Industrial pollutants

Mum: why do our beautiful rivers have so many dead fish floating along their banks?

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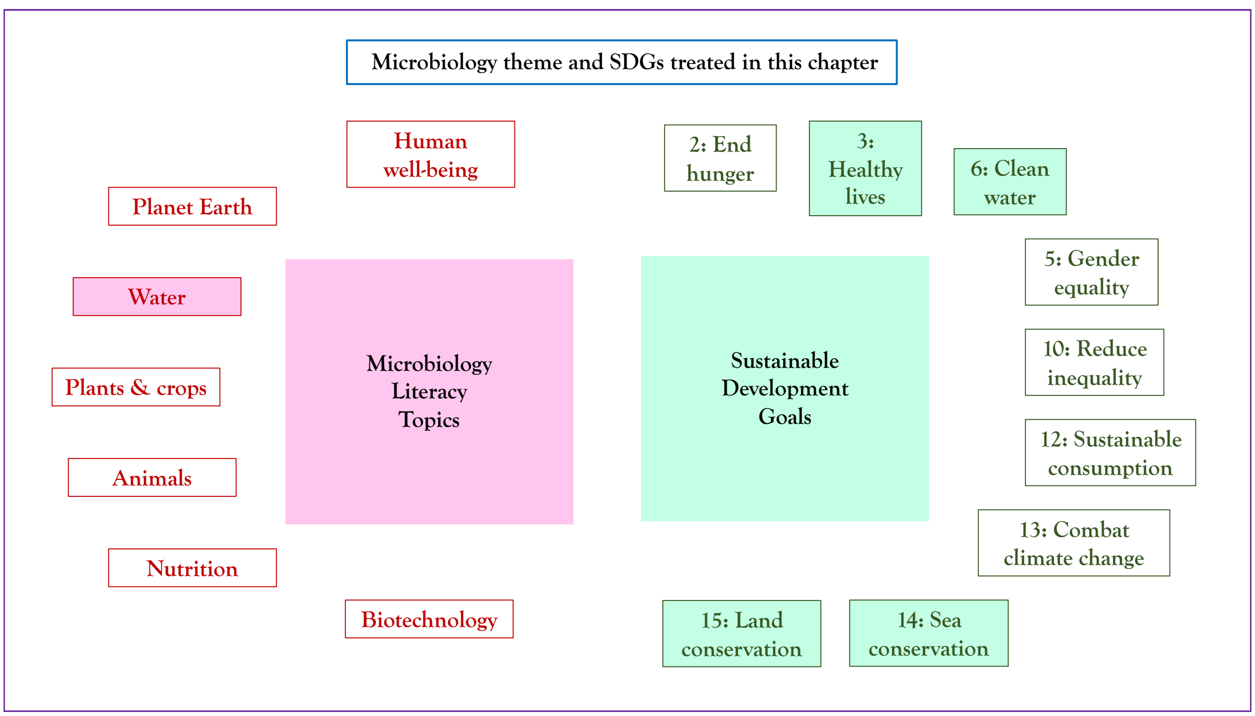
Storyline

This lesson on industrial pollutants explores how industrial and other pollutants enter our rivers, lakes, streams, and oceans. We discuss the sources of some common (excess nutrients, persistent organic pollutants (POPs)) and emerging pollutants of concern (POPs and pharmaceuticals and personal care products (PPCPs)), as well as the potential for exposure to microbial pathogens in contaminated waters. We also examine the application of physical and (micro)biological applications in the treatment of wastewater. Despite continued advancements in wastewater treatment, industrial and other pollutants still end up in our ecosystems and contribute to poor water quality with severe ecological consequences. We present sustainable solutions to address water quality issues that include (micro)biological water treatment during wastewater processing, native plants and wetland plantings to reduce stormwater run-off, and student involvement in local government.

The Microbiology and Societal Context

The microbiology: pathogenic microorganisms; infectious disease; toxin production; pollution; sanitation, wastewater treatment. *Sustainability issues*: human health, environmental health, safe water, environmental pollution.



Industrial Pollutants: the Microbiology

Large populations of people often rely on a common water supply making this water the most important potential common source of infectious disease and exposure to toxic chemicals. Thus, knowledge on the microbiology of water and proper treatment of industrial wastewater is extremely important in maintaining public and environmental health.

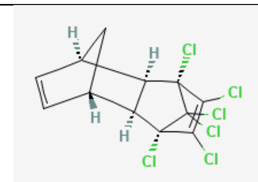
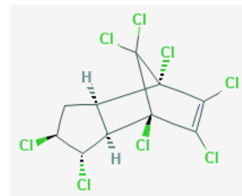
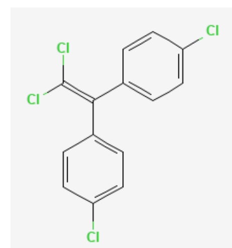
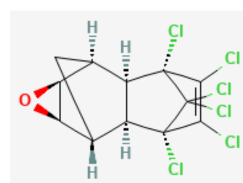
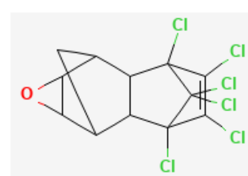
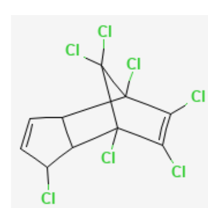
We explore the role of microorganisms in both the sanitation of industrial wastewater as well as the processing of industrial pollutants once these contaminants enter the environment.

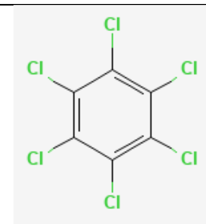
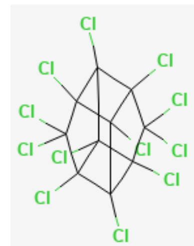
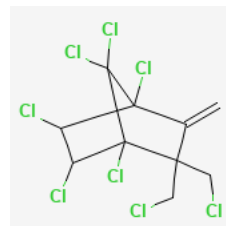
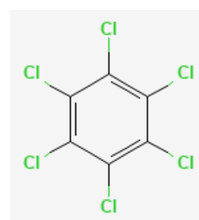
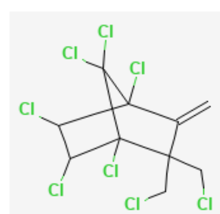
1. ***Industrial pollution.*** Industrial pollution is one of the leading causes of pollution worldwide. Industrial activities often occur along urban estuarine and riverine systems that historically provided convenient transportation route access and where industrial waste products have historically been released. As a result, pollutants produced by industrial processes enter into surface waters and accumulate in aquatic sediments where they have the potential to severely impact water quality as well as ecological and human health.

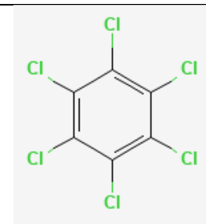
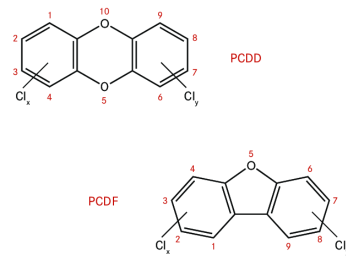
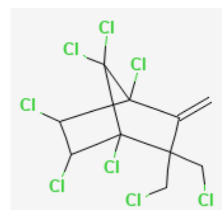
Today, wastewater may travel through underground pipes to a central treatment facility. Wastewater treatment plants (WWTPs) are responsible for the sanitation of water before effluent is returned to local streams, rivers, lakes, and estuaries. Wastewater is sanitized through a series of physical, biological, and chemical processes designed to purify the water according to the source of the waste. The sanitation process of domestic wastewater results in a reduction in the number of pathogenic microorganisms which may include viruses such as enteroviruses and hepatitis, bacteria such as *Salmonella*, *Shigella*, and *Vibrio*, as well as *Cryptosporidium* and other disease-causing protozoa.

Chemicals common in industrial wastewater, water that contains contaminants that can trace their immediate source to industrial practices, include persistent organic pollutants (POPs) such as the nutrients and pesticides from agricultural practices, heavy metals from combustion of coal and other industrial processes, pharmaceutical and personal care products (collectively referred to as PPCPs), and microplastics (MPs). Industrial wastewater may also contain POPs of global concern, initially identified as the "Dirty Dozen" under treaty known as the Stockholm Convention on Persistent Organic Pollutants and targeted for reduction and elimination in 2001. The "Dirty Dozen" include toxic chemicals that may be intentionally or unintentionally produced through industrial processes, carried throughout the world and adversely affect human health and the environment. Since ratification, sixteen additional chemicals have been added to the list with more proposed and under review. Most recently, there has been increasing concern with environmental contamination by per- and polyfluoroalkyl substances (PFAS), which because of their very slow degradation are often referred to as "forever chemicals".

The Initial Dirty Dozen			
Category	**Chemical Name**	**Molecular Formula**	**Chemical Structure**
Pesticides	Aldrin	$C_{12}H_8Cl_6$	

			
	Chlordane	$C_{10}H_6Cl_8$	
	Dichlorodiphenyltrichloroethane (DDT)	$C_{14}H_9Cl_5$	
	Dieldrin	$C_{12}H_8Cl_6O$	
	Endrin	$C_{12}H_8Cl_6O$	
	Heptachlor	$C_{10}H_5Cl_7$	
	Hexachlorobenzene (also an industrial chemical and by-product)	C_6Cl_6	

			
	Mirex	$C_{10}Cl_{12}$	
	Toxaphene	$C_{10}H_8Cl_8$	
Industrial chemicals	Hexachlorobenzene (also a pesticide and by-product)	C_6Cl_6	
	Polychlorinated biphenyls (PCBs; also a by-product)	$C_{10}H_8Cl_8$	
By-products	Hexachlorobenzene (also a pesticide and industrial chemical)	C_6Cl_6	

			
	Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/PCDF)	Unavailable through NLM	
	PCBs (also an industrial chemical)	$C_{10}H_8Cl_8$	

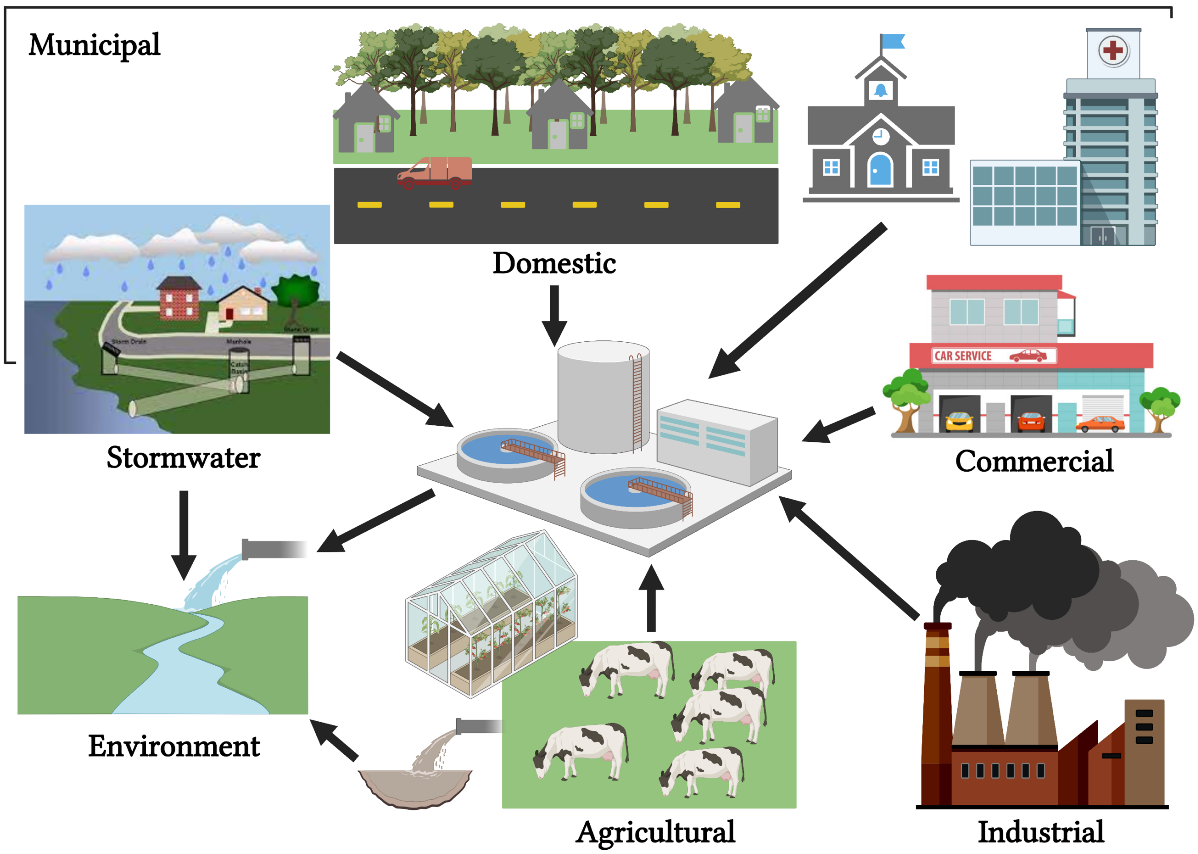
The initial dirty dozen persistent organic pollutants under the Stockholm Convention. Chemical images obtained from PubChem National Library of Medicine (NLM). The molecular formula provides a link to the safety data sheet (SDS) for each chemical, when available.

Many of these industrial chemicals can be removed through treatment processes and industrial wastewater treatment measures have proven to be extremely effective in eliminating some toxic chemicals. However, chemical contaminants may still enter our local streams, rivers, lakes, and estuaries, through pipes situated along these waterways or runoff produced during storm events.

Points of discharge, where effluent enters the waterway through pipes, are regulated to ensure that the water is safe and free of dangerous contaminants. Unfortunately, chemicals that are not eliminated in the wastewater treatment process, not regulated, or present in runoff that is not subject to treatment to begin with, pose a threat to our health and the environment. We will explore the role of microorganisms in both the sanitation of industrial wastewater as well as the processing of industrial pollutants once these contaminants enter the environment.

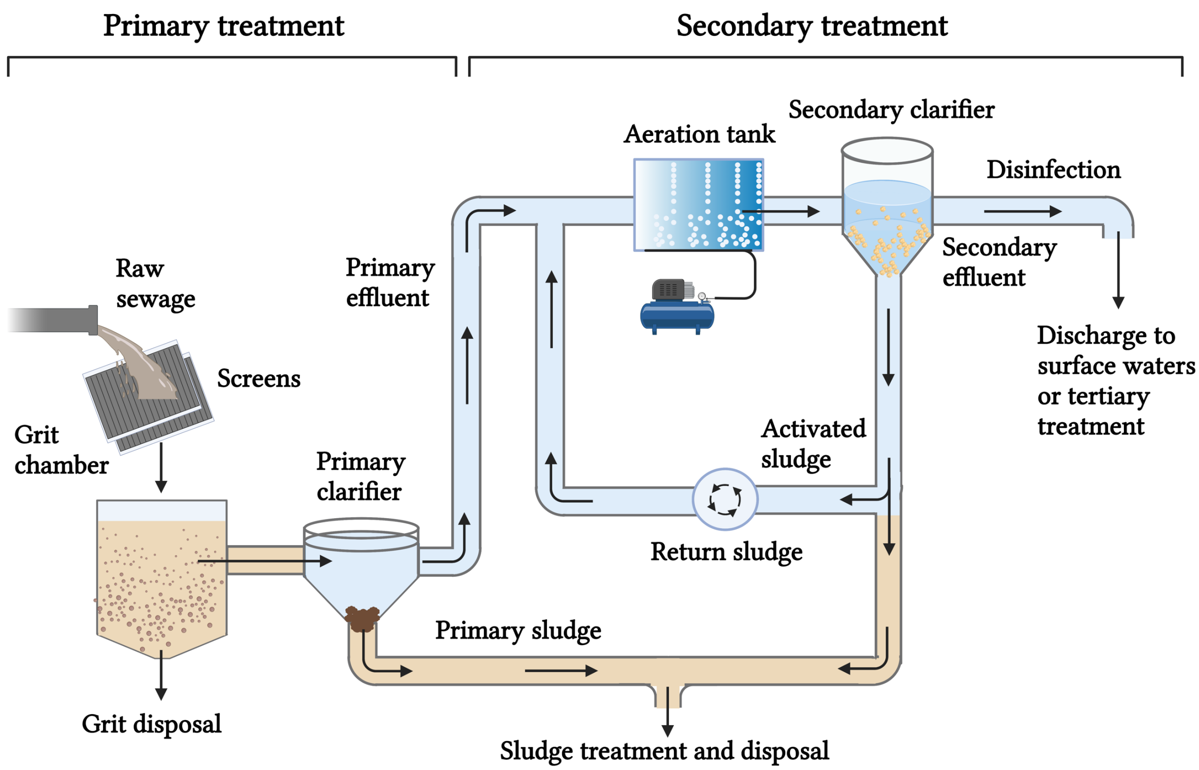
2. ***Microbes play an instrumental role in sanitation of wastewater.*** WWTPs harness the power of microorganisms to ensure that water is safe and free of pathogens after the sanitation process Wastewater is classified by its source; domestic, industrial, commercial, agricultural or urban/municipal. WWTPs may also receive material from combined sewer overflows, where stormwater, sewer water, and industrial wastewater are all present in the same system and must

be treated. The practice of combined sewer overflows is less common today and stormwater is often separated and sometimes treated before discharged back into the environment. Facilities may operate differently from place to place, but the overall concepts are similar and employ a series of physical, chemical and biological techniques to remove pathogens and regulated chemicals.



Wastewater treatment facility inputs and outputs into the environment. Wastewater from municipal, commercial, industrial, and agricultural is treated and discharged into the environment. Untreated wastewater and stormwater runoff may enter from combined sewer outflow and non-point sources. Created with BioRender.com.

During the primary treatment stage, wastewater is screened, or passed through a filtering system where large material and debris are removed. Sewage that passes through the initial screening stage now contains a mixture of dissolved organic material, nutrients, and suspended solids. In the secondary treatment stage, the biological breakdown of the organic material typically occurs in stages. Microorganisms degrade the organic material under oxic conditions, created by aeration of large tanks to provided oxygen to these microbes. This aeration allows the growth of heterotrophs that utilize dissolved organic carbon compounds converting these to carbon dioxide (CO_2) and more microbial biomass. Microbes tend to congregate here and form flocs, as they attach to particulate material and essentially form biofilms upon themselves. These flocs continue to absorb and remove soluble organic material as they grow and settle rapidly and can thus later be removed as activated sludge. Activated sludge is made up of a diverse microbial community within a slimy, extracellular polymeric substances, excreted by the microbes to facilitate floc formation. Aerobic bacteria such as *Zoogloea ramigera*, filamentous bacteria and fungi, protists and even small microscopic animals reside in these communities. Following secondary treatment, effluent can be chlorinated or treated with ozone to remove potential pathogens and released into local waterbodies.

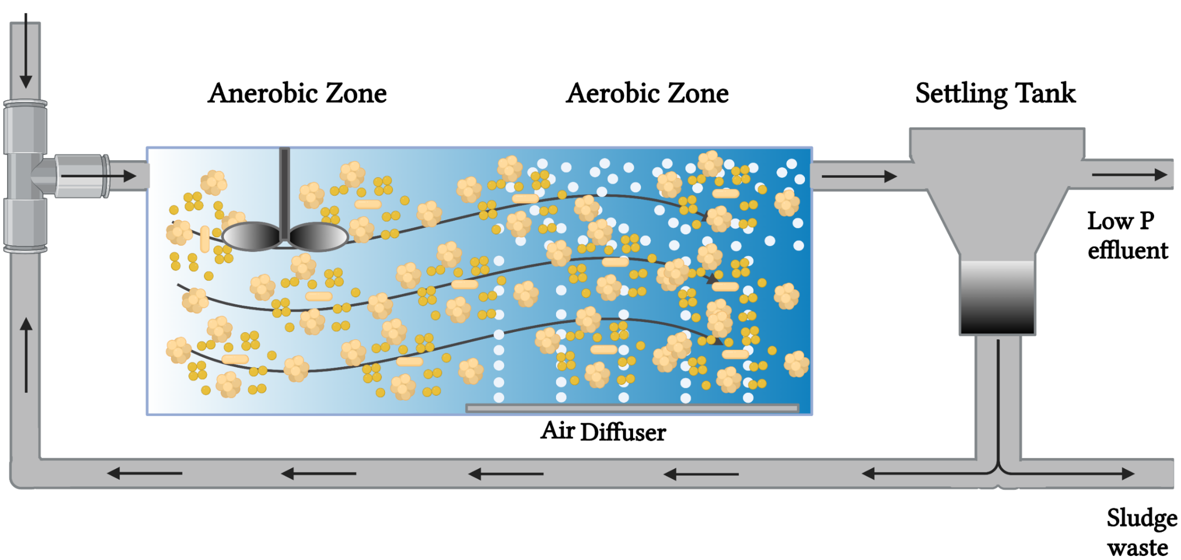


Overview of wastewater treatment process. Created with BioRender.com.

3. ***WWTP processing is insufficient to treat all chemicals and some escape into our waterways.*** While pathogens, readily biodegradable organic matter and heavy metals are efficiently processed by conventional secondary treatment in WWTPs, some potentially harmful pollutants are not removed from wastewater effluent and make their way into our environment. Pharmaceuticals, personal care products, and MP's were not originally considered during the development of WWTPs. Pharmaceuticals and personal care products, collectively known as PPCPs are not sufficiently processed during purification of our wastewater. Alteration of aquatic communities, creation of carcinogenic compounds, and bioaccumulation of toxic chemicals in the food web are some of the concerns that arise as these PPCPs and other emerging pollutants continue to enter our natural systems. We now are starting to understand the consequences that our personal use of these chemicals are having on our environment.

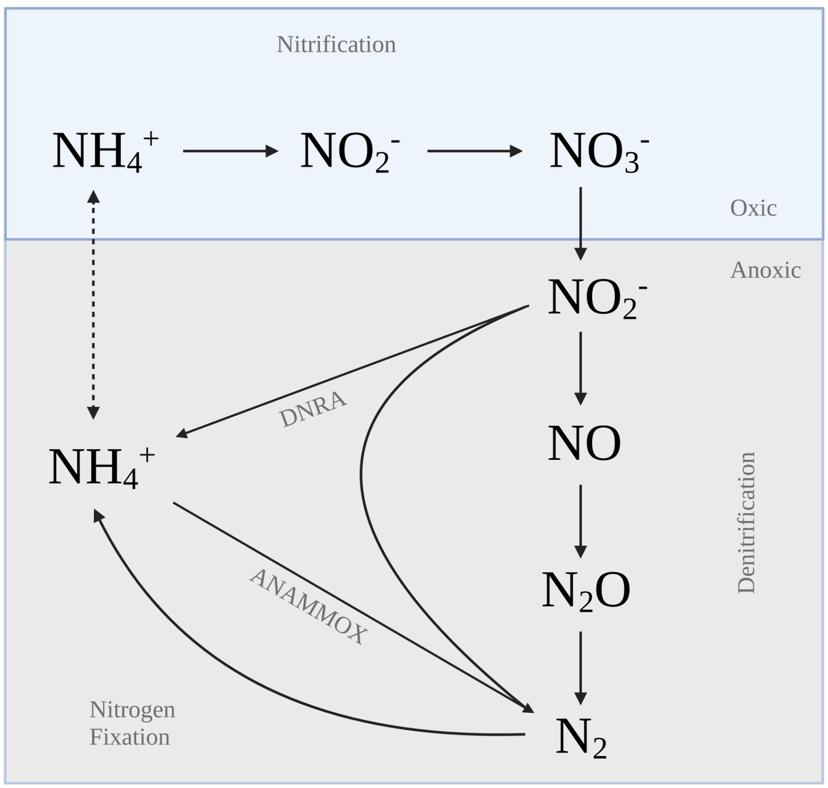
Conventional secondary treatment removes most organic material and small amounts of inorganic nutrients such as phosphorous and nitrogen. Removal of the remaining organic material, nutrients, and toxins may occur in a tertiary treatment stage. Tertiary treatment provides higher quality effluent and even allows the potential reuse of water. This reduces ecological impacts of nutrient pollution when effluent is released, especially in sensitive places including coral reefs. The additional processing and generation of cleaner effluent in tertiary treatment is not without limitations. The processing of nutrients and removal of remaining organic material and contaminants generates toxic waste that must be disposed of properly. Depending on the wastewater source and processing, waste generated in this stage may contain metals, chlorine, nutrients such as nitrogen, phosphorous, and microbes, leading to additional operation and disposal costs. It is for these reasons that tertiary treatment of wastewater, while common throughout Europe, is not yet widely implemented throughout the world.

Following conventional treatment of wastewater, prior to tertiary treatment, most of the phosphorous remains. Phosphorous is often the nutrient limiting algal growth in freshwater and some estuarine systems and when additional phosphorous is released into the environment, it can reduce water quality and contribute to eutrophication. Additional phosphorous removal or recovery can be achieved through chemical or biological processing. Chemical precipitation of phosphorous uses iron or aluminum to create insoluble forms of phosphorous, creating a metal-rich toxic sludge that requires proper disposal. Alternatively, phosphorous accumulating bacteria can be used to remove up to 90% of phosphorous without the generation of a toxic sludge. A series of anaerobic and aerobic phases are used to allow for microorganisms such as *Accumulibater phosphatis* and *Tetrasphaera* spp. to take up phosphorous and carbon under anaerobic conditions and use storages for growth in the presence of oxygen.



Biological phosphorous removal Created with BioRender.com.

The nitrogen that remains following secondary treatment can also be removed biologically through a series of reduction-oxidation (redox) reactions. This conventional transformation of reactive nitrogen (ammonium, nitrate and nitrite) to the largely biologically unavailable nitrogen gas takes place in stages. Autotrophic nitrifying bacteria and archaea convert ammonia into nitrite and nitrate. The oxidation of ammonia and nitrite occurs in two stages in the presence of oxygen by ammonia- and nitrite- oxidizing microbes. The subsequent anaerobic respiration of nitrate by heterotrophic denitrifying bacteria results in the complete removal of nitrogen, reducing the potential for excess nutrients to enter a natural system in wastewater effluent. Recently, an exciting newly discovered process in the nitrogen cycle, anaerobic ammonium oxidation (anammox), is gaining use for the removal of dissolved nitrogen in wastewater treatment plants.

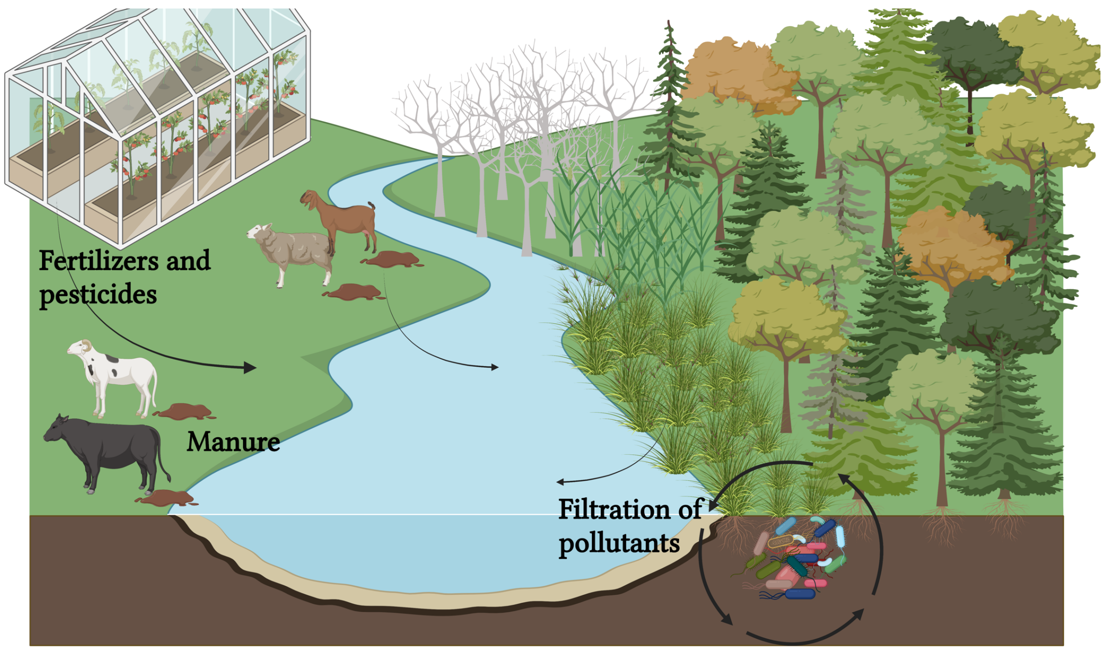


Biological nitrogen cycle. Created with BioRender.com.

4. ***Constructed wetlands provide an additional option for treatment of agricultural and municipal wastewater.*** Agricultural activities are often conducted adjacent to waterbodies where runoff containing contaminants such as fertilizers, pesticides, antimicrobial compounds, and pathogens, contributes to a significant portion of non-point source pollution. Nutrient pollution contributes to eutrophication and the degradation of coastal waterbodies, while other pollutants such as glyphosate and atrazine herbicides, as well as pyrethroid insecticides, have been shown to cause disruptions in aquatic microbial and invertebrate communities.

Constructed wetlands are artificial wetlands that harness the natural filtering process of plants and wetland vegetation, soils, and microbial communities to remove pollutants in runoff, improve water quality and even provide wildlife habitat. Living plants present within the system slow runoff and allow for chemicals to sorb or bind to sediments, where processing and removal may take place. Once slowed, contaminants in runoff may be removed through a variety of mechanisms which include volatilization, plant uptake, photodegradation, or biodegradation through microbial processing.

Chemicals subject to microbial processing include chlorinated compounds and polyaromatic hydrocarbons, persistent organic pollutants, that bind to the sediment matrix in constructed wetlands. Sediment type, the chemical contaminant, presence or absence of oxygen, flooding frequency, as well as the solubility of the secondary compounds, all influence the efficiency of the biodegradation process in these constructed wetlands.



Constructed or intact marshes and associated microbes filter pollutants generated by land use practices that would otherwise directly enter waterbodies. Created with BioRender.com.

5. ***Addressing the impacts of legacy pollutants and the "dirty dozen".*** Persistent organic pollutants (POPs) are chemicals that pose a threat to human health and ecosystems around the world (see above Table). POPs have been found to be useful in a wide variety of industrial applications including pesticides, herbicides, textiles, nonstick coatings, electrical conductance, and fire retardants. However, the characteristics that make POPs so useful in industry also allow these chemicals to remain in the environment for extended periods of time. POPs in the environment are transported globally through atmospheric and oceanic currents and accumulate in the environment as well as in lipid-rich tissues and proteins in humans and wildlife. According to the Stockholm Convention, POPs have been associated with allergies, cancer, damage to the central and peripheral nervous systems, immune system damage, and endocrine disruption. Endocrine disruption is alteration of the hormonal system by chemicals that mimic, interfere with, or block proper functioning of hormones. Disruption of hormonal balance in individuals may lead to harmful reproductive effects which can be passed on to offspring in humans and wildlife.

The fate and transport combined with the toxicity of POPs and their metabolites make them a global concern. The detection of POPs in remote regions such as the Arctic, where they have never been used or produced, led to the formation of the Stockholm Convention Persistent Organic Pollutants (Stockholm Convention Link) in 2001. The global treaty was enacted to protect human health and the environment from these persistent chemicals through the prohibition and elimination of POPs or restriction on the production and distribution of these chemicals based on their designations. POPs identified in the treaty as priority pollutants include polychlorinated biphenyl organochlorine pesticides, most notably dichlorodiphenyl, trichloroethane, DDT, and industrial chemicals including polychlorinated biphenyls (PCBs). Unintentional byproducts of industrial processes and combustion include polynuclear aromatic hydrocarbons (PAHs), and polychlorinated dibenzo-*p*-dioxins (PCDD) and dibenzofurans (PCDF), commonly referred to as 'dioxins'.

Once in the environment, accumulation in sediments, as well as bioaccumulation and biomagnification of POPs in the food chain present serious threats to top predator species, including humans. Exposure to POPS have been associated with adverse health and reproductive effects in wildlife species, with the effects of DDT and the decline of apex bird populations being one of the most well documented examples, made famous by Rachel Carlson in her book *Silent Spring*.

Microbial degradation of various POPs in soils and sediments has been observed under varying environmental conditions. The dechlorination of PCDD by dehalogenating bacteria has been shown to reduce the toxicity of chlorinated dibenzo-*p*-dioxins and other chlorinated dioxin-like compounds.

6. ***Water quality monitoring serves as a way to ensure safe water.*** We can use water quality monitoring and tests for specific indicators to ensure our water is safe and free from pollutants that may be too small to see with our unaided eye. Monitoring of pathogens and chemicals present in runoff or effluent produced by industry is imperative as many industrial operations take place on or near waters that support fisheries, recreation, and serve as a drinking water supply.

Tests for nutrients are standardized by regulatory agencies in most countries and heavy metal testing may be performed in waterbodies that serve as sources of drinking water. Tests also identify pathogenic microbes that may be present in drinking or recreational waters. Nutrient pollution is regulated to ensure that excess nutrients do not contribute to algal blooms in local waterbodies, that may lead to the creation of hypoxic and anoxic conditions with devastating consequences on aquatic life.

Heavy metals and POPs, present in agrochemicals, coal ash, and industrial waste, can enter drinking water supplies and private wells and lead to chronic disease or acute life-threatening health conditions. Consumption of contaminated fish can have acute or chronic toxic effects on humans. Filter feeders such oysters, clams and other shellfish harvested from polluted water may contain heavy metals, plastics, and pathogenic microbes responsible for shellfish poisoning. Apex predators such as tuna and swordfish may contain unsafe levels of mercury as a result of bioaccumulation of toxins with increasing trophic level.

7. ***Updating regulations may also serve as a way to ensure safe water.*** Widespread contamination of groundwater has been linked to storage of toxic material produced by industrial processes across the world. In many cases, storage or disposal of material predated regulations, which sometimes allows for these practices to continue, contributing to contamination of local environments. One example can be seen with the coal industry and storage of waste (Earth Justice Map of Contaminated US Sites). While the world begins to move away from the combustion of coal as an energy source, the coal ash legacy remains. Coal ash, fine and course material produced during the combustion of coal, contains arsenic, radium and other toxic materials. Traditionally, coal ash has been carted away from facilities to unlined pits, nearby. Spills and breaches of these containment areas have plagued local communities and threaten drinking water supply, but regulations are lacking to offer any solution. Arsenic, present in concentrations that far exceed US regulatory groundwater standards, have the potential to leak into nearby drinking water supplies and private wells across the country. Flooding and storm surges also pose a threat, as breaches in pits near local waters have resulted in the release of toxic material into waterways and major fish kills. Extreme weather events linked to global warming are likely to increase the frequency and severity of such events.

8. ***Planning for the future should consider global climate change and antibiotic resistance.*** The industrialization of livestock practices and fish production enables the production of food to support our growing human population. These operations consequently bring together large numbers of animals adjacent to communities, often of lower socioeconomic status, where they serve as a potential source for the emergence of zoonotic diseases. Agricultural practices in these concentrated animal feeding operations (CAFOs) also include the subtherapeutic use of antibiotics, extensive use of antibiotics to treat infections, and application manure as fertilizer in nearby fields, which have led to increased spread of antibiotic resistance among microbial communities within CAFOs and in the surrounding areas.

In addition to human health concerns, ecological consequences of industrial livestock operations continue to emerge. Runoff from large-scale operations may alter efficient cycling and removal of nutrients, further exacerbating the effects of eutrophication. Furthermore, increases in major storm events and frequency of flooding have highlighted the need for better planning in industrial livestock operations to consider improved waste management practices and reduction of pharmaceuticals present in the waste, protect water resources from nutrient runoff, prevent the spread of antibiotic resistance, and ensure the safety of surrounding communities.

9. ***Solving the industrial pollutants problem.*** It is now recognized that we need to use our ability through preventative measures to stop pollutants entering an ecosystem. Proper use and disposal of pharmaceuticals, efficient treatment of waste, and consumer demand for safer products result from knowledge of our pollution problems as well as our concern for our own impact on our environment and health.

Regular monitoring of pipes releasing treated effluent from domestic, commercial, industrial, and urban sources can determine the extent of a particular pollutant entering a system. Once the contaminant can be identified, measures can be taken to resolve the issue and eliminate the pollutant at the source.

Changes in the way we approach industrial waste are needed to build a sustainable future. The repurposing of waste material for methanogenic anaerobic digestion, biological hydrogen production, microbial fuel cells, and fermentation has the potential to produce valuable products and reduce the amount of toxic material introduced to our environment. As an example, methanogenic anaerobic digestion of organic material employs a series of steps mediated by microbes to convert complex organic matter into methane. The first two steps involve the initial hydrolysis of complex organic molecules and subsequent fermentation. Proteins, polysaccharides, and lipids are hydrolyzed into amino acids, sugars, and fatty acids. These monomers are then fermented to produce small organic acids such as propionate and butyrate as well as alcohols by fermentative bacteria. Next, acetogenic bacteria continue to oxidize acids and alcohols produced during fermentation to acetic acid, hydrogen, and carbon dioxide. Finally, methanogens convert the acetate to methane and carbon dioxide, which can then be used as a fuel source.

Relevance for Sustainable Development Goals and Grand Challenges

- **Goal 3. Ensure healthy lives and promote well-being for all at all ages** (*improve health, reduce preventable disease and premature deaths).* Human health and the health of our environment are intrinsically tied. In July 2022, the United Nations General Assembly declared "access to a clean, healthy and sustainable environment, a universal human right." Clean water, free of industrial and other pollutants, inherently falls within this universal human right. Understanding the role of microorganisms in both the contamination and purification of water as well as the limitations to the purification processes, particularly when it comes to POPs, PPCPs, and other industrial pollution, will reduce the prevalence of preventable diseases and premature deaths. Recognizing the connection between human health and a healthy environment will also better equip us with the right tools to find solutions to current and emerging water quality issues. Improved water quality contributes to a healthy environment and the overall well-being for all those reliant on the waterbody for everyday needs.
- **Goal 6. Ensure availability and sustainable management of water and sanitation for all** (*assure safe drinking water, improve water quality, reduce pollution, protect water-related ecosystems, improve water and sanitation management).* With our human population continuing to grow, more people will become increasingly dependent on safe water sources. The dependence on safe water is coupled with the continued emergence of new industrial pollutants. Hence, the value of understanding the role microorganisms play in our management and sanitation of our water becomes clear. The discovery of microbes that can remove contaminants, such as nutrients, during the wastewater treatment process provides a glimpse of the powerful potential of microbes to help maintain water quality and implement this on a global scale.
- **Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development** *(reduce pollution of marine systems by toxic chemicals/agricultural nutrients/wastes like plastics, develop mitigation measures for acidification, enhance sustainable use of oceans and their resources).* Just as human health is intimately linked to a clean environment, healthy marine ecosystems support diverse marine life that humans rely on for our survival. Oceans and the microorganisms that inhabit the water column provide

over half of the oxygen that we breathe (one in every two breaths is thanks to a microbe). Alternatively, pathogens from raw sewage, excess nutrients from agricultural runoff, and the accumulation of toxic chemicals and metals in our marine food web can have profound negative consequences on our health as we are reliant on healthy fisheries and oceans.

- **Goal 15**. **Land conservation.** Understanding the link between land and water will allow us to place a true value on the ecosystem services provided by properly functioning lands. Marshes comprised of (native) plants and their symbiotic microbes living at the interface of the land and water filter out pollutants before they enter waterbodies. Filtration and bioremediation capabilities of marshes are one example of services provided by the land to the water. Recognition of the critical role that watersheds play in the promotion of a healthy waterbody and true values placed on these services will support proper land conservation efforts.

Potential Implications for Decisions

1. ***Individual*** Consider your role as a consumer in supporting the production of products that contribute to the release of nutrients, POPs, PPCPs and MPs into the environment. Discuss how you as an individual might change your everyday habits to address the issue of legacy and emerging pollutants.

2. ***Community*** Research local community ordinances and regulations regarding runoff and the treatment of industrial wastewater and release of effluent into local waterways. Investigate policies that are currently in place to regulate wastewater effluent and runoff. Discuss how effective these policies are in protecting your local waterways from emerging pollutants and nutrient pollution. Determine whether these ordinances and regulations can be improved to address emerging pollutants and nutrient pollution. Collaborate with your local environmental commission or organization to develop community awareness on any issues that you may discover and work to find solutions for these issues.

3. ***National*** Explore existing national policies which regulate the treatment of industrial wastewater and discharge of effluent. Discuss how effective these national policies are in protecting your local waterways and whether these policies can be improved to address emerging pollutants. Contact you representatives at the national level to discuss your findings and potential solutions to address emerging pollutants on a national level.

Pupil participation

1. ***Class Discussions***

a. Discuss how your local WWTP processes waste and how regulations guide this process. Discuss the potential consequences of releasing raw sewage into your local stream or river. Discuss what might happen if your municipality only required primary treatment of wastewater. Discuss why it is beneficial that the heterotrophic microbes active in the secondary treatment stage form flocs. Discuss the ecological benefits of tertiary wastewater treatment.

b. Microorganisms possess the ability to degrade a variety of toxic chemicals and thus have the potential to clean up contaminants through bioremediation. However, little is known about the toxic effects of some of the byproducts that may accumulate during the bioremediation process. Discuss the concept that microorganisms may provide a solution to legacy and emerging pollutants and the need for continued research surrounding this concept. Discuss how this might influence the implementation of bioremediation projects depending on the contaminants.

2. Pupil Stakeholder Awareness.

a. Have a discussion about the PPCP's and MP's that are not processed during the traditional wastewater treatment process. What are the sources for these emerging pollutants? Can you identify three items in your house that contain chemicals that will not be processed during wastewater treatment. How do microorganisms process these chemicals? What byproducts may be created during these various metabolisms? How might this impact the environment and human health?

b. Environmental justice is defined as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (US EPA 2017). Discuss the role of environmental justice as it relates to industrial contaminants and the location of facilities, landfills, CAFOs, or discharge sites. Discuss the role that global treaties such as the Stockholm Convention play in the pursuit of environmental justice.

3. ***Exercises***

a. Rachel Carlson's "*Silent Spring*" book club. Read "*Silent Spring*" as a class and use the following questions to guide the class: What impressed you most about the book? What surprised you? What questions were raised after reading this book? What would you have done if you were in this position? How does this book allow you think about the environmental issues we face today? What can we do to draw attention to these issues?

b. *We are what we eat*. Explore the concept of bioaccumulation and biomagnification in the food chain. Humans are among the apex predators. What potential pollutants might we be eating? Consider legacy and emerging pollutants such as microplastics, PPCPs, POPs. Are these toxins entering our waters and foods through point or non-point sources, or both? What are the impacts on environmental and human health? What are the potential sources for these various pollutants? How can we monitor them? How might microorganisms be used to solve our pollution problem?

c. *Construct your own artificial wetland*. Identify an area on school property that might benefit from a constructed wetland or rain garden to capture and filter storm water runoff. Determine the best location and variety of plants that may be included to best treat the pollutants of concern. Discuss the microbial community that may be involved in the bioremediation of these pollutants before the pollutants have the opportunity to enter into the WWTP or environment.

Additional Activities

a. *Field trip*. Embark on a field trip to your local municipality wastewater treatment plant. Compare and contrast how your municipality's wastewater treatment facility operates with respect to the overview discussed in this framework.

The Evidence Base, Further Reading and Teaching Aids

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Glossary

activated sludge (noun): material that consists of sludge particles, teeming with living organisms, produced in either raw or settled wastewater by the growth of organisms (which include bacteria) in aeration tanks where dissolved oxygen is present
acute (adjective): having a sudden onset, sharp rise, and short course
agrochemical (noun): a substance used in agriculture, including chemical fertilizers, herbicides, and insecticides

algal blooms (noun): a rapid growth of microscopic algae or cyanobacteria in water, often resulting in a colored scum on the surface
anoxic (adjective): designating a process or environment in which oxygen is not involved or present
apex predators (noun): animals at the top of a food chain, not preyed upon by any other animal
aquatic (adjective): relating to water
archaea (noun): unicellular, prokaryotic organisms that make up one of three domains of organisms and consist of five described phyla: *Crenarchaeota*, *Euryarchaeota*, *Korarchaeota*, *Nanoarchaeota*, and *Thaumarchaeota*
arsenic (noun): the chemical element of atomic number 33, a brittle steel-gray metalloid
bacteria (noun): unicellular, prokaryotic organisms that make up one of three domains of organisms on earth and consist of 30 major phylogenetic lineages and thousands of described species
bioaccumulation (noun): the accumulation over time of a substance and especially a contaminant (such as a pesticide or heavy metal) in a living organism
biofilms (noun): assemblages of surface-attached, structured microbial communities containing sessile cells (bacteria and/or fungi) embedded in a self-produced extracellular matrix composed of polysaccharides, DNA, and other components
biomagnification (noun) the increased concentration of a toxic chemical the higher an animal is on the food chain
biomass (noun): the total mass of organisms in a given area or volume
byproducts (noun): incidental or secondary compounds made in the manufacture or synthesis of something else
carcinogenic (adjective): having the potential to cause cancer
chemicals (noun): any basic substance that is used in or produced by a reaction involving changes to atoms or molecules
chronic (adjective): persisting for a long time or constantly recurring
combined sewer overflows (noun): sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe
constructed wetlands (noun): a type of artificial wetland that harness the natural filtering process of plants and wetland vegetation, soils, and microbial consortia to improve water quality
contaminant (noun): a polluting or poisonous substance that makes something impure
discharge (verb): allow (a liquid, gas, or other substance) to flow out from where it has been confined
discharge (noun): products (liquid, gas, or other substance) that are released as waste from pipes
diverse (adjective): showing a great deal of variety; very different
domestic (adjective): relating to the running of a home
effluent (noun): liquid waste discharged into a river or the sea
emerging pollutants (noun): contaminants that are increasingly being detected in the environment and have the potential to impact human health and the environment, but are not yet widely regulated; also known as contaminants of emerging concern (CEC's)
eutrophication (noun): the increase in the rate of supply of organic matter to an ecosystem. Most commonly fueled by excess nutrients that supports an increase in primary productivity in estuaries and coastal systems

excreted (verb): separated and expelled
extracellular polymeric substances (noun): molecules having a range of sizes, compositions, and chemical properties that are produced and secreted by bacteria and other microorganisms, and contribute to the cell adaptability, resiliency, and functional roles in environments
fertilizers (noun): natural or artificial substances containing the chemical elements that improve growth and productiveness of plants
filamentous (adjective): composed of long, threadlike structures
filter feeders (noun): animals that feed or capture food by filtering out plankton or nutrients suspended in the water.
flocs (noun): a loosely clumped mass of fine particles
food web (noun): a system of interlocking and interdependent food chains
fungi (noun): eukaryotic organisms that make up the kingdom *Fungi* within the domain Eukarya
gas (noun): a fluid substance that has neither independent shape nor volume but tends to expand indefinitely; plural gasses
gray water (noun): wastewater that does not contain serious contaminants
grit chamber (noun): long narrow tanks that are designed to slow down the flow so that solids such as sand, coffee grounds, and eggshells will settle out of the water
growth rate (noun): the time it takes for single-cell organism to divide
heavy metals (noun): naturally occurring elements that have a high atomic weight and a density at least 5 times greater than that of water
homogeneous (Adjective): uniform structure or composition throughout
hypoxic (adjective): resulting from, causing, or experiencing inadequate levels of oxygen in the tissues and cells of the body
indicators (noun): organisms or ecological communities so strictly associated with particular environmental conditions that their presence is indicative of the existence of particular conditions
industrial (adjective): relating to or characterized by industry or the economic activity concerned with the processing of raw materials and manufacture of goods in factories
industrial waste (noun): material that is not wanted; the unusable remains or byproducts of something produced during the processing of raw materials and manufacture of goods in factories, that has undesired effects
industrial pollutant (noun): a substance, produced during the processing of raw materials and manufacture of goods in factories, that has undesired effects
infectious disease (noun): an illness or sickness caused by pathogenic microorganisms, such as bacteria, viruses, parasites or fungi
inoculum (noun): a biological substance or material being transferred
inorganic (adjective): of, relating to, or denoting compounds which are not derived from living organisms or do not contain carbon
insoluble (adjective): incapable of being dissolved
landfill (noun): a place to dispose of refuse and other waste material by burying it and covering it over with soil, especially as a method of filling in or extending usable land
legacy pollutants (noun): contaminants that are strongly associated with industrial processes (intentional and unintentional production) and remain in the environment long after their introduction, posing long-term effects and stress on human health and the environment

microscopic (adjective): too small to be seen by the unaided eye
microorganism (noun): a life form too small to be seen by the unaided human eye
microplastics (noun): plastic particles that measure less than five millimeters
nitrifying microorganisms (noun): organisms capable of carrying out the biological oxidation of ammonia to nitrite and nitrate
nutrients (noun): substances that provide nourishment essential for growth and the maintenance of life
nutrient pollution (noun): the process by which excess nutrients, mainly nitrogen and phosphorus, contaminate bodies of water causing challenging environmental problems
organic (adjective): of, relating to, or denoting compounds which are derived from living organisms or contain carbon compounds
organisms (noun): life forms
oxic (adjective): designating a process or environment in which oxygen is involved or present
pathogen (noun): a specific causative agent of disease
pathogenic (adjective): capable of causing disease
per- and polyfluoroalkyl substances (PFAS): chemicals that resist grease, oil, water, and heat that are used in many different products including stain- and water-resistant fabrics, cleaning products, paints, and fire-fighting foams.
persistent organic pollutants (noun): ubiquitous environmental contaminants that are not readily degraded in the environment
persistent synthetic polymers (noun): human-made substances composed of very large molecules that are multiples of simpler chemical units that are not readily degraded in the environment
personal care products (noun): items mainly used to improve the quality of daily life
pharmaceuticals (noun): prescription or over the counter therapeutic drugs used to prevent or treat human and animal diseases
phosphorous (noun): the chemical element of atomic number 15
point-source pollutant (noun): any contaminant that enters the environment from an easily identified and confined place
pollution (verb): the introduction of harmful materials into the air, land and water
pollutant (noun): something introduced into the environment that harmfully disrupts it
polycyclic aromatic hydrocarbons (PAH's; noun): a class of hydrocarbon molecules that have multiple carbon rings, and that include carcinogenic substances and environmental pollutants. PAH's occur naturally in coal, crude oil, and gasoline and are also are produced when coal, oil, gas, wood, garbage, and tobacco are burned.
polychlorinated biphenyls (PCB's; noun): any of several compounds that are produced by replacing hydrogen atoms in biphenyl with chlorine, have various industrial applications, and are toxic environmental pollutants which tend to accumulate in animal tissues
primary producers (noun): organisms capable of converting an abiotic source of energy (e.g. light) into energy stored in organic compounds
primary treatment stage (noun): the stage in wastewater treatment that removes material that will either float or readily settle out by gravity
protists (noun): single-celled eukaryotic organisms that make up the kingdom *Protista* within the domain Eukarya
purify (verb): remove contaminants from

reduction-oxidation (redox; noun): a type of chemical reaction that involves a transfer of electrons simultaneously between two species
regulate (verb): to control or maintain
remineralization (noun): the process by which organic matter is broken down or transformed into its simplest inorganic forms
remineralize (noun): the process by which organic matter is broken down or transformed into inorganic forms
renewable energy (noun): energy from sources that are naturally replenished
sanitation (noun): conditions relating to public health, especially the provision of clean drinking water and adequate sewage disposal
screened (verb): passed through
secondary treatment stage (noun): the second step in most wastewater treatment systems during which microorganisms consume the organic parts of the wastes
sedimentation tank (noun): a clarifier, component of a modern system of water supply or wastewater treatment
sewage (noun): wastewater and excrement conveyed in sewers
sludge (noun): thick, soft, wet mud or a similar viscous mixture of liquid and solid components, especially the product of an industrial or refining process
soluble (adjective): able to be dissolved
stormwater (noun): rainwater or melted snow that runs off streets, lawns and other sites
suspended solids (noun): small solid particles which remain in suspension in water and can be trapped by filter
tertiary treatment stage (noun): the advanced treatment process, following secondary treatment of wastewater, that includes removal of nutrients such as phosphorus and nitrogen and practically all suspended and organic matter from wastewater
trickling filter (noun): an artificial bed of broken rock or other coarse material through which sewage or industrial wastes trickle after being sprayed on intermittently so that organic matter present is oxidized and removed by biological growths formed on the surfaces of the rock
trophic level (noun): each of several hierarchical levels in an ecosystem, comprising organisms that share the same function in the food chain and the same nutritional relationship to the primary sources of energy
toxic (adjective): of, pertaining to, affected with, or caused by a poisonous substance
toxins (noun): biologically produced chemical substance that is capable of causing harm to cells or living organisms
waste (noun): material that is not wanted; the unusable remains or byproducts of something
wastewater (noun): water that has been used in the home, in a business, or as part of an industrial process
wastewater treatment plant (WWTP; noun): a facility in which a combination of various processes (e.g., physical, chemical and biological) are used to treat municipal and industrial wastewater and remove pollutants
water quality monitoring (noun) the sampling and analysis of water and physical, chemical, and biological characteristics conditions of the waterbody
waterbody (noun): any significant accumulation of water such as a river, lake or a bay

zoonotic disease (noun): any disease or infection that is naturally transmissible from vertebrate animals to humans; also referred to as zoonosis