

ANNEX 2: SUPPLEMENTARY REFERENCE MATERIALS



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Annex 2 provides supplementary reference materials that can be used for both Parts I and II of the Resource Guide, and includes the following reference materials:

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SECTION A: WASTEWATER TERMINOLOGY GLOSSARY

(For Health terminology see Section C.)

Term	Definition
Activated Sludge Process	A biological wastewater treatment process that speeds up the decomposition of wastes in the wastewater being treated. Activated sludge is added to wastewater and the mixture is aerated and agitated. After some time in the aeration tank, the activated sludge is allowed to settle out by sedimentation and is disposed of or reused as needed. The remaining wastewater then undergoes more treatment.
Aeration	Addition of air to water resulting in increased dissolved oxygen concentrations.
Aeration Tank	The tank where raw or settled wastewater is mixed with return sludge and aerated.
Aerobic Oxidation Condition	Relating to, involving, or requiring free oxygen for metabolic processes.
Algal Toxins	Organic molecules produced by a variety of algae either via Harmful Algal Blooms of phytoplankton or cyanobacteria that cause harm to organisms when present in large quantities in water.
Ammonia Nitrogen (mg/l)	Ammonia nitrogen (NH ₃ -N), is a pollutant often found in landfill leachate and in waste products, such as wastewater and treated wastewater effluent, liquid manure and other liquid organic waste products. In surface water bodies it can be toxic to some aquatic organisms under certain temperature and pH conditions.
Anaerobic Digester (Anaerobic Tank)	A wastewater solids treatment device in which the solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen.
Anaerobic Oxidation Condition	Not involving, or requiring free oxygen for metabolic processes of wastewater treatment.
Anoxic	Characterized by low or zero dissolved oxygen concentrations. Anoxic surface waters have dissolved oxygen concentrations of 0.5 mg/l or lower.
Biochemical Oxygen Demand (BOD)	The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. BOD can be used as a gauge of the effectiveness of wastewater treatment plants and the impact of their effluent discharges on receiving water bodies.
Biochemical Oxygen Demand 5 Day (BOD ₅)	A measure of the amount of oxygen required or consumed for the microbiological decomposition (oxidation) of organic material in water; measured as mg/l of oxygen consumed in 5 days at a constant temperature of 20°C in the dark. BOD ₅ is used to determine the level of organic pollution in a stream or lake.
Blackwater	Liquid and solid human body waste and the carriage water generated through toilet usage.
Centralized Wastewater System	A wastewater system that provide for most or all of a town's wastewater management needs, and that might be suitable for serving portions of neighboring towns.
Chemical Oxygen Demand (COD)	A measure of the oxygen-consuming capacity of organic matter present in wastewater. COD is expressed as the amount of oxygen consumed from a chemical oxidant in mg/L during a specific test.
Cluster Wastewater System	A wastewater system that can serve up to approximately 30 homes with aggregate wastewater flows of less than 10,000 gallons per day.
Coliform bacteria (Total and Faecal)	Coliform bacteria are a collection of relatively harmless micro-organisms that live in large numbers in the intestines of man and warm and cold-blooded animals. Both groups have widely been used as indicators of enteric (intestinal) bacterial

	pathogens. The total coliform group is not as specific an indicator of faecal contamination as faecal coliforms.
Constructed Wetland	An artificial wetland created for the purpose of treating anthropogenic discharge such as municipal or industrial wastewater or stormwater runoff.
Discharge	Subsurface irrigation, rapid infiltration, reuse, or discharge to surface water bodies.
Dissolved Organic Matter (DOM)	That portion of the organic matter in water that passes through a 0.45 µm pore-diameter filter.
Dissolved Oxygen (DO)(DO) (mg/l)	The level of free, non-compound oxygen present in water or other liquids. It is an important parameter in assessing water quality because of its influence on the organisms living within a body of water.
Domestic Wastewater	Wastewater from domestic sources including households, businesses (hotels, inns, restaurants), and public facilities.
Downstream	Water flow or site that is in the direction of the current and at a distance from the water or pollution source.
Ecosystem	An ecosystem is a community of living organisms in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system.
Ecosystem services	Benefits that humans obtain from ecosystems.
Effluent	Water or other liquid—raw (untreated), partially treated, or completely treated—flowing from a reservoir, basin, treatment process, or treatment plant.
Enteric Bacteria	Bacteria of the intestines; may refer to gut flora, which is always present and usually harmless. Pathogenic bacteria of bacterial gastroenteritis. The taxonomic family Enterobacteriaceae.
Enterococci (mg/l)	A subgroup of fecal streptococcal bacteria (mainly <i>Streptococcus faecalis</i> and <i>Streptococcus faecium</i>) found in the intestinal tracts and feces of warm-blooded animals. It is used as an indicator of the potential presence of pathogens.
Eutrophication	<p>The degradation of water quality due to enrichment by nutrients, primarily nitrogen (N) and phosphorus (P), which results in excessive plant (principally algae) growth and decay. When levels of N:P are about 7:1, algae will thrive. Low dissolved oxygen (DO) in the water is a common consequence.</p> <p>Degrees of Eutrophication typically range from Oligotrophic water (maximum transparency, minimum chlorophyll-<i>a</i>, minimum phosphorus) through Mesotrophic, Eutrophic, to Hypereutrophic water (minimum transparency, maximum chlorophyll-<i>a</i>, maximum phosphorus).</p>
Flow	The movement of water. Flow is usually expressed as the rate at which water moves through a cross-sectional area. Common units of expression include cubic meters per day, million gallons per day, and cubic feet per second unit time.
Greywater	Wastewater other than sewage, such as from household sink, bathtub or washing machine drainage.
Groundwater	Subsurface water in the saturation zone from which wells and springs are fed. In a strict sense the term applies only to water below the water table.
Harmful Algal Bloom (HAB)	A proliferation of algae, or phytoplankton. Severe blooms of even non-toxic algae can spell disaster for cultured animals, because blooms deplete the oxygen in the shallow waters of many marine and freshwater systems.

Individual On-Lot Systems	Wastewater systems that can serve a single property and are located on the property where the wastewater is generated.
Membrane Bioreactor (MBR)	A wastewater treatment process that uses a suspended growth bioreactor (typically found in activated sludge treatment processes) coupled with a membrane filtration process like microfiltration or ultrafiltration.
Nonpoint Source	A runoff or discharge from a field or similar source, in contrast to a point source, which refers to a discharge that comes out the end of a pipe or other clearly identifiable conveyance.
On-site system	A system relying on natural processes and/or mechanical components that is used to collect, treat, and disperse/discharge wastewater from single dwellings or buildings.
Outfall	The point, location, or structure where wastewater or drainage discharges from a sewer, drain, or other conduit area.
Parts Per Million (PPM)	A measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/L), which is the preferred term.
Phytoplankton	Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.
Pit latrines	A type of toilet that collects human feces in a hole in the ground. Pit latrine designs range from simple unimproved pit latrines, through Ventilated Improved Pit latrines (VIPs) to alternating twin pit systems. A VIP is a pit latrine with a pipe fitted to the pit and a screen at the top outlet of the pipe. In a twin pit system, the second pit is only used when the first pit is filled. The first pit is left sealed for a year or more before emptying during which time disease-causing organisms are destroyed by natural processes. After such storage, without the addition of fresh wastes, the contents become safe to handle, and may be used as compost.
Point Source	A discharge that comes out the end of a pipe or other clearly identifiable conveyance. Examples of point source conveyances from which pollutants may be discharged include: ditches, channels, tunnels, conduits, wells, and landfill leachate collection systems.
Pollutant	Any substance that causes an impairment (reduction) of water quality to a degree that has an adverse effect on any beneficial use of the water.
Potable Water	Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.
Primary Treatment	Removal of solid material from wastewater through mechanical screening or settling. Primary treatment removes floating and suspended solids, which comprise about 30-35% of pollutants
Receiving Water	A stream, river, lake, ocean, or other surface or groundwater into which treated or untreated wastewater is discharged.
Rotating Biological Contactors	A compact secondary treatment process that can be used following solids removal. Clarified wastewater enters a tank where a series of closely-spaced and partially-submerged vertical discs with attached microorganism populations are rotated in the wastewater. The microorganisms consume organic matter in the sewage.
Runoff	That part of rain or other precipitation that runs off the surface of a drainage area and does not enter the soil or the sewer system as inflow.
Satellite System	A system that can serve from 30 to 1,000 homes (or wastewater flows between 10,000 and 300,000 gallons per day), intended to treat and dispose of wastewater from one area of a town. Also known as community or cluster system.
Secondary Treatment	A biological process for removing biodegradable organic matter from wastewater. It follows a primary treatment step of removing settleable solids and floating materials. In the secondary process, growing populations of microorganisms metabolize biodegradable organic matter to carbon dioxide and water. Secondary

	treatment can remove up to 65 percent of the BOD and suspended solids in the wastewater.
Sedimentation	The process of settling and removing suspended matter from the wastewater. Also known as clarification.
Septic Tank	A settling tank in which solids in the incoming flow settle to the bottom of the tank and the remaining liquid portion exits the tank and typically enters an external subsurface drain system that releases the flow into the soil where it receives natural treatment as it moves downward to the water table. Septic tanks must be pumped out on a regular basis to remove the settled solids or they will cease to function properly.
Sewage	Domestic sewage is used household water from toilets, sinks, and washing machines that is discharged to sewers and conveyed to wastewater treatment plants. Industrial sewage is wastewater discharged to sewers from industrial sources.
Sewerage	A collective term for systems that collect, convey, and treat wastewater or stormwater runoff. They are comprised of collection sewers, large interceptor sewer, pumping stations (if needed) and treatment works.
Sludge	<p>Solid matter that settles to the bottom of sedimentation tanks in a sewage treatment plant and must be disposed of by digestion or other methods or recycled on land.</p> <p>Activated sludge is mainly the mass of the biological organisms that provide the secondary treatment by metabolizing organic matter in the wastewater. Given their excess food supply, these populations grow rapidly and their excess mass must be removed on a continuous basis (waste activated sludge). The wasted sludge typically is then dewatered and or dried, and stabilized by various methods to reduce pathogens and odors. When properly treated, sludge can be re-used in several beneficial ways including energy production, phosphorus recovery, and as a soil amendment. Known as biosolids in the United States.</p>
Soakaway	Also known as a soak pit. A covered underground chamber that allows water to slowly percolate into the ground. It can be used to provide partial treatment for grey water (water from sinks or washing machines) or stormwater. Blackwater (sewage) must first undergo primary treatment before discharge to a soakaway. Siting of soak pits requires proper soil and depth-to-ground water conditions.
Storm Sewer	A pipe, conduit, or open channel that carries runoff from storms, surface drainage, and street wash, but does not include domestic and industrial wastes.
Surface Runoff	The water that reaches a stream by traveling over the land surface or falls directly into the stream channels, including not only the large permanent streams but also the tiny rills and rivulets.
Suspended Solids, Total Suspended Solids	Small solid particles in colloidal suspension in water. The particles can be from a variety of sources including slit, sediment, algae, plankton, and other organic matter. Total suspended Solids (TSS) is closely associated with turbidity and water clarity is a standard measure of water quality in surface waters. Particles below 2 microns in size are considered dissolved and are not included in TSS.
Tertiary Treatment	Tertiary treatment is any treatment beyond secondary. It can include additional BOD and TSS removal and nitrogen and phosphorus removal.
Total Nitrogen (mg/l)	The total nitrogen concentration in a water sample. It is the sum of organic nitrogen, ammonia-nitrogen, and nitrates-nitrites, which all must be measured separately. Nitrogen is a key nutrient for algae, especially in marine waters and can be a major cause of eutrophication.

Total Phosphorus (mg/l)	The total phosphorus in a water sample. It is the sum of dissolved and particulate phosphorus. Like nitrogen, it is a key nutrient for algae, especially in fresh waters and can be a major cause of eutrophication.
Trickling Filter	A fixed-bed biological treatment system in which pre-settled wastewater is continuously sprayed on the surface of a filter medium. A biofilm of microscopic organisms forms on the filter media and aerobically degrades organic material in the wastewater as it slowly moves downward through the media.
Turbidity (Nephelometric Turbidity units or NTU)	Turbidity is a measure of water clarity, or how much the material suspended in water decreases the passage of light through the water. Turbidity is caused by suspended materials such as clay, silt, sand, algae, plankton, microbes, and other substances. Turbidity can also affect the color of the water. Higher turbidity has multiple adverse impacts on a water body. It increases water temperatures because suspended particles absorb more heat, which in turn reduces the concentration of dissolved oxygen. It reduces the amount of light penetrating the water, reducing photosynthesis oxygen production.
Upstream	The direction against the flow of water; or, toward or in the higher part of a river or sewer collection system.
Waste Stabilization Pond / Wastewater Lagoon	Natural or man-made lagoons used to treat domestic wastewater in which organic matter is decomposed by natural processes, and algae. Lagoons can be un aerated (known as facultative lagoons) or mechanically aerated. Ponds can be used individually, or linked in a series for improved treatment. Also known as Waste Stabilization Ponds.
Wastewater	A community's water that has been for various purposes such as toilet flushing or washing and then discharged, or wastewater discharged from an industrial source.
Wastewater catchment	The wastewater area draining to a point of interest, such as monitoring site or other watercourse (stream, wetlands, etc.).
Wastewater Collection System	The pipe system for collecting and carrying water and water-carried wastes from domestic and industrial sources to a wastewater treatment plant.
Wastewater Treatment	Biological, mechanical and/or chemical processes used to remove pollutants from wastewater in order to make it suitable for discharge to surface waters or reuse. It includes primary, secondary, and tertiary treatment.
Wastewater Treatment Plant	A facility and its associated processes of treating wastewater and generating effluent of a suitable quality.
Water catchment area	The geographical area drained by a river or stream or river. Also known as watershed or basin.
Water Table	The upper surface of the zone of saturation of groundwater in an unconfined aquifer.
Watershed	The geographical area drained by a river or stream or river. Also known as water catchment area or basin.

This glossary draws from glossaries and other resources available on the websites of the following organizations, networks and projects (Accessed between June 2015 and August 2015):

- American Rivers: <http://www.americanrivers.org/green-infrastructure-training/2013/08/27/example-gray-infrastructure-wastewater-and-pollution/>
- Australian Government, Australian Water Information Dictionary: <http://www.bom.gov.au/water/awid/>

- U.S. Environmental Protection Agency, 2002. Onsite Wastewater Treatment Systems Manual Systems Manual Systems Manual Wastewater Treatment Systems Manual. Office of Water Office of Research and Development U.S. Environmental Protection Agency:
http://water.epa.gov/aboutow/owm/upload/2004_07_07_septics_septic_2002_osdm_all.pdf
- MIT, Water and Sanitation:
<http://web.mit.edu/urbanupgrading/waterandsanitation/resources/definitions.html>
- Sacramento State, Office of Water Programs, Glossary of Water and Wastewater Terms:
<http://www.owp.csus.edu/glossary/index.php>
- Texas Commission on Environmental Quality, Glossary for Surface Water Quality:
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- UNEP, Water Quality for Human and Ecosystem Health, 2008 United Nations Environment Programme Global Environment Monitoring System/Water Programme.
http://www.unwater.org/wwd10/downloads/water_quality_human_health.pdf (Accessed July 17 2015)
- World Health Organization, 2006, Guidelines for the Safe Use of Wastewater, Excreta and Greywater. http://www.who.int/water_sanitation_health/wastewater/gsuweg3/en/ (Accessed August 7 2015)
- Winnipeg, Glossary of Wastewater Terms:
<http://winnipeg.ca/waterandwaste/pdfs/sewage/projects/glossary.pdf>

SECTION B: ECOSYSTEM IMPACTS FROM EXPOSURE TO WASTEWATER POLLUTION

This Section provides an overview of how ecosystems may be impacted by pollutants found within domestic wastewater, and an overview of recent studies that have estimated these impacts. In general, wastewater pollution enters ecosystems either directly or indirectly via untreated wastewater effluent, partially treated wastewater effluent or sludge. Secondary wastewater treatment does not always remove nutrients sufficiently (Lapointe et al. 2010).

Domestic wastewater pollution effluent and sludge is known to carry a variety of pollutants that directly and indirectly impact ecosystem health, including pathogens, nutrients, sediment, heavy elements, toxic chemicals, pharmaceuticals, and other organic and inorganic substances (e.g., faecal matter). Nutrient pollution (primarily nitrogen and phosphorus) is a concern for freshwater and coastal ecosystems as it can deplete water bodies of oxygen (i.e., eutrophication), result in algal blooms, can lead to the release of hydrogen sulphide and ammonia, which are toxic to some organisms. Excess nutrients can lead to enhanced plant growth which can alter ecosystem function and structure. Sediment and other suspended solids can smother ecosystems and deprive of light need for photosynthesis and growth. Sewage sludge is another concern as it can decrease species biodiversity and increase heavy metal concentrations in soils and plants. Pathogens can be transferred to marine and freshwater species from bacteria like *salmonella* (Islam and Tanaka 2004).

By negatively impacting ecosystem health, wastewater pollution also impacts the ecosystem services provided by ecosystems including fish production, shoreline protection, tourism, and recreation. The following table gives examples of studies estimating impacts of wastewater pollution on relevant ecosystems.

Table 1: Examples of studies of the impacts of domestic wastewater contamination in coastal, freshwater and land-based ecosystems

Ecosystem	Wastewater Contaminant (s) of Concern	Ecosystem Impact(s)	Study location	Reference
Coastal Ecosystems				
Coral Reefs	Nutrients	Eutrophication; Macro-Algae overgrowth; Low dissolved oxygen content; Coral die-off; Beach Erosion; Habitat Loss	Caribbean	DeGeorges et al., 2010
	Nutrients and suspended particles	Increased macroalgal density; Lower cover of hard corals; Decline in fish abundance	Thailand	Reopanichkul et al. 2009
	Nutrients	Higher macroalgal biomass; Blooms of chlorophytes overgrowing reefs in the Buccoo Reef complex; Turtle grass invasion of the Nylon Pool area	Tobago	Lapointe et al. 2010
	Nutrients	Decrease in live coral cover, species richness, and juvenile coral density.	China	Huang et al. 2013

Mangroves	Nutrients	Changes in biodiversity for peri-urban mangroves receiving sewage (increase in crab biomass and decrease in gastropod abundance)	Kenya and Mozambique	Cannicci et. al. 2009
Seagrasses	Ammonium and nutrients	Higher biomass due to nutrient enrichment; Decreased biomass due to ammonium enrichment; Change in population structure	Portugal	Cabaço et. al. 2008
	Nutrients	Reduced rhizome growth rates	United States	Lapointe et. al. 1994
Estuaries	Nutrients	Decreased biodiversity; Increased dominance of opportunistic species	General	Alve 1995
	Nutrients	Decrease in net photosynthetic capacity	United States	Driscoll 2003
Terrestrial Ecosystems				
Heathlands	Nutrients	Shift in the species composition and diversity of the ecosystem; Effects on soil chemistry	Netherlands	Smith et al. 1999
Prairies			United States	
Grasslands				
Agriculture	Heavy metals	Soil and plant contamination with heavy metals due to wastewater irrigation	India	Sharma et al. 2007
Freshwater Bodies				
Lakes and Rivers	Nutrients	Eutrophication; Algal Blooms;	China	Le et. al 2010
	Pharmaceuticals	Biodiversity Loss; Reduced algal biomass production; Proliferation of antibiotic resistant bacteria.	General	Kim 2007
	Nutrients	Shift towards dominance of cyanobacteria which produce toxic compounds harmful to aquatic lake life;	General	Smith et al. 1999
	Inorganic suspended solids	Restriction of light penetration and limitation of growth of benthic and suspended algae in rivers.		

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Alve, E., 1995. Benthic Foraminiferal Responses to Estuarine Pollution: A Review. *Journal of Foraminiferal Research*. Vol. 25 (3): 190-203.

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Cannicci, S., Bartolini, F., Dahdouh-Guebas, F., Fratini, S., Litulo, C., Macia, A., Mrabu, E.J., Penha-Lopes, G., Paula, J., 2009. Effects of urban wastewater on crab and mollusc assemblages in equatorial and subtropical mangroves of East Africa. *Estuarine, Coastal and Shelf Science*. Vol. 84 (3): 305–317.

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Kim, S., Aga, D. S., 2007. Potential Ecological and Human Health Impacts of Antibiotics and Antibiotic-Resistant Bacteria from Wastewater Treatment Plants. *Journal of Toxicology and Environmental Health, Part B: Critical Reviews*. Vol. 10 (8).

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Le, C., Zha, Y., Li, Y., Sun, D., Lu, H., Yin, B., 2010. Eutrophication of Lake Waters in China: Cost, Causes, and Control Environmental Management. Vol. 45 (4): 662-668.

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Sharmaa, R.K., Agrawala, M., Marshallb, F., 2007. Heavy Metal Contamination of Soil and Vegetables in Suburban Areas of Varanasi, India. *Ecotoxicology and Environmental Safety*. Vol. 66 (2): 258–266.

Smith, V.H., Tilmanb, G.D., Nekolac, J.C., 1999. Eutrophication: Impacts of Excess Nutrient Inputs on Freshwater, Marine, and Terrestrial Ecosystems. *Environmental Pollution*. Vol. 100 (1–3): 179–196.

SECTION C: HUMAN HEALTH RISKS FROM EXPOSURE TO WASTEWATER POLLUTION

This section provides an overview of common human health risks related to exposure to untreated and improperly treated domestic wastewater release into fresh and coastal water bodies. These health risks are extensively documented and well understood. There are five main pathways of exposure: consumption of fish and shellfish from contaminated waters; bathing or swimming in contaminated waters; inhalation of contaminated waters; in the case of infectious diseases, direct contact with an infectious person; and mosquito bites.

Health issues related to consumption of fish and shellfish include:

- Amnesic Shellfish Poisoning
- Azaspiracid Shellfish Poisoning
- Ciguatera Fish Poisoning
- Diarrheic Shellfish Poisoning
- Neurotoxic Shellfish Poisoning
- Paralytic Shellfish Poisoning

Health issues related to contact with contaminated water through swimming or bathing include:

- Acute Febrile Respiratory Illness
- Acute Respiratory Disease
- Cryptosporidium
- Cyanobacteria
- E. Coli Food Poisoning
- Otitis external ("swimmers ear")
- Eye, ear, and skin infections
- Febrile Respiratory Illness
- Gastroenteritis
- Staphylococcus aureus

Health issues related to inhalation of the water vapors of contaminated wastewater:

- Acute Febrile Respiratory Illness
- Acute Respiratory Disease

Infectious diseases:

- Cholera
- Hepatitis A
- Typhoid

Human health issues associated with mosquito bites include:

- Encephalitis

Table 2: Common human health risks associated with untreated and improperly treated domestic wastewater

Health Risk	Symptoms	Pathways	Cause	Source
Acute Febrile Respiratory Illness	Fever, dry cough and/or sore throat, respiratory congestion, chills, headache, myalgia, malaise and sometimes additional gastrointestinal issues	Bathing or Inhalation	Bacteria or virus	Fleisher et al. 1996; Fleisher et al. 2010
Acute Respiratory Disease	Difficulty breathing, rapid breathing or shortness of breath, low blood pressure, organ failure	Bathing or Inhalation	Virus	Dwight et al. 2005; McCann et al. 2011
Amnesic Shellfish Poisoning	Nausea, vomiting, diarrhea, dizziness, disorientation, lethargy, seizures, permanent loss of short-term memory, acute respiratory distress may be fatal within minutes to hours, debilitating chronic neurologic symptoms lasting months to years	Consumption of Shellfish	Diatom (algae)	Fleming et al. 2006; Van Dolah 2000
Azaspiracid Shellfish Poisoning	Nausea, vomiting, severe diarrhea, stomach cramps	Consumption of Shellfish	Azaspiracid (nitrogen-containing toxin)	Fleming et al. 2006
Cholera	Watery diarrhea, vomiting, abdominal cramps, in extreme cases can cause premature labor and fetal death	Bathing and consumption of fish	Bacteria	Fleming et al. 2006; McCann et al. 2011

Health Risk	Symptoms	Pathways	Cause	Source
Ciguatera Fish Poisoning	Nausea, vomiting, diarrhea, numbness of the perioral area and extremities, reversal of temperature sensation, muscle and joint aches, headache, itching, tachycardia, hypertension, blurred vision, paralysis, acute respiratory distress may be fatal within minutes to hours, debilitating chronic neurologic symptoms lasting months to years	Consumption of Fish	Dinoflagellates (such as <i>Gambierdiscus toxicus</i> , that adhere to coral, algae and seaweed)	Fleming et al. 2006; Van Dolah 2000
Cryptosporidiosis	Diarrhea, stomach cramps or pain, dehydration, nausea, vomiting, fever, weight loss	Bathing	Parasite (<i>Cryptosporidium</i>)	DiGiovanni et al. 2006; Fleming et al. 2006
Cyanobacteria poisoning	Skin irritation, stomach cramps, vomiting, nausea, diarrhea, fever, sore throat, headache, muscle and joint pain, asthma, eye irritation, rashes, blisters of the mouth and nose, liver damage	Bathing	Bacteria (Blue-green algae)	Boehm et al. 2009
Diarrheic Shellfish Poisoning	Vomiting and diarrhea	Consumption of Shellfish	Okadaic acid (biotoxin)	Fleming et al. 2006; Van Dolah 2000
E. Coli Food Poisoning	Diarrhea, urinary tract infections, neonatal meningitis	Consumption of contaminated food or water	Bacteria	Boehm et al. 2009; Mazari-Hiriart et al. 2008; Rabinovici et al. 2004
Ear infections	Congestion and swelling of the nasal passages, throat and Eustachian tubes	Bathing	Bacteria or virus	Dwight et al. 2005; Fleisher et al. 1996; Fleming et al. 2006
Encephalitis	Most people exhibit no symptoms but in cases of severe infections, symptoms include high fever with head and body aches, stiff neck,	Mosquito bites	Virus	Indiana State Department of Health 2015

Health Risk	Symptoms	Pathways	Cause	Source
	muscle weakness, disorientation, tremors, convulsions and, in the most severe cases, coma or paralysis			
Eye infections	Inflammation	Bathing	Bacteria, virus or parasite	Boehm et al. 2009; Dwight et al. 2005; Fleisher et al. 1996; Fleming et al. 2006
Febrile Respiratory Illness	Cough or shortness of breath, fever or chills	Bathing	Bacteria or virus	Fleming et al. 2006
Gastroenteritis	Diarrhea, itchy skin, fever, lack of energy, loss of appetite	Bathing	Typically a virus (e.g. rotavirus or norovirus), but can also be bacteria (e.g. E. coli or salmonella)	Alexander et al. 1992; Dwight et al. 2005; Fleisher et al. 1993; Fleisher et al. 2010; Fleming et al. 2006; Given et al. 2006; Rheingans et al. 2009
Giardiasis	Violent diarrhea, excess gas, stomach or abdominal cramps, upset stomach, nauseas	Bathing and consumption of fish	Protozoan parasites	DiGiovanni et al. 2006; McCann et al. 2011
Hepatitis A	Jaundice, fatigue, abdominal pain, loss of appetite, nausea, diarrhea, and fever.	Consumption of contaminated food and water; Direct contact with an infectious person	Virus	Indiana State Department of Health 2015; World Health Organization 2015a
Neurotoxic Shellfish Poisoning	Nausea, tingling and numbness of the perioral area, loss of motor control, severe muscular ache, seizures, unconsciousness	Consumption of shellfish	Brevetoxins	Fleming et al. 2006; Van Dolah 2000
Otitis external ("swimmers ear")	Inflammation of the outer ear canal	Bathing	Bacteria (commonly caused by streptococcus, staphylococcus or pseudomonas)	Boehm et al. 2009

Health Risk	Symptoms	Pathways	Cause	Source
Paralytic Shellfish Poisoning	Tingling and numbness of the perioral area and extremities, loss of motor control, drowsiness, incoherence, respiratory paralysis, acute respiratory distress may be fatal within minutes to hours	Consumption of shellfish	Saxitoxins	Fleming et al. 2006; Van Dolah 2000
Poliomyelitis (Polio)	Sore throat, fever, nausea, vomiting, abdominal pain, constipation, and occasionally diarrhea	Consumption of food or water from contaminated waters; Contact with an infectious person	Virus	Center for Disease Control 2015
Salmonellosis	Diarrhea, abdominal cramps, vomiting, headache, body aches, fever	Consumption of food carrying feces; Consumption of contaminated water	Bacteria	Indiana State Department of Health 2015; Mazari-Hiriart et al. 2008
Skin irritation	Skin rash, ulcers or sores	Bathing	Bacteria	Boehm et al. 2009; Dwight et al. 2005; Fleming et al. 2006; Fleisher et al. 2010
Staphylococcus aureus	Skin infections, respiratory disease, food poisoning	Bathing	Bacteria	Boehm et al. 2009
Typhoid and Paratyphoid fever	Sustained high fever, malaise, anorexia, headache, constipation or diarrhoea, rose-coloured spots on the chest area and enlarged spleen and liver	Water consumption; eating or drinking beverages handled by someone with typhoid.	Bacteria	WHO 2015b

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SECTION D: COMPARISON OF WASTEWATER TREATMENT TECHNOLOGIES APPLICABLE FOR THE CARIBBEAN

Table 3 compares wastewater treatment technologies commonly found in the Caribbean region by a number of factors (described below). This table is designed to provide economic valuation practitioners with a general sense of how technologies compare to one another in terms of wastewater technology design, costs, and externalities like odor that may be useful for completing the Characterization Form for a study site.

Table 3: Wastewater Infrastructure Comparison by Treatment Technology/Design

Treatment technology	Oxidation conditions	Treatment level	BOD removal efficiency	Nutrient removal efficiency	Coliform removal efficiency	System Type	Odor nuisance	Land requirement	Investment cost	Operational complexity	Operating and maintenance Cost
Conventional/Intensive systems											
Activated Sludge	Aerobic	Secondary	>90%	Organic waste, Some Nitrogen and Phosphorus	90-98%	Centralized	None	Low	High	Complex	Medium
Membrane Bioreactor	Aerobic	Secondary and Tertiary	96-99%	Organic Waste, Some Nitrogen and Phosphorus	90%	Centralized or Satellite	None	Low	High	Complex	High
Aerated Lagoon	Aerobic	Secondary	up to 95%	Incidental	60-99%	Centralized	Can be considerable	Low-Medium	Low-Medium	Moderate	Medium
Rotating Biological Contactor	Aerobic	Secondary	94.20%	Incidental	High	Centralized or Satellite	Can be considerable	Low	High	Complex	High
Trickling Filters	Aerobic	Secondary	80-90%	Incidental	90-95%	Centralized or Satellite	Can be considerable	Medium (requires 4x amount of land as activated sludge)	High	Simple	Low
Non-conventional /Extensive systems											
Constructed Wetlands	Aerobic and anaerobic	Secondary	50-90%	30-90% N 20-50% P	80-99%	Cluster, Satellite, Centralized	None	High	Low	Simple	Low
Waste Stabilization Ponds	Aerobic and anaerobic	Primary and Secondary	>50%	Organic Waste, (passive Nitrogen and Phosphorus)	90-99%	Centralized	Some potential	High	Low-Medium	Simple	Low
On-site systems											

Treatment technology	Oxidation conditions	Treatment level	BOD removal efficiency	Nutrient removal efficiency	Coliform removal efficiency	System Type	Odor nuisance	Land requirement	Investment cost	Operational complexity	Operating and maintenance Cost
Pit Latrines	Aerobic and Anaerobic Zones	Primary	Organic Waste	Does not remove nutrients	N/A	Individual; On-lot	Can be considerable	Low	Low	Simple	Low
Soakaway	Aerobic	Primary and Secondary	Organic Waste	Does not remove nutrients	N/A	Individual; On-lot	Can be considerable	Low	Low	Simple	Low
Septic tanks	Anaerobic	Primary and Secondary	Organic Waste	Good phosphorus removal	N/A	Individual; On-lot	Moderate	Low	Low	Simple	Low

Brief overview of comparison factors (*terms underlined are defined in the Glossary*):

- **Oxidation Conditions:** Oxidation conditions can be either aerobic anoxic, or anaerobic for metabolic processes of wastewater treatment.
- **Treatment Level:** There are three levels of wastewater treatment generally used in the Caribbean: primary, secondary, and tertiary.
- **Biochemical Oxygen Demand (BOD) Removal Efficiency:** Efficiency of a treatment technology in the removal of BOD.
- **Nutrient Removal Efficiency:** Efficiency of a treatment technology in the removal of nutrients from wastewater, most significantly organic waste, nitrogen, and phosphorus.
- **Coliform Removal Efficiency:** Efficiency of treatment technology in the removal of coliforms from wastewater.
- **System Type:** Refers to the gallons per day that can be treated and the applicable geographical area. Classified by Bedford et al. 2015 as:
 - Individual on-lot systems
 - Cluster systems
 - Satellite systems
 - Centralized systems
- **Odor Nuisance:** The degree to which mal odor associated with domestic wastewater is present near or around an application of a given treatment technology.
- **Land Requirement:** Scale of High, Medium to Low based on land requirements needed to create functioning treatment technology relative to other treatment technologies listed.
- **Investment Cost:** Scale of High, Medium to Low based on required investments to create functioning treatment technology relative to other treatment technologies listed.
- **Operational complexity:** Scale of Complex, Moderate to Simple based on level of complexity and skill required to operate and maintain treatment technology.

- **Operating and Maintenance Cost:** Scale of High, Medium to Low based on costs required to operate and maintain treatment technology relative to other treatment technologies listed.

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