Water Quality Monitoring: Lesson Plan for Exploring Time-Series Data

(By Dr. Janet Vail, Grand Valley State University Annis Water Resources Institute (GVSU-AWRI), Ashley Meyer, Hamilton Middle School, Anthony Weinke, GVSU-AWRI, and Dr. Bopaiah Biddanda, GVSU-AWRI)

Rationale for lesson

Ceaselessly cycling through the biosphere, water touches every aspect of our lives. Therefore, water monitoring is an engaging way for students to link chemical, biological, and physical measurements with everyday environmental conditions. More often than not, monitoring of rivers, streams, or lakes happens only one or two times a year so students do not get a sense of the variability in water quality over the course of a day, season or year. Modern observatories provide novel opportunities for educators to explore rich time-series environmental data sets and introduce concepts like ecosystem dynamics in the classroom.

Lesson Overview

Engage: Observing a body of water and generating questions

Explore: Introducing the time-series data set and the Data Graphing tool of the Muskegon Lake Buoy Observatory using the buoy observatory website at https://www.gvsu.edu/wri/buoy/

Explain: Analyzing data and drawing connections

Elaborate: Analyzing data to explore Next Generation Science cross-cutting concepts Patterns and Cause and Effect

Evaluate: Revisiting and improving the initial questions that students developed in the Engage section and further exploration using additional data sets

Grade Level/ Time to Complete Lesson

Middle School and High School/ between two and three hours

Objectives

Upon completion of this lesson, students will be able to

- Explain the advantages of using times-series data sets for water monitoring versus single (one time) measurements.
- Construct and interpret graphs of real-time environmental data.
- Formulate a question about water quality and select the appropriate data to answer the question.
- Explore patterns as well as cause and effect relationships.

Next Generation Science Standards Connections

Using authentic data helps students to identify patterns, change through time, and cause and effect. The lesson sequence above follows the science and engineering practices of asking questions, defining problems, analyzing and interpreting data, constructing explanations, and engaging in argument from evidence.

Lessons involving time-series data from robust data sets can be used to support the Next Generation Science Standards performance expectations. Key performance expectations are:

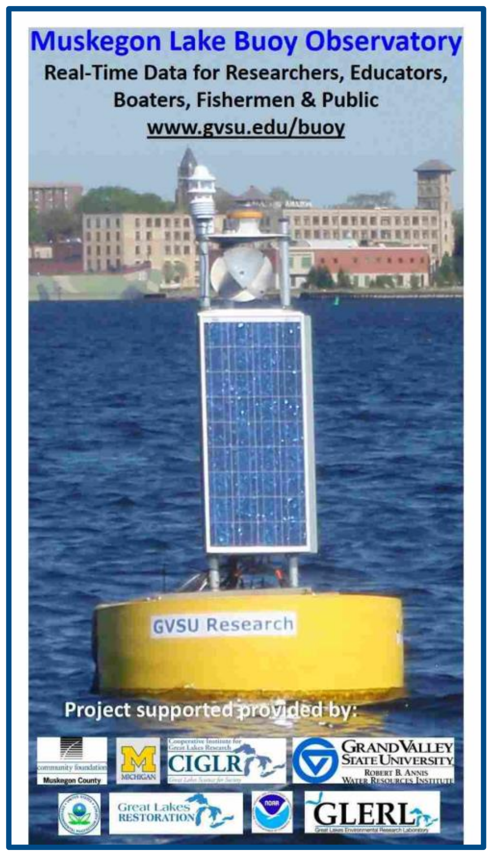
- *MS-ESS3-2 Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.*
- *HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*
- *HS-ESS3-1 Evaluate or refine a technological solution that reduces the impacts of human activities on natural systems.*
- *HS-ESS3-6 Use a computational representation to illustrate the relationships among Earth systems and how these relationships are being modified due to human activity.*

Data can be used in the classroom for varying topics including climate change, photosynthesis, carbon cycling, ecology, human impacts and others. Showing students data from their local ecosystem shows them relevance to topics that happen locally.

Teacher Background Information

Observatories in Lake Ecosystems

The world around us is in constant change. Observatories are situated all around the world in various ecosystems to track this change by collecting real-time data. Analyzing and recording time-series data in lakes can be helpful as scientists begin to look to lakes to predict effects of anthropogenic activity on ecosystems and climate change. Lakes act as sentinels of climate change, in fact, freshwater systems like lakes are one of Earth's most valuable resources that are susceptible to and influenced by climate change (Williamson et al, 2009). Because lakes integrate signals from their entire watersheds and have a worldwide distribution, they can serve as the "canary in the coal mine" for ecological and climatic change (Biddanda, 2012). Data records from lakes and other inland bodies of water may provide important insight to address both potential impacts from climate change as well as the increased human footprint (Williamson et al, 2009)



The Muskegon Lake Observatory With the assistance of federal grants and other funding, the Grand Valley State University Annis Water Resources Institute (AWRI) has deployed a multi-sensor buoy that has tracked physical, chemical, and biological changes in Muskegon Lake since 2011 (Biddanda, 2014). Due to historical environmental degradation, Muskegon Lake has been designated as an Area of Concern by the Environmental Protection Agency and work is progressing to restore the lake (MDEQ, 2011).

The Muskegon Lake Observatory sensors collect real-time meteorological data (every 5 minutes) and water data (every 15 minutes) during the field season by transmitting a signal from the buoy to an on shore site at AWRI. Data are backed up on a separate server in addition to being uploaded to a real-time data website (https://www.gvsu.edu/wri/buoy/). Data are then shared on databases that include information from other observatory networks such as the Great Lakes Observing System (GLOS; www.glos.us/). GLOS is the regional node of the larger global program: Integrated Ocean Observing System (IOOS; www.ioos.noaa.gov/).

Data collected from the buoy deployed on Muskegon Lake includes: wind speed/direction, air temperature, barometric pressure, precipitation, humidity, dissolved oxygen, conductivity, water temperature, pH, turbidity, photosynthetically active radiation (PAR), nitrates, Chlorophyll a, phycocyanin, colored dissolved organic matter (CDOM), and water velocity/direction (Biddanda 2012, 2014). All of these variables are important in determining productivity and ecosystem health. A specially designed graphical interface allows for easy retrieval of data and there is online graphing capability.

The following inquiry-based 5E middle or high school lesson explores time-series data using the Muskegon Lake Observatory's online **Interactive Data Plotting Tool**.

Lesson Plan: What can time-series lake data tell us about seasonal ecosystem dynamics and upstream influences?

Engage

1. If possible, take the students outdoors to observe a body of water and the surrounding landscape. Encourage students to generate questions about the water body. For example, What is the quality of the water? What is the temperature of the water? How does shade affect the water? What might be living in the water? Are there excess nutrients in the water? Will weather conditions affect water quality measurements? Is the water flowing or still? How does the surrounding land use affect the water body? Then have them list what they would like to monitor in their water body.

2. Back in the classroom, review some of the commonly measured water quality parameters as they relate to land use (Table 1, next page). Nonpoint source pollution includes runoff from both agricultural and urban areas and is considered the greatest threat to overall water quality. How does Table 1 compare to what the students have listed?

Source	Water Quality Parameters Measured for Common Associated Pollutants
Cropland	Turbidity, phosphorus, nitrates, temperature, total solids
Forestry harvest	Turbidity, temperature, total solids
Grazing land	Fecal bacteria, turbidity, phosphorus, nitrates, temperature
Industrial discharge	Temperature, conductivity, total solids, toxics, pH
Mining	pH, alkalinity, total dissolved solids
Septic systems	Fecal bacteria (i.e., *Escherichia coli*), nitrates, phosphorus, dissolved oxygen/biochemical oxygen demand, conductivity, temperature
Sewage treatment plants	Dissolved oxygen and biochemical oxygen demand, turbidity, conductivity, Phosphorus, nitrates, fecal bacteria, temperature, total solids, pH
Construction	Turbidity, temperature, dissolved oxygen and biochemical oxygen demand, total solids, and toxics
Urban runoff	Turbidity, phosphorus, nitrates, temperature, conductivity, dissolved oxygen and biochemical oxygen demand

Table 1. *Sources and associated pollutants, U.S. EPA, 2015*

Explore

In this phase of the lesson, students are introduced to the time-series data found at the Muskegon Lake Observatory. Demonstrate features of the buoy website before letting students explore the site.

Access https://www.gvsu.edu/wri/buoy/, online. Use the left-hand menu under Buoy System to show the whole class the **Buoy Location** in Muskegon Lake (Figure 1). Muskegon Lake is a drowned river mouth that flows into Lake Michigan. Water from the Muskegon River watershed flows through Muskegon Lake.

Student Question: *Why is the buoy located where it is?*

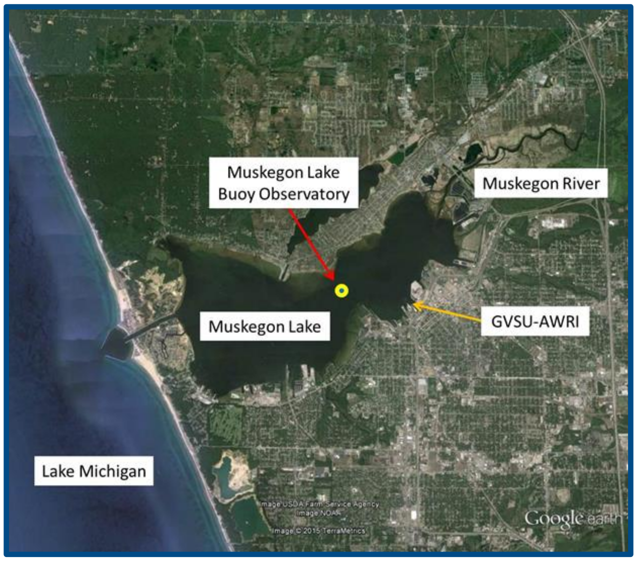


Figure 1. Location of the Muskegon Lake Buoy Observatory

Also using the left-hand menu under Buoy System, explore the **System Diagram and Sensors** (Figure 2). The buoy system will typically be deployed on the lake from April to November, and some sensors may be in the lake year round. Water sensors have measured over 13 parameters including temperature, oxygen, nutrients, light, pH, conductivity, algal pigments, bacterial pigments, and current speed and direction. Air sensors measured 8 parameters including temperature, wind, humidity, and precipitation.

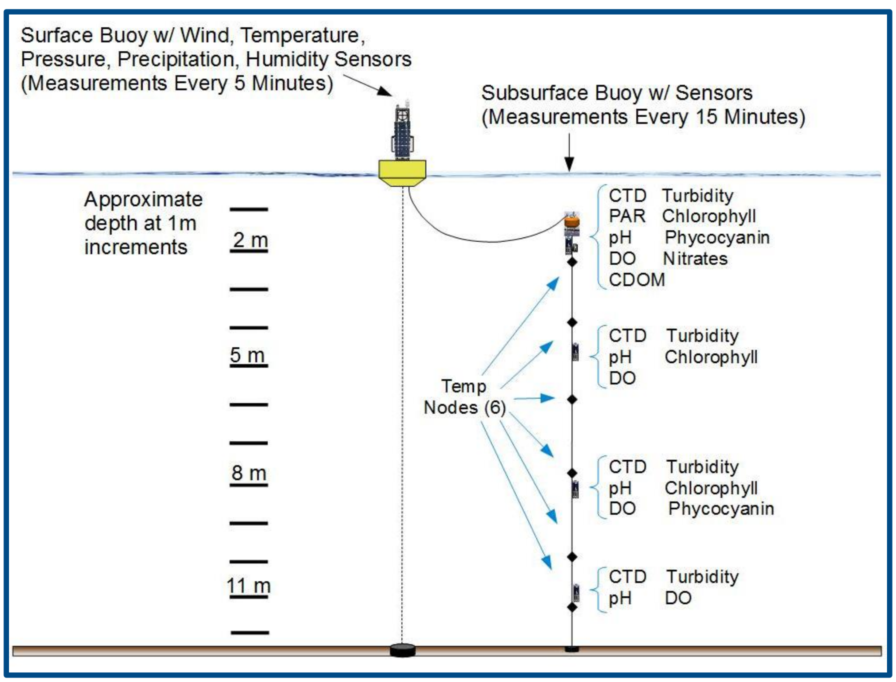


Figure 2. Components of the Muskegon Lake Observatory

From the left hand menu, select **Data Graphing**. Review the four main parts: X Variable (usually the date is used), Y Variable(s), Date/Time Filters, Advanced Options. Illustrate how a graph is produced by using the following settings: X Variable = *date*, Y Variable = *air temperature*, Date/Time Filters = *all dates*, Advanced Options = *line graph*.

Use "Plot the Data" to generate a graph (see example in Figure 3). Ask students to point out and explain trends in the data. Is the highest data point legitimate? Note that this is an uncensored data set so occasionally there will be anomalies and other issues.

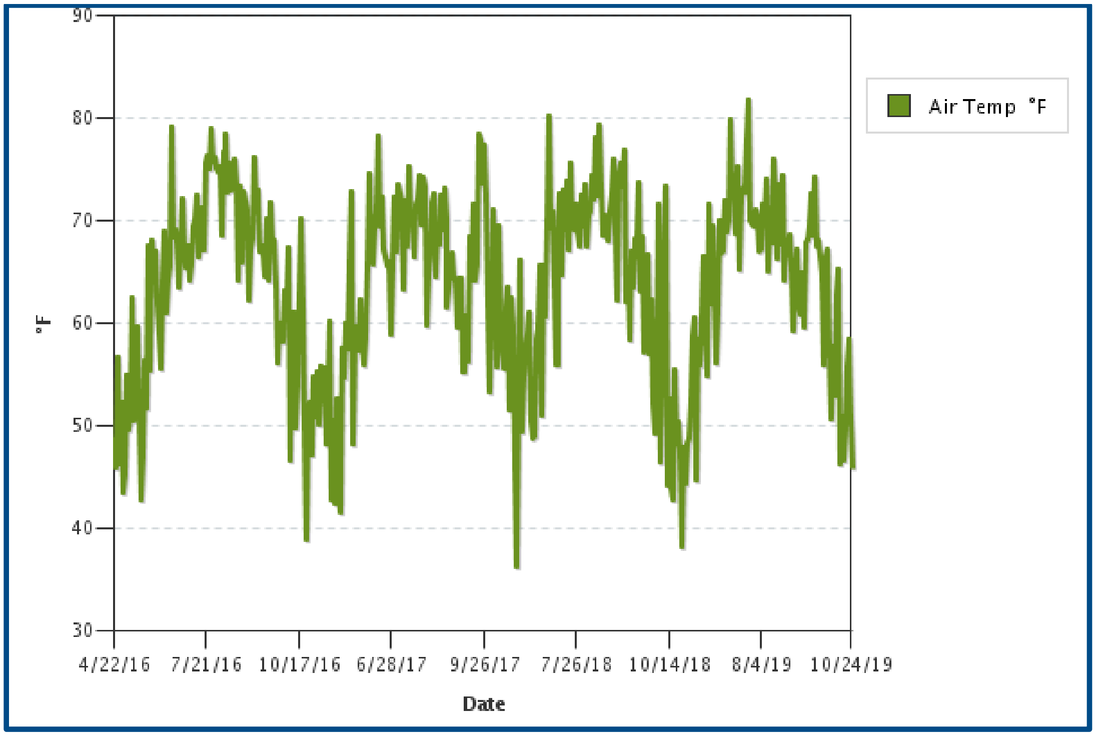


Figure 3. Air Temperature at the Muskegon Lake Observatory

2. Present the students with the following situation: suppose each year a class can do one day of water monitoring. When should the monitoring be done? If we compare the data from one year to the next, how can we know that any trends are meaningful? How will we know if things have changed or remained the same? Would more data give a different story about the water body?

3. Provide an opportunity for the students to answer the above questions by exploring the **Data Graphing** tool. They can use the sequence in the student page, *Exploring Water Temperature* to reinforce the idea that a single data point provides limited information about a site. Be sure to remind students to click on "Reset" before creating each new graph.

Name: ________________________________ **Student Page**

Exploring Water Temperature

Directions: Using the Data Graphing tool at https://www.gvsu.edu/wri/buoy/, plot the data after inputting the Water Quality Parameter (y variable) and the date(s) (date/time filter). Make sure the x variable is set to Date.

Water Quality Parameter (Y variable)	**Date**	**Rough Sketch of Graph and Observations About Data in Graph**
a. Water temperature at 2 M Date/Time Filters: specific date, start date, every X minutes, 15 minutes Advanced Options: Scatter Plot	5/15/2019	
c. Water temperature at 2 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 6/15/19	
d. Water temperature at 2 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 10/15/19	
e. Water temperature at 2 M and Water temperature at 9 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 10/15/19	

Exploring Water Temperature, continued

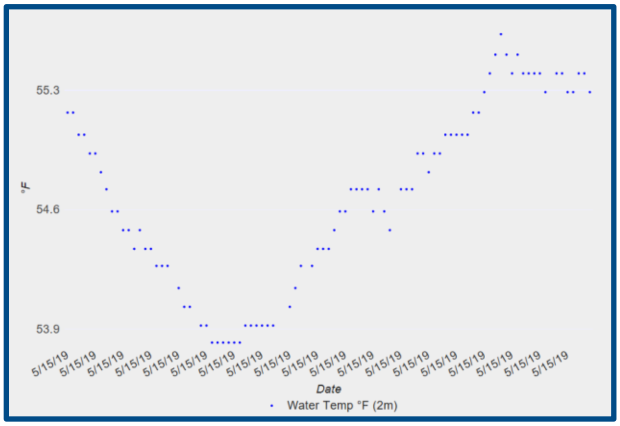
Directions: Using the Data Graphing tool at https://www.gvsu.edu/wri/buoy/, plot the data after inputting the Water Quality Parameter (y variable) and the date(s) (date/time filter). Make sure the x variable is set to Date.

Water Quality Parameter (Y variable)	Date	Rough Sketch of Graph and Observations About Data in Graph
a. Water temperature at 2 M Date/Time Filters: specific date, start date, every X minutes, 15 minutes Advanced Options: Scatter Plot	5/15/2019	
c. Water temperature at 2 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 6/15/19	
d. Water temperature at 2 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 10/15/19	
e. Water temperature at 2 M and Water temperature at 9 M Date/Time Filters: range of dates, every X minutes, 720 minutes Advanced Options: Line Graph, uncheck show missing data points	5/15/19 through 10/15/19	

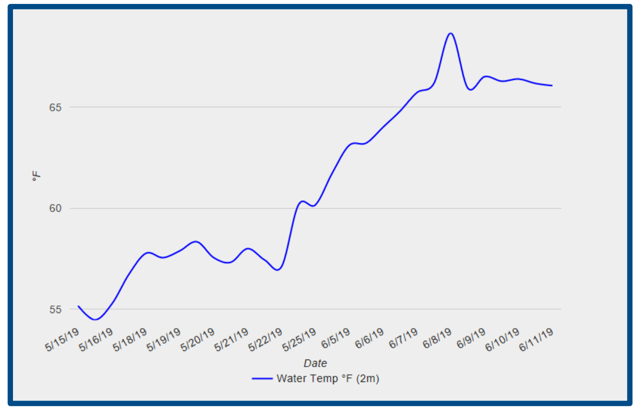
Answer Key

Below are the answers the students page, *Exploring Water Temperature*, for each row of the table, a-e. The graphs pictured are the graphs that students will have generated to make observations.

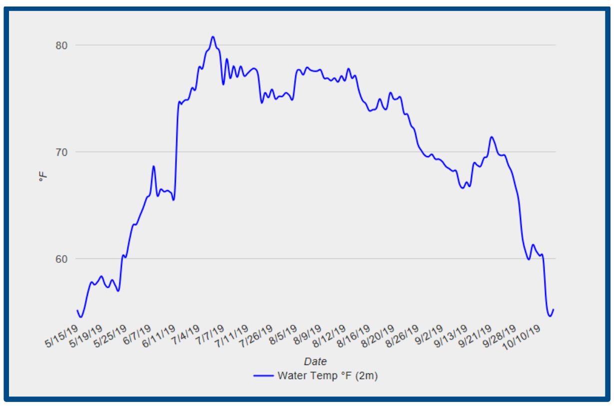
a. Single day at 2 M



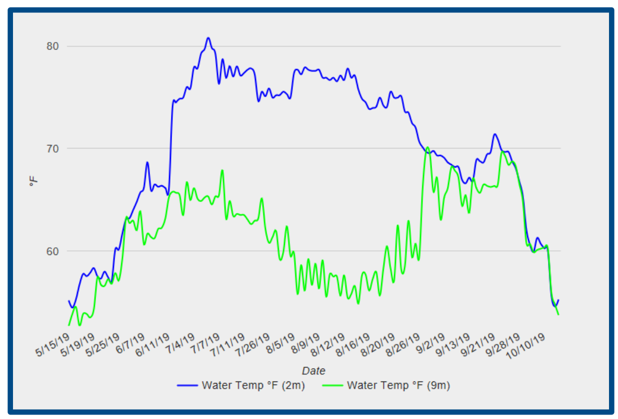
b. Range of dates at 2 M = 1 month



c. Range of dates at 2 M = 5 months



d. Range of dates at 2 M and 9 M = 5 months



4. After the students are comfortable using the **Data Graphing** tool, they should continue their exploration by choosing a time scale to place on the x-axis of their graph (year? season? month? daily?). Then they should also select a lake parameter (y variable) to investigate as they create a graph from the menu of choices. It is recommended that students use dissolved oxygen, water temperature and chlorophyll readings from 5m as 5m in this particular lake can give students a good reading on the “pulse” of the lake. Once students have chosen their criteria, prior to plotting the data, they should predict what they believe their particular graph will look like, and sketch the trend they expect to see. Students should be able to explain why they predicted the trend they sketched in terms of changing weather, day/night period, or season.

After making a prediction about the trend their data should show as well as giving an explanation as to why they predicted that way, student should plot their data, and make an accurate sketch of the trend that they see.

Optional: this exercise could be done by downloading data in an XLS file and plotting graphs in Excel. The advantage to this would be that anomalous data could be removed prior to plotting the graphs.

Explain

After students have plotted the desired data, they should analyze what the data are telling them. Students could be prompted with the following questions:

- What trends do the data show?
- Why do the data show those trends?
- Is the trend different or the same than you predicted? If it's the same, justify. If it's different, justify why?

Students should then put their findings for their prediction/explanation and plotted graph/explanation together and report to the class or pair-share.

Elaborate

Time-series data are useful for exploring crosscutting concepts as articulated in the Next Generation Science Standards. In independent or group projects using the buoy data, have students formulate and answer questions such as the following:

1. *Patterns*:

a. Are there seasonal patterns in water temperature? Does water temperature vary with depth? In what way? Why?

b. Are there relationships between dissolved oxygen and water temperature? Or air temperature? What explains any patterns that you see?

c. How do water quality parameters compare at different depths? Depths of sensor clusters are listed in Table 2 along with example inquiries that may be carried out at each depth. The underwater measurements are gathered at various depths by the buoy (2m, 5m, 8m, 11m). The 2 meter dynamics are highly influenced by wind, and other weather conditions impacting mixing, thus this zone may a good measure of maximum dynamics in the lake. At 5 meters, there may be an integrated signal as to what is happening in the lake that is not impacted by other variables as much as in the surface or bottom layers. At 8m, it is below the point where light is going to reach, thus photosynthetic organisms are not likely to be occurring in great number there - except during mixing events. With a lake depth of 13m at the buoy site and mean depth of 7m throughout the lake, the 11 meter data set proves to be impacted by sediment re-suspension and benthic organisms – it also may be a significant zone for tracking the evolution of bottom water hypoxia.

~Buoy Depth (with sensor cluster)	Sample Student Investigations
2 meters	There is a high amount of variability of data at this depth. What might the variability be correlated to? Solar heating? Storm events? Boating/summer events? Shipping channels? River flow?
5 meters	Does water temperature/DO/chlorophyll/etc. mirror daily, seasonal or yearly patterns? What are the anomalies in the data and why might this occur?
8 meters	When looking at temperature and dissolved oxygen across a season, what patterns are there? Is there a significant correlation between storm events and dissolved oxygen at 8 meters?
11 meters	When looking at temperature and dissolved oxygen across a season, what patterns are there? Is there a significant correlation between storm events and dissolved oxygen at 11 meters?

Table 2. Depths of Muskegon Lake Observatory sensor clusters

2. *Cause and Effect:*

a. Given that Muskegon Lake is a drowned river mouth, what could be the connection between its water quality and activities upstream? In looking at the pollutants in Table 1, is there evidence that human impacts may affect the water quality of Muskegon Lake? How could these human impacts be reduced? Specifically, look at flow, water temperature, dissolved oxygen, conductivity, nitrates, and turbidity. Note: the Muskegon River Watershed is about 25.5% agricultural land, 7.5% developed areas, and 55.2% forest.

b. Is there any correlation of the presence of algal blooms as noted by spikes in Chlorophyll a and harmful algal blooms as noted by spikes in phycocyanin with any other parameters?

c. What would be a model for the expected air temperature and the lake temperatures at various depths during the spring, summer, fall and winter? Include energy concepts and properties of matter in the model. Note: Muskegon Lake usually totally freezes during the winter.

After students have presented their findings and evidence to the class, the instructor can facilitate a discussion talking about how inter-annual and daily cycles within a lake are important to the bigger picture of human impacts and climate change.

- What do the daily, seasonal, and yearly trends of Muskegon Lake show in long terms of human impact and climate?
- How can monitoring of lake dynamics help to predict climate change or monitor environmental quality?

Evaluate

Students should be able to answer the original questions with a greater degree of sophistication based on data:

- Suppose each year a class can do one day of water monitoring. When should the monitoring be done?
- If we compare the data from one year to the next, how can we know that any trends are meaningful?
- How will we know if things have changed or remained the same?
- How can human activities impact the aquatic environment and what evidence do we have (or require) to evaluate and mitigate that impact?

Availability of Other Data Sets

Over 156,000 students, teachers, and others have experienced hands-on science on the Grand Valley State University Annis Water Resources Institute's research and education vessels as they monitor water quality in Lake Michigan and its connecting waterways. Students in grade 4 and above have an opportunity to participate in these educational trips that have been offered since 1986 (www.gvsu.edu/wri/education). The Muskegon Lake Observatory is highlighted on trips on the Muskegon Lake trips. Student-generated data sets for Lake Michigan, Spring Lake and Muskegon Lake have been compiled. Also, GVSU-AWRI scientists conduct water monitoring in Muskegon Lake using more sophisticated instruments than are used in the education program.

Water quality and other data sets can be readily procured from a variety of government agencies, non-profit organizations, and universities (Table 3). The quality and coverage of these data sets and their ease of retrieval varies greatly but they can serve as sources of data sets for further analysis.

Great Lakes Water Quality Data Source	Description
Great Lakes Observing System (GLOS) Data Portal (www.glos.us/)	Near-real-time and archived observations including lake conditions, water levels, wave heights, air and water temperatures, and forecasts.
Integrated Ocean Observing System (www.ioos.noaa.gov/)	Students can explore and track conditions over different parts of the world ocean, coastal waters and the Great Lakes
United States Geological Survey (USGS) (waterdata.usgs.gov/mi/nwis/rt)	Real-time data for stream flow and other parameters. Time-series graphs and data sets can be generated online
Teaching Great Lakes Science (https://www.michiganseagrant.org/topics/education/)	This website features a suite of lessons, activities and data sets focused on the Great Lakes.
Great Lakes Monitoring (greatlakesmonitoring.org/)	Easy access to long-term, environmental monitoring data collected throughout the Great Lakes. There are a range of environmental parameters to choose from such as nutrients, contaminants and physical properties of water.
How's My Waterway? (Formerly called MiSWIMS) (https://www.michigan.gov/egle/about/organization/water-resources/glwarm/my-waterway)	The application on the website is an interactive map-based system that allows users to view information about Michigan's surface water.
Cooperative Lakes Monitoring Program (MI Corps) (https://micorps.net/about-data-exchange/)	An online data set is searchable for lakes and streams in Michigan.
Grand Rapids Water Quality Reports (https://www.grandrapidsmi.gov/Government/Departments/Water-System/Water-Quality)	The City of Grand Rapids has monitored the Grand River and selected tributaries with data going back several decades
World Water Monitoring Challenge™ (WWMC) (www.worldwatermonitoringday.org)	WWMC provides a venue for students to use simple test kits to monitor water quality and their results can be posted online.
Global Learning and Observations to Benefit the Environment (GLOBE) (www.globe.gov)	A world-wide environmental monitoring program where students at GLOBE schools follow standardized monitoring protocols and post their results online. Data sets can be retrieved and analyzed with graphical visualization capability.
Great Lakes Fieldscope (greatlakes.fieldscope.org)	Students can explore maps and graphs and contribute water quality data from across the Great Lakes watershed region.

Table 3. Online Great Lakes and water quality data sets

Acknowledgements

An EPA-Great Lakes Restoration Initiative grant (2010-2014), and a joint NOAA-Great Lakes Environmental Research Laboratory and University of Michigan-Cooperative Institute for Limnology and Ecosystem Research grant (2015-2016) supports the Muskegon Lake Observatory. Funding from the National Science Foundation for the Target Inquiry Program at GVSU provided a teacher-internship to Ashley Meyer at the AWRI during 2013.

Literature Cited

Biddanda, B. A. 2012. Lake Sentinel: Observatory for Ecosystem Changes in Muskegon Lake. InterChange, Newsletter of the Regional Math and Science Center, Grand Valley state University. May 2012.

Biddanda, B. A. 2014. Observatory for Ecosystem Changes in Muskegon Lake Area of Concern. Final Project Report submitted to US EPA Great Lakes National Program Office, Chicago, December 2014.

Great Lakes Literacy Principles. 2019. https://www.cgll.org/principles/.

Michigan Department of Environmental Quality (MDEQ). 2011.Stage 2 Remedial Action Plan Muskegon Lake Area of Concern.

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Williamson, C. E., Saros, J. E., Vincent, W. F., and J. P. Smol. 2009. Lakes and reservoirs as sentinels, integrators, and regulators of climate change. Limnology and Oceanography. 54**:** 2273-2282.