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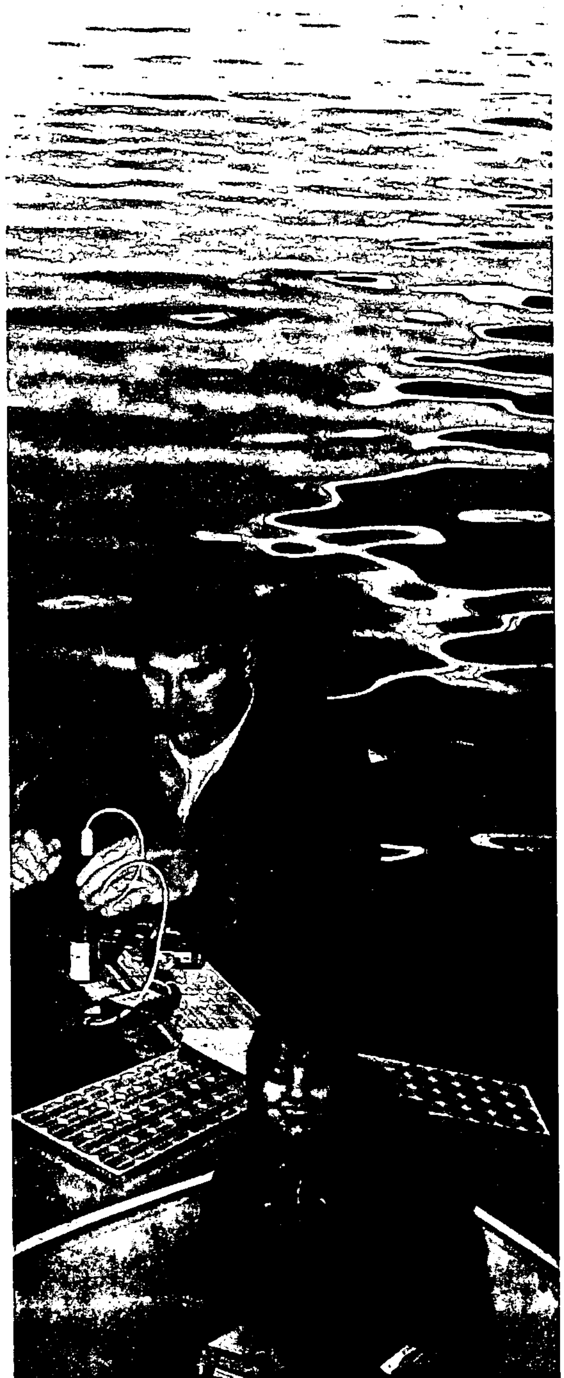
ABSTRACT

Water on the Web (WOW) curriculum materials help students understand data taken from several water sampling robots called Remote Underwater Sampling Station (RUSS) units located in Ice Lake, Lake Independence, Lake Minnetonka, and Grindstone Lake in Minnesota. WOW allows high school and college students to monitor Minnesota lakes over the Internet. This project integrates state-of-the-art environmental monitoring with geographic information systems, data visualization, and in-depth educational materials. The goal is to train students to solve real world problems. The RUSS units provide remotely-programmable vertical profiling of temperature, dissolved oxygen, pH, electrical conductivity, and turbidity. Data and monitoring schedules are transmitted via cellular phone to the WOW Web site and ultimately the classroom. Students then conduct interactive inquiries of lakes and watersheds, conduct basic science experiments, and learn data analysis techniques. The curriculum is used to train students in water resources and advanced technology, helping them to better manage natural resources in the future. This booklet provides information about the project development, using and accessing water resources on the Web, curriculum materials for teachers and students, and other aspects of the project. (Contains 14 references.) (ASK)

http://wow.nrri.umn.edu

INTEGRATING REAL-TIME DATA INTO EDUCATIONAL CURRICULA OVER THE INTERNET



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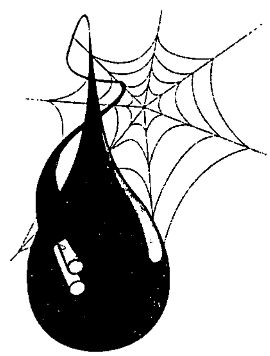
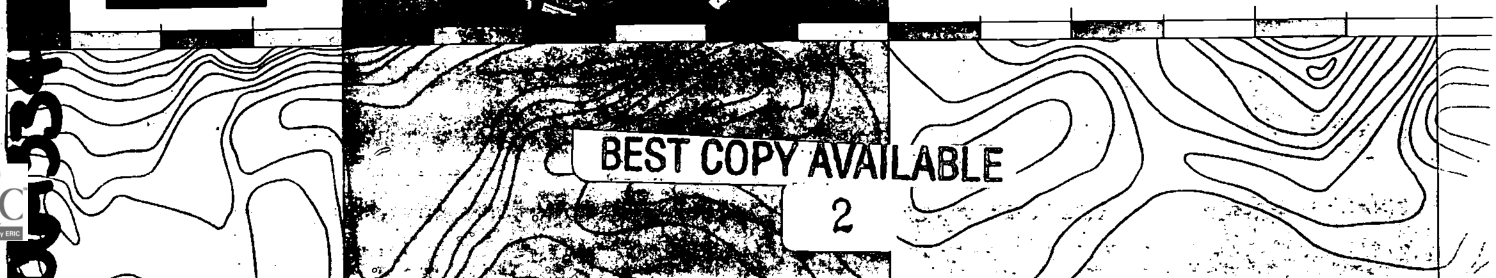
WATER ON THE WEB





WATER ON THE WEB

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Water on the Web (WOW) is a science curriculum project involving state-of-the-art technologies. WOW allows first year college and advanced high school students to use real environmental data. It integrates environmental monitoring with Geographic Information Systems (GIS), data visualization, and in-depth educational materials. The ultimate goal of the project is to contribute to the training of a more scientifically and technologically competent workforce, able to solve real world problems. The WOW lessons encourage students to learn and apply basic science concepts through real-time remote sensing technology, GIS, data visualization, computer-supported data management and analysis, and the Internet.

Water on the Web continues to grow as a collection of individual, yet integrated, lessons designed to enrich and enhance student learning in general science courses. Teachers of introductory science classes are almost certain to find a WOW lesson that illustrates or applies a basic concept they can infuse into an existing science curriculum. WOW lessons can be completed in science and computer lab environments by classes of students working in small groups; most WOW lessons can alternatively be completed as homework assignments.

For the most complete and recent version of WOW, please visit the project website at http://wow.nrri.umn.edu. A CD version of the curriculum, database, and supporting resources is available upon request.

"Any science teacher can use the WOW site to help teach water concepts, from water characteristics to complex ecological interactions. It's the next best thing to taking your class to the lake every day of the year!"

SUE HUTCHINS
Biology Instructor
Itasca Community College
Grand Rapids, Minnesota

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RATIONALE

Technological and scientific literacy have been identified as critical areas for educational reform if the United States is to remain competitive in the global economy (NRC, 1996). At the same time these issues are challenging education, advancing technology is providing improved access to data and resources through the Internet. As former U.S. Secretary of Education Terrel Bell stated, "The technological revolution that has greatly enhanced the efficiency of industry, business, and publishing has had little impact on the classrooms of America...American education is truly wobbling down the electronic avenue in an ox-cart." (Bell, quoted in *Microcomputers for Twenty-First Century Educators*, 1994, p. 388.)

Water on the Web seeks to improve students' technological and scientific literacy by allowing them to develop and apply scientific concepts using advanced technologies and real environmental data. Through Water on the Web lessons, teachers can teach to national and state standards for science by incorporating selected lessons into their existing curriculum.

NAT CRITICAL SKILLS AND ABILITIES NEEDED FROM STUDENTS TRAINED IN THE SCIENCES

PROBLEM SOLVING SKILLS

SCIENTIFIC LITERACY
an understanding of and appreciation for science

TECHNOLOGICAL SKILLS
ability to use computer technologies including GIS, databases, spreadsheets, etc.

ANALYTICAL SKILLS
ability to interpret graphs and conduct mathematical analyses

THINKING SKILLS
ability to apply inquiry skills, and engage in creative and critical thought processes

BASIC COMMUNICATION
including collaboration skills

BASIC MATHEMATICS SKILLS

ABILITY TO APPLY SKILLS TO REAL WORLD

THE CURRICULUM DEVELOPMENT PROCESS

The strategy and overall framework for creating the WOW curriculum materials began with the help of two project teams: the Curriculum Development Team (CDT) and the National Advisory Team (NAT). Past and current members of these teams are identified below.

At the initial meeting of NAT some of the critical skills and abilities for environmental technicians and scientists were identified. Note how these critical skills and abilities align with the WOW curriculum model components (see section on curriculum materials, page 7), which have guided the development of WOW lessons (Knowledge Base, Experimental Design, Data Collection, Data Management and Analysis, Interpretation of Results, Reporting Results). The NAT also worked with the CDT to identify curriculum and technology design considerations based on opportunities and constraints that may affect teachers' ability to use the WOW curriculum materials (see Appendices 1 and 2). The NAT meets annually to ensure the project remains connected with the needs of the industries and agencies that will eventually employ the students trained in the sciences.

The CDT worked with the project staff to develop a framework identifying key science concepts that could be taught or applied using near real-time water quality data provided by the Remote Underwater Sampling Station (RUSS). They proposed key concepts and ideas for lessons that would integrate smoothly into existing science curriculums and teach to national and state standards (see Appendix 3). Throughout the project, the CDT met periodically to generate lesson ideas, review materials, and discuss continued directions for the project. They also review and pilot-test curriculum materials as they are developed.

NATIONAL ADVISORY TEAM

Dr. Earl Byron	CH2M Hill	Sacramento, CA
Dr. Gerald Filbin	US EPA	Washington, DC
Dr. Shirley Fiske	National Sea Grant Program	Washington, DC
Charlie Fitzpatrick	ESRI	St. Paul, MN
Dr. Charles Goldman	UC-Davis	Davis, CA
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Dr. Michael McDonald	US EPA	Durham, NC
Victor Omelczenko	National Sea Grant Program	Washington, DC

CU[RRICU]LUM DEVELOPMENT TEAM

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Jon Rowe	Grand Rapids High School	Grand Rapids, MN
Jay Sandal	Great Lakes Aquarium	Duluth, MN

Integrating perspectives and input from the NAT and CDT reinforced the WOW curriculum approach and identified topics for lesson development. The combined input provided direction and priorities for developing lessons.

Individuals or teams representing the CDT, project staff and regional teachers developed the lessons. Scientists working in the field have reviewed all the lessons for scientific accuracy and experimental design. The lessons have been pilot-tested in several settings by classroom teachers. Feedback was used to revise the curriculum materials. The general process for curriculum development is illustrated in Figure 1.

Additional general information about the Water on the Web project and its development can be found on the website by clicking "Overview" on the home page.

USING WATER ON THE WEB

The WOW materials can be used on either a Windows or Macintosh operating system. The Water on the Web site can be accessed by Internet Explorer, Netscape Navigator, or any other HTML-compliant web browser. Considerable effort has gone into ensuring WOW's unique data visualization applications (applets) work across all platforms, primarily through the use of the Java programming language in application development. However, not all operating systems are equally compliant with Java specifications. These problems will be resolved as the operating systems and languages become more uniform. In the meantime, a few WOW users may find they cannot use the data visualization tools unless their operating systems or browsers are updated.

MINIMUM SYSTEM REQUIREMENTS:

- 16 Mb RAM
- Windows 95 or Mac 7.5 or later operating system
- Netscape or Internet Explorer browsers versions 3.x or better
- CD-ROM player at least 8x (if using WOW from a CD)

PREFERRED SYSTEM REQUIREMENTS:

- 64 Mb RAM
- Adobe Acrobat Reader loaded and linked to browser
- Shockwave plug-in
- Excel 5.0/95 or more recent loaded and linked to browser
- To run the Java applets:
  - Windows: Netscape versions 4.06 or better, or Internet Explorer browsers versions 4.x or better
  - Mac: Mac OS Runtime for Java (MRJ) 2.1 or greater with Microsoft Internet Explorer - current version, configured to use MRJ (Apple and Netscape are working together to develop a future version of Netscape's browser that will use MRJ).

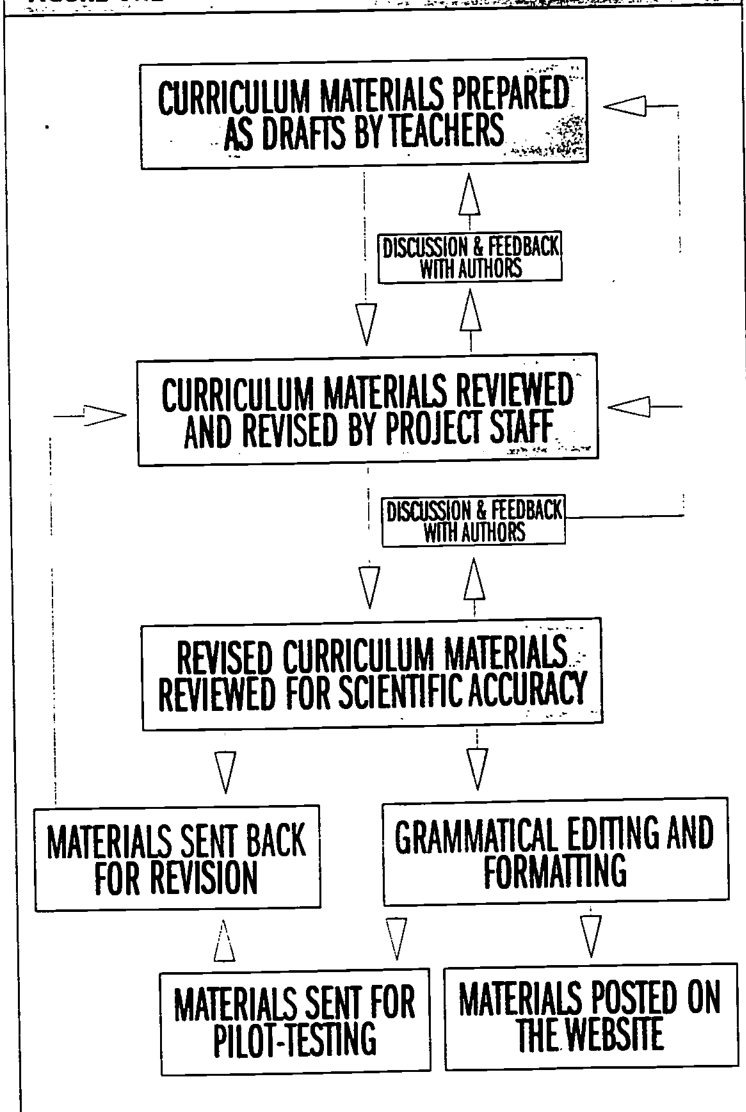
ACCESSING WATER ON THE WEB

Water on the Web can be easily accessed using any web browser on the computer and connecting to http://wow.nrri.umn.edu.

For computers without Internet access, the optional CD provides access to the WOW materials as they were captured during October 2000. General instructions for working with the CD-ROM are provided below for both Windows and Macintosh users:

1 With your computer turned on, insert the CD into your CD drive.
2 Open your web browser.
3 Under the browser's "File" menu, select "Open" or "Open Page."
4 Follow the options provided to find and select the file "index.html" on the CD.
5 Once the WOW website is opened, you can navigate the entire site.

FIGURE ONE - THE WOW CURRICULUM DEVELOPMENT PROCESS



You may want to begin your review of the website by looking at the data and data visualization features of the curriculum materials. Check out the Excel spreadsheets, Profile Plotter, and Color Mapper. Then review examples of the lessons to see how they might be useful for your classes. Water on the Web also offers practical resource materials in the "Understanding" section of the website.

Depending on how your computer and browser are configured, you may have access to all parts of the website or you may be limited in your ability to use some of the data visualization techniques and downloading opportunities. However, if you meet the minimum system requirements, you will still be able to work with the curriculum and data.

Please be aware that the website is never static. WOW is always evolving and the optional CD-ROM is simply a snapshot of the evolution of these materials. The CD-ROM may be useful in your classroom or lab, but the WOW website at http://wow.nrri.umn.edu will always offer the most recent water quality data, new data visualization approaches, and valuable supporting resource materials.

TIME REQUIREMENTS

The WOW lessons are designed to blend into your existing curriculum. The lessons are structured so they may be assigned for homework, or completed in a class or computer laboratory. Portions of each lesson are delineated to be completed within a standard class period.

PROJECT DATA

Water on the Web offers several unique opportunities for students learning science. One of the unique features of this project is that students learn and apply basic science concepts through the use of real water quality data. Quantitative analysis and the ability to use and manipulate numbers to understand the world are essential parts of doing science. The Water on the Web project provides numerical data on several water quality parameters through remotely controlled sampling devices. RUSS units (see the details about these units in the section on technology, page 16) rest in several Minnesota lakes. RUSS technology allows us to sample water quality indicators at specified depths from the surface to the bottom of the lakes. This numerical data is provided in tables and in Excel spreadsheets (see Figure 2). Data is easily accessed from the website by clicking the heading "Data" on the WOW home page.

The teacher lesson plans and student lessons provide guidance on how the data might be used. However, some teachers may prefer to develop their own lessons using the data. Teachers who take this approach are invited to submit their lessons for possible inclusion on the WOW website.

For many students it is difficult to see and interpret patterns in numerical data. For this reason WOW offers interactive data visualization opportunities. Teachers may want to use these data visualization approaches to motivate students by illustrating trends or relationships among the data. Key data visualization techniques provided as of this printing include: the Profile Plotter, seasonal profiles, and the Color Mapper.

The Profile Plotter allows students to view graphs of selected dates, times, and specific water quality parameters and to see how these graphs change over time. By interacting with the plotter students can infer relationships among water quality parameters and discover trends over time. For example, look at the three separate plots of Ice Lake showing temperature and dissolved oxygen (see Figures 3-5). With guiding questions from the teacher, most students can infer a relationship between these two parameters: a relationship that contradicts Le Chatelier's Principle and raises questions.

Trends can also be seen through programs like WOW's temperature/depth charts that help students visualize changes over time. Notice how Figure 6 indicates that a dramatic change occurred in the temperature profile in September, around day 200. Reviewing the actual data from this period can lead students to an understanding of the concept of turnover in a lake.

FIGURE TWO - EXAMPLE OF WOW EXCEL DATA

Site	Sample Date	Sample Time	Sched Depth m	Sample Depth m	Temp °C	pH	Cond µS/cm	DO mg/L	DO %sat	Turb NTU
IceLake	07/06/1999	10:08:30	1.0	0.8	22.5	8.3	97	8.4	101	15
IceLake	07/06/1999	10:28:42	2.0	2.1	22.5	8.3	97	8.4	101	15
IceLake	07/06/1999	10:40:57	3.0	3.1	22.5	8.2	97	8.4	101	14
IceLake	07/06/1999	10:50:25	4.0	4.2	17.7	8.2	105	10.2	111	18
IceLake	07/06/1999	10:58:42	5.0	5.2	12.1	7.7	112	9.7	94	17
IceLake	07/06/1999	11:10:46	6.0	6.0	9.3	6.8	117	3.3	30	14
IceLake	07/06/1999	11:19:42	7.0	7.2	7.1	6.7	122	0.3	3	12
IceLake	07/06/1999	11:32:18	8.0	7.9	6.1	6.6	121	0.1	1	14
IceLake	07/06/1999	11:41:31	9.0	9.0	5.7	6.6	125	0.1	1	17
IceLake	07/06/1999	11:53:25	10.0	10.1	5.2	6.7	135	0.1	1	18
IceLake	07/06/1999	12:02:07	11.0	11.1	5.0	6.7	138	0.1	1	16
IceLake	07/06/1999	12:16:09	12.0	12.2	4.9	6.8	141	0.1	1	17
IceLake	07/06/1999	12:29:49	13.0	13.0	4.9	6.8	144	0.1	0	16

FIGURE THREE

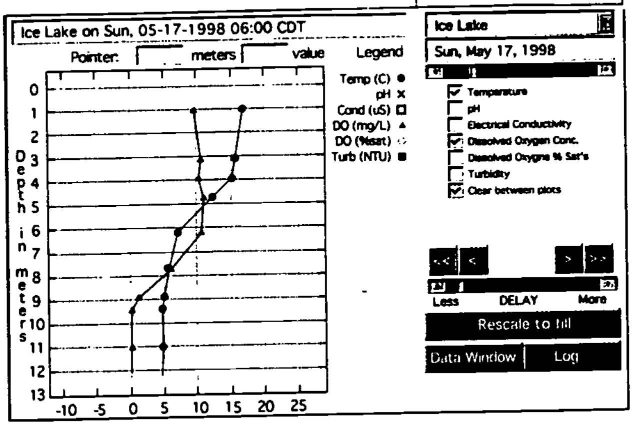


FIGURE SIX - ICE LAKE TEMPERATURE PROFILE 1998

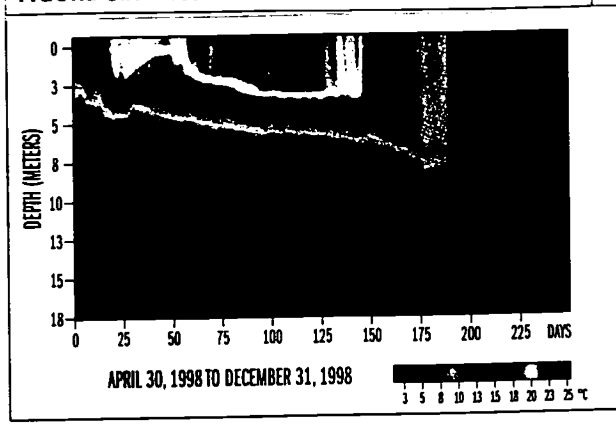


FIGURE FOUR

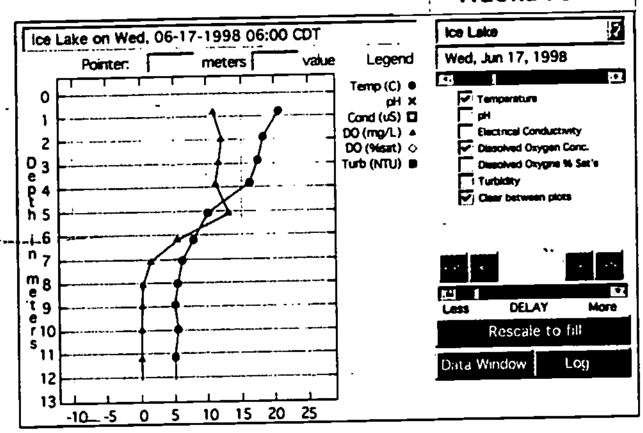


FIGURE SEVEN - COLOR MAPPER DISPLAY

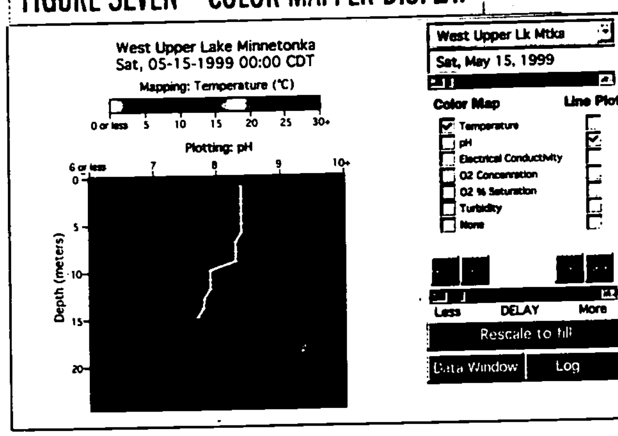


FIGURE FIVE

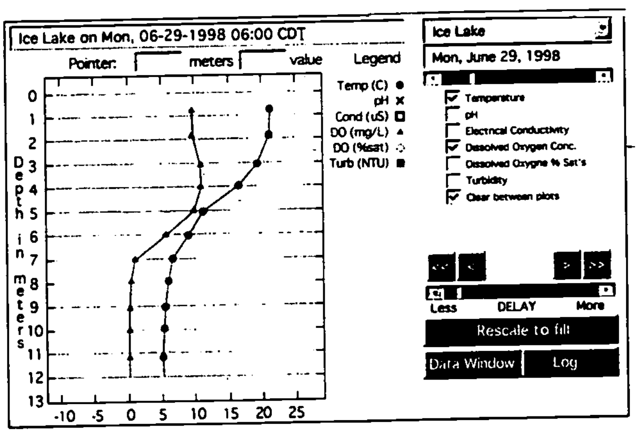
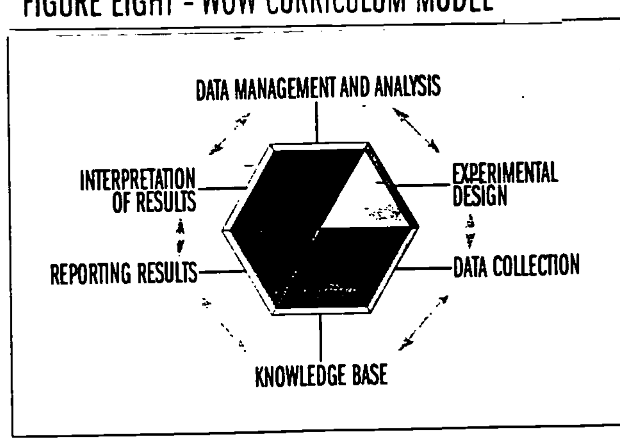


FIGURE EIGHT - WOW CURRICULUM MODEL



The color mapper integrates the features of the two previous visualization approaches. With this third tool, students can see how a graph superimposes on the color-coded profile. This helps students interpret the data. For example, look at the color mapper display, Figure 7. Notice how the color-coding reinforces the rate of temperature change at the thermocline.

Teachers must decide when it is best to use the data visualization approaches offered through WOW. They may want to project data for the whole class to set the stage and motivate students. In other cases, teachers may want to use data visualizations to conclude a lesson by reinforcing key concepts.

CURRICULUM MATERIALS FOR TEACHERS AND STUDENTS

The WOW curriculum materials vary in complexity and approaches, even though all lessons have been designed for college freshmen and advanced high school students. The lessons use the aquatic environment and real lake data to explore basic science concepts through two different approaches: a directed study ("Studying") and an inquiry ("Investigating") approach. The directed studies allow students to apply and learn concepts through direct, guided experience. The inquiry lessons provide a more open-ended opportunity for students to discover the same concepts. Click on the "Teachers" or "Students" link on the WOW home page to access lessons. The potential of the lessons is most apparent when viewed in the web format for which they were designed. However, two examples are printed here to demonstrate how the lessons may be useful for the classroom.

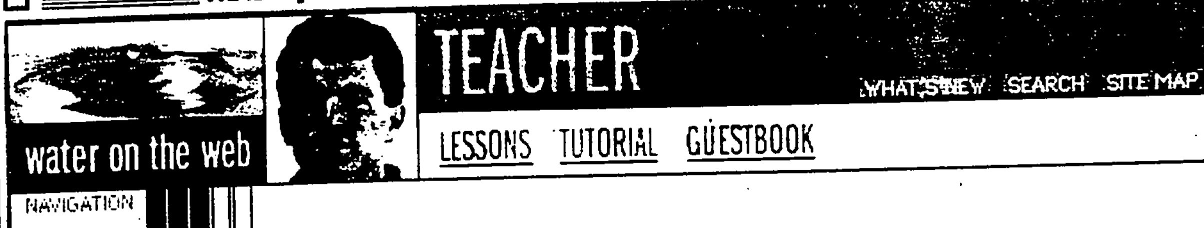
THE WOW CURRICULUM MODEL

Based on the advice of the project's national advisory and curriculum development teams, the WOW lesson approach incorporates six components that are critical to improving scientific and technological literacy (Knowledge Base, Data Collection, Experimental Design, Data Management and Analysis, Interpretation of Results, and Reporting Results, see Figure 8). One component may be emphasized more than the others in a lesson, but, the lesson model provides a thinking framework that should enable students to use science and technology to investigate real world problems. Notice how the WOW lesson components provide a framework for the lessons in the following examples. These lessons and others can be reviewed on the CD.

WOW LESSONS

Example lessons from the WOW website are included in this section. The teacher's lesson is followed by two student lessons. Please review these lessons and others on the website to see how they use data and resource materials.

Netscape: water on the web – teacher – on line lessons



TEACHING ABOUT FISH STOCKING DECISIONS

Credits
Glenn Merrick and Kent Montgomery developed this lesson.

Goals
Students will learn about the relationship between dissolved oxygen (DO) concentrations and water temperature and the limits oxygen concentration and water temperature may impose on fish species.

Introduction
This lesson introduces students to the basic relationship between dissolved oxygen (DO) concentrations and water temperature. Students use that information as they determine whether a lake association should stock lake trout (*Salvelinus namaycush*) into Ice Lake. This lesson builds on familiar observations, such as bubbles forming in a glass of water as it warms and minnows dying in a bait bucket when water isn't changed. Students explore the ability of lake trout to survive in a specific environment.

Students can meet the goals for this lesson by completing a directed study or an inquiry lesson.

The directed study lesson consists of a student worksheet that analyzes oxygen-solubility and temperature. Students will need to print the worksheet. The directed study lesson is found in the student section of WOW under the title: "Studying Fish Stocking Decisions."

The student inquiry lesson places students as Minnesota Department of Natural Resources fisheries biologists. Students collect and analyze data and develop a final presentation. The instructor specifies the format of the final presentation: written paper, oral presentation, poster, or multi-media presentation. They need to print directions for the student inquiry lesson. The student inquiry lesson is found in the student section of WOW under the title: "Investigating Fish Stocking Decisions."

Outcomes
Students will:
1. Describe and graph the basic relationship between oxygen solubility and water temperature.
2. Explain the physical basis for declining O_2 concentration with increasing temperature.
3. Graph oxygen/temperature profiles.
4. Use real data to make decisions about the suitability of specified lakes for fish species given the physiological limits of the species.

Keywords
Oxygen, solubility, temperature, lake trout

Prerequisites
There are no prerequisites, but basic graphing skills and knowledge of abiotic environmental factors help students complete the lesson successfully.

Materials/Resources/Software
- Printed copies of "Studying Fish Stocking Decisions" (for directed study lesson)
- Access to the Internet to retrieve WOW data

Time Required
1-2 hours

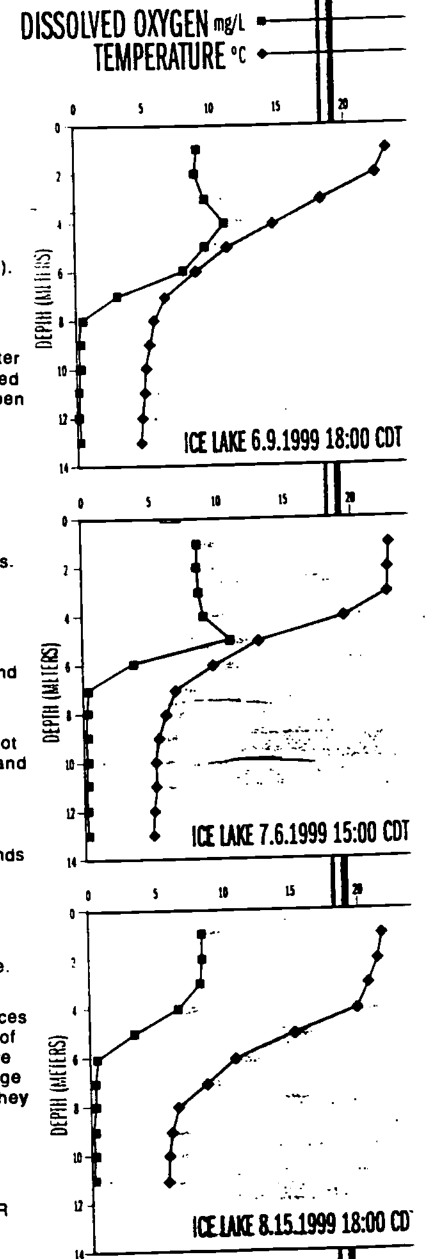
Curriculum Connections
Biology - abiotic factors, fish physiology, stratification, thermocline
Chemistry - oxygen solubility, nonpolar gases, saturation
Resource Management - fish stocking, lake associations

WOW Curriculum Links
Thermal Stratification, The Effect of Photosynthesis and Respiration on Aquatic Chemistry, Properties of Water, Aquatic Respiration

Procedure
Students can meet the goals for this lesson plan by completing a directed study or an inquiry lesson. Students may want the directions for their lessons printed. The directed study lesson is found in the student section of WOW under the title: "Studying Fish Stocking Decisions." The inquiry lesson is found in the student section under the title: "Investigating Fish Stocking Decisions."

Knowledge Base
The WOW data visualization tools can help illustrate changes in DO and temperature during an extended period of sampling. These changes could be demonstrated by advancing the Profile Plotter through several sampling periods or by creating graphs in Excel (see graphs to the right). You may want to display these for the students. This could be done either during your initial discussions for this lesson, or as part of the discussion and closure for the lesson.

Directed Study and Student Inquiry
Discuss the students' knowledge of fish, focusing on the survival needs of lake trout. What water qualities are necessary for lake trout to survive in a given lake? What factors need to be considered before stocking a lake? What social and economic issues are related to stocking? What can happen if a lake is "incorrectly" stocked?



Experimental Design
Directed Study
Divide students into pairs to work on the lesson. The students need in-class work time where they can retrieve WOW data to complete the worksheet.

Student Inquiry
Present the Minnesota Department of Natural Resources fisheries biologist scenario to students. As fisheries biologists, students need to determine whether or not to stock Ice Lake with lake trout. They should use DO and temperature to make the decision about stocking.

Data Collection
Directed Study
Students use WOW temperature and DO levels for Ice Lake after an analysis of temperature and oxygen concentrations for Mackinaw Lake, provided in Studying Fish Stocking Decisions.

Student Inquiry
Students need to decide how they will use WOW data to answer the question of whether or not to stock. They should choose as many dates as they feel necessary for data on temperature and DO in Ice Lake.

Data Management and Analysis
Directed Study and Student Inquiry
Students graph DO and temperature. Remind students to label axes and include titles and legends on their graphs.

Interpretation of Results
Directed Study
When the presentations are over, the class should play the role of the Lake Association and discuss the feasibility of stocking before voting on whether or not to stock lake trout in Ice Lake.

Student Inquiry
Students should explore the lake survey data of the Minnesota Department of Natural Resources (http://www.dnr.state.mn.us/lakefind). Ask students to consider the physical characteristics of Clearwater, Greenwood, Saganaga, and Seagull Lakes (all in Cook County). Lake trout lakes are most common in Northeastern Minnesota, but even there lake trout are near the southern edge of their range. Students should come to a conclusion about stocking lake trout in Ice Lake. They need to be able to explain the reasoning behind their decision.

Reporting Results
Directed Study
When the students have completed the lesson, call on at least two groups to present their findings. Ask the rest of the class to serve as area fishermen who want to know why the DNR has chosen to stock or not stock lake trout in Ice Lake.

Student Inquiry
Students need to make a presentation to concerned anglers about the ability of lake trout to survive in Ice Lake. The data and analysis should provide most of the information needed to complete the report. Specify the presentation format: a written paper, an oral presentation, a poster, or multi-media presentation. Remind students to be prepared to answer any questions about their research findings.

Evaluation
The completed data tables and graphs demonstrate students' ability to retrieve and present temperature data from a lake using WOW. Completion of the worksheet or the final presentation provides evidence of their level of understanding of the conceptual material contained in the lesson.

Resources
Minnesota Department of Natural Resources Lakefinder

Extensions
Explore the Minnesota Department of Natural Resources lake survey data in greater detail.

Netscape: water on the web – student

STUDENT

WHAT'S NEW SEARCH SITE MAP

water on the web

LESSONS GUESTBOOK

NAVIGATION

STUDYING FISH STOCKING DECISIONS

The issue of stocking a lake can be volatile. Anglers, local residents, and business owners may believe that a certain lake should be stocked with lake trout. After all, it may improve fishing in the lake, which can have a positive effect on the local economy. Like many issues faced by natural resources personnel, the issue of stocking is not that clear-cut. Before stocking a lake, natural resources personnel must determine if lake trout can succeed in a given lake. Like all animals, lake trout depend on specific environmental conditions for their survival. In this lesson, you will decide whether the temperatures and oxygen concentrations of Ice Lake provide some of the basic physical conditions required to support lake trout.

Knowledge Base
Imagine the Ice Lake Association asked you if lake trout would survive if they were stocked in Ice Lake. You plan to investigate this question by looking up summer and winter temperature and oxygen levels in a typical Northeastern Minnesota lake that does support lake trout.

Before you begin, consider what you know about the water quality needs of lake trout.
1. What factors need to be considered before stocking a lake?
2. What social and economic issues are related to stocking?
3. What can happen if a lake is "incorrectly" stocked?

Experimental Design
A natural resources technician has provided you with the following information (see table below) for a typical good lake where lake trout flourish.
4. Construct a graph of the concentration of oxygen at each depth for each season and describe the pattern you see. Now add the temperature data to the graphs you have constructed.
5. Do you observe declining oxygen levels with increasing temperature in any of your graphs?

The technician reminds you that lake trout seek out water temperatures of about 9–13°C in the summer. If summer temperatures exceed approximately 20°C or if oxygen concentrations fall below about 8 mg/L conditions are not ideal for the survival of adult lake trout.

You know Mackinaw Lake supports lake trout. Now you need to collect data from Ice Lake to see if it can support lake trout. You will organize and analyze your data in the same way you have just reviewed the data from Mackinaw Lake. You need to begin by collecting data from one sampling period in each of the seasons: spring, summer, and fall.

Data Collection
Collect the temperature and DO data for Ice Lake on three different dates. Record the data in Excel or another spreadsheet program.

Data Management and Analysis
6. Create graphs for each season showing the temperature and dissolved oxygen profiles.

Interpretation of Results
7. Based on the data you have collected, would lake trout succeed in Ice Lake? Explain how you have arrived at your conclusion.
8. If you found habitat limitations for lake trout because of low oxygen levels or temperatures that are too high, would you expect these conditions to persist through times of the year for which you do not have data? Why or why not?
9. Explain why you would or would not recommend the Ice Lake Association should attempt to stock lake trout?

Reporting Results
Turn your answers and your graphs in to your teacher. Check to see if other groups got similar results. Your group may be asked to make a presentation of your findings to the class.

MACKINAW LAKE

O_2

WINTER

0	14.0	0
2	13.5	2
4	13.0	3
6	13.0	3
8	13.0	3
10	12.8	4
12	12.7	4
14	12.7	4
16	12.7	4
18	12.7	4

SUMMER

0	8.3	23
2	8.3	23
4	8.6	21
6	10.1	13
8	11.8	7
10	12.1	6
12	12.7	4
14	12.7	4
16	12.7	4
18	12.7	4

mg/L

Netscape: water on the web – student

STUDENT

water on the web

LESSONS GUESTBOO

NAVIGATION

INVESTIGATING FISH STOCKING DECISIONS

The issue of stocking a lake can be volatile. Anglers, local residents, and business owners may believe that a certain lake should be stocked with lake trout. After all, it may improve fishing in the lake, which can have a positive effect on the local economy. Like many issues faced by natural resources personnel, the issue of stocking is not that clear-cut. Before stocking a lake, natural resources personnel must determine if lake trout can succeed in a given lake. Like all animals, lake trout depend on specific environmental conditions for their survival. In this lesson, you will decide whether the temperatures and oxygen concentrations of Ice Lake can support lake trout.

Knowledge Base
Consider what you know about the needs of lake trout. What water qualities are necessary for lake trout to survive in a given lake? What factors need to be considered before stocking a lake? What social and economic issues are related to stocking? What can happen if a lake is "incorrectly" stocked?

Lake trout require specific environmental conditions for their survival. They seek out water temperatures of about 9–13°C during the summer. In the cool, relatively unproductive lakes that lake trout commonly inhabit, oxygen concentrations are near saturation. If summer temperatures exceed approximately 20°C or if oxygen concentrations fall below about 8 mg/L conditions are not ideal for the survival of adult lake trout.

Experimental Design
As a Minnesota Department of Natural Resources fisheries biologist you need to determine whether or not to stock Ice Lake with lake trout. Your decision will be based primarily on dissolved oxygen (DO) and temperature (two very important water quality measures for fish survival).

Think about how to efficiently approach answering the question of whether or not to stock lake trout. You know you have the temperature and DO data available from WOW. How many sampling times and different days do you feel you will have to analyze? How will you organize and analyze this data so you can make your decision?

Data Collection
Make sure you have an organized way to record your DO and temperature data before you visit the "Data" area of the WOW website.

Data Management and Analysis
You may want to construct a graph(s) of temperature and oxygen concentrations in Ice Lake. If you do, be sure to label axes and include titles and legends on your graphs.

Interpretation of Results
Explore the lake survey data of the Minnesota Department of Natural Resources (http://www.dnr.state.mn.us/lakefind). Consider the common physical characteristics of Clearwater, Greenwood, Saganaga, and Seagull Lakes (all in Cook County). These lakes all support healthy lake trout populations. Lake trout lakes are most common in Northeastern Minnesota, but even there lake trout are near the southern edge of their range.

According to your data, can lake trout succeed in Ice Lake? How would you explain your reasoning to area anglers?

Reporting Results
You need to make a presentation to the DNR and concerned local citizens about the ability of lake trout to survive in Ice Lake. The data and your analysis should provide most of the information you need to complete the report. Your teacher will specify the format: a written paper, an oral presentation, a poster, or multi-media presentation. Be prepared to answer any questions about your research findings.

Netscape: water on the web – te

TEACHER

water on the web

LESSONS TUTORI

NAVIGATION

TEACHING ABOUT THERMAL STRATIFICATION

Credits
Jon Rowe developed this lesson.

Goals
Students will build an understanding of lake stratification and the characteristics of lake stratas.

Introduction
Thermal stratification, or layering, occurs in many Minnesota lakes. Whether or not a lake stratifies depends on a number of factors: the shape and depth of the lake, the amount of wind, and the orientation of the lake (lakes that are oriented east-west are more affected than lakes oriented north-south). When layering occurs the upper, warmer layer is referred to as the epilimnion, and the colder, deeper layer is referred to as the hypolimnion. The boundary between the layers where the rate of temperature change is most rapid is referred to as the thermocline. Temperature stratification is often paralleled by stratification of other water quality measurements such as pH and dissolved oxygen.

Students can meet the goals for this lesson by completing a directed study or an inquiry lesson.

The directed study lesson consists of a brief demonstration of stratification, turnover and an analysis of WOW data. The six lesson components are divided among the demonstration and analysis of WOW data. Students may want to print directions for the lesson. The directed study lesson is found in the student section of WOW under the title: "Studying Thermal Stratification."

The student inquiry lesson is divided in two parts. The first part challenges students to demonstrate thermal stratification in the laboratory. Students develop a protocol, complete their experimental demonstration, and orally present their results. In the second part, students use WOW data to provide evidence of thermal stratification. Students develop a written paper, oral presentation, poster, or multi-media presentation based on their research. Each part of the lesson contains the six components. They may want to print directions for the student inquiry lesson. The student inquiry lesson is found in the student section of WOW under the title: "Investigating Thermal Stratification."

Outcomes
Students will:
1. Graph WOW data to determine whether or not a lake is stratified.
2. Label the stratified layers of lakes.
3. Identify variables that affect temperature stratification in lakes.
4. Describe and explain the process of turnover in stratified lakes.

Keywords
Temperature, stratification, thermocline, hypolimnion, epilimnion

Prerequisites
Students need basic graphing skills, and they need to know how to use the computer to retrieve WOW data before beginning this lesson.

Materials/Resources/Software
- Two clear cups or glasses per group
- One colored ice cube per group (add food coloring to water before freezing)
- One gallon of cold (the colder the better) colored water
- Access to the Internet for temperature profile data of a lake (or handouts of temperature data that have been printed from the WOW website)

In the student inquiry lesson students are challenged to demonstrate thermal stratification. The above materials may be provided, teachers can supply additional materials, or students can generate an original demonstration of thermal stratification.

Time Required
Directed Study
This lesson requires approximately one hour.

Student Inquiry
The lesson requires approximately two hours.

Curriculum Connections
Biology - thermocline, lake stratification, turnover
Physics - temperature, density, convection

WOW Curriculum Links
Diel Temperature Variation, Heat Budgets of Lakes

Procedure

PART I - LABORATORY DEMONSTRATION

Knowledge Base
The WOW website resources for teachers and students includes several movies. The movies will take awhile to download, but are useful illustrations of lab demonstrations showing thermal stratification and mixing in water.

Directed Study
Discuss students' observations about the temperature of lake water. Compare the temperature at the surface to the temperature near the bottom of the lake. Introduce this lesson as an activity that will investigate temperature relationships in lakes.

Student Inquiry
Introduce the concept of thermal stratification. Have students observed distinct temperature layers in lakes? What might cause these layers? Might it be possible to replicate these layers in a laboratory setting? How?

Experimental Design
Directed Study
Divide students into groups of two, and distribute a clear glass to each group. Ask for predictions about what will happen after the ice cube is placed in a glass of water. Have each group fill the glass with warm water and place a colored ice cube in the glass. Ask them to observe and record what happens for 5 minutes. Each group should brainstorm possible explanations for what happened.

Questions
- Why did the colored water sink?
- What are convection currents?
- Could you see convection currents in the glass?
- Why do you think convection currents might/might not be found in lakes?

Notes: The colored water is colder and denser than the water in the glass and sinks to the bottom. Convection currents occur in liquids and gases as colder molecules are pulled downward by gravity, forcing the warmer molecules upward. The convection movement downward of the cold colored water can be seen in the glass. Convection currents occur in many temperate lakes when weather events cool the surface water. The cooled water is pulled downward, forcing the warmer water upward. In lakes this process may occur in the fall and be accompanied by wind driven mixing of the lake. The total process is known as seasonal "turnover."

Students should empty their glasses and fill the glasses halfway with cold colored water. Ask students to carefully pour 1/4 glass of warm, clear water into their glass. (It is often best if the warm water is poured slowly in from the side of a tilted glass to avoid mixing.) They should try to create a glass of water that has two distinctly separate layers.

Discuss the similarities and differences between the layered water and what students might expect to find in regional lakes during the summer.

Questions
- How does this demonstration relate to what happens in lakes?
- Why might layering occur in lakes?

Notes: Layering occurs in many Minnesota lakes, depending on the shape and depth of the lakes and the degree to which they are affected by winds. When layering occurs the upper, warmer layer is referred to as the epilimnion, and the colder, deeper layer is referred to as the hypolimnion. The boundary between the layers where the rate of temperature change is most rapid is referred to as the thermocline.

Students completing the directed study lesson proceed to Part II.

Student Inquiry
Challenge students to demonstrate thermal stratification. The materials listed in the Materials/Resources/Software section may be provided. Alternately, students can be challenged to create original demonstrations of thermal stratification.

Students should write a protocol for their demonstration. The protocol should provide clear, step-by-step directions for other researchers to follow. Students should be ready to explain the rationale for decisions about experimental design.

Data Collection
Student Inquiry
Students should proceed with their experimental plan. Remind students to consider variables that might affect the outcome of their experiment. Students should take notes about their observations and, if possible, repeat their experiment to substantiate their results.

Data Management and Analysis
Student Inquiry
Students should analyze their results in a way suited to their experimental design. If multiple demonstrations were performed or data were measured over time, a chart or graph is helpful. For other students a narrative analysis best communicates their results.

Interpretation of Results
Student Inquiry
Ask students to consider the following questions as they prepare to complete a final report.
- Did they succeed in replicating thermal stratification in a lab? Why?
- Were there other materials that might have aided their research?
- Would they expect the same results if another researcher completed the experiment?
- Would they proceed differently if repeating the experiment? Explain.

Reporting Results
Student Inquiry
Ask student groups to orally present their experimental design, results, and their interpretations of results. Which groups or designs were most successful? Why?

PART II - RESEARCHING THERMAL STRATIFICATION IN LAKES

Knowledge Base
The WOW data visualization tools can help illustrate temperature profiles in the WOW lakes. You may want to display the profiles in Figure 6 on page 6 for the students. This could be done either during your initial discussions of thermal stratification or as part of the closure to the lesson.

Student Inquiry
Ask students to consider the following questions as they prepare to research thermal stratification in a lake:
- How do their laboratory experiences relate to a lake environment?
- Will stratification be more or less pronounced in a lake setting?

Experimental Design
Student Inquiry
Students need to demonstrate whether or not a RUSS lake is stratified. They should consider what measures indicate stratification. How many measures are necessary to decide whether or not a lake is stratified? How many dates are necessary?

Students should be prepared to explain their experimental design decisions.

Data Collection
Directed Study
Assign student teams to collect archival data from the WOW website from 6 consecutive dates for a lake. (All student teams should work with the same lake.) Students can choose a set of dates between May 15 and September 15.

Student Inquiry
Students collect WOW data to determine whether or not a lake is stratified. Students need to decide how many dates are necessary to prove whether or not the lake remains stratified.

Data Management and Analysis
Directed Study
Using the data, each group should create temperature profile graphs. If stratification is evident, the students should label each of the layers (epilimnion, thermocline, hypolimnion).

Student Inquiry
Students should graph the data collected. If stratification is evident, the students should label each of the layers (epilimnion, thermocline, hypolimnion).

Interpretation of Results

Directed Study
Discuss observations of temperature profile graphs for the selected lake.

Student Inquiry
Discuss observations of students graphs. Compare results for various measures. Which measure best shows stratification? Do other measures correlate to stratification?

Questions
- Does the lake appear to stratify?
- Does the lake remain stratified throughout the summer?
- What variables might affect whether or not the lake remains stratified throughout the summer?
- How might temperature profiles of other lakes in the region compare to the lake monitored by RUSS?
- Why is this type of information important to people who monitor and manage or use our lakes?

Reporting Results

Directed Study
Each student team should present its graph and interpretations to the entire class. Arrange the graphs in chronological order in the front of the room.

Student Inquiry
Students develop a summary of their data. Remind students to reflect on questions discussed as the class interpreted the data. Specify the final format: a written paper, oral presentation, poster, or multimedia presentation.

Notes: Many deeper Minnesota lakes stratify during the summer. Some lakes remain stratified throughout the summer. Lakes with large, open surfaces may be mixed periodically by the wind and temporarily lose some of their temperature stratification. The amount of wind, depth of the lake, surface area of the lake, and orientation of the lake (lakes that are oriented east-west are more affected than lakes oriented north-south) determine whether or not a lake will remain stratified throughout the summer. Temperature stratification is often paralleled by stratification of other water parameters such as the availability of dissolved oxygen for fish. Anglers often find some types of fish near the thermocline. Lakes that seldom mix are likely to have a lower layer that cannot support fish life due to lack of dissolved oxygen in the hypolimnion.

Evaluation
The completed temperature profile graphs will demonstrate the students' ability to interpret and use temperature data from a lake. A journal of students' exploration of temperature relationships in lakes will reveal their understanding of the conceptual material contained in the lesson.

Resources
"Productivity of Waters" by Dave Sonnenburg, Education Section, Bureau of Information and Education, MN Department of Natural Resources: St. Paul, MN.

Extensions
1. Compare temperature profiles of the selected lake during different seasons of the year.
2. Compare temperature profiles of different lakes.
3. Collect and graph temperature profiles of a lake that illustrate the process of turnover.
4. Create and compare graphs that include temperature, dissolved oxygen, and pH at increasing depths.

Netscape: water on the

STUDYING THERMAL STRATIFICATION

Knowledge Base
Consider your knowledge of thermal stratification. What does stratification look like in a lake? What evidence supports thermal stratification? Why does stratification occur? What factors might relate to thermal stratification?

A Demonstration of Thermal Stratification

You will need:
- Two clear cups or glasses
- One colored ice cube (add food coloring to the water before freezing)
- One gallon of cold (the colder the better) colored water (use food coloring in the water)

1. What do you think will happen when warm water is poured gently into a glass with cold colored water? Carefully pour 1/4 glass of warm, clear water into the glass. It is best if the warm water is poured slowly in from the side of a tilted glass to avoid mixing. Try to create a glass of water that has two distinctly separate layers.
2. What do you think will happen when a colored ice cube is placed in a glass of warm water? Fill a glass with warm water. Place a colored ice cube in the glass. Observe and record what happens for 5 minutes. Empty the glass and fill it halfway with cold colored water.

You should be prepared to answer the following questions for class discussion:

3. Why did the colored water sink?
4. What are convection currents?
5. Could you see convection currents in the glass? Explain.
6. Why do you think convection currents might/might not be found in lakes?
7. What similarities and differences exist between the layered water and what you might find in regional lakes during the summer?
8. Why might layering occur in lakes?

Experimental Design
9. You will be investigating temperature data from a WOW lake to determine if there is evidence of thermal stratification. Does your lake appear to act the same way as the glasses of water you observed in your demonstration?

Data Collection
Your teacher will assign a lake and six dates to collect data for temperature profile graphs. After data is collected and analyzed the class will examine all of the temperature profile graphs in chronological order.

Data Management and Analysis
10. Using the WOW data for your lake, create temperature profile graphs. If stratification is evident, label each of the layers (epilimnion, thermocline, hypolimnion).

Interpretation of Results
Consider the following questions as you prepare for your final report:
11. Does the lake remain stratified throughout the summer?
12. What variables might affect whether or not the lake remains stratified throughout the summer?
13. How might temperature profiles of other lakes in the region compare to the lake monitored by RUSS?
14. Why is this type of information important to people who monitor and manage or use our lakes?

Reporting Results
Turn your temperature profile graphs and any written responses to questions in to your teacher.

Netscape: water on the web – student

STUDENT

WHAT'S NEW SEARCH SITE MAP

LESSONS GUESTBOOK

NAVIGATION

INVESTIGATING THERMAL STRATIFICATION

Thermal stratification, or layering, occurs in many Minnesota lakes. Whether or not a lake stratifies depends on a number of factors: the shape and depth of the lake, the amount of wind, and the orientation of the lake (lakes that are oriented east-west are more affected than lakes oriented north-south). When layering occurs the upper, warmer layer is referred to as the epilimnion, and the colder, deeper layer is referred to as the hypolimnion. The boundary between the layers where the rate of temperature change is most rapid is referred to as the thermocline. Temperature stratification is often paralleled by stratification of other water quality measurements such as pH and dissolved oxygen. This lesson is divided into two parts. In the laboratory part, you are challenged to develop two distinct layers of water in a glass. In the technology application, you will determine whether or not a specific WOW lake is stratified during the summer.

PART I - LABORATORY DEMONSTRATION

Knowledge Base
Review your knowledge of thermal stratification. Have you observed distinct temperature layers in lakes? What might cause these layers? Might it be possible to replicate these layers in a laboratory setting? How?

Experimental Design
Can you demonstrate thermal stratification in the laboratory? Your teacher will supply materials.

You need to write a protocol for your demonstration. The protocol should provide clear, step-by-step directions for other researchers to follow. Be ready to explain the rationale for decisions about experimental design.

Data Collection
Proceed with your experimental plan. Consider variables that might affect the outcome of the experiment. Take notes about your observations and, if possible, repeat your experiment to substantiate the results.

Data Management and Analysis
Analyze your results in a way suited to your experimental design. If multiple demonstrations were performed or if data were measured over time, a chart or graph is helpful. For other designs a narrative analysis best communicates results.

Interpretation of Results
Consider the following questions as you prepare to complete a final report:
- Did you succeed in replicating thermal stratification in a lab? Why?
- Were there other materials that might have aided your research?
- Would you expect the same results if another researcher completed the experiment?
- Would you proceed differently if repeating the experiment? Explain.

Reporting Results
You should be prepared to orally present your experimental design, results, and your interpretations of results.
Which groups or designs in your class were most successful? Why?

PART II - RESEARCHING THERMAL STRATIFICATION IN LAKES

Your parents own a cabin on a WOW lake. Your mother claims that the lake remains stratified throughout the summer, while your father is positive that the opposite is true. As a biology students, you have decided to settle this argument by proving whether or not the lake remains stratified throughout the summer.

Knowledge Base
Consider the following questions as you prepare to research thermal stratification in a lake:
- How do your laboratory experiences relate to a lake environment?
- Will stratification be more or less pronounced in a lake setting?

Experimental Design
You need to demonstrate whether or not your parents' lake is stratified. Consider what measures indicate stratification. How many measures are necessary to decide whether or not the lake is stratified? How many dates are necessary? Be prepared to explain your experimental design decisions.

Data Collection
Collect the data necessary to decide whether or not your parents' lake is stratified. Use as many dates and measures as you feel are necessary to prove whether or not the lake remains stratified.

Data Management and Analysis
Graph the data you collected for your parents' lake. Based on your graphs, does the lake remain stratified throughout the summer? If stratification is evident, label each of the layers (epilimnion, thermocline, hypolimnion).

Interpretation of Results
Consider the following questions as you prepare for your final report:
- Does the lake remain stratified throughout the summer?
- What variables might affect whether or not the lake remains stratified throughout the summer?
- How might temperature profiles of other lakes in the region compare to the lake monitored by RUSS?
- Why is this type of information important to people who monitor and manage or use our lakes?

Reporting Results
It is time to settle the argument. Use your graphs and knowledge of thermal stratification to prove whether or not the lake remains stratified. Your teacher will specify whether you should make an oral argument, written presentation, a poster, or a multi-media presentation.

UNDERSTANDING AND INTERPRETATION

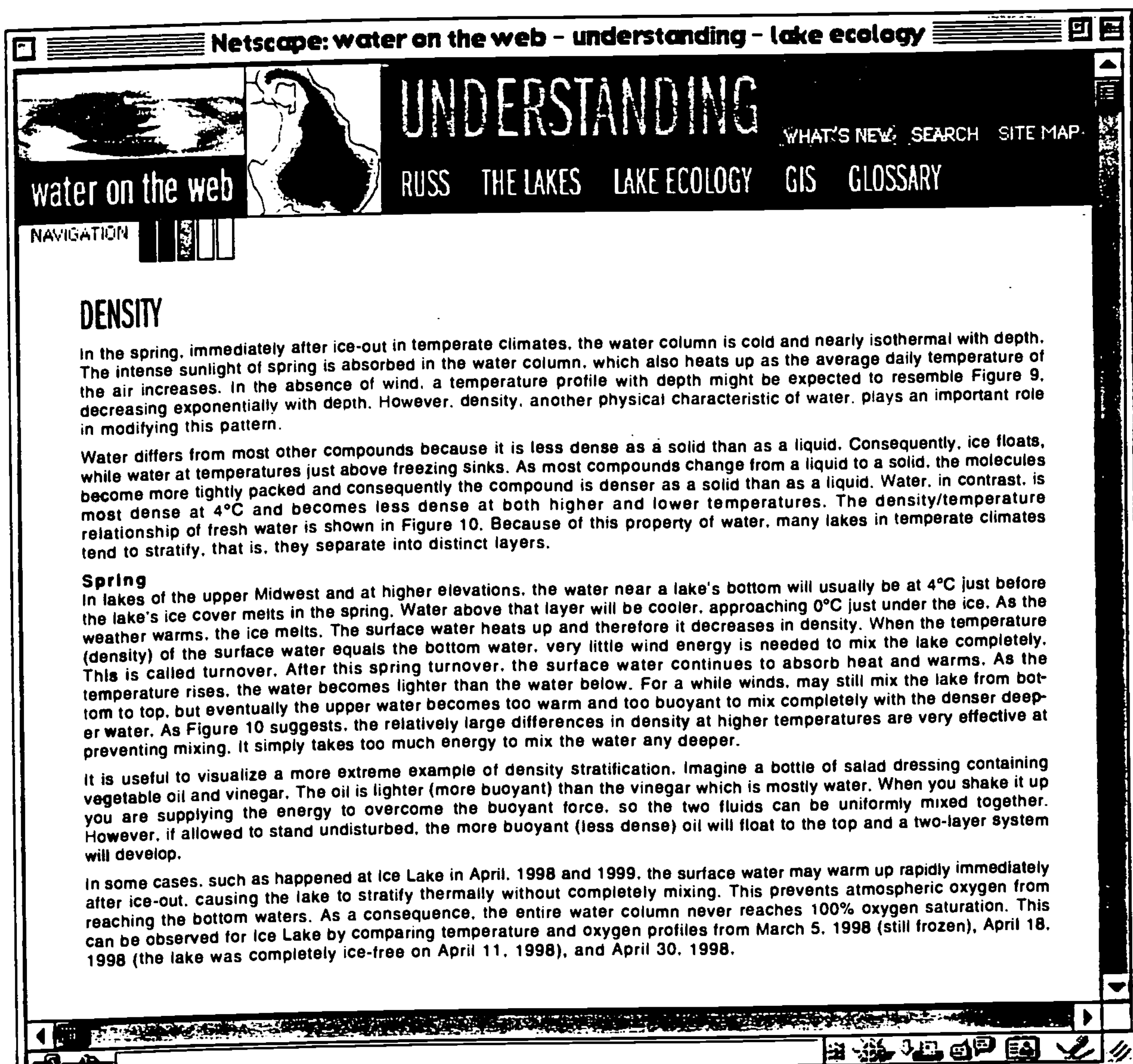
Water on the Web provides on-line resources that can help students and teachers understand and interpret water quality data. The five primary resources currently available are the overview of the RUSS unit, the glossary, the GIS data and maps, the extensive section on understanding lake ecology, and the details on the Minnesota lakes involved. These elements of the website can be found under the "Understanding" link on WOW's home page.

The entire Water on the Web site is based on water quality measurements provided by RUSS units. An introduction to these measurements identifies reporting limits and instrument accuracy. For students who are just becoming familiar with water quality, a synopsis is presented for each RUSS measurement. The summary explains why the parameter is important, describes why there may be natural variations in the measurements of this parameter, and suggests how measurements of this parameter may be affected by human activities.

A glossary is provided for complex scientific terms. All glossary terms are linked to definitions throughout the entire website. In addition, many terms are linked to pop-up explanations so students do not have to navigate to the glossary and then back to the text.

An extensive on-line reference, the lake ecology primer, the GIS data and maps, and the details about the WOW lakes provide a context for examining the WOW water quality parameters and how they interrelate. Lake ecology information is provided from physical, chemical, and biological perspectives. This important resource section offers illustrations and links to other sites that could help students access the scientific concepts that are fundamental to lake ecology.

The following excerpt is directly taken from the "Physical" section of the reference materials on the WOW website.



DENSITY

In the spring, immediately after ice-out in temperate climates, the water column is cold and nearly isothermal with depth. The intense sunlight of spring is absorbed in the water column, which also heats up as the average daily temperature of the air increases. In the absence of wind, a temperature profile with depth might be expected to resemble Figure 9, decreasing exponentially with depth. However, density, another physical characteristic of water, plays an important role in modifying this pattern.

Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently, ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures. The density/temperature relationship of fresh water is shown in Figure 10. Because of this property of water, many lakes in temperate climates tend to stratify, that is, they separate into distinct layers.

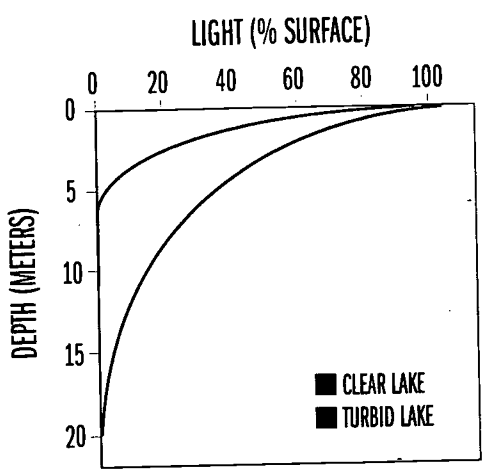
Spring

In lakes of the upper Midwest and at higher elevations, the water near a lake's bottom will usually be at 4°C just before the lake's ice cover melts in the spring. Water above that layer will be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. The surface water heats up and therefore it decreases in density. When the temperature (density) of the surface water equals the bottom water, very little wind energy is needed to mix the lake completely. This is called turnover. After this spring turnover, the surface water continues to absorb heat and warms. As the temperature rises, the water becomes lighter than the water below. For a while winds, may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser deeper water. As Figure 10 suggests, the relatively large differences in density at higher temperatures are very effective at preventing mixing. It simply takes too much energy to mix the water any deeper.

It is useful to visualize a more extreme example of density stratification. Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar which is mostly water. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can be uniformly mixed together. However, if allowed to stand undisturbed, the more buoyant (less dense) oil will float to the top and a two-layer system will develop.

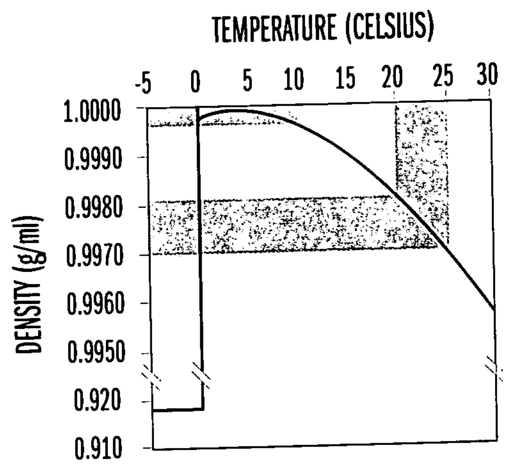
In some cases, such as happened at Ice Lake in April, 1998 and 1999, the surface water may warm up rapidly immediately after ice-out, causing the lake to stratify thermally without completely mixing. This prevents atmospheric oxygen from reaching the bottom waters. As a consequence, the entire water column never reaches 100% oxygen saturation. This can be observed for Ice Lake by comparing temperature and oxygen profiles from March 5, 1998 (still frozen), April 18, 1998 (the lake was completely ice-free on April 11, 1998), and April 30, 1998.

FIGURE NINE - LIGHT VERSUS DEPTH



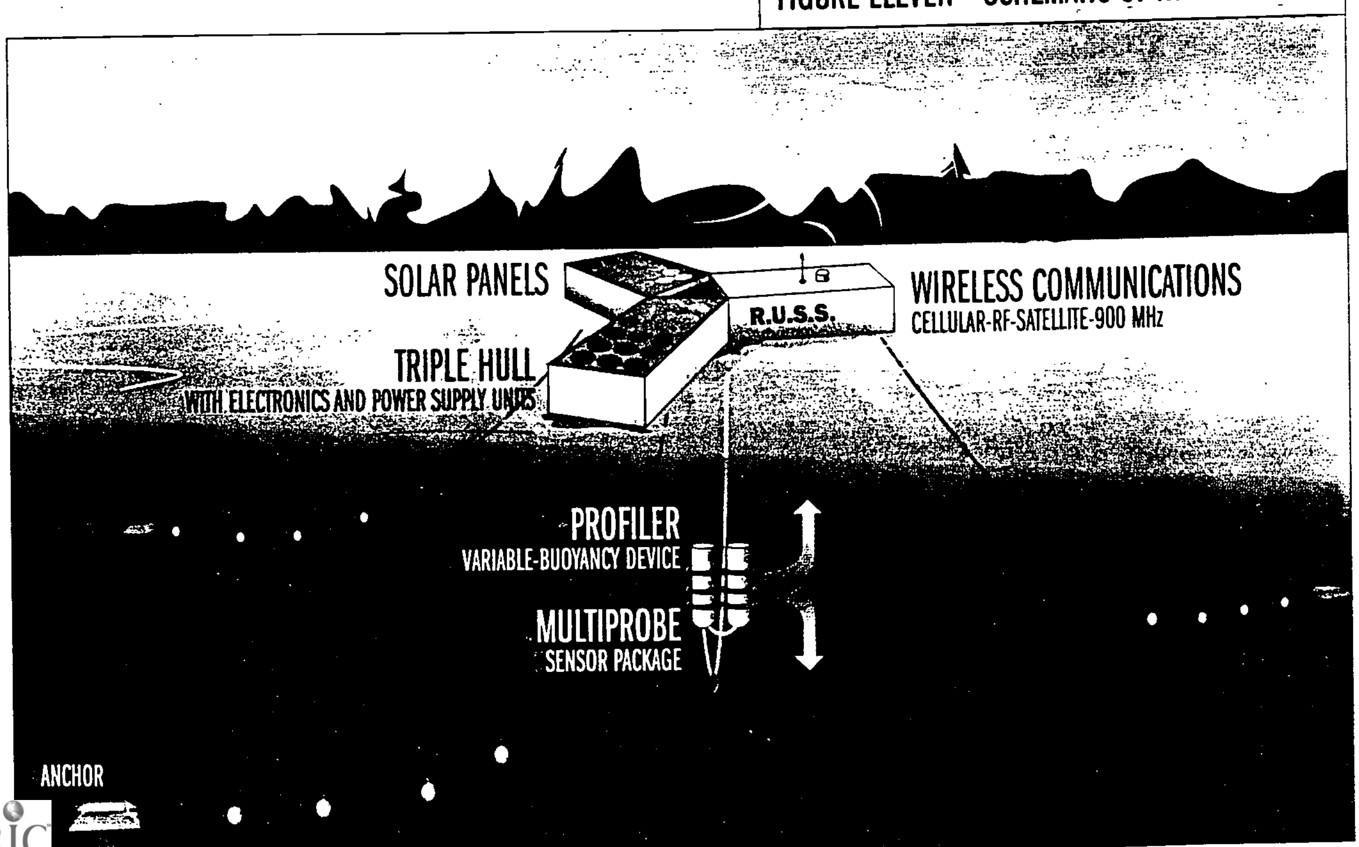
LIGHT VERSUS DEPTH PROFILES FOR A CLEAR LAKE (k=0.2 M-1) AND A TURBID LAKE (k=0.9 M-1)

FIGURE TEN - DENSITY VERSUS TEMPERATURE



DENSITY/TEMPERATURE RELATIONSHIP FOR DISTILLED WATER SHADED AREAS SHOW RELATIVE DIFFERENCES IN DENSITY FOR 5°C TEMPERATURE CHANGES

FIGURE ELEVEN - SCHEMATIC OF THE RUSS UNIT



FIGURES

REMOTE UNDERWATER SAMPLING STATION

Water on the Web centers around a suite of advanced-technology remote sensors developed at the Natural Resources Research Institute of the University of Minnesota Duluth, in cooperation with a number of departmental and commercial partners. Now produced by Apprise Technologies, Inc., the Remote Underwater Sampling Station or "RUSS" unit represents the state-of-the-art in water quality sampling technology. The RUSS unit consists of a floating platform containing solar panels, a series of deep-cycle batteries, and an on-board computer and communications package (Figure 11). A data cable connects the computer to a combination leveling device and sensor package that floats freely below the RUSS unit. The leveler uses a buoyancy compensation technology to position the unit at programmed depths within the water column. The leveler is designed to accommodate standard water quality sensor packages like the Hydrolab sensor pictured below. The unit is powered by deep-cycle cell batteries that are recharged by solar cells. Buoyancy compensation technology is used to move the sensor package up and down the water column; this system can sample at user-specified intervals to depths of 100 m with a precision of 0.2 m of the requested depth. The RUSS units are thus able to provide near real-time water quality data at user-specified sampling intervals, virtually independent of lake conditions (Betts, 1998; Water Environment Federation, 1997).

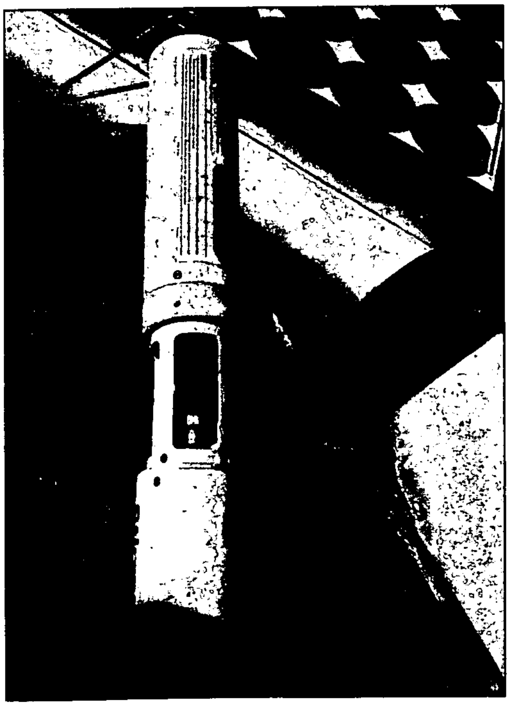
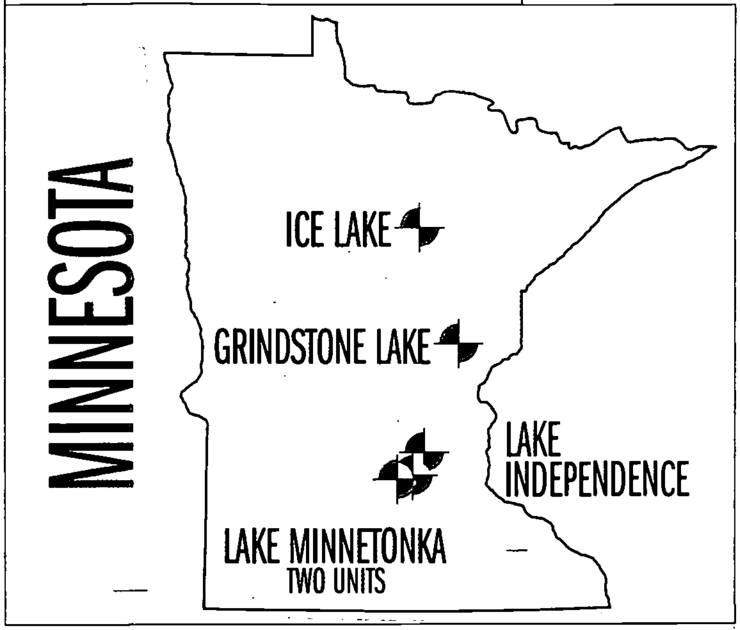


FIGURE TWELVE - LOCATIONS OF RUSS UNITS



The RUSS units currently sample five critical water quality parameters: pH, conductivity, turbidity, dissolved oxygen and temperature. The only effective time limitations to sampling frequencies are the times required for the sensor unit to descend to a specified depth and for the individual sensors to equilibrate. In reality, the relevance of the data is specific to the event being sampled; turbidity might be relevant on a daily basis, whereas oxygen profiles may change hourly. The precise sampling frequency depends, therefore, on the question being asked. The RUSS unit has been initially programmed to collect 1 m interval profiles periodically (every 4-6 hours) over each 24 hour period, seven days per week. The data is then transmitted to the Water on the Web server, http://wow.nrri.umn.edu/data.html.

Data are stored on the RUSS unit and transmitted to the base station as comma-separated ASCII data. A parsing program on the server converts the raw data into a spreadsheet format and adds it to a comma-separated value (CSV) data archive; one data archive is maintained for each lake. Data are also incorporated into an object-oriented database for access by customized data visualization utilities. This use of multiple formats allows the data to be accessed with a variety of tools, from simple visual inspection of the raw data, to analysis by standard spreadsheet and statistical software, to advanced analytical and visualization tools.

RUSS units are currently deployed on four Minnesota lakes, representing a wide range in size, morphometry, depth, and seasonal dynamics (Figure 12). Ice Lake is a small (16 ha area, 16 m depth) lake in a residential district of Grand Rapids, MN. Grindstone Lake, in contrast, is nearly 50 m deep, and supports both warm and cold-water fisheries. Three units are located in the suburban Minneapolis region, two in contrasting bays of Lake Minnetonka, and one in the largely agricultural watershed of Lake Independence. The differences in size, morphometry, and surrounding land use among these lakes provide a unique opportunity to compare and contrast-fine-scale temporal dynamics in water quality variables.

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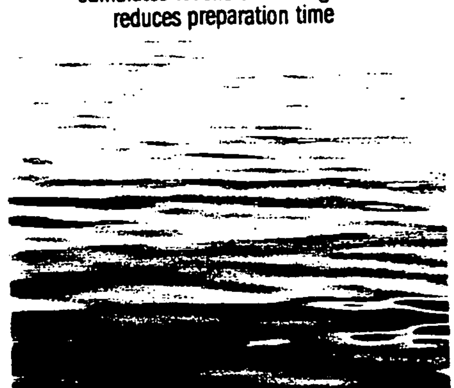
CURRICULUM DESIGN CONSIDERATION	RATIONALE	POSSIBLE SOLUTION(S)
Teachers already have a "full" curriculum	Teachers need to meet national, state, and district standards with limited class time	Design modular. independent materials meeting standards for infusion into existing curriculum
Teachers have limited time	Teachers have little preparation time and many time demands	Design complete, self-explanatory materials that direct teachers and students to important and interesting data
Teachers may have limited background in portions of their subject area	Teachers usually have general training in their subject, but have had limited opportunities to study all subjects in depth	Design supporting resource materials for use by teachers and students
Teachers have limited educational budgets	Teachers and their departments have only a small budget for purchasing science supplies	Provide WOW materials free through the Internet
Teachers need to teach in discrete units of class periods	Most teachers present materials in class or lab periods of about 1 or 2 hours	Design materials so all of the lesson or discrete portions may be completed within normal class periods
Teachers want students to complete some coursework outside of class time	Teachers believe learning can be extended by having students learn and apply their knowledge through "homework" and projects	Design materials written for students so students can understand and complete the work outside of class
Teachers want to use "real world" connections in their teaching	Teachers know students are more motivated if students can relate to the material as "real"	Design materials using data from real Minnesota lakes and provide enough information about the lakes to make them "real" for students
Teachers enjoy creating and adapting materials for their classes	Many teachers don't like to teach exactly from the book and adapt materials to fit their teaching style and students	Design materials with a recognition they will be adapted and include extension ideas for teachers to build upon
Teachers want to use a "hands-on" approach to learning	Teachers know "hands-on, minds-on" learning motivates students and is remembered longer	Design materials that use a "hands-on, minds-on" approach in both the laboratory or field and the technology settings where possible
Students should be encouraged to make predictions	Making educated predictions is part of the scientific process and helps engage students in the study	Design materials that include predicting as part of the investigative processes
Teachers want suggestions for questions that can encourage students' reasoning	Having sample questions available stimulates teachers' thinking and reduces preparation time	Design materials that include sample questions for teachers



TECHNOLOGY DESIGN CONSIDERATION	POSSIBLE SOLUTION(S)
School computers operate primarily on Macintosh or Windows operating systems	Design website and materials for use on both systems
Schools may have limited Internet access	Design materials so they can also be accessed from a CD Design materials to be accessible from most commonly used browsers (Netscape or Internet Explorer) Design materials so teacher can print portions to provide to students
Teachers and students may have limited experience with the computer technologies to be used by WOW	Design materials to include technology "help" components Design materials that guide teachers and students into making workable choices when navigating the website Provide templates where possible to make use of computer software easy for teachers and students
Schools vary considerably in the computer operating systems and software they have available	Clearly identify minimum and preferred system and software requirements to use the curriculum materials Design materials for use by the majority of teachers for a 3 - 5 year time frame (Don't design for just the most or least advanced systems used by teachers) Design the site so that data can be retrieved in different formats
WOW data availability may vary depending on RUSS technology and project status	Design data portion of site to clearly identify when data are and are not available
Teachers and students need to be able to communicate with each other regarding use of WOW and for conducting WOW projects	Develop a section of the WOW website that provides a discussion thread or forum for users
Students and teachers expect computer materials to be interactive	Design WOW website and lessons to include interactive components
Computer technologies permit unique data visualization opportunities	Develop and apply data visualization tools that help students understand the concepts being taught

"Thank you for the wonderful data and project....This project puts symmetry on the year for us. They (the students) have to use the chemistry they know and some they don't know. They have to analyze data. They don't have obvious answers. I tell them I don't know. I tell them to tell me. They have to look at data and figure out how much is necessary. They really wanted to get to the data immediately. They don't like reading for understanding the issues in water chemistry. I refuse to answer their questions except to refer them to your website's features and other websites I had located for them. They really like the project. I have them for a double block each day this semester: 90–110 minutes. The focus and quiet as they delve into the data and resources is great."

ILONA ROUDA
Chemistry Teacher
The Blake School
Minneapolis, Minnesota

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APPENDIX 3 – LESSON TOPIC ORGANIZED BY SUBJECT AREAS

SUBJECT CATEGORIES

BIOLOGY	CHEMISTRY	PHYSICS	EARTH SCIENCES	AQUATIC SCIENCE	MATH & DATA ANALYSIS	TECHNOLOGY	ENVIRONMENTAL STUDIES	
							■	ACID RAIN
■								ALGAL ECOLOGY
						■		INSTRUMENTAL ANALYSIS
	■	■						ARCHIMEDES PRINCIPLE (BUOYANCY; DENSITY)
		■						CALORIE
				■				CLASSIFICATION OF LAKES
			■					CLIMATE CHANGE
	■			■				CONDUCTIVITY
■				■				CYCLES (DIEL)
					■			DATA ANALYSIS AND PRESENTATION
						■		DATA CAPTURE
■	■			■			■	DISSOLVED OXYGEN
							■	ENVIRONMENTAL IMPACT ANALYSIS
	■							EQUILIBRIUM (CHEMICAL)
			■					EROSION
■							■	EUTROPHICATION
■							■	FISH ECOLOGY (PREFERENCES, NEEDS, PRODUCTIVITY)
	■	■						GAS SOLUBILITY
	■	■	■	■	■	■	■	GIS
						■		GRAPHICS
	■	■						HEAT BUDGETS OF LAKES
		■					■	HYDROLOGY TOPICS
						■		INTERNET USE
	■							IONIC STRENGTH
							■	LAND USE PLANNING
							■	LIMNOLOGY
					■			MEASURES OF VARIABILITY
■								METABOLISM (O_2 & pH CHANGES)
					■	■		MODELING
■	■	■	■	■	■	■	■	NATURAL VARIATIONS IN LAKES
■				■				PHOTOSYNTHESIS
	■							pH, ACIDITY (CO_2)
							■	POINT AND NONPOINT SOURCE POLLUTION
■								PRIMARY PRODUCTIVITY
						■		PROGRAMMING
	■							PROPERTIES OF WATER
■								RESPIRATION
							■	ROAD SALT IMPACTS
					■			SAMPLING DESIGN
			■					SEDIMENT SUSPENSION
						■		SOFTWARE
	■							SOLUTIONS (SOLUTES, SOLVENT)
				■				STRATIFICATION (LAKES)
		■		■				TEMPERATURE
					■			TREND ANALYSIS
						■		TROUBLE-SHOOTING
						■		USE OF SPREADSHEETS
	■		■					WATER CHEMISTRY (INCLUDING pH)
							■	WATER QUALITY
							■	WATER RESOURCE PLANNING
			■				■	WATERSHED LINKAGES
							■	WEATHER & CLIMATE EFFECTS ON LAKES
						■		WEB NAGIVATION

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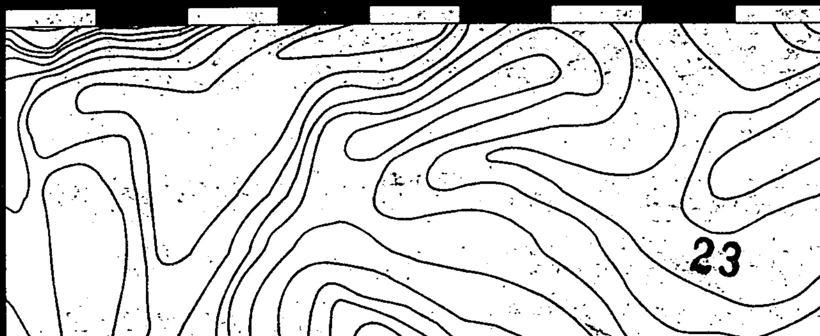

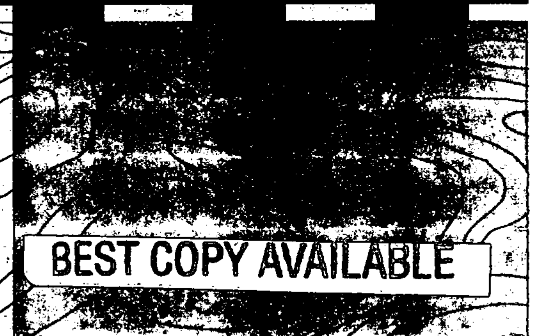

WOW.NRRI.UMN.EDU | WATER ON THE WEB

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Water on the Web (WOW) allows high school and college students to monitor Minnesota lakes over the Internet. This project integrates state-of-the-art environmental monitoring with geographic information systems, data visualization, and in-depth educational materials. Our goal is to train students to solve real world problems.

Water on the Web is a three-year educational project funded by the National Science Foundation that began in 1997. WOW curriculum materials are available that help students understand data from several water sampling robots, called Remote Underwater Sampling Station (RUSS) units, located in Ice Lake, Lake Independence, Lake Minnetonka, and Grindstone Lake in Minnesota. In essence, WOW allows students to monitor lakes across Minnesota without leaving their classrooms.

The RUSS units provide remotely-programmable vertical profiling of temperature, dissolved oxygen, pH, electrical conductivity, and turbidity. Data and monitoring schedules are transmitted via cellular phone to the WOW website and ultimately the classroom. Students can then conduct interactive inquiries of lakes and watersheds, conduct basic science experiments, and learn data analysis techniques.

The curriculum is used to train students in water resources and advanced technology, helping them better manage our natural resources in the future. The RUSS units help current water managers because they provide continuous, year-round information on the conditions of lakes; something that's not readily available now. The information is also useful to anglers, lake associations and shoreland property owners.

Final curricula are being disseminated through printed materials, an interactive compact disk distributed through the Sea Grant network, the Internet, and in-service training workshops. The project is funded through a grant from the NSF-Advanced Technology Education program (DUE-9752017).

WOW links University of Minnesota institutions with private industry, community and tribal groups, Minnesota's high schools, community colleges, technical colleges, and natural resource and regulatory agencies.

We invite formal or informal collaboration from interested scientists and educators. Critical comments are also welcome via the site, http://wow.nrri.umn.edu.

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