Unit Title: Where does the sewage go?
Subject/target grade: Biology 9

Unit Summary:

This unit is a combination of water quality and water treatment lessons, with the intention of teaching students about assessing water quality and how to improve water quality by wastewater treatment. In the first lesson, students will explore basic ideas concerning water quality and wastewater. They will define several water quality parameters as well as wastewater and its importance with respect to the water cycle, its impact on water quality, and its relation to drinking water. Conventional wastewater treatment options will be discussed. In the second lesson, centralized sewage treatment will be discussed in an inquiry-based manner, allowing students to develop ideas on how and in which order different contaminants are removed in a wastewater treatment plant. A KWL (know, want to know, learn) activity will stimulate student thinking. At the beginning of the lesson, students will write down what they know about wastewater treatment (WWT) and what they would like to know. The teacher will use a PowerPoint presentation and interactive online modules to discuss the components of sewage and processes to remove pollutants follows. At the end of the lesson, students will summarize what they learned. Here, a field trip to the local wastewater treatment plant will allow students to gain an impression and a better understanding of how the processes they learned about are implemented in reality. The third lesson will focus on other means to treat wastewater (e.g., in a rural community with limited means to implement a centralized wastewater treatment system). The ideas of composting human waste and the use of constructed wetlands for wastewater treatment will be introduced. If accessible, students will read one chapter of the *Humanure Handbook* by Joseph Jenkins and summarize and reflect on their reading in a 1-page writing assignment. Findings and ideas will be shared in class. In the final lesson, there will be a discussion about emerging water pollutants such as microplastics and pharmaceuticals and personal care products (PPCPs). Students will complete a final project in which they will choose and research an emerging pollutant and a solution for managing them. Alternatively, they may choose a non-conventional treatment method (e.g., constructed wetlands) and design it such that it may be used to remove existing and emerging pollutants more efficiently than by conventional treatment. Students will work in groups of 2-3 and prepare a PowerPoint presentation to describe their findings and design, including their choice of materials and cost and aesthetic considerations.

The lessons and field trip experience will stimulate student thinking about waste, wastewater treatment, and waste management in general. There will be opportunities to emphasize personal responsibility in contributing to keep our environment clean and healthy (e.g., by not littering or flushing pharmaceuticals and personal care products down the toilet) and by considering alternative options for wastewater treatment (e.g., composting toilets).

Prior knowledge that students will need to master the learning objectives include reading, writing, and analytical skills as well as basic knowledge of Excel and PowerPoint or similar software (e.g. Google Docs). Students should have basic presentation skills and be respectful.

Next Generation Science Standards:

HS-ESS3-2	Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
HS-ESS3-4	Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-LS2-2	Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
HS-LS2-3	Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
HS-LS2-7	Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
HS-LS4-5	Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.
HS-LS4-6	Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.
HS-ETS1-1	Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
HS-ETS1-2	Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
HS-ETS1-3	Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Learning Objectives:

Students will be able to:

I. Identify at least 3 examples of beneficial uses of water and relate the importance of water quality.

II. Define sewage or wastewater.

III. Explain the role of wastewater in the water cycle, why it is necessary to treat wastewater, and its relation to drinking water.

IV. Explain in detail how changes in one assigned water quality indicator affect biodiversity and populations in an aquatic ecosystem. Include quantitative data and equations where applicable.

V. List at least 5 water quality parameters and how they serve as an indicator for water quality.

VI. Describe how household sewage can be treated by 1) a septic system or 2) a centralized wastewater treatment plant.

VII. Explain the components of a septic system, how pollutants are removed, and maintenance of a septic system.

VIII. Explain primary, secondary, and tertiary wastewater treatment. Include the reasoning behind the sequence of processes and which pollutants are removed in each process.

IX. Discuss the advantages and disadvantages of septic systems and municipal wastewater treatment in terms of economics, aesthetics, society, and the environment.

X. Name and describe at least one alternative wastewater treatment option (e.g., constructed wetlands and composting toilets).

XI. Name and describe at least two emerging contaminants and why they are of concern (e.g., microplastics and pharmaceuticals and personal care products).

XII. Design an unconventional treatment system to remove an emerging contaminant from wastewater. Describe economic, aesthetic, social, and environmental impacts.

Table of Lessons:

Lesson Title and Brief Description	**Learning Objectives**	**NGSS Addressed (codes)**	**Materials**
1. Water Quality *Students will learn which metrics are measured to assess water quality and quantitatively show how an aquatic ecosystem is affected. Wastewater and its role in the water cycle will be discussed.*	I, II, III, IV, V	HS-LS2-2 HS-LS2-3 HS-LS4-5	- WaterQuality.pptx - WaterQualityParameters - MindMap.jpg - StudentSheet_FactSheetAssignment.pdf - Quiz_WaterQualityParameters.pdf - Computer - Document viewer - Projector - Internet access
2. Conventional Wastewater Treatment (WWT) *Students will share ideas and learn how septic systems and centralized wastewater treatment works.*	VI, VII, VIII	HS-ESS3-2 HS-ESS3-4 HS-LS2-3 HS-LS4-5 HS-ETS1-2	- Computer - Projector - Internet access - ConventionalWWT.pptx - KWL_WWT.pdf - Quiz_WWT.pdf - Toronto_wastewater_poster.pdf
3. Alternative Wastewater Treatment Methods	IX, X	HS-ESS3-4 HS-ETS1-2 HS-ETS1-3	- AlternativeWWT.pptx - ReadingWritingAssignment.pdf - Computer - Projector - Internet access

Students will explore the advantages and disadvantages of conventional WWT and discuss the issue of emerging contaminants.			
4. Engineering Design *Based on their understanding and research, students will design their own wastewater treatment process focusing on removing a particular pollutant and considering economic, social, and environmental impacts.*	XI, XII	HS-ETS1-1 HS-LS2-7 HS-ESS3-2 HS-ESS3-4 HS-ETS1-2 HS-ETS1-3	- EmergingContaminants.pptx - StudentSheet_DesignProject.pdf - Computer - Projector - Internet access

Lesson 1: The teacher will introduce this lesson with a brainstorming activity. Students will be asked to create a mind map around the topic of water quality. This will begin a discussion on what students associate with the term as the teacher calls on students to share one related idea at a time. This way, students will explore basic ideas concerning water quality and with the help of guiding questions incorporate wastewater as a topic. The teacher will have students define several water quality parameters as well as wastewater. The water cycle and will be reviewed with emphasis on the role of wastewater and its relation to drinking water. The lesson will end with an assignment requiring students to find and explain (in the form of a fact sheet) a quantitative example on how a pollutant affects biodiversity and populations in an aquatic ecosystem. Each parameter/indicator will be discussed in class. A quiz on water quality parameters may be given at the end of the lesson or unit.

Lesson 2: This lesson will focus on conventional wastewater treatment systems. To introduce the topic, students will do a Know-Write-Learn (KWL) activity on septic systems and on wastewater treatment plants (WWTPs). The students' ideas will be gathered and organized and the teacher will use a PowerPoint presentation with images to help guide an inquiry-based discussion on septic system and WWTP processes. Student will learn how and in which order different contaminants are removed in a wastewater treatment plant. They will follow the discussion by writing descriptions and drawing schematics of the processes (a concept map) and how they may be simulated in a WWT activity in which they design bench scale WWT processes. This will enhance learning by means of hearing, speaking, seeing, writing/designing, and doing. To finish the lesson, a field trip to the local wastewater treatment plant would allow students to gain an impression and a better understanding of how the processes they learned about are implemented in reality. Alternatively (or additionally), short videos can be shown to demonstrate real life WWTP operations. A quiz on diagramming the WWT processes may be given at the end of the lesson or unit.

Lesson 3: The teacher will introduce the topic of alternative WWT options by asking students to brainstorm with their table partner the benefits and shortcomings of conventional WWT options with regard to economics, aesthetics, society, and the environment. Student ideas will be gathered on the board. The brainstorming activity is to be repeated, asking students to think of alternative treatment options. The main ideas that should be discussed are those of composting human waste and the use of constructed wetlands for wastewater treatment. If accessible, students will read one chapter of the *Humanure Handbook* on composting human waste by Joseph Jenkins (or other reading material, see websites listed under Resources) and summarize and reflect on their reading in a 1-page writing assignment.

Lesson 4: The final lesson will be introduced with a series of images showing pollution through microplastics and pharmaceuticals and personal care products (PPCPs). Students will be asked the question of what they think the images depict. Once that is established, students will complete a final project in which they will choose and research an emerging pollutant and a solution for managing it. Alternatively, they may choose a non-conventional treatment method (e.g., constructed wetlands) and design it such that it may be used to remove existing and emerging pollutants more efficiently than by conventional treatment. Students will work in groups of 2-3 and prepare a PowerPoint presentation to describe their findings and design, including their assumptions (e.g., centralized treatment or personal system at home), choice of materials, costs, aesthetics, and overall effectiveness (i.e., does it get the job done?).

Safety Considerations: Students will be respectful and follow instructions in the classroom and lab safety rules when completing their WWT activity in the lab.

Evaluation Plan: At the end of the trimester, the unit will be assessed through exam questions covering the main concepts of water quality assessment, wastewater, conventional and alternative WWT methods, and emerging contaminants and potential removal or remediation methods. This will require students to review the material on their own in preparation for the exam and the act of reading questions and individually drawing schematics and writing out answers (short and in paragraph form) during the exam will reinforce the material covered in the unit. Credit may also be given for notebooks with neatly organized materials (worksheets, notes, schematics) pertaining to the material covered in this unit. This will hone and emphasize the importance of organizational skills.

Lesson 1: Student mastery of the learning objectives will be assessed by 1) creation of a fact sheet requiring the students to research their assigned water quality parameter and provide information on how to test it and how to interpret test results, and 2) a short quiz (Quiz_WaterQualityParameters.pdf), asking students to list 5 water quality parameters and explain how to test for it and how it affects humans as well as biodiversity and populations in an aquatic ecosystem.

Lesson 2: At the end of the lesson, students will take a quiz in which they will be asked to draw a schematic of a septic system and another of the processes that make up conventional WWT. All processes should be briefly described including the pollutant that is being removed and the removal process.

Lesson 3: Assessment will be through oral participation in group brainstorming activities and class discussions as well as through the written response to the reading assignment.

Lesson 4: Presentation of WWT design to the class and evaluation of the quality of the presentation material (the PowerPoint itself) and the presentation of the research.

Resources (websites):

Mind mapping and fact sheets:
www.mindmapping.com
Example fact sheet: http://iffculture.ca/fact-sheets/water-quality-fact-sheet/.

Videos on the sewage treatment process:
https://www.youtube.com/watch?v=8isr9nSDCK4

Septic systems:
http://www.epa.gov/septic/learn-about-septic-systems
http://www.nesc.wvu.edu/subpages/septic_defined.cfm

Local wastewater treatment plant in Houghton, MI:
http://www.plwsa.org/

Wastewater treatment lab activity by Rand Water's Water Wise Education Team:
http://www.waterwise.co.za/export/sites/water-wise/education/activities/wastewater-cleaned/downloads/Making_a_Model_of_a_Wastewater_Treatment_Works.pdf

Humanure Handbook by Joseph Jenkins:
http://humanurehandbook.com/contents.html

Other potential reading assignments:

- Composting toilet system: http://www.neverendingfood.org/design-ideas/composting-toilet-systems/
- Composting toilet: http://www.letsgogreen.com/how-composting-toilets-work.html
- Blog on composting toilet: http://www.gonewiththewynns.com/composting-toilet
- Blog on composting toilet: http://www.cityfarmer.org/CFcomposttoilet.html#toilet
- Composting toilets: http://greywateraction.org/contentabout-composting-toilets/
- Constructed Treatment Wetlands: 1st file on http://www.epa.gov/wetlands/constructed-wetlands
- Constructed Wetlands: http://dirt.asla.org/2010/09/10/using-constructed-wetlands-for-wastewater-treatment/
- Constructed Wetlands in Israel and the U.S.: http://cleantechnica.com/2013/12/07/constructed-wetland-offers-low-cost-wastewater-treatment/
- Constructed Wetlands Company: http://www.wetlandsolutionsinc.com/services/treatment-wetlands/
- Constructed Wetlands MN: http://www.extension.umn.edu/environment/water/onsite-sewage-treatment/innovative-sewage-treatment-systems-series/constructed-wetlands/index.html

Constructed wetlands for wastewater treatment:
http://www.epa.gov/wetlands/constructed-wetlands

http://en.wikipedia.org/wiki/Constructed_wetland

EPA on pharmaceuticals and personal care products (PPCPs):
http://www.epa.gov/ppcp/

Boxall, Alistair, et al. "Pharmaceuticals and personal care products in the environment: what are the big questions?." *Environmental Health Perspectives* 120.9 (2012): 1221-1229.

Microplastics:

http://thinkprogress.org/climate/2015/07/14/3679715/zooplankton-eating-plastic/
http://environment.about.com/od/pollution/fl/What-Are-Microplastics.htm
https://www.thedodo.com/community/animalperspectives/microplastics-are-bad-bad-bad-636104127.html

Microplastics Story of Stuff video (2:11 min):
https://creeklife.com/blog/microplastics-could-kill-us

PPCPs:

Boxall, Alistair, et al. "Pharmaceuticals and personal care products in the environment: what are the big questions?" *Environmental Health Perspectives* 120.9 (2012): 1221-1229. http://ehp.niehs.nih.gov/1104477/

****Brief description of how this unit relates to your graduate research**:

This unit seeks to educate high school students on water quality assessment and traditional and alternative wastewater treatment methods. The first lesson begins with an introduction to testing water quality parameters, which directly relates to my field of expertise: the relationship between phosphorus and nuisance algal growth (*Cladophora* in the Great Lakes) within the larger field of surface water quality. Wastewater treatment plants are primary sources for algal growth as they often discharge significant amounts of phosphorus to rivers and lakes. The phosphorus-algae relationship is emphasized in Unit 1 (Phosphorus and Algal Blooms) and if that unit was completed prior to this one, students will have a good grasp on the concept of nutrients as pollutants. In this unit, the focus shifts somewhat away from the receiving water bodies, though they are not ignored, to the wastewater treatment processes themselves. How many high school students think about where the water goes after they flush or shower? The goal of this unit is to open students' eyes and minds to waste management solutions, designs, and challenges, something many people hardly think about.

The focus of my research is not on wastewater treatment technologies but on *Cladophora*, which is a macroalga that grows at nuisance levels in Lake Ontario by Ajax, ON (near Toronto) and is driven by excessive phosphorus discharges to the area. I have performed analyses on the effluent, testing for phosphorus concentrations and assessing phosphorus bioavailability by means of bioassays. I have performed similar assays for locations other than Lake Ontario (e.g., Lake Erie and Cayuga Lake) and am familiar with different options for phosphorus removal from wastewater. I find it important for students to understand not only the effects of phosphorus on algal growth and associated problems but also the impacts of other pollutants in untreated sewage in the environment. Student should first and foremost understand why we treat sewage and what the consequences of discharging untreated sewage into our water bodies are.

Once students have not only an intuition but a good working knowledge and the ability to give examples of what may happen to a water body if we were to continuously dump untreated sewage into it, the next goal is to teach students how wastewater is treated. I find this an incredibly interesting topic that never came up when I was in grade school, even though everyone should be concerned about it, because every human creates waste. My research seeks to protect and remediate surface waters and although I do not focus on developing new wastewater treatment technologies, the subject is closely related and highly interesting.

I am also drawn to the idea of alternative wastewater treatment technologies that may be more sustainable than traditional, centralized wastewater treatment. I came across the *Humanure Handbook* by Joseph Jenkins during my time as an undergrad in Civil Engineering when I took a water and wastewater treatment course, for which we had to complete a final project: designing a waste treatment facility in a remote location in Peru, where floods and limited access to materials were a challenge. Composting toilets and latrines are a great option for remote locations, if appropriately maintained. This unit is supposed to challenge students to think outside the box and consider options that are not (yet) the norm but may be more sustainable than conventional wastewater treatment. How much energy and money does it cost to use water to flush toilets and move the waste through pipes to a central location and then treat it? How competitive could composting toilets or constructed wetlands become? These are questions that students cannot be expected to answer but early exposure to complex, real life questions like this can only prepare high school students for future challenges.

Apart from critically evaluating our current approach to wastewater treatment, emerging contaminants such as microplastics and pharmaceuticals and personal care products (PPCPs) are becoming more and more prominent in our environment and are currently not being removed in traditional treatment plants. It is a serious challenge to grasp the magnitude of this problem and predict potential environmental impacts that many scientists and engineers are researching, as I have seen presented at the International Association for Great Lakes Research (IAGLR) conference in the past three years. It is a growing global concern, much like climate change, that students should be aware about.