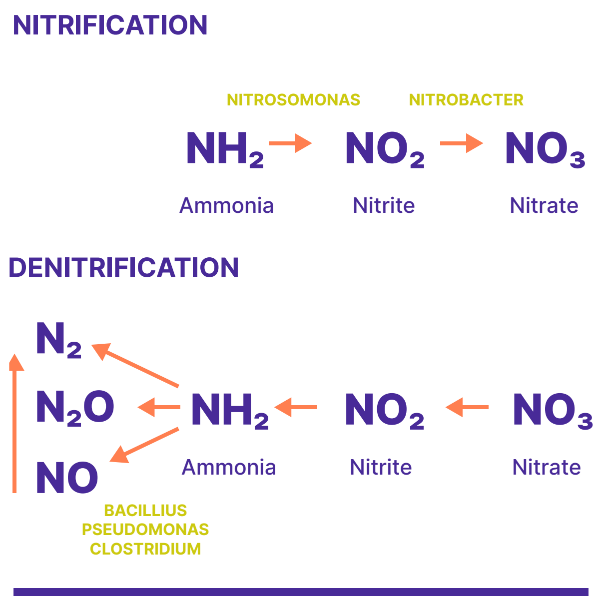


Figure 2. Nitrification-Denitrification Process

Source: AboutCivil

Superstorm Sandy (October 2012) provides an example of the havoc that can result from extreme weather events interacting with storage challenges in wastewater treatment. For example, heavy rainfall from Sandy caused approximately 776 million gallons of wastewater spills in the U.S. Mid-Atlantic. In Washington alone, more than five inches of rain in 24 hours led to a sewage overflow of 475 million gallons (Kenward et al., 2013). In other areas, record storm surges overwhelmed treatment facilities. In the eight states most damaged by the storm, a total of 11 billion gallons of untreated or partially treated wastewater flowed into rivers, bays, canals and streets due to plant failures (Kenward et al., 2013). New York's Bay Park Sewage Treatment Plant, on Long Island, was one of them. Hit by a tidal surge on October 29th, the plant flooded residents' yards and homes with raw sewage and spilled 2 billion gallons of partially or untreated wastewater into coastal waters (Kenward et al., 2013). The result has been the destruction of coastal marshlands – the very habitat that protects these communities from flooding.

Septic systems, especially cesspools, are also highly vulnerable to the impacts of climate change. Septic systems rely on the surrounding soil (the drain field) to remove bacteria, phosphorus, carbon, and nitrogen from effluent. As sea-level rise pushes up groundwater in coastal areas, the distance between septic systems and water can shrink, resulting in environmental contamination (Cooper et al., 2016).

Septic systems around the world are compro-

mised. In the U.S. alone, sea-level rise could affect the septic systems of 60 million Americans (EPA, 2014). With one in five American homes on the coast using septic, this problem will only get worse. Places like New England, with half of households on septic systems, and Florida, with 12% of the country's septic systems, will be hit especially hard. In Miami-Dade County, for example, approximately 56% of households are already experiencing problems with their septic systems, and that number is projected to rise to 64% by 2040 (Miami-Dade County DERM, 2018).

Synergistic Impacts of Climate Change and Ocean Wastewater Pollution

Wastewater pollution and climate change stressors can have synergistic, as well as additive, impacts on ocean and human health. Wastewater pollution can make ecosystems more vulnerable to warmer temperatures, acidification, species invasions, and sea-level rise, among other stressors.

Take salt marshes, for example. As the sea-level rises, marshes affected by high levels of wastewater pollution can sink and drown. When polluted with high levels of nitrogen from wastewater, marsh plants shift their resources from below-ground (building roots) to above-ground (building leaves and stems). The result is weakened marsh soils that are no longer held together by thick root mats. This increases rates of erosion on the marsh surface and on creek bank edges, which ultimately causes creek banks to calve and shorelines to erode at a growing pace. Marshes with high levels of nutrient pollution also experience increased invasion by exotic plants. Since studies show that both nutrient pollution and sea-level rise increase decomposition and CO_2 emissions, it is also likely that these factors interact to make salt marshes less effective as carbon sinks.

For oyster reefs, anoxic or hypoxic zones generated by wastewater pollution make them more vulnerable to multiple climate stressors. The connection is time delayed and is set in motion when anoxic events kill off large areas of oysters (Lenihan et al., 2001). These events greatly lower the number of live oysters on reefs, decreasing the overall ability of that reef to buffer against increasing temperatures, sea level rise and storm action. Sublethal hypoxic events also interact with oyster diseases and water cycles that have been altered by climate change. For example, an increase in freshwater runoff into estuaries increases parasite load in oysters, while exposure to sublethal **hypoxia** induces immunosuppression in oysters and increases their vulnerability to pathogens (Barnett et al., 2020).

Interactions between nutrient pollution and climate stressors also imperil coral reefs. When nutrient pollution is elevated on reefs, corals are more susceptible to both disease and bleaching and are less likely to fully recover (Osborne et al., 2017; Vega Thurber et al., 2014). For example, on the Great Barrier Reef and in the Florida Keys, large-scale surveys and experiments found that nutrient pollution increased disease incidence and bleaching in corals (Vega Thurber et al., 2014). Importantly, after termination of nutrient additions, there was a return to pre-enrichment water quality, followed by reduction in disease and bleaching – a result that bodes well for a future where wastewater pollution is reduced. The mechanisms underlying the intensifying effect of wastewater pollution on climate stress in corals are three-fold. First, wastewater pollution fuels growth of disease-causing bacteria by providing a ready supply of nitrogen. Second, wastewater carries pathogens into the ocean that attack corals directly. And third, the heavy metals and toxic chemicals found in wastewater effluent suppress immune response in corals (Tracy et al., 2020). These results suggest that reefs experiencing high loads of wastewater effluent are far less likely to resist and recover from climate change stressors such as warming. This predicted outcome has recently been shown in a large-scale study in French Polynesia that examined climate-nitrogen pollution interactions. Here, researchers found that nitrogen pollution increases susceptibility to temperature stress and increases bleaching across seascapes (Donovan et al., 2020).

Wastewater pollution is an even greater problem in the context of increased atmospheric carbon dioxide deposition. The normal pH of the ocean is around 8.1. As the pH lowers, the waters become more acidic, straining metabolic activity in marine organisms. The increasing concentrations of carbon dioxide in the atmosphere lowers pH in the oceans, because as carbon dioxide dissolves, a small portion interacts with water to form carbonic acid. While most research on ocean acidification has focused on climate change as the culprit, recent research shows that wastewater pollution also lowers pH in coastal waters, often has a bigger impact locally than global climate change (He & Silliman, 2019; Wallace et al., 2014). The primary mechanism at work is that wastewater pollution generates algal blooms that eventually die, thereby releasing massive amounts of carbon dioxide into the water which lowers the pH, sometimes below 7.

It is very likely that wastewater pollution and climate change will act synergistically to drive extreme drops in coastal water pH, as both forces fuel growth of HABs (EPA, 2013; He & Silliman 2019). Increased wastewater pollution in coastal waters will fuel more HABs, while climate change will likely promote the growth and dominance of HABs through a variety of mechanisms including: 1) warmer water temperatures, 2) changes in salinity, 3) increases in atmospheric carbon dioxide concentrations, 4) changes in rainfall patterns, 5) intensifying coastal upwelling, and 6) sea-level rise. The synergistic interaction between wastewater pollution and climate change in driving HABs, is especially likely in semi-enclosed basins with high-density human populations, such as the Baltic Sea, Mediterranean Sea, San Francisco Bay, Chesapeake Bay, Puget Sound, and Hudson Bay.

CROSS-SECTOR COLLABORATION

→ Key Sectors for Collaboration

It is important to acknowledge that there have been significant efforts to improve how human waste is managed, both for public and environmental health. Likewise, there is a massive global undertaking to address the global sanitation crisis, that includes hundreds of organizations, as well as national governments, that make meeting this critical human need a top priority. While not perfect, these efforts are making progress and bringing a range of exciting solutions to the table. However, by not having the environmental sector more engaged in the solutions, a huge opportunity is missed. Even worse, unintended consequences result, such as ocean habitat degradation. By including the environmental sector more explicitly in the solution space, new perspectives and experts are added, who understand environmental processes that may contribute to the problem or be a part of the solution.

For example, many WASH projects are dealing with triage situations where the most urgent need is to ensure safe drinking water; one of the easiest and cheapest interventions is to provide chlorine tablets to instantly make the water free from life-threatening pathogens. However, the bigger problem of an unsafe water source remains. Looking at this from a whole systems or holistic approach, that considers the environmental context, might lead to considering the condition of the watershed, or what sort of harmful activities are happening upstream that need to be addressed.

Additionally, understanding the roles forests and vegetated land play in purifying, and even providing, water is critical for long-term sustainable solutions. By addressing the source, the need for chlorine tablets down the line is lessened, and other benefits may result by improving environmental conditions or ecological function of surrounding areas. There is also an opportunity to create additional benefits from the combined effort of providing safe sanitation and reducing wastewater pollution. The benefits of resource recovery has massive potential, and when considered as part of a more holistic approach, the end result could be extraordinary environmental and economic benefits, yielding a massive return on investment (see Resource Recovery for more detailed discussion).

A more holistic approach is also a cross-sector approach. That is, the siloed ways of problem solving must become a part of the past. Cross-sector collaboration provides a great opportunity to bring new voices and solutions to the forefront, as well as fortifying and improving upon solutions that create multiple benefits (Wear, 2019). The environmental perspective cannot continue to be an after-thought or an extra benefit, but rather essential to long-term success. And likewise, the environmental sector cannot solve the problem of ocean wastewater pollution without working with the public health, development, and WASH sectors.

Once practitioners fully appreciate the extent and seriousness of this threat to ocean and human health, there will be interest in initiating threat mitigation interventions right away. However, it is important to ensure, or create, enabling conditions for long-term success. Experts from multiple sectors gathered recently to determine the best approach or entry point for the conservation sector. It was determined that there are multiple intervention types, but the first step should be to employ enabling conditions. These strategy sessions considered four main tactical areas: top-down government intervention, on-the-ground threat abatement, building bridges across sectors to influence existing efforts, and building awareness of the threat. It became clear that all four were necessary to achieve the desired outcomes, and that there was an interdependency on each other. For example, on-the-ground support likely requires or benefits from government mandate or support; building bridges depends on an understanding of the threat space. All approaches are necessary, but before real progress can be made, it is important to get everyone on the same page. Thus, raising awareness around the impacts of wastewater pollution in ocean environments must be the first step to pave the way for engagement across stakeholder groups and ensure long-term success.

Key Sectors for Collaboration

In this section we describe the range of sectors, that are likely to be involved or are absolutely essential to any effort to address the threat of ocean wastewater pollution. We provide some background on the responsibilities or mission they have, and how they might play a role in the solution space. This list is not meant to be comprehensive, and may expand as we learn more, and as collaborations evolve.

They are listed alphabetically to avoid signifying importance or priority as a solution partner.

Government: Utilities and Regulators

So much of the success of the Sustainable Development Goals (SDGs, see The Policy Component below for description) and an end to ocean wastewater pollution is dependent on the action of national and local governments. Often there is infrastructure involved that is paid for, and managed by, government funds. It is generally the duty of the government to ensure public health and responsibly manage natural resources. The government has the power to create mandates, define policy, enforce regulations, and even spur innovation. The management of waste is usually carried out as a public service by a public utility or in some sort of public-private partnership. These utilities have a range of responsibilities including water collection, treatment, supply for domestic and industrial needs, and operation of sewered systems and treatment facilities that collect, treat, and dispose of wastewater. They provide an important public service and are critical partners in solving local pollution issues. They understand perhaps better than any other entity in the system how the system works and how it can be improved for better public health and environmental outcomes. There are regional associations of utilities that are also excellent resources as the challenge is addressed. Regulators (those that set the usage fees) are also critical partners given their intimate knowledge and influence in how water and sanitation is paid for in a particular place. Some regional and international examples include:

Eastern and Southern Africa Water and Sanitation (ESAWAS)

Caribbean Water and Wastewater Association (CWWA)

Pacific Water and Wastewater Association (PWWA)

International Water Association (IWA)

Government partners are going to be critical in almost every scenario in one form or another; and should be consulted early in any process to address ocean wastewater pollution.

Industry

Depending on the geography, there are a range of industry partners that either have an interest in reducing ocean wastewater pollution or a role in reducing this type of pollution. The tourism industry is an example of both, with their success depending on consumers having a positive and disease-free visit, as well as tourists themselves to wastewater pollution if their waste is not properly managed. The cruise and hotel industries are subsets of the tourism industry that must play a role in the solution, as both have a responsibility to manage the waste produced by their clientele while on board or staying at their establishments. Depending on the region, it may also be advisable to engage with tourism associations that work with different businesses and countries. Sanitation providers are also a key industry to engage, as they could potentially identify innovative ways to improve upon existing practices and technologies. Given the opportunities around fuel, water, and fertilizer recovery from wastewater, associated utilities and sectors are important to include. Engaging with local entrepreneurs may also provide an opportunity to create new business and value around waste management and treatment.

Philanthropy

The philanthropy sector has an important role to play, as a catalytic force that creates enabling conditions for action, innovation, and partnership. Currently, addressing wastewater pollution is not a priority for philanthropic organizations, but that is starting to change. There is growing interest from this community and an appreciation for what is at stake if investments are not made to improve water quality. Recent surveys of marine resource managers have shown that philanthropic funding can drive priorities. There is a real opportunity for philanthropic organizations and individuals to influence how action is taken, especially by encouraging cross-sector partnerships and prioritizing solutions that aim to recover resources from human waste. Although the cost to address this problem is significant and cannot be shouldered by philanthropy alone, it still can play a critical role in capturing the attention of governments and unilateral organizations that take on a large portion of the costs (Bos et al., 2015).

Policymakers

In many parts of the world, ocean friendly sanitation policy is either not a priority or is totally absent. The priority is often on the immediate public health need which, while understandable, misses the longer-term negative effects that can result. Defining and enacting policy that addresses both public and environmental health is critical for sustainable solutions. Having more holistic policy strategies can also be more cost effective and support aspirations towards a range of co-benefits that go well beyond public health. Working with policymakers at the local, national, and international level is a critical part of creating enabling conditions for threat mitigation, as well as taking a longer view and more holistic approach to wastewater treatment and management.

Public Health

While public health is most often considered a responsibility of the government, the significant impacts of wastewater pollution require that we call it out separately from other government roles in order to highlight the importance and unique role of those working in the public health sector. The public health domain includes ensuring adequate public health infrastructure (including public and nonpublic water supplies), promoting healthy communities and behavior, preventing the spread of communicable disease, protecting against environmental health hazards, and preparing for and responding to emergencies. Given all of this, the impacts of wastewater pollution in coastal and other receiving waters are of prime concern to those working in the public health sector. Polluted water is associated with a range of health concerns beyond diarrheal disease, including cancer linked to nitrate exposure in drinking water, liver disease associated with contaminated seafood, neurological illnesses caused by toxic harmful algal blooms, and violence against women and girls who do not have access to safe sanitation. Many of the solutions to the problems we face both in environmental and human health will come either directly from or in collaboration with those responsible for public health in a community. The public health sector is an absolutely critical partner in any effort to address the challenges of wastewater pollution in coastal areas.

Science

Scientists have an important role to play in both articulating the impacts of this threat and developing action-oriented monitoring protocols. There is currently a lack of scientific evidence across marine habitats. Increased scientific attention is needed to further strengthen the case for action. The value of "before and after" controlled experiments cannot be overstated. Scientists can also play a role in evaluating the efficacy of different solutions, once deployed.

Technology

The technology space around sanitation, mitigation, and monitoring is growing rapidly as investments are being made in areas including, but not limited to, environmentally friendly collection, storage, treatment, and sensor capabilities. The more engineers and innovators understand how treated and untreated wastewater discharge impacts the ocean, the better able they are to incorporate those considerations into their designs. The technology sector has a critical role to play in innovation, pilot testing, and development of more affordable solutions, so that everyone has access to safe sanitation.

WASH

WASH is a collective term used to represent a growing sector that focuses on **water, sanitation**, and **hygiene**. While each of these areas are their own field of study and work, their connectivity and interdependence are widely understood, and therefore grouped together. Work on water and sanitation in this space focuses on access to safe drinking water and sanitation respectively – with the ultimate goal of improved public health and wellbeing. Hygiene-based work is more focused on good handwashing practices, and is less relevant to the immediate problem of ocean wastewater pollution; but is not unrelated, as sick people have the potential to lead to disease spread in the marine environment. Much of the work in this space is working to address an immediate need; for example, people must have access to safe drinking water immediately and consistently. So, rather than look at systemic causes of dirty water and addressing them, those in the WASH sector are more likely to provide a solution that produces immediate results, such as chlorine tablets for drinking water. The same goes for sanitation – a pit latrine is better than no toilet at all, despite the fact that the pit latrine is likely to pollute the environment in which people live, ultimately causing other illness somewhere down the line. Working with this sector to solve these problems at a more holistic level will be good for both the WASH sector and the environmental sector. Many times, nature can provide solutions to the problems the WASH sector is facing. Additionally, often the goal of separating people from their waste leads to the ocean or other aquatic habitat becoming the destination, and therefore the solution for that waste. Working with the WASH sector to avoid the unintended consequences of efforts to protect public health can result in better outcomes for both people and nature. Examples of sustainable sanitation groups and tools include:

Sustainable Sanitation Alliance

Sustainable Sanitation and Water Management Toolbox

THE POLICY COMPONENT

- → Laws, Regulations, and Codes
- → Monitoring
- → National and Regional Policy Examples

We face real policy challenges because so many people are currently without safe sanitation. Triage is necessary. However, we do see places that are more progressive in their policy structures and progress. It is not surprising that more developed countries often have more supportive policies and regulations in place to reduce the level of water pollution that occurs. Even so, countries with extensive regulatory support still fall short in many cases. This is due to a range of challenges, including existing infrastructure that is expensive to update or replace (e.g., combined sewer overflows), political factors (e.g., rollbacks of existing regulations), and ingrained social systems that create additional complexity. For example, the European Union Water Framework Directive (WFD) laid out ambitious goals with a reasonable timeline. However, the absence of the paradigm shift towards "systems thinking" that the WFD was grounded upon has created implementation challenges (Voulvoulis et al., 2017). Because water flows through seemingly everything in our daily lives, a more holistic systems approach must be taken, but can be difficult on larger scales.

Currently, the global priority in this space is to give all people access to safe sanitation. However, as previously stated, approximately 2.5 billion people are without access to **improved sanitation.** Another 2 billion have unsafe sanitation, i.e., sanitation that it is not hooked up to sewer or septic, and thus discharges into the environment and surface waters. And, because the global community is in a triage mode focused on getting safe sanitation to all, the issue of discharging into the environment is secondary. This is likely due to the current thinking that discharging into coastal waters dilutes and treats any potentially harmful components of human waste that remain after treatment (or in untreated water). This has been the ongoing assumption by decision makers, regulators, and managers. Yet, anecdotal evidence suggests that very few have attempted to check that assumption, to ensure that we are not polluting the environment with wastewater discharges.

International goals, laws and regulations, and effective monitoring, are all critical parts of correcting the course of flawed or missing sanitation policy, which ultimately results in ocean wastewater pollution.

Sustainable Development Goals

The United Nations adopted the Sustainable Development Goals (SDGs) in 2015. Now, with the new SDGs at WHO, there is a global focus and effort. These goals lay out an ambitious vision for protecting the planet and improving the lives of people around the world by 2030. This sweeping set of seventeen goals replaced the Millennium Development Goals, agreed to in 2000, which focused on developing countries. Adopted by consensus after three years of negotiations, the SDGs apply to all countries and serve as "the world's shared plan to end extreme poverty, reduce inequality, and protect the planet by 2030."

The SDGs provide an opportunity to advance efforts and collaborate across sectors. Opportunities for commitments by countries to approach these goals together do exist, and should be encouraged and facilitated wherever possible. Evidence suggests that both conservation and development goals can be achieved in joint endeavors without increasing the cost of work or hindering outcomes (Kareiva et al., 2008). Making the case for better coordination and consideration of these goals would increase the likelihood of good environmental and human well-being outcomes, as well as increase efficiencies. This is consistent with the intention of the SDGs and presents an opportunity to build bridges across sectors for longer term collaborations (Wear, 2019).

Reducing Ocean Wastewater Pollution Impacts SDGs

Due to the interrelatedness of SDGs, reducing ocean wastewater pollution can directly impact many of the goals. Using it as a mechanism for achieving SDG goals provides the opportunity to leverage ocean wastewater pollution tools and ongoing work to the benefit of almost all of the SDGs. For example, the ocean wastewater pollution toolset includes established metrics for success that are commonly used around the world to facilitate monitoring and assessing change in nutrient concentrations in coastal waters. As an important part of ocean wastewater pollution efforts, the broad application of these metrics has the potential to meaningfully impact the success of SDGs; at least two of the SDG goals are directly relevant to reducing ocean wastewater pollution and improving human and environmental health:

- **Goal 6** "Ensure availability and sustainable management of water and sanitation for all."
- **Goal 14** "Conserve and sustainably use the oceans, seas and marine resources for sustainable development."

In fact, the nature of these two goals, #6) Clean Water and Sanitation, and #14) Life Below Water, connects them to most of the remaining SDGs. There is a great opportunity to take advantage of the potential synergy in addressing ocean wastewater pollution and the SDGs in a coordinated manner. Ocean health impacts livelihoods, nutrition, and economies, as do public health efforts to improve sanitation, nutrition, gender equality, and education. [See Table 2 on the next page].

Sustainable solutions to ocean wastewater pollution will minimize health risks, preserve fisheries and ecosystems, combat disease and suffering, free time from securing clean water, offer employment opportunities to waste collectors and fishermen, and contribute to the stability, sustainability, and dignity of local communities.

Table 2 Sustainable Development Goals

Contribution of Integrated Health and Conservation Response to Ocean Wastewater Pollution to all 17 SDGs	**1. No Poverty** Marine-related livelihoods, Sanitation-related livelihoods, Sustainable fisheries, Eco-tourism, Disease reduction, Agricultural productivity, Improved water quality, Access to clean water, Resource recovery, Revenue from recovered products, Safe sanitation	**2. Zero Hunger** Sustainable fisheries, Agricultural productivity, Improved water quality, Stability in marine temperature/pH/turbidity/salinity
3. Good Health and Well-Being Sanitation-related livelihoods, Sustainable fisheries, Disease reduction, Agricultural productivity, Improved water quality, Access to clean water, Safe sanitation, Improved wastewater treatment	**4. Quality Education** Menstrual and maternal care, Access to clean water, Safe sanitation	**5. Gender Equality** Menstrual and maternal care, Access to clean water, Safe sanitation
6. Clean Water and Sanitation Sanitation-related livelihoods, Disease reduction, Agricultural productivity, Improved water quality, Access to clean water, Resource recovery, Revenue from recovered products, Safe sanitation, Improved wastewater treatment	**7. Affordable and Clean Energy** Resource recovery, Revenue from recovered products	**8. Decent Work and Economic Growth** Marine-related livelihoods, Sanitation-related livelihoods, Eco-tourism, Agricultural productivity, Resource recovery, Revenue from recovered products, Marine and coastal conservation
9. Industry, Innovation, and Infrastructure Sanitation-related livelihoods, Eco-tourism, Agricultural productivity, Access to clean water, Resource recovery, Revenue from recovered products, Safe sanitation, Marine and coastal conservation, Improved wastewater treatment	**10. Reduced Inequalities** Marine-related livelihoods, Sanitation-related livelihoods, Sustainable fisheries, Disease reduction, Agricultural productivity, Improved water quality, Access to clean water, Resource recovery, Revenue from recovered products, Safe sanitation, Improved wastewater treatment	**11. Sustainable Cities and Communities** Eco-tourism, Disease reduction, Agricultural productivity, Access to clean water, Resource recovery, Safe sanitation, Improved wastewater treatment
12. Responsible Consumption and Production Sustainable fisheries, Species protection, Agricultural productivity, Improved water quality, Access to clean water, Resource recovery, Revenue from recovered products, Carbon sequestration	**13. Climate Action** Sustainable fisheries, Species protection, Agricultural productivity, Resource recovery, Marine and coastal conservation, Carbon sequestration, Stability in marine temperature/pH/turbidity/salinity	**14. Life Below Water** Sustainable fisheries, Species protection, Improved water quality, Resource recovery, Marine and coastal conservation, Improved wastewater treatment, Stability in marine temperature/pH/turbidity/salinity
15. Life on Land Species protection, Disease reduction, Agricultural productivity, Improved water quality, Access to clean water, Resource recovery, Improved wastewater treatment	**16. Peace, Justice, and Strong Institutions** Improved water quality, Access to clean water, Resource recovery	**17. Partnerships** Interdisciplinary approach to marine wastewater pollution by health and conservation sector experts and resources

SDG Challenges

The work to achieve the SDGs is riddled with social, economic, and political hurdles. The Joint Monitoring Programme (JMP) is the arm of the United Nations (UN) devoted to tracking progress towards Sustainable Development Goals. Standardization remains a serious problem for adequate tracking of progress towards goals; clear protocols and consistent widespread assessment are not guaranteed. This metric gap in measuring success towards goals leaves open the possibility for claiming success toward SDGs when the bare minimum has been reached.

Unfortunately, willingness by companies, countries, and NGOs to fund the SDGs in general has fallen far short of what is necessary. The United Nations (2019) cited a 2.7% decrease in official development assistance and 8% decrease in humanitarian aid between 2017 and 2018. For every dollar in public investment, about $0.37 of private investment is mobilized, according to a report by the Overseas Development Institute (Attridge & Engen, 2019).

Even within the WASH sector, sanitation attracts less attention than the goal to provide clean drinking water. For instance, during the Millennium Development Goal period, the global target for drinking water was met five years ahead of schedule, but the target for sanitation was missed by nearly 700 million people (UNICEF & WHO, 2015). This may reveal a mental disconnect around the relationship between safe sanitation and clean drinking water; it's very difficult to have one without the other. Although sanitation has been declared a basic human right by the United Nations (2009), access to a toilet is still out of reach for many worldwide. As mentioned previously, more than 4.5 billion people do not have access to toilets where waste is treated and disposed of safely (UNICEF & WHO, 2017).

Clearly, there is much work to be done to address budget shortfalls and questionable commitment by some key parties. It would also be helpful if there were a clear target (i.e., an indicator for water quality) so that governments and industry have something to guide them, or even move them, to act.

Laws, Regulations, and Codes

For decades, there have been local and regional environmental efforts focused on reducing wastewater impacts on coastal ecosystems. While policy will vary based on the social, economic, political, and environmental conditions, we offer some basic guidelines from which to begin, taken from recommendations generated by Our Shared Seas. We also recommend advocating for full implementation of any existing laws and monitoring frameworks that address all types of coastal pollution in addition to proposing new regulations to specifically address ocean wastewater pollution. Examples of some frameworks at both the country and regional level are also provided later in this section, (see National and Regional Policy Examples), and are meant only to provide information about existing frameworks, not necessarily recommend those approaches. Here are some useful categories to consider for creating, amending, or influencing laws, regulations, and codes:

1. **Agricultural run-off and other land-based pollution source laws, regulations, and codes, such as**:
   - EU Nitrates Directive
   - Animal waste lagoon regulations
   - Pesticide, herbicide, and nutrient regulations
2. **Wastewater management laws, regulations, and codes, such as:**
   - Total maximum daily loads
   - Stormwater permitting
3. **Water quality laws, regulations, and codes, such as:**
   - US Clean Water Act
   - State Water Quality Standards, including laws for monitoring of water quality
   - BEACH Act
4. **Plastics and solid waste management laws, regulations, and codes, such as:**
   - International, national, and local policies such as city-wide bag and straw bans
   - Fees for single-use items
   - Requirements to track fishing gear, dumping bans
   - Waste and wastewater recycling, re-use, and byproduct laws, regulations, and codes
5. **Solid waste recycling, re-use, and management laws, regulations, and codes**
6. **Writing national legislation on improving water quality**
7. **Ballot initiatives to fund wastewater, stormwater, and waste management infrastructure**
8. **Writing town and county regulations for wastewater**

Monitoring

Why Monitor for Wastewater Contamination?

Effective and economically viable monitoring techniques, that inform coastal managers of the spatial and temporal variation in the intensity and composition of wastewater discharge into coastal waters, are key to the success of these pollution reduction efforts. Domestic wastewater contains high organic loads, and often a variety of toxic chemicals and substances, such as plastics and heavy metals. Ultimately, these chemicals impair the health and future well-being of both humans and nature. Detailed monitoring information is essential to managers and policy makers, as it allows them to:

- Focus limited resources in areas that are most heavily affected,
- Understand the spatial and temporal extent and variation of pollution threats,
- Understand and communicate if the contaminants pose threats to both humans and nature,
- Identify hotspots of contaminants,
- Assess the effectiveness of enacted interventions, and ultimately,
- Inform future actions and decisions using adaptive-based management.

How do we currently monitor wastewater contamination?

There are currently a diverse set of monitoring techniques for wastewater discharge. These techniques can be broken down into two general categories: a) Proportion of Discharge Water Treated: percent and total flow of industrial and household discharge that is treated versus non-treated; and b) Performance of Treatment: spatial and temporal extent of wastewater derived contaminants, and their impacts on **biological oxygen demand** in water coming out of treatment plants, as well as in surrounding aquatic ecosystems. The former category gives an idea of how much untreated wastewater enters the system, while the latter provides an evaluation of the performance of wastewater treatment in the area of focus. Hydrologists and civil engineers work together to generate the first estimate, while environmental scientists and modelers, working both in the field and in the lab, combine their efforts to provide the second estimate.

When monitoring performance, what is measured typically differs when assessing threats to humans versus nature. Traditionally, public health threats are quantified by indicator microorganisms, such as fecal coliform or total count of heterotrophic bacteria, to infer presence of human pathogens, human feces, and process change (e.g., increased oxygen demand) in wastewater discharge; or water receiving wastewater discharge. For threats to nature, scientists have focused on monitoring nutrient loads that can change due to increasing wastewater discharge, primarily nitrogen, phosphorus, and oxygen concentrations in the water column. More recently, there has been expanded interest in measuring factors that threaten both humans and nature: toxic chemicals such as heavy metals, hormones, pharmaceuticals, industrial by-products, and plastics. Thus, measuring extent and impact of wastewater contamination involves measuring a large number of response variables – a list that is expanding over time.

What limits effective monitoring of the extent of wastewater contamination and its potential impacts on coastal ecosystems?

While the technological know-how (in the scientific literature) does not generally limit our ability to measure a great number of chemicals and pathogens that occur in waters experiencing increasing wastewater discharge; cost, human resources, materials, and lab supplies, do. Other factors that limit effective monitoring and better treatment of wastewater discharge include:

- Most countries fail to integrate monitoring data at a national level.
- Few countries collect data at on-site wastewater treatment (septic systems).
- Most countries have only a small percentage of industries use permits to discharge; and those that do are rarely monitored.
- Monitoring of collected and recorded data from local areas is challenging due to differences in reporting and storage locations, making it hard to combine data to assess temporal and spatial trends.
- When wastewater contamination is monitored, most of the time variables are measured that predict impacts on human health, rather than environmental health. Thus, only a small subset of contaminants is measured.

National and Regional Policy Examples

While policy can be made at the local, national, or even international level, the national and regional level policy examples below are intended to inspire the development and improvement of wastewater management policy and water quality, as well as provide cautionary tales of what to avoid when designing policy frameworks. Even the best designed policy frameworks are limited by implementation, compliance, and enforcement.

African Union's Africa Water Vision for 2025

The African Union (AU) has developed The Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socioeconomic Development, a comprehensive vision for water use to address natural and human threats from a broad scope of areas, that includes competing demands for basic water supply, sanitation, food security, economic development, and environmental threats such as variability in climate and rainfall, climate change, and desertification. The complexity of human threats is daunting; it includes:

- "Inappropriate governance and institutional arrangements in managing national and transactional water basins;
- Depletion of water resources through pollution, environmental degradation, and deforestation;
- Failure to invest adequately in resource assessment, protection and development;
- Unsustainable financing of investments in water supply and sanitation."

While the AU does not yet have an overall policy model to address African water quality and sanitation challenges, they have made important first steps with the Africa Water Vision for 2025 and the recruitment of an Africa Water and Sanitation Policy Officer. Additionally, the Africa Sanitation Policy Guidelines (ASPG), led by the African Ministers' Council on Water (AMCOW), provide African governments with the guidance necessary for developing sanitation policy. The usage of ASPG by local governments serves as a basis for developing larger scale national sanitation policy and programs. The ASPG are ambitious, aiming to catalyze reforms needed to realize access to **safely managed sanitation** for all by 2030. AMCOW has also developed a Pan-African Water and Sanitation Sector Monitoring and Reporting System. With the complexity and diversity of the African water and sanitation challenges, these efforts by AMCOW, in addition to the AU vision, are fundamental to providing universal access to safe water and sanitation for all Africans.

Australia National Water Quality Management Strategy

The NWQMS strategy is to develop and maintain a voluntary, nationally coordinated framework, supported by all Australian governments; to facilitate water quality management for the productive and sustainable use of Australia's water resources, and to protect community values. Australia, through the Council of Australian Governments, Australian, State and Territory governments, revised the 2000 version of the National Water Quality Management Strategy (NWQMS) in 2018. Per its charter, the Water Quality Guidelines are required to maintain currency to ensure it retains value as a national best practice tool for water quality management. Comprising 24 documents, the NWQMS consists of nationally agreed policies, guidelines, and tools to assist governments and other organizations and institutions to steward water quality while also taking account of local conditions and community values. As testament to the NWQMS's impact, most jurisdictions have incorporated the guidelines into relevant environmental policies, plans, legislation, and/or regulations.

The NWQMS addresses development, maintenance, and update of a suite of tools, and the science. It also assesses and monitors developments in policies to address:

- Inputs or changes that reduce environmental health
- Fragmented approaches and/or risks to environmental water quality
- Lack of science and/or tools to inform management action

The desired outcome is effective water quality management for the delivery of fit-for-purpose water that supports community values of:

- Aquatic ecosystems
- Cultural and spiritual values
- Drinking water
- Industrial water
- Primary industries and agriculture
- Recreation and aesthetics

The Pressure–Stressor–Response on Community Values (CV), illustrated here in Figure 3, is an example of a tool, available through the NWQMS, that can assist water resource stakeholders in linking what is occurring in and around the water resource to the problems that have been observed.

Additionally, the NWQMS monitors and assesses its own effectiveness, as well as providing for the monitoring and assessment of water quality, i.e., "Is the NWQMS achieving its intent as a toolset?" and "Is the toolset resulting in 'fit for purpose' water quality?". In summary, the NWQMS provides the foundation for, and facilitates the actual implementation and

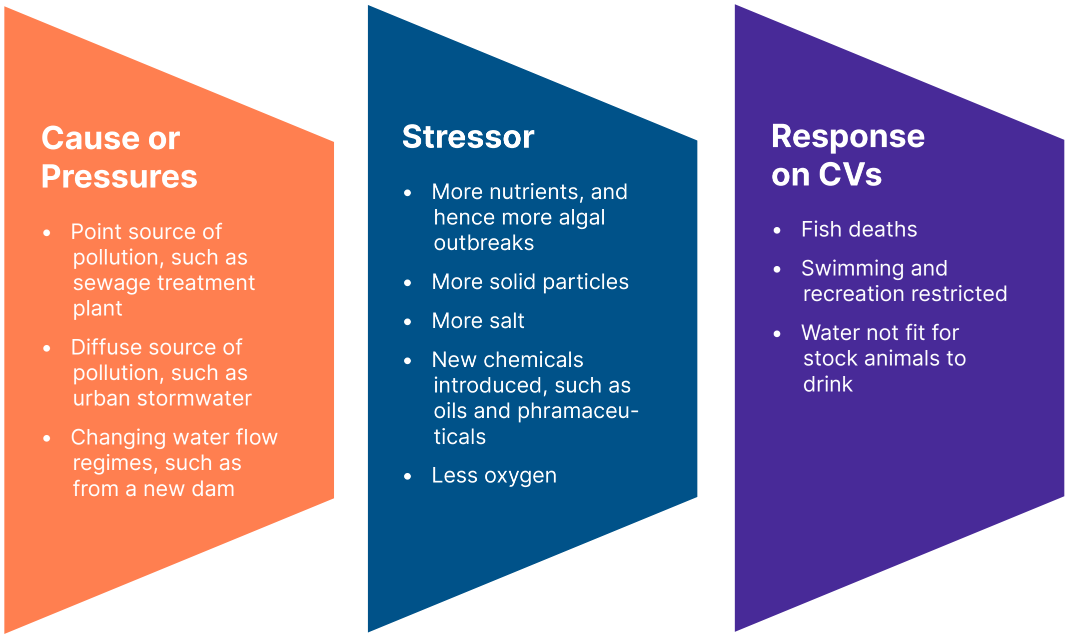


Figure 3. Pressure-Stressor-Response on Community Values

Source: Australian Government, 2018

management of water quality stewardship, tailored to meet local and/or regional needs. This seems a viable approach for the challenges inherent in a landscape that is vast, and as socioeconomically and environmentally complex as Australia. More information about the NWQMS is available on the NWQMS website.

Useful links:
Australia Water Quality Home
"Guidelines for the management of water quality in Australia were developed as part of the National Water Quality Management Strategy (NWQMS). Guideline documents provide information tailored to meet the needs of water quality managers in achieving quality and supply of water that is fit for purpose."

Effluent management guidelines - Historical guidelines, so the information may be dated. Users are encouraged to contact local jurisdictions for updated practice.

Monitoring and evaluation plan

Australian and New Zealand guidelines for fresh and marine water quality

Cartagena Convention

Adopted in 1983 and implemented in 1986, the Cartagena Convention is a regional legal agreement for the protection of the Caribbean Sea. One of the major foci of this agreement is development of legal protocols for dealing with land-based sources of marine pollution. Details on the specific protocols for this particular portion of the agreement took longer to be ratified by countries in the region, and did not come into effect until 1999. The agreement sets out specific effluent limitations on domestic wastewater and land-based pollutants (e.g., nitrogen, phosphorus), and requires development of plans to deal with run-off from non-point pollution. There is also agreement that each country will participate in coordinated activities and practices that prevent, reduce, and control sources of land-based pollution across the region. During this process, parties agree to share technologies, successes, and scientific information that will help partners become more efficient in controlling land-based pollution. Also included in this sharing are commitments to hold cross-country meetings and training workshops, as well as country specific and region-wide public campaigns. One of the most important stipulations in the agreement is that all participating countries have agreed to treat all domestic wastewater in their countries, so that effluent meets specified standards. This requires that participating countries increase monitoring of effluent from wastewater treatment plans, as well as monitoring the condition and effectiveness of septic systems.

China: Water Pollution Control Law

Management and monitoring of wastewater in China is governed by the Water Pollution Prevention and Control Law of 2017, as well as goals set out in the Five-Year Plans of the Communist Party. Until recently, wastewater management has been low on the priority list for the Chinese government, and has always taken a back seat to economic advancement and the more recent focus on reduction in air pollution. For example, to meet economic output goals set forth by the communist government in their Five-Year Plans, wastewater treatment plants of entire cities would be shut down for long periods of time to reduce cost. In addition, not until the most recent Water Pollution Prevention and Control Law in 2017, was monitoring and setting standards for water quality in rivers a part of the national policy. The 13th Five-Year Plan of the Chinese Communist party now includes increased funding for, and focus on, availability of traditional wastewater collection and treatment facilities for villages and cities. Much of this funding will focus on installing wastewater piping and treatment plans in areas where it was not before. As of 2019, only 11 percent of Chinese villages have access to wastewater treatment facilities. Until very recently, China's municipal wastewater treatment plants were decentralized and under the jurisdiction of local governments. The Water Pollution Prevention and Control Law of 2017, however, initiates a more country-wide policy on wastewater management. There are 4 key elements in the law: 1) pollution-reduction targets for rivers are not set at the national level; while local and regional officials are responsible for meeting them, 2) agricultural pollution and fertilizer use standards were improved, and a more national system of monitoring and accountability was enacted, 3) drinking water standards were improved, and local officials now must report standards to the public, and 4) fines will be used to enforce these rules.

Useful links:

Quest for Clean Water: China's Newly Amended Water Pollution Control Law - Wilson Center

Revised 'Water Pollution Prevention and Control Law' Approved - CWR

Law of the People's Republic of China on Prevention and Control of Water Pollution

China's 13th Five Year Plan: What Role Will Wastewater Play? - WaterWorld

European Union Water Framework Directive (WFD)

The EU Water Framework Directive (WFD) was enacted in 2000 and came about after determining that a clear policy framework was needed. In the previous few decades, the EU had enacted a range of water quality policies that were specific to drinking water, nitrate pollution, wastewater treatment, bathing water quality, among others, which while useful, were not consolidated or comprehensive. Thus, the WFD was developed with the following aims:

- Expanding the scope of water protection to all waters, surface waters and groundwater
- Achieving "good status" for all waters set by a deadline
- Water management based on river basins
- "Combined approach" of emission limit values and quality standards
- Getting the prices right (adequate water pricing)
- Getting the citizen involved more closely
- Streamlining legislation

An important aspect of this framework is that it uses a single system of water management approach: river basin management. That is, it uses the natural geographical and hydrological unit, rather than administrative or political boundaries. This translates into a river basin management plan that can include multiple states and countries; and in some cases even going beyond the EU territory. The framework outlines protections for surface water that include ecological, chemical, and other protections. The intent was to ensure water was safe for drinking and bathing, as well as protecting the environment to a high level "in its entirety." These protections applied to both surface and groundwater, to keep with the whole system approach. The details of the framework can be found on the European Commission website; which provides historical background, framework details, and current status. It should be noted that this effort to take a holistic cross-boundary approach is ambitious and ideal, in the sense that these problems are without boundaries, and need to be managed as such. However, there are real challenges to seeing it through. To date, this effort has not been very effective with only 40% of surface waters in good ecological condition (EEA, 2018). Some of this is due to the novelty of taking a holistic approach in a system that wasn't quite prepared for a new structure like this. It is not to say that this system is a failure, or that we cannot learn from it. Rather, it is important to acknowledge that it takes time to put structures in place that take a holistic approach. More details around the challenges can be found in the literature (Junier & Mostert, 2012; Wiering et al., 2020). In general, the WFD is a great example to draw a range of lessons from and worth a deeper dive if we are interested in designing water quality policy frameworks at a regional scale.

Singapore

Singapore is the third most densely populated country in the world, but also 6th in the world in per capita nominal GDP for a country, meaning that there are considerable resources available to solve challenges generated by such high population density. As an island nation, Singapore is greatly limited by both space (e.g., for living, waste disposal, water storage), and available in-country natural resources (e.g., freshwater, energy sources). Water security has long been a national priority for Singapore, as it has historically imported most of its freshwater from neighboring Malaysia. The two-country agreement ends in 2061, and by that time, Singapore plans to be fully self-sufficient in its freshwater needs. Singapore outlined its strategy to generate a portfolio of diversified water resources in its 1972 Water Master Plan. This plan's approach to self-sufficiency in water supply was three-pronged: build more desalinization plants; collect more run-off during rain events; and greatly increase wastewater recycling. To address the latter approach, and to simultaneously help solve other intense problems it faced as a small island nation (pollution, solid waste disposal and energy), Singapore developed one of the most efficient and integrated wastewater systems in the world. A key facet in this system is the world's largest wastewater energy recovery facility, which is located next to the largest water reclamation plant in the world (Tuas WRP). Together, the facilities efficiently collect, treat and discharge used water, enhance water sustainability by enabling large-scale water recycling, and reap the potential synergies of the water-energy-waste through sludge incineration. By locating facilities next to each other, huge efficiencies are generated, including reduced/eliminated transportation costs and greenhouse gas emissions. On the recycled water side, one of the more important technological advances Singapore has made is the development of the NEWater system. Through a four-step series of barriers and membranes, wastewater is made free of solids, microorganisms, nutrients, and contaminants, resulting in potable water supplies that can be delivered directly into the public water supply. After one decade, this technology generates 40% of the water needs of Singapore. Of course, another key wastewater policy is to decrease wastewater generation. In 1991, Singapore initiated a water conservation tax (graded on income), that was designed to provide an incentive to increase efficiency in water use by households and business, and also provide funds to support innovation in wastewater recycling technologies. This tax has been successful, and has been increased more recently to further fund technology advancement and incentivize conservation.

United States Clean Water Act

The precursor to the U.S. Clean Water Act (USCWA) of 1972 was the Federal Water Pollution Control Act of 1948. While the USCWA was transformative at the time and even with major amendments in 1977 and 1987, it continues to fall short of adequately protecting U.S. water quality for a range of reasons. The USCWA provides a permitting structure for regulating discharge of pollutants as well as regulating water quality standards in surface waters. The USCWA aims to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."

The USCWA provides permits, via the EPA's National Pollutant Discharge Elimination System (NPDES), to businesses and municipalities that allow specific amounts of pollutants to be discharged into surface waters. More specifically, the USCWA has made it unlawful to discharge a pollutant from a point source (e.g., pipe, ditch, sewer, vessel) into navigable waters, unless a permit is obtained. Some stormwater discharges are included under an NPDES permit including:

- Discharge associated with industrial activity
- Discharge from a large or medium municipal separate storm sewer system, or
- Discharge which EPA or the state/tribe determines contributes to a violation of a water quality standard, or which is a significant contributor of pollutants to waters of the United States

However, other types of stormwater are not regulated, and lead to significant pollution in waterways. For example, when combined sewer overflows are in use, non-regulated or unmanaged stormwater has the potential to become a severe environmental problem in that municipality. One of the greatest omissions in the USCWA is that non-point sources (e.g., runoff from fields and lawns, paved areas and clear cuts, septic tanks, **CAFO** runoff, and abandoned mines) of pollutants are not regulated. Because of this, **non-point source pollution** is worse than even industrial pollution. The act also regulates national and local pretreatment standards, by requiring industrial users to pretreat wastewater that is discharged to publicly owned treatment plants, to ultimately protect the quality of sludge generated by the treatment plants. The act regulates sewage sludge and disposal to ensure certain standards for land application, surface disposal, incineration, and disposal in a municipal landfill.

While the USCWA has succeeded in reducing the amount of pollutants discharged into surface waters, as well as preventing massive losses of wetlands, it has been plagued by limited funding and inability to adequately enforce regulations. Nearly two thirds of the United States' coastal rivers and bays are moderately to severely impaired by nutrient pollution; resulting in eutrophication, dead zones, and harmful algal blooms. These events can lead to fish kills, mass-death events of marine mammals and seabirds, and the loss of seagrass, kelp, and coral reef habitats. In contrast to the WFD, this regulatory framework does not take a holistic approach, but rather breaks the system down into parts; which ultimately limits positive outcomes. For example, the water quality standards program emphasizes water chemistry over environmental flow; which compromises the ecological integrity of the system.

Additionally, with regard to identifying wastewater pollution, the key indicator is Enterococcus. In places like Hawai'i, Enterococcus is found naturally in soils, therefore it is challenging to use this indicator to identify whether pollution from human waste is present or not (Mezzacapo, 2020). The USCWA is in need of a major update and overhaul, to address both the ageing infrastructure of wastewater management in the US, as well as the lack of inclusion of **non-point source pollution**. Much of the challenge ahead will come down to politics, as the US continues to struggle to protect its natural resources and environmental health, due to significant pressure from anti-regulatory efforts.

Useful links:

US Clean Water Law Needs New Act for the 21st Century - Circle of Blue

UNDERSTANDING THE OPPORTUNITIES

- → Solution Space
- → Role of Behavioral Science and Design
- → Funding Landscape

Wastewater pollution has been part of life since human populations expanded, and people started living in close proximity to each other. Likewise, ocean dumping is an age-old problem, because the ocean seems vast and limitless, and capable of absorbing whatever we need to dispose. Why is ocean wastewater pollution a problem that needs to be urgently addressed now? The answer is that it should have been addressed long ago; and while the impact has always been there, the extent of the impact has multiplied as our coastal populations have increased. We have a global sanitation crisis giving rise to the need to address this very human problem of better managing and treating human waste. Innovation is happening in this space, and the marketplace is beginning to see and capture the value of human waste. Addressing wastewater pollution, and how we manage and treat waste, presents an opportunity to create multiple benefits for both people and the environment, with the same effort.

Understanding that human waste can be a valuable resource is critical to developing appropriate solutions that benefit both people and nature. Solutions, such as those catalyzed by the Bill and Melinda Gates Foundation, Reinvent the Toilet Initiative, are beginning to make their way into communities. These new technology solutions are being adapted to meet the needs of people and modified for increased function, efficiency, and greater benefits. The initiative's specific requirements of this new toilet tech includes that the toilets do not pollute, and that they generate benefits through producing a valuable resource such as fertilizer, energy, or drinking water. These criteria are great news for those working in the ocean space, as they limit pollution, and provide other resources that otherwise tax what natural resources we have left. As the value of human "waste" is better understood and fully realized, there is an opportunity for those working in the environmental space to capitalize on this understanding, as well as the new technology. While these technological developments are exciting, and good for people in developing areas, they are only the beginning of what needs to be a bigger effort to reduce wastewater pollution in the environment.

Because the global sanitation crisis is largely seen as a problem of the poor, we miss the fact that the developed world is fraught with challenges around wastewater management and treatment. With systems designed to pollute whenever it rains, coupled with aging infrastructure and outdated technology, the developed world must also pay attention, and encourage innovation.

Now more than ever, there is an opportunity to address the infrastructure needs in both developed and developing countries. With a new emphasis on coastal resilience, and concerns around climate adaptation increasing, now is the time to make sure that improvements around wastewater treatment and management are included in efforts to ensure coastal security. The environmental sector has both an interest in solutions that promote coastal resilience, and shoreline protection. Green infrastructure (e.g., constructed wetlands) can provide natural solutions in some situations, but grey infrastructure (e.g., treatment plants) is also a critical piece of the equation. Also, calls for improvements and upgrades from the environmental sector will be important. Finding the balance between green and grey infrastructure is important when considering solutions.

Working across sectors to solve these challenges is essential. The stakeholder space is complex, with a range of expertise needed to solve a problem of this scale. We review the key players in an earlier section to help better understand the roles and opportunities for each sector (See Key Sectors for Collaboration). Given the value of human waste, the opportunity to remove "waste" from the term "wastewater" is more likely now than ever. Not only are funds becoming available to improve sanitation, reduce pollution, and increase human well-being, we can also create value, and even fund the costs of these efforts, by capturing resources and realizing the value around human waste (see Resource Recovery).

Solution Space

Immediate vs Long-term Solutions

The range of solutions to address the phenomenon of ocean wastewater pollution is as diverse as the places it occurs. Every place will have its own unique environmental conditions (e.g., geology, hydrology, habitat types) and socioeconomic situation (e.g., population density, cultural practice, demographics). These factors will help define the best long-term solutions, that are both sustainable for the communities that employ them, and reduce the negative impacts on human and environmental health. The perfect wastewater treatment solution does not yet exist. There is no silver bullet or prescription for every place. However, there are many different types of solutions, each with their own benefits, costs, and complexities.

It has been said in one form or another by famous philosophers that 'one should not let perfect be the enemy of good'. This is certainly the case when it comes to wastewater treatment. Some kind of treatment is better than no treatment. So while this report aims to provide a range of treatment technologies and solutions to consider that are ocean friendly, there are always limitations to what can be done at any point in time. It is more important to address the immediate need of even the most basic treatment, than to spend years trying to find the perfect solution. Treatment and pollution reduction can always be improved, but it is important to start somewhere, and work your way toward the longer-term goal of sustainable solutions.

Cultural and Social Considerations

An important aspect of the solution space is consideration of the socioeconomic context, and special consideration of cultural practices, around how human waste is managed and treated, as well as defecation habits of the local community. The following sections include information about toilet types and treatment technology. It is important to appreciate that technology is only part of the solution; especially when the focus is on toilet technology. Depending on where you live, the solutions employed could literally be a matter of life and death. This is particularly relevant to the health and well-being of women and girls. As mentioned previously in this document, girls are often disproportionately impacted by the global sanitation crisis, because of the high drop-out rates for girls attending schools once they hit puberty and begin menstruating. A school without a toilet is a school without very many girls. This is clearly a huge social problem, as well as one of great inequity, and should be considered in how solutions are employed. In addition, there are places in which going to a community toilet can mean risking sexual assault for women. The addition of a beautifully engineered toilet, that provides clean water or fuel to a community, will go unused by the female population if it is not safe for women and girls to actually use it. These are examples of context, and the importance of considering cultural situations, safety issues, gender equity, accessibility, tradition, social structure, and so much more. There is an important role for behavior science to help understand and address the socioeconomic conditions of a particular place. There are groups that focus entirely on these challenges, and are important to include as collaborations in the solution development process. A recent Solution Search contest that is focused on behavior change around ocean pollution is a great place to start for inspiration and ideas.

Resource Recovery

While the primary concern of this report is the problem of ocean wastewater pollution; as one digs deeper it becomes clear that the solutions can create other benefits that are just as valuable; both from an environmental and economic perspective. To put it simply, by flushing away human waste, we not only pollute the environment, but we also miss an opportunity to address other environmental problems and needs, such as climate change, water scarcity, and sustainable agriculture. Recycling our human excretions is the ultimate recycling. Seeing waste management as a closed loop to support a circular economy; where our human waste is seen as a resource rather than waste; capturing the value of the resource, while avoiding environmental degradation, is the way of the future. With limited resources such as water, phosphorus, and fuel becoming scarcer, and more expensive, and even damaging to procure, it makes sense to focus future solutions on capturing the value of human excretions. See Appendix for great examples that already exist.

According to Heal the Ocean, 1.1 billion gallons of treated water a day are discarded into the ocean and estuaries in California alone (Hawkins et al., 2018). Instead of releasing this water, some communities are treating it to meet US standards and reusing it as drinking water. Orange County, in Southern California, has been operating the world's largest wastewater-to-drinking-water plant for the past 40 years. It provides reclaimed water to its customers through an indirect system, and is projected to supply 130 million gallons of drinking water to 1 million customers by 2023. Similar large-scale systems are in places with dense populations such as Singapore (Leslie, 2018). With only 2.5% of the world's water resources being freshwater, and only 0.49% of that accessible for use (Shiklomanov, 1993), freshwater is just too rare to be throwing it away.

The value of human feces alone is estimated to be $10 billion (USD 2020) per year, with the poop of 1 billion people producing $400 million in methane gas annually (Kluger, 2015). That is enough gas to provide power to 10-18 million households. Additionally, given how important phosphorus is for increasing crop yields, and generating food for billions of people, not capturing this limited resource and reusing it contributes to more problems than just pollution. Releasing phosphorus into the ocean stimulates growth of nuisance algae in tropical systems, and can lead to death and overgrowth of highly valuable seagrass systems by leafy algae. The potential for mining phosphorus from human waste is tremendous, with each human producing close to 1 pound of phosphorus annually. The world supply of phosphorus - which is essential for both animal and plant life, as it forms the basis of our energy compounds, or ATP - is often considered finite, and only available through mining of phosphate rock; as the phosphorus cycle does not have a gas phase, like the nitrogen cycle, that would result in recirculation. For this reason, phosphorus supply is often, like oil, considered a nonrenewable resource. Harvesting it from human waste could change that. In addition, phosphorus mining creates its own environmental hazards, so recycling, rather than allowing it to pollute, has multiple environmental benefits.

There are a range of ways to capture resources from human waste, and more technological solutions are in development. This is a huge growth area and opportunity for innovation and new business. Below we include several general types of technologies as examples.

Recovery Technology

In any given context, the technology choices for sanitation system components generally comprise the following factors:

- Socioeconomic characteristics
- Cultural considerations
- Availability of space
- Soil and groundwater characteristics
- Type and quantity of input products
- Local availability of materials
- Desired output products
- Availability of technologies for subsequent transport
- Financial resources
- Management considerations
- User preferences
- Maintenance requirements

These factors are both interdependent and delimiting. Ultimately, decisions are made according to what is feasible, what the local priorities are, and what is necessary.

What is exciting about sanitation technologies today, beyond the growing number of solutions that mitigate wastewater pollution and its impact on the oceans, is that the industry recognizes this as a growth area, and that human waste products have great value, both in the marketplace and the environment. It is a game changer for the health of oceans, the environment, and for human beings. This section highlights some resource recovery technologies that are part of this change.

Biochar is a stable form of carbon, with a charcoal-like appearance, consisting of carbon (70%), hydrogen, oxygen and nitrogen (CTCN). It is made by burning organic material in a controlled process called pyrolysis. Figure 4 provides an overview of the process typically used to recover biochar for reuse. The process is efficient, producing biochar that is a fine-grained, highly porous structure that can be used as an ideal soil amendment for carbon sequestration (Lehmann, 2007). It is useful for soil amendment and remediation (Agriculture Nutrient Management and Fertilizer), as fuel (Biochar Stoves), and as water treatment (Biochar-Based Water Treatment Systems) among other uses. Biochar from human waste is a high value resource. While human waste is the main source of interest in this context, it is important to be aware that crop residues, yard waste, food and forestry wastes and animal manures are also viable and valuable targets for creating biochar. Currently, agricultural, municipal, and forestry biosolids are burned or left to decompose, releasing CO_2 and methane into the air. Livestock as well as human wastes are significant sources of ground and surface water pollution. Unsafe disposal from on-site sanitation negatively impacts public and environmental health in developing regions. Implementing biochar production technologies (Biochar Technology) protects surface and groundwater, directly affecting ocean health and sustainability.

Table 4. Resource Recovery Potential of Human Excreta*

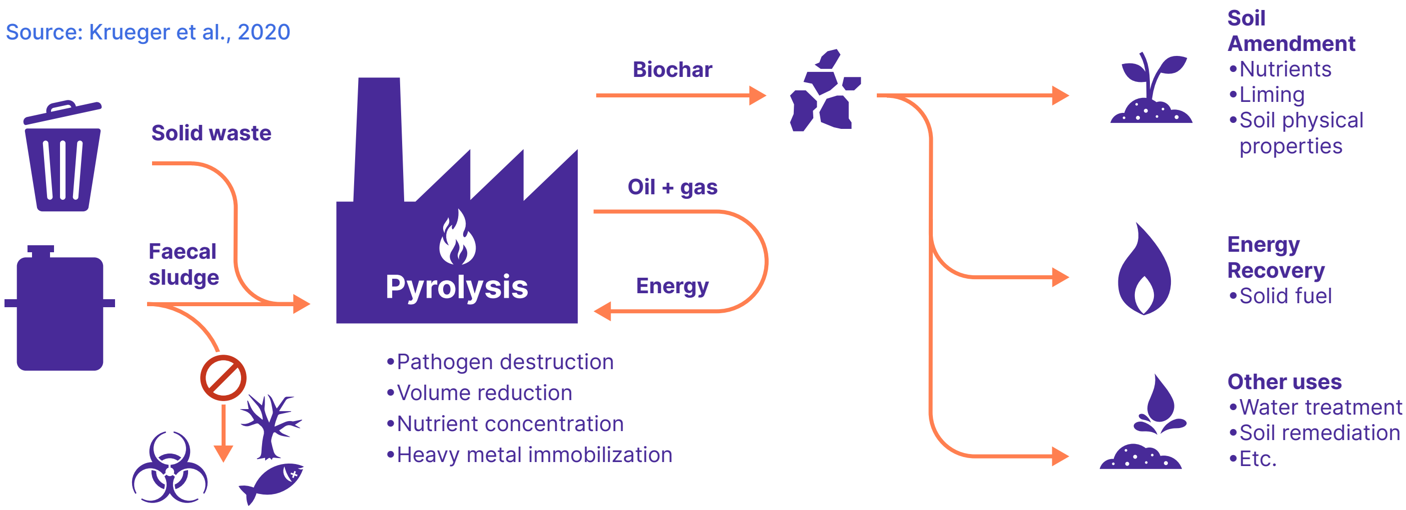
Source: Time

Excreta	Recovery Value
Human feces	55-75% water, 25-35% gaseous methane and solid residue (coal-like in energy content when dried & concentrated
Human feces converted to fuel	$10 billion value per year
Poop of 1 billion people	$400 million in methane production (enough to power 10-18 million households)
Poop of 1 billion people	85 million tons of charcoal-equivalent for industrial use
1000 liters of urine	.66 lbs phosphorus .66 lbs potassium 1 lb of sulphur
Single person's urine and feces	9.9 lbs of nitrogen annually

*Dollar amounts are all adjusted from 2015

Figure 4. Resource recovery and biochar characteristics from full-scale fecal sludge treatment and co-treatment with agricultural waste

Source: Krueger et al., 2020



Useful Links:
Resource recovery and biochar characteristics from full-scale faecal sludge treatment and co-treatment with agricultural waste - Krueger et al.

Biochar - Climate Technology Centre & Network

Biochar Technology - International Biochar Initiative

Biochar-based water treatment systems as a potential low-cost and sustainable technology for clean water provision - Gwenzi et al.

Biodigesters

Biodigesters, also known as anaerobic digesters (AD), are anaerobic treatment systems used to convert animal waste, human excreta and other organic waste to a nutrient-rich slurry suitable for fertilizer and burnable biogas (methane). The waste is digested through anaerobic fermentation by microorganisms naturally present in the waste. The fertilizer is pathogen-free, rich in nitrogen, phosphorus and potassium providing a sustainable means of enhancing agricultural soils through recovery and reuse. Waste digestion is usually accomplished via an airtight container in which the organic waste matter is diluted with water and the application of various mixing methods. There are several basic types of biodigesters for human waste:

- **Stand-alone** - fee-based biodigesters accepting organic waste, organics recycling, and on-site industry based typically accommodating food waste but can also include other wastes
- **Water Resource Recovery Facilities** (WRRF) - municipal or publicly owned plants focused on resource recovery
- **Septic tank and Latrines (**Bio Latrines**)** - variations on the conventional septic tank and pit latrines that facilitate bio digestion; Typically residential and commercial single site.(Bio Latrines, PODTANKS Non-Electric Sewage Treatment Plant System).

Federal and state governments in the U.S., as well as in industry, are now referring to Wastewater Treatment Facilities as Water Resources Recovery Facilities (WRRF), in which the management of waste includes anaerobic digesters in the production of clean water, recovery of nutrients, and renew-

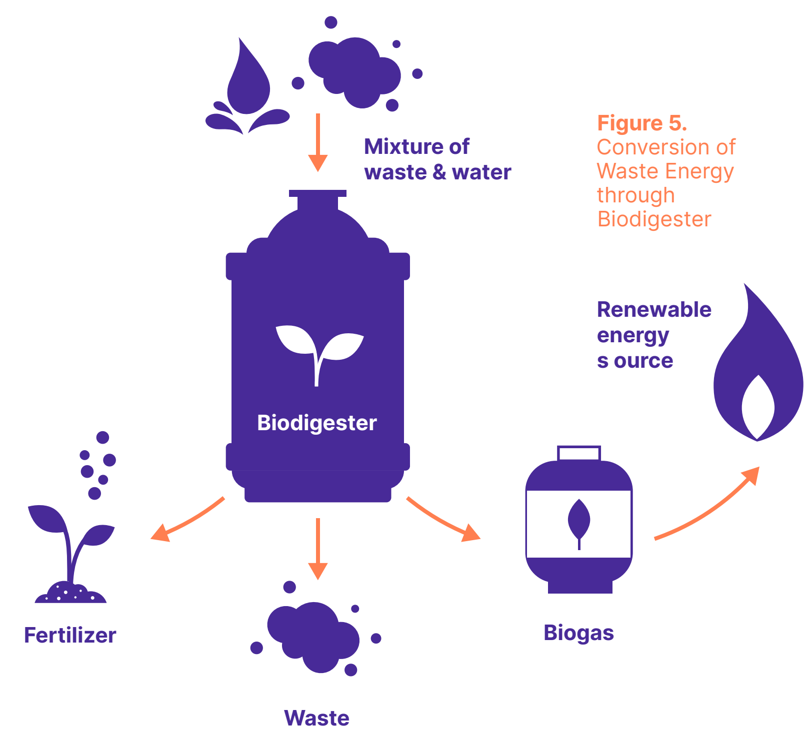


Figure 5. Conversion of Waste Energy through Biodigester

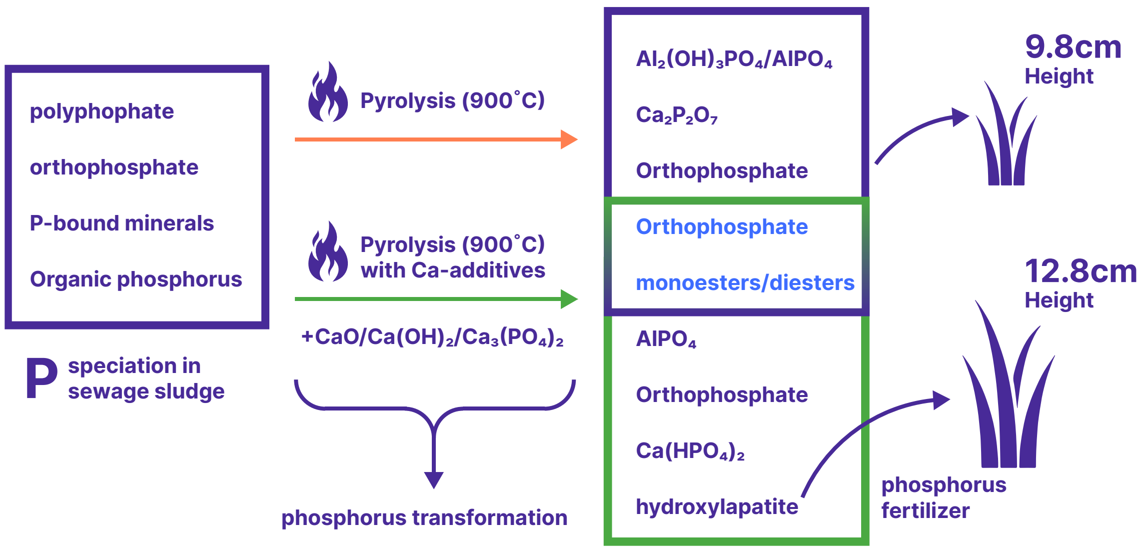


Figure 6.
Efficient recovery of phosphorus in sewage sludge through hydroxylapatite enhancement formation aided by calcium-based additives.

Source: Chen et al., 2020

able energy; clearly a progressive turn toward mainstreaming resource recovery in environmentally sustainable ways. There are over 1,200 water resource recovery facilities in the United States, with over half using the biogas they produce as an energy resource for electricity or heating (Water Environment Federation). Thirty percent generate electricity from biogas to run the facility, ten percent are able to sell electricity back to the grid, and two percent generate biogas of high enough quality for natural gas pipelines. On a smaller scale, conventional septic tanks include both **aerobic** and anaerobic digestion to degrade the biomass that settles in the tank, leaving sludge that needs to be periodically pumped out for disposal. However, septic tank conversions to biodigesters (Septic Tank Conversion) are commercially available for single residences, as are biodigester wastewater treatment systems based on the same technology. Another promising emerging biodigester technology is the Omni Processor, which produces clean drinkable water, energy and ash that can be used in construction. The Omni Processor is currently processing about one third of Dakar's sludge.

Useful Links:

Recovering Value from Waste: Anaerobic Digester System Basics - EPA

Biodigester - Climate Technology Centre & Network

This Is How a Biogas Digester is Built - Our Better World

How a biodigester works - Saskatchewan Research Council

Agriculture Nutrient Management and Fertilizer - EPA

How Does Anaerobic Digestion Work? - EPA

Biodigester Models - MAK Biodigester

Biodigesters Facts & Figures - PodTanks

Regular septic tanks vs Biodigester septic tanks - SuSanA

Types of Anaerobic Digesters - EPA

Biodigester Septic Tank - Blueflame

Solar C^{3}ITIES

Fertilizer Recovery

Nitrogen and/or phosphorus based fertilizer can be recovered from human excreta biosolids (Munasinghe-Arachchige & Nirmalakhandan, 2020) and stored urine (Rich Earth Institute). Stored urine requires wastewater management sources that incorporate urine diversion technology. Biosolids are a byproduct of centralized wastewater treatment facilities and from on-site waste treatment in which feces and urine are collected and treated separately. When treated and processed properly, these waste treatment byproducts can be recovered; both are nutrient-rich organic materials suitable for reuse (Simha & Ganesapillai, 2017).

Biosolids are appropriate for and have been used successfully for the following agricultural uses:

- Soil enhancement
- Establishing vegetation in reclamation sites
- Soil erosion control
- Regenerating soils
- Promoting timber growth in forestry
- Landscaping purposes for homes, gardens and other venues

While treatment allows them to be handled safely, both biosolids and stored urine must be managed carefully within the regulatory constraints and health standards of the region in which they are recovered and applied.

There is increased interest in phosphorus recovery from human waste due to depletion of global stores of phosphorus. The looming shortage of phosphorus provides a strong market-based incentive for pursuing this technology. The recovery of fertilizer from human waste is an elegant solution that saves resources, improves water quality, prevents pollution and contributes to sustainable agriculture.

Useful Links:
Removal and recovery of nutrients from municipal sewage: Algal vs. conventional approaches - Abeysiriwardana-Arachchige et al.

Slough sewage plant turns human excrement into high-quality fertiliser - The Guardian

Fertilizer-Grade Phosphate Recovery From Wastewater Treatment Plants, Part II - USDA

Urine Diversion

Urine diversion is the practice of separating urine from feces through the use of urinals or urine diverting toilets or latrines (see Sanitation Health in Transition). The technology is both low cost and low technology implementable in urban and rural communities in developing and developed regions and countries (GIZ, 2011; Graves, 2019).
The impact is two-fold. First, it acts as a fertilizer recovery mechanism. Urine contains 80-85% of the nitrogen and 66% of the phosphorus in human waste. Annually, this equates to approximately 9 pounds of nitrogen and 0.8 pounds of phosphorus recoverable from the urine of one adult (Rich Earth Institute). These essential plant nutrients make it the source of an excellent liquid fertilizer for agricultural use. And, because urine is nearly sterile, it can be handled easily, usually with little risk, and subsequently stored in containers and later transported to fields in the same way as bulk water or sludge. Secondly, urine diversion prevents these nutrients from contributing to ocean wastewater pollution in which these nutrients result in algal growth overwhelming coastal waters and devastating healthy marine life.

Water Recovery

Wastewater reuse is the use of treated wastewater to replace or augment the use of water for non-potable uses, such as landscape and agricultural irrigation and industrial water supply, and for indirect potable uses, including groundwater recharge and surface water augmentation. Indirect potable reuse), involving the discharge of treated wastewater to public sources such as rivers, lakes, or aquifers, is more widely encountered. However, direct potable reuse (e.g., The Omni Processor, toilet to tap) is an increasing trend worldwide, particularly in water scarce areas, if membrane treatment, advanced oxidation, filtration, and disinfection are provided. **Secondary treatment** water, with or without nitrogen and phosphorus reduction, is filtered and then disinfected for irrigation use for landscape or other non-potable (and sometimes potable) needs. The treated wastewater from cluster systems, satellite systems, or centralized systems can be used for a broad range of community sizes for irrigation or other non-potable uses. Small scale wastewater reuse is also being employed at, for example, resort communities or for agricultural purposes.

Useful Links:
From Wastewater to Drinking Water - Columbia Climate School

Recycled drinking water - is it safe to drink treated effluent? - CHOICE

More of us are drinking recycled sewage water than most people realise - The Conversation

Wastewater Treatment - Safe Drinking Water Foundation

Why we all need to start drinking toilet water - BBC Future

From toilet to tap: Getting a taste for drinking recycled waste water - CNN

Water Reuse 101 - WateReuse

Indirect potable reuse: a sustainable water supply alternative - Rodriguez et al.

Nature-Based Solutions

While the emphasis in the sanitation space as well as in the threat mitigation space has been on grey infrastructure, there is a growing body of examples of nature-based solutions that yield benefits beyond wastewater treatment. Nature-based solutions can take a range of forms and include not only treatment technologies but also natural infrastructure that can protect coastal treatment plants and septic systems from flooding and storm surge. For example, living shorelines addressing flooding that compromises wastewater treatment. By restoring habitats that naturally protect coastlines from flooding and storm surge, improvements in important economic activities such as fishing and tourism can result. In addition, horizontal flow treatment wetlands can be used for secondary and tertiary wastewater treatment, and can also support biodiversity, recreation and provide water for reuse in agriculture. A more comprehensive guide of nature-based solutions for sanitation managers is under development via a SNAPP working group and is expected in 2021. Here we detail a few examples of nature-based solutions but there are many others to explore.

Algal Turf Scrubbers

Algal Turf Scrubbers (ATS) are an engineered turf comprising an algal community growing on screens in a shallow basin. Nutrients are removed from the untreated water as it is pumped through the 'turf' and the algal community ingests inorganic compounds and, via photosynthesis, releases dissolved oxygen. The 'treated' water can then be released back into the water body it was sourced from, resulting in lower nutrient, higher oxygenated waters. In practice, the algae are harvested frequently to remove the nutrients "scrubbed" from the water and to maintain the health and growth of the algal community. ATS biomass production are among the highest of any recorded values for natural or managed ecosystems (Adey & Loveland, 2007.). Due to ATS' extraordinarily fast algae growth rate, it can remove nutrients and produce oxygen at a high rate, and the cost of producing biofuels from the cleaning of wastewaters by ATS can be quite low (R&D to produce ethanol, butanol, and methane is ongoing). ATS design variables include the flow rate of water, the slope of the water basin (i.e., raceway), the loading rate of nutrients in the water, and the type of screen used to grow algae. Here is an example of an Algal Turf Scrubber.

Constructed Wetlands

Constructed wetlands (see "Constructed Wetlands," EPA and factsheet from the Center for Clean Water Technology) are engineered systems for wastewater treatment, reuse or disposal that use natural biological treatment technologies that incorporate wetland vegetation, soils and associated microorganisms to remove contaminants. **Constructed wetlands** are found worldwide and are designed to meet a variety of objectives, including both **secondary treatment** (e.g., mangrove microcosms in Hong Kong) and **tertiary treatment** (e.g., an engineered wetland in New Delhi). In general, there are two basic types of **constructed wetlands**:

- Subsurface Flow Systems, also called root-zone systems, rock-weed filters, and vegetated submerged bed systems, that are media-based using soil, sand, gravel and/or crushed rock. Essentially, wastewater flows through natural wetland filters. As designed and operated, these systems provide limited opportunity for benefits other than water quality improvement.
- Free Water Surface Systems simulate natural wetlands in which water flows over the soil. In these systems, break-down and decomposition of solids is facilitated by the algae and bacteria that live in the oxygenated water, while larger plants also growing in the system take up the abundance of nutrients that are produced during decomposition. These systems are often designed to maximize wetland habitat value and reuse opportunities, while providing water quality improvement (e.g., Green Cay Treatment Wetlands).

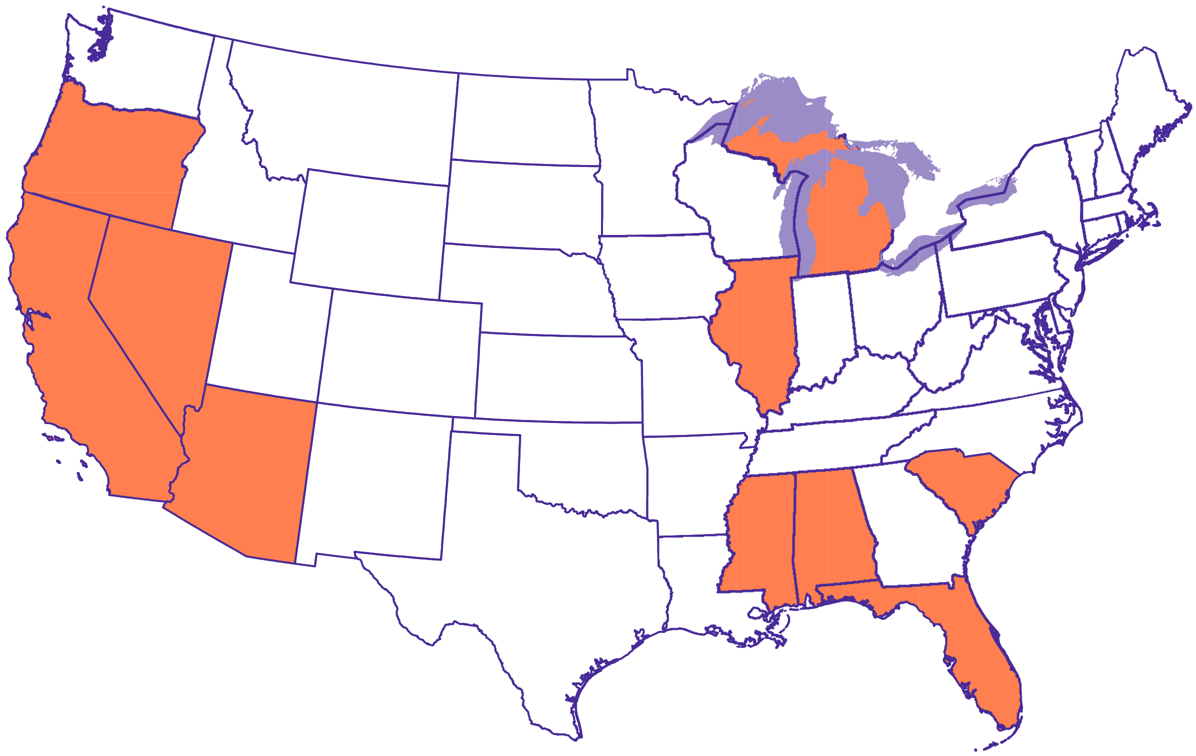
Constructed wetlands can be used to both create and restore wetlands. Many free water surface systems also function as wildlife refuges and/or parks. These systems provide an area for public education and recreation in the form of birding, hiking, camping, hunting, and more. See Figure 7 for some free water surface systems in the US. It is an elegant eco-friendly solution that converts the problem of wastewater management into a natural benefit for the environment and its inhabitants (see EPA case studies). They are typically decentralized solutions suitable for both small communities and as upgrades to large treatment facilities.

Nitrogen Removing Biofilters

On-site conventional septic tanks and **cesspools** disperse nitrogen rich effluent into the surrounding soils. By design, these systems rely on these soils to filter out nutrients before they can leach into the groundwater, and in turn, pollute surface waters ("Sources and Solutions," EPA). A typical septic system with a drain field reduces nitrogen to around 30mg/L (**cesspools** have much higher levels) which is still environmentally unsafe (WADOH, 2020). Poorly designed, mismanaged and/or aging septic systems result in much higher release of nutrients, overwhelming the soil's ability to reduce both the nitrogen and phosphorus to even that level. NRBs are attached to conventional septic systems via a passive system in which effluent from the septic tank is gravity fed into an NRB that includes a layer of nitrifying sand and a denitrifying layer of a sand lignocellulose (wood) mix. The development and use of nitrogen removing biofilters (NRBs) provide a highly efficient method of ensuring septic effluent can be safely released into the environment with approximately 90% of the nitrogen removed (Heufelder, 2015). They also reduce the presence of pathogens, pharmaceuticals, and personal care products. NRBs are a low technology, highly efficient, and low-cost way to ensure the release of clean, safe water into our ground and surface waters. This is a promising solution for on-site waste treatment (Schaefer, 2016).

Figure 7. Location and characteristics of 17 free water surface system success stories.

Source: EPA, 1993



OREGON

Hillsboro (Jackson Bottom Wetlands Preserve)
- natural bottomland/15 acres constructed wetlands
- polishes/reuses secondary effluent
- wildlife enhancement, research, water quality improvement, public recreation and education

Cannon Beach
- natural alder/spruce/sedge wetlands (15 acres)
- polishes pond effluent (0.68 mgd)
- June thru Oct operation since 1984

CALIFORNIA

Arcata Marsh and Wildlife Sanctuary
- polishes/reuses secondary effluent 2.3 mgd
- 7.5 acres treatment wetland; 31 acres refuge; plus pond, tidal sloughs and estuary habitat
- managed as wildlife sanctuary for wildlife use, research and extensive public use
- Ford Foundation award for innovation in 1987

Hayward Marsh (Union Sanitary Dist.)
- constructed wetlands for habitat creation
- restoration of historical wetlands area
- secondary effluent and stormwater reuse
- 172 acres of fresh & brackish marshes part of a 400 acre marsh restoration effort

Marin Co. (Las Gallinas Valley Sanitary Dist.)
- constructed wetlands for habitat enhancement
- polishes/reuses secondary effluent (2.9 mgd)
- 20 acres wildlife marsh; 40 acres ponds; 200 acres pasture (summer irrigation)
- operational since 1984; no summer discharge

Martinez (Mt. View Sanitary Dist)
- 85 acres constructed wetlands created for habitat value
- restoration of historical wetlands area
- polishes/reuses secondary effluent (1.3 mgd)
- staged wetlands construction since 1974

NEVADA

Incline Village
- constructed (total evaporative) wetlands
- polishing/disposal of secondary effluent (3.0 mgd from Lake Tahoe Basin)
- 390 acres of non-discharging wetlands; 770 acre project site also includes some existing warmwater wetlands and 200 acres of uplands
- operational since late 1984

ARIZONA

Show Low, AZ
(Pintail Lake/Redhead Marsh)
- effluent (1.42 mgd) currently supports 201 acres of ponds and constructed marshes (total evaporative wetlands)

Pinetop/Lakeside, AZ
(Jacques Marsh)
- effluent (2mgd) currently supports 127 acres of ponds and constructed marshes (total evaporative wetlands)
    - polishing/disposal of secondary effluent
    - habitat creation on National Forest lands
    - initiated in 1970; expanded in 1977, 1978, 1980 and 1985
    - managed as wildlife habitat and for public use

ILLINOIS

Des Plaines River
- constructed wetlands w/450 acres riparian land
- demo of improving river water quality
- incorporates 2.8 miles of river drainage
- drainage area 80% agricultural, 20% urban
- private and government sponsored demo
- ESA Special Recognition Award 1993

MICHIGAN

Houghton Lake
- natural peatland wetlands (1,500 acres}
- polishes pond effluent (2.6 mgd summer only)
- 16 years of May-Sept operation
- ASCE Award of Engineering Excellence 1977

Vermontville
- polishes pond effluent (0.1 mgd)
- 11.5 acres wetlands self established
- continuous operation for 19+ yrs.

SOUTH CAROLINA

Grand Strand , SC (Carolina Bays)
- natural pocosin wetlands (702 acres); mostly previously disturbed
- polishes/reuses secondary effluent (2.5 mgd)
- wetlands managed as Nature Park
- critical refuge for rare plants and animals
- ACEC Grand Conceptor Award 1991

ALABAMA

Fort Deposit
- constructed treatment wetlands (15 acres)
- polishes pond effluent (0.24 mgd)
- ACEC Grand Award 1992

MISSISSIPPI

West Jackson County
- constructed treatment wetlands (56 acres)
- polishes pond effluent; 1.6 mgd w/ additional rainwater input (2.6 mgd total)

FLORIDA

Orlando Easterly Wetlands Reclamation Project
- 1,220 acres of constructed wetlands habitat
- restoration of historical wetlands area
- polishes/reuses 20 mgd AWT effluent
- operational since 1987
- ASCE Award of Engineering Excellence 1988

Lakeland
- polishes/reuses secondary effluent (14 mgd)
- mixed with power plant blow down water
- restoration of abandoned phosphate mines
- 1,400 acres constructed wetlands habitat
- operational since 1987

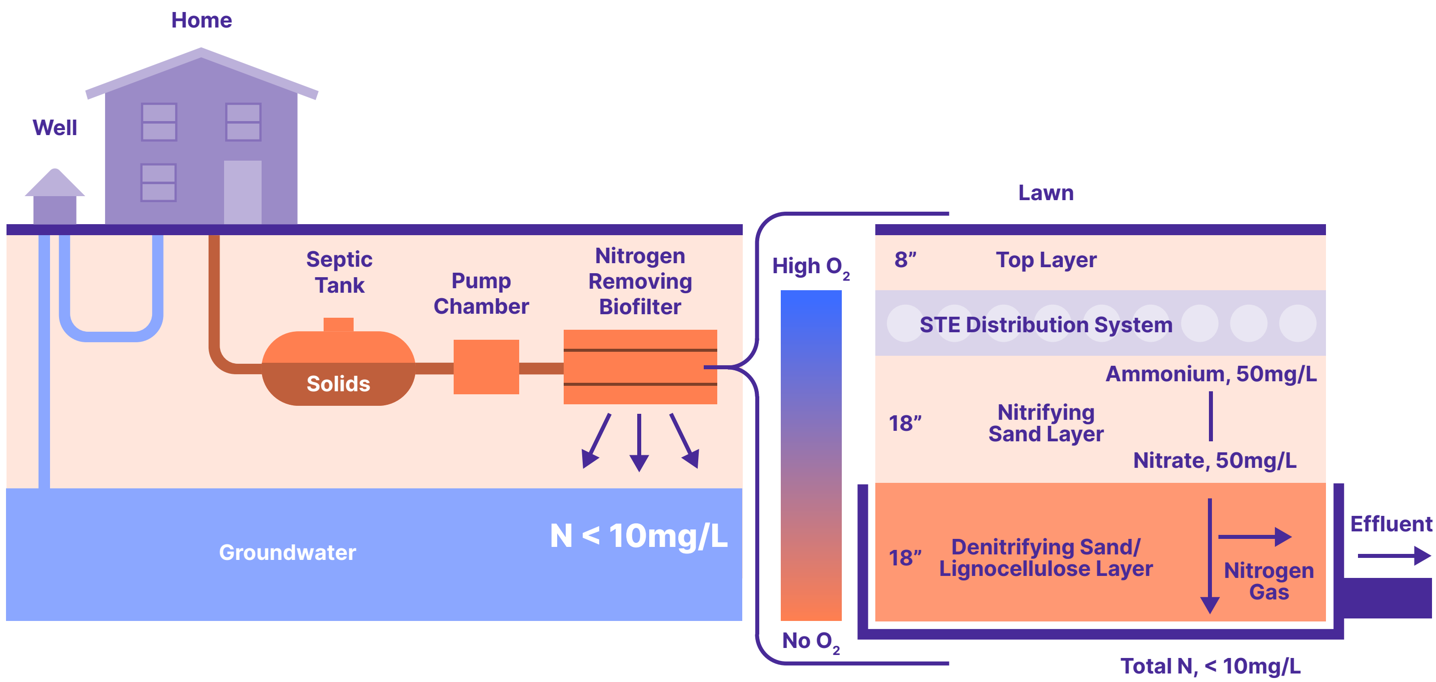


Figure 8. Nitrogen Removing Biofilter.

Source: Center for Clean Water Technology, Stony Brook University

Useful Links:

Onsite Wastewater Treatment Systems - Center for Clean Water Technology, Stony Brook University

Massachusetts Alternative Septic System Test Center - Barnstable County Department of Health and Environment

Nitrogen Removing Biofilters for Onsite Wastewater Treatment - Center for Clean Water Technology, Stony Brook University

The Gobler Laboratory - SUNY Stonybrook

Role of Behavioral Science and Design

Wastewater pollution can often be the result of human activity. Open defecation, unmaintained or improperly managed sewage and septic systems, illegal dumping and more all contribute to the excess nitrogen and phosphorous entering our waterways. Furthermore, while technological innovation and policy reform are often necessary precursors to change, the adoption, implementation and enforcement of these mechanisms require additional efforts to ensure successful reductions of wastewater pollution.

Behavior-centered design can help overcome many of the remaining barriers to this challenge. Traditionally, environmental practitioners have relied heavily on three levers for changing behaviors: rules and regulations (such as policies and laws), material incentives (such as financial payments or taxes) and information campaigns (such as sharing data). While they can be effective, these levers rely heavily on an assumption that people make all their decisions in purely rational, maximizing terms.

Recent research in social and behavioral sciences indicates that environmental interventions, such as those addressing wastewater pollution, should incorporate a more holistic set of levers underpinning human decision-making and behavior, including the following premises:

1. Emotions are often more powerful than reason.
2. People are inherently a social species and influenced as such.
3. The context and timing of our decision-making matters.

These levers are relevant across all types of interventions. They can be applied in smaller communities or across large urban areas. Similarly, they can be used effectively across diverse types of audiences. While many consider behavior change campaigns to be most relevant for public-facing efforts, recent research also indicates that social norms can be effective in encouraging compliance of discharge limits by wastewater utilities.

Yet knowing when, where and how to apply these behavioral levers can be challenging for practitioners. Behavior-Centered Design (BCD) is a method that combines behavioral science and design thinking to develop and implement successful change interventions. Practitioners can follow this process to strategically design solutions that leverage behavioral science and drive towards the desired reduction in pollution. These methods are widely recognized among behavior change experts and often emerge through other best practices. For example, the Strategic Communications Planning Process promotes similar steps and analyses to develop effective messaging campaigns. The approaches lead practitioners to develop interventions that specifically target the key stakeholders with messages that resonate and come from those that influence them the most.

Combining behavioral design with the necessary expertise in the biological and natural sciences, policy reform, and sanitation system management provides a more comprehensive toolkit for tackling the wastewater pollution problem facing our oceans.

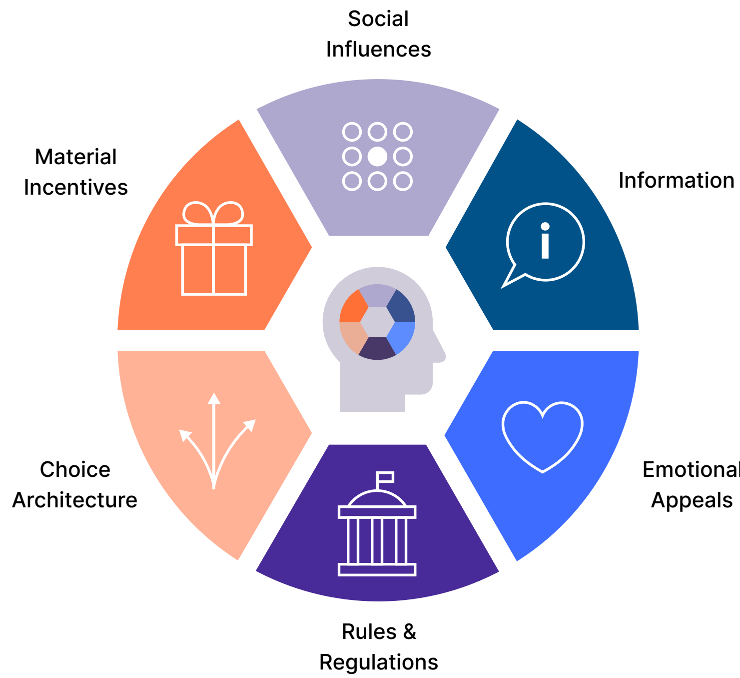


Figure 9. Levers of Behavior Change.

Source: RARE

Funding Landscape

While it is generally challenging to understand the funding landscape, with both private and public funding coming from a range of sources, some of which are not well tracked; it is safe to say that mitigating the threat of ocean wastewater pollution is grossly underfunded. This can be said with confidence because in general, when compared to a range of other social causes and philanthropic pursuits, environmental conservation takes up a tiny slice of the charitable funding pie. In a recent review of general philanthropy in 2018 and 2019 by Giving USA (2020), the majority of charitable dollars went to religion (29%), education (14%), human services (12%), grantmaking foundations (12%), and health (9%). The environment, which includes animal organizations, consistently receives about 3% of charitable gifts. A review of data from Candid's database of all publishable grants between 2006 and 2019, showed that grants related to marine wastewater pollution averaged about $6 million annually, with about $80 million granted over that 14-year period. While these data are not all inclusive, and present many limitations, they do give a general sense of the level of attention this problem has received from philanthropic sources. The priorities include a range of strategies to improve waste management; including wastewater treatment and infrastructure, wastewater reuse, clean-up of wastewater pollution, and green infrastructure.

While community foundations and place-based funders tended to fund sanitation-related work from an environmental lens, or an urban development/improvement lens, it is clear that there is just not enough funding flowing from these sources to amount to meaningful change. This means one of two things, or perhaps both: that an effort to increase philanthropic giving around this issue would be worth pursuing, or a focus on mobilizing public funds to address this threat would yield more resources to tackle the threat. While American philanthropic giving topped $449 billion in 2019 overall (Giving USA, 2020), the problems we face are clearly much more expensive to solve. Charitable giving is not a fix-all solution. Rather it is an opportunity to catalyze important change, bring new ideas to light, and de-risk solutions that are otherwise ignored. This is one important piece of the puzzle.

However, the bigger contributor to solving these funding gaps is likely a combination of impact investing, public funding, and low-cost financing available from development banks; such as KfW Development Bank, a German bank that has consistently prioritized improving sanitation infrastructure at the global scale. For example, in 2019 alone, KfW provided around EUR 1.09 billion toward projects to address SDG 6 (Clean Water and Sanitation). In 2018, KfW partnered with the European Investment Bank (EIB), and the French development agency (AFD), to address marine debris in developing countries via a "Clean Oceans Initiative"; with a commitment to provide EUR 2 billion by 2023 to reduce the amount of plastic waste discharged into the ocean. This will have a direct impact on how much wastewater is discharged by default, since so much plastic debris makes its way to the ocean via wastewater discharges. They will focus on wastewater treatment, waste disposal and rainwater management. They are investing heavily in places like South Africa, Indonesia, and Latin America. More recently, they have welcomed other development banks to the initiative, including Instituto de Crédito Oficial (ICO) from Spain, and Cassa Depositi de Prestiti (CDP) from Italy, which will further magnify the impact these efforts will have on ocean health. The Australian state of Queensland has partnered with a national bank to create reef credits (similar to carbon credits); a creative financing mechanism to reduce coastal pollution by paying farmers not to pollute. These kind of funding opportunities and strategies have the potential to create real change. The challenge can be accessing funding for smaller countries with fewer resources, and less ability to put together a comprehensive plan, to address their sanitation and pollution mitigation needs. This is where private philanthropy can play a role as a catalyst; by providing planning funds that ultimately create the enabling conditions for countries to access game changing funding.

So, while we are seeing increases in funding that is specific to the threat of ocean wastewater pollution, it is important to consider other strategies that accomplish the same end result. For example, while the WASH sector works to solve the problem of unsafe drinking water and sanitation, when they achieve their goals; it is possible that the environment also benefits from achieving these goals, depending on the strategy employed. Partnering with the WASH sector, and making the case for using tactics that benefit both people and nature, is one way to address the threat while not needing to raise large amounts of funding. Looking for ocean wins in “non-ocean” spaces may be a very efficient and effective way to make progress across sectors. A similar opportunity likely exists around climate adaptation funding and blue carbon initiatives; especially for small island countries, and those with significant coastlines vulnerable to sea level rise. Part of the vulnerability these countries face is related to the risk of damage to sanitation infrastructure. As sanitation infrastructure is installed or improved in these areas, there is an opportunity to ensure that any new installation is “ocean friendly.” Doing so will also further increase the coastal and community resilience to climate change.

RESEARCH AND TECHNOLOGY PRIORITIES

- → Knowledge Gaps
- → Technology Needs
- → Tool Needs

While ocean wastewater pollution is not a new problem, actively working to reduce it at meaningful scales is new to the environmental sector. Because of this, there are few resources or guides that currently exist to support action. This report begins to fill that gap by providing an overview, but so much more is needed in order for practitioners to be successful in their wastewater pollution mitigation endeavors. Below are some of the gaps that need to be addressed.

Knowledge Gaps

In a 2015 review by Wear and Vega Thurber, it was made clear that impacts of wastewater pollution on coral reefs and other marine systems have been understudied. There is a general need to better tease apart the range of negative impacts on sensitive marine habitats, in order to make a case for action. This understanding will help in monitoring and quantifying effects observed over time on coastal habitats exposed to wastewater pollution. While "How much wastewater exposure is too much?" is an important question that should be answered, it is safe to say that there are some ecosystems (e.g., coral reefs) where any amount of wastewater pollution is problematic, because they require water clarity and low nutrient waters (i.e., oligotrophic conditions).

Urgent Questions:

1. What are the functional relationships between ecological variables and wastewater pollution? Are the relationships linear or non-linear (e.g., unimodal or thresholds)?
2. What effects do commonly used pharmaceuticals (e.g., antibiotics, hormone replacement therapy, pain relievers) have on important marine organisms?
3. What are the priority geographies for wastewater pollution mitigation?
4. Which geographies already have enabling conditions to initiate wastewater pollution mitigation efforts?
5. Where is ocean wastewater pollution having the biggest negative effects on coastal habitats? On human communities?
6. How can we best measure the impacts of wastewater pollution mitigation on coastal habitats? On nearby human communities?
7. What is the easiest and most effective way to monitor coastal water quality to protect human and environmental health?
8. What is the differential effect of wastewater pollution vs agricultural pollution? Are there synergistic effects when both are present and prevalent?
9. How does climate change affect the impacts of wastewater pollution? Are wastewater hotspots more vulnerable to climate change impacts?
10. What level of pollution is acceptable vs damaging to marine and coastal habitats?

This list will grow as the work evolves. Please share your questions with us to be included here, and shared with others.

Technology Needs

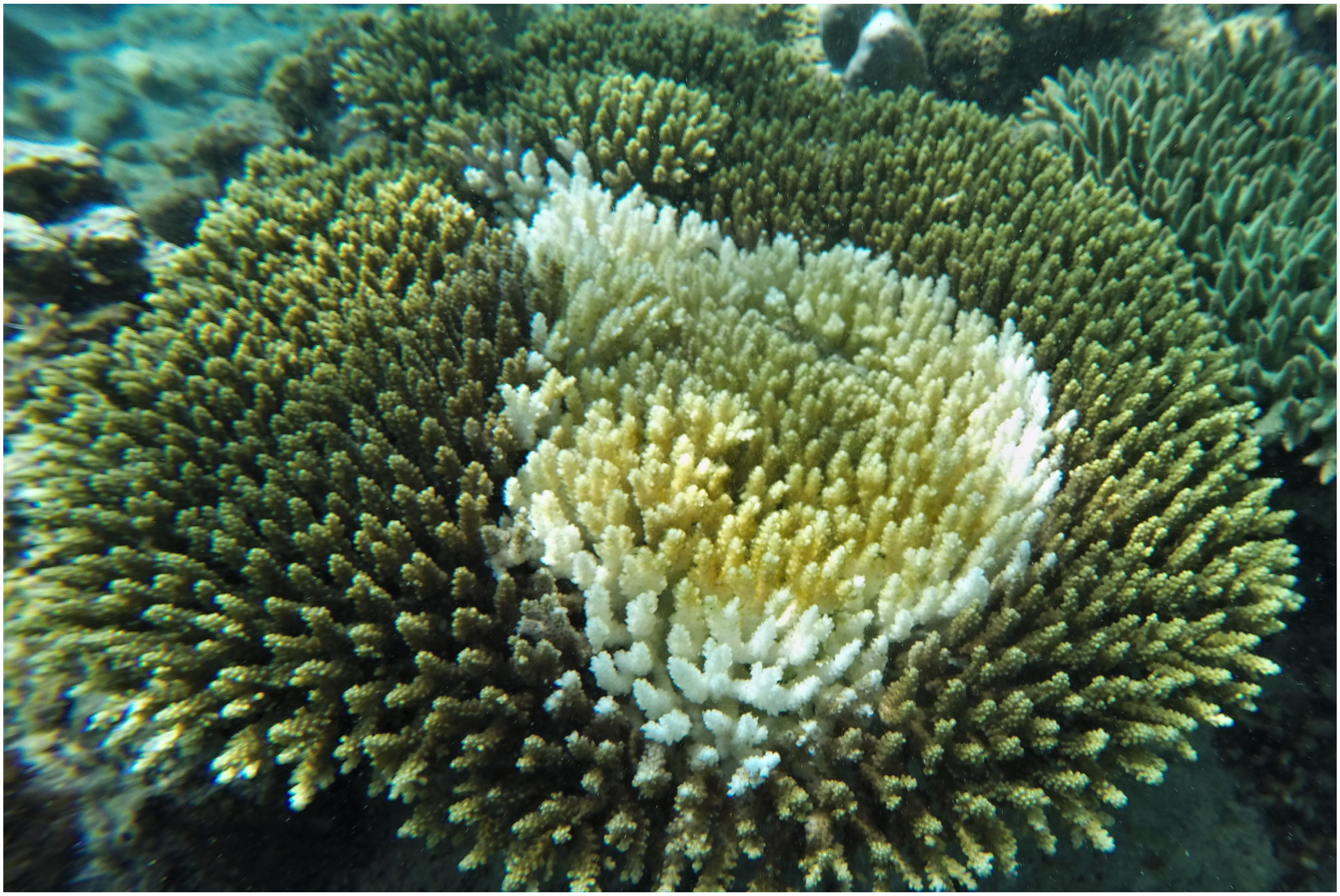
While there are a range of technology needs, probably some of the more important include:

- The ability to rapidly measure important water quality measurements, prioritizing nutrients and wastewater contamination indicators
- Develop cheaper methods to monitor nitrogen, phosphorus, oxygen, and wastewater markers, such as enriched isotopic nitrogen or anthropogenic compounds in the field
- Set up integrative networks for monitoring that use autosamplers, cell phones, and drones
- To more efficiently remove nitrogen in the treatment process
- To efficiently remove or degrade pharmaceuticals and other contaminants of concern that are not currently included in treatment technologies
- To efficiently capture/generate resources such as water, nutrients, and fuel from wastewater
- To improve upon water-less technologies to avoid water pollution from the start
- To improve on urine-diversion technologies (as above)
- To increase efficiency of treatment plants to become carbon neutral or negative
- To increase efficiency of retrofitting and transitioning combined sewer overflows

Tool Needs

While this report provides a broad overview of ocean wastewater pollution, decision-makers also need a decision-support tool to assist in determining best options for threat mitigation as well as monitoring and evaluation of implemented strategies. We will share that when it becomes available. Similar guides or decision-support tools would be useful for other types of solutions. There is also a need for uniform national and global databases to archive monitoring data, and allow for off-site meta-analysis.

There are organizations and businesses around the world that are addressing different aspects of this problem; whether it is specific to ocean or environmental health or not, it is helpful to have a better understanding of who those institutions and individ-



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uals are. There are some existing networks that are very specific to WASH and sanitation, such as the Sustainable Sanitation Alliance (SuSanA) that are a great place to start.

There is also a need for more case studies, so that others may both get inspired and learn from projects that are underway, or completed. If you are embarking on a project, please reach out to us at info@oceansewagealliance.org so that we can share your progress along the way. Many assume that a project must be completed and deemed successful to be shared as a case study. However, mitigation projects can take several years, and there is so much to learn through the process; both what works and what doesn't. It is invaluable to others to share those experiences.

SANITATION 101

- → Basic Sanitation Terminology
- → System Types
- → Degrees of Treatment
- → Overview of Sanitation Systems
- → Treatment Technologies

This section provides an introductory overview of the components and technologies pertaining to human waste and its management. It is not intended to be exhaustive but rather provide a reference for those addressing **human waste management** in its various contexts. Sanitation 101 contains subsections on:

- Basic terminology - provides the reader with some basic terminology applicable to human waste and wastewater pollution to increase readability of Sanitation 101. The Glossary section of the document provides a more comprehensive list of terms and concepts
- System Types - differentiates individual, decentralized and centralized implementations of sanitation systems; it introduces the typical functional elements of system types, providing context the variety of ways in which a system may be designed and implemented
- Degrees of Treatment - defines the degrees of treatment that are used to characterize the sanitation processes and products (outputs) in a sanitation system
- Overview of Sanitation Systems - describes sanitation system processes and includes a subsection on the treatment technologies that may be used in different sanitation systems

In general, a sanitation system is a stepwise series of technologies and services for the collection, containment, transport, transformation, utilization and/or disposal of waste. It comprises waste products that travel through functional elements that employ various context sensitive technologies that are specific to the type of waste and the local sanitation requirements; requirements that include the physical environment as well as cultural norms and the local infrastructure. Some waste products are generated directly by humans (urine and feces/excreta), others are required in the functioning of technologies (the use of flush water to move excreta through sewers), and some are generated as a function of storage or treatment (e.g., sludge). The design of a sanitation system includes the definition of all of the waste products flowing into and out of each of the technologies in the system.

The efficacy of a sanitation system depends on its fit to the human and environmental context and the feasibility of actually operating and managing the system safely and sustainably in that context.

Furthermore, Ownership, Operations and Management (OO&M) deserve consideration as it can pose significant challenges to implementing sanitation solutions. These models include nonprofit, private, municipal, public-private partnerships etc. as well as financing options, all of which will vary depending on the OO&M model. Innovation and policy change is needed to facilitate easier OO&M models. An example of a broken system is the County systems in Hawaii; the capital cost is funded through Community Improvement Project funding, then operations is funded through taxing users... but there is no system to ensure capture of capital improvement and emergency funds that are needed when components need replacing due to their age, or are damaged in storms. What typically happens is the County must lobby for additional CIP funds after systems have fallen into disrepair (e.g., after a wastewater spill). Practitioners need to be aware of and have reasonable knowledge of the different management systems as well as understand how local policy needs to change to support implementation. As an example, Working Together for Clean Water provides insight into OO&M for a specific project.

Use Sanitation 101 as a foundation for understanding the components and functions comprising human waste management and sanitation systems.

Basic Sanitation Terminology

The following are terms commonly found in content describing the management of human waste.

Blackwater - Liquid and solid human body waste and the carriage water generated through toilet usage [EPA, 1996].

Biological Oxygen Demand (BOD) - The amount of dissolved oxygen needed by **aerobic** organisms to break down organic matter in a water sample at a given temperature and time period. BOD is commonly expressed as milligrams of oxygen consumed per liter of sample over 5 days at 20 °C (Delzer & McKenzie, 2003). It is often used to describe the level of organic pollution of water. Total BOD is the amount of oxygen required to completely oxidize the organic compounds to carbon dioxide and water through **microbial metabolism**.

Effluent - The general term for a liquid that leaves a technology, typically after blackwater or sludge has undergone solids separation or some other type of treatment. Effluent originates at either a Collection and Storage or a (Semi-) Centralized Treatment technology. Depending on the type of treatment, the effluent may be completely sanitized or may require further treatment before it can be used or disposed of.

Excreta - Urine and feces not mixed with flush water or other waste components.

Flush water - the carriage water generated through toilet usage.

Greywater - Wastewater other than effluent containing human waste, such as sink drainage or washing machine discharge [EPA, 2009].

Sanitation - Refers to conditions related to public health, especially the provision of clean drinking water and adequate disposal of human waste.

Sewage - Technically the term *sewage* refers to human excrement that has been conveyed through a conduit, using water. However, outside the sanitation sector, *sewage* has come to mean any human excrement, regardless of where and how it has been stored or transported.

Sludge - Mainly excreta and water that may contain other matter such as sand, grit, metals, trash and/or various chemical compounds, depending on the source of the sludge.

Fecal Sludge Comes from on-site sanitation technologies; sewage sludge originates from sewer-based wastewater collection and sewage treatment processes. Sludge composition determines treatment and potential disposal and/or end use options.

Stormwater - Precipitation from rain and snowmelt that flows over land or impervious surfaces without being absorbed into the land.

Wastewater - Used water and solids, including sewage, from a community that flow to a treatment plant. Used water includes water from industrial processes. Storm water, surface water, and ground-water infiltration also may be included in the wastewater that enters a wastewater treatment plant [University of Florida].

Wastewater treatment - Preparation and transformation of wastewater and related products (e.g., blackwater, fecal sludge, greywater, non-biodegradable waters, etc.) for safe reuse or disposal in order to minimize health risks for people and protect the environment from pollution.

System Types

In general, sanitation systems can be characterized as decentralized or centralized. A decentralized system treats human waste co-located with or near the source of the waste in contrast to a centralized system where waste is collected and transported to a centralized treatment plant. Decentralized systems can provide an effective, low-cost alternative to a centralized system and often serve rural and smaller communities as well as communities in which centralized systems may not be feasible due to distance, terrain, or other factors.

Sanitation systems, ranging from household/business to neighborhood to city systems, are categorized according to the location of the system components and associated functions, and whether they are owned and managed by a household/business, shared by a group of households/businesses or are publicly owned and managed as with city/community utilities.

- **Decentralized systems**, supported by a variety of technologies, range from individual septic systems, to cluster systems that serve multiple properties, to advanced systems that include treatment technologies that remove pollutants such as nutrients. These systems tend to be smaller, more affordable systems treating wastewater closer to the point of generation. These systems include:
    - **Individual on-lot systems** serving a single property in which source, collection and treatment are on the property. These typically serve a household or business. The systems are owned and managed by the property owner. A septic system is a common example of an on-site system but there are a variety of other technologies that are suitable for on-site systems that are feasible in developed and/or developing regions.
    - **Cluster systems** have shared ownership and management and serve a neighborhood or cluster of up to 30 properties with aggregate wastewater flows of less than 10,000 gallons per day (Barnstable County Wastewater Cost Task Force, 2010).
    - **Satellite collection systems** are owned by a municipality or utility that does not own a wastewater treatment facility. These systems serve from 30 to 1,000 properties in which discharge 10,000 to 300,000 gallons per day into another municipality's wastewater collection or treatment system (Barnstable County Wastewater Cost Task Force, 2010).

- **Centralized systems**, owned by a municipality or utility, collect and transport waste to a centralized treatment plant. These systems provide for most or all of a town's wastewater management and may provide service to neighboring areas.

Functional Elements of System Types

The following functional elements apply to the system types described above: individual on-lot systems, cluster systems, satellite systems, and centralized systems. The scale of the system determines the distance, and infrastructure needs, between collection and discharge. The functional elements of a typical sanitation [wastewater treatment] system is described below:

- **Collection**. For centralized systems, collection pertains to the sewers and pumping stations that bring wastewater to a single point. For decentralized systems, a variety of technologies may be employed, such as septic systems and various pit technologies, including pit latrines and cesspools, while not optimal and often problematic, are widely used, especially in developing regions.
- **Collection/Treatment**. For individual on-lot systems, the technologies of collecting, storing, and sometimes treating the products occur on site. Treatment provided by these technologies is often a function of storage and usually does not require added energy. However, treated waste products may require subsequent treatment before use and/or disposal.
- **Conveyance to treatment**. For more modern centralized systems pipelines and pumping facilities that carry collected wastewater to the treatment facility are typically employed. For decentralized systems that include off site treatment, vehicular transport may be used. Conveyance, as with most other components, depends on the human and environmental context of the system. What is possible and safe dictates means and method.
- **Treatment**. The facility and its associated processes for treating waste and generating effluent.
- **Conveyance of treated water**. Pipelines and pumping facilities that carry the effluent to the discharge or reuse location if not co-located.
- **Discharge**. Subsurface irrigation, rapid infiltration, reuse, or discharge to surface water bodies.

Degrees of Treatment

Wastewater treatment is the physical, chemical or biological process that reduces the concentrations of organic waste through settling or organic matter conversion; nitrogen through the conversion of organic nitrogen to nitrogen gas; and phosphorus through assimilation and sedimentation and through biological and chemical processes. Some wastewater requires pretreatment filtering to remove objects such as tree branches, dead animals, automobile parts from wrecks, guns and "fatbergs," (giant blobs of baby wipes and grease that coagulate and interfere with subsequent treatment processes).

All wastewater treatment harnesses the natural abilities of microbial communities to digest waste, typically aiming to create an optimal environment that can both speed up and control the process. Degrees of waste treatment describe the levels of treatment provided by a given system and its processes and technologies. These degrees of treatment include:

- **Primary treatment**. Mechanical screening, active screening or settling of solids, and some reduction of organic matter (BOD) but typically no reduction on nutrients.
- **Secondary treatment**. Biological treatment for removal of BOD (including soluble BOD), additional clarification, and some reduction of nutrients.
- **Secondary treatment** with extended aeration; **Nitrification of effluent.**
- **Tertiary treatment**. These are polishing treatments that can be used to remove a variety of pollutants left over after **secondary treatments**. It includes the use of filters for chemical removal of phosphorus with clarification, aeration, and nutrient removal through biological or chemical processes; denitrification is also possible through carbon-amended filters. Most common **tertiary treatments are disinfection techniques such as chlorination, reverse osmosis, UV radiation or ozone treatment** to remove bacteria and viruses. **Tertiary treatment** can result in effluent qualities of 5 mg/L total suspended solids, 5 mg/L BOD, 3 mg/L total nitrogen, and less than 1 mg/L total phosphorus (Evans et al., 1978; Ragsdale, 2007). While this is an advanced level of treatment, it is not sufficient for ocean or groundwater disposal without risking impacts to sensitive habitats or organisms. For example, a recent study looking at TSS thresholds in corals showed that adverse effects occurred as low as 3.2 mg/L in adult corals causing bleaching and mortality (Tuttle & Donahue, 2020).
- **Quaternary treatmen**t. Advanced oxidation and or ultra-low phosphorus reduction (<0.2 mg/L); term is not commonly used (Ragsdale, 2007).

Some systems may offer only minimal treatment before releasing effluent, while newer state-of-the art treatment plants are experimenting with resource recovery methodologies that create clean water that meet national standards, provide energy and fertilizer.

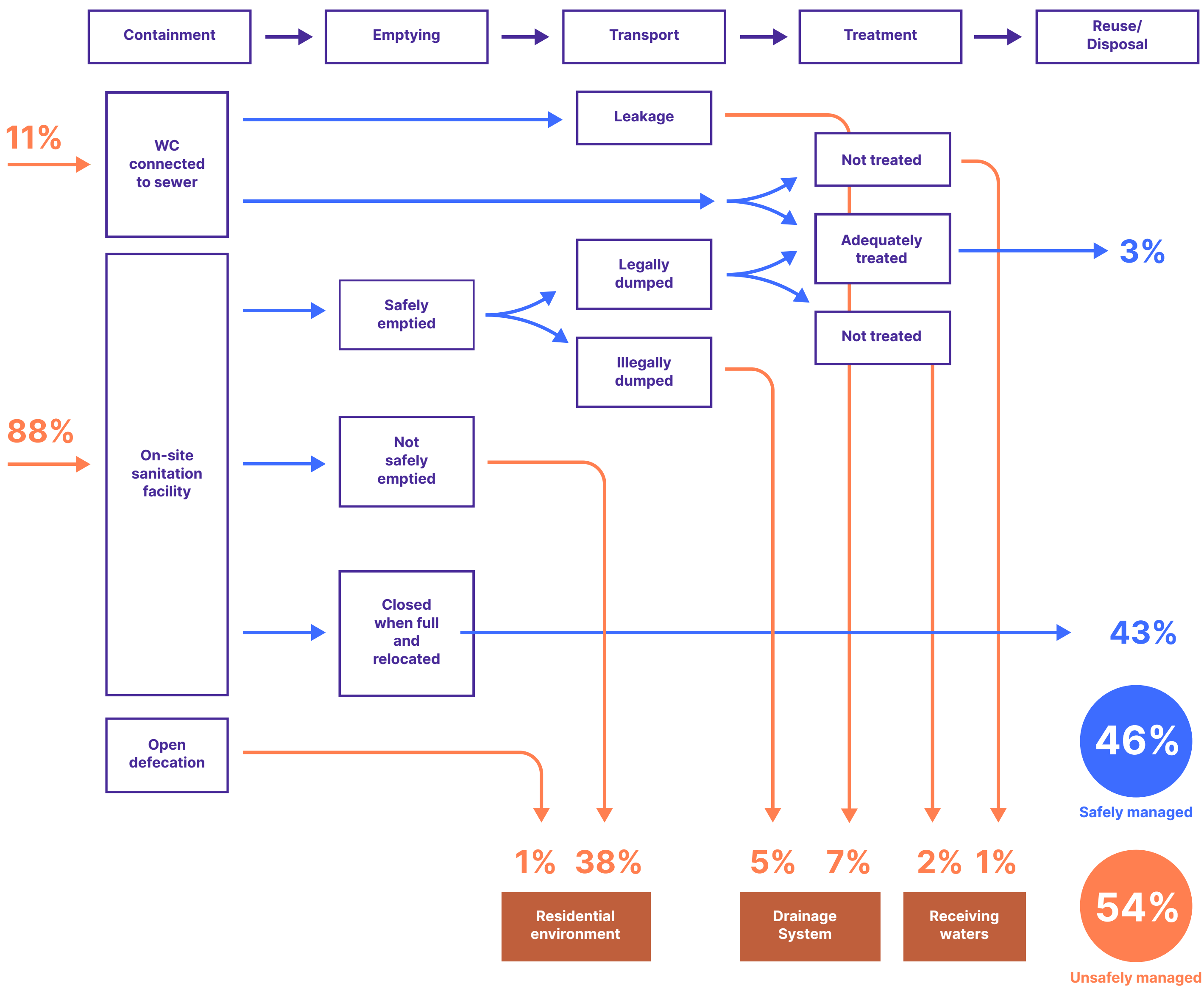
Overview of Sanitation Systems

Sanitation systems have a range of component technologies for each functional element of the sanitation process. It can be generally described as a stepwise process that begins with the user interface, collection, storage/containment, conveyance, treatment and ends with disposal/reuse. Different system types serve different needs and scenarios/ground conditions and as a consequence, these elements may become modified, combined, or omitted. Generally, they all address collection, and containment in some form, most involve conveyance and some level of treatment and disposal, and some also include reuse.

The Shit-Flow Diagram serves as a tool for professionals and practitioners to characterize and compare the various functional elements of a sanitation system at a more generalized level and from different perspectives. This diagram illustrates a central sewer, OSWT and open defecation. There are obviously other systems, such as decentralized systems or variations on sewer and on-site, but it serves to highlight safety in a way that is useful. In actuality, the functional elements and their component technologies are system dependent and exhibit a lot of variability across system types. Some functional elements may be combined and/or be co-located, or each may be implemented separately in separate locations. Some of these component technologies are common and have been in use for decades or more; others are more recent innovations attempting to solve environmental issues such as

Figure 10. Example of a Shit-Flow-Diagram

Source: Hawkins, P., WaterAid



wastewater discharges that pollute coastal waters, unsafe human wastewater management, or regional challenges where limited infrastructure, resources and even cultural barriers exist. The challenges are multifaceted and vary across regions and cultures. But wherever the system is implemented, to be successful, the criteria for sanitation system technology must:

- Be healthy and safe for the populations they serve
- Be sustainable and maintainable
- Not pollute the environment at any stage from collection through disposal/reuse
- Complete the sanitation process by appropriate disposal of the treated waste and/or reuse of the waste treatment products

Sometimes local conditions and resources are so constrained that only the most innovative and resource sensitive solutions are viable. In other situations, resources are not constrained but other barriers prevent investment in healthier systems. Additionally, sustainability and maintainability are critical as even well designed and implemented sanitation systems can fall into disrepair and leak pollutants into groundwater and subsequently degrade the environment and pollute coastal waters. There are other tools (as discussed in GRASP Generation & Assessment of Sanitation Systems for Strategic Planning) that support planning and design of systems that weigh the technology options in the context of applicable criteria and stakeholder preferences (see Sustainable Sanitation diagram below).

User Interface

Users typically have a toilet inside, and human waste is discharged outside into a pit, septic or sewer. Toilets can range from a primitive toilet such as a latrine to various pour, flush, urine diverting, to dry toilets, as well as urinals. Whichever toilet technology is used, it must be matched functionally to the collection/storage unit that it feeds. Water may also be discharged into the collection/storage mechanism. This is more likely to occur with public sewers and septic systems.

Collection, Storage and Treatment

Pit Technology

Pits have been used to solve human sanitation needs since early times. In modern times, the use of pits of various designs are often the only viable option for regions that are rural, or resource constrained. The most primitive type of pit is the **cesspool**, essentially a reinforced pit that leaches wastewater into the surrounding soil, and while banned in many countries, is still commonly used. **Cesspools** do offer a safer immediate user experience than an open latrine, but depending upon construction methods and soil characteristics also may pose a hazard to the environment from liquid waste that leaks into the surrounding soil. Rainstorms can cause a **cesspool** to flood and overflow. **Cesspools** built near low-lying coastal areas are at risk of being submerged and breached by rising sea levels. In areas where with porous soils, wastewater can seep directly into the groundwater. Some of these risks also exist for more modern implementations, consequently, the technology must meet the criteria highlighted above.

All contemporary designs leverage the basic concept of a pit and from there, innovate to create healthier, more human friendly and more environmentally sound implementation. Variations include the use of such things as multiple pits, facilitating ventilation, optimizing safe biodegradation of waste, alternating waterless pits, harvesting both waste for agricultural use or as fuel and/or managing the use of water.

Septic Tanks

Septic tanks are a **primary treatment** collection system for greywater and blackwater that are commonly used for a single property or a small group of properties in rural areas or where city wastewater utilities are unavailable. It is a watertight chamber of concrete, fiberglass, or plastic that relies on the settling and anaerobic processes to reduce solids and organics and the disbursement of fluids into leach fields (or similar technologies) in which the effluent can be absorbed into the soils. The sludge and scum accumulate in the tank and need to be periodically removed. Septic tanks may be implemented in various configurations (see Types of Septic Systems) and advanced options (e.g., Aerobic Treatment Units (ATUs)).

Figure 11. Decision-making process for implementing a sustainable sanitation system

Source: Spuhler, D., Eawag

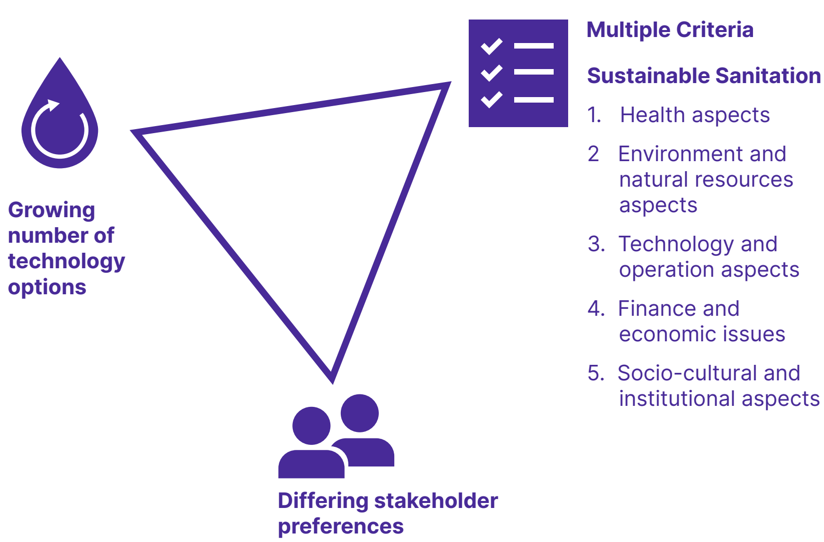
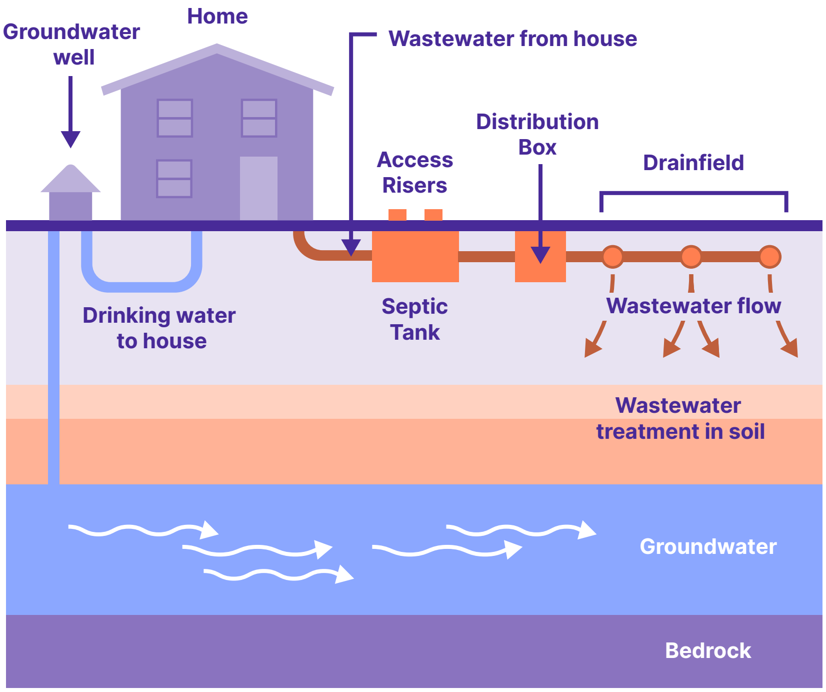


Figure 12. A conventional septic system

Source: EPA, 2018



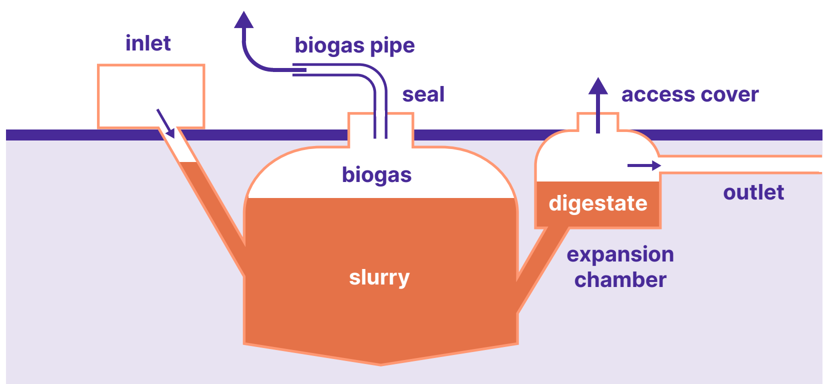


Figure 13. Biogas Reactor Example

Source: AD Biogas Tech News Blog

Filtering Technology

Filter technology comprises a broad category of various types of filters ranging from rudimentary filters that screen out debris (from stormwater) prior to treatment to membranes for nutrient removal and production of potable and non-potable water reuse. Filters are commonly used for solid separation, allowing removal of effluent for further treatment or disposal using drip irrigation/systems or leach fields into the surrounding soils. Treatment plants may include a series of baffles in which the wastewater passes from one treatment area to another, progressively becoming cleaner and cleaner. Systems may incorporate anaerobic filters and trickling filters as part of sophisticated nutrient removal mechanisms. Nutrient removal filters may be constructed of cloth, engineered materials, or even sand as a final polishing medium. Effluent Reverse Osmosis, a membrane filtering technology, frequently found in homes to ensure healthy drinking water, is also used on a larger scale in the wastewater process to produce potable water. Two-stage passive biofilters are used in the denitrification/nitrification multi-chamber nutrient removal process. Filters are a fundamental part of blackwater and greywater treatment incorporating passive, mechanical and/or active filtering involving pressure, chemicals, and electrolysis as part of the process. The waste treatment industry has dozens of companies focused on engineering better processing and treatment systems, with filtering devices and mechanisms found in all phases of treatment. The technology is extensive.

Biogas Reactor

A biogas reactor uses a three-step process in which sludge is pretreated prior to putting it into an airtight reactor chamber. The chamber serves as an anaerobic digester that converts **blackwater**, sludge and/or biodegradable waste to digested sludge and biogas. It does this by breaking down the organic matter in the sludge and, through the fermentation process, producing a biogas mixture of methane and carbon dioxide. Additionally, in this step the digested sludge is stabilized, and its dry matter content is reduced. The final step in the process is post treatment of the reactor products for resource recovery and disposal. The biogas can be used as fuel for electricity, heat and biofuel production and the stabilized sludge can be safely disposed of into the environment.

Container-based sanitation systems have evolved over the last decade into a viable low-cost sanitation option, and "are particularly well-suited to low-income urban settlements where demand for sanitation is high and on-site sanitation and sewerage are not feasible or cost-effective"(Russel et al., 2019). These systems address the entire sanitation service chain (including emptying, collection, transport, treatment and reuse), offer a variety of service-based models and are affordable to people living in marginalized and informal urban settlements. These systems capture wastes in sealable containers that are then transported to treatment facilities. The Container-based sanitation solutions are affordable, cost-effective, flexible, adaptable, and modular. They reduce water usage and have low greenhouse gas emissions. They are hygienic and provide protection for women and girls.

Conveyance

Conveyance technologies are simply the way in which waste moves from one location to another as it passes from one functional element of the sanitation system process to another. Other than manual transport that may occur in some developing regions,

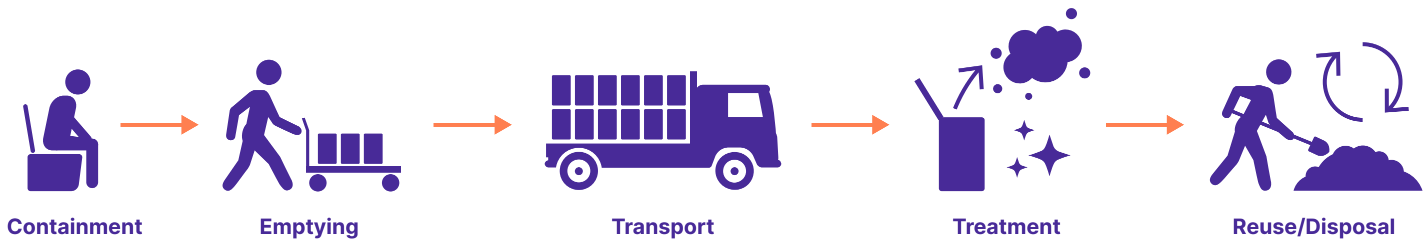


Figure 14. Container-based sanitation

Source: Russel et al., 2019

conveyance, appropriate for systems that do not include on-site treatment and disposal/reuse, is typically accomplished either by a network of municipal sewer lines that convey wastewater from a property to a centralized treatment plant or by transport by truck to centralized locations for further treatment or disposal. Specialized septic trucks transport sludge or, in situations where on-site systems support urine collection, urine storage tanks or jerrycans may be transported by trucks directly to agricultural locations or to storage locations for later distribution. Urine is safe to store and valuable for reuse in agriculture. Sludge requires further treatment.

Disposal and Reuse

Apart from untreated human waste, all sanitation system outputs are eventually returned to the environment, either as useful resources or reduced-risk materials. The challenge is to ensure safe and sustainable disposal and, where possible, recover and reuse valuable resources. The nutrients that pollute our waterways can be harvested. Water can be recycled into potable and non-potable supplies. Outputs from different types of treatments vary with the treatment. Overall, these outputs include effluent, sludge, desiccated feces, urine, **pit humus**, compost, nutrients (phosphorus and nitrogen), and water, both potable and non-potable. Of these, urine, compost, recovered nutrients, and desiccated feces can be reused as fertilizer for agriculture. This is common practice in some places and treated with greater caution in others depending on cultural context and experience. Non potable water can be reused for irrigation for agriculture and public/private lands, used as flush water, recycled back into the treatment process, used as process water for industry, (e.g., power plants, refineries, mills, and factories, concrete mixing and construction), and environmental restoration as well as supply artificial ponds/lakes and inland or coastal aquifers. Wastewater can be recycled for municipal water supplies to be used for drinking water. Water reuse is becoming more common, and examples are available at WateReuse's Water360, an interactive map to learn about specific projects around the world. Reframing wastewater as a valuable resource has a huge socioeconomic and environmental upside.

Treatment Technologies

This section provides a sampling of some of the major types of treatment technologies that may be implemented in a sanitation system. As with the component technologies of the functional elements of sanitation, there are a myriad of ways in which treatments can be configured. The exact configuration is dependent on the environmental variables, what can be supported sustainably and safely and the regional infrastructure and resources that are available. Additionally, a given treatment system may have delimiters that are determined by the source (i.e., stormwater, wastewater, or even waterless), user interface, supportable conveyance, whether it is intended for individual, cluster, satellite, or centralized systems as well as other factors. The design can be simple or complex, feasible in a rural environment or only urban environment, low technology or high technology, or it may incorporate resource recovery.

On-site Sewage Treatment Disposal (OSTDS)

On-site sewage treatment disposal systems (OSTDS) are typically individual on-lot systems sized for a home, apartment building, or a small neighborhood and are appropriate for rural areas. They can be connected to form a local neighborhood or small community-scale treatment cluster system. OSTDS comprises septic tank technology constructed of watertight chambers made of brick work, concrete, fiberglass, PVC, or plastic. Blackwater and greywater pass through a pipe from inside a building or an outside toilet to the septic tank and then flow on for **primary treatment**. Settling and anaerobic processes reduce solids and organics. Effluent is infiltrated into the ground or transported via a sewer to a community-scale, centralized treatment plant. Septic tank systems are relatively inexpensive and simple to maintain. While this technology is typically used for **primary treatment** of blackwater and greywater, it can be upgraded to include nitrogen and phosphorous treatment as **secondary treatment**.

Wastewater Stabilization Ponds

Wastewater **stabilization ponds** are engineered ponds or lagoons that may be **aerobic** (mixed) or facultative (no mixing, but deeper) to allow settling and in situ decomposition of wastes. Wastewa-

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ter **stabilization pond** technologies are typically designed for centralized systems and can be used in a range of community sizes from small towns to large cities. These are low-tech systems most commonly used for treating blackwater and stormwater, removing suspended solids, treating organic waste, and providing passive reduction of nitrogen and phosphorus. Wastewater **stabilization ponds** are typically constructed to provide **primary treatment** and **secondary treatment** but can be constructed in a series or to include floating wetland islands to yield **tertiary treatment** water quality. They are simple to operate, with appropriate planning, and can be enlarged as communities grow. Advanced systems can be designed to enhance nitrogen and phosphorus removal.

Constructed Wetlands

Constructed wetlands are shallow water bodies or gravel (or engineered media) filled basins vegetated with plants adapted to continuous or periodic inundation. They range in size from small to large and provide natural treatment by settling solids, degrading organic wastes, and assimilating nitrogen and phosphorus through natural biological transformations. Water quality is improved through system sizing, uniform depth, and flow distribution to maximize contact between water and the wetland sediments and biological communities. They are typically used as a **secondary treatment** for blackwater, greywater, and stormwater after primary pretreatment. They are relatively simple to implement on small scales, and can be modified to increase the degree of wastewater treatment, including providing **tertiary treatment** through enhanced nitrogen and phosphorus removal. **Constructed wetlands** function as wastewater polishing for cluster systems, satellite systems, or centralized systems, and as such, can serve populations of fewer than 50 all the way up to city-sized populations. They can also be used to address overflow during high flow conditions such as they also have the added benefit of being ecologically important and aesthetically beautiful.

Activated Sludge Technology

Activated sludge technology is a biological treatment process for treating blackwater and greywater. **Activated sludge** treatment removes organic wastes, and treats nitrogen and phosphorus. The process degrades organic matter and assimilates nutrients by using fixed film systems or using mechanical aeration and mixing and clarification to suspend bacterial communities in wastewater. Treatment typically provides **secondary treatment** and can be modified

Figure 15. Sanitary and storm sewers (separated)

Source: STORM

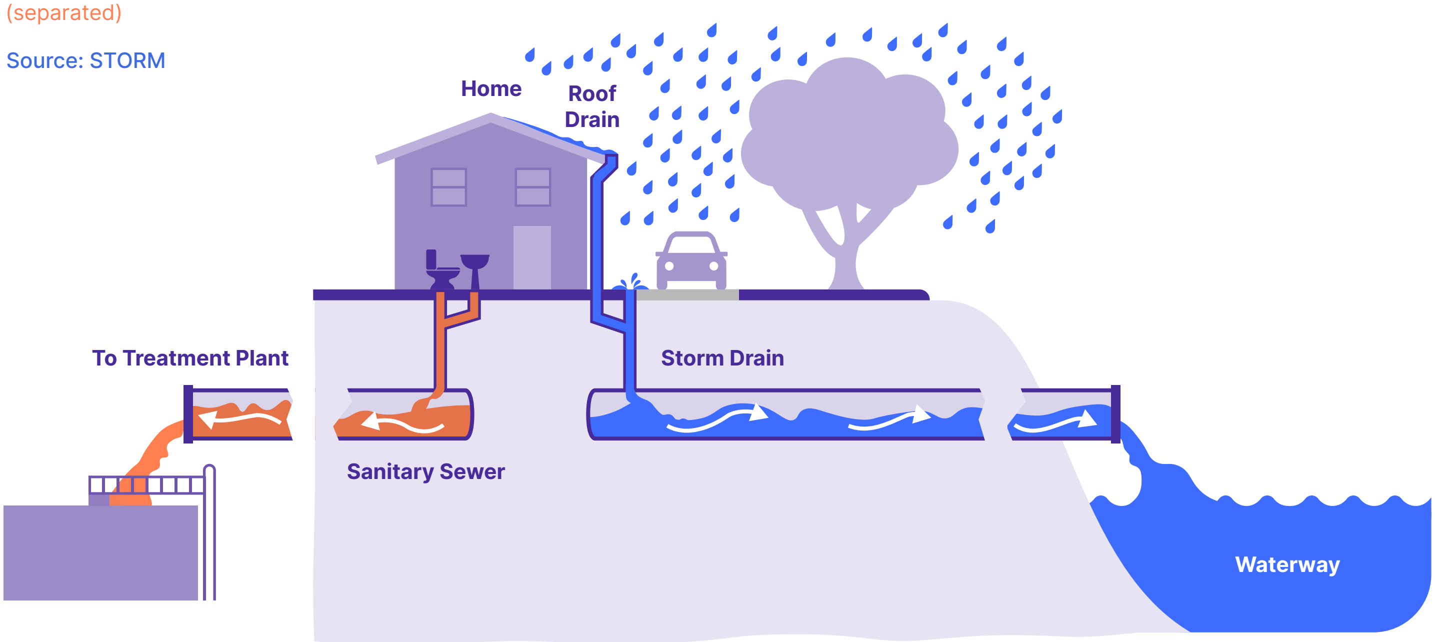
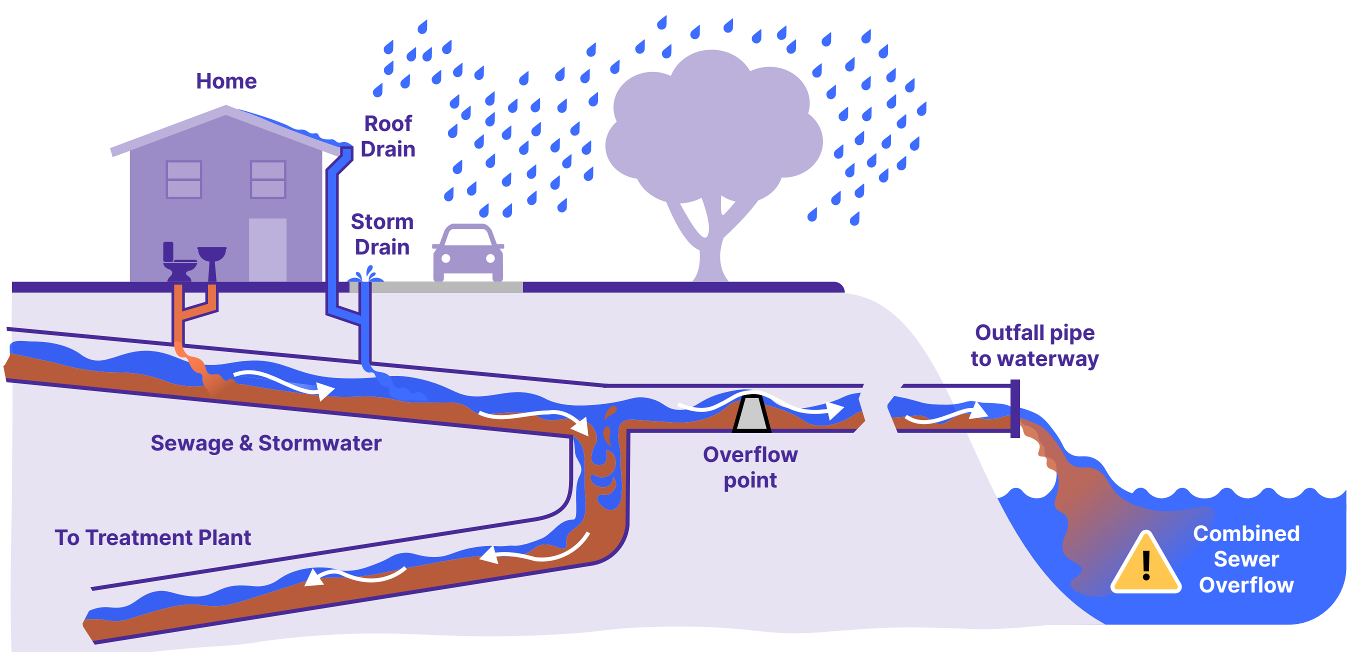


Figure 16. Combined sewer

Source: The Construction Index



to provide **tertiary treatment**. Sludge systems can achieve enhanced phosphorus reduction by adding **aerobic** and anaerobic stages for removal of biological nutrients. Additionally, the biological process can be speeded up to achieve treatment goals within a few hours by adding aeration. **Activated sludge** plants are, generally, centralized systems that serve small to large cities.

Package Plants

Package plants are pre-engineered and prefabricated wastewater treatment plants using an **aerobic activated sludge** process typically used for treating blackwater and greywater. Systems treat organic waste but can be modified or expanded to provide nitrogen and phosphorus treatment. They are often designed to achieve specific discharge standards or to yield a product water suitable for non-potable use for agricultural and aquaculture production, industrial uses, water sustainability, and reclamation uses such as irrigation, washdown, and artificial recharge. These scalable plants can serve a range of community sizes, from small towns to medium-sized cities, and are often used for small villages and towns, housing subdivisions, mobile-home parks, marinas, resorts, military installations, schools, manufacturing facilities, and other small facilities; flows can range from 50 gallons per day (gpd) to 5 million gpd (C&M Mining Machinery, 2020). They can be readily built on-site and modified for enhanced degrees of wastewater treatment. They have a compact footprint, are easily transportable, relatively simple to operate and have low labor requirements.

Package plants combine mechanical and chemical processes for **primary treatment** and **secondary treatment**; they may include nutrient control through chemical or biological processes to achieve **tertiary treatment**. Package plants typically function as cluster systems, satellite systems, or smaller-scale centralized systems intended to serve a broad range of community sizes.

Membrane Bioreactors (MBRs)

Membrane bioreactors (MBRs) are used for treating blackwater and greywater through a combination of suspended growth **activated sludge** with immersed membrane equipment separating solids and liquids. MBRs provide secondary and **tertiary treatment** for organic waste, phosphorus, and nitrogen and can be enhanced to increase removal efficiency. Pretreatment for MBRs includes screening and **primary treatment** (settling and clarification). MBRs yield very good effluent quality due to their very high solids removal efficiency, require only a compact area, are scalable to accommodate community growth, and can be combined with other technologies. The primary uses for MBRs have been for facilities requiring water quality for wastewater reuse or very low outflow nutrient concentrations and facilities with significant land area restrictions. They are relatively high-tech systems used in moderate to high density communities to provide treatment for satellite systems (including resorts, buildings) or centralized systems and have been sized to treat small to large communities.

Sewer Treatment Systems

Sewer treatment systems collect wastewater from a community or a larger urban area via a sewer system consisting of a network of sewer pipes to a treatment plant. The sewers from individual homes and business, are typically a privately owned lateral network of small sewer lines that feed into larger community sewer lines and finally into very large main sewer lines (mains) that deliver the wastewater to the treatment plant. These shared public sewer lines typically rely on gravity to deliver the wastewater to the treatment plant, so the lines are constructed at progressively deeper levels as the wastewater drains to the treatment plant. Consequently, the treatment plant's collection structures may be deep in the ground or conveyance through the sewer may include pump mechanisms to raise the wastewater level to flow into the plant at a higher level. The effluent is processed through a variety of plant dependent mechanisms and finally, when cleaned of pathogens and most of the nutrients, is released to the environment. The sludge and solid waste are removed and disposed of offsite in landfills or by incineration, or in the case of biosolids, recycled to the soil by use in agriculture, mine reclamation, landscaping, or horticulture. Sludge can potentially undergo additional processing at another plant for recovery and be recycled or used as fuel.

In most of the urban developed world, where incomes are high enough for significant taxes that can fund infrastructure investments, centralized sewer systems are the norm.

There are three types of sewers:

- Sanitary sewers take kitchen and bathroom waste to either a discharge point, such as a river or estuary, or in more regulated environments, to a sewage treatment plant, where it is treated and discharged to the environment.
- Surface water sewers take rainwater from roofs, roads and other surfaces to a discharge point in a river, estuary or other waterway.
- Combined sewers collect both sanitary and surface water and take it to a sewage treatment works, where it is treated and discharged to the environment (Blackburn et al., 2017). During high flow events, such as storms, combined sewage and surface water may be discharged into groundwater, compromising local water quality.

APPENDIX

- → Case Studies
- → Glossary
- → References

Case Study: Long Island

Long Island, NY: Water quality

Long Island is a densely populated island in southeastern New York State, USA, that stretches east from New York City into the Atlantic Ocean, south of eastern Connecticut. The island is governed by four counties. The two westernmost counties, Queens and Kings counties (aka Brooklyn) are boroughs of New York City. The two eastern most counties, Suffolk and Nassau have a combined population of nearly 3 million people (US Census, 2019) and are the focus of this project.

The Water Quality Challenge

Long Island is surrounded by bays and estuaries, and once boasted robust fisheries that made it one of the nation's top shellfish producers. However, fisheries landings have diminished 99% since the 1980s with lobsters, clams, and scallops having all but disappeared (LICWP). In 2001, The Nature Conservancy accepted a donation of 13,000 acres of the bay bottom —nearly a third of the Great South Bay, which was once a highly productive clam fishery, and began an effort to restore the fishery (Rather, 2008). Despite repeated efforts and heavy investments of time and money, progress with clam restoration remained elusive. Harmful algal blooms repeatedly wiped-out progress and made it impossible for healthy shellfish beds to thrive, despite repeated restoration attempts. It became clear that the poor water quality in Long Island's waters needed to be addressed.

Actions Taken

Beginning in the early 2000s, The Nature Conservancy and partners began an ambitious, multi-stage process to reverse years of declining water quality. This included scientific research, public communication, government relations, and implementation.

Science: Understanding what was causing the poor water quality

Working with scientists from the Marine Biological Laboratory at Woods Hole in Massachusetts and using a Nitrogen Load Model for Great South Bay waters, septic systems were identified as the major source of nitrogen pollution, overturning assumptions that stormwater and agricultural runoff were the primary culprits.

Communication: Educate Long Islanders about nutrient pollution

Nitrogen pollution as a result of septic systems was an unknown problem to the public and homeowners on Long Island. The project team invested in a robust communications effort to educate Long Islanders about the issue, its scale, and the urgent need to address it. This included focus groups, public polling, message testing, and media outreach.

Government relations: Create policy, regulatory, and funding mechanisms

Using lessons learned from the communications efforts, the project team worked with local and state agencies to underscore the need for certain policy and funding mechanisms to address nutrient pollution. This included the passage of legislation and regulations, and the creation of funding streams from the state, the county, and several towns to support septic improvement efforts.

Implementation: Replace old septic systems with nitrogen-reducing systems.

The project team helped county agencies identify suitable clean water septic system technologies and gain their approval for residential use. These innovative systems can reduce nitrogen pollution by as much as 90% compared to the typical system (Heufelder, 2015). They worked with manufacturers, builders, architects, engineers, and relevant regulators to overcome challenges with installing the new systems at scale.

Results

In 2014, NY Governor Cuomo announced a $338 million investment in expanding sewer infrastructure for Suffolk County, focused on reducing nitrogen pollution in four rivers (Forge, Patchogue, Connetquot and Carlls). Securing this funding required careful explanation of the environmental benefits of replacing septic systems with sewer infrastructure and building support and trust within the community.

As of October 2020, 1,500 old septic systems have been replaced with clean water septic systems that remove nitrogen, while other innovative systems, such as the piloted designs developed at the New York State Center for Clean Water Technology are being tested and show promising results. An upgraded system with a shallow leach field can remove about 95% of the nitrogen in wastewater. These 1,500 new systems thus prevent about 21,800 pounds of nitrogen from going into the surface water the first year of operation (Galst, 2020).

To finally bring this work to scale, a dedicated funding stream worth about $70 million a year could replace all the old polluting residential systems in less than 20 years. Once that consistent funding stream has been created, an additional 7,000 systems are expected to be replaced annually. Additionally, eventual legislation requiring installation of clean water septic technology upon the sale of a home could more than double that rate of installation.

On March 17, 2020, the Suffolk County Legislature unanimously approved the State Environmental Quality Review Act (SEQRA) Statement of Findings for the Final Generic Environmental Impact Statement for the Suffolk County Sub-watersheds Wastewater Plan (SWP). The statement "recognize(s) Nitrogen discharge from onsite wastewater sources represents the single greatest factor that can be managed to restore and protect our waters from the impacts of nutrient enrichment-related water quality degradation." This landmark nitrogen pollution reduction plan has also recently been approved by the NY DEC as a final 9 Element Plan to reduce nitrogen pollution in NY State, opening the doors for more NY State funding and assistance in this remediation work on Long Island.

In October of 2020, the planned $19.6 million upgrade to the Bay Park Wastewater Treatment Plant was completed. The plant, originally built in 1945, was heavily damaged during Hurricane Sandy and was a major source of nitrogen pollution in Nassau County. The system is currently operational and removing more than 40 percent total nitrogen from wastewater, meaning an additional 5,000 pounds of nitrogen is no longer being discharged into Reynolds Channel. The plant currently treats 50 million gallons per day of wastewater on average from more than half a million Nassau County residents (New York State, 2020).

Lessons Learned

Do the science. Scientific mapping and analysis that identified down to the sub-watershed level where nitrogen is coming from helped allay fears around being forced to adopt a "one-size-fits-all" solution and helped people understand the scope of the problem.

This is systemic change. To address the problem, an entire system needed to be changed, including allowing the system to adapt. This is a decades long effort and patience is required.

Community relationships are key. Understanding community-members' concerns, what's important to them, and what they are interested in helping with, helps keep the issue relevant and engaging.

Failures are an opportunity to learn and move forward. Team members on this project made a hard push in 2013 to pass a statute that would limit nitrogen in effluent to 1mg per liter of water throughout the state, but there was not enough consensus among developers, the real estate industry and farmers and the bill failed. However, this effort helped get the issue of wastewater pollution on the radar statewide, and in 2015 the governor of New York approved the Long Island Nitrogen Action Plan, with $5 million in funding.

Communications are key. Team members invested considerable resources of time and money in building and promoting key messaging throughout the geography. Using a "message triangle" that centered on the threat of nitrogen pollution and focused on how that threat could be mitigated, they were able to change the water challenge narrative on Long Island, inserting the concept of "nitrogen pollution" into the media playing field.

Partners

Lead Organization: The Nature Conservancy, Long Island chapter

Founding members of the partnership: Citizens Campaign for the Environment; Group for the East End; Long Island Pine Barrens Society; School of Marine and Atmospheric Sciences; Stony Brook University

Communications firm: Fairbank, Maslin, Maullin, Metz & Associates

Partners on the initial Woods Hole report: The Nature Conservancy; New York Department of State; Suffolk County

Funding

$1 million – clam restoration project that failed
$300,000 - focus groups and polling
$300,000 - ad campaign
Total Cost estimated at $4 million

Resources

Long Island Clean Water Partnership

Nature.org: Long Island Water Quality

Stony Brook University: Center for Clean Water Technology

Stony Brook University, Dr. Christopher Gobler lab

Draft 2019 Report on The Performance of Innovative and Alternative Onsite Wastewater Treatment Systems, Suffolk County

Nutrient Reduction Case Studies

Case Study: Puerto Rico

Guánica Bay, Puerto Rico

Puerto Rico is an island in the Caribbean Sea, and an unincorporated United States territory. The Rio Loco watershed, a 151-square mile area, drains into Guánica Bay along the island's southern border. This case study focuses on reducing wastewater pollution at a hotel along the perimeter of the Bay.

The Pollution Challenge

The Rio Loco watershed that drains into Guánica Bay has been subjected to intense development over the past several decades, to support agriculture, energy production, housing, and tourism. All of these activities increased nutrient and sediment pollution flowing into the Bay by about 5-10 times over and above natural levels (Warne et al., 2005). Adjacent to Guánica Bay are some of the most extensive coral reef systems in Puerto Rico, but coral bleaching increased in tandem with pollution and declining water quality. Live coral coverage has declined by about half over the past few decades, including the loss of about 90% of *Acropora palmata* (elkhorn) and *Acropora cervicornis* (staghorn) (Sturm et al., 2012). A 2008 study of the watershed showed that the reefs around Puerto Rico were seriously degraded, with the worst damage manifesting in reefs immediately offshore of large human populations (CWP, 2008). Threats to coral reefs also threaten livelihoods and food security. About 5% of the residents in the town of Guánica are full time fishers (Reef Resilience Network, 2021).

In 2013, non-profit organization Ridge to Reefs and partner Protectores de Cuencas conducted a pollution tracking survey throughout the Bay, testing for nutrients, enterococcus bacteria, and chlorophyll a. The survey helped pinpoint areas where bacteria and chlorophyll a were high. One of these areas was near a 27-room hotel, where water quality indicators were high for wastewater pollution.

Actions Taken

Installing a green infrastructure solution

Ridge to Reefs staff approached the hotel owners to assess interest in a green infrastructure, or nature-based solution to their wastewater pollution. Advantages to green infrastructure solutions include cost effectiveness; low maintenance; reliance on gravity to pull wastewater through the system; and may provide wildlife habitat or add to the aesthetics of a property. Green infrastructure solutions harness the power of plants and their root systems to absorb toxic wastewater and turn toxins into fuel for their own growth. Microbes also play a key role in green infrastructure systems, digesting nitrogen and turning it into inert N_2 gas, which is a natural and non-harmful component of the atmosphere. Under the right conditions, bacteria can also digest chemicals and pharmaceuticals. This project is significant because it combines two innovative wastewater treatments—*a denitrifying bioreactor* and a *wastewater/rain garden* into one low-cost project. In previous projects at other locations, Ridge to Reefs had installed these systems separately. Both approaches have proven effective, and so here the methods were combined to maximize results.

While initially skeptical of the proposed solution, the hotel owners agreed to the project and were reassured that the project would both improve their image and eliminate a potential water quality violation.

Components of the green infrastructure system

The bioreactor was constructed by digging a 36-inch-deep trench in the ground, and lining it with 45 mil pond liner (rubber sheeting), to contain wastewater and prevent leaching. The trench was filled with layers of biochar (to absorb chemical contaminants) and wood chips, and a level perforated pipe was installed to drain the wastewater evenly over the woodchips. As the water comes in contact with the wood chips and sits for between 12-24 hours, bacteria associated with the wood begins to digest pollutants. The wood chips were covered with a layer of sand and soil and planted with vetiver grass and hibiscus. Vetiver is capable of withstanding harsh conditions, including salt, acidity, alkalinity, heavy metals and high levels of nitrogen and phosphorus —and it also reduces pathogens. Hibiscus was planted, mostly for the natural beauty of the flowers, but it can also help remove heavy metals. After the water is drawn up into the vetiver grasses' stems, it is expelled through evapotranspiration. Underground pipes direct any remaining treated water to an infiltration trench down gradient.

How Well Did It Work?

The plants needed a few months to take root, but once they did, the system began working so well that, during times of average hotel occupancy, there was typically no effluent coming out of the system. During higher volume periods, when effluent was discharged into the infiltration gallery, lab analysis showed that total nitrogen was reduced by 51 percent, and total phosphorous was reduced by 45 percent. The last few rows of vetiver grass started dying back from lack of water, demonstrating that essentially all of the wastewater was being taken up by upstream grasses during typical conditions, resulting in zero nitrogen or other pollution being discharged into Guánica Bay.

Lessons Learned

Nature-based solutions work and can be an affordable water treatment solution. Tropical ecosystems such as coral reefs have lower tolerance for nutrient pollution than more temperate systems. This requires stricter standards for places like Puerto Rico and Hawaii. However, these higher standards can be economically challenging to meet with traditional septic systems. Nature-based systems are affordable and effective at creating better conditions for, seagrass and fish habitats, safe swimming, and recreational tourism while also reducing coastal erosion. Nature-based solutions can also be used to raise awareness of the wastewater pollution issue and help gather support for finding effective solutions. Sometimes wastewater pollution problems can seem overwhelming, but just getting started using nature as a model to make it a little better can raise awareness and lead to larger-scale change down the road. Approaching watersheds holistically from "ridge-to-reef" is critical. This is the most effective way to identify problems and create targeted nature-based solutions that are effective and can potentially lead to large scale change in the future. Pairing targeted scientific analysis with active implementation also helps to show proof of concept and lend legitimacy to a natural infrastructure project.

It is critical to understand the sanitation needs and wastewater flow patterns of a project to ensure appropriate design solutions are installed. Designing green infrastructure for a hotel is different from designing for schools or other users, mostly because of peak flow periods. The hotel rain garden was designed to handle 6,000 gallons of wastewater per day. In reality, flows vary wildly throughout the day, with flows peaking dramatically in the early evenings on weekends and holidays, as people come in from the beach and shower before dinner. An additional rain garden/infiltration area was planted to help accommodate these peak flow periods.

Careful project management and oversight is needed to ensure success. Contractors are often unfamiliar with this type of infrastructure project. Even with careful instructions and oversight, the project may not be built perfectly to the specifications. For instance, the hotel rain garden was supposed to be built with only a 1% slope across the bottom, to maximize the volume the pond could hold, but in actuality the slope ended up being slightly steeper. The completion of this project provides a model for landscape architects and other contractors to show how projects like this can be successfully implemented.

Finding the right partners can be challenging but is necessary for success. When scoping Puerto Rico's south shores for an appropriate project, there were many places where communities use septic systems that are leaching nutrient pollution into the water. Before approaching the hotel owners, the team first approached a restaurant with a sanitation issue. The owners were initially amenable to participate, but there were logistical challenges that prevented the project from moving forward. The bathrooms were at the back of the restaurant, almost overhanging the water, and it would have been more difficult and expensive to build a pipe that would bring the water around to a garden. It is also important to work with local collaborators to develop trust in your organization and in the concepts being developed.

Project costs and timelines can be hard to estimate. Another area identified in the initial water pollution survey is located near a wastewater treatment plant discharge pipe. The plant treats water for pathogens, but not nutrients, and is discharging an estimated 20,000 pounds of nitrogen into Guánica Bay. Ridge to Reefs approached the operators of the wastewater treatment plant and proposed a 5.5 acre constructed wetland to be built surrounding the treatment plant, and the proposal was accepted. Unfortunately, the project has faced several delays, legal hurdles, and rising administrative and funding needs. A project at this scale can benefit from adding between 50% -100% to estimated costs. It's also helpful, if possible, to make sure the project is fully funded before proceeding to avoid unnecessary financial delays.

Funding

$25,000 coastal and freshwater pollution tracking efforts
$50,000 Hotel Nature-Based Wastewater Gardens (including staff time)

Partners

Lead Organization: Ridge to Reefs

Protectores de Cuencas (Treatment wetlands and Pollution Tracking)

Hotel Parador Guánica 1929

Local builder with a backhoe

A local engineer supplied the vetiver grass

University of Maryland Center for Environmental Science Horn Point Laboratory

Resources

Ridge to Reefs

Links to Other Case Studies

Reef Resilience Case Studies (Search "sewage")

Water Quality in Australia's Great Barrier Reef by Government

Water Quality Monitoring in Honduras by Local NGOs

State of Water Quality Monitoring in Fiji

Lack of Water Quality Monitoring in Indonesia

Implementation of Philippines Clean Water Act

Glossary

Activated sludge - a central component of conventional wastewater treatment, where the ability of microbes to remove nitrogen, organic matter and other contaminants is harnessed in sequential **aerobic** and anoxic processes.

Aerobic - describes a process in conventional wastewater treatment where microbes use oxygen in a metabolic process that removes nitrogen from the water. Typically requires the use of blowers and mixers to whisk oxygen into the wastewater. This process accounts for a significant portion of a treatment plant's energy usage.

Aerobic Treatment Units (ATU) - multi-chamber tank or a series of tanks that applies a series of treatment processes to the wastewater. The wastewater enters the first tank or chamber, which serves as a small gravity settling tank where large, heavy solids settle out of the water. The clarified water from the settling tank or chamber then passes into the aeration chamber where it is aerated to digest (or stabilize) the biological waste. By periodically stopping the aeration pump in the aeration tank much of the nitrogen in the wastewater can also be gassed off. Finally, the effluent from the aeration tank is pumped into the clarifier where the biological solids settle to the floor and the treated water is pumped out of the tank to an absorption field.

Adsorption - a process where a thin layer of atoms, ions or molecules adhere to a surface. Often used in wastewater treatment to remove pollutants such as viruses, bacteria, heavy metals and volatile organic compounds, or in **tertiary treatments** to dechlorinate or remove odors. Activated carbon, which is extremely porous, is a popular material used for adsorption, but existing rocks and soil systems are more commonly relied upon.

Anoxia - an environment where there is no molecular oxygen (O_2). In the water, dissolved oxygen is absent.

Anaerobe - an organism which is able to thrive without molecular oxygen (O_2).

Anaerobic bacteria - bacteria that only grow in the absence of free elemental oxygen. [EPA, 2004]; Microorganisms that live in oxygen deprived environments [DOE].

Biogas - gas resulting from the decomposition of organic matter under anaerobic conditions. The principal constituents are methane and carbon dioxide [EPA, 2004].

Biofilm - a living collection of diverse microbes that form a plasma and can work together to filter out and digest contaminants from wastewater.

Biological nitrification - When microbes convert ammonia/ammonium into nitrite and nitrate. In wastewater treatment—the ammonia primarily comes from urine and feces.

Biological oxygen demand - see oxygen demand

Blackwater - Liquid and solid human body waste and the carriage water generated through toilet usage [EPA, 1996].

CAFO - a concentrated animal feeding operation. CAFOs are agricultural facilities that house and feed a large number of animals in a confined area for 45 days or more during any 12-month period.

Cesspool (a term often used interchangeably with cesspit) - a tank pit, sometimes lined with bricks or concrete, used for the temporary collection and storage of human waste. In cases where the pit is constructed water-tight, it needs to be emptied frequently, which can result in high operation and maintenance costs. If not watertight, liquids leach out, while solids decay and collect in the base. Cesspools offer a high risk of contaminating nearby ground, surface and coastal waters. Prone to overflowing during heavy rain, and if located near low coastal areas, are at risk of being inundated by rising sea-levels.

Constructed wetlands - shallow water bodies or gravel or engineered media filled basins vegetated with plants adapted to continuous or periodic inundation. Constructed wetlands are engineered to improve water quality by creating a flow system that maximizes contact between water, wetland sediments and its associated biological communities.

Container-based sanitation - service in which toilets collect excreta in sealable removable containers, which need to be collected regularly and transported to treatment facilities. Qualifies as a type of "improved sanitation" under the UN's Joint Monitoring Programme (See: Sustainable Development Goal 6.2).

Effluent - The general term for a liquid that leaves a technology, typically after blackwater or sludge has undergone solids separation or some other type of treatment. Effluent originates at either a Collection and Storage or a (Semi-) Centralized Treatment technology. Depending on the type of treatment, the effluent may be completely sanitized or may require further treatment before it can be used or disposed of.

Effluent organic matter (EfOM) - carbon, hydrogen and oxygen. Can also contain nitrogen, phosphorus, sulfur, and many other compounds. Measured by its **Biological Oxygen Demand**.

Eutrophication - (from Greek *eutrophos*, meaning "well-nourished") When a body of water becomes overly enriched with minerals and nutrients, which induce excessive growth of algae and cause **hypoxia**.

Fecal sludge - a component of on-site sanitation systems, made up of a mixture of human excreta, water and items such as toilet paper and tampons that people dispose of in pits tanks or vaults. Also called "night soil."

Flocculant - a chemical compound such as alum that causes molecules to coagulate. Added during primary stages of wastewater treatment.

Greywater - wastewater other than effluent containing human waste, such as sink drainage or washing machine discharge [EPA, 2009].

Hypoxia - in ocean and freshwater environments, refers to low or depleted oxygen in a water body. Hypoxia is often associated with the overgrowth of certain species of algae, which can lead to oxygen depletion when they die, sink to the bottom, and decompose [NOAA].

Improved sanitation - a facility that hygienically separates human excreta from human contact and includes flush toilet, pit latrine with slab, composting toilet, ventilated improved pit latrine, septic and other examples.

Leach field (also drain field, disposal field, *soil absorption system*) - The area in which treated wastewater is discharged and filtered as it trickles through gravel and sand layers. More advanced systems may include trenches and perforated pipes to evenly distribute the water.

Nitrogen - An essential element necessary to life. Nitrogen gas (N2) makes up about 78% of the atmosphere (NASA, 2016), is a key component of proteins.

Nitrification of effluent - Nitrification is a two-step microbial process by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and nitrate. In the first step, ammonia-oxidizing bacteria oxidize ammonia to nitrite, and in the second step, nitrite-oxidizing bacteria oxidize nitrite to nitrate.

Non-point source pollution - pollutants that come from multiple sources / can't be traced to one single source - encompasses chemicals, oils, toxins. (e.g., nitrogen, phosphorous, bacteria from septic tanks).

Nutrients - Chemical forms of nitrogen, phosphorus and silica, that are essential building-blocks of plant and algae cells. These chemicals can have toxic impacts when present in ratios higher than normal.

Open defecation - the practice of defecating outside - on the ground, or in a body of water - instead of contained and concentrated within a designated place, such as a latrine.

oxygen demand - mass of dissolved oxygen needed by microorganisms to degrade organic and some inorganic compounds. **a measure used in wastewater treatment systems as an** indicator of how much organic content is in the wastewater. i.e., Ammonia for instance creates an oxygen demand as it is converted to nitrate. (also called BOD for **biological oxygen demand**. say more about the difference).

Pit humus - material that has been removed from a double pit technology — such as a fossa Alterna, double ventilated improved pit, or twin pits for pour-flush toilets, composting toilets, terra preta toilets, or arbor loss — because it's produced underground passively and is made up slightly differently than standard compost. It contains a high volume of nutrients and organic matter.

Point-source pollution - includes wastewater and illegal chemical dumping. The pollution originates from a single source.

Primary treatment - mechanical screening, active screening or settling of solids, and some reduction of organic matter (that is, *biological oxygen on demand*, or BOD); no focus on nutrients, typically.

Safely managed sanitation - refers to facilities that are not shared and incorporate treatment of human waste, either in-situ, through storage, collection and eventual treatment, or sewer systems.

Sanitation - refers to conditions related to public health, especially the provision of clean drinking water and adequate* human waste disposal.

Sanitation system - Sanitation systems are a combination of different functional units that together allow managing and reusing or disposing the different waste flows from households, institutions, agriculture or industries in order to protect people and the environment. The systems are designed to address the whole water as well as the nutrients cycle, from the toilet user where wastewater is generated, over the collection, treatment up to reuse or discharge. In order that sanitation systems function reliably, the technical know-how for the installation of functional units as well as their management, operation and maintenance must be guaranteed.

Secondary treatment: biological treatment for removal of BOD (see **biological oxygen demand**) which may also achieve some reduction of nutrients.

Septic systems: An on-site system that consists of an underground septic tank and a drain field.

Stabilization ponds are engineered water bodies most commonly used for treating wastewater. (**aerobic**)

Stormwater - Generated when precipitation from rain and snowmelt events flows over land or impervious surfaces and does not percolate into the ground.

Stratification: a layering of water, with lighter water on top. Water that is fresh (contains little salt) and warm is lighter than cool salt water.

Tertiary treatment: filtration (may also include chemical removal of phosphorus with clarification), aeration, and nutrient removal through biological or chemical processes.

Wastewater Treatment - preparation and transformation of wastewater and related products (e.g., blackwater, fecal sludge, greywater, non-biodegradable waters, etc.) for safe reuse or disposal in order to minimize health risks for people and protect the environment from pollution.

References

Adey, W. and Loveland, K., 2007. *Dynamic Aquaria: Building and Restoring Living Ecosystems.* Elsevier.

Attridge, S. and Engen, L., 2019. Blended finance in the poorest countries: the need for a better approach. Overseas Development Institute. Available at: https://www.odi.org/sites/odi.org.uk/files/resource-documents/12666.pdf

Barnett, A.F., Gledhill, J.H., Griffitt, R.J., Slattery, M., Gochfeld, D.J. and Willett, K.L., 2020. Combined and independent effects of hypoxia and tributyltin on mRNA expression and physiology of the Eastern oyster (Crassostrea virginica). *Scientific reports, 10*(1), pp.1-13.

Barnstable County Wastewater Cost Task Force, 2010. Comparison of Costs for Wastewater Management Systems Applicable to Cape Cod. Available at: https://www.wellfleet-ma.gov/sites/g/files/vyhlif5166/f/file/file/wastewater_costs.pdf

Bejarano, A.C., VanDola, F.M., Gulland, F.M., Rowles, T.K. and Schwacke, L.H., 2008. Production and toxicity of the marine biotoxin domoic acid and its effects on wildlife: a review. *Human and Ecological Risk Assessment, 14*(3), pp.544-567.

Bill and Melinda Gates Foundation, 2020. Water, Sanitation & Hygiene Strategy Overview.

Blackburn, H., O'Neill, R., and Rangeley-Wilson, C., 2017. Flushed Away: How Sewage is Still Polluting the Rivers of England and Wales. World Wildlife Fund-United Kingdom (WWF-UK). Available at: https://www.wwf.org.uk/sites/default/files/2017-12/Flushed%20Away__Nov2017.pdf

Bos, M., Pressey, R.L. and Stoeckl, N., 2015. Marine conservation finance: The need for and scope of an emerging field. *Ocean & Coastal Management, 114,* pp.116-128.

Breitburg, D., Levin, L.A., Oschlies, A., Grégoire, M., Chavez, F.P., Conley, D.J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K. and Jacinto, G.S., 2018. Declining oxygen in the global ocean and coastal waters. *Science, 359*(6371).

Bulseco, A.N., Giblin, A.E., Tucker, J., Murphy, A.E., Sanderman, J., Hiller-Bittrolff, K. and Bowen, J.L., 2019. Nitrate addition stimulates microbial decomposition of organic matter in salt marsh sediments. *Global change biology*, *25*(10), pp.3224-3241.

Carrera, J.S. and Flowers, C.C., 2018. Sanitation inequity and the cumulative effects of racism in colorblind public health policies. *American Journal of Economics and Sociology, 77*(3-4), pp.941-966.

Chahal, C., Van Den Akker, B., Young, F., Franco, C., Blackbeard, J. and Monis, P., 2016. Pathogen and particle associations in wastewater: significance and implications for treatment and disinfection processes. *Advances in applied microbiology, 97,* pp.63-119.

Codispoti, L.A., 2010. Interesting times for marine N2O. *Science, 327*(5971), pp.1339-1340.

Cooper, J.A., Loomis, G.W. and Amador, J.A., 2016. Hell and high water: Diminished septic system performance in coastal regions due to climate change. *PloS one*, *11*(9), p.e0162104.

CTCN. "Biochar." Climate Technology Centre & Network. United Nations Environment. Available at: https://www.ctc-n.org/technologies/biochar

CWP (Center for Watershed Protection), 2008. Guánica Bay Watershed Management Plan: A Pilot Project for Watershed Planning in Puerto Rico. NOAA Coral Reef Program and Departamento de Recursos Naturales y Ambientales. Accessible at: https://owl.cwp.org/mdocs-posts/guanica-bay-watershed-mngt-plan/

C&M Mining Machinery, 2020. "Packaged Treatment Plant for Sale." Accessible at: https://www.edubio.pl/oman/2020_Sep_04_5307/

Delzer, G.C. and McKenzie, S.W., 2003. Chapter A7. Section 7.0. Five-Day Biochemical Oxygen Demand (No. 09-A7. 0). US Geological Survey.

Depledge, M.H. and Billinghurst, Z., 1999. Ecological significance of endocrine disruption in marine invertebrates. *Marine Pollution Bulletin, 39*(1-12), pp.32-38.

Diez, S.M., Patil, P.G., Morton, J., Rodriguez, D.J., Vanzella, A., Robin, D.V., Maes, T., and Corbin, C., 2019. Marine Pollution in the Caribbean: Not a Minute to Waste. Washington, D.C. : World Bank Group.

DOE (United States Department of Energy). "Glossary." Bioenergy. Office of Energy Efficiency & Renewable Energy. Accessible at: https://www.energy.gov/eere/bioenergy/glossary

Donovan, M.K., Adam, T.C., Shantz, A.A., Speare, K.E., Munsterman, K.S., Rice, M.M., Schmitt, R.J., Holbrook, S.J. and Burkepile, D.E., 2020. Nitrogen pollution interacts with heat stress to increase coral bleaching across the seascape. *Proceedings of the National Academy of Sciences*, *117*(10), pp.5351-5357.

EEA (European Environment Agency), 2018. European Waters: Assessment of status and pressures 2018. Available at: https://www.eea.europa.eu/publications/state-of-water/at_download/file.

EPA (United States Environmental Health Protection Agency), 1996. Research and Development: Assessing Nitrogen Leaching in Unsaturated Media from Septic Tank Waste for the North Animas Valley, La Plata County, Colorado. Ecosystems Research Division. U.S. Environmental Protection Agency. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/9100N978.PDF?Dockey=9100N978.PDF

EPA (United States Environmental Health Protection Agency),

2001. Report to Congress: Implementation and Enforcement of Combined Sewer Overflow Control Policy. Available at: https://www3.epa.gov/npdes/pubs/csortcexecsum.pdf

EPA (United States Environmental Health Protection Agency), 2004. AgSTAR Handbook Glossary. Vocabulary Catalog. Office of Air and Radiation. Accessible at: https://sor.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=AgSTAR%20Handbook%20Glossary

EPA (United States Environmental Health Protection Agency), 2006. Terms of Environment Beginning With 'E'.

EPA (United States Environmental Health Protection Agency), 2009. Drinking Water Glossary: A Dictionary of Technical and Legal Terms Related to Drinking Water. Vocabulary Catalog. Office of Water/Office of Ground Water and Drinking Water. Accessible at: https://sor.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do?details=&glossaryName=Drink%20Water%20Tech/Legal%202009#formTop

EPA (United States Environmental Health Protection Agency), 2013. Impacts of Climate Change on the Occurrence of Harmful Algal Blooms. Office of Water, EPA 820-S-13-001.

EPA (United States Environmental Health Protection Agency), 2014. Decentralized Wastewater Program Annual Report 2013. EPA-832-R-140006.

Evans, R.L., Schnepper, D.H., Brooks, G. and Williams, J., 1978. Performance evaluation of tertiary wastewater treatment systems. *Illinois State Water Survey*. Illinois Environmental Protection Agency.Fleming, L.E., Kirkpatrick, B., Backer, L.C., Bean, J.A., Wanner, A., Reich, A., Zaias, J., Cheng, Y.S., Pierce, R., Naar, J. and Abraham, W.M., 2007. Aerosolized red-tide toxins (brevetoxins) and asthma. *Chest, 131*(1), pp.187-194.

Galst, L., 2020. 'Suffolk County Legislature Passes Landmark Legislation to Cut Pollution, Improve Water Quality, Protect Public Health, and Create Good-Paying Jobs.' Newsroom. The Nature Conservancy. 6 October. Accessible at: https://www.nature.org/en-us/newsroom/ny-suffolk-county-water-quality-legislation/

Giving USA, 2020. The Annual Report on Philanthropy for the Year 2019. Giving USA Foundation.

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), 2011. Technology review of urine diversion components: Overview of urine diversion components such as waterless urinals, urine diversion toilets, urine storage and reuse systems. GIZ. Federal Ministry for Economic Cooperation and Development. Accessible at: http://www.susana.org/_resources/documents/default/2-875-giz2011-en-technology-review-urine-diversion.pdf

Glasl, B., Herndl, G.J. and Frade, P.R., 2016. The microbiome of coral surface mucus has a key role in mediating holobiont health and survival upon disturbance. *The ISME journal*, *10*(9), pp.2280-2292.

Graves, S., 2019. "The Future of Urine Diverting Toilet Technology." C-Head. Available at: https://www.c-head.com/post/the-future-of-urine-diverting-toilet-technology

Greer, F.R. and Shannon, M., 2005. Infant methemoglobinemia: the role of dietary nitrate in food and water. *Pediatrics, 116*(3), pp.784-786.

Hawaii DHEM (Department of Health, Environmental Management Division), 2017. Report to the Twenty-Ninth Legislature, State of Hawaii, 2018 Regular Session: Relating to Cesspools and Prioritization for Replacement. Available at: https://health.hawaii.gov/opppd/files/2017/12/Act-125-HB1244-HD1-SD3-CD1-29th-Legislature-Cesspool-Report.pdf

Hawkins, J., Radis, C., and Bennett, A., 2018. Inventory of municipal wastewater discharges to California coastal waters. Heal the Ocean. Available at: https://bd2a711c-b9a0-41e8-a711-7f9707f990de.filesusr.com/ugd/595077_33f2d11140d345b3926dff8b6ddcd318.pdf

He, Q. and Silliman, B.R., 2019. Climate change, human impacts, and coastal ecosystems in the Anthropocene. Current Biology, 29(19), pp.R1021-R1035.

Heufelder, G., 2015. The attenuation of selected contaminants of emerging concern in shallow-placed soil absorption systems. *NOWRA*.

Howarth, R.W., Anderson, D.B., Cloern, J.E., Elfring, C., Hopkinson, C.S., Lapointe, B., Malone, T., Marcus, N., McGlathery, K., Sharpley, A.N. and Walker, D., 2000. Nutrient pollution of coastal rivers, bays, and seas. *Issues in ecology,* (7), pp.1-16.

Jagai, J.S., Li, Q., Wang, S., Messier, K.P., Wade, T.J. and Hilborn, E.D., 2015. Extreme precipitation and emergency room visits for gastrointestinal illness in areas with and without combined sewer systems: an analysis of Massachusetts data, 2003–2007. *Environmental health perspectives, 123*(9), pp.873-879.

Junier, Sandra and Mostert, Erik. (2012). The implementation of the Water Framework Directive in The Netherlands: Does it promote integrated management? *Physics and Chemistry of The Earth*. 47-48. 10.1016/j.pce.2011.08.018.

Kabir, E.R., Rahman, M.S. and Rahman, I., 2015. A review on endocrine disruptors and their possible impacts on human health. *Environmental toxicology and pharmacology, 40*(1), pp.241-258.

Kareiva, P., Chang, A. and Marvier, M., 2008. Development and conservation goals in World Bank projects. *Science, 321*(5896), pp.1638-1639.

Kayser, G.L., Rao, N., Jose, R. and Raj, A., 2019. Water, sanitation and hygiene: measuring gender equality and empowerment. *Bulletin of the World Health Organization, 97*(6), p.438.

Kenward, A., Yawitz, D., and Raja, U., 2013. Sewage overflows from Hurricane Sandy. Climate Central.

Kirkpatrick, B., Bean, J.A., Fleming, L.E., Kirkpatrick, G., Grief, L., Nierenberg, K., Reich, A., Watkins, S. and Naar, J., 2010. Gastrointestinal emergency room admissions and Florida red tide blooms. *Harmful algae, 9*(1), pp.82-86.

Lamb, J.B., Van De Water, J.A., Bourne, D.G., Altier, C., Hein, M.Y., Fiorenza, E.A., Abu, N., Jompa, J., Harvell, C.D., 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science, 355 (6326), 731-733.

Landrigan, P., Stegeman, J., Fleming, L., Allemand, D., Anderson, D., Backer, L., Brucker-Davis, F., Chevalier, N., Corra, L., Czerucka, D. and Bottein, M.Y.D., 2020. Human Health and ocean pollution. *Annals of global health, 86*(1), p.151.

Latini, G., Knipp, G., Mantovani, A., Marcovecchio, M.L., Chiarelli, F. and Soder, O., 2010. Endocrine disruptors and human health. *Mini-Reviews in Medicinal Chemistry*, *10*(9), p.846.

Lehmann, J., 2007. A handful of carbon. *Nature, 447*(7141), pp.143-144.

Leker, H.G. and MacDonald Gibson, J., 2018. Relationship between race and community water and sewer service in North Carolina, USA. *PloS one, 13*(3), p.e0193225.

Lenihan, H.S., Peterson, C.H., Byers, J.E., Grabowski, J.H., Thayer, G.W. and Colby, D.R., 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications*, *11*(3), pp.764-782.

Leonard, A.F., Zhang, L., Balfour, A.J., Garside, R., Hawkey, P.M., Murray, A.K., Ukoumunne, O.C. and Gaze, W.H., 2018. Exposure to and colonisation by antibiotic-resistant E. coli in UK coastal water users: Environmental surveillance, exposure assessment, and epidemiological study (Beach Bum Survey). *Environment international, 114,* pp.326-333.

Leslie, J., 2018. 'Where water is scarce, communities turn to reusing wastewater', *Yale Environment 360,* 1 May. Accessible at: https://e360.yale.edu/features/instead-of-more-dams-communities-turn-to-reusing-wastewater

LICWP (Long Island Clean Water Partnership). The Case for Protection and Comprehensive Management of Long Island's Groundwater and Surface Water. Accessible at: http://www.hobaudubon.org/pdfs/LICWP-Full-Case-Statement.pdf

Littman, R.A., Fiorenza, E.A., Wenger, A.S., Berry, K.L., van de Water, J.A., Nguyen, L., Aung, S.T., Parker, D.M., Rader, D.N., Harvell, C.D. and Lamb, J.B., 2020. Coastal urbanization influences human pathogens and microdebris contamination in seafood. *Science of the Total Environment, 736,* p.139081.

Mara, D., Lane, J., Scott, B. and Trouba, D., 2010. Sanitation and health. *PloS Med*, *7*(11), p.e1000363.

Meador, J. P., Yeh, A., Young, G., and Gallagher, E. P. (2016). Contaminants of emerging concern in a large temperate estuary. *Environmental Pollution, 213,* 254-267.

Mezzacapo, M., 2020. Identifying potential knowledge gaps for Hawai'i's cesspool conversion plan. Water Resources Research Center. The University of Hawai'i at Mānoa. Available at: https://health.hawaii.gov/wastewater/files/2020/04/Identifying_Potential_Knowledge_Gaps.pdf

Miami-Dade County DERM (Department of Environmental Resources Management), 2018. Septic Systems Vulnerable to Sea-level rise. Final Report in support of Resolution No. R-911-16.

Munasinghe-Arachchige, S.P. and Nirmalakhandan, N., 2020. Nitrogen-fertilizer recovery from the centrate of anaerobically digested sludge. *Environmental Science & Technology Letters, 7*(7), pp.450-459.

Naquin, A., Shrestha, A., Sherpa, M., Nathaniel, R. and Boopathy, R., 2015. Presence of antibiotic resistance genes in a sewage treatment plant in Thibodaux, Louisiana, USA. *Bioresource technology, 188*, pp.79-83.

NASA, 2016. "10 interesting things about air." Features. Global Climate Change. Accessible at: https://climate.nasa.gov/news/2491/10-interesting-things-about-air/.

New York State, 2020. "Governor Cuomo Announces Completion of $19.6 Million Biological Nutrient Removal System at Bay Park Wastewater Treatment Plant." Pressroom. New York State. Accessible at: https://www.governor.ny.gov/news/governor-cuomo-announces-completion-196-million-biological-nutrient-removal-system-bay-park

NOAA. "Hypoxia." Ocean Facts. Accessible at: https://oceanservice.noaa.gov/hazards/hypoxia/

NYSDEC (New York State Department of Environmental Conservation), 2008. Wastewater infrastructure needs of New York State. Available at: https://www.dec.ny.gov/docs/water_pdf/infrastructurerpt.pdf

OECD (Organisation for Economic Co-operation and Development), 2013. Water and Climate Change Adaptation: Policies to Navigate Uncharted Waters. OECD Studies on Water, OECD Publishing.

O'Neill, J., 2016. Tackling drug-resistant infections globally: Final report and recommendations. Wellcome Trust and UK Government.

Osborne, K., Thompson, A.A., Cheal, A.J., Emslie, M.J., Johns, K.A., Jonker, M.J., Logan, M., Miller, I.R. and Sweatman, H.P., 2017. Delayed coral recovery in a warming ocean. *Global change* *biology, 23*(9), pp.3869-3881.

Patterson, K.L., Porter, J.W., Ritchie, K.B., Polson, S.W., Mueller, E., Peters, E.C., Santavy, D.L. and Smith, G.W., 2002. The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, Acropora palmata. *Proceedings of the National Academy of Sciences*, *99*(13), pp.8725-8730.

Prüss-Üstün A., Bos R., Gore F., and Bartram J., 2008. Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. World Health Organization, Geneva.

Prüss-Ustün, A., Wolf, J., Bartram, J., Clasen, T., Cumming, O., Freeman, M.C., Gordon, B., Hunter, P.R., Medlicott, K. and Johnston, R., 2019. Burden of disease from inadequate water, sanitation and hygiene for selected adverse health outcomes: an updated analysis with a focus on low-and middle-income countries. *International journal of hygiene and environmental health*, *222*(5), pp.765-777.

Pusceddu, F.H., Choueri, R.B., Pereira, C.D.S., Cortez, F.S., Santos, D.R.A., Moreno, B.B., Santos, A.R., Rogero, J.R. and Cesar, A., 2018. Environmental risk assessment of triclosan and ibuprofen in marine sediments using individual and sub-individual endpoints. *Environmental Pollution*, *232*, pp.274-283.

Ragsdale, D., 2007. Advanced wastewater treatment to achieve low concentration of phosphorus. EPA Region, 10.

Rather, J., 2008. 'For Scallops, New Signs of Life in the Peconics.' The New York Times. 8 August. Available at: https://www.nytimes.com/2008/08/10/nyregion/nyregionspecial2/10scallopsli.html

Reef Resilience Network, 2021. "Puerto Rico – Sewage Pollution." Reef Resilience Network. 9 March. Accessible at: https://reefresilience.org/case-studies/puerto-rico-sewage-pollution/

Rich Earth Institute. "Environment." Rich Earth Institute. Accessible at: https://richearthinstitute.org/rethinking-urine/environment/

Rich Earth Institute. "Farming." Rich Earth Institute. Accessible at: https://richearthinstitute.org/rethinking-urine/farming/

Riverkeepers, 2011. How is the water? A story of sewage contamination on the Hudson. Available at: https://www.riverkeeper.org/news-events/news/water-quality/how-is-the-water/

Rodríguez-Molina, D., Mang, P., Schmitt, H., Chifiriuc, M.C., Radon, K. and Wengenroth, L., 2019. Do wastewater treatment plants increase antibiotic resistant bacteria or genes in the environment? Protocol for a systematic review. *Systematic reviews, 8*(1), pp.1-8.

Russel, K.C., Hughes, K., Roach, M., Auerbach, D., Foote, A., Kramer, S. and Briceño, R., 2019. Taking container-Based sanitation to scale: opportunities and challenges. *Frontiers in Environmental Science, 7*, p.190.

Schaefer, T., 2016. "Nitrogen Removing Biofilters Could be Solution to Preventing Sewage Pollution." Save the Water. Accessible at: https://savethewater.org/nitrogen-removing-biofilters-could-be-solution-to-preventing-sewage-pollution/

Schullehner, J., Hansen, B., Thygesen, M., Pedersen, C.B. and Sigsgaard, T., 2018. Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. *International journal of cancer, 143*(1), pp.73-79.

Shiklomanov, I.A., 1993. 'World freshwater resources' in Gleick, P.H. (ed.) *Water in crisis: A guide to the world's fresh water resources*. New York: Oxford University Press.

Shuval, H., 2003. Estimating the global burden of thalassogenic diseases: human infectious diseases caused by wastewater pollution of the marine environment. *Journal of water and health, 1*(2), pp.53-64.

Simha, P. and Ganesapillai, M., 2017. Ecological Sanitation and nutrient recovery from human urine: How far have we come? A review. *Sustainable Environment Research, 27*(3), pp.107-116.

Singh, S. and Tiwari, S., 2019. Climate Change, Water and Wastewater Treatment: Interrelationship and Consequences. In: Singh R., Kolok A., Bartelt-Hunt S. (eds). *Water Conservation, Recycling and Reuse: Issues and Challenges* (pp. 203-214). Springer, Singapore.

Sturm, P., Viqueira, R., Ferguson, R., and Moore, T., 2012. "Addressing land based sources of pollution in Guánica, Puerto Rico." *Proceedings of the 12th International Coral Reef Symposium*. Cairns, Australia. Available at: http://www.icrs2012.com/proceedings/manuscripts/ICRS2012_21A_3.pdf

Sutherland, K.P., Shaban, S., Joyner, J.L., Porter, J.W., Lipp, E.K., 2011. Human pathogen shown to cause disease in the threatened elkhorn coral *Acropora palmata*. PLOS One, 6 (8).

Tarrant, A.M., Atkinson, M.J. and Atkinson, S., 2004. Effects of steroidal estrogens on coral growth and reproduction. *Marine Ecology Progress Series*, *269*, pp.121-129.

Temkin, A., Evans, S., Manidis, T., Campbell, C. and Naidenko, O.V., 2019. Exposure-based assessment and economic valuation of adverse birth outcomes and cancer risk due to nitrate in United States drinking water. *Environmental Research, 176*, p.108442.

Tracy, A.M., Weil, E. and Harvell, C.D., 2020. Warming and pollutants interact to modulate octocoral immunity and shape disease outcomes. *Ecological Applications, 30*(2), p.e02024.

Tseng, L.Y., Robinson, A.K., Zhang, X., Xu, X., Southon, J., Hamilton, A.J., Sobhani, R., Stenstrom, M.K. and Rosso, D., 2016.

Identification of preferential paths of fossil carbon within water resource recovery facilities via radiocarbon analysis. *Environmental Science & Technology*, *50*(22), pp.12166-12178.

Tuttle, L.J. and Donahue, M.J., 2020. Thresholds for Sediment Stress on Corals: A systematic review and meta-analysis. NOAA Fisheries Pacific Islands. Available at: Thresholds for Sediment Stress on Corals: A systematic review and meta-analysis

UN (United Nations), 2009. Report of the independent expert on the issue of human rights obligations related to access to safe drinking water and sanitation, United Nations, Available at: http://www.ohchr.org/Documents/Press/IE_2009_report.pdf

UN (United Nations), 2017. Factsheet: People and Oceans. The Ocean Conference. Available at: https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf

UN (United Nations), 2019. The Sustainable Development Goals Report – 2019. United Nations, New York. Available at: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

UNICEF (United Nations Children's Fund) and WHO (World Health Organization), 2015. Progress on sanitation and drinking water: 2015 update and MDG assessment. WHO/UNICEF. Available at: https://apps.who.int/iris/bitstream/handle/10665/177752/9789241509145_eng.pdf?sequence=1

UNICEF (United Nations Children's Fund) and WHO (World Health Organization), 2017. Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. WHO/UNICEF. Available at: https://apps.who.int/iris/bitstream/handle/10665/258617/9789241512893-eng.pdf?sequence=1

UNICEF (United Nations Children's Fund) and WHO (World Health Organization), 2019. Progress on household drinking water, sanitation and hygiene 2000-2017. Special focus on inequalities. WHO/UNICEF JMP. Available at: https://www.who.int/water_sanitation_health/publications/jmp-2019-full-report.pdf. Accessed: 9 June 2020.

University of Florida. "Common Terms Used in Wastewater Treatment." Office of Professional and Workforce Development. University of Florida. Available at: https://treeo.ufl.edu/media/treeoufledu/waterwastewater/student-resources/Glossary-of-Common-WW-Terms.pdf

US Census, 2019. "QuickFacts: Suffolk County, New York; Nassau County, New York." Population Estimates, American Community Survey. United States Census Bureau. Accessible at: https://www.census.gov/quickfacts/fact/table/suffolkcountynewyork,nassaucountynewyork/PST045219

Vega Thurber, R.L., Burkepile, D.E., Fuchs, C., Shantz, A.A., McMinds, R. and Zaneveld, J.R., 2014. Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. *Global change biology*, *20*(2), pp.544-554.

Voulvoulis, N., Arpon, K.D. and Giakoumis, T., 2017. The EU Water Framework Directive: From great expectations to problems with implementation. *Science of the Total Environment, 575*, pp.358-366.

WADOH (Washington State Department of Health), 2020. On-Site Wastewater Technical Advisory Group: Meeting Summary. https://www.doh.wa.gov/Portals/1/Documents/Mtgs/2020/20200304-MN-TAG.pdf

Wallace, R.B., Baumann, H., Grear, J.S., Aller, R.C. and Gobler, C.J., 2014. Coastal ocean acidification: The other eutrophication problem. *Estuarine, Coastal and Shelf Science, 148*, pp.1-13.

Ward, M.H., Jones, R.R., Brender, J.D., De Kok, T.M., Weyer, P.J., Nolan, B.T., Villanueva, C.M. and Van Breda, S.G., 2018. Drinking water nitrate and human health: an updated review. *International journal of environmental research and public health, 15*(7), p.1557.

Warne, A.G., Webb, R.M. and Larsen, M.C., 2005. Water, sediment, and nutrient discharge characteristics of rivers in Puerto Rico, and their potential influence on coral reefs. US Department of the Interior, US Geological Survey.

Water Environment Federation. 2015. "Biogas Data." Water Science & Engineering Center. Water Environment Federation. Available at: http://www.resourcerecoverydata.org/biogasdata.php

Wear, S.L., Acuña, V., McDonald, R. and Font, C., 2021. Sewage pollution, declining ecosystem health, and cross-sector collaboration. *Biological Conservation*, *255*, p.109010.

Wear, S.L., 2019. Battling a common enemy: joining forces in the fight against sewage pollution. *BioScience, 69* (5), 360-367.

Wear, S.L., 2016. Missing the boat: Critical threats to coral reefs are neglected at global scale. *Marine Policy, 74,* 153-157.

Wear, S. and Vega Thurber, R., 2015. Sewage pollution: mitigation is key for coral reef stewardship. *Annals of the New York Academy of Sciences*.

WHO (World Health Organization), 2011. Pharmaceuticals in Drinking-water. WHO/HSE/WSH/11.05. Public Health and Environment-Water, Sanitation, Hygiene and Health. Geneva, Switzerland. 35 pp.

WHO (World Health Organization), 2015. WHO estimates of the global burden of foodborne diseases: foodborne disease burden epidemiology reference group 2007-2015. World Health Organization.

Wiering, M., Liefferink, D., Boezeman, D., Kaufmann, M., Crabbe, A., and N. Kurstjens. 2020. The Wicked Problem the Water Framework Directive Cannot Solve. The Governance Approach in Dealing with Pollution of Nutrients in Surface Water in the Netherlands, Flanders, Lower Saxony, Denmark and Ireland.

Water, 12, 1240.

Winkler, I.T. and Flowers, C.C., 2017. America's dirty secret: The human right to sanitation in Alabama's Black Belt. *Columbia Human Rights Law Review, 49*, p.181.

Yang, W.B., Yuan, C.S., Chen, W.H., Yang, Y.H., & Hung, C.H.J., 2017. Diurnal Variation of Greenhouse Gas Emission from Petrochemical Wastewater Treatment Processes Using In-situ Continuous Monitoring System and the Associated Effect on Emission Factor Estimation. *Aerosol and Air Quality Research*. *17*.

Yashadhana, A., Pollard-Wharton, N., Zwi, A.B. and Biles, B., 2020. Indigenous Australians at increased risk of COVID-19 due to existing health and socioeconomic inequities. *The Lancet Regional Health-Western Pacific, 1*.

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