

**Projet EDDIE: NUTRIENT LOADING**

**Instructor's Handout**

This module was initially developed by Castendyk, D.N., T. Meixner, and C.A. Gibson. 6 June 2015. Project EDDIE: Nutrient Loading. Project EDDIE Module 7, Version 1. <http://cemast.illinoisstate.edu/data-for-students/modules/nutreint-loading.shtml>. Module development was supported by NSF DEB 1245707.

**Overall description**

The assignment will take students from a general understanding of why loads are important, to a qualitative understanding of the connection of discharge to nitrate concentrations, to focused correlation analyses of the connection between discharge and nitrate concentrations, to estimating nutrient loads at a site and along a river network, and finally to develop an understanding of the influence of sampling frequency on robustness of load estimates. The module is designed to address the following concepts: the nitrogen cycle, the impact of nutrients on downstream lake health, and coastal “dead zones”, and the Clean Water Act and federal management of water quality in the United States

**Pedagogical connections:**

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| **Phase** | **Functions** | **Examples from this module** |
| Engagement | Introduce topic, gauge students’ preconceptions, | Pre-class readings, reflection questions, short introductory lecture, in-class discussions of readings |
| Exploration | Engage students in inquiry | exploring EPA Impaired Waters list and animated maps of nitrate concentration, |
| Explanation | Engage students in scientific discourse, evidence-based reasoning | In-class discussion, module activities |
| Expansion | Broaden students exploration and schemata to account for more observations | Application questions in the module |
| Evaluation | Assess students’ understanding, formatively and summatively | Suggested questions to ask during discussions (often in italics in the presentation notes). |

Learning objectives:

* Analyze and interpret data to deepen knowledge and increase understanding of hydrogeological concepts and nitrogen cycling in aquatic systems in the context of increased nutrient availability.
* Explore advantages and disadvantages of different ways to investigate, sample, and quantify nutrients in aquatic systems.
* Develop skills for critical data analysis, graphing, and statistics.

How to use this module:

This module is designed for two 50-minute lecture periods and two 1-hour-and-50-minute lab period. The instructor may complete only some of the activities, or may allocate work for before or after class, depending upon the level of the students, the time available, and the goals of the course.

Quick overview of activities in this module, with approximate times)

* *Activity A*: (Lecture and background - 1 hour) Background of nutrient issues in surface waters by exploring EPA Impaired Waters list and animated maps of nitrate concentration, and learning about concentration, discharge, their relationship, and the calculation of load.
* *Activity B*: (Calculations and graphing -1 hour) Accessing USGS data sets and combining concentration and discharge data to investigate nutrients loads from agricultural systems in Iowa, graphing the data as time -series and scatter plots as well as investigating calculations that can be made with these data.
* *Activity C*: (Calculations and graphing - 1 hour) Quantifying correlations between the two variables at different time scales and in different ways using both graphs and statistical correlations.
* *Activity D*: (Calculations of load - 1 hour) Calculating loads of nutrients exported from a catchment and comparing an upstream and a downstream catchment to see how concentration and discharge change along with nutrient load with distance downstream.
* *Activity E*: (Sample frequency - 1 hour) Calculate loads of nutrients exported from a catchment with varying sample frequency. It is rare to have high frequency data like the ones used in the earlier parts of this module. In this exercise students will work with desampled data to investigate the effects of sample frequency on the calculation of nutrient loads.

Workflow of this module:

Prior to using this module, it is helpful if students are familiar with the following concepts: components of the hydrologic cycle, stream discharge and its measurement, hydrographs, nutrient cycling, and rudimentary operation of Microsoft Excel.

1. Assign pre-class readings
2. Give students their handout
3. Instructor gives PowerPoint presentation.
4. Discussion of the readings can be integrated into the presentation or separate.
5. After presentation, students work on their computers (possibly in pairs) to complete the module activities.

Suggested pre-class readings:

To engage the students, the instructor should assign the class a few background readings the week prior to running the module. At a minimum, we recommend media articles about the Toledo water crisis in August 2014 and an article about the Gulf of Mexico dead zone – we have provided some below, but there will undoubtedly be other similar, more recent articles available over time that might be more appropriate. We encourage instructors to use locally-relevant stories if possible, or to provide broader comparisons by including stories about other lakes around the world.

The following background reading articles are available:

* Wines, M. 2014. Behind Toledo’s Water Crisis - a Long-Troubled Lake Erie, *New York Times*, August 4: 4 pages. <https://www.nytimes.com/2014/08/05/us/lifting-ban-toledo-says-its-water-is-safe-to-drink-again.html>
* Zimmer, C. 2014. Cyanobacteria are far from just Toledo’s problem. *New York Times*, August 7: 3 pages. <https://www.nytimes.com/2014/08/07/science/cyanobacteria-are-far-from-just-toledos-problem.html>
* Shipley-Hiles, S. 2012. Dead zone pollutant grows despite decades of work. *Scientific American*, July 9: 6 pages. <https://www.scientificamerican.com/article/dead-zone-pollutant-grows-despite-decades-work/> Note: The size of the dead zone is determine every year, so it is possible to find the most recent one online.
* USGS Fact Sheet. 2000. Nitrogen in the Mississippi Basin – Estimating sources and predicting flux to the Gulf of Mexico <https://ks.water.usgs.gov/pubs/fact-sheets/fs.135-00.pdf>
* Lake Atitlan, Guatamala: Webster, M. 2010. Pollution, algae mar beautiful lake. *LiveScience*  <http://www.livescience.com/29571-pollution-algae-mar-once-beautiful-lake.html>
* Lake Taihu, China: Stone, R. 2011. On Lake Taihu, China moves to battle massive algae blooms. *YaleEnvironment360* <http://e360.yale.edu/features/on_lake_taihu_china_moves_to_battle_massive_algae_blooms>

These articles may be appropriate for a more advanced class and can provide additional background information for an instructor. These articles explain the role that instream and stream groundwater interactions can have on nitrogen export from watersheds.

* Alexander, Richard B., Richard A. Smith, and Gregory E. Schwarz. "Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico." Nature 403, no. 6771 (2000): 758-761.
* Peterson, Bruce J., Wilfred M. Wollheim, Patrick J. Mulholland, Jackson R. Webster, Judy L. Meyer, Jennifer L. Tank, Eugènia Martí et al. "Control of nitrogen export from watersheds by headwater streams." Science 292, no. 5514 (2001): 86-90.
* Hedin, Lars O., Joseph C. von Fischer, Nathaniel E. Ostrom, Brian P. Kennedy, Michael G. Brown, and G. Philip Robertson. "Thermodynamic constraints on nitrogen transformations and other biogeochemical processes at soil–stream interfaces." Ecology 79, no. 2 (1998): 684-703.

Useful internet sources:

These are supplemental resources which students or instructors may wish to explore during the module.

Managing the Problem:

* Information on State “303D Lists”: <http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overview.cfm>
* Information on Total Maximum Daily Load (TMDL): <http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/overviewoftmdl.cfm>

US Water Quality Criteria

* Aquatic Life Water Quality Guidelines: <http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm>
* National Primary Drinking Water Regulations: <http://water.epa.gov/drink/contaminants/index.cfm>

Nutrient Pollution:

* Overview, background, and solutions: <http://www2.epa.gov/nutrientpollution>

Response to nutrient loading estuaries (hypoxia):

* Chesapeake Bay Hypoxia: <http://www.cbf.org/about-the-bay/issues/dead-zones/nitrogen-phosphorus>
* Gulf of Mexico Hypoxia: <http://water.epa.gov/type/watersheds/named/msbasin/hypoxia101.cfm>

**Presentation**

The PowerPoint presentation introduces the key concepts and terminology referenced in this module. Short-duration, classroom demonstrations/activities are described within the PowerPoint. The instructor may choose to: a) show the entire presentation during one, 50 minute class period at the beginning of the module; b) break the presentation into smaller components, and show these components between the activities; c) assign the PowerPoint along with the pre-reading.

* Summary of nutrients – the purpose of this section is to provide students with an understanding of what a nutrient is, and how higher concentrations can potentially be harmful. Because this module focuses on nitrogen, examples are provided of how nitrogen can be toxic at high concentrations. Make a note of the 10 mg/l drinking water limit, because in a few slides there is a map with data on it allowing you to observe where stream levels are above drinking water limits. Since many streams flow into reservoirs, this is an indication of potential drinking water issues (which are not uncommon in the Midwestern USA).
* Nitrogen Cycle and redox – To understand how nitrate concentrations in a stream can vary over time, students will need to at least conceptually understand the nitrogen cycle, and how nitrogen and is transformed. It may be helpful to list the different forms of nitrogen on the board for future reference or to have students draw their own conceptual diagrams of the nitrogen cycle and discuss them before showing the diagrams here. For more advanced classes, it may be appropriate to include detailed discussions of redox conditions and how they influence the nitrogen cycle, or it may be sufficient to just say that denitrification occurs at low oxygen levels, such as those found in where there is water that is not flowing rapidly (e.g. wetlands, wet soil, hyporheic flow paths deeper in the stream bed). The important take-home message is that students understand that biological processes can influence nitrogen concentrations in a stream, through the uptake of nitrogen (by either algae or microbial communities).
* Nitrogen in streams – the next set of slide focuses on demonstrating some of the environmental problems associated with nitrogen in streams and the role of human activity.
* The US map showing nitrogen concentrations in streams is from the Wadeable Streams Assessment in 2006. Note the high concentration in the Midwest in the upper Mississippi River watershed, that are near or above the drinking water limit.
* Nitrogen inputs to the Mississippi River watershed. *What do you think the high inputs are associated with?* These inputs occur in areas of high corn and soybean production.
* Sources of nitrogen. This is an older graph (cannot find an updated one) that shows how N inputs have changed. Legumes introduce nitrogen because they are nitrogen-fixing plants. This is a good place to ask students the *difference between point-source and non-point-source, or ask them to identify which might be which*. The EPA only regulates point-source inputs, which becomes an important point to make during later discussions about management.
* Sources of nitrogen inputs. Here you can see that on main input source that’s changed has been fertilizer inputs. These are used mainly for growing corn. Increased soybean (legume) cropping can also contribute nitrogen, as legumes fix atmospheric nitrogen, which then can be lost from the watershed as nitrogen exuded from roots into the soil or through the decomposition of the organic matter. Note that point sources are not major contributors. The Haber-Bosch process was originally developed to create nitrogen explosives, but it’s use to create nitrogen fertilizer has allow food production to increase and support a growing human population.
* Nitrogen losses and consequences – this set of slides show how much of nitrogen actually leaves these areas and drains into the Mississippi River as well as the general impacts of nutrient inputs to freshwater and near-shore marine ecosystems.
* Nitrogen yields visibly spatially related to nitrogen inputs.
* Eutrophication causes algae blooms in freshwater systems. For cyanobacteria (also called blue-green algae), phosphorus is often the main nutrient that triggers these blooms. Other factors, like warmer and calmer water also contribute. Large algal blooms are unsightly, and also begin to smell as the algae die and decompose. Some types of cyanobacteria produce toxins, and these toxins can make the water. Microcystin is the toxin that the cyanobacteria bloom produced in Lake Erie in August 2014, causing 500,000 people to be without water in Toledo, Ohio, which draws its drinking water from the lake. Even touching water when the concentrations of these toxins is high can be dangerous, and pets have died from swimming in the water.
* Decomposition of dead algal blooms consumes oxygen from the water, creating anoxic environments that can kill organisms like fish and benthic invertebrates.
* Nutrient inputs are also associated with oceanic dead zones, which are caused by the decomposition of algae blooms. In this case, nitrogen is generally the main culprit. Inflowing fresh river water is less dense than salt water, depositing the nitrogen-rich water right near the surface sunlight where algae can grow rapidly.
* The most well-known dead zone is the Gulf of Mexico. There are many social and economic consequences to this dead zone, as it has impacts on fishing. There are many other locations around the world where impaired rivers enter the ocean and create dead zones.
* The concept of nutrient loading – this set of slides asks student to think about what is really required to understand how much of a nutrient is moving down a stream. One cannot just think about the concentration of a nutrient, but also the volume of water moving down the stream (discharge). *This is a great set of slides to pose to students and have them discuss (think-pair-share). I*deally, they will identify the concept of load as well as the mathematics behind it by themselves.
* The final set of slides moves more directly into management and some of the activities at the beginning of the module. Load is used for management purposes, and students will have to use 303(d) lists in the module.

At this point, the students can then begin working on the module.