From Here to There with Woodchip Bioreactors

A Collection of Curriculum Modules for 7-12 Grade

Based on the Research of Dr. Michelle Soupir

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Special Thanks to: Lance Baetsle and Cara Rinehart for their use of the modules and providing valuable feedback to improve the project during its development

The activities and labs within these curriculum modules are designed to use low-cost and locally-available supplies. Teachers should, however, feel comfortable substituting materials and supplies where necessary, when specified items are not available.

Some materials will need to be obtained from other sources such as local home centers or online retailers.

As with any hands-on science experiences, teachers and students should observe all appropriate safety guidelines, whether explicitly mentioned in this booklet, or not.

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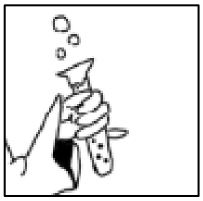

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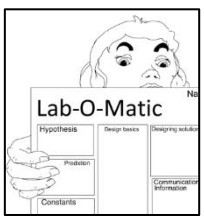

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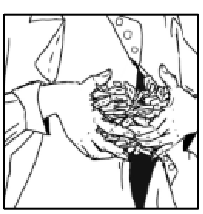

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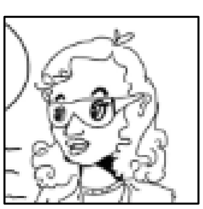

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EQUITABLE LEARNING

Our promise…

This innovative collection of curriculum modules has been developed with a focus on promoting students' access to learning. While teachers will need to deploy context-specific instructional strategies to ensure skillful implementation of any science experience, we have considered these key points during curriculum development:

Students build understanding through carefully sequenced learning

The storyline approach to sequencing learning experiences allows for a diverse range of pedagogical nuances that are often absent from "textbook" curriculum materials. Introducing a relevant, meaningful problem (phenomenon) before students have learned core ideas can improve the chances that students will learn transferrable knowledge and skills (National Research Council, 1999). The curriculum modules contained in this booklet build on one another and help students find meaning in each investigation that leads them closer to making sense of the anchor phenomenon.

Students use scientific practices to make sense of a phenomenon

Through the purposeful use of hands-on investigations, students will engage with many of the NGSS Science and Engineering Practices. This engagement will help them to connect what they are learning to problems that impact their own family and community. By doing so, students may be driven to use those discoveries to help solve issues of global significance. This leads them to better understand scientific ways of thinking and to value science in greater ways (National Research Council, 2012).

Students' own questions and wonderings drive learning

Activities presented in this curriculum unit are designed to encourage student-student discourse. These academic conversations provide teachers valuable insight into student thinking and provide evidence that can be used to guide the next instructional steps. By eliciting students' questions and helping them use their own funds of knowledge to make sense of relevant phenomena, teachers support student motivation and agency (Harris, Phillips, & Penuel, 2011).

INTRODUCTION

A Focus on Research

More than a Decade Ago

In 2008, Dr. Michelle Soupir joined the Agriculture and Biosystems Engineering department at Iowa State University. The goal of Dr. Soupir's research program is to conduct basic research to move us toward more sustainable water systems. Dr. Soupir uses lab- and field-based research projects to monitor the occurrence, fate and movement of nutrients and microorganisms in surface and drainage water.

In 2013, Dr. Soupir's lab began a project on which these curriculum modules are based. Experimental woodchip bioreactors were designed and installed at the Agricultural Engineering Research Farm near Ames, Iowa. These pilot-scale woodchip bioreactors are used to evaluate the nutrient removal from agricultural drainage water. Dr. Soupir's students manipulate a variety of variables including hydraulic retention times, bioreactor fill materials, and influent nutrient conditions to determine the effectiveness and efficiency of the bioreactors and investigate ways to make bioreactors work better.

Bioreactor Basics

Many parts of the Upper Midwestern United States have wet soils that require drainage in order for them to be used for agriculture. Draining of subsurface water (tiling) in farm fields is a practice that farmers have used for more than 100 years because doing so results in a significant increase in crop yield. Concerns have grown, however, about the effect this practice has on the movement of pollutants (i.e., nitrates and phosphates) through fields and into waters. systems. Nitrate (NO_3^{-1}), which can be present in high amounts in drainage water, makes its way into streams, rivers and lakes where it unbalances ecosystems and can result in hypoxic conditions, as we have seen develop in the Gulf of Mexico, also known as the Gulf Dead Zone.

Woodchip bioreactors have proven to be a simple, yet highly effective way to remove nitrate pollution without impacting current land management practices. Field runoff water is collected via tiling and diverted into the bioreactor, which is essentially a buried trench filled with woodchips. Denitrification occurs when microbes living on the surface of woodchips (or other suitable material) use the wood as a carbon source to convert nitrate to nitrogen gas (N_2). The result is cleaner water which can be discharged into existing streams and rivers.

What to Expect

The information, activities and assessments included in these curriculum modules aim to tell a story. This storyline will help students learn the basics of denitrification and the nitrogen cycle to make sense of our anchor phenomenon - the Gulf Dead Zone. Students will learn that local conditions and actions can have a significant impact on global issues. The activities with which students will engage constitute a meaningful pathway to understanding and are not intended to be used in isolation. As you make plans for how these modules will be used, carefully consider the connections and interdependence of the activities, which make it difficult to separate the activities and is not advised.

Each module consists of two or three activities. Each activity provides opportunities to develop and use specific elements of the Next Generation Science Standards (NGSS) science and engineering skills and practice(s) to make sense of phenomena and/or to design solutions to problems. They also provide students with the chance to use conceptual understanding that spans scientific disciplines and develop deep understanding of core ideas and content.

Finally, please maintain your own sense of curiosity as you use these materials. Resources and ideas for classroom implementation are included at the end of this guide. Consider your own professional growth an integral part of implementation - always value your own learning, as well as that of your students.

Why Focus on Woodchip Bioreactors?

Over the past several years, dozens of teachers have experienced the simplicity and awesome potential of woodchip bioreactors as part of workshops at Iowa State University. These educators often speak of the woodchip bioreactor as an effective way to introduce several key ideas to students. Many say that they overlook the importance of the nitrogen cycle and some leave it out of the curriculum completely. Woodchip bioreactors offer a hands-on way to connect students with locally-important issues and the chance to engage with a unique research experience that's happening in our own backyards.

Although the construction of full-scale bioreactors might not be feasible, classroom-scale bioreactors can be easily constructed and used in "proof-of-concept" experiments. Students will use this hands-on experience to begin developing solutions for local issues in an attempt to solve a global problem. Teachers, then, can use woodchip bioreactors to engage students with important content and conceptual understanding that may have been previously passed over.

SUGGESTED LEARNING SCHEDULE

Teacher Planning and Suggested Pacing

Each 🕒 represents approximately 1 hour of class time. This includes time for the entire activity, including pre- and post-activity discussions or work.

Although the activities listed below should be done in the order listed, they <u>need not be done on consecutive days</u>. Please use the schedule below as a guide as you determine how each activity will support the learning your students will do throughout the year.

Module 1
Activity #1: Get to Know the Gulf Dead Zone 🕒
Activity #2: Hello, My Name is 'Nitrogen' 🕒
Activity #3: Sorting out the Nitrogen Cycle 🕒

Module 2
Activity #4: Water Quality Mini-lab 🕒
Activity #5: Bioreactor Materials Research 🕒
Activity #6: Bioreactor Experiment with the Lab-O-Matic 🕒 🕒 . . . . 🕒
Activity #7: DNA Analysis of Bioreactor Microbe Ecosystems 🕒 🕒 🕒

Module 3
Activity #8: Chesapeake Bay Case Study 🕒 🕒
Activity #9: A Part of the Solution (summative task) 🕒

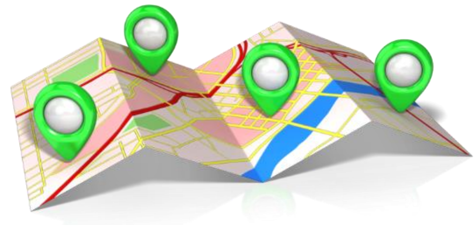
NGSS CONNECTIONS

The connections seen here should be considered POSSIBLE connections. Depending on how each module and activity is implemented, teachers may choose to emphasize additional/different science & engineering practices, disciplinary core ideas, and cross cutting concepts beyond those indicated below.

	SCIENCE & ENGINEERING PRACTICES								DISCIPLINARY CORE IDEAS				CROSS CUTTING CONCEPTS						
	Asking Questions & Defining Problems	Planning & Carrying out Investigations	Analyzing & Interpreting Data	Developing & Using Models	Constructing Explanations & Designing Solutions	Engaging in Argument from Evidence	Using Mathematics & Computational Thinking	Obtaining, Evaluating & Communication Info	DCI: Physical Science	DCI: Life Science	DCI: Earth & Space Science	DCI: Engineering, Technology & Applications	Patterns	Cause & Effect	Scale, Proportion & Quantity	Systems & System Models	Energy & Matter: Flows, Cycles, & Conservations	Structure & Function	Stability & Change
MODULE 1 ACTIVITY 1	X							X			ESS3.C			X			X		
MODULE 1 ACTIVITY 2				X		X			PS1.A									X	
MODULE 1 ACTIVITY 3				X	X				PS1.A	LS2.A,B,C						X	X		
MODULE 2 ACTIVITY 4			X					X	PS1.A									X	
MODULE 2 ACTIVITY 5						X		X	PS1.A					X					
MODULE 2 ACTIVITY 6		X	X					X				ETS1.B,C	X	X			X		
MODULE 2 ACTIVITY 7		X	X			X				LS2.C				X					
MODULE 3 ACTIVITY 8						X		X		LS2.A,B,C	ESS3.C					X			
MODULE 3 ACTIVITY 9	the summative task provides opportunities for students to demonstrate the SEPs, DCIs and CCCs indicated above																		

STORYLINE

A Plan for Student Learning



Driving Question

How can such a large-scale problem possibly be managed in our own community?

Anchoring Phenomenon

The Gulf Dead Zone

Phenomenon-driven Lessons	Making Sense (Learning)	Connection with Next Investigation
What is the Gulf Dead Zone?	The problems associated with the Gulf Dead Zone affect many facets of life and are caused by many factors.	One of the most significant causes of the GDZ is the elevated amounts of nitrogen-based nutrients flowing in from the Mississippi River.
How does nitrogen move through the Earth system?	Nitrogen is essential for life and travels in a nonlinear fashion between living things and the physical environment.	As nitrogen moves through the Earth system, the molecules and compounds it forms change.
How is nitrogen transformed through natural process we call the nitrogen cycle?	The forms that nitrogen takes as it moves through the Earth system are associated with the events of the GDZ phenomenon.	Human activities can impact the movement of nitrogen through the Earth system. This knowledge may help mitigate the GDZ phenomenon.
What opportunities for nitrate mitigation exist and how might they look in our community?	Woodchip bioreactors decrease the amount of nitrate flowing into waterways and may serve as one way to address the GDZ problem.	Woodchip bioreactors are only one piece of a complicated puzzle that involves many people, places and beliefs.
How can we optimize woodchip bioreactors to most efficiently address the GDZ problems?	Analyzing bacteria ecosystems can provide insights into what makes one bioreactor more efficient than another.	Now that we “know what we know”, how do we act to meaningfully improve lives and environments?

Curriculum Overview:

1. Reconnect with anchor phenomenon
2. Activity 1: Getting to know the GDZ
3. Activity 2: Hello, my name is: nitrogen
4. Activity 3: Sorting out the nitrogen cycle
5. Module 2 Investigations
6. Module 3 learning consolidation

GETTING TO KNOW THE GULF DEAD ZONE

Module 1, Activity #1

Overview

This activity will allow students to begin developing questions related to the anchor phenomenon - the Gulf Dead Zone (GDZ). It's organized in such a way that students are presented with a variety of sources of information related to the GDZ and after each new artifact is presented, students generate additional questions. These student-generated questions should remain visible in the classroom for the duration of the unit and be referenced when class time is spent investigation a question or collection of similar questions.

Students will…

- …obtain and evaluate information from a variety of sources.
- …write, categorize and prioritize questions generated by themselves and other class members.
- …ensure questions developed relate directly to the phenomenon.

Time Required: Approximately 60 minutes

Materials Needed

- ✓ 3 large pieces of poster paper (24x36"). Title the posters: SCIENCE, SOCIAL/POLITICAL, SOLUTIONS, and OTHER. Hang them around the classroom.
- ✓ 3x3" sticky notes, approximately 5 per student
- ✓ 10-15 color prints of photos related to the Gulf of Mexico and Gulf Dead Zone (could include maps, diagrams, photos of wildlife…anything that might spark conversation about the phenomenon)

Teacher Tips

- Get students excited by having the photos out when they come into the classroom. It helps if photos are laminated, but they don't have to be. It's okay (and even encouraged) if students start talking about the phenomenon before class "starts".
- Monitor students closely when creating questions on the sticky notes. Each student should write at least a couple questions, that way they're invested in subsequent conversations which reference the questions. If they don't have a question posted, they're less likely to be interested in the discussion.
- Leave the posters and sticky notes UP for the duration of the unit/project. It helps you remember to reference them at various times during learning.

Activity Procedure

1) Place GDZ photos on students' desks before class begins. (not all students need one, as they can share during discussion)
2) As students enter the classroom, encourage them to discuss the photos.
3) To begin the activity, as students to quietly generate questions about the photos they've seen. Write one question per sticky note.
4) As a class, watch the CBS This Morning video on YouTube: https://youtu.be/MuyH68g9HaE
5) After watching the video, again ask students to quietly generate more questions and write them on sticky notes.
6) Lastly, read this article (or one similar, depending on the reading level of your students): https://www.noaa.gov/media-release/noaa-forecasts-very-large-dead-zone-for-gulf-of-mexico
7) One more time, allow students to generate and write down questions on sticky notes.
8) Now, students should categorize their questions according to the titles on the poster papers hanging around the room. Students should quietly move from one poster to another and leave their questions on the appropriate poster. The OTHER poster is for questions that don't fit into the other 3 categories.
9) Using a 'gallery walk' or similar strategy, ask students to look over the questions one last time to ensure that all questions directly relate to the phenomenon.
10) Then, ask students to visit each poster and prioritize the questions by considering the question: "which questions do we think are more important when considering how to deal with the Gulf Dead Zone problem?". Highest priority questions should be moved to the top of the poster, and so on.
11) Let students know that these questions will guide their learning over the coming days, and that they will eventually be able answer many of the questions they've posed.

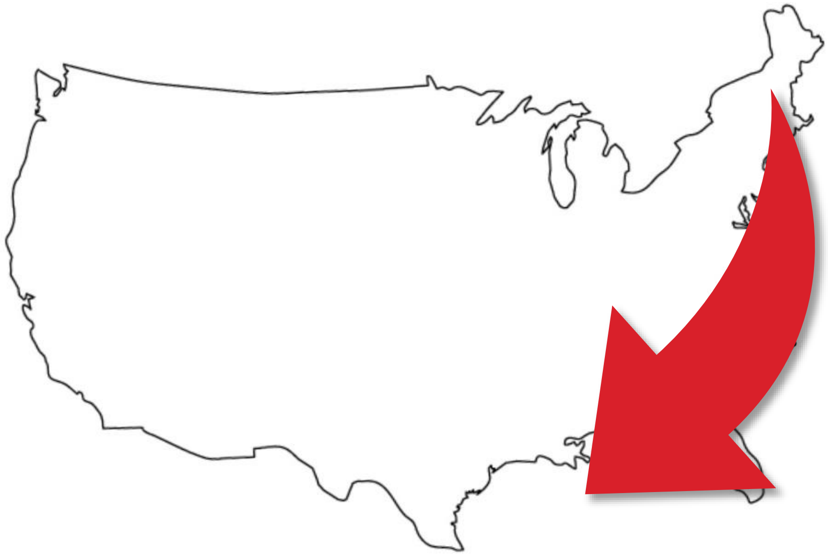
Don't Forget to Loop Back!

As students complete each activity, don't forget to help them connect with the anchor phenomenon. Doing activities in isolation is not what science is about. Continue building the storyline with students by asking questions like:

- How does what we just learned help us understand the Gulf Dead Zone?
- Does this activity help you answer any of the questions on your sticky notes?
- What questions did this activity bring up for you? How should we try to answer these?
- At this point, what solutions to the Gulf Dead Zone problem do you have?

The Gulf Dead Zone

Our Anchor Phenomenon



According to an August 2017 report by the National Oceanic and Atmospheric Administration (NOAA), that year's Gulf Dead Zone was one of the largest on record. An area roughly the size of New Jersey was forecasted to develop in the Gulf of Mexico, which scientists refer to as a hypoxic zone.

This large dead zone is caused primarily by nutrient pollution that comes from agriculture and urban land runoff which ends up in the Mississippi River. This hypoxic zone has been present for decades, but each year the size and other characteristics of the area change.

When nutrients from the Mississippi River watershed run into the river and eventually the Gulf of Mexico, they stimulate algal growth. These algae eventually die and decompose, which uses up oxygen which is needed to support fish and other wildlife in the Gulf. Fish can lose habitat and experience a decrease in reproductive abilities or even begin to die off.

In addition to wildlife being impacted, humans are also affected by the Gulf Dead Zone. In a recent Duke University study, the Gulf dead zone seems to be slowing shrimp growth, which leads to fewer large shrimp. The price of shrimp has seen a corresponding decrease, which has had negative consequences to the area's economy.

Scientists continue to monitor the Gulf dead zone and incoming water from the Mississippi River watershed in an effort to better understand how upstream impacts can be mitigated. New technologies and discoveries from scientific research projects are an integral part of continuing to improve our knowledge of the environment and its complex, interconnected systems.

How can we help Dr. Soupir and other researchers? We first must learn about the nature of the Gulf Dead Zone and the system(s) of which it's a part. Knowing about the nitrogen cycle, denitrifying bacteria and some of the ideas being worked on to reduce the amount of pollution in runoff water will ensure that we are informed before considering solutions to the problem.

HELLO, MY NAME IS: NITROGEN

Module 1, Activity #2

Overview
Students play the role of nitrogen atoms traveling through the nitrogen cycle to gain understanding of the varied pathways through the cycle and the relevance of nitrogen to living things.

Credit: this activity was developed by Lisa Gardiner of the UCAR Center for Science Education; permission was granted for use in this curriculum module

Students will…

- …explain where nitrogen is found on Earth and that nitrogen cycles indefinitely through the Earth system.
- …learn that the cycle is nonlinear traveling between living things and the physical environment.

Time Required: 45 minutes

Materials Needed

- ✓ Copies of stations signs and passport worksheets, as detailed on the UCAR science education website: https://scied.ucar.edu/activity/nitrogen-cycle-game
- ✓ 11 six-sided dice (one for each station)

Teacher Tips

- Putting the materials together for this activity will take about 1 hour. They are all completely re-usable, though, especially if things are laminated.
- Use the discussion questions on the website above to spark conversation. Many of them ask students to make predictions based on the data they've collected.

Activity Procedure

1) Follow instructions indicated on the website shown above.
2) Possible extensions might include:
    a. Ask students to graph the number of times they stopped at each station,
    b. and how many times each station was stopped at total, by all students.
    c. Discuss these results. Do they make sense based on other sources?

SORTING OUT THE NITROGEN CYCLE

Module 1, Activity #3

Overview

Although nitrogen gas (N_2) accounts for about 78% of Earth's atmosphere by volume, much of the nitrogen that's around is unusable by plants and animals, including humans. This activity asks students to sort out the various 'parts' of the nitrogen cycle through the completion of an inductive card sort so that they begin to understand the complex relationships involved.

Students will…

- …create a visual model of the nitrogen cycle.
- …begin to develop an understanding of how nitrogen is transformed through natural processes.

Time Required: 45 minutes

Materials Needed

- ✓ 1 set of cards for each student or group of students

Teacher Tips

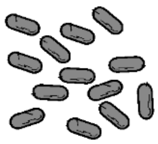
- Inductive card sorts can be a source of struggle for students. Do your best to allow this struggle, as long as it's productive. Ask students to work for 5, 10 or maybe even 15 minutes before they're permitted to ask you questions.
- Encourage student discourse. Conversations within and across groups is a good thing, especially if it's not just seeking the "correct" answer.
- Do your best to NOT provide answers or to do the work for your students.

Activity Procedure

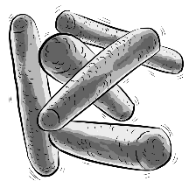
1) Each student or group should be provided a full set of cards (9 pieces).
2) Let students know that the goal of the card sort is to create a visual model of the nitrogen cycle that shows the correct relationships among the various parts represented on the cards. Students SHOULD INCLUDE arrows and any connecting words that help make sense of their model.
3) Allow time for students to work through the card sort. Monitor work closely, listen to discussions and ask probing questions when appropriate.
4) Once students can show you a model that correctly represents the relationships involved, ask students to copy the model into a notebook or onto a separate sheet of paper for future reference.

NITROGEN CYCLE CARDS

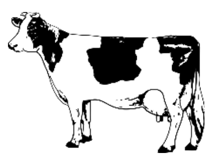
Nitrogen is 'fixed' by bacteria



Nitrifying bacteria convert NH_3 to NO_3^{-1}



Denitrification by bacteria



Animals produce NH_4^{+1} (ammonia), which is converted to NO_2^{-1}

NH_3

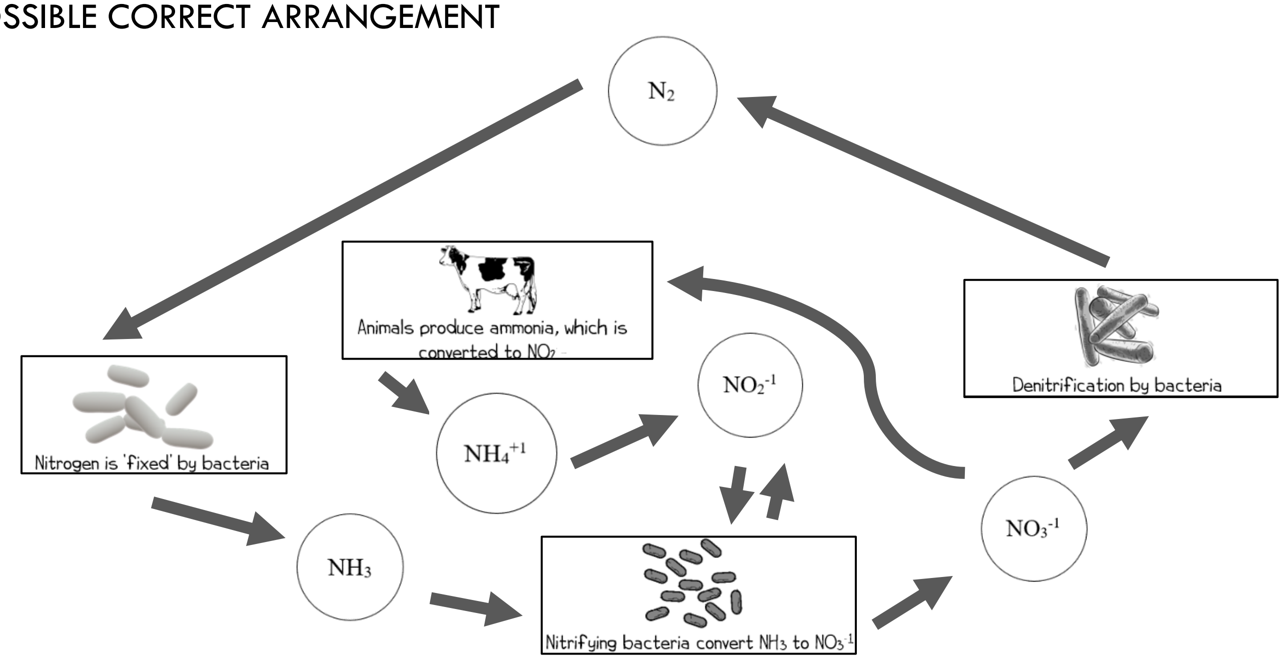
NO_2^{-1}

NH_4^{+1}

NO_3^{-1}

N_2

POSSIBLE CORRECT ARRANGEMENT



MODULE 1 DEBRIEF

Helping Students Make Sense

What did we learn from Activity #1?
The 'Get to Know the Gulf Dead Zone' activity was designed to introduce students to our anchoring phenomenon. Students should have generated questions that aligned with one of the aspects of study written on the posters: the science of the GDZ, social and political issues associated with the GDZ or possible solutions to the GDZ problem. It's important to remind students of these posters and sticky notes as we progress through the unit and continually ask students to revise their questions and answer them, as well.

What did we learn from Activity #2?
The nitrogen cycle game should provide students with a concrete experience that reinforces the learning from their models in activity #2. Students should start to understand that the movement of nitrogen through a system can be impacted by humans and other factors. When the number of organisms is changed, or a farmer spreads fertilizer on a field, the movement of nitrogen is altered in predictable ways. Students should start to form ideas of how these impacts could eventually lead to possible solutions as we continue to learn about the GDZ problems.

What did we learn from Activity #3?
Students should have begun to develop a deeper understanding of the complex system that is the nitrogen cycle. It's important that students begin to connect the various 'parts' of the cycle with events associated with the GDZ phenomenon. The notion of teaching 'scale' may come into play when discussing this activity, given that the nitrogen cycle can take place in a small field while also playing out on a regional or even global scale.

Putting the Pieces Together
At this point in the unit, some students may see the Gulf Dead Zone and nitrogen cycle as unrelated concepts. Other students might be starting to develop conceptual understanding of how human activities can impact the movement of nitrogen, which impacts our anchor phenomenon. Essentially, module 1 is all about setting the stage by putting the pieces of the puzzle on the table. In subsequent modules, students will begin to experience the science that will help them develop possible solutions to the GDZ problems and put the pieces together in a way that creates a clear picture of the issues.

Photo credit: Iowa State University

WHAT'S IN MY WATER?

Module 2, Activity #4 Water Quality Mini-investigation

Overview

In general, we trust that the water we drink and otherwise use in our daily lives is safe. We assume it's free of harmful levels of bacteria, heavy metals, nitrates, and other substances. In this mini-investigation, students will learn about the testable characteristics of a water sample and practice evaluating the quality of a water sample. This learning is important, as it connects module 1's focus on the nitrogen cycle (and nitrates, in particular) to the upcoming woodchip bioreactor investigation.

Students will…

- …explore parameters concerning water quality from different sources.
- …practice analytical skills when accurately collecting data.
- …analyze and interpret data obtained to determine overall quality of water samples.

Time Required: 60 minutes

Materials Needed

- ✓ 5 samples of water from various sources (i.e., tap water, pond water, bottled water, etc.)
- ✓ 5 water quality test strips per group (can be purchased at a pet/aquarium store or similar)
- ✓ Results spreadsheet (hard copy or electronic)
- ✓ 5oz paper or plastic cups (optional)
- ✓ Thermometers (optional)

Teacher Tips

- As you would with any other lab/investigation, review lab safety guidelines prior to beginning the activity. Although there aren't any specific dangers associated with this lab, reviewing general lab safety procedures is required.
- If test strips are in limited supply, you can easily adjust the instructions so that students are using fewer strips (maybe each group only tests one water sample).
- Emphasize the importance of recording data accurately and in an organized manner. The use of labels on data should be required.

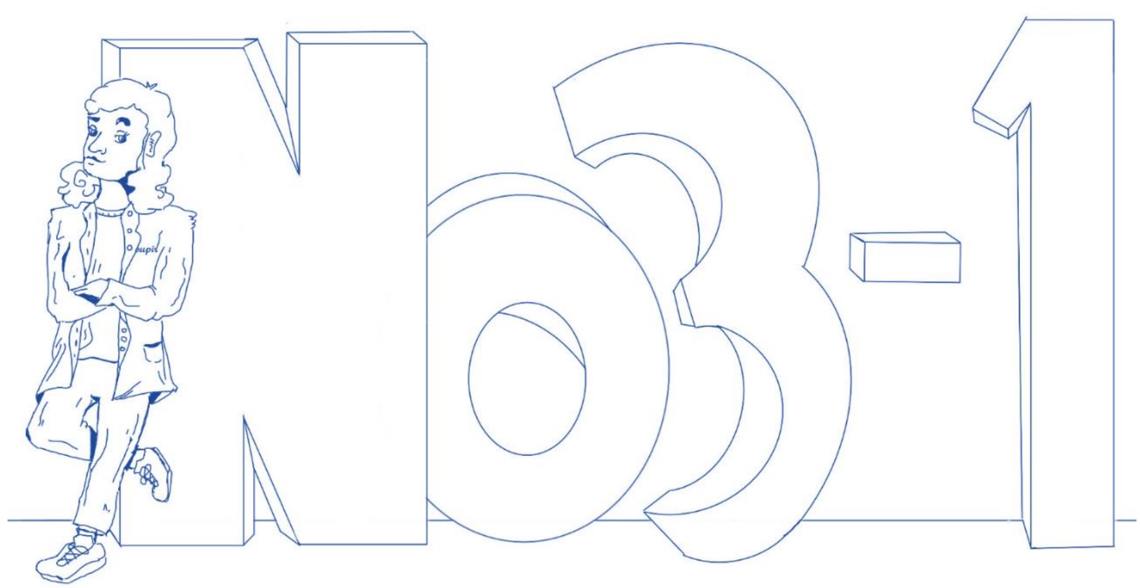
Activity Procedure

1) Each lab group should obtain a small quantity of each water sample. Using small 5oz cups works well, as they're deep enough to completely submerge the test strips.
2) Determine which characteristics (pH, nitrates, chlorine, temperature, etc.) of the water students will test. You may have all students test all characteristics or assign certain characteristics to only a few groups. *This decision is largely dependent on the kind of test strip you have.*
3) Students use their test strip(s) to collect data for their assigned characteristic(s), while recording their data in the provided table.

4) After data has been obtained, ensure that all students have all data points. This can happen through a class discussion, use of an online, sharable spreadsheet or facilitating small group discussions during which students share data with each other.
5) Ask students to analyze the data to determine the quality of each water sample. What are some of the characteristics on which we place higher importance? Why?
6) Provide students with the EPA's drinking water guidelines, which can be found as a PDF at the link below. Ask students to 1) analyze their findings against the EPA's acceptable limits for the characteristics they tested and 2) discuss why the different water quality parameters being tested are important. EPA Guidelines link: https://www.epa.gov/sites/production/files/2016-06/documents/npwdr_complete_table.pdf

SAMPLE DATA TABLE (students should create a table based on the data being collected)

	Bottled Water	Pond Water	Tap Water	Water from Local Stream	Swimming Pool Water
pH					
Temperature (deg C)					
Total chlorine (ppm)					
Iron (ppm)					
Nitrates (ppm)					
Lead (ppm)					



BIOREACTOR MATERIALS RESEARCH

Module 2, Activity #5

Overview

Prior to investigating the effectiveness of various materials in classroom-scale "woodchip" bioreactors, it is important for students to know a little about the materials being used and the criteria for materials if they're to be used in a denitrifying bioreactor. Can any material be used to remove nitrates from groundwater? In this activity, students will investigate the various material options in order to be better informed moving into activity #6.

Students will…

- …obtain, evaluate and communicate information about the basic properties of various materials and potential usefulness as a substrate in a denitrifying bioreactor.
- …begin to develop an understanding of what criteria are necessary for materials to serve as substrates in denitrifying bioreactors.

Time Required: 45 minutes

Materials Needed

- ✓ Sources of information to use for research (computers, smart phones, encyclopedias, etc)
- ✓ Samples of each material for students to interact with:
  - Cedar mulch
  - Carbon sticks, ceramic rings, "bio balls" (filter media kit available from Amazon.com at this link: http://a.co/de2cV0B)
  - Hickory, oak or pine wood chips/mulch
  - Rubber mulch (available at most home centers)
  - Other substrates, which might include lava rock, charcoal, corn stover, corn cobs.

Teacher Tips

- It's important that students physically interact with the various materials used in this activity. Make the materials available to be handled and felt.
- Through conversations and discussions, the teacher should help students start to equate the physical properties of the materials with their abilities to house denitrifying bacteria, and thus, have the ability to denitrify water.
- Results from the research done in this activity should be kept in a notebook for use during activity #6.
- In order for denitrifying bioreactors to work, there are 3 important conditions that are necessary: anaerobic conditions, food (carbon source) and the presence of denitrifying bacteria.

Activity Procedure

1) Briefly discuss with students the idea that woodchip/denitrifying bioreactors offer one possible solution to the Gulf Dead Zone problems observed during activity #1. The goal of this activity is to begin to understand how bioreactors work, and to consider alternative materials to woodchips (and/or the best type of woodchip) that might be used in bioreactors.
2) Introduce students to the available materials. Pass samples around the classroom or have students look at the samples at lab stations. Students should record observations in a table similar to the one below, and/or in a science notebook, for use later.
3) Once students have recorded physical observations, they should move on to doing online research to learn more about each material. Students should record what the materials are made of and whether or not they could serve as a food source for denitrifying bacteria (do they contain usable forms of carbon?).
4) Discuss findings with students. This can be structured as a whole-class discussion or managed in small groups or pairs. Consider the following questions:
   a. Which materials contain carbon that could serve as a food source for bacteria?
   b. Do any of the materials have surfaces that might be preferred by bacteria?
   c. What additional questions do you have as you consider these possible materials for use in denitrifying bioreactors?

SAMPLE INFORMATION TABLE (students should record data in a way that best makes sense)

Material	Physical Characteristics		What is the material made of?	Do you think it contains carbon in a useable form?	Would this make a good material to use in a denitrifying bioreactor?
	Surface texture	Density (1=low density, 5=high density)			
Cedar mulch					
Ceramic rings					
Carbon sticks					
Plastic "bioballs"					
Rubber mulch					
Other wood/mulch types					

DENITRIFYING BIOREACTOR EXPERIMENT

Module 2, Activity #6

Overview

Activity #6 is divided into two parts. Activity #6a focuses on helping students use what they've learned to plan and carry out an investigation. They will use the Lab-O-Matic to organize themselves and design a well-developed, valid experiment that can be done in the classroom. The goal of these experiments will be to determine the effectiveness of various materials as substrates in denitrifying bioreactors. Classroom-scale bioreactors can be set up and monitored over time, which is the primary focus of activity #6b. Teachers can decide how much freedom is given to students when developing their experiments, but all experiments should address questions related to the anchor phenomenon - the Gulf Dead Zone.

Students will…

- …plan an investigation which is valid and addresses issues raised as part of the anchor phenomenon.
- …analyze and interpret data collected during the investigation.
- …communicate findings to classmates in appropriate ways.

Time Required:

Activity #6a 45-60 minutes
Activity #6b 30 minutes to set up, ongoing monitoring for 3-10 days

Activity #6a

Materials Needed

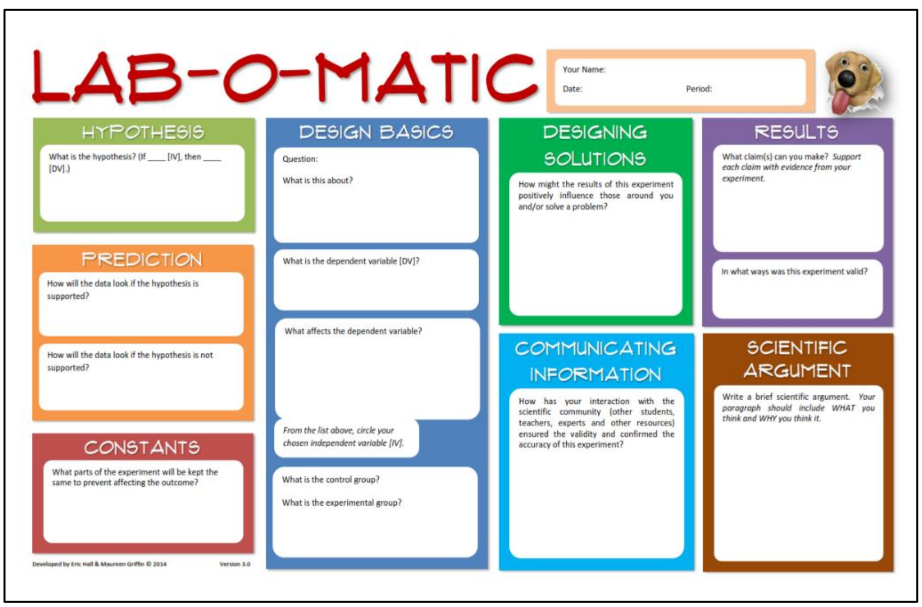
- ✓ Copies of the Lab-O-Matic, either from this booklet or downloaded from https://hallscience.us/lab-o-matic. Note: the online version must be printed on 11x17" paper, however the version in this booklet can be printed front/back on 8.5x11" paper.
- ✓ Vocabulary Lab-O-Matic support materials (optional)
- ✓ Mini Lab-O-Matic (optional)

Teacher Tips

- If you haven't already, it is essential that you read through the Companion Guide to the Lab-O-Matic, which can be found at https://hallscience.us/lab-o-matic. It contains valuable information about each section of the Lab-O-Matic as well as rubrics and discussions about how to best introduce students to this innovative tool.
- You know your students! If the "full" Lab-O-Matic seems too daunting for some students, you may opt to use the mini Lab-O-Matic, instead. Also, if this is one of the first times experimental design has been discussed, using the vocabulary-building resources at https://hallscience.us/lab-o-matic would be wise. You'll find vocabulary cards and sample experiments with key aspects identified to help students better ease into the Lab-O-Matic experience.
- It's important that the Lab-O-Matic be evaluated before students move on to activity #6b. Misconceptions about various aspects of experimental design can be dealt with at this time, before students begin carrying out their investigations.

Activity #6a Procedure

1) Provide students with a copy of the full Lab-O-Matic, unless you've determined that using the mini Lab-O-Matic is a better option (see teacher tips, above).
2) As mentioned in the Lab-O-Matic Companion Guide, students may begin in any section and work their way around the Lab-O-Matic, until all aspects of their investigation have been thought out and recorded.
3) Circulate and help students who might struggle with the Lab-O-Matic. Students often have difficulty identifying a testable hypothesis, so teachers are encouraged to use the "If, then" method of hypothesis writing. For example, "if I double the mass of wood chips used, then the amount of nitrates present will decrease by half in a given time".
4) All portions of the Lab-O-Matic should be completed, except for "Communicating Information, Results, and Scientific Argument". These sections should be completed after the experiment is done.



Activity #6b

Materials Needed

- ✓ Materials for use as substrates in students' bioreactors, selected from activity #5
- ✓ 1-quart plastic containers with lids
- ✓ Standard nitrate solution, enough for approximately 500mL per container used (see Appendix B for instructions)
- ✓ Water quality test strips, as needed
- ✓ Gloves for lab safety (latex, nitrile, etc)

Teacher Tips

- As you would with any other lab/investigation, review lab safety guidelines prior to beginning the activity. Students should wear gloves when interacting with the inside of the "bioreactor" containers.
- Students should focus on manipulating one variable at a time, of course. Ensure that each experiment is set up in a way that will yield valid results and allow students to collect meaningful data for analysis.
- Bioreactors should be constructed in 1-quart plastic containers, with lids. It is suggested that each container be filled ½ with the substrate material (woodchips, ceramic rings, etc.) and then filled up completely with standardized nitrate solution.
- Over time, some of the bioreactors will begin to smell due to bacteria growth. This is both good and bad, since bacteria are necessary for denitrification, but it can make a classroom stink! Keep the lids on the containers as much as possible and things should be fine.
- Remember - these experiments will serve as "proof-of-concept" investigations, and do not exactly replicate a denitrifying bioreactor. The main difference is that full-scale bioreactors move water through, flowing over the substrate (woodchips). Students would need to assess the ability of the water to flow over/through their chosen material.

Activity #6b Procedure

5) Once students have successfully planned their investigations, it's time to begin the experiments. Each student should be provided with the materials he/she wants to use in the experiment (i.e., wood chips, ceramic rings, etc.).
6) To standardize the baseline/starting amounts of nitrates in the bioreactors, teachers should make a standard nitrate solution using the instructions in Appendix B.
7) Students should set up their experiments as explained in the Teacher Tips above, take initial measurements (based on the variables they selected) and record their data.

Photo of bioreactor setup in 1-quart plastic containers.

8) It is suggested that bioreactors be monitored daily using test strips for at least 3 days to see significant changes in nitrate concentrations or other water quality factors.
9) Students should record all data in a notebook and/or shared spreadsheet for analysis after experiments have been completed.
10) Students should take time to finish the "Communicating Information, Results, and Scientific Argument" sections on their Lab-O-Matic.
11) As you consider ways to best debrief this activity, consider the following as options:
    a. Show the video at: https://youtu.be/pQKtbDFd4A0, and ask students to consider how their classroom-scale bioreactors were similar/different to the ones in the video.
    b. Discuss the validity of the experiments - were all aspects of a well-designed experiment present? If not, how could we improve them?
    c. Finally, connect back to the anchor phenomenon: how might the results of our experiments help us to develop a possible solution to the Gulf Dead Zone problem?

Lab-o-Matic

Name ________________________ Class ______________ Date _______

HYPOTHESIS

What is the hypothesis? (If ____ [IV], then ____ [DV].)

PREDICTION

How will the data look if the hypothesis is supported?

How will the data look if the hypothesis is not supported?

CONSTANTS

What parts of the experiment will be kept the same to prevent affecting the outcome?

DESIGN BASICS

Question:

What is this about?

What is the dependent variable [DV]?

What affects the dependent variable?

From the list above, circle your chosen independent variable [IV].

What is the control group?

What is the experimental group?

 Version 3.0

DESIGNING SOLUTIONS

How might the results of this experiment positively influence those around you and/or solve a problem?

RESULTS

What claim(s) can you make? *Support each claim with evidence from your experiment.*

In what ways was this experiment valid?

COMMUNICATING INFORMATION

How has your interaction with the scientific community (other students, teachers, experts and other resources) ensured the validity and confirmed the accuracy of this experiment?

SCIENTIFIC ARGUMENT

Write a brief scientific argument. *Your paragraph should include WHAT you think and WHY you think it.*

DNA ANALYSIS OF BIOREACTOR MICROBE ECOSYSTEMS

Module 2, Activity #7

Overview

Water quality researchers frequently study the types and quantities of denitrifying bacteria that make their homes in woodchip bioreactors. Samples of water from streams, ponds, and even soil from farmland contain many different types of bacteria. In this investigation, one particular type of bacteria catches the interest of a researcher. They know that these bacteria efficiently remove nitrates from groundwater and farmland run-off, but they're unsure what kind of bacteria it is. So, let's plan to investigate and find out!

They have collected several different known kinds of bacteria, along with an unknown bacteria sample from a super-efficient woodchip bioreactor. DNA was extracted from the bacterial cells and collected it in small microcentrifuge tubes. Now, the researcher needs to use high-tech biotechnology processes and equipment to determine if your unknown sample matches any of the known bacteria.

Students will…

- …use appropriate biotechnology tools to analyze and evaluate DNA fingerprinting data.
- …evaluate the impact of new DNA fingerprinting data on the working explanation of what's causing the Gulf dead zone.
- …ask additional questions to clarify and continue refining their model and explanation.

Time Required:

2 or 3 45-minute class periods

Activity #7

Materials Needed

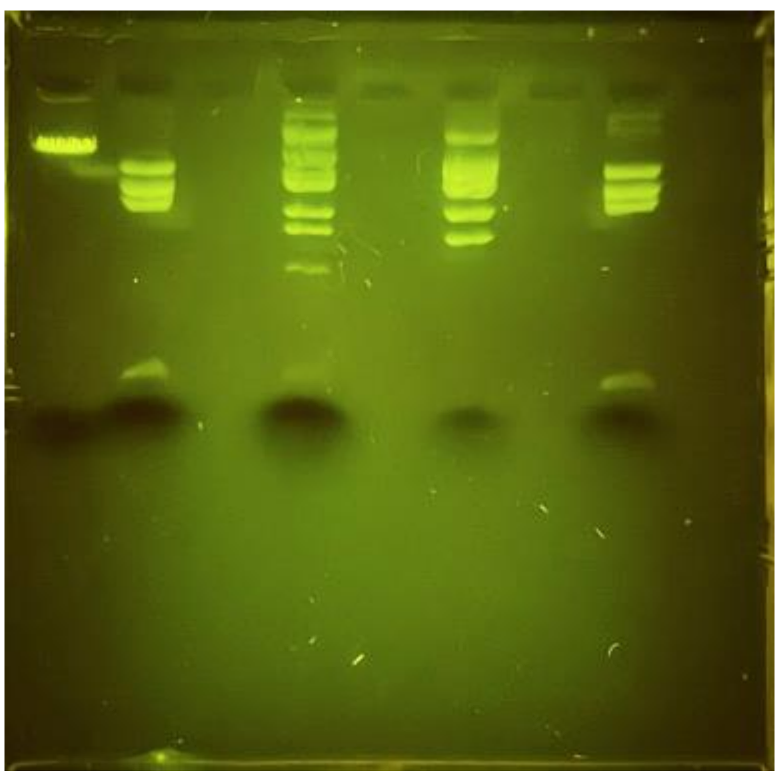
- ✓ Copies of the "DNA Fingerprinting with blueGel™ 2022" student booklet
- ✓ blueGel™ gel electrophoresis system from the Biotech Outreach Education Center (BOEC)
    - o One gel for every two groups
    - o Groups may contain 3-5 students, depending on class size
    - o The BOEC will lend up to 5 blueGel systems per teacher at one time
- ✓ DNA and other consumables needed for gel electrophoresis
    - o This can be requested from the BOEC
    - o The BOEC can provide supplies for up to 5 classes of students

Teacher Tips

- This investigation is optional for most classrooms. While it provides students with an engaging experience in using biotechnology to help solve the Gulf dead zone problem, it's not required for students to successfully navigate the unit storyline.
- Free supplies and equipment can be requested by teachers who have successfully participated in the "Innovative Practices: Woodchip Bioreactors" workshop at Iowa State University. The Biotechnology Outreach Education Center (BOEC) will send consumables and gel electrophoresis equipment to those needing it.
- Bacterial DNA provided by the BOEC was not actually collected from woodchip bioreactors. We send various types of common plasmid DNA to help students understand how gel electrophoresis can be used to make arguments and solve problems.
- If successful, students will find out that the unknown bacterial sample from the "super-efficient" bioreactor matches one of the known samples. While not overly-helpful in solving the GDZ problem, students may use the information to consider questions about how to further improve the efficiency of a woodchip bioreactor by modifying the bacteria found within.

Activity #7 Procedure

1) Use the supplemental "DNA Fingerprinting" booklet for student instructions.



MODULE 2 DEBRIEF

Helping Students Make Sense

What did we learn from Activity #4?
Students became more familiar with the analysis of water and some of its properties/qualities that we can study. The Gulf Dead Zone phenomenon is all about water quality, so it only makes sense that students need to know what aspects of water are most closely related to the GDZ issues. Although many of the properties students measured in this activity will not be part of the final solution, having a context and perspective on which they can draw later will be helpful.

What did we learn from Activity #5?
Activity #5 was all about learning how denitrifying bioreactors work…or, are supposed to work. Although much of the current research is being done using woodchips, scientists are looking into other options, and trying to decide if woodchips are the most effective material to use. This activity is really all about students learning about the requirements necessary for denitrification to take place in a bioreactor, and which substances will best support those conditions.

What did we learn from Activity #6?
This activity was packed with learning! Not only were students tasked with carrying out an investigation to continue making sense of our anchor phenomenon, but they were introduced to the Lab-O-Matic and some of the more complex aspects of experimental design. Through their experimentation, students should have learned that some materials/substrates are capable of helping to create the conditions necessary for denitrification to take place (i.e., semi-rough surface, usable carbon source for 'food', and a lack of antibiotic properties). Results from their experiments are sure to be mixed, and there are some inherent difficulties with the investigation, but it should have sparked some discussion around bioreactor set-up and effectiveness.

What did we learn from Activity #7?
This DNA fingerprinting investigation was designed to help students incorporate one more piece of information into their mental model relating to the GDZ problem. Students should have discovered that one type of bacteria was present in greater quantities than others in the "super-efficient" bioreactor it was collected from. Conversations can be had about how this knowledge might help improve the efficiency and effectiveness of woodchip bioreactors as they're used to remove nitrates from surface water sources.

Putting the Pieces Together
At this point, students should be able to see how nitrogen (nitrates), woodchip bioreactors and the Gulf Dead Zone are related. Students should be asking questions like "if nitrates are part of the problem in the Gulf, how can we help reduce the amount of them that comes from our area?" or "how many of these bioreactors would we need to really impact the Gulf Dead Zone problem?". It's crucial that teachers help connect each activity back to the anchor phenomenon in concrete ways, and allow students to reflect on their initial sticky note questions so they understand how their work has helped them to answer some of their questions.

CHESAPEAKE BAY CASE STUDY

Module 3, Activity #8 Debating an Approach to Improved Water Quality

Overview
This activity will engage students in a case study-style research project, culminating in a classroom debate. Students will be asked to support one of five parties involved in the Chesapeake Bay water quality problem, create an argument and briefly present the position to other students.

Students will…

- …engage in argument from evidence provided in a variety of sources.
- …obtain, evaluate and communicate information in a way that persuades others to appreciate the position presented.
- …generalize information in a way so that it can be used in other settings.

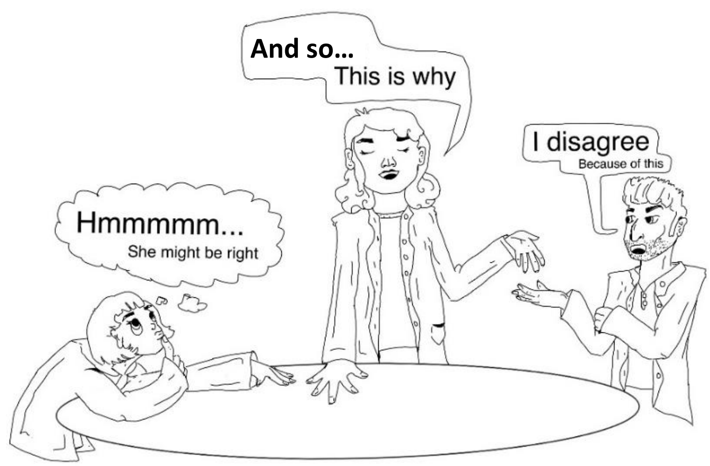
Time Required: 60 minutes

Materials Needed

- ✓ Copies of the Chesapeake Bay Total Maximum Daily Load (TMDL) EPA Fact Sheet
- ✓ Computers or smart phones for online research
- ✓ Notebook or other way to organize findings

Teacher Tips

- The goal of this activity is to begin looking at the social and political issues that surround water quality and watershed management. Students should develop and understanding and empathy for those involved in these complex problems and use that information as they develop solutions to the Gulf Dead Zone.
- Students should be placed in "expert groups" to do the initial learning about their stakeholder's perspective. The debate portion of the activity will take place as a whole-class discussion, so make sure strategies are used to ensure equal voice among all students.



- Appendix A contains some talking points that may be of use when preparing for and facilitating this discussion.

Activity Procedure

1) Ask students to quietly read the Chesapeake Bay TMDL Fact Sheet. You may want to use a close-reading strategy, highlighting, or annotating to help students process the information in the fact sheet. Discuss any questions briefly as a class.
2) Divide students into five groups. Each group will represent one of the stakeholders: agricultural interests (i.e., Farm Bureau), Environmental Protection Agency (EPA), Municipalities/point source dischargers, the fishing industry, and the TMDL model development team.
3) Students should research their stakeholders' positions on the Chesapeake Bay TMDL development and enforcement. Students should work together in these "expert groups" to develop a 3-5 minute presentation which outlines whether or not the TMDL development and implementation should change, or why the current approach is best. It is important that students include background research to support their position.
4) Once research has been done and groups have had a chance to develop their arguments based on the evidence they gathered, each group should present their position to the rest of the class. Students with other positions should be allowed to question and rebut the presented argument.
5) As a class, attempt to come to consensus regarding how the Chesapeake Bay TMDL should move forward, including any recommended changes in the process.
6) During discussion, consider the following questions:
    a. Was the public participation component of TMDL development sufficient?
    b. Are students personally - regardless of the position they were asked to assume - supportive of or against the EPA's approach to implement the watershed management plans?
    c. Are there any flaws in the EPA's approach to developing the TMDL?
7) Finally, relate this activity back to our anchor phenomenon. Discuss questions like "could a TMDL like the one for Chesapeake Bay be considered as a possible solution for the Gulf Dead Zone problems?".

CHESAPEAKE BAY TMDL FACT SHEET

What is the Issue?

On December 29, 2010, the U.S. Environmental Protection Agency established the Chesapeake Bay Total Maximum Daily Load (TMDL), a historic and comprehensive "pollution diet." This TMDL includes accountability features to guide sweeping actions to restore clean water in the Chesapeake Bay and the region's streams, creeks and rivers.

Map of the Chesapeake Bay Watershed. The watershed encompasses six states and the District of Columbia.

Despite extensive restoration efforts during the prior 25 years, the TMDL was prompted by insufficient progress and poor water quality in the Chesapeake Bay and its tidal tributaries. The TMDL was required under the federal Clean Water Act and responded to consent decrees in Virginia and the District of Columbia from the late 1990s. It was also a keystone commitment of a federal strategy to meet President Barack Obama's Executive Order to restore and protect the Bay.

The TMDL is the largest ever developed by EPA, encompassing a 64,000-square-mile watershed. The TMDL identifies the necessary pollution reductions from major sources of nitrogen, phosphorus and sediment across the Bay jurisdictions and sets pollution limits necessary to meet water quality standards. Bay jurisdictions include Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia and the District of Columbia.

Specifically, the TMDL set Bay watershed limits of 185.9 million pounds of nitrogen, 12.5 million pounds of phosphorus and 6.45 billion pounds of sediment per year. This equates to a 25 percent reduction in nitrogen, 24 percent reduction in phosphorus and 20 percent reduction in sediment.

The pollution limits were further divided by jurisdiction and major river basin based on state-of-the-art modeling tools, extensive monitoring data, peer-reviewed science and close interaction with jurisdiction partners. The TMDL is designed to ensure that all pollution control measures needed to fully restore the Bay and its tidal rivers are in place by 2025. The TMDL also calls for practices to be in place by 2017 to meet 60 percent of the overall nitrogen, phosphorus and sediment reductions. The final TMDL was shaped by an extensive two-year public involvement effort and, in large part, by final Phase I Watershed Implementation Plans (WIPs). The Phase I WIPs were developed by the jurisdictions and detailed how and when the jurisdictions would meet pollution allocations.

The TMDL also included targeted “backstop allocations” for areas where the WIPs did not meet the allocations or EPA’s expectations of reasonable assurance that those allocations would be met. These areas required a plan for enhanced oversight and contingency actions to ensure progress. Also, EPA committed to reducing air deposition of nitrogen to the tidal waters of the Bay from 17.9 to 15.7 million pounds per year through federal air regulations.

The Chesapeake Bay TMDL is unique because of the extensive measures EPA and the jurisdictions have adopted to ensure accountability for reducing pollution and meeting deadlines for progress. The accountability framework includes the WIPs, two-year milestones, EPA’s tracking and assessment of restoration progress and specific federal actions if the jurisdictions do not meet their commitments.

Addressing the Challenges

A TMDL is the calculation of the maximum amount of pollution a body of water can receive and still meet state water quality standards. Water quality standards are designed to ensure waterways meet a national primary goal of being swimmable and fishable. When the TMDL was established, monitoring data continued to show that the Bay had poor water quality, degraded habitats and low populations of many species of fish and shellfish.

The Bay and its rivers are overweight with nitrogen, phosphorus and sediment from agricultural operations, urban and suburban runoff, wastewater, airborne contaminants and other sources. The excess nutrients and sediment lead to murky water and algae blooms, which block sunlight from reaching and sustaining underwater Bay grasses. Murky water and algae blooms also create low levels of oxygen for aquatic life, such as fish, crabs and oysters.

The Bay TMDL is actually a combination of 92 smaller TMDLs for individual Chesapeake Bay tidal segments. It includes pollution limits sufficient to meet state water quality standards for dissolved oxygen, water clarity, underwater Bay grasses, and chlorophyll a, an indicator of algae levels. This image shows a newly planted riparian buffer in the Chesapeake Bay Watershed. This is just one best management practice (BMP) that jurisdictions are implementing to help restore the Chesapeake Bay.

Actions under the TMDL will also have significant benefits far beyond the Chesapeake Bay itself. Benefits include helping to clean rivers and other waterways that support local economies and recreational pursuits like fishing and swimming, and serve as drinking water sources.

In 2012, the jurisdictions submitted Phase II Watershed Implementation Plans designed to strengthen the initial cleanup strategies and reflect the involvement of local partners. They also submitted sets of two-year milestones in 2012 and 2014 outlining near-term restoration commitments. Phase III WIPs in 2017 will be designed to provide additional detail of restoration actions beyond 2017 and to ensure that the 2025 goals are met.

A PART OF THE SOLUTION

Module 3, Activity #9 — A Document-Based Case Study

Overview

This is the final activity in the unit. It is designed to be a summative task, of sorts. Document-based case studies (DBCS) ask students to make a decision or evaluate a possible solution based on information presented in a variety of "documents". Students should use the information presented in the case study and what they learned during the previous activities to draw conclusions and create a final product that demonstrates the targeted learning. In this case, students will write an email to a family friend either supporting or refuting the notion of using woodchip bioreactors as a possible, partial solution to the nitrate runoff problem that's ultimately contributing to the Gulf Dead Zone problem.

Students will…

- …use evidence presented to engage in argument from evidence.
- …write a cohesive, substantive response to the provided prompt.
- …demonstrate knowledge of woodchip bioreactors, the nitrogen cycle and the Gulf Dead Zone and how the 3 are interrelated.

Time Required: 45-60 minutes

Materials Needed

- ✓ Copies of the "A Part of the Solution" document-based case study

Teacher Tips

- It is sometimes helpful to model the analysis of a document, prior to students beginning work. Read through a sample document with students, discuss the analysis prompts provided, and review the final product with them.
- Although not provided in this booklet, a rubric for the final written response is necessary. Students should be provided the rubric prior to beginning the activity to ensure clear communication of expectations and grading requirements.

Activity Procedure

1) Each student should have a copy of the case study, including cover page, document collection and final summary/argument page.
2) Read through the cover page with students, then model the first document (or a sample document) analysis as mentioned in the Teacher Tips above.
3) Provide students time to work through the case study and write up their final summary and argument.

A Part of the Solution

A Document-based Case Study

Student name ____________________________ Class ____________ Date ___________

INSTRUCTIONS
You are about to begin an activity that is designed to measure your skills in critical thinking, reasoning, problem solving and written communication. In addition to these "think-like-a-scientist" skills, your knowledge about the nitrogen cycle, woodchip bioreactors and the Gulf Dead Zone will also be evaluated.

You will be preparing a written response to a hypothetical, but realistic situation. This activity contains a series of documents that includes a range of information sources. While your personal values and experiences are important, you should base your response on the evidence provided in these documents and the learning you've done as part of this unit.

THE SCENARIO
A friend of your family, Patty Stover, has come to you asking for help. She's a farmer just outside of your city and knows that you have been studying about nitrates and water quality in school. Your parents have invited Patty over for dinner, but a soon as she enters your home, she starts asking you questions about what she should do!

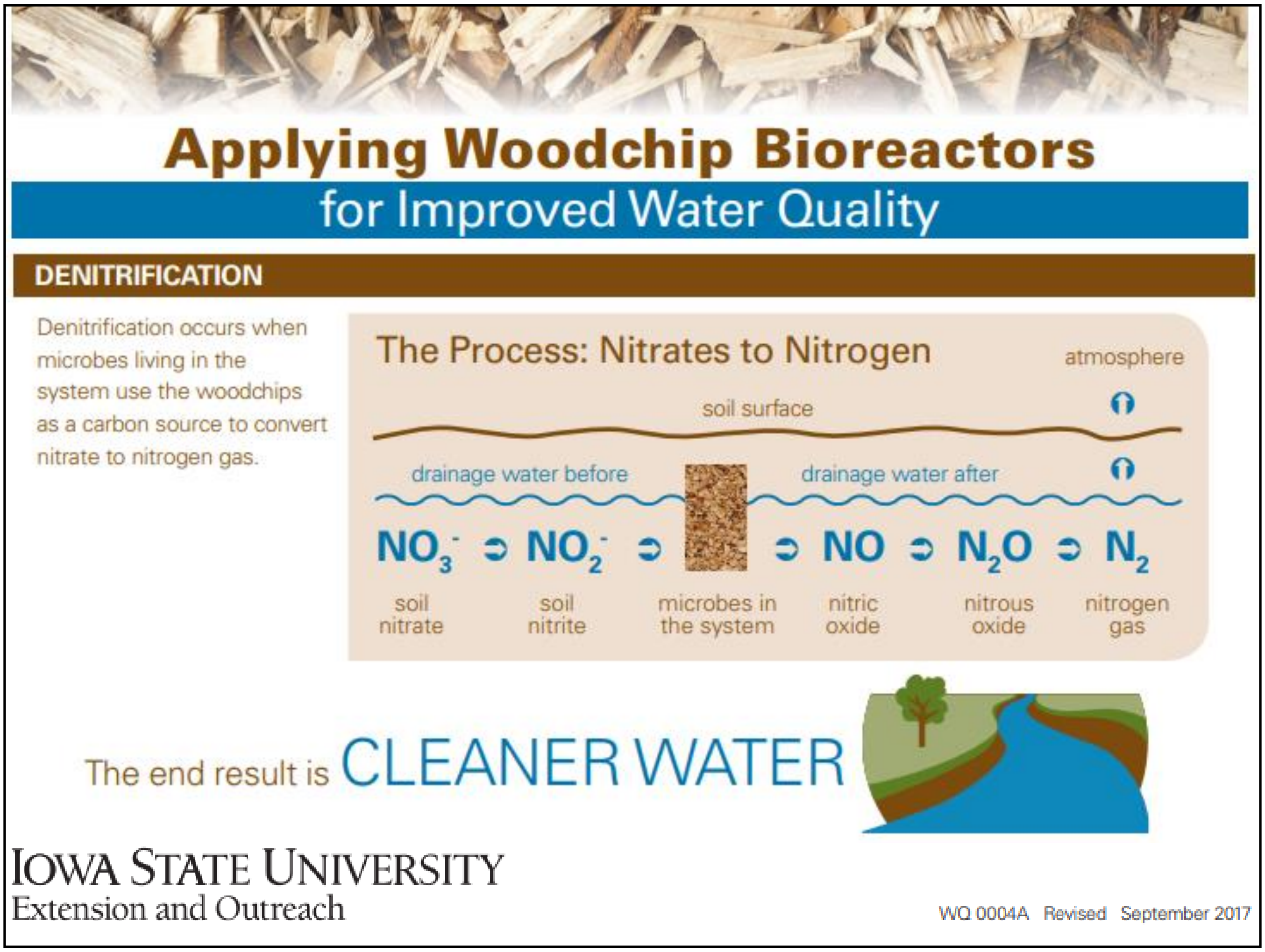
Patty's been fined by the local government because of the amount of nitrates she's putting into a small stream that runs through her farmland. The stream eventually empties into a larger river, which flows into the Mississippi River. Patty farms mostly corn and soybeans and is generally very conscientious when it comes to using sustainable practices.

By the end of dinner, Patty has asked you to advise her on a new technology she's heard about. Woodchip bioreactors, she says, are being researched at Iowa State University and might just be the answer she's looking for to reduce the amount of nitrates going into nearby water ways. But she also knows there are some problems that go along with them, as well.

THE QUESTION
After analyzing the following documents, and using the knowledge you've gained during this unit, you must answer the following question: should Patty implement the use of woodchip bioreactors on her farmland?

Once you decide on an answer, you need to write a brief email to Patty. Let her know what your answer is and include specific evidence that supports your decision. Your argument may include information from the activities you've done as part of your class work, too.

Document A



Document description: ____

Source (if known):_________________________________ Date: ___________

What aspects of the problem does it address?

- ☐ Water quality
- ☐ Social or political issues
- ☐ Woodchip bioreactors
- ☐ Nitrogen Cycle

How does this document support the use of woodchip bioreactors?

How does this document support NOT using woodchip bioreactors?

Document B

IA NRS Cost Tool Overview Tyndall & Bowman, 2016

Edge of Field Practice

Table 2. First year and annualized costs of a denitrifying bioreactor designed for a 50-acre drainage area. Annualized using a 4% discount rate. Costs are in 2016$.

First year costs (Design and installation)	$10,150 [1,2]
Annualized costs over 20 year lifespan	$675 [3]
Annual management costs	~ $50

1. No productive land is removed from production so opportunity costs are negligible. The vast majority of total costs are in installation and in chip replacement after 20 years; **2.** Iowa 2016 EQIP program will pay $24.85 per cubic yard of bioreactor pit excavation assuming the practice is maintained for at least 10 years. (The Iowa 2016 EQIP payment schedule: http://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd420279&ext=pdf (Bioreactors, page 108);
3. Costs were calculated and annualized using standard discounted cashflow procedures for structural water quality Best Management Practices. For more detail see Tyndall and Roesch, 2014.

Document description: ____

Source (if known):__________________________________ Date: ___________

What aspects of the problem does it address?

- ☐ Water quality
- ☐ Social or political issues
- ☐ Woodchip bioreactors
- ☐ Nitrogen Cycle

How does this document support the use of woodchip bioreactors?

How does this document support NOT using woodchip bioreactors?

Document C

Woodchip Bioreactors for Nitrate in Agricultural Drainage

Water Quality

How much nitrate will a woodchip bioreactor remove? How big an impact will I have?

A bioreactor's annual nitrate load reduction can range from about 10 percent to greater than 90 percent depending on the bioreactor, the drainage system, and the weather patterns for a given year. Based on research from Iowa, Illinois, and Minnesota, most bioreactors show performance of about 15 to 60 percent nitrate load removed per year. It may be best to target fields or watersheds that have higher nitrate loads in order to have the biggest impact.

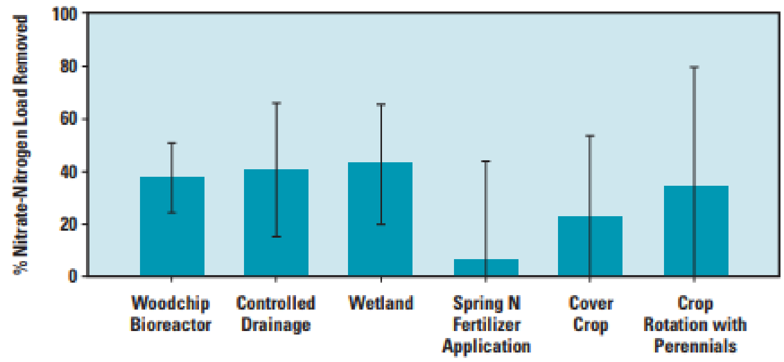


Figure 8. Comparison of nitrate removal from bioreactors and other practices; bar shows the average removal with the whisker showing plus and minus one standard deviation (adapted from data from the authors)

IOWA STATE UNIVERSITY
Extension and Outreach

Document description: ____

Source (if known):_________________________________ Date: ___________

What aspects of the problem does it address?

- ☐ Water quality
- ☐ Social or political issues
- ☐ Woodchip bioreactors
- ☐ Nitrogen Cycle

How does this document support the use of woodchip bioreactors?

How does this document support NOT using woodchip bioreactors?

Document D

STORY COUNTY, Iowa — When the Iowa legislature convenes in Des Moines, politicians say addressing the state's water quality will be near the top of the agenda. Senate File 512 proposes to increase funding and expedite the installation of water-cleaning equipment, such as bioreactors, by farmers.

Wood chips are used in bioreactors to filter out nitrates found in farm run-off.

"They're quite expensive, and to be honest, we don't benefit economically from bioreactors as farmers," said Patty Stover, who farms 1100 acres in Polk and Story counties. "We feel good knowing our water is cleaner leaving our farm than it was coming in, but the economics aren't there unless you can obtain some help from a federal or state government."

In June of 2020, Stover installed a bioreactor on her property. Stover's installation of a bioreactor was swift; the entire operation took less than two months from start to finish. Stover claims that her bioreactor now filters 55-60 acres of land and nearly eliminates the nitrates present in his farm's water run-off.

Stover, who produces maize and soybeans as well as several dozen acres of hay, said, "In my view, we started the process this spring and it's still involved in the engineering portion of it."

Document description: ____

Source (if known):________________________________ Date: ___________

What aspects of the problem does it address?

- ☐ Water quality
- ☐ Social or political issues
- ☐ Woodchip bioreactors
- ☐ Nitrogen Cycle

How does this document support the use of woodchip bioreactors?

How does this document support NOT using woodchip bioreactors?

Your Decision

What will you tell farmer Patty about the use of woodchip bioreactors on her land?

In the space below, write an email to Patty. Make sure you include your decision about her use of woodchip bioreactors to reduce the amount of nitrates running off her farm fields, as well as the evidence that you used to make your decision. Evidence can come from Documents A-D and from the activities you've done during your study of bioreactors and the Gulf Dead Zone.

APPENDIX A

CHESAPEAKE BAY CASE STUDY TALKING POINTS

Use the following teacher notes as a guide for Module #3, Activity #7.

Representing…	**Key argument points**
Farm Bureau & commodity groups	• Farmers have low profits and cannot afford to spend money on conservation practices or to take any land out of production (same argument when prices are high) • They care about the environment, soil conservation, and rural communities – just can't afford to change the system • Federal policy is the problem
EPA	• Agency is trying to meet the demands and expectations of many different groups • They are using the best science out there, even if some disagree • Cannot please everyone
Municipalities/point source dischargers	• Regulated as a nonpoint source • Technological advances for further nutrient reduction in discharges will be very expensive • Because they are regulated, they have been forced to already meet reductions, not fair because the agriculture community is not regulated
Fishing industry	• Our industry is suffering (students can look up details on declining fish populations due to pollution) • High demand for seafood • Community suffers when fishing can no longer support families

APPENDIX B

MAKING A NUTRIENT SOLUTION

The following protocol should be used to make the nutrient solution for the bioreactor experiment – Module #2, Activity #6

Easy Recipe- Artificial Tile Drainage-Nutrient Solution

The synthetic tile drainage recipe used for our denitrifying bioreactor studies include calcium chloride, potassium phosphate, boric acid, manganese sulfate, zinc sulfate, cupric sulfate, sodium molybdate, potassium nitrate, potassium sulfate, and magnesium sulfate. **For classroom purposes, a much simpler method (or recipe) for synthetic tile drainage solution can be made using readily available plant food.** A short list of products, including their nutrient contents, is included for reference. **It is important to make sure the product you use includes nitrate (NO_3) as one of its nitrogen forms.**

To determine the quantity of product needed to make your solution, first decide the concentration of NO_3-N you will use, then the volume of solution you will need for your classroom. I will use common high NO_3-N concentration of 20 mg N/L for an example calculation. It is also easier to prepare an extremely high concentrated working solution so there is more room for error in your product measurements.

Preparing a working solution. If making small batches of nutrient solution, it is easier to first prepare a highly concentrated working solution because of the small amount of plant food that would be needed in a single 10 L batch of solution.

a. For this example, we will prepare 1-L of working solution, and plan to add 10 mL of working solution per 1-L of 20 mg NO_3-N/L synthetic drainage solution.

b. For each 10 mL of working solution, we will add 20 mg NO_3-N.

   20 mg NO_3-N/10 mL working solution × 1-L working solution = 2000 mg NO_3-N

c. Using the first product on the short list of plant foods, General Hydroponics MaxiGro, we know the NO_3-N is 8.5% the product weight. Using this value, we know that 100 mg of the product will contain 8.5 mg NO_3-N.

d. Now calculate the amount of plant food you will need to get 2000 mg (2.0 g) NO_3-N.

e. 100 mg MaxiGro/ 8.5 mg NO_3-N × 2.0 g NO_3-N = **23.5 grams Miracle-Gro**. Note that the product units have been converted to grams (1000 mg = 1 g).

To prepare a 1-L batch of working solution with 20 mg NO_3-N / 10 mL working solution, you would need 23.5 grams of General Hydroponics MaxiGro.

Prepare 1-L of 20 mg NO_3-N/L synthetic drainage solution from the working solution.

a. Follow the procedure to prepare the working solution.

b. Add 10mL of the working solution per 1-L of prepared synthetic drainage solution for your experiment/project.

There may be some variability in your prepared solution NO_3-N concentrations due to heterogeneity of the fertilizer, so be sure to measure the NO_3-N concentration of your prepared drainage solution to ensure that your achieved concentration is within the expected range on the nitrate test strips.

Products- Short list of products with nutrient % listed. Make sure your product contains Nitrate Nitrogen.

General Hydroponics MaxiGro for Gardening (2.2 lbs. dry wt.)

- Available through Amazon ~ $17
- (10-5-14) 8.5% NO_3-N
- Approximately 84.8 grams NO_3-N per package.

Total Nitrogen (N) 10%
• 1.5% Ammoniacal Nitrogen
• 8.5% Nitrate Nitrogen
Available Phosphate (P2O5) 5%
Soluble Potash (K2O) 14.0%
Magnesium (Mg) 2.0%
• 2.0% Water Soluble Magnesium (Mg)
Sulfur (S) 3.0%
Iron (Fe) 0.12%
• 0.12% Chelated Iron (Fe)
Manganese (Mn) 0.05%
• 0.05% Chelated Manganese (Mn)
Derived from: Ammonium Molybdate, Ammonium Nitrate, Calcium Nitrate, Calcium Sulfate, Copper Sulfate, Iron DTPA, Magnesium Sulfate, Manganese EDTA, Potassium Borate, Potassium Nitrate, Potassium Phosphate, and Zinc Sulfate.

Miracle-Gro Performance Organics All Purpose Plant Nutrition (1 lbs. dry wt.)

- available through Amazon ~$8.00
- (11-3-8) 1.63% NO_3-N
- Approximately 7.4 grams NO_3-N per package

Total Nitrogen (N) 11%
• 0.36% Ammoniacal Nitrogen
• 1.63% Nitrate Nitrogen
• 8.92% Other Water Soluble Nitrogen
• 0.09 Water Insoluble Nitrogen
Available Phosphate (P2O5) 3%
Soluble Potash (K2O) 8%
Calcium (Ca) 3%
• 3% Water Soluble Magnesium (Mg)
Copper (Cu) 0.05%
• 0.05% Chelated Copper (Cu)
Iron (Fe) 0.10%
• 0.10% Chelated Iron (Fe)
Manganese (Mn) 0.05%
• 0.05% Chelated Manganese (Mn)
Zinc (Zn) 0.05%
• 0.05% Chelated Zinc (Zn)
Derived from: Soy Protein Hydrolysate, Nitrate of Soda, Rock Phosphate, Bone Meal, Potassium Chloride, Sulfate of Potash, Copper Sulfate, Ferrous Sulfate, Manganese Sulfate, and Zinc Sulfate

FoxFarm Grow Big Liquid Concentrate (1-quart)

- Available through Amazon ~ $20
- (6-4-4) 3.1% NO_3-N

Total Nitrogen (N) 6%
• 2.9% Ammoniacal Nitrogen
• 3.1% Nitrate Nitrogen
Available Phosphate (P2O5) 4%
Soluble Potash (K2O) 4%
Magnesium (Mg) 0.60%
• 0.60% Water Soluble Magnesium (Mg)
Boron (B) 0.02%
Copper (Cu) 0.05%
• 0.05% Chelated Copper (Cu)
Iron (Fe) 0.10%
• 0.10% Chelated Iron (Fe)
Manganese (Mn) 0.05%
• 0.05% Chelated Manganese (Mn)
Zinc (Zn) 0.05%
• 0.05% Chelated Zinc (Zn)
Derived from: Ammonium Nitrate, Ammonium Phosphate, Potassium Phosphate, Potassium Nitrate, Earthworm Castings, Magnesium Nitrate, Norwegian Kelp, Magnesium Sulfate, Potassium Sulfate, Iron EDTA, Manganese EDTA, Copper EDTA, Chelating Agent, Disodium Ethylendiamine Tetra Acetate (EDTA), and Sodium Borate.

Miracle-Gro Aerogarden (1-liter)

- Available through Amazon ~ $26
- (4-3-6) 3% NO_3-N

Total Nitrogen (N) 4%
• 1.0% Ammoniacal Nitrogen
• 3.0% Nitrate Nitrogen
Available Phosphate (P2O5) 3%
Soluble Potash (K2O) 6%
Calcium (C) 1%
Magnesium (Mg) 0.5%
• 0.5% Water Soluble Magnesium (Mg)
Derived from: Potassium Nitrate, Calcium Nitrate, Mono Potassium Phosphate, Ammonium Nitrate, and Magnesium Sulfate.

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THOUGHTS & IDEAS…