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**Project EDDIE WATER QUALITY**

**Instructor’s Manual**

This module was initially developed by Castendyk, D. and Gibson, C. Project EDDIE: Water Quality. Project EDDIE Module 6, Version 1. <http://cemast.illinoisstate.edu/data-for-students/modules/water-quality.shtml>. Module development was supported by NSF DEB 1245707.

Overall description:

Human activities often lead to impaired water quality. This module aims to help students understand the variability of concentrations of dissolved nutrients in stream water and identify some reasons for this variability. Students explore and evaluate water quality concerns with real-time data from regulatory entities, and learn about water quality ecosystem and human health implications.

Pedagogical connections:

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| **Phase** | **Functions** | **Examples from this module** |
| Engagement | Introduce topic, gauge students’ preconceptions, call up students’ schemata | Pre-class readings, introductory lecture, in-class discussion |
| Exploration | Engage students in inquiry, scientific discourse, evidence-based reasoning | Students locate and explore water quality data for their state |
| Explanation | Engage students in scientific discourse, evidence-based reasoning | Students discuss specific contaminants and their implications, statistical probability in this context |
| Expansion | Broaden students’ schemata to account for more observations | Students calculate exceedance probabilities of contaminants, analyze different water quality scenarios, and generate hypotheses |
| Evaluation | Assess students’ understanding, formatively and summatively | In-class discussions and student application activities (application questions, generating plots and making conclusions) |

Learning objectives:

This module introduces students to the following Scientific Concepts:

* The concept of “concentration” with an emphasis on nitrate.
* Natural and anthropogenic fluxes to the nitrogen cycle.
* Impacts of elevated nitrate on drinking water quality (i.e. blue baby syndrome). Passing reference is made to ecological impacts, however, because these impacts vary from environment to environment, we only introduce concepts of eutrophication and hypoxia.
* An introduction to water law and water management.
* Exploration of point-source, non-point source, and land use impacts on water quality.
* Exploration of the nitrogen cycle.

Quantitative skills gained by students from this module include:

* An understanding of data variability, both natural and anthropogenic.
* The calculation and interpretation of probability.
* An understanding of how to access online datasets from the USGS.
* The ability to perform calculations and generate graphs using MS Excel.
* An appreciation for the value of large datasets.

How to use this module:

This complete module is designed to be implemented over four 1-hour classes, requiring internet access and Microsoft Excel for students. Activities may be broken up and used separately as instructors see fit. This module is intended for introductory to mid-level, Earth Science, Biological Science and Environmental Science students. It is helpful if students have a little knowledge of chemistry, however, this is not required. It will also be useful for the students to understand the fundamentals of the hydrological cycle prior to this module as concepts of storm water runoff and base flow play a key role in the interpretation of the results of Activity D. The Excel skills used in this activity involve calculating probability and generating a graph.

Quick overview of the activities in this module

* *Activity A*: Students are introduced to water quality concerns via background readings and PowerPoint presentation
* *Activity B*: Students acquire and investigate EPA data and real-time concentrations
* *Activity C*: Students collect data, calculate probabilities, and engage in in-class discussion
* *Activity D*: Students compare data across regions, generate plots and hypotheses
* *Activity E*: Students explore the nitrogen cycle, generate plots, and analyze data while this time, considering nitrate as a nutrient vs. a pollutant
* *Activity F (Optional take home assignment)*

Workflow of this module:

1. Assign pre-class readings
2. Disperse student handouts in class
3. Discussion of pre-class readings (Activity A; prior to starting unit in class)
4. Instructor gives brief PowerPoint presentation on water quality, and environmental implications. (Activity A; in-class, 30 minutes)
5. Students explore variability in nitrate concentrations over time through searching for and exploring EPA 303(d) regional data (Activity B;1-hour class time)
6. Students assess acute, local, water quality impacts by collecting, plotting and explaining water quality data (Activity C; 1-hour class time)
7. Students explore rural vs. urban land use impacts by using Google Earth and generating hypotheses, plot data, and discuss results (Activity D; 1-hour class time)
8. Students learn about nutrient concentrations, and water quality and biotic controls using Google Earth, USGS sites, and test hypotheses, answer questions and finish with whole class discussions (Activity E; 1-hour class time)
9. Instructors may assign take-home assignment for further expansion/evaluation (Activity F)

Suggested pre-class readings:

Articles discussing water quality issues are not uncommon in the media. Below we list some that we used, but the instructor should feel free to look for other articles.

* Smith, M. (2015). Conflict Over Soil and Water Quality Puts ‘Iowa Nice’ to a Test. *New York Times*, June 24: 5 pages: <http://www.nytimes.com/2015/04/19/us/conflict-over-soil-and-water-quality-puts-iowa-nice-to-a-test.html>
* Wines, M. (2014). Behind Toledo’s Water Crisis - a Long-Troubled Lake Erie, *New York Times*, August 4: 4 pages: <http://www.nytimes.com/2014/08/05/us/lifting-ban-toledo-says-its-water-is-safe-to-drink-again.html?_r=0>
* Zimmer, C. (2014). Cyanobacteria are far from just Toledo’s problem. *New York Times*, August 7: 3 pages: <http://www.nytimes.com/2014/08/07/science/cyanobacteria-are-far-from-just-toledos-problem.html>
* Rejmánkováa, E., Komárek, J., Dixc, M., Komárková, J., and Giróne, N. (2011). Cyanobacterial blooms in Lake Atitlan, Guatemala. *Limnologica 41*: 296–302.

Data providers’ citations:(Instructors and students will obtain their own regional data from the following sources)

* US Environmental Protection Agency (EPA). Integrated Water Quality Report and 303d Lists <http://www.epa.illinois.gov/topics/water-quality/watershed-management/tmdls/303d-list/>
* US Environmental Protection Agency (EPA). Drinking Water Contaminants- Standards and Regulations. (Accessed 2014 during the development of this module). <https://www.epa.gov/dwstandardsregulations>
* Google Maps. (2014). [Fairbury, IL] [Satellite Imagery] <https://www.google.com/maps/place/Fairbury,+IL+61739/@40.7459502,-88.5507917,8431m/data=!3m1!1e3!4m5!3m4!1s0x880c670059c34109:0xd3a20ab67fe04cf6!8m2!3d40.7472566!4d-88.5147789>
* USGS. WaterQualityWatch, Continuous Real-Time Water Quality of Surface Water in the United States (Accessed 2014). <http://waterwatch.usgs.gov/wqwatch/>

**Presentation**

The notes below apply to slides within the PowerPoint presentation and serve as a preparation tool for instructors, or to use as discussion prompts during the presentation. Instructors can pick and choose from the PowerPoint as needed for their classroom.

1. Cover slide
2. Overview: This presentation will provide a brief review of aqueous chemistry, define nutrients and their importance, discuss impacts of nutrients, sources of nutrients, and the management of nutrients.
3. These are some general questions for the class to identify existing knowledge. Use this time to gauge your students’ experience.
4. Water is a v-shaped polar molecule with a + end and a – end. Dissolution occurs when… (read slide)
5. Image shows how negative ends of water surround a positively charged sodium ion to keep it in solution. Note, this process does not work on non-polar molecules, like petroleum, which is why oil and water do not mix.
6. Provide a working definition of concentration. This would be good for students to write down in notes as this topic will be revisited several times.
7. Each element on the periodic table can occur in different combinations with other elements in solution. We call these combinations “species.” Nitrogen commonly occurs in several species based on the oxidation state and the pH of the solution, including: ammonia NH3 (the cleaning product), ammonium NH4+ (found in human urea), dissolved nitrogen gas N2 (80% of Earth’s atmosphere, responsible for the diving accident, “the bends”), nitrite (NO2-), nitrate (NO3-). Here, we are most interested in ammonium, nitrite, and nitrate.
8. Depending on the instrument used to measure concentrations, Nitrate and Nitrite may be reported in different ways, shown here. We could report in terms of mass, where 1 mg is dissolved in one kilogram of solution. Because 1 kg of solution is 1 million mg of solution, this mass measurement is called “parts per million” (ppm). We could also report dissolves species as milligrams (mg), or one thousandth of a gram, present in a volume of one liter of solution (mg/L). For dilute solutions, like most natural waters, ppm is assumed to equal mg/L. It is important to know how nitrogen is reported before comparing concentrations from different sources. For example, concentrations of Nitrate-Nitrogen in mg/L cannot be directly compared to concentrations of Nitrate in mg/L. We must first convert Nitrate-Nitrogen (mg/L) into Nitrate (milli moles/L) and then back to Nitrate (mg/L) to make this comparison.
9. Transition to the topic of Nutrients: Ask class new questions to gauge their knowledge and to break up the lecture.
10. This slide gives a brief description of nutrients.
11. Here we try to differentiate between nutrients and toxins. The key message is that the concentration dictates toxicity. The same element can be a nutrient at low concentrations and a toxin at high concentrations. Cadmium and selenium are good examples. Here we explore nitrogen.
12. In low concentrations, ammonium and nitrate are essential nutrients for plants. Ammonium is toxic to plants and humans at high concentrations. Nitrate is toxic to humans in high concentrations, which may cause blue baby syndrome, where nitrate from drinking water binds to hemoglobin in the blood of infants and causes asphyxiation.
13. Nitrogen cycles from the atmosphere to the soil, to plants, to animals (by digestion), to groundwater and surface water. Each step of the cycle has a name and is numbered here. Ultimately, N is returned to the atmosphere.
14. Have students draw a picture of the nitrogen cycle. Have them compare their cycle to their neighbor’s cycle. Draw a master Nitrogen cycle on the board, adding or subtracting elements as you like. Emphasize the role of human waste management in adding nitrate to surface and groundwater.
15. This figure illustrates the nitrogen cycle. Encourage students to add new loops and arrows to their cycle.
16. Transition to impacts. Read quote from EPA website. The main impact we will focus on is Cyanobacteria blooms, and other impacts include blue baby syndrome and hypoxic zones.
17. Provide a brief description of cyanobacteria.
18. The Redfield ratio introduces the concept of “limited nutrients.” Each cyanobacteria cell needs a certain number of carbon, nitrogen, and phosphorous atoms to be present in water in order to grow. If there is plenty of carbon and phosphorous, but not enough nitrate, the system is called “nitrogen limited.”
19. If plenty of C, N, and P are available, cyanobacteria can grow. If growth occurs rapidly in a lake or sometimes a stream, this is called a “bloom.”
20. Here is a close up image of a cyanobacteria bloom. Ask students: How much light can penetrate below the bloom? (not much light penetrates). What does this do to plants living below the lake surface? (they die). What happens to all of this organic matter when it dies (it settles to the bottom, decomposes and consumes oxygen). How does the reduction of oxygen impact fish populations? (significantly).
21. Photo of a cyanobacteria bloom in a residential/tourist area. What impacts can you imagine? (people don’t want to swim, bad fishing, very smelly, loss of property value/tourism)
22. This slide introduces students to cyanotoxins and the impact of cyanotoxins on humans.
23. Because many cities obtain drinking water from lakes and rivers, elevated nutrients can threaten drinking water supplies due to the risk of cyanotoxins and blue baby syndrome.
24. In March 2012, a cyanobacteria bloom in Lake Erie impacted the drinking water supply of Toledo, Ohio, a major city with a population of 280,000 people.
25. This issue is not limited to the United States. Lake Atitlan in Guatemala supplies drinking water to tens of thousands of people, mostly indigenous Mayan. A bloom in 2009 threatened public health and had a major impact on the regional tourist industry, upon which, many depend as their sole source of income.
26. This slide summarizes some of the secondary impacts of cyanobacteria blooms.
27. A final impact is accelerated eutrophication, or the filling of a lake with sediment over time. This process is natural but is accelerated by the addition of nutrients. A lake with high nutrient levels is called “eutrophic.”
28. This image shows a small kettle pond in New York that has turned into a wetland due to the addition of nutrients and the accumulation of organic sediment which nearly filled the pond with sediment.
29. Ultimately the accumulation of sediment converts a wetland into a grassland, show here for a former kettle pond depression in New York.
30. A final concern of excess nutrients is the reduction in dissolved oxygen. Hypoxia defines low oxygen conditions where fish may die in “fish kills.” This can occur in lakes, rivers, and estuaries. Ice cover in winter can cause fish kills in some lakes. Persistent “hypoxic zones” are found in the Gulf of Mexico and in the Chesapeake Bay and have heavily impacted these ecosystems.
31. This slide shows an example of “fish kill” in a eutrophic lake.
32. This summarizes the impacts of nutrients on lake and river systems.
33. Transition to discuss sources of nutrients. Ask class for sources.
34. Two major sources of nutrients are fertilizers and municipal waste water.
35. This slide shows a map of the Mississippi River catchment and identifies the kilograms of Nitrogen applied to each hectare (100 m x 100 m) parcel of land. This drives the hypoxic zone in the Gulf of Mexico.
36. This slide shows the breakdown of sources of nitrogen to the Chesapeake Bay, which drives the hypoxic zone there. Ask students, what are the largest sources?
37. Here we transition to our final topic, management. Ask students these lead in questions.
38. Introduce the Clean Water Act. This law dictates national priorities for water quality.
39. All states are required to compile a list of impaired streams and lakes, called the 303(d) list. An effort must be made to clean these streams over time.
40. Summarize the key points from the lecture as you see fit. This is a good point to assign an investigation of your state’s 303(d) list from the module as a simple homework assignment.

**Activity A**: Pre-reading (at home, before class) and presentation (Class 1, 1 hour)

Note: This portion of the module provides an introduction to water quality and sets up focal topics for the module. PowerPoint slides can be tailored to individuals’ needs as various courses may demand. Instructors may choose to incorporate whole-class discussions using topic questions within the PowerPoint presentation, or perhaps have students break into small groups for reflection, then regroup with the class to discuss.

1. Before class) provides optional background readings to be completed by students prior to the start of the model. There are provided links to three texts for you, the instructor, to select from.
   * One New York Times article describes legal action occurring in Iowa in 2015 between upstream and downstream water users due to excess nitrate. This is the most relevant article for this activity and it is recommended to assign this reading prior to the start of the module.
   * Two other optional readings are New York Times articles dealing with the cyanobacteria bloom in Lake Erie in 2014, which shut down Toledo’s drinking water supply.
   * There is also a reference for a final full-length journal article that discusses a cyanobacteria bloom in 2009 in Lake Atitlan, Guatemala, which impacted tourism and drinking water supplies.
2. The instructor gives an in-class PowerPoint presentation that introduces concepts of concentration, water quality, the nitrogen cycle, water quality impacts associated with nitrate, and federal water management tools. Budget 30 minutes to give this presentation. The presentation ends with an introduction to Activity B1. The following are some example questions to lead discussion with the students at certain points during the presentation:

* Slide 3: Questions to ask prior to starting lecture to gauge student understanding
  + *What is a solution?*
  + *How do you imagine a substance dissolved in a liquid?*
  + *How does dissolution occur?*
* Slide 9: Transition to the topic of Nutrients
  + *What are nutrients?*
  + *Where do you find nutrients?*
  + *Are nutrients always “good”?*
  + *Can you every have too much?*
  + *What are toxins?*
* Slide 14: Have students draw a picture of the nitrogen cycle, discuss with neighbors and draw a master cycle on the board. Instructors may walk through how different elements are impacted by human activities, and emphasize the role of human waste management in adding nitrate to surface and groundwater.
* Slide 20: Cyanobacteria bloom
  + *How much light can penetrate below the bloom?* (not much light penetrates)
  + *What does this do to plants living below the lake surface?* (they die)
  + *What happens to all of this organic matter when it dies?* (it settles to the bottom, decomposes and consumes oxygen)
  + *How does the reduction of oxygen impact fish populations?* (significantly)
* Slide 21: Cyanobacteria bloom in residential/ tourist area
  + *What impacts can you imagine? (People don’t want to swim, bad fishing, very smelly, loss of property value/tourism)*
* Slide 33: Think about the Nitrogen Cycle
  + *What are some of the largest sources of nutrients?*
* Slide 37: Transition into a discussion of water quality management
  + *How would you manage these impacts?*
  + *What challenges can you imagine?*
* Slide 40: Key points- Instructors may fill out as they see fit

**Activity B:** Exploring impaired streams and real-time nitrate concentrations

1. Students explore the 303(d) lists for their state; the list of the most impacted streams. The instructor will want to test the exact pathway starting in Google to link to this list before the start of class. Because every state is different, we have not provided these links. Write a list of common contaminants on the board that students found and *lead students to the realization that nutrients and nitrate occur frequently on these lists*. Hence, this activity focuses on a common contaminant: nitrate.
2. This section simply involves opening the US EPA’s federal drinking water regulations and collecting data on nitrate, and students are asked to fill in some short answer questions. The regulations can be found here: [http://waterwatch.usgs.gov/wqwatch/](http://www.google.com/url?q=http%3A%2F%2Fwaterwatch.usgs.gov%2Fwqwatch%2F&sa=D&sntz=1&usg=AFQjCNFbkjKPMnYHIs9p8mPdSnXpbc8XDw) Students like to see these, and it is convenient to have a hard number to refer to for impaired waters. Some class discussion topics might be:

* *Should this drinking water concentration apply everywhere in the US, and at all times?*
* *How could this be monitored and enforced?*
* *Should penalties be applied for every exceedance infraction, or should some other approach be used?*
* *Should these regulations be applied internationally?*
* *What conditions might require greater flexibility in management, and when should public health come first?*

1. Students explore the variability of nitrate concentrations again using the U.S. Geological Survey’s “Water Quality Watch” web page, filling in parameters and answering questions as they go. An animation feature on the website provides a great opportunity to allow students to freely explore.

* Consider allowing students to complete questions in this section as homework, and start the next class with a discussion of their answers. (Greater detail in Student Handout.)

**Activity C:** Collecting, plotting and explaining the water quality data (Class 2, 1 hour)

* In this portion, students review assessment of acute, local, water quality impacts. They collect data from a significantly contaminated stream and determine if concentrations will exceed drinking water guidelines. These data can be downloaded directly from the USGS, and it will take a little time to trim the unnecessary data and organize the columns. This activity is directly linked to the 2015 New York Times article with the intention of generating discussion.
* Alternatively, we have provided a clean, reduced dataset with this exercise which you are welcome to distribute.
* At the conclusion of this exercise, lead students in a class discussion on:
  + The meaning of probability
  + The accuracy and applicability of the data provided. Hopefully, they will realize that these data are only for part of the year and do not reflect the year as a whole. They also are only for one summer.
  + *Should the federal government enforce fines on Iowa based on these results?*
  + *How does this activity undermine or reinforce students’ opinions of water management in Iowa gained from the New York Times article?*

**Activity D**: Exploring rural vs. urban land use impacts (Class 3, 1 hour)

1. Here, students identify land use characteristics using Google Earth. The sampling point in the Rural Illinois Stream they are asked to focus on is clearly surrounded by agricultural fields, whereas the sampling point in the Urban Kansas Stream is in the middle of a city. Tell students that a wastewater treatment plant is located a little upstream of the urban sampling point.
2. Students make hypotheses about how they expect the streams in both settings to respond to storm events. Students can hate making hypotheses, so there may be some silence, and prompting questions can be helpful here. This would be a good time to review the water cycle and to ask them to think about:
   * *How might rainfall, surface runoff, and base flow separately influence nitrate concentrations in both streams?*
   * *Which hydrogeologic component is likely to be largest in each setting? Which stream is likely to be “flashy” and why?*

3 and 4. This portion asks students to download stream discharge and nitrate data for both focal streams during the same storm event, plot these data, and consider the mechanisms driving change in both systems. As the instructor, you have three options:

1. Have students generate plots of discharge and nitrate using the auto-plot capacity of the USGS web page (fastest option)
2. Have students download the data and generate all four plots using Excel (longest option which provides the most Excel practice)
3. Use the Excel sheets provided with this activity, which have already been simplified. When designing this activity, it was noticed that the data used herein are listed as “Provisional” by the USGS, and consequently, these data may not be available in the future. We recommend exploring the online data before giving having the students access the online data.

* Students will notice that in the Rural Illinois Stream, nitrate concentration *increases* as a function of stream discharge. The cause of this is most likely that the rainfall event causes an increase in surface runoff (containing farm fertilizer) as well as an increase in groundwater discharge (also nitrate-rich groundwater). Both of these changes increase stream concentrations. We deliberately selected a storm at the start of the growing season, after fertilizer application, to illustrate this impact on nitrate variability.
* Next, students will notice that in the Urban Kansas Stream, nitrate concentration *decreases* as a function of stream discharge. Initially high concentrations of nitrate in stream water are most likely caused by effluent from the upstream wastewater treatment plant. This concentration is diluted by urban storm water runoff during the rain event.
* Once students have figured this out, the logical next step is to *lead a discussion* on:
* Watershed management options for both urban and rural settings.
* Whether students think a similar process would exist at other times in the year (they can test their hypothesis using online data).
* Make concluding statements about the natural and anthropogenic variability of nitrate in stream water.

**Activity E**: Biotic controls on nutrient concentration and water quality (Class 4, 1 hour)

In part E, students explore potential instream controls on nitrogen concentrations. Here, students move from thinking about nitrate as a pollutant, to thinking about it as a nutrient. Moreover, this part of the module moves away from ways nitrogen is delivered from the watershed to ways the stream uses and potentially retains nitrogen. This portion utilizes a site that has real time discharge, photosynthetically active radiation, dissolved oxygen, and nitrate monitoring (Indian Creek at State Line Road, Kansas).

1. Students explore the nitrogen cycle. Students list potential biological activities that might influence nitrate concentration. Then, they need to decide which one of these activities might dominate an urban stream in mid-July, and write equations for photosynthesis and decomposition. They are also asked to sketch a diel oxygen curve. Finally, students use the diel oxygen curve they sketched to predict a diel nitrate curve.
2. Here, students explore the Urban Kansas Stream site in greater detail. They look at pictures of the stream and think about physical characteristics of the area. Instructors should guide them to look at the riparian zone and the proportion of the channel that is shaded by stream-side vegetation.
3. This portion of the activity asks students to download stream discharge, photosynthetically active radiation, dissolved oxygen, and nitrate data for a 24-hour period, plot these data against time, and consider the mechanisms driving nitrate concentrations. You may opt to:
   * Have students generate plots using the auto-plot capacity of the USGS web page (fastest option)
   * Have students download the data and generate all four plots using Excel (longest option which provides the most Excel practice)
   * Use the Excel sheets provided with this activity which have already been simplified.

\*Note: Again, the data used to design this activity are listed as “Provisional” by the USGS.

1. Ask the class to think about physical conditions that might lead to biological control on nitrate uptake and if they would predict similar dynamics in streams draining agricultural or forested areas. Instructors may choose to have a closing discussion here recapping information covered in this activity/ and or the entire module.

**Activity F**: Optional take home assignment

Instructions for Part F are not given in the student handout. Options include:

* Have students explore the response of nitrate to other storm events at other times of the year in both settings.
* Have students calculate exceedance probabilities for both streams using an extended set of nitrate data.
* Have students pick different sites from the USGS database (anywhere in the country) to explore and define nitrate variability and exceedance probability.