Food and Agriculture Center for Science Education

Better Bioreactors

High School, Earth Science

Task Overview

In this task, students are introduced to a new technology–bioreactors–that help farmers reduce nitrates in their agricultural drainage water. Caroline installed two bioreactor systems on her farm, one with and one without a gate in the outlet, and she needs help figuring out which she should recommend to other farmers. Students first review and do calculations with sensor data to compare the total number of nitrates exiting each bioreactor system. They then use this data to decide whether to recommend gates or no gates in bioreactor systems, drawing a model to help Caroline explain the recommendation, including how it will increase the sustainability of Caroline's farming practices.

Background Information

New technologies are helping farmers reduce nitrates in their agricultural drainage water. Water with high nitrate loads are problematic because they can fuel algal blooms that disrupt fish and wildlife. Thus, managing nitrate levels is an important goal for farmers.

Bioreactors are one recent technological innovation that use bacteria to reduce nitrate loads. Bioreactor tanks are buried underground at the edges of a crop field. The tanks are filled with wood chips and fitted with pipes that bring water into and through the wood chips. Bacteria living on the wood chips do a special kind of cellular respiration that converts nitrates into nitrogen gas. When tanks are at full capacity, water is diverted at the inlet to bypass the bioreactor.

Bioreactors can be installed with gates and without gates. Bioreactors with gates retain water longer than bioreactors without gates (8 hours versus 2 hours). The benefit of having gates is that it gives more time for nitrates to be extracted from the water, so fewer nitrates are emitted from the bioreactor into the environment (only 28,000 vs. 47,000 mg nitrates per 1000 L of water). However, since the gated bioreactor is filled with water for longer, this means that in times when there is lots of agricultural drainage water, more water is diverted around the bioreactor without any nitrates removed (10% vs. 2.5% water diverted to bypass the bioreactor).

Next Generation Science Standards

Three-Dimensional Claim

Use models and patterns identified from mathematical representations to explain how a technology (bioreactors) can produce less pollution and waste from farming, preventing ecosystem degradation and

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sustainability of human societies.

This task is intended to elicit student learning of the following **NGSS elements** for each of the three dimensions:

Disciplinary Core Ideas

ESS3.C: Human Impacts on Earth Systems (HS)

- Sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources, including the development of technologies (HS-ESS3-3).
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation (HS-ESS3-4).

Science and Engineering Practices

Using Mathematics and Computational Thinking (HS)

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Developing and Using Models (HS)

- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

Crosscutting Concepts

Patterns (HS)

- Mathematical representations are needed to identify some patterns.

Suggestions for Use

This task is intended to be used for formative assessment purposes—to identify students' strengths and needs with the above dimensions to provide feedback to students and guide shifts in instruction.

Assumptions

Students should have engaged with instructional experiences that ask them to use mathematics to identify patterns in data, as well as use evidence to develop or revise models of systems. Students should also have an understanding of technologies that have been developed to produce less pollution and waste in order to sustain human societies and the biodiversity that supports them.

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Materials Needed

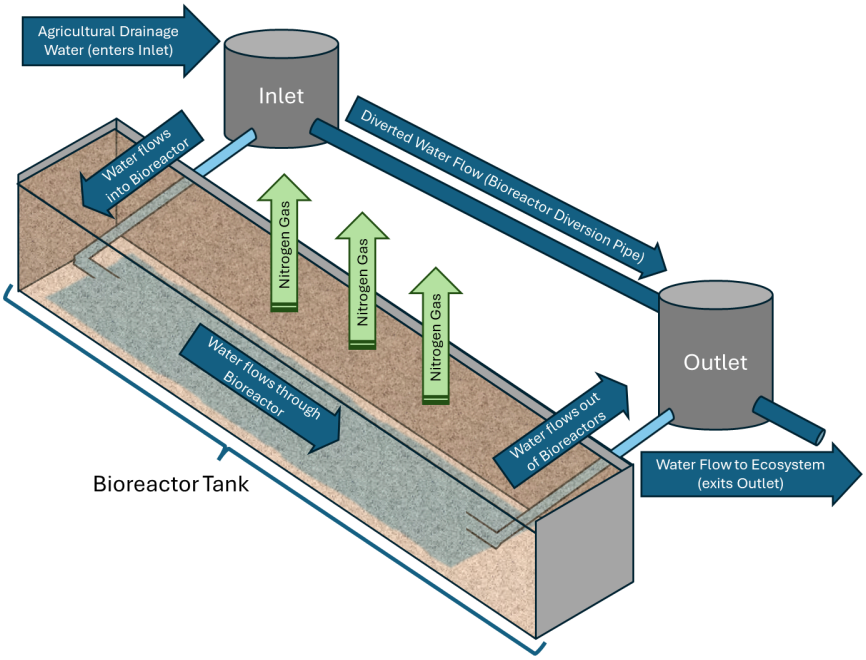
- Better Bioreactors Student Task

Assessment Guidance

Introduction

New technologies are helping farmers reduce nitrates in their agricultural drainage water. Water with high nitrate loads are problematic because they can increase the amount of algae present in water sources downstream, which harms other organisms in those ecosystems. Farmers are receiving lots of public pressure to better manage nitrate levels in their drainage water.

Bioreactors are one recent technological innovation that use bacteria to reduce nitrate loads. Bioreactor tanks are buried underground at the edges of a crop field (see images to the left). Review the model of a **bioreactor system** (shown below). The tanks are filled with wood chips and fitted with pipes that bring water into and through the wood chips. Bacteria living on the wood chips do a special kind of cellular respiration that converts nitrates into nitrogen gas. When tanks are at full capacity, such as during heavy rains, water must be diverted at the inlet through a **diversion pipe.** This bypasses the bioreactor, sending the untreated water straight into the ecosystem.



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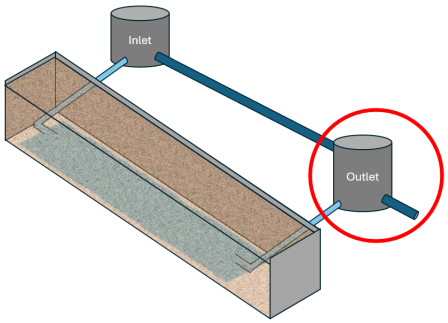
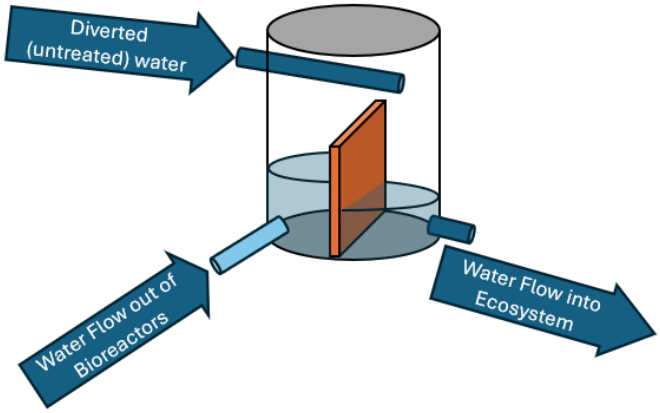
Caroline is a farmer that installed a bioreactor system to help remove nitrates from the agricultural drainage water of her 50-acre crop field.

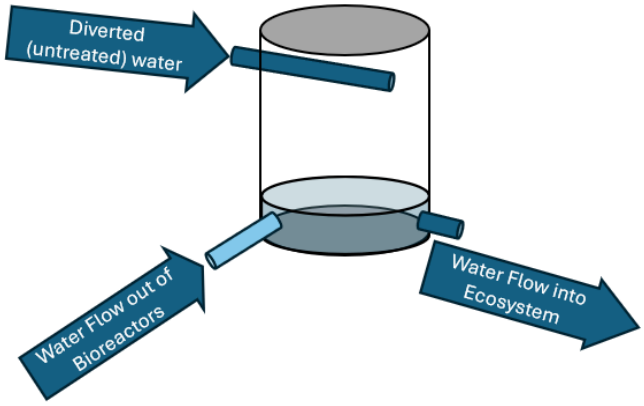


She installed one system **with a gate** within the outlet (circled in red) and one **without a gate** to test which design to recommend to other farmers (*see images below)*. Bioreactors with gates retain water longer than bioreactors without gates, and Caroline isn't sure which is better for nitrate removal.

Gate in Outlet of Bioreactor System



No Gate in Outlet of Bioreactor System



Help Caroline figure out whether she should recommend a bioreactor system **with a gate** or **without a gate** within the outlet to other farmers.

Prompt 1

Caroline's bioreactor systems were installed with sensors that can be used to collect data to determine how well they are removing nitrogen. Sensors in Caroline's bioreactors measure:

- Nitrate levels in water entering and leaving the bioreactor system (mg nitrates / 1000 L water)
- Percent of water diverted around the bioreactor directly to ecosystem (when tanks are full)

Caroline shows you data she's collected a few weeks after she installed her system and needs your help to interpret the data.

a. Review the data on the next page and do calculations to be able to compare the total number of nitrates exiting each bioreactor. ***Show your work on the table.***

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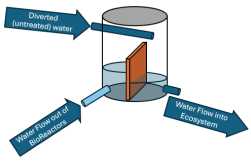
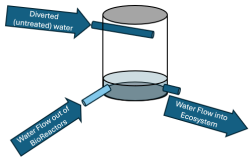
	Total Nitrates Entering the System (Bioreactor OR Diversion Pipe)	**% Water Exiting the Diversion Pipe** (untreated because tanks were full)	**<u>Calculate</u> the Nitrates Exiting the Diversion Pipe** (from untreated water)	**Nitrates Exiting the Bioreactor** (nitrates remaining after water was treated)	**<u>Calculate</u> the Total Number of Nitrates Exiting Diversion Pipe AND Bioreactor**
Gate in Outlet of Bioreactor System 	63,000 mg nitrates per 1000 L of water	10%	**63,000 mg * 0.10 = 6,300 mg**	28,000 mg nitrates per 1000 L of water	**28,000 mg + 6,300 mg = 34,300 mg nitrates per 1000 L**
No Gate in Outlet of Bioreactor System 	63,000 mg nitrates per 1000 L of water	2.5%	**63,000 mg * 0.025 = 1,575 mg**	47,000 mg nitrates per 1000 L of water	**47,000 mg + 1,575 mg = 48,575 mg nitrates per 1000 L**

b. Which bioreactor system is better at preventing nitrates from entering natural ecosystems? Use evidence from your calculations to support your response.

Prompt 1 Performance Outcome:
Complete mathematical calculations within bioreactor systems to identify patterns that indicate how a technology (i.e., gate within bioreactor outlet) produces less pollution and waste (i.e., nitrate runoff).

SEP	Create a computational model or simulation of a phenomenon, designed device, process, or system.

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DCI	Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
CCC	Mathematical representations are needed to identify some patterns.

Prompt 1 Rubric

	Emerging	Developing	Proficient
Sample Student Response	a. 6,300 | 34,300 1,575 | 48,575 b. The gated one OR the first one because the numbers are higher which I think is better	a. 63,000/10 = **6,300** | **31,500** 63,000 * 0.025 = **1,575** | **48,575** b. The gated one because it helps get rid of the nitrates.	a. 63,000 * .10 = **6,300** | 28,000 + 6,300 = **34,300** 63,000 * .025 = **1,575** | 47,000 + 1,575 = **48,575** b. The gated bioreactor is more efficient because there are fewer nitrates exiting. More of the water is treated because it holds the water longer and the bacteria will have longer to go through cellular respiration. The gated bioreactor ended with 34,300 mg of nitrates while the ungated bioreactor ended with 48,575 mg of nitrates.
Look-Fors	• Creates a mathematical model **with major inaccuracies in calculations or calculations are missing**	• Creates a **relevant** mathematical model **with minor inaccuracies or missing steps** in calculations	• Creates a **relevant** mathematical model that shows **accurate** calculations

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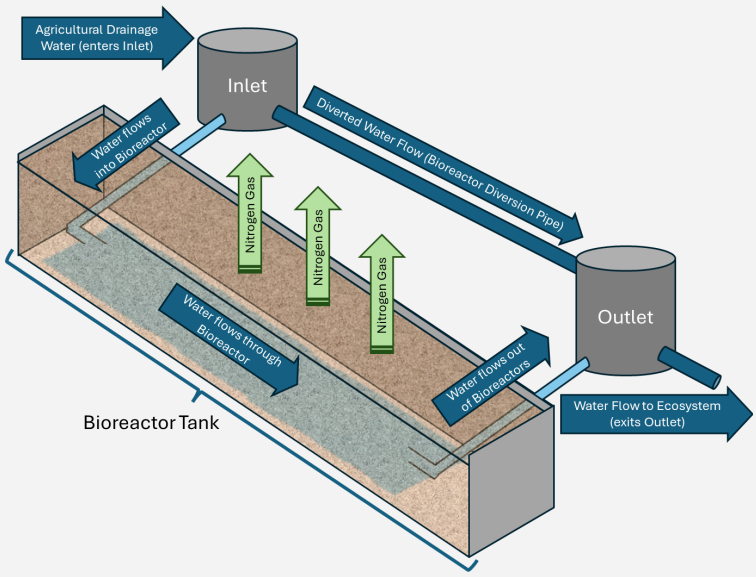
	• Makes an **accurate** claim about a technology that produces less pollution (i.e., which bioreactor system is better at removing nitrates) • Patterns from mathematical model (i.e., calculations) are **irrelevant** to supporting their claim **or missing**	• Makes an **accurate** claim about a technology that produces less pollution (i.e., which bioreactor system is better at removing nitrates) • Uses **relevant** patterns from mathematical model (i.e., calculations) to **partially** support their claim	• Makes an **accurate** claim about a technology that produces less pollution (i.e., which bioreactor system is better at removing nitrates) • Uses **relevant** patterns from mathematical model (i.e., calculations) to **completely** support their claim

Prompt 2

a. Should Caroline recommend a bioreactor system <u>with</u> a gate or <u>without</u> a gate within the outlet to other farmers?

b. Add to the model below to help Caroline illustrate the evidence for her recommendation to other farmers. Include all of the following:
- If you've decided to add gates to the outlet, revise the model accordingly
- Add labels with numbers and calculations (from the table) to show how your recommendation reduces the amount of nitrates
- Add captions to explain why you made your recommendation



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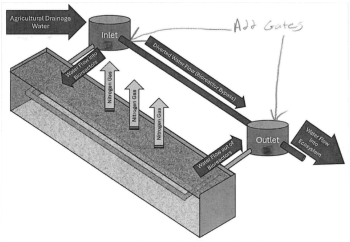
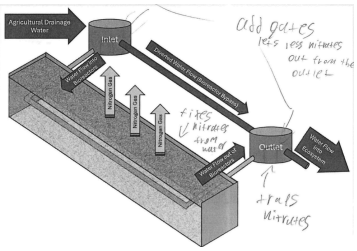
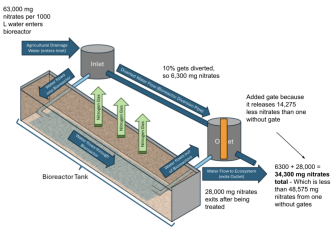
c. Explain how your recommendation for Caroline's improved bioreactor will help to protect nearby rivers and lakes. Support your explanation with:
- a description of how the bioreactors will reduce the impacts of her farm on nearby ecosystems
- your mathematical calculations in Prompt 1
- information from the model you added to above (Prompt 2b)

Prompt 2 Performance Outcome:
Revise and use a model based on patterns from mathematical representations to predict how the use of a sustainable farming technology (bioreactors) will protect natural ecosystems from degradation.

SEP	Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
DCI	Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. Sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources, including the development of technologies.
CCC	Mathematical representations are needed to identify some patterns.

Prompt 2 Rubric

	Emerging	Developing	Proficient
Sample Student Response	a. Add b.  c. If there are less leaks then the farms will be more efficient **OR**	a. Add gates b.  **OR**	a. Caroline should add gates b. *See below the table for larger image*  c. Adding gates would let fewer nitrates get into nearby lakes and rivers. You

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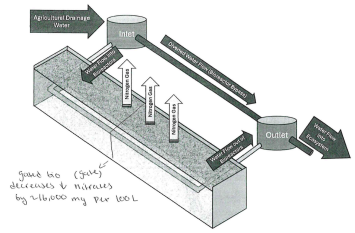
	I have shown math and reasons to prove why to add gates.	 c. Adding gates will let out less nitrates, allowing the farming to go smoother. The table shows that less nitrates escaped when there were gates.	can see in my model that only 28,000 mg of the 63,000 mg comes out of the bioreactor after being treated and even though 10% was diverted, that is only another 6300 mg released. You don't want a lot of nitrates to come out like the 48,578 mg without gates; they hurt the ecosystems downstream.
Look-Fors	In labels and captions on the model and/or in the explanation: • Adds drawings and/or labels to a model to recommend a **relevant** technology that produces less pollution (i.e., add gates) • Description of patterns from a mathematical model are **missing and** explanation of how the technology (i.e., gates) produces less pollution (i.e., nitrate runoff) is **missing or vague** • Explanation of why the technology (i.e., gates) protects natural ecosystems is **missing or irrelevant**	In labels and captions on the model and/or in the explanation: • Adds drawings and/or labels to a model to recommend a **relevant** technology that produces less pollution (i.e., add gates) • Describes **general** patterns from a mathematical model to **partially** explain how the technology (i.e., gates) produces less pollution (i.e., nitrate runoff) • Explanation of why the technology (i.e., gates) protects natural ecosystems **is implicit**	In labels and captions on the model and/or in the explanation: • Adds drawings and/or labels to a model to recommend a **relevant** technology that produces less pollution (i.e., add gates) • Describes **specific** patterns from a mathematical model to **sufficiently** explain how the technology (i.e., gates) produces less pollution (i.e., nitrate runoff) • Explanation of why the technology (i.e., gates) protects natural ecosystems **is explicit**

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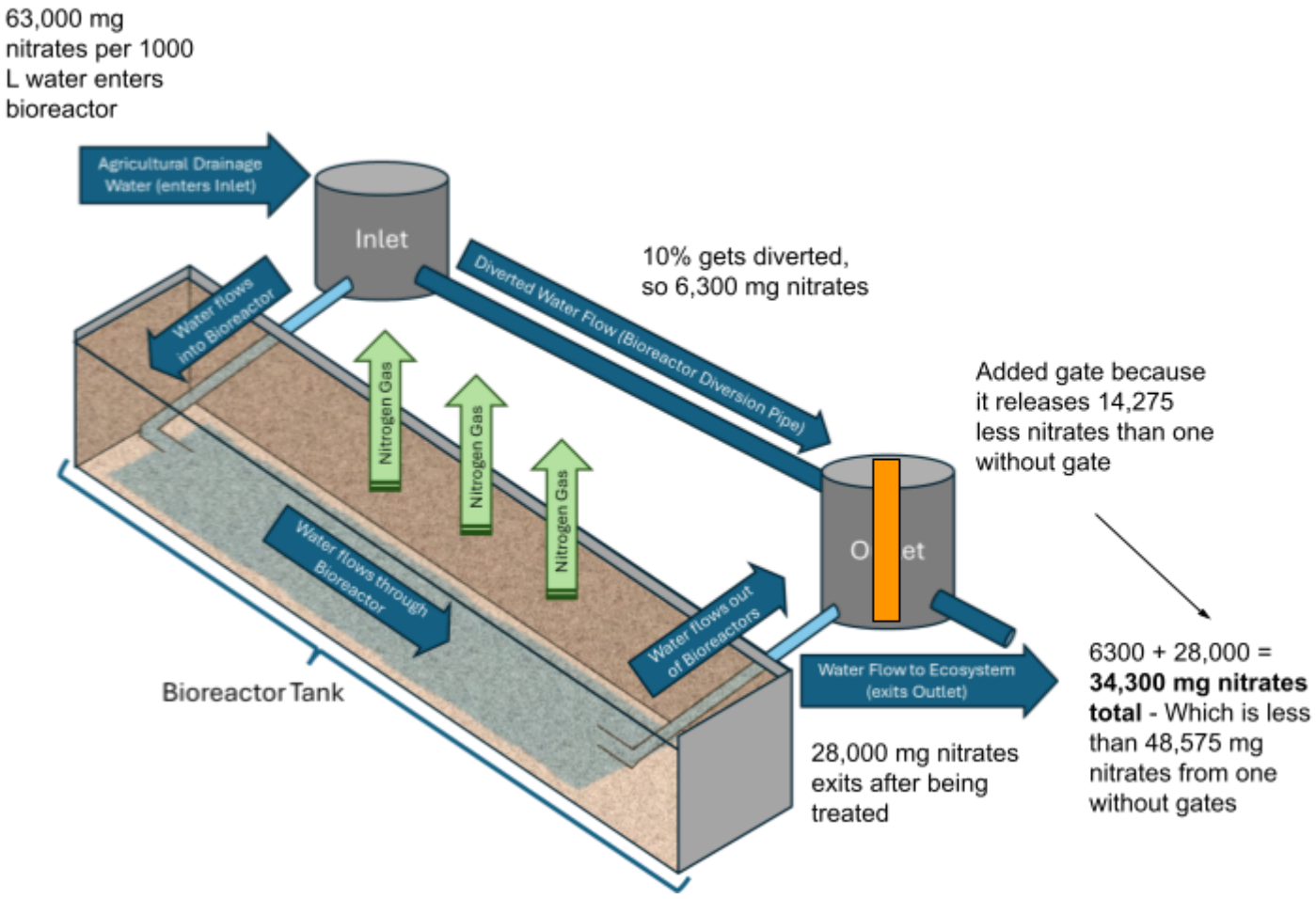
Sample Student Model for Proficient Level:



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