Unit VIII:

Introduction to Water Quality Issues

Unit VIII Water Quality Issues
Introduction

Minimum water quality standards for all states are established by the US Environmental Protection Agency (EPA), based on the mandates of the Clean Water Act. Additionally, most states also set minimum water quality standards, often more stringent than that of EPA. Counties, cities and towns may add additional requirements, especially concerning drinking water standards. These standards not only protect the environment but also protect human health. If a water body is not meeting these standards, then the state or EPA may require that a Total Maximum Daily Loading (TMDL) be conducted. This means that the problem pollutant(s) must first be identified. Then the maximum allowable daily dosage of the pollutant into the water body that will not cause environmental damage needs to be determined. Finally, management plans need to be formulated that will reduce the daily dosage, or loading, of the pollutant to less than the maximum that was calculated.

The Rhode Island Department of Environmental Management (RIDEM) has established water quality standards for waterbodies throughout Rhode Island. These standards reflect water quality goals and designate appropriate uses for classified waters. The water quality standard set for Narrow River is Class SA; defined as suitable for bathing and contact recreation, shellfish harvesting for direct human consumption, and fish and wildlife habitat. However, according to several reports, the River's water quality is more characteristic of Class SB; water suitable for bathing and other primary contact recreation, shellfish harvesting but only after depuration, and fish and wildlife habitat. In other words, Narrow River is not living up to the standards set for it.

Since 1959, the Narrow River has consistently failed state standards set for total coliform bacteria levels. High coliform levels have prompted RIDEM to restrict shellfishing activities in portions of the estuary since 1979, and bacterial levels have regularly exceeded safe standards set for swimming. Stimulated by high levels of nitrogen and phosphorous, increased algal growth has been observed in the River since the early 1970's. Recorded numbers of finfish and shellfish have also dramatically decreased over the years. Clearly, the Narrow River estuary has suffered a serious degradation of its water quality, fisheries, and recreational value.

The Narrow River Preservation Association (NRPA) has been conducting volunteer water quality monitoring since 1992 through the URI Cooperative Extension Watershed Watch program. In 2002 they monitored twelve sites, including three freshwater sites on Gilbert Stuart Stream, Mettatuxet Brook, and Mumford Brook. Every other week monitors take Secchi depth measurements to check for water clarity. They also record temperature, test for salinity and dissolved oxygen, and take chlorophyll samples. Five times during the monitoring season, about once a month, monitors collect water samples and bring them to the Watershed Watch labs to be tested for bacteria, nitrogen, phosphorus, and pH. This citizen monitoring program provides vital information to the regulatory agencies to supplement their data. NRPA monitoring data have been used in both the 1999 Revised Special Area Management Plan (SAM Plan) for Narrow River *generated by the RI Coastal Resource Management Council and the 2001 Fecal Coliform TMDL for the Pettaquamscutt reported by the RIDEM.*

Most of the studies conducted on water quality in the Narrow River indicate that there are two major kinds of pollution in the estuary: bacterial contamination and nutrient loading. Bacterial contamination is measured by monitoring for coliform bacteria. Coliforms themselves are not harmful, but serve as an indicator of fecal contamination and the possibility that pathogenic (disease-causing) organisms may be present in the water. Direct measurements of pathogens are not used for three reasons: 1) there are dozens of disease-causing organisms; measurements for each one would take too much time and cost too much money, even if it were possible; 2) easy and reliable methods for identifying and counting most pathogens in a water sample are not available; and 3) since the numbers and kinds of disease-causing bacteria may differ from one day or location to the next, monitoring for these organisms would have to be exhaustive. The best solution is to periodically test the water for coliform bacteria, and to estimate the potential for human health hazards based on these measurements. According to the 1999 Narrow River SAM Plan, the primary sources for bacterial contamination are old or failing septic systems, storm drains, and fecal material from domestic animals and wildlife.

The other major kind of pollution documented in the Narrow River is nutrient loading. Excessive levels of nitrogen and phosphorus can cause excessive algal growth and a decrease in oxygen levels, resulting in eutrophic conditions. Eutrophic waters are characterized by low water clarity, abundant algae and/or rooted aquatic plants, mucky bottom sediments, and periods of oxygen depletion. Nutrient loading in the watershed is often the result of septic system failures and lawn/garden fertilizers.

Other water quality problems in the Watershed include petroleum hydrocarbons that may enter Narrow River from recreational boating and road runoff through storm drains. Boats may also introduce solvents, antifreeze, antifouling paints, heavy metals, acids/alkalis, surfactants present in most detergents and other cleaning agents, nutrients, bacteria, floatables/plastics, and creosote from pilings. There is also concern about commercial and residential structures that may have underground fuel tanks storing heating oil. It is nearly impossible to identify how many of these tanks still exist in older homes until they are sold.

Water quality problems in the Narrow River are compounded by the basin's physical characteristics, primarily steep slopes that drain into a narrow, poorly flushed river. Because the Narrow River's unique geological structure, a composite of an estuary, fjord-like ponds, and a river, it is less able to handle increased pollutant loadings. Constricted and poorly flushed, the River's sluggish flow severely restricts its ability to cleanse itself. This allows pollutants to accumulate both in the water column and in bottom sediments. Because the upper basins are highly stratified and very deep, and exhibit minimal overturn, they act as huge catch basins for pollutants. Substances introduced from the River's headwaters, surface runoff, and groundwater flow can be expected to remain in the basins for long periods of time. Under average conditions, a *contaminant introduced into the upper basin will take 77 days to move down the estuary and out the mouth off Narragansett Beach. When these basins do "overturn" (mix), the effect of the turnover may be much greater due to the accumulation of pollutants and their sudden release from the bottom waters.*

Due to the consistently high bacteria counts in the Narrow River and its tributaries, RIDEM completed a TMDL study for Fecal Coliform for the Pettaquamscutt River Watershed in 2001. TMDL stands for Total Maximum Daily Loading of a contaminant. This study established where bacterial contamination was entering the River system and what maximum daily limits should be set in order to improve and maintain the River at the intended use classification of SA. The study also made recommended mitigation measures that would achieve the goals set for TMDL of fecal coliform in the Watershed. A significant remedial action is the retrofitting of storm drains to include structural BMPs designed to treat current flows and pollutant loadings at the storm sewer outfalls. Other recommendations are: 1) replace an outhouse adjacent to Gilbert Stuart Stream on the grounds of the Gilbert Stuart Birthplace (done in 2002); 2) identify/repair failing septic systems near Mumford Road; 3) connect to town sewers and eliminating illicit sanitary and gray-water connections to storm sewers; 4) properly dispose of pet waste; 5) minimize fertilizer applications; 6) leave an uncut vegetated buffer along river-front property lines to discourage grazing waterfowl, such as Canada geese; and 7) encourage residents and visitors not to feed the waterfowl.

Water quality is directly related to human activity in the Watershed. Since land use activities in the Watershed are primarily residential, this means that most of the pollution comes from Watershed residents. Water quality can be improved by eliminating or altering common everyday activities that pollute, such as picking up after pets, making sure that household hazardous wastes are properly disposed, being careful about how lawn and garden products are used, taking care of cars so that they don't leak oil or antifreeze, keeping storm drains clean and free of pollutants, and not feeding wildlife. The Narrow River Handbook is an excellent source of information, ideas, and alternative methods for Watershed residents. To learn more about water quality in the Narrow River Watershed call NRPA at (401) 783-6277. For more information on monitoring contact URI Watershed Watch at (401) 874-2905.

References:

Applied Science Associates, Rhode Island Watershed Watch, SAIC Engineering, Inc., Urish, Wright, and Runge. 1995. *Narrow River Stormwater Management Study Problem Assessment and Design Feasibility,* prepared for the Towns of Narragansett, South Kingstown, and North Kingstown.

Ernst, L. M., L. K. Miguel, and J. Willis. 1999. *The Narrow River Special Area Management Plan.* Coastal Resources Management Council, South Kingstown, RI.

Green, L. T., and E. Herron. 2002. *URI Watershed Watch Land and Pond Monitoring Manual.* Natural Resources Science Technical Report 98-3, College of Environment and

Life Sciences, Department of Natural Resources Science, URI Cooperative Extension, Kingston, RI.

Lehrer, A. 1992. *Bacterial Monitoring of Surface Waters.* Natural Resources Fact Sheet 92-1, University of Rhode Island, College of Resource Development, Department of Natural Resources Science, URI Cooperative Extension, Kingston, RI.

Narrow River Preservation Association. 2002. *The Narrow River Handbook – A Guide to Living in the Watershed*, second edition. Narrow River Preservation Association, Narragansett, RI.

Office of Water Resources, Rhode Island Department of Environmental Management. 2002. *Fecal Coliform TMDL for the Pettaquamscutt (Narrow) River Watershed, Rhode Island*. Rhode Island Department of Environmental Management, Providence, RI. http://www.state.ri.us/DEM/programs/benviron/water/quality/rest/pdfs/narrivdr.pdf

ACTIVITY I: **WHO DIRTIED THE WATER?**

OBJECTIVE: Students will learn about current sources of water pollution, how they represent water quality issues, and ways that these sources of pollution are being controlled.

METHOD: Students will actively participate in a visual representation of a body of water that receives various sources of pollution. Students will discuss what problems underlie the sources of pollution represented and how alternatives can be found to help reduce these sources.

MATERIALS: labeled film canisters filled with various materials, which represent different pollutants (see chart below); a large, clear, wide mouth glass jar, bowl, or small aquarium; “pollution clean-up tools” such as sponge, paper towels, baking soda, sieve, coffee filters, spoon, pH paper

BACKGROUND INFORMATION:

1. Substances get into our water supply in many different ways. Water pollution is classified into two main categories: point and non-point source pollution. Point sources originate from a specific point on the landscape such as a discharge pipe from a factory or sewage treatment plant. Non-point sources originate over a widespread area of the landscape, and thus it is difficult to determine exactly where the pollution comes from.

2. See discussion chart below for more information.

3. The effect of a contaminant depends on the concentration of the contaminant, the volume of water in the receiving water body, and the rate of flow of water through the water body. Thus contaminants entering a river may travel much farther and become more widespread than those entering a lake with a limited outflow.

PROCEDURE:

1. Ask students: what is an issue? Emphasize that an issue is a problem caused by differing opinions based on different values that result in different ways of doing things.

2. Explain that this activity focuses on water quality issues, or water pollution issues.

3. Pass out film canisters containing materials which represent different forms of point and non-point source pollution. Make sure each canister has some sort of label that identifies it as a character in the story (see below). Ask students to note which character they are representing.

4. Show students a large clear glass jar of clean water, and tell them it represents a very clean lake. Ask them if they would boat on the lake. How about swim in it? If there was a treatment plant, would they drink the water from the lake? Why or why not?

5. Explain that you will be telling them a story about the lake, and as their character is mentioned, they should come up to the lake and pour the contents of their film canister into the lake. Tell the story of the lake, introducing each character from the chart below, one at a time. After each character pollutes the lake, ask students if they would still boat, swim, or drink water from the lake. Why or why not?

6. What happens to the organisms and plants living in the lake? At what point (after which pollutants) do they begin to become affected?

7. Draw the chart below on the board to help discuss what real life problem or source of pollution each character represents. Is it a point or non-point source? What ways can each source be prevented or reduced? These details will be discussed more in later units.

8. How would the pollution effects be different if the lake was a river?

9. Who is responsible for cleaning up the lake? Give students “pollution clean-up tools” and see if they can get the water clean again. (Baking soda can be used to neutralize the vinegar; use pH paper to test for neutralization).

Who Dirtied The Water?

Note: after each paragraph, after a substance is added to the jar of water, ask the following questions to the class:
Would you drink from the lake if it had a drinking water treatment plant?
Would you swim in the lake? Would you boat on the lake?
Note also that this is merely our version of this story; feel free to modify it to fit your particular needs.

Once there was a large lake surrounded by acres of green forests and brushland. It was a clear lake, and the only pollution the lake received was natural, from **TREES**. This was not a problem since the lake was not being used for drinking water.

In a little while, though, the **1st HOME OWNER** moved in. They had a septic system, but did not use it wisely. The **1st HOME OWNER** used toxic household cleaners and dumped them down the drain. They ended up in the lake after passing through the septic system.

Not too long after that, a **2nd HOME OWNER** moved in, close by to the first one. They also had a septic system for their house. A few years went by and they did not keep their septic system maintained. The septic tank began to leak, and this also ended up in the lake.

At almost the same time, a **3rd HOME OWNER** moved in next to the second one. They had a large green lawn, which the homeowner was quite proud of. Unfortunately, they used too much fertilizer and watered too often. A lot of the fertilizer washed down and away from the grass roots and eventually also ended up in the lake.

Now that a small neighborhood was around the lake, people began to visit its beach. There weren't too many **BEACH GOERS**, but they did not pick up after themselves. They left litter on the shores and some of the litter ended up in the water of the lake, too.

There was a lot of flat, stone free land around the lake, and 2 farms moved into the area. The **1st FARMER** used poor erosion control of his cropland, and sediment from the farm's fields made its way to the lake, clouding it up. The **2nd FARMER** that moved in made an orchard of apples, and they required the use of pesticides to keep insects from eating all the apples. The farmer used too much of the pesticides, and it ended up in the soil, which of course, ended up in the lake eventually.

As the area around the lake became more and more developed, a shopping mall was built near the neighborhood. The shopping mall had a large parking lot, and it was always filled with cars from people out of town and from in town. Stormwater that fell on the **SHOPPING MALL LOT** was carried off, containing oils from the cars, litter, and salt from the roads. The stormwater drainage system was not well designed and the stormwater runoff made its way to the lake.

Along a river that fed the lake, an industrial area was built. The first building to go up was the electric company. The **ELECTRIC COMPANY** burned coal to power its generators. The smoke that came from the smokestacks stayed in the clouds and formed acid rain, which fell onto the river and the lake. The next two buildings that were built were a **CHEMICAL PLANT** and a **SEWAGE TREATMENT PLANT**.

The chemical plant discharged heavy metals and organic chemicals into the river and the sewage treatment plant discharged raw sewage into the river when the amount of sewage reaching the plant was too much. Both of these ended up in the lake.

The last thing to be built near our now-developed lake was a **GAS STATION**. The gas station was very busy, but to save on costs they used cheap quality underground tanks to store their gasoline. In a few years, the tanks began to leak and the gasoline flowed through the soil, reached the groundwater and flowed to the lake.

How can we possibly clean this up?!?!

Discussion Chart for "Who Dirtied the Water?"

character	**canister contents**	**pollution**	**type**	**alternatives for prevention**
trees	leaves	natural organic	non-point	no problem except for reservoirs; clear trees/brush from shores
1st home owner	liquid	toxic cleaners	non-point	use biodegradable cleansers; if use toxics, bring to special toxic waste sites
2nd home owner	sludgy coffee	leaking septic tank	non-point	maintain septic tank properly
3rd home owner	sugar	lawn fertilizers	non-point	leave clippings on lawn; use organic fertilizers; don't worry about a "perfect" lawn
beach goers	soda tops popcorn	litter	non-point	don't litter; pick up litter, even if it isn't yours
1st farmer	soil	sediment (erosion)	non-point	plant cover crops to hold the soil in the winter; contour or strip plowing
2nd farmer	sugar	pesticides	non-point	<u>integrated pest management</u> (IPM): monitor fields and spray only the minimum amount needed <u>organic farming</u>: organic pesticides, natural predators, crop rotation
shopping mall lot	pencil shavings	stormwater runoff heavy metals, oils	non-point	detention basins; created wetlands; swales; sweep lots; low sodium salts

character	canister contents	pollution	type	alternatives for prevention
electric company	vinegar	acid rain	non-point	conserve electricity; smokestack scrubbers; alternative energy sources
chemical plant	tumeric	heavy metals, organic chemicals	point	alter industrial processes; improve pretreatment before discharge; consumer choices (don't buy from companies that pollute)
sewage treatment plant	sludgy coffee	organic nutrients toxic chemicals	point	better system design; don't throw toxic materials down the drain
gas station	corn oil	leaking under-ground storage tank (L.U.S.T.)	non-point	better tank design and maintenance; conserve gasoline use

ACTIVITY II: WATER QUALITY ISSUES – WHERE DO YOU STAND?

OBJECTIVE: Students will learn about how differing opinions and values create issues.

METHOD: Students will take a survey asking their opinions about water quality issues and compare and discuss results.

MATERIALS: surveys, pencils

PROCEDURE:

1. Discuss how issues are formed from people having different beliefs and values about a particular topic. Have students list examples of environmental issues.

2. Explain that they will be filling out a survey that asks them about their beliefs and values as they pertain to certain water quality issues. Remind them that there are no “correct” answers; everyone is entitled to have their own beliefs and values.

3. After they fill out their surveys, use chart to summarize the responses.

4. For which statements were there wide differences of opinion? Why do these differences exist?

5. Ask students to analyze the values that underlie their responses. Which of their responses reflect ecological values? Which reflect economic values? What other values are reflected?

6. Did the class responses load on the “neutral” category? If so, why? Could this be changed with more information? If so, why information would be needed? For example, if in statement #4 you knew that all factories pre-treated their waste so that their effluents would not alter the water quality of the river, would this change your response?

7. Why is it difficult to resolve an environmental issue where there are strong and differing value positions? See if the class can come up with working compromises to any or all of the statements.

WATER QUALITY ISSUES SURVEY

Below, you will find a list of belief statements with which you may agree or disagree. Following each is a response line ranging from “Strongly Disagree” to “Strongly Agree”. Please circle the response which best reflects how you feel about the statement.

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1. No development should occur along rivers.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

2. Only homes and farms should occur along rivers.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

3. Homes, farms, resorts, and shopping centers should be allowed to be built along rivers, but not industrial factories.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

4. Factories should be allowed along rivers because they need the water for their operations and their waste disposal.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

5. Factories that pollute should be closed even if it means that people will lose their jobs.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

6. There is too much hype about water pollution and conservation these days. We have plenty of fresh clean water and don’t need to worry.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

7. People have the right to use as much water as they want.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

8. It makes a difference when people conserve water by not leaving the tap running while doing dishes or brushing their teeth.

   Strongly Disagree   Disagree   Neutral   Agree   Strongly Agree

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WATER QUALITY ISSUES SURVEY

Summary Chart

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					

YOU CAN HELP KEEP THE (YOUR WATERSHED HERE) WATERSHEDCLEAN!

- Use the least toxic product you can find and never buy more than needed.

- Dispose of or recycle chemicals properly. All paints, oils, grease, antifreeze and cleaning products should be disposed of properly. Many of these items need special processing which dumping down the storm-drain or even a household drain cannot do. Watch the papers for household hazardous waste collection days.

- Take used motor oil and antifreeze to a gas station with an oil-recycling program.

- Use fertilizers sparingly, only as needed and follow directions carefully – **MORE IS NOT BETTER.**

- Do not over water your lawn. Over watering causes fertilizer to move too far down into the soil. The roots cannot reach it and the underlying groundwater can become contaminated with fertilizer. Local news broadcasters often give suggestions during the summer months.

- Conserve water, this will help conserve money.

- Test for leaking toilets by adding food coloring to the tank. Without flushing, note if any color appears in the bowl after 30 minutes. If color appears, you have a leak.

- Run dishwashers only when you have a full load.

- Take short showers instead of baths.

Give it some thought; we’re sure you can come up with lots of ways to conserve water and other resources.

Clean water is an asset to all, young and old. We owe it to our children to provide it for their future.

SUPPLEMENT: **FIELD INVESTIGATIONS –**

To get students involved with community issues, you could consider looking for water quality concerns near your school. Enforcement personnel who work for the local stormwater manager often welcome assistance in identifying illegal discharges. Be sure to check with them first before you take your students out. In the field, teachers and students could look for the following:

1. Discharges from pipes – Sometimes this is difficult to distinguish from storm water discharges which do not require a permit. It is best to look during a period of dry weather. Pipes that still have some sort of flow in the absence of any rain could be an illegal discharge. Document where the pipes are situated, what water body they flow into, date and time flow noticed, and weather at least one week before the flow is noticed. Also note the color, odor, and amount of discharge (trickle vs. strong flow).

2. Floating Foam, oil sheen, or solids – No discharger is permitted to discharge effluent with these characteristics. Be careful not to be fooled by natural foam. Even pristine streams may have some white or coffee colored foam downstream of a falls or dam. This foam is from the natural oils in trees and vegetation. One way to distinguish the difference is to see if the foam breaks apart easily. If it does not, it may be an illegal discharge.

3. High temperatures – Check the temperature of the effluent of permitted discharges to make sure they are not exceeding their permit limit (Usually 83° F)

4. Compliance with pH requirements – Check the pH of the effluent of permitted discharges to make sure it is within the permit limits.

5. Water flowing over dams – The water level should never be below the dam. A rule of thumb is that the water running over the dam should match the run of the river (flow upstream and downstream of the dam site).

If you have any questions or would like to report a possible illegal discharge into the watershed or its tributaries, contact your local Public Works Department.

SUPPLEMENT: **LITTER CLEANUP**

A Volunteer's Guide to Organizing a Litter Cleanup And Survey in Rhode Island

Applicable to Coastal and Freshwater Areas

Henry Herbermann and Meg Kerr
The University of Rhode Island
Coastal Resources Center
Graduate School of Oceanography
Narragansett, Rhode Island 02882

During a late afternoon walk on a nearby beach or along a stream bank, you notice an excessive amount of litter or debris. Is it harming the environment? Where did it come from? What can be done to get rid of it?

Apart from being an eyesore, man-made debris is clearly a threat to the environment. Plastics, which can last hundreds of years are an especially serious problem. Birds, fish and mammals often become entangled in such items or mistake plastics for food. With plastic filling stomachs, animals may die of starvation or poisoning. Other types of debris left or thrown around coastal or watershed areas can interfere with spawning beds, leak toxic substances, as well as injure wildlife and people.

Participating in a volunteer group cleanup or organizing one yourself are two ways to rid Rhode Island's coastline and freshwater banks of debris. A record or tally of the debris collected, however, is even more valuable than the actual cleanup. Chances are, if you return to the area you cleaned several weeks or even days later, you'll find it in its pre-cleanup condition. To permanently rid a shoreline of litter you need to identify and stop its source. Data from a cleanup may identify the source and force the offenders to change their habits.

Participating in an Annual Cleanup & Survey

Every September the Center for Marine Conservation in Washington, DC organizes an international coastal cleanup day. In 1991, volunteers across 35 states and 12 foreign countries descended on the world's coastline to cleanup and survey litter. Over 2,800,000 pounds of debris were tallied and removed.

The Audubon Society of Rhode Island along with the Department of Environmental Management are this state's coordinators for the event. If you wish to become involved call the Audubon Society, (401) 231-6444, for the date and a list of cleanup sites in your area. Volunteers, who show up at designated sites on the morning of the cleanup, are given 30 gallon paper bags and inventory sheets to tally the garbage they collect. The surveys are recorded as part of an international database which in the past, was presented at congressional hearing in support of the Marine Plastic Pollution Research and Control Act (MPPRCA) and currently to aid in enforcement of the act. (The MPPRCA bans all dumping of plastics in rivers, streams, lakes, or coastal waters of the US.)

On a smaller scale, biannual cleanups in the Providence area are run by Keep Providence Beautiful. These are usually held every April and October. Call KPB at (401) 351-6440 for more information.

Planning Your Own Group Cleanup/Survey

The first step in planning a litter clean-up/survey is to designate a coordinator and/or a steering committee. Their roles are to logistically plan the clean-up/survey and, if it is a large scale event, interact with the media.

<u>Utilize Local Resources and Involve the Community</u>

1. Coordinators should directly contact local environmental and school groups, scout troops, etc., about participating.
2. Generating media coverage can help to increase public awareness and recruit more volunteers. Posters, brochures or press releases should be sent to local newspapers,

television and radio stations. Public service announcements (PSAs) are a great way to get your message on the radio for free. Type an announcement that takes between 10 seconds and one minute to read and send it to the station along with a cover letter.

3. Write a letter to your local grocery store asking for free food and refreshments for this community project.

4. Contact hardware stores about donating rakes, trash bags, gloves, etc.

5. Be sure to credit any store or organization which donates equipment for your clean-up/survey.

<u>Safety Considerations for Volunteers</u>

1. Volunteers should ALWAYS work in pairs.

2. Permission slips are a good idea for minors who would like to participate. A sample of one is included here.

3. The water is not safe to drink.

4. Volunteers should not attempt to walk across streams that are swift and above the knee in depth. These can be dangerous.

5. Volunteers should be careful to avoid:

    medical wastes
    slippery rocks
    ticks, poison ivy, poison oak, nettles, insects, etc.
    unfamiliar dogs

<u>Organizing the Event</u>

1. Contact the area municipality's Sanitation Department or a private trash hauler about removing the collected litter.

2. If working on a coastal area, schedule the clean-up survey to begin about 2 hours before low tide.

3. Coordinators make sure to secure landowners permission if any part of the shoreline is on private land.

4. Supplies your volunteers will need:

    Bags, gloves, data cards, pencils, a list of important phone numbers:

    - Fire and Police Departments
    - Central Command Center
    - Coordinator
    - RI Dept of Environmental Management
    - Contacts if someone discovers an entangled marine mammal (see Post Cleanup)

    Some supplies your volunteers *may* need:

    Rakes, shovels, brooms, dust pans, brochures or fliers

5. Choose team leaders to lead groups over pre-measured clean-up/survey areas. Team leaders are also responsible for: bringing extra trash bags, looking out for everyone's safety and collecting equipment at the end of the day.

6. Some things to consider when designating a cleanup area:

    - Terrain (beach, streambank, rocky shore, etc.)
    - Age and physical capabilities of volunteers
    - Time of year (and weather)
    - Expected amount of trash to be removed

7. Designate spots along the clean-up zone for depositing trash and debris. Arrange for trash pick-ups at those sites.
8. It is recommended that you use the same debris tally sheets sued during the annual coastal cleanup, a sample of which is included here. You can either make copies of this sheet or obtain additional ones from the Center for Marine Conservation (CMC, address below). Data from a litter survey is very important, as was explained in the introduction to this manual. A publication of compiled data from litter surveys around the world can be obtained from the CMC.
9. Some items volunteers should be encouraged to bring on a cleanup/survey:
    - Comfortable rubber boots or shoes
    - Old clothing that is also snag and thorn proof. (Clothes may be ruined.)
    - Gloves
    - Insect repellent
10. A short training session or even just a pep talk to better prepare volunteers is recommended. This could be run either the evening before the cleanup or immediately before it. Things volunteers should be made aware of:
    - Private property
    - Volunteers should avoid walking on delicate shoreline areas (dunes) and unstable stream banks. Their footsteps could speed erosion.
    - Volunteers should not walk on or near nesting or fish spawning areas. Spawning areas will look round or elliptical and clean of gravel.
    - Volunteers should disturb vegetation as little as possible.

<u>On Day of the Survey</u>

1. At the beginning sign-up sheets should be available for all volunteers so the coordinator knows exactly who is working in where at all times. This sheet may be used later to request help with similar projects.
2. Each pair of volunteers should be given a large paper bag and a tally sheet to record the types of litter removed from the shoreline.
3. Food and refreshments should be available for participants during as much of the day as possible.
4. Have a thank you party for all volunteers.

<u>Post Cleanup</u>

If the cleanup was along a coastal or freshwater area,
please send any survey data to:

Center for Marine Conservation
1725 DeSales Street, Northwest, Suit 500
Washington, DC 20036

If you notice any pipes discharging waste or chemicals, or evidence of a faulty septic system, like heavy algal growth, write or call the Department of Environmental Management (listed below). Be sure to include: name of the town, street address if possible, your own name and a description of the problem.

Division of Water Resources, RI Dept. of Environmental Management
291 Promenade Street, Providence, Rhode Island 02908
(401) 277-3961

If you should encounter an entangled marine mammal please contact:

Mystic Aquarium & Institute for Exploration's 24 hour Marine Animal Rescue Hotline at 860.572.5955 x 107 (until 5 pm) or x 134 (after 5 pm). Leave your name and a phone number where you can be reached.

For their help in preparing this guide, special thanks to:

Audubon Society of RI
Center for Marine Conservation
Graduate School of Oceanography, URI
Keep America Beautiful
Keep Providence Beautiful
RI Department of Environmental Management
Save the Bay

BEACH CLEANUP DATA CARD

Thank you for completing this data card. Answer the questions and return to your area coordinator or to the address at the bottom of this card. This information will be used in the Center for Marine Conservation's National Marine Debris Database and Report to help develop solutions to stopping marine debris.

Name __________________________ Affiliation _________________________________

Address _________________ Occupation ______________ Phone (_____)___________

City ___________________________ State _______ Zip ________ M __ F __ Age: ____

Today's Date: Month:_______ Day_____ Year_____ Name of Coordinator_____________

Location of beach cleaned _____________________ Nearest city ____________________

How did you hear about the cleanup? ____

Number of people working together on this data card_____

Estimated distance of beach cleaned _______ Number of bags filled ______________

SAFETY TIPS

1. Do not go near any large drums.
2. Be careful with sharp objects.
3. Wear gloves.
4. Stay out of the dune areas.
5. Watch out for snakes.
6. Don't lift anything too heavy.

WE WANT YOU TO BE SAFE

SOURCES OF DEBRIS. Please list all items with foreign labels (such as plastic bleach bottles from Mexico) or other markings that indicate the item's origin (such as cruise line names, military identification or debris with names and/or address of shipping/freighting or fishing companies, or oil/gas exploration activities

SOURCE	ITEM FOUND
Ex: ABC Shipping Company	**plastic strapping band**

STRANDED AND/OR ENTANGLED ANIMALS (On the other side, please describe type of animal and type of entangling debris. Be as specific as you can.

What was the most unusual item you found?

NITROGEN DILUTION MODEL
HANDOUT

Using annual loading and annual recharge for aquifer and estuarine protection

Purpose: To maintain a target (permissible) concentration of nitrate-N in groundwater as development proceeds. Excess nitrate-N can be a drinking water pollutant, a problem for estuarine ecosystems. Nitrate-N is a common groundwater contaminant this is often found at elevated concentration in association with unsewered residential developments, certain agricultural practices and livestock farming. A number of simple models rely on a strong research base that has defined annual loading of nitrate-N from a variety of land uses. Nitrate dilution models are in use in Cape Cod, RI, the NJ Pinelands, California and many other urbanizing locations.

Target (Permissible) Concentrations of Nitrate-N (recall that mg/l is equivalent to g m^{-3}):

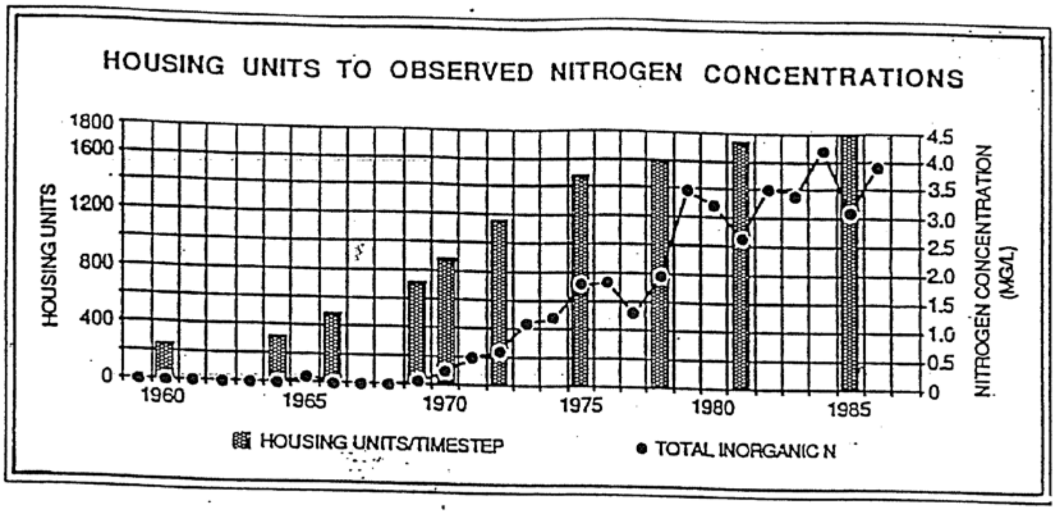
a. National drinking water standard, 10 mg/l
b. Long Island Recommendation, 6.2 mg/l (based the variation noted in sampling various wells – with a target or mean of 6.2, the risk of exceeding the drinking water standard of 10 mg/l will be less than 5%.)
c. New Jersey Pine Barrens, 2 mg/l ("no degradation" goal)
d. North Smithfield, RI, 5 mg/l

Approach: The average concentration of a pollutant (mass per volume), such as nitrate-N, entering the groundwater can be computed for a given parcel of land from the quotient of:

i. The annual amount (**mass**) of the pollutant discharged to the groundwater (this is the **annual load**). This is often expressed as mass per unit area per time (lbs $acre^{-1}$ yr^{-1}) or mass of nitrate-N per septic system. In computation, the load should be converted to g yr^{-1}.

Divided by:

ii. The annual amount (**volume**) of water that is recharging the groundwater (this is the **annual recharge flow**). This is often expressed as either length of recharge (inches per year) and multiplied by the area of a given land use to get volume per time (ft^3 yr^{-1}) or it is expressed as volume per septic system. In computation, the volume recharge should be converted to m^3 yr^{-1}.



" Legal" Premise

The water quality effects of the recharge water leaving a parcel of land should be evaluated from a cumulative perspective and not solely as the effect of that one parcel on the overall aquifer or estuary that is receiving the recharge. If each land parcel generates a pollution level below the target concentration an acceptable concentration of nitrate will flow to the aquifer or estuary that is to be protected.

If a town or municipality permits developments that generate pollution levels above the permissible limit at the property line:

a) The town is relying on the remaining lands of the aquifer or watershed to dilute the pollution to acceptable limits.
b) If all development generates pollution above the permissible level, eventually the receiving water will be above the permissible limit and the water resource will be degraded.

Example:

Compute the expected nitrate-N concentration (g/m^3) in the groundwater recharge from the following situation. The recharge and N loading values are given.

Proposed: A 20 acre subdivision. The subdivision is to have:

- 40 homes with septic systems
- 12,000 ft^2 of lawn per home (0.275 acres/home)

- 0.175 acres per home of impervious cover (includes roofs, patios, roads and driveways; where the runoff is directed offsite to storm drains that do not recharge the groundwater.
- 2 acres of forest

Modeled Scenario:

Source	Number of Units (You can change the number of homes)	Area per source unit (acres)	Total area in subdivision
Septic systems (equal to number of homes)	**40**	0 (assume area is buried under vegetated cover)	0
Lawns (equal to number of homes)	**40**	0.275 acres	11
Forest	1	2 (this will change to reflect increases or decreases in the number of homes)	2
Impervious surface per home	**40**	0.175	7
			20 acres

Note: Compute Forest area per source unit as the area remaining after lawn area and impervious surface area is computed.
Forest area per source unit = 20 acres – [total lawn area + total impervious area] = 2 acres

I. Computing Annual Volume of Recharge From the Site

Land Use (Nitrate Source)	**Water Recharge per unit (given)**	Total Volume from Source
40 homes with Septic Systems	**200 gallon per day per septic system**	391,280 Ft^3/yr
40 lawns with 0.275 acre/lawn	**20” of recharge per year**	800,000 Ft^3/yr
2 acres forest	**20” of recharge per year**	145,200 Ft^3/yr
40 homes with 0.175 acres of impervious cover per home	**0.0**	0.0
	Total Recharge (Ft^3/yr)	1,336,480
	Total Recharge (m^3/yr)	**37,845**

Computations:

Total Volume of Recharge from Septic Systems:

40 homes * 200 gallon per day per home = 8,000 gallons per day for subdivision.

8,000 gallons per day * 365 days per year * 0.134 ft^3/gal = 391,280 ft^3/yr

Total Volume of Recharge from lawns:

Area of lawns in square feet:

40 lawns/subdivision times [0.275 acres/lawn *43,560 ft^2/acre] = 480,000 ft^2 of lawn per subdivision

Volume of lawn recharge: 480,000 ft^2 * (20 inches/yr recharge) * (0.0833 ft/inch) = 800,000 ft^3/yr

Total Volume of Recharge from Forest:

2 acres of forest * 43,560 ft^2/acre = 87120 ft^2

87,120 ft^2 * (20" recharge) * (0.0833 ft/inch) = 145,200 ft^3/yr

Total volume of recharge from impervious cover:

40 homes at 0.175 acres/home = 7 acres of impervious cover

7 acres of impervious cover * (43,560 ft^2/acre) = 305,000 ft^2

305, 0000 ft^2 * (0.0 inches/yr of recharge) * (0.0833ft/inch) = 0.0 ft^3 /yr

II. Computing Annual Mass of Nitrate-N in Recharge From the Site:

Land Use (Nitrate Source)	Total Area of land use in subdivision	**Mass Recharge per unit (given)**	Total Mass from Source
40 homes with Septic Systems	0	**30 lbs per yr per septic system**	1,200 lbs/yr
40 lawns with 0.275 acres/lawn	11 acres	**30 lbs per acre per year**	330 lbs/yr
2 acres forest	2 acres	**2 lbs per acre per year**	4 lbs/yr
40 homes with 0.175 acres per home of impervious cover	7 acres	**0.0**	0.0
		Total Mass per year (lbs/yr)	1534 lbs/yr
		Total Mass Recharge (kg/yr)	**696**
		Total Mass Recharge (g/yr)	**696,000**

Computations:

Total Mass of Nitrate-N in Recharge from Septic Systems:

40 homes * 30 lbs of Nitrate-N per home per year = 1,200 lbs per year of Nitrate-N for subdivision.

Total Mass of Nitrate-N in Recharge from lawns:

40 lawns at 12,000 ft^2/lawn = 480,000 ft^2 of lawn per subdivision

480,000 ft^2 * (1 acre/43,560 ft^2) = 11 acres

11 acres * 30 lbs of Nitrate-N/acre per year = 330 lbs per year of Nitrate-N

Total Mass of Nitrate-N in Recharge from Forest:

2 acres of forest * 2 lbs of Nitrate-N/acre per year = 4 lbs per year of Nitrate-N

Total Mass of Nitrate-N in recharge from impervious cover:

40 homes at 0.175 acres/home = 7 acres of impervious cover
7 acres of impervious cover * (43,560 ft^2/acre) = 305,000 ft^2
305,000 ft^2 * (0.833ft/inch) * (0.0 lbs per ft^2 per year of Nitrate-N in recharge) = 0.0 lbs of Nitrate-N/yr

FINAL COMPUTATION TO OBTAIN CONCENTRATION FROM THE ENTIRE SUBDIVISION:

(MASS/YR) $\div$ (VOLUME/YR)

Or

(696,000 g/yr) $\div$ (37845 m^3/yr) = 18.3 g/m^3 which is the same as 18.3 mg/l of nitrate-N

NITROGEN DILUTION MODEL
HOMEWORK

Using the values (recharge and nitrogen loading) provided in the example handout (entitled Nitrogen Dilution Model: "Areal Load Model"), create a housing development on 20 acres of land that has a mean groundwater recharge nitrate-N concentration of 4.6 to 5.0 ppm (or g/m^3) . I ask that you create a spread sheet to conduct this analysis. You can then solve the problem through trial and error. Many combinations will work. You can (and should) change:

- the number of homes
- the area of lawns/home
- The area of forest (this should be changed automatically within the spread sheet to account for the lands not used by the home lots)
- Impervious zones to pervious zones

Whatever you do, <u>the total area needs to add up to 20 acres</u>. You can't create new land or eliminate land. To make your scenarios add up to 20 acres, compute the area of the forest within the spread sheet as: Forest = 20 acres – (Sum of the other areas)

Please model 3 different scenarios – each scenario solution requires a separate excel analysis and answer sheet:

1) *Density Restriction*: Obtain the desired concentration by limiting the number of homes and the number of home lawns. (So, there will be substantially fewer homes and substantially more forest.
2) *Sustainable Hydrology Scenario:* Combine density restrictions with methods that increase infiltration from developed areas. In this case all the water on the site is directed to the groundwater through either pervious pavement, infiltration beds or other devices. The infiltrating water is assumed to carry negligible nitrate (use 0.0 as the nitrate-N concentration for infiltrating water from pervious cover. See Figure I.
3) *Nitrogen Removal Septic System Scenario:* Combine density restrictions with the effect of using alternative septic system technologies that remove nitrogen from wastewater. These systems are expected to reduce the nitrogen loading (recharge mass of Nitrate-N) by 50%, yielding 15 lb. of Nitrate-N per unit per year. See Figure II.

4) ***Also include a spread sheet that models the example problem that we went over during class.***

Requirements:

1. Turn in 4 separated spread sheets, each representing a different scenario – with your best mix of homes, lawn area, forest area that create a recharge nitrate-N concentration between 4.6-5.0 ppm (g/m3).

2. **Include a sheet that has the computation and conversions for each part of the excel sheet.** You only need to show one example of each type of computation. You may need to do this by hand if you find that equations are hard to put into either Word or Excel.

Note that the **current** (example problem) scheme proposes:

- **20 acres total. This includes the lawns, roads, forest and other impervious cover.**
- 40 houses, each with a septic system generating 30 lbs per year of nitrogen and 200 gallons per day of recharge water.
- 40 lawns, each with 12,000 sq. feet (0.275 acres) of lawn/home (**total of 11 acres of lawn** in the subdivision).
- **Throughout this exercise assume that each home site is associated with 0.175 acre/home of impervious cover** (house print, patios, driveways, roads, etc.) for a total of 7 acres of impervious cover. The runoff is assumed to be directed to storm drains which feed directly to a local stream and do not recharge the groundwater.

Forest computation:
Given that:
Total area is fixed at 20 acres
the number of homes are fixed at 40;
the lawn area per home is fixed at 0.275 acres per home = 11 acres of lawn
the impervious area per home is **fixed** at 0.175 acres per home = 7 acres of impervious cover.

Then:
Forest area has to equal = 20 acres – [(40 homes * 0.275 acres lawn home) + (40 homes * 0.175 acres impervious/home)]

Or
Forest area = 20 acres – 18 acres = 2 acres.

When you are doing the problem if you decide to change the number of homes to 15, then the forest acreage would have to be:

Forest area = 20 acres – [(15 homes * 0.275 acres lawn home) + (15 homes * 0.175 acres impervious/home)]
Or
Forest area = 20 acres – 6.75 acres = 13.25 acres

Build this calculation right into your spread sheet

Assume you are working with the developer and want to help him/her get a reasonable number of lots to sell.

For full credit, you will need to show a series of “spread sheets” with the assumptions and computations, similar to the way the example problem is formulated.

What can you change?

- Area of lawn per home can change. You can make it as small as 0.05 acres/home or as large as 0.275 acres/home. You can change this in all 3 scenarios.
- Number of homes – remember that we assume that the developer makes money by building as many homes as possible within the nitrate loading rules. You can change this in all 3 scenarios.
- Forest area will usually change whenever you change the number of homes.
- Extent of infiltration – this is what you will explore with scenario number 2.
- Level of nitrogen inputs from septic systems – this is what you will explore with scenario number 3.

What can’t you change?

- Area of impervious cover that surrounds each home is fixed at 0.175 acres/home (in scenarios 1 and 3, this area will reduce the amount of recharge to the groundwater, in scenario 2, this area will contribute extra recharge to the groundwater).

Source and (Unit)	Number of units (just put numbers into spread sheet)	Area per source unit (acres)	Total Acres per subdivision: Number of units times acres per source unit	Water Vol./unit Or Recharge/unit *Ft^3/yr per unit*	*Recharge (ft^3/yr) (Multiply number of units by recharge per unit)*	Recharge Mass of Nitrate-N per unit *Lbs/yr per unit*	*Total Recharge Mass of Nitrate-N*
Septic System (equal to number of homes)	Equal to number of homes in a given scenario	Assume 0 (area will be within the vegetated area)		200 gal/day per home *(Convert to cubic feet per year)*		30 lbs/home (change for scenario 3)	
Lawns (acre/home)	Equal to number of homes in a given scenario	0.275 acres per lawn home (You can change this!):		(20"/yr)* times area/home (convert to cubic feet)	**	30 lbs per acre	***
Forest (total acres)	1 forest per subdivision	?? acres (You will change this area to make sure that your subdivision is 20 acres)	Same as cell to the left. To do this rapidly, compute Forest acres **after** you change the other sources = 20-(sum of the area of the other sources)	20"/yr* times total area (convert to cubic feet)		2 lbs per acre	
Imperv cover (acre per home)	Equal to number of homes in a given scenario	0.175 acres per home		0.0 inches/yr times area/home (Convert to 40 inches per year for sustainable hydrology scenario)		0.0	
			Total Acres must equal 20 acres		***Sum** this Column Recharge (ft^3/yr)*		***Sum** this column Mass (Lbs/yr)*
					Sum Recharge (M^3/yr)		*Sum Mass (g/yr)*

* Express recharge per unit as volume by multiplying area times recharge depth and making appropriate conversions from inches of recharge into feet of recharge to obtain recharge as ft^3/source.
** Example: Total recharge for lawns (Ft^3/yr): Find total area of lawns {(sq ft. per home) times (number of homes)} and multiply by depth of recharge (convert inches/yr to ft/yr).
*** Total Recharge Mass of Nitrate-N: (find total area of all the lawns, convert to acres and multiply by nitrate-N recharge (expressed in lbs/acre of lawn).

Then: Concentration will equal: Sum Mass/Sum Recharge and the units will be g/m^3
The current scenario assumes that impervious areas do not contribute recharge water or nitrate to the groundwater. When you eliminate homes, the impervious cover needs to be converted to lawns or forest.

Density Restriction Scenario: You can reduce the number of homes, which will reduce the number of lawns and the number of impervious areas. Also, you can minimize the area of the lawns per home from 0.275 acres/home to some lower area per home. As you eliminate homes you can convert the 0.175 acres of impervious area/lot into either forest or lawn. As you shrink the area of the lawns, convert that area to forest. Remember that each septic system generates 30 lb. of Nitrate-N per unit per year.

Sustainable Hydrology Scenario: You will explore the effects of a "sustainable hydrology development" where all the water on the "impervious cover" at the site is directed to the groundwater through pervious pavement, infiltration beds or other devices. In that situation, keep the "footprint" per home as 0.175 acre but assume that 40 inches of rain can infiltrate and recharge the groundwater on those areas that have been converted from impervious to pervious. For this exercise, assume that any recharge from permeable pavement or infiltration beds carries 0.0 kg of nitrogen to the groundwater. You can change the number of homes and lawn area (and forest area) as well. Remember that each septic system generates 30 lb. of Nitrate-N per unit per year.

Nitrogen Removal Septic System Scenario: You may wish to explore the effect of using alternative septic system technologies that remove nitrogen from wastewater. These systems are expected to reduce the nitrate loading (recharge mass of Nitrate-N) by 50%, yielding **15 lb** of Nitrate-N per unit per year. These systems cost about $10,000 more than a conventional system and require extra maintenance. You can change the number of homes and lawn area (and forest area) as well.

Figure I: Sustainable Hydrology: Infiltrate all Runoff from Site: Permeable pavement and/ or recharge basins

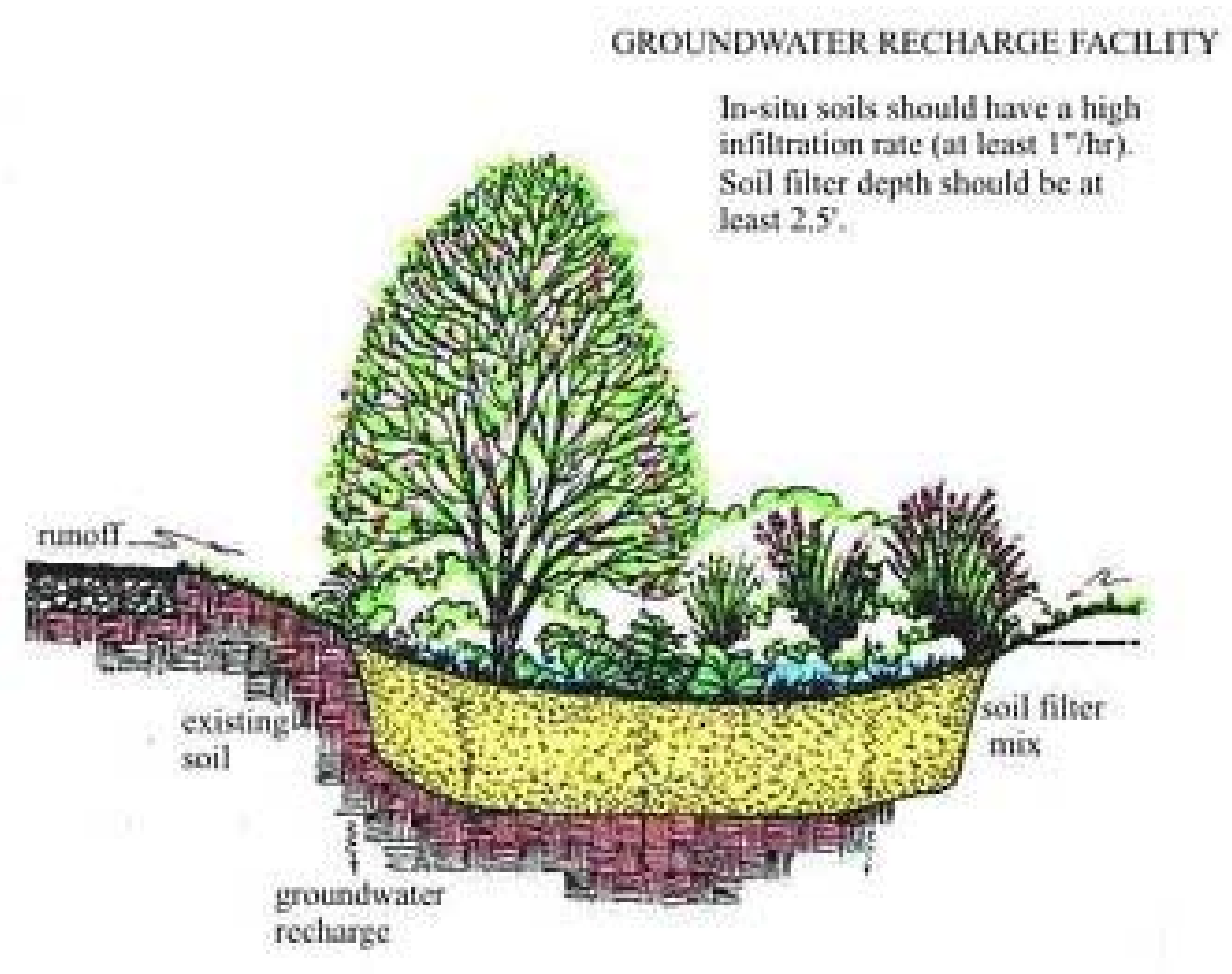
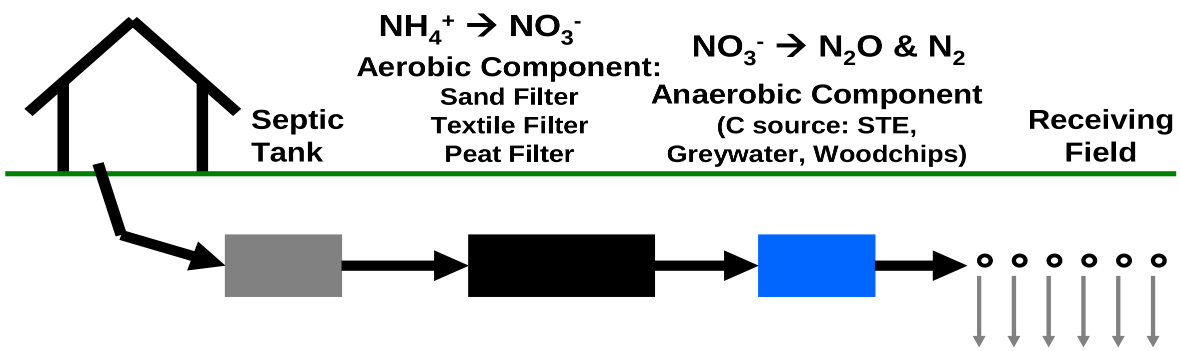


Figure II. Potential Scenario for Nitrate Dilution Model (Scenario #3): Nitrogen Removal Septic Systems

Simplified Onsite Wastewater Treatment Train:

"Denitrification" System



- **Long term removal = 40 – 85% of TN**
- **Most removal likely to be denitrification**
  < 5% TN remains in septic tank sludge

Natural Resources Facts

University of Rhode Island • College of Resource Development
Department of Natural Resources Science • Cooperative Extension

August, 1996 **Fact Sheet No.96-4**

Algae in Aquatic Ecosystems

Kelly Addy and Linda Green

Algae play a vital role in all aquatic ecosystems. Algae form the food and energy base for all organisms living in lakes, ponds, and streams. However, unnatural or excessive growth of algae (nuisance algal blooms) may interfere with our enjoyment of aquatic resources and may even be harmful. Because of their importance to aquatic ecosystems and susceptibility to changes in the environment, algal measurements are often key components of water quality monitoring programs. This fact sheet will describe algae and their role in aquatic ecosystems; characterize algal succession; describe how algal levels are measured and what these measurements indicate; and discuss how algal populations, especially nuisance algal blooms, may be controlled.

What are Algae?

There are two main forms of algae: micro and macro algae. This factsheet will focus on micro algae—microscopic, often unicellular plants. Unlike their larger plant relatives, algae do not have roots, stems, or leaves. Not all algae are green; algae come in a wide range of colors depending on which pigments are dominant in their cells. For example, if chlorophyll *a* is present in high concentrations, algae tend to be green, but orange and red colored algae are caused by high levels of carotene pigments. Micro algae are divided into two general groups: phytoplankton and periphyton. **Phytoplankton** live suspended in the water column. **Periphyton** live attached to rocks, sediment, plant stems, and aquatic organisms. Algae usually are single-celled (unicellular) with these cells either solitary or grouped in clusters (colonies) or strings (filaments).

Like their aquatic and terrestrial plant relatives, algae are primary producers, known as **autotrophs**. Autotrophs convert water and carbon dioxide to sugar (food) in the presence of sunlight. This process, **photosynthesis**, generates oxygen as a by-product. This oxygen contributes to the survival of fish and other aquatic organisms in lakes. Algae also form the base of lake food chains; all lake organisms depend either directly or indirectly on algae as a food source.

Phytoplankton need to stay near the water's surface in order to absorb sunlight for photosynthesis. Algae come in an amazing number of sizes and shapes which are actually adaptive strategies to prevent them from sinking away from the sunlight in the upper portion of the water column. These anti-sinking adaptations include flat, wide cell shapes and spines which increase friction and lessen gravitational influences. Some phytoplankton have developed mechanisms to move actively (Caduto 1990). Tail-like extensions, **flagella**, of some algae can move them through the water (Fig. 1). Some phytoplankton adjust the size of gas-filled sacs, **vacuoles**, to move through the water column.

Some algae reproduce via asexual reproduction, where the parent splits into two or more cells, while other algae are capable of sexual reproduction (Caduto 1990 and St. Amand 1995). A few algae can reproduce by either method with some algae alternating methods depending on environmental conditions. Some even adapt reproduction rates in response to water flow rates. For example, an alga may reproduce faster in turbulent waters, to replace cells swept downstream, than in still waters where algal biomass can accumulate (Caduto 1990).

Role in Aquatic Ecosystems

Increases in algal cell numbers are affected by season, temperature, amount of sunlight penetrating the water column, amount of available inorganic nutrients, competition from other algae and aquatic plants, and how

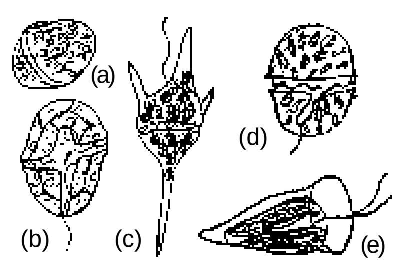


Fig. 1: *Peridinium* (a & b), *Ceratium* (b), *Gymnodium* (c), and *Dinobryon* (d) are algae very common in Rhode Island lakes (Source: St. Amand & Wagner 1995). They all have flagellae to move them through the water column. *Size:* Microscopic detail shown.

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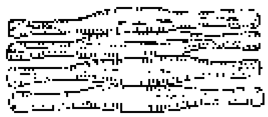
long the water stays in the lake (**residence time**) (Simpson 1991). When enough sunlight is available, such as in summer, the amount of phosphorus in the lake often controls the abundance of algae. Therefore, phosphorus is considered the **limiting nutrient** in most fresh waterbodies.

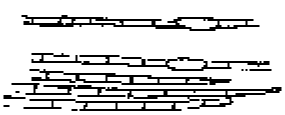
Some phosphorus enters a lake naturally. For example, autumn leaf fall, animal wastes, waterfowl, and atmospheric deposition contribute phosphorus tolake ecosystems. However, human activities often increase the amount of phosphorus. Man-made contributors of phosphorus to aquatic ecosystems include: phosphate containing detergents, lawn and garden fertilizers, improperly sited or maintained septic systems, urban storm runoff, agricultural drainage, wastewater treatment effluent, and road de-icers. As land becomes more developed, the amount of runoff and the nutrient concentration of runoff increases. When excess nutrients enter a waterbody, algal growth rates are stimulated, increasing populations to abnormally large sizes. Excessive amounts of algae on the surface of the lake may also occur as dense, smelly mats. Any excess of algal biomass is often referred to as an **algal bloom**.

Some Types of Algae

When viewed under a microscope, the symmetrical geometric patterns of **diatoms** can be seen (*Fragilaria* is shown here in microscopic detail). Silica is the primary component of the diatom skeleton, which cannot be decomposed. Preserved diatom skeletons in lake sediments are an important tool for scientists interested in determining a lake's history (Caduto 1990). The ancient remains of diatoms have even contributed to our current fossil fuel supplies (Caduto 1990).



Blue-green algae are actually blue-green bacteria, **cyanobacteria** (*Aphanizomenon* is shown here in microscopic detail) (Caduto 1990 and Monson 1992). Many blue-green algae are capable of converting atmospheric nitrogen into useful forms in a process known as nitrogen fixation. These species tend to flourish in mid to late summer when lake nitrogen concentrations are low. These species are also particularly resilient, they are able to over-winter as spores in the lake. The large colonies of blue-green algae are not a preferred food of lake organisms, which improves survival rates. Some blue-green algae produce toxins that, in high concentrations, have the potential to kill animals. Blue-green algae are best known as the dominant species of most algal blooms.



Seasonal Changes in Algae

Algae are a very diverse group of organisms. More than 40 species can coexist in one lake! Throughout the year, however, algal species dominance of lakes changes in a yearly cycle, known as **algal succession** (Kortmann & Henry 1990). This natural succession of algae occurs in response to changes in season, temperature, wind, precipitation patterns, and nutrient cycles (Moore & Thornton 1988). Algal populations are abundant in spring and early summer when available light and nutrients are high and few organisms are present to feed on the algae. Toward the end of this stage, a phenomenon, commonly known as the **clear water phase** , occurs in many lakes. Spring algal populations are usually composed of small, highly edible species. As this phase approaches, zooplankton populations increase dramatically. These zooplankton consume algae rapidly, causing algal populations to crash, resulting in very clear water for a few weeks, hence the name "clear water phase."

These small, edible algal populations are gradually replaced by larger, colonial, non-edible species that are often covered by gelatinous sheaths. Because available nutrient concentrations are often limited in the summer, the total concentration of algae in summer can be less than in spring before the clear water phase. In late summer and fall, nutrients stored at the bottom of the lake become mixed through the water column generating a fresh supply of nutrients. This allows algal populations to flourish again and late season algal blooms to develop. During winter months, algae are able to survive, but usually at low concentrations due to colder water temperatures and lower amounts of available sunlight.

Nuisance algal blooms

Algae are necessary and beneficial to aquatic ecosystems. They form the food and energy basis for nearly all other aquatic organisms. However, unnaturally elevated levels of algal growth may interfere with use and enjoyment of lakes, ponds, and even streams. Nuisance algal levels usually decrease aesthetic beauty, by reducing water clarity, and often create taste and odor problems. Extremely high levels of algae can generate enough shade to prevent sunlight from reaching rooted aquatic plants (macrophytes), limiting their plant growth or even causing them to die (Fig. 2). Also, as more algae grow within the lake, there are more dead algae to be decomposed. Decomposition by bacteria consumes oxygen and may decrease or even completely deplete dissolved oxygen contents of some lakes during the summer. Complete lack of oxygen is a condition known as **anoxia** which can cause fish kills (see Natural Resources Facts, Fact Sheet No. 96-3, "Dissolved Oxygen and Temperature").

High levels of algae may raise the pH of waterbodies. Elevated pH levels are thought to be a by-product of photosynthetic uptake of carbon dioxide. Daily cycles of pH

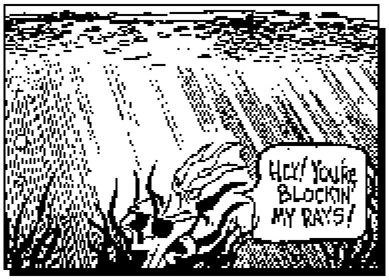


Fig. 2: Nuisance algal blooms may prevent sunlight from reaching aquatic plants lower in the water column.

can be observed. Higher pH levels may be noted late on sunny summer afternoons after photosynthesis has consumed carbon dioxide throughout the day. After sunset, pH levels may fall noticeably since photosynthesis has ended. These extreme fluctuations in pH stress sensitive aquatic life.

There is also concern that excessive amounts of algae may form the organic matter base of a reaction with the chlorine used at many water treatment facilities. This generates trihalomethanes (Moore & Thornton 1988). Trihalomethanes may be associated with cancer risks.

It is important to realize that algae occur in natural cycles of abundance in aquatic ecosystems (Fig. 3). Blooms of algae should only be considered problematic if they occur with increasing frequency as a direct result of human influence on the environment. Lake management emphasis should be geared toward maintaining healthy, natural levels of algae within waterbodies.

How are Algal Concentrations Measured?

Because algae are strong indicators of environmental change, many water quality monitoring programs measure algal concentrations to determine changes in water quality. In all plants and algae, photosynthesis requires the green pigment **chlorophyll *a***. Although the ratio of chlorophyll *a* to biomass can vary among algal groups, measurement of chlorophyll *a* concentration is considered a reasonable estimate of algal concentrations.

To measure chlorophyll *a* concentration, a lake water sample is taken. A known quantity of water from this sample is passed through a glass fiber filter disk. The filter catches the algal cells from the sample. The filter is stored in the cold and dark to minimize additional algal growth or degradation. Chlorophyll *a* is extracted with an acetone solution. Concentrations are determined by analysis with a fluorometer or a spectrophotometer. This method may be the most reliable method of determining algal concentrations because chlorophyll *a* is chemically extracted from the algal cells (Simpson 1991). Other benefits of this method include the ease and consistency of sampling which appeals to many volunteer water quality monitoring groups, including URI Watershed Watch.

There are some limitations associated with measuring algal biomass, the quantity of algae, using this technique. One limitation is that algae are not uniformly distributed through a waterbody. To compensate for this patchiness, multiple water samples should be taken on each sampling date. Alternatively, subsamples may be taken from a larger composite sample. A number of volunteer monitoring programs, including groups in Vermont, address this patchiness by taking an integrated sample, as suggested by EPA. In this approach, monitors extend a garden hose down to two times the Secchi depth measurement, producing a water sample representative of the water column.

Another limitation of this chlorophyll *a* measurement method is that some species of algae have naturally higher chlorophyll *a* levels than other algal species. Additionally, the chlorophyll *a* concentration within algae fluctuate during the day in order to maximize the efficiency of photosynthesis. Uniform and repeated measurements are the best way of dealing with these limitations. Taking water samples at the same time of day and at the same depth in the water column each time a sample is collected can reduce inconsistencies. URI Watershed Watch recommends taking chlorophyll *a* samples between 10am and 2pm at the deepest spot on the pond at a 1 meter depth.

A way to measure algal concentrations indirectly is by taking Secchi depth measurements, a measure of water clarity (see Natural Resources Facts, Fact Sheet No. 96-1, "Measuring Water Clarity). The degree of water clarity is a result of the amount of suspended materials in the water column. In areas of low sediment inputs to lakes, there is a strong relationship between Secchi depth measurements and chlorophyll a concentrations. Total phosphorus concentrations may also be used to estimate the potential amount of algae in a lake (see NRS Facts 96-2 "Phosphorus and Lake Aging").

What do algal measurements mean?

Algal concentrations can be used to determine the trophic status of a lake. Trophic status is an indicator of the stage of the lake in terms of the natural process of lake aging, known as eutrophication.

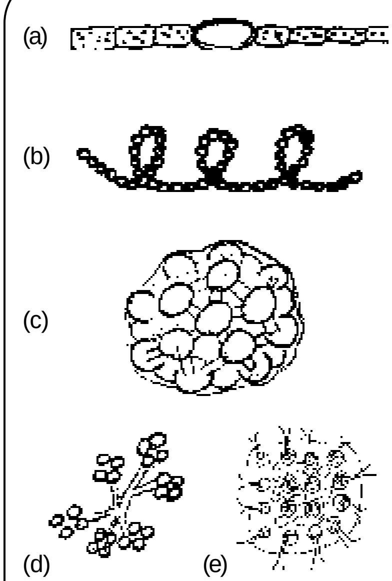


Fig. 3: *Anabeana* (a & b) are very common forms of blue-green algae found in RI lakes. *Coelastrum* (c), *Dictyosphaerium* (d), and *Gonium* (e) are very common forms of green algae found in RI lakes. *Size:* microscopic detail shown. (Source: St.Amand & Wagner 1995)

Oligotrophic waters are clear to great depths and have few algae. Waterbodies with abundant algae are described as **eutrophic**; these are often turbid. In the middle of the spectrum, with moderate algal levels, are **mesotrophic** waterbodies.

Trophic status can be estimated from chlorophyll *a* concentrations, Secchi depth measurements, or total phosphorus concentrations. Each parameter used alone has its weaknesses, but when considered together, they help to create a more complete picture of a lake's water quality and the relationship between water quality and algal growth. By evaluating which particular algal species resides in a lake, even more information can be obtained about a lake's water quality.

How can Algal Populations be Controlled?

Due to the growing concern about nuisance algal growth in many lakes, mechanisms have been explored to limit algal growth (McComas 1993). The best way to limit algal growth is to limit the amount of nutrients that enter the lake (see Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging" for suggestions). However, alternative methods of algal control have been developed. (McComas's 1993 edition of *LakeSmarts: The First Lake Maintenance Handbook* is highly recommended for more information on control strategies since this discussion is very general and brief.)

Chemicals can be added to lakes to reduce algal growth. Copper sulfate and various synthetic organic compounds are frequently used as herbicides. Buffered alum and/or calcium compounds are sometimes added to bind up phosphorus and make it unavailable for algal use. This approach works well if phosphorus is supplied by recycling within the lake, and inputs from surrounding areas are kept to a minimum. While these chemicals are effective in reducing algal growth, application requires RI DEM permits and must be applied by a licensed applicator. Even though considerable research has been conducted to assure the safety of these herbicides, controversy still exists over their long-term effects on ecosystems.

Other artificial control strategies include aeration, introduction or manipulation of biological controls, and physical removal of algae. Mechanical aeration adds oxygen to lakes in order to inactivate phosphorus or reduce the effects of algal blooms. Biological controls, such as grazers that consume algae, can limit the number of algae living in the lake. Physical removal of algae often involves filtering algae from the water. These control methods may be costly, and efficiency varies.

The best control method is limiting algal growth before it accelerates by limiting the amount of nutrients entering the waterbody. As long as algae do not reach nuisance levels, they play an important, essential role in a healthy aquatic ecosystem (Fig. 4).

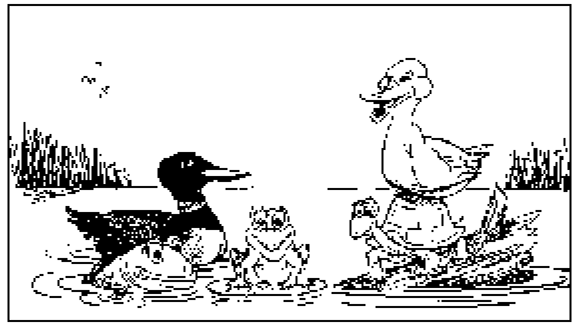


Fig. 4: Algae are at the base of what makes a happy, healthy aquatic ecosystem.

Special thanks to URI Professor Dr. Saran Twombly, URI Research Associate Elizabeth Herron, and Dr. Kenneth Wagner of Fugro East, Inc. for reviewing and commenting on this fact sheet. Algae graphics were obtained from St.Amand and Wagner's 1995 algal workshop (reference below). The University of Wisconsin Extension and Wisconsin DNR provided the other graphics used in this fact sheet.

For more information:

Caduto, M.J. 1990. *Pond and Brook: A Guide to Nature in Freshwater Environments*. Prentice Hall, Inc. Englewood Cliffs, N.J.

Kortmann, R.W. and D.D. Henry. 1990. *Mirrors on the Landscape: An Introduction to Lake Management*. Connecticut Institute of Water Resources. University of Connecticut, Storrs, CT. Phone # (203) 833-8317.

McComas, S. 1993. *Lake Smarts: the First Lake Maintenance Handbook*. Terrene Institute, 4 Hebert St., Alexandria, VA 22305. Phone # (703) 548-5473.

Monson, Bruce A. 1992. *A Primer on Limnology, Second Edition.* Water Resources Research Center, College of Natural Resources, University of Minnesota, Room 302, 1518 Cleveland Avenue, N., St. Paul, MN 55108. Phone # (612) 624-9282.

Moore L. and K. Thornton, ed. 1988. *The Lake and Reservoir Restoration Guidance Manual*. First Edition. EPA 440/5-88-002. Phone # (904) 462-2554.

Natural Resources Facts, Fact Sheet No. 96-1, "Measuring Water Clarity," 1996. Cooperative Extension, URI.

Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging," 1996. Cooperative Extension, URI.

Natural Resources Facts, Fact Sheet No. 96-3, "Dissolved Oxygen and Temperature," 1996. Cooperative Extension, URI.

Simpson. 1991. *Volunteer Lake Monitoring: A Methods Manual*. EPA 440/4-91-002. Phone # (202) 260-7018

St. Amand, A. 1995. Algae—nature's artwork. *Lakeline*. September: 10-11, 24-26.

St. Amand, A. and K.J. Wagner. 1995. Algal workshop: collection, identification, and ecology of freshwater algae. NALMS workshop series, Madison, WI.

For more information about URI Watershed Watch:
Please call Watershed Watch at (401) 874-2905
or e-mail riww@uriacc.uri.edu

Bacterial Monitoring

URI WATERSHED WATCH, Cooperative Extension
College of the Environment and Life Sciences (CELS)
Department of Natural Resources Science (NRS)
Coastal Institute in Kingston, 1 Greenhouse Road, Kingston, Rhode Island 02881-0804

Kelly Addy, Elizabeth Herron, and Linda Green

URIWW-2, March 2003

Why Monitor Bacteria?

Is it safe to swim in the water? That's a question we often hear when we say we are monitoring a favorite swimming spot. Researchers and regulatory agencies have determined that one way to answer that question is to conduct bacterial monitoring. They do this to determine the human health risk associated with recreational water contact. The bacteria selected for water quality monitoring rarely cause human illness; rather the occurrence of these bacteria *indicates* that fecal contamination may have occurred and pathogens may be present in the water. Pathogens are microorganisms that cause illnesses; they may be viruses, bacteria or protozoans. Direct measurement of pathogens, including giardia, cryptosporidium, and Norwalk virus, is expensive and impractical because:

- There are innumerable types of pathogens that may be in waterbodies; it would be impossible to check for all these pathogens.
- The presence of one pathogen may not indicate presence of others.
- Generally, simple laboratory techniques do not exist to measure pathogens.

Bacterial monitoring is a practical method to determine the potential health risk of water exposure. Bacteria are microscopic, single-celled organisms that can be found in virtually any environment. Bacterial indicators of pollution are in the intestines of warm-blooded animals, including humans, where many pathogens also originate. Indicator bacteria in a waterway come from many sources (Figure 1), e.g., animal droppings, faulty or leaking septic or sewage systems, combined sewage overflows (CSOs, see Box 1), stormwater runoff, boat sanitary waste and disturbed sediments.

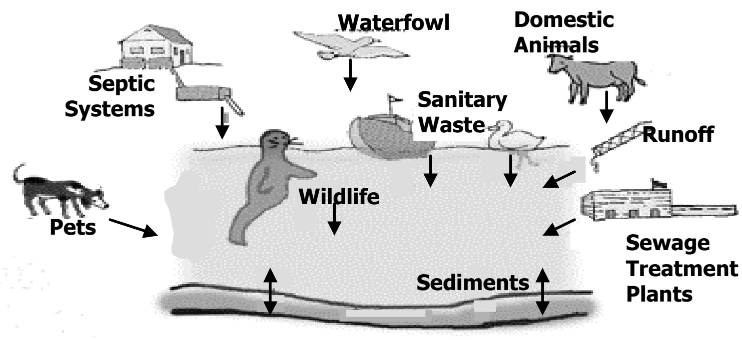


Figure 1: Potential sources of bacteria to a waterway (from Ely, 1997).

What bacterial indicators are monitored?

Bacterial indicators should meet as many of the criteria listed in Box 2 as possible to ensure safe swimming water. Water quality monitors screen water samples most frequently for fecal coliform (F.C.), *Escherichia coli* or enterococci as bacterial indicators (see Box 3 for details). These indicators are prevalent in the intestines of warm-blooded animals and associated with fecal contamination. Total coliforms are a group of closely related bacteria, fecal coliforms are a subgroup of total coliforms and *E. coli* are a specific species of F.C. bacteria (Figure 2). Enterococci are another group of bacteria unrelated to the coliforms.

Box 1: Combined Sewage Overflows (CSOs)

Combined Sewage Overflow systems carry storm water from roadways and untreated sewage from home and businesses in the same pipes. On a dry day, all this waste water is treated by the sewage treatment plant. However, on very rainy days, the sewage treatment plant may not be able to treat all the water and may release some untreated waste water into waterways. CSO control plans are in progress in the Providence area to minimize these inputs to Upper Narragansett Bay.

Box 2: Criteria for a good bacterial indicator (adapted from Ohrel and Register, 2001).

Good Bacterial Indicators Are:
Present whenever intestinal pathogens are present
Useful in fresh and marine waters
Alive longer than the hardiest intestinal pathogen
Found in a warm-blooded animal's intestines
Analyzed with an easy testing method
Directly correlated with the degree of fecal contamination

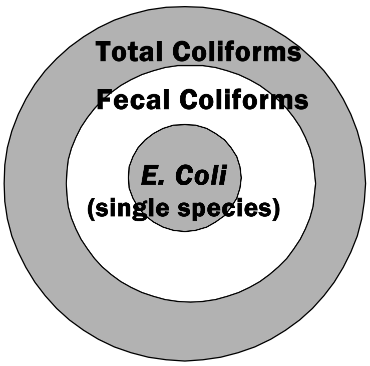


Fig. 2 (left): Breakdown of coliform bacteria (adapted from Ely, 1998).
Fig. 3 (bottom left): Filtering a water sample for the Membrane Filtration Method.
Fig 4 (below): Checking for positive bacterial results using the MPN method (Photo by E.Ely).

Box 3: Common Indicator Bacteria.

Total Coliforms and Fecal Coliforms:
Total and fecal coliforms have been bacterial indicators since the 1920's. Total coliforms (T.C.) as a general group are *not* particularly useful in terms of estimating human health risks because they can also be found in soil and plants naturally. Fecal coliforms (F.C.), a subgroup of the total coliforms, are considered a more useful indicator of human health risk, even though a few non-fecal species exist, and are widely used to test recreational waterways and classify shellfish waters.

***E. coli* and Enterococci**
E. coli and enterococci are bacteria that occur primarily in the intestinal track of warm-blooded animals. The US Environmental Protection Agency (US EPA) and other researchers have found better correlations between swimming-associated gastrointestinal illness and *E. coli* and enterococci in fresh waters and enterococci in marine waters than with T.C. or F.C. (US EPA 2002).

How are bacteria monitored?

Since bacteria are everywhere, great care must be taken to avoid contamination when collecting water samples for analysis. Water sample containers must be sterile and non-toxic. Plastic bottles that have been autoclaved (an autoclave is like a giant pressure cooker where the objects to be sterilized are placed inside a chamber at high temperature and pressure) are most frequently used. Monitors open the sample container just before sampling, collect the sample without touching the inside of the container or lid with anything other than the desired water sample, and close the sample container immediately after sample collection. Water samples are stored on ice and should be analyzed within six hours of sample collection. In the laboratory, samples are most commonly processed with either Membrane Filtration (MF) or multiple tube fermentation methods. The multiple tube fermentation method yields the Most Probable Number (MPN) of bacteria and is commonly referred to as MPN.

The MF method is an US Environmental Protection Agency (US EPA)-approved, well-established method to assess bacterial concentrations. Water is pulled through a filter that traps all the bacteria from the sample (Figure 3). The filter is then placed in a petri dish with growth medium and incubated at a specific temperature. The resultant bacterial colonies that grow are visible to the human eye and easily counted. Varying the type of growth medium, temperature and incubation periods help laboratories to isolate particular species of bacteria. URI Watershed Watch (URIWW) uses MF methods to process samples for F.C., *E.coli* and enterococci.

The MPN method while more labor, time and space intensive, is the *only* method approved by the National Shellfish Sanitation Program (NSSP) for F.C. for classifying shellfish waters. Unlike with the MF method, the MPN method does not give a specific count of bacteria. Rather, it is based on a statistical probability that the sample contained a certain number of bacteria based on a series of test tube analyses with water and different liquid media that positively identify the presence of the indicator bacteria (Figure 4).

What are the water quality standards for bacteria?

Current RI regulations for bacteria uses T.C. and F.C. as the bacterial indicators. RI bacterial standards for recreational use are listed in Table 2. These listed standards are based on geometric means of multiple samples. Information on regulations dealing with smaller subsets of samples, public drinking waters or shellfish harvesting waters can be found at the RI DEM

Standards (continued)....

website (www.state.ri.us/dem/programs/benviron/water/index.htm). The US EPA criteria (US EPA, 1986, 2002) are based on *E. coli* and enterococci as the bacterial indicators (Table 2).

The federal Beach Act of 2000 mandates that states with coastal recreational waters adopt the US EPA criteria for designated beaches by 2004. However, most public health agencies and water quality monitors continue to use T.C. or F.C. as their indicator of choice, possibly because of their familiarity with analytical protocols and their extensive datasets for these indicators. Rhode Island is evaluating the US EPA indicators. In 2002, RI waterways were tested for enterococci to compile baseline data to compare to the F.C. currently mandated. URIWW can analyze water samples for F.C., *E. coli* and enterococci.

Table 2: Bacterial standards for recreational water uses by RI[1] and EPA

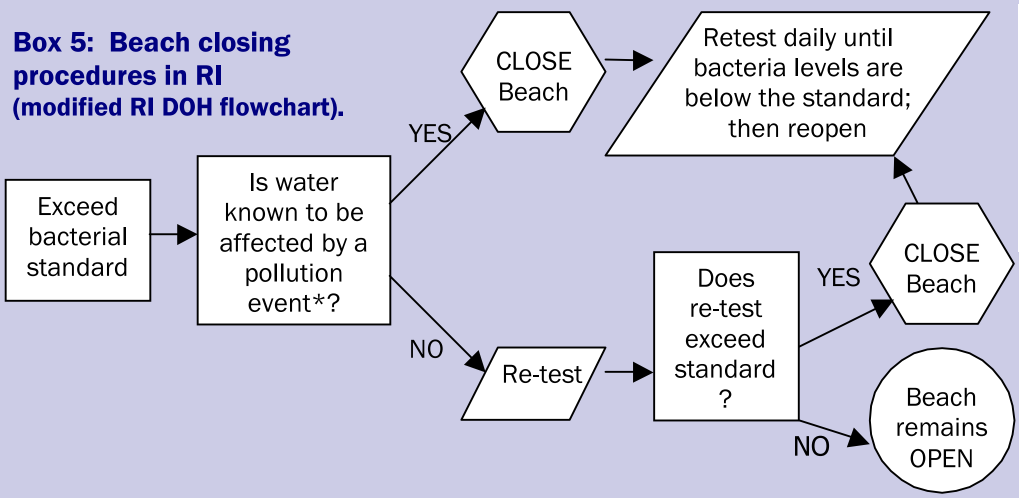
Water Type	Current RI Standard[2]		EPA Criteria[2,3]	
	——— count per 100 ml water sample ———			
Freshwater	Total coliform	1000	Enterococci	33
	Fecal coliform	200	*E.coli*	126
Saltwater	Total coliform	700	Enterococci	35
	Fecal coliform	50		

[1] *For more details on RI water classes and other bacterial standards please contact RI DEM:* www.state.ri.us/dem/programs/benviron/water/index.htm
[2] *Standard represents the geometric mean of multiple samples. For more details on RI bacterial standards, visit the above RI DEM website.*
[3] *From US EPA 1986 and 2002.*

Box 4: Who monitors bacteria in RI?

The RI Department of Health (DOH) monitors bacteria at 123 RI salt and freshwater beaches and posts subsequent beach closings (Box 5). The RI Department of Environmental Management (DEM) Shellfish program collects samples regularly in shellfish waters and conducts sanitary surveys. RI DEM, with help from URI Watershed Watch (URIWW) and other volunteer monitoring programs, monitors bacterial levels in additional water bodies. URIWW monitors waterways for indicator bacteria to augment the state's dataset and to point out potential areas of concern.

Box 5: Beach closing procedures in RI
(modified RI DOH flowchart).



** Pollution event may be a storm related CSO discharge.*

Corner illustration from the University of Wisconsin Cooperative Extension

What do bacterial standards mean?

Recreational contact with waters at or above standard levels of indicator bacteria does not mean you will definitely get sick; however, your chances of getting sick are increased. The US EPA criteria are based on health risk of contracting gastrointestinal illnesses (EPA, 1986). More research is needed on the risk of contracting upper respiratory and skin ailments from recreational water contact. RI's procedures for beach closings are outlined in Box 5.

As in any facet of water quality monitoring, the US EPA and other water quality professionals emphasize the importance of repeat analysis of waterbodies for indicator bacteria. Single samples may give the most recent information about the water quality and a basis on which to post beach closings or advisories for potential health risks. However, repeat sampling should be conducted to determine variability in indicator bacterial levels or if a chronic contamination problem exists.

What can YOU do to minimize the amount of bacteria entering waterways?

- Have your septic system inspected and pumped regularly.
- Properly dispose of pet waste.
- Don't feed waterfowl.
- Pump out boat waste at approved pumping stations.
- Support community plants to construct or upgrade sewage treatment plant and eliminate CSO's.

For further information on bacterial monitoring:

Ely, E. 1998. Bacteria Testing Part 1: Methods Primer. *The Volunteer Monitor*. Volume 10, No. 2.

Ely, E. 1998. Bacteria Testing Part 2: What Methods do Volunteer Groups Use? *The Volunteer Monitor*. Volume 10, No. 2.

Heufelder, G. 1997. Interpreting Fecal Coliform Data: Tracking Down the Right Sources. *The Volunteer Monitor.* Volume 9, No. 2.

Miceli, G.A. 1998. Bacterial Testing Q & A. *The Volunteer Monitor*. Volume 10, No. 2.

Ohrel Jr., R.L. and K.M. Register. 2001. *Volunteer Estuary Monitoring: A Methods Manual*. Second Edition. U.S. EPA. This manual is available on-line at: www.epa.gov/owow/estuaries/monitor/

Turin, D. and M. Liebman. 2002. Keeping Posted: Communicating Health Risks at Public Beaches. *Journal of Urban Technology* 9:45-69.

US EPA. 1986. *Ambient Water Quality Criteria for Bacteria-1986*. EPAA440/5-84-002.

US EPA. 2002. *Draft Implementation Guidance for Ambient Water Quality Criteria for Bacteria*. EPA-823-B-02-003.

RI DEM Office of Water Resources:
www.state.ri.us/dem/programs/benviron/water/index.htm

RI DOH's Bathing Beaches Program:
www.health.state.ri.us/environment/beaches

Issues of the *Volunteer Monitor* :
www.epa.gov/owow/volunteer/vm_index.html

What can be done about high bacteria levels?

Repeat measurements should be performed to determine if there is a long-term bacterial problem within a waterway and to identify any seasonal variation in bacterial levels. Waterbodies surrounded by summer communities can experience a surge in bacteria levels due to increased near-shore population and the resultant waste during the summer. In addition, warmer water may protect bacteria and promote growth. Conversely in the winter, bacteria tend to die off in cold waters. It may also be useful to sample for bacteria following storm events when CSOs may overflow and runoff may wash fecal waste from the land into water. These seasonal and storm event data often guide agencies in advisory protocols and may help to track bacterial sources.

If a chronic bacterial problem is diagnosed, sanitary shoreline surveys are usually conducted to determine the source of the bacteria. Such a survey involves an investigator looking throughout the watershed for evidence of failing septic systems, broken sewer pipes, and storm drains discharging water during dry weather. Additional observations of large congregations of waterfowl, wildlife, farm animals or pets are noted. Dyes or tracers may be used to determine the pathways of some potential pollutants. Once the source of the high levels of bacteria is determined, remediation action can be taken.

There have been many advances in bacterial source tracking using state-of-the-art microbiological techniques. Researchers compare the DNA of the bacteria in the water sample with DNA of known sources of fecal contamination. It is important to note that the US EPA no longer allows broad exemptions to their regulations for waterbodies that have identified the source of high bacteria loads as non-human (US EPA, 2002). More research needs be conducted on the potential of human health risk from the exposure to non-human fecal contamination. Therefore, the goal of this DNA fingerprinting is to help identify the source of the contamination for remediation purposes.

In some instances where bacterial contamination cannot be resolved, most likely due to economic or social restraints, EPA allows states to deem waterbodies suitable for only secondary recreational contact. Activities such as canoeing or motor boating are allowed because water contact and immersion seem unlikely.

To learn more about the URI Watershed Watch program or their bacterial monitoring, please contact:

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www.uri.edu/ce/wq/ww/html/ww.html

Kelly Addy, M.S., Elizabeth Herron, M.S., and Linda Green, M.S., are members of the Dept. of Natural Resources Science, College of the Environment and Life Sciences, University of Rhode Island. Contribution #3983 of the RI Agricultural Experiment Station, with support from RI Cooperative Extension, RI Department of Environmental Management, and RI Seagrant. Cooperative Extension in Rhode Island provides equal opportunities without regard to race, age, religion, color, national origin, sex or preference, creed or handicap.

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Department of Natural Resources Science • Cooperative Extension

March, 1997 **Fact Sheet No. 96-3**

Dissolved Oxygen and Temperature

Kelly Addy and Linda Green

Dissolved oxygen and temperature are two of the fundamental variables in lake and pond ecology. By measuring dissolved oxygen and temperature, scientists can gauge the overall condition of waterbodies. Aquatic organisms need dissolved oxygen for their survival. While water temperature also directly influences aquatic organisms, it regulates dissolved oxygen concentrations within a lake. Dissolved oxygen and temperature are also used to classify lakes. This fact sheet describes why lakes need dissolved oxygen, characterizes daily and seasonal dissolved oxygen concentrations, discusses how temperature affects lakes and dissolved oxygen concentrations, explains methods of classifying lakes using dissolved oxygen and temperature, and specifies how dissolved oxygen and temperature are measured.

Why Do Lakes Need Oxygen?

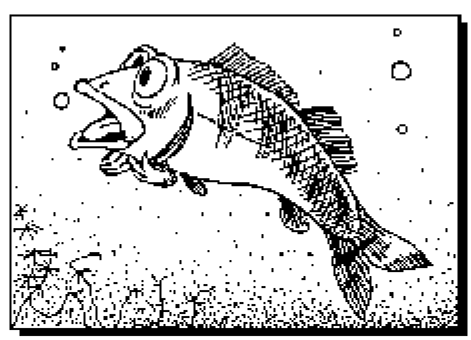
Dissolved oxygen (DO) is the amount of oxygen in solution. Without oxygen, lakes could not support life. <u>All</u> organisms in a lake, from fish to insects to microscopic zooplankton, need oxygen for **respiration**. During respiration, organisms consume oxygen and give off carbon dioxide while absorbing food molecules to obtain energy for growth and maintenance (Caduto 1990).

Since different organisms survive at different optimal oxygen levels, the amount of DO determines which organisms a lake can support. High oxygen contents are needed by some species, such as trout. Other species, including carp, catfish, water fleas, and zooplankton, have adapted to survive under low oxygen conditions. Some organisms can even live in environments where oxygen levels fluctuate significantly. Even plants respire at night when lack of sunlight prevents photosynthesis. Decomposition of dead plant and animal material also requires DO. In addition, DO concentration controls important chemical reactions in bottom sediments of lakes.

Oxygen is introduced into lakes in a variety of ways. Wind and wave action bring oxygen into waterbodies. Inflowing streams can also carry DO into lakes and ponds. In sunlight, aquatic plants and algae produce oxygen within aquatic ecosystems through photosynthesis. Turbulence and currents circulate DO throughout waterbodies.

Dissolved Oxygen Fluctuates Daily

The DO concentration within a waterbody can experience large daily fluctuations. Aquatic plants and algae produce oxygen as a by-product of photosynthesis by day. But at night, they consume oxygen through respiration. **Productive lakes**, lakes with large populations of aquatic plants or algae, are likely to experience the greatest DO fluctuations. In such lakes, the DO concentration is usually lowest just before sunrise, and highest in late afternoon (Caduto 1990). In some highly productive waterbodies, DO is consumed by night-time respiration faster than it is replaced by oxygen diffusing from the atmosphere. Consequently, fish and other lake organisms may die from lack of oxygen (Simpson 1991).



What Affects Dissolved Oxygen Levels?

The amount of oxygen dissolved in a waterbody is affected by salinity, altitude, groundwater inflow, and water temperature. Salinity is how much salt is in the water. Although it is generally not a concern in most freshwater lakes, salinity can greatly affect oxygen solubility in estuaries, brackish waters, bogs, and waterbodies

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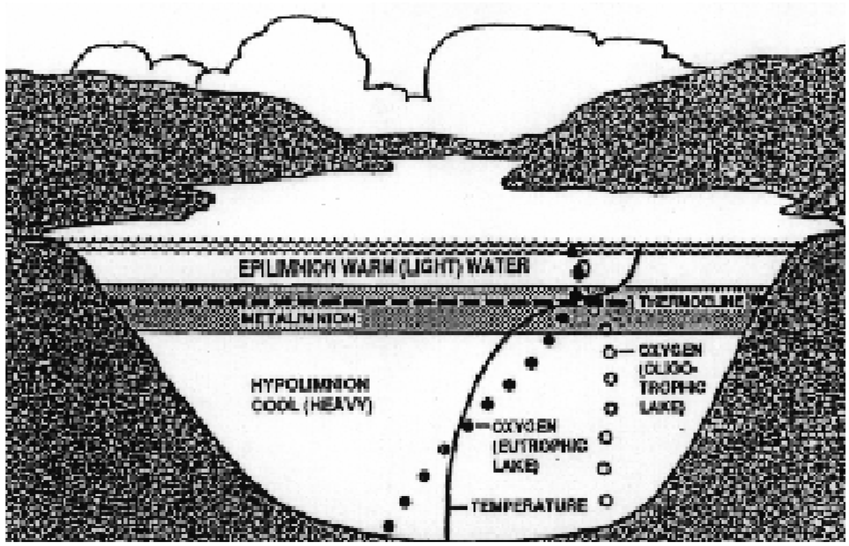

Figure 1: In summer, deep lakes may undergo thermal stratification. A stratified lake is separated into three thermal layers: the epilimnion (warm surface layer), the metalimnion (transition zone), and the hypolimnion (cool bottom layer). Adapted from *The Lake and Reservoir Restoration Guidance Manual*, EPA 440/5-88-002

in agricultural areas (Campbell and Wildberger 1992). Higher salinity reduces the amount of oxygen that can dissolve in the water. Due to lower atmospheric pressure, lakes in higher altitudes usually have lower levels of DO. Groundwater, which does not have contact with the atmosphere, typically has lower levels of DO than surface waters. When groundwater enters a lake, DO concentrations are initially reduced near the spring (Caduto 1990). However, groundwater is generally colder than surface waters (Caduto 1990). Colder water holds more oxygen than warmer water. By reducing lake water temperature, groundwater inputs increase the ability of a waterbody to hold oxygen in the long term. Of these variables, temperature most directly effects DO in lakes and ponds.

How Does Temperature Affect Lakes?

Many factors influence lake and pond water temperature, including seasonal air temperature, water depth, groundwater inflow, stream flow, mixing due to wind and water currents, and the amount of sunlight and shade. Water temperature plays an important role in aquatic ecosystems. It limits the migration, spawning, egg incubation, growth, and metabolism of aquatic organisms. As with DO, each aquatic organism has an optimal temperature range for its metabolism. Warmer water promotes higher metabolism and respiration rates.

Water temperature also affects lakes indirectly by influencing DO concentrations. Warm water holds less oxygen in solution than cold water. **Percent saturation** can be used to describe the DO status of a lake. Percent saturation is calculated as:

$$\frac{\text{DO concentration measured in the lake}}{\text{maximum DO concentration at that temperature}}$$

The bottom half of this equation indicates the importance of temperature in relation to DO capacity of water bodies.

Water temperature can vary within a lake, tremendously influencing lake ecology. **Thermal stratification**, or temperature layering, generally occurs in lakes and ponds greater than 5 meters (16.4 feet) in depth. Stratification occurs because water at different temperatures has different densities. The typical annual cycle of thermal stratification has several phases (Caduto 1990, Kortmann and Henry 1990, Simpson 1991). The first phase, **spring overturn**, occurs in early spring when rising air temperatures warm surface water and melt ice cover. The entire water column stabilizes to a uniform temperature as wind action mixes the water from top to bottom.

As air temperatures increase in spring and summer, lake water also warms up. Surface water warms more rapidly than deeper water. Because the warmer, surface water is lighter than the colder, deeper water, these lakes separate into three distinct thermal layers (Fig. 1). The surface layer, the **epilimnion**, is warmed by sunlight and mixed by wind action. The middle layer, the **metalimnion**, is a transition zone. The bottom layer, the **hypolimnion**, receives minimal sunlight and does not mix with the upper layers. As summer progresses, the depth of the epilimnion increases as the warm temperature water penetrates deeper into lakes.

During autumn, lower air temperatures cool the surface water. When the surface water (epilimnion) cools to the same temperature as the hypolimnion, stratification is broken, and all the water in the lake circulates freely in response to wind action. This process, similar to spring overturn, is called **fall overturn**.

In winter as air temperatures grow colder, lakes may stratify again. As opposed to summer stratification, during winter stratification, the upper zone is colder than the bottom waters. An ice layer may form on the surface of the lake preventing sunlight and oxygen from entering the water.

Thermal stratification causes extreme DO conditions within a waterbody. Since there is no replenishment of oxygen to the bottom waters, oxygen in these bottom waters may gradually become depleted by **decomposers** that live in, or on bottom sediments. Decomposers are bacteria, fungi, and other organisms that consume oxygen in order to break down **detritus**, dead plant and animal material. If DO concentration drops below 2 milligrams/liter, fish kills may occur. If oxygen levels are reduced below 1 milligram/liter, nutrients once bound to bottom sediments are released into the water through a chemical reaction (Simpson 1991). When stratification breaks down in autumn, algae are able to utilize these nutrients. As a result, an **algal bloom**, a tremendous growth of algae, may occur (See Natural Resources Facts, Fact Sheet No. 96-4, "Algae in Aquatic Ecosystems").

Classifying Lakes by Temperature

Water temperature is the basis for **thermal classification** of lakes and ponds (Hutchinson and Loffler 1956). Scientists often categorize lakes according to their thermal structure since it is believed that these lakes function similarly. Lakes with the typical thermal stratification scheme described previously would fall under the classification of **holomictic**. Water in holomictic lakes circulates freely throughout the entire water column sometime during the year. Holomictic lakes are further subclassified into monomictic, dimictic, and polymictic. As the name suggests, **monomictic** lakes stratify once per year, usually during summer. **Dimictic** lakes stratify twice during the year with summer and winter stratification and waters that freely circulate in the spring and fall. Most lakes in Rhode Island are monomictic or dimictic. **Polymictic** lakes stratify irregularly throughout the year possibly due to chemically induced density differences. If a lake is not holomictic, it may be **meromictic** which is stratified throughout the entire year often due to chemically induce density differences.

There are many shallow ponds in Rhode Island that do not experience thermal stratification during summer. In these shallow ponds, oxygen usually remains evenly distributed throughout the water column due to complete mixing of the water by wind and waves. However, lakes on hot, windless days may experience DO depletion, and shallow lakes may experience winter stratification when covered by ice.

Classifying Lakes by Dissolved Oxygen

DO concentration can also be used as a water quality criterion in order to classify lakes and ponds. The State of Rhode Island uses surface DO as one of the water quality criteria in its five category classification system of lakes and ponds (Table 1).

What is Trophic Status?

Another way to classify lakes is by trophic status. As lakes age, they gradually fill in with sediment, silt, and organic matter in the natural process of **eutrophication**. This process has been divided into sequential steps, each indicated by a different trophic state. Degree of DO depletion in bottom waters of deep lakes can be an indicator of its trophic state. **Oligotrophic** waters are clear with few aquatic plants and algae. Little oxygen is needed for decomposition, so oxygen remains fairly constant in the hypolimnion. **Eutrophic** waterbodies are cloudy and have an abundance of aquatic plants and algae. In eutrophic lakes, available oxygen will be rapidly consumed by decomposition processes and may become completely depleted, a condition called **anoxia**. Dissolved oxygen concentrations in deep lakes typically progress toward anoxic conditions throughout the summer. **Mesotrophic** waterbodies are in the middle of the trophic status spectrum. Decomposition processes will partially deplete available oxygen supply in mesotrophic lakes. For more information on trophic status, see Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging." Dissolved oxygen concentration in the hypolimnion commonly acts as an "early warning" of trophic state changes in a lake because oxygen depletion can occur before other indicators of trophic state change, such as increased algal productivity (Carlson and Simpson 1996).

Clas	Designated Uses	Dissolved Oxygen Criteria
A, B	Public water supply with appropriate treatment; agricultural uses; bathing; fish and wildlife habitat (Bacterial levels distinguish these two classes)	75% saturation 16 hours/day, but not < 5 mg/l at any time
C	boating; fish and wildlife habitat; industrial processes and cooling	> or = 5 mg/l at any time
D	migration of fish; good aesthetic value	> or = 2 mg/l at any time
E	nuisance conditions; certain industrial processes and cooling; power; navigation	< 2 mg/l at any time

Table 1: This five category classification system, based on surface dissolved oxygen concentrations, is used by the State to classify RI lakes and ponds.

How are Temperature and Dissolved Oxygen Measured?

Temperature is perhaps the easiest water quality measurement that can be made on a lake. All that is needed is an accurate thermometer and a little patience while the thermometer equilibrates to the water temperature. Care must be taken to ensure that the temperature reading does not change due to contact with air. It is best to read the thermometer while it is still in the water. Thermometers are commonly attached to water sampling devices. Electronic thermistor thermometers are also available.

The Winkler titration method is the standard method for measuring DO content and has been adapted for use in field kits. The kits are widely available, ranging in price from $30 - $50. The first step of the Winkler titration is to "fix" the water sample. Once a sample is fixed, the monitor need not be concerned about oxygen diffusing into or out of the sample. The sample is fixed by adding manganous sulfate solution, alkaline potassium iodide azide solution, and a strong acid. During these steps, for each molecule of oxygen in the water, a molecule of free iodide is released into the water. The remainder of the titration is concerned with the iodide concentration, which is equivalent to oxygen concentration but cannot diffuse out of the sample as readily as oxygen. The final stages of the procedure includes a drop by drop addition of sodium thiosulfate. When all of the iodide has reacted, the solution becomes clear. The concentration of DO is related to the amount of sodium thiosulfate added to the sample to produce a clear solution.

Dissolved oxygen samplers are used to collect samples. A principle feature if these samplers is that they have a mechanism to allow sample collection at specific depths, after first purging the sampler of air. Dissolved oxygen and temperature measurements from the lake surface to the bottom are compiled into a DO profile (Fig. 2). These measurements can be made using samplers, DO kits and thermometers. However, it is easier to make multiple DO measurements using a dissolved oxygen meter. Unfortunately, the cost of meters, ranging from hundreds to thousands of dollars, is often prohibitive for volunteer monitoring groups (Simpson 1991).

Analysis of DO and temperature measurements give an indication of a lake or pond's general condition. Volunteers in the URI Watershed Watch program make DO measurements every other week using DO samplers and field kits. These measurements are made at the deepest spot of lakes and ponds with a maximum depth greater than or equal to five meters (16.4 feet). Water samples from depths of one meter from the surface and one meter from the bottom are routinely collected and tested.

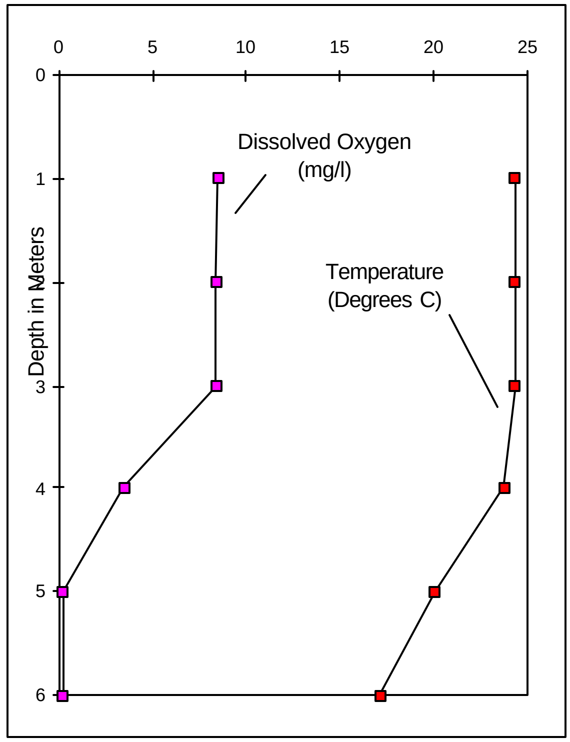

Figure 2:
Dissolved Oxygen and Temperature Profile
Dissolved oxygen and temperature can be taken at every meter in a lake's water column. As typical with most thermally stratified deep lakes, this profile shows that both temperature and dissolved oxygen concentrations decreased with depth.

For more information:

Caduto, M.J. 1990. *Pond and Brook: a guide to nature in freshwater environments*. Prentice-Hall, Inc. Englewood Cliffs, NJ.

Campbell, G. and S. Wildberger. 1992. *The Monitor's Handbook*. #1507. LaMotte Company, Chestertown, MD, pp. 30-32,36-39. Phone # 1-800-344-3100.

Carlson, R. and J. Simpson. 1996. *A Coordinator's Guide to Volunteer Lake Monitoring Methods*. NALMS.

Hutchinson, G.E. and J. Loffler. 1956. *The thermal classification of lakes*. Proc. Nat. Acad. Sci., Wash. 42: 84-86.

Kortmann, R.W. and D.D. Henry. 1990. *Mirrors on the Landscape: an introduction to lake management* Connecticut Insitute of Water Resources. University of Connecticu, Storrs, CT. Phone # (203) 742-0744.

Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging." 1996. Cooperative Extension. URI.

Natural Resources Facts, Fact Sheet No. 96-4, "Algae in Aquatic Ecosystems." 1996. Cooperative Extension, URI.

RI Water Quality Standards. 1981. *Water quality tegulations for water pollution control*. RI DEM.

Simpson, J.T. 1991. *Volunteer Lake Monitoring: A Methods Manual*. EPA 440/4-91-002. pp. 16-21,70-72. Phone # (202) 260-7018.

Natural Resources Facts

University of Rhode Island • College of Resource Development
Department of Natural Resources Science • Cooperative Extension

May, 1996 **Fact Sheet No. 96-2**

Phosphorus and Lake Aging

Kelly Addy and Linda Green

Since the early 20th century, scientists have attempted to classify lakes and ponds into categories in order to describe their condition and thus encourage appropriate lake management. Nutrient levels, especially phosphorus, are particularly important in influencing water quality conditions and hastening lake aging. To be useful, a classification system must recognize that lakes change in response to climatic fluctuations, watershed activities, and nutrient inputs. This fact sheet will describe the process of lake aging in northern temperate ecosystems, such as found in New England; explain trophic status classifications; discuss the role of phosphorus in aquatic ecology; introduce Carlson's Trophic State Index; and offer suggestions for limiting phosphorus inputs to lakes.

Eutrophication

Sediment, silt, and organic matter gradually fill lakes as they age. Nutrients flushed into a lake from its watershed stimulate the growth of aquatic plants and algae, creating a more productive waterbody. **Productivity** is a measure of the amount of plant and algal biomass in a lake or pond. A lake with larger quantities of aquatic plants and algae tends to be more productive than a lake with fewer aquatic plants and algae.

Eutrophication is the natural process that describes increasing lake productivity, nutrient enrichment, and general lake aging. Throughout the eutrophication process the physical, chemical, and biological composition of lakes change (Simpson 1991). In the early 20th century, **limnologists**, scientists who study lakes and freshwater ecosystems, devised a classification system to describe lakes as they proceed through the eutrophication process. Each **trophic state** indicates the lake's general level of water clarity, nutrient enrichment, and algal and aquatic plant abundance. However, trophic state should not be considered a discrete category, but rather part of a continuous spectrum.

Lakes in early stages of eutrophication are typically characterized by limited algal and plant productivity and low nutrient levels. These **oligotrophic** lakes have very clear water, are nutrient poor, and maintain high dissolved oxygen concentrations throughout the water column and throughout the summer (Fig. 1a) (Simpson 1991, Moore & Thornton 1988). Sand, stones, or other mineral deposits usually line the lake bottom. These lakes may support cold water fisheries, including trout. Organic matter accumulates slowly on the bottom of the lake basin.

Eutrophic lakes are at the opposite end of the trophic status spectrum (Fig. 1c). In these highly productive waterbodies, algal and plant growth is stimulated by high nutrient levels (Simpson 1991, Moore & Thornton 1988). In addition to abundant algae and plants, high sediment inputs contribute to decreased water clarity. Bottom sediments are commonly organic muck. These lakes may also experience severe algal blooms. Deep waters become depleted of dissolved oxygen during the summer (see Natural Resources Facts, Fact Sheet No. 96-3, "Dissolved Oxygen and Temperature"). These lakes typically cannot support cold water fisheries. Extremely eutrophic lakes of "pea-soup quality" are further subclassified as **hypereutrophic** lakes. Eventually, the lake basin may fill in so much with sediment and plants that it becomes a marsh, bog, or other wetland area.

Mesotrophic lakes are in the range between oligotrophic and eutrophic lakes (Fig. 1b). These lakes have intermediate nutrient availability with corresponding intermediate algal and plant growth and intermediate water clarity (Simpson 1991, Moore & Thornton 1988). Many Rhode Island lakes and ponds fall into this mesotrophic range.

Some lakes and ponds are naturally eutrophic. This occurs because trophic state is also a reflection of the lake's physical condition, such as size and shape of the lake, length of time water remains in the waterbody (**residence time**), geology, soils, and size of the watershed (Moore & Thornton

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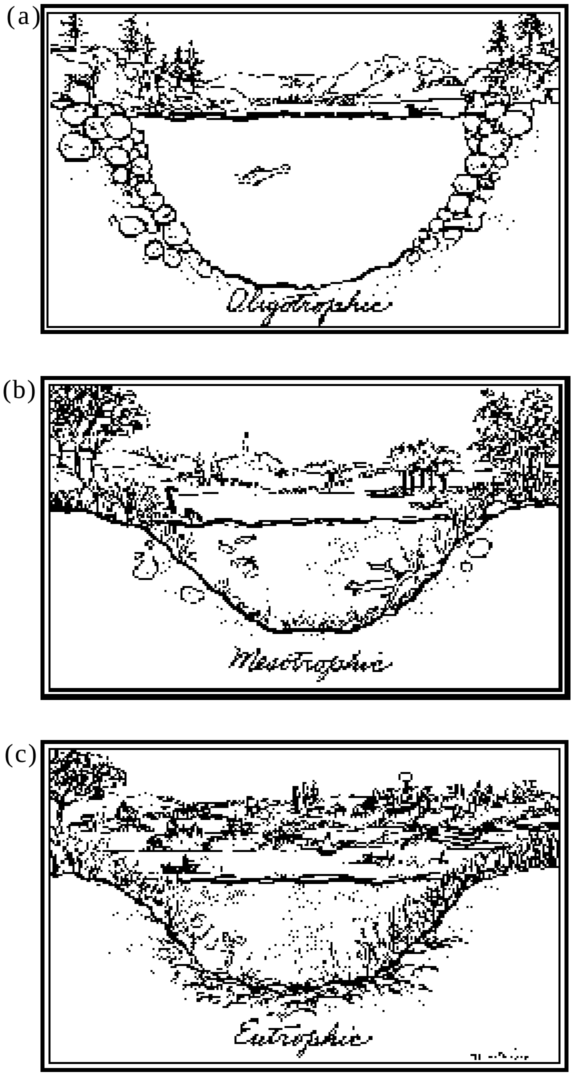


Fig. 1: As lakes age, they progress through the trophic status spectrum. **(a)** Oligotrophic lakes are very clear and nutrient poor. (b) Mesotrophic lakes have moderate clarity and nutrient levels. (c) Eutrophic lakes have high algal and plant growth stimulated by high nutrient levels. These lakes tend to have low clarity. (Illustrations by Carol Watkins for the lakes program book *Life on the Edge*.)

1988, Monson 1992). In addition, man-made reservoirs tend to become eutrophic more rapidly than natural lakes since there is a tendency for these reservoirs to revert back to their original state, typically a stream system or marsh (Moore & Thornton 1988, Monson 1992). Alternatively, some lakes may become more oligotrophic as they age.

Oligotrophic versus eutrophic lakes is not simply "good" versus "bad." Different trophic classes are more suitable for different lake activities (Monson 1992, NYDEC/FOLA 1990). For example, fishermen may desire a more eutrophic waterbody because abundant aquatic plants provide excellent food and cover for fish. However, swimmers and boaters prefer more oligotrophic lakes with few aquatic plants to tangle legs and boat motors. The goal of lake and fishery managers, biologists, and limnologists is not as simple as oligotrophy, mesotrophy, or eutrophy for all lakes, but to maintain a variety of lake types to satisfy a variety of people (Jones 1995).

Cultural Eutrophication

Natural eutrophication takes place over hundreds, even thousands of years. However, human activities have greatly accelerated the process of eutrophication. **Cultural eutrophication** can take place in as few as ten years. Runoff, especially from urban and agricultural areas, may carry industrial effluent, fertilizers, pesticides, and/or sediment. These by-products of human activity can be discharged into a waterbody and consequently accelerate eutrophication. Most human-oriented land uses, including logging, agriculture, and residential and commercial developments, contribute to cultural eutrophication.

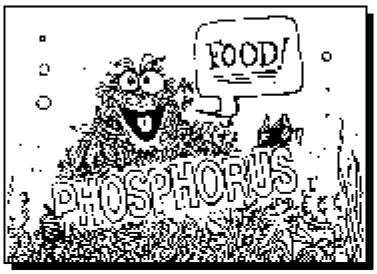
Many water quality monitoring programs, such as URI Watershed Watch, are geared toward monitoring cultural eutrophication in order to provide management information. The good news is that eutrophication is a reversible process, at least to some extent, with sufficient funding (Monson 1992). If problem sources can be identified and land use practices modified, eutrophic lakes can become mesotrophic or even oligotrophic once again.

Role of Phosphorus in Eutrophication

The phosphorus content of increased inputs to a lake frequently stimulate cultural eutrophication. Just as you need nutrients to grow and survive, aquatic plants and algae require certain nutrients for growth. Phosphorus is the **limiting nutrient** of most freshwater lakes, ponds, and streams. This means that the amount of phosphorus in a lake determines or limits aquatic plant and algal productivity. Without phosphorus, few aquatic plants and algae would be able to grow. However, even minute amounts of phosphorus, parts per billion levels, can cause tremendous increases in growth. The presence of phosphorus in lakes also enables plants to use other nutrients more efficiently, further increasing productivity.

As aquatic plant and algal biomass increases, there is a corresponding increase in the amount of biomass to be decomposed after these plants die. Decomposition by bacteria and fungi consumes dissolved oxygen. Plants and algae undergo night-time respiration which also consumes oxygen. If a lake's dissolved oxygen content decreases significantly, fish kills may occur or fish species composition may shift to those with lower oxygen needs. If lakes lose oxygen faster than it can be replaced by photosynthesis and atmospheric exchange, the lake may become **anoxic**, without oxygen. When anoxia occurs, a chemical reaction takes place in bottom sediments which releases sediment-bound phosphorus into the water column. This additional supply of phosphorus perpetuates the cycle of more and more plant and algal growth and decreased water clarity. Nuisance algal blooms may occur more and more frequently.

Typically, any form of land use development contributes more phosphorus to a waterbody than undeveloped forested land. Some significant contributors of phosphorus are: phosphate-based detergents, lawn and garden fertilizers, improperly sited and maintained septic systems, waterfowl, agricultural drainage, urban storm runoff, wastewater treatment effluent, animal wastes, road deicers, and atmospheric deposition.



Total phosphorus in northern lakes typically ranges from 14-17 ppb under natural conditions (Monson 1992). In 1976, the EPA recommended phosphorus limits of 50 ppb for streams where they enter a lake and 25 ppb within the lake to prevent or control eutrophication. Many monitoring programs measure total phosphorus concentrations to detect trends in water quality of lakes and ponds. URI Watershed Watch evaluates total phosphorus concentrations in its lakes and incoming streams on at least a tri-season basis, in May, July, and November.

In coastal ponds, nitrogen often replaces phosphorus as the limiting nutrient. In these waterbodies, total nitrogen concentrations can be measured as an indicator of eutrophication. Similar to freshwater responses to phosphorus, increased nitrogen loads to a coastal pond may shift the pond toward the eutrophic end of the trophic status spectrum.

Carlson's Trophic State Index

Water clarity is a widely accepted indicator of lake trophic status. The Secchi disk is the typical tool used to measure water clarity. The common assumption is that the deeper the Secchi disk is visible from the surface of the water, the clearer and more oligotrophic the lake (see Natural Resources Facts, Fact Sheet No. 96-1, "Measuring Water Clarity"). Using Secchi depth measurement data, Dr. Robert Carlson (1977) developed the **Carlson's Trophic State Index** (TSI). The index was developed to alleviate difficulties in communicating with the public using the traditional oligotrophic, mesotrophic, eutrophic classification system.

Since all lakes classified into the same trophic status are not identical, TSI quantitatively describes the trophic status of a lake within a numerical range of 0-110 (Table 1). Shallow Secchi depth measurements, indicative of low water clarity, correspond to higher TSI numbers. Higher TSI numbers indicate more eutrophic waterbodies. An increase by 10 on the TSI scale correlates to a doubling of lake algal biomass and halving of water clarity (Carlson 1977, Monson 1992).

Two other types of measurements, chlorophyll *a* concentration and total phosphorus concentration, may also be used to calculate TSI. These two measurements can be used to estimate lake productivity. Higher chlorophyll *a* and total phosphorus concentrations translate into higher TSI numbers. Natural log transformations of Secchi disk values, chlorophyll *a* concentrations, or total phosphorus concentrations are calculated to determine TSI values as such:

$$TSI=60-14.41 \ln \text{Secchi depth (meters)}$$

$$TSI=9.81 \ln \text{Chlorophyll } a \text{ (ppb)} + 30.6$$

$$TSI=14.42 \ln \text{Total Phosphorus (ppb)} +4.15$$

If one of these measurements is known, the other measurements can be predicted from these equations (Carlson 1977, Monson 1992). TSI was developed for use on lakes with few rooted aquatic plants and little non-algal cloudiness, therefore, TSI should only be used on lakes with these characteristics. Scientists associate ranges on the TSI scale with the classic oligotrophic, mesotrophic, and eutrophic trophic status classifications (Table 1).

As TSI suggests, total phosphorus, chlorophyll *a*, and water clarity are inter-related components. When additional phosphorus enters a waterbody, aquatic plant and algal growth is stimulated. Chlorophyll *a* concentrations, indicative of algal levels, subsequently increase (see Natural Resources Facts, Fact Sheet No. 96-4, "Algae in Aquatic Ecosystems"). With greater algal and plant growth, water clarity decreases, progressing the lake toward the eutrophic end of the trophic status scale.

Table 1: The Carlson's Trophic State Index describes the trophic state of lakes quantitatively. Scientists associate ranges of the TSI scale with the classic oligotrophic, mesotrophic, eutrophic classifications.

	TSI Value	Secchi Depth Measurement	Chlorophyll a	Total Phosphorus
Oligotrophi	<39	>4 m (>13 ft)	<2.6 ppb	<12 ppb
Mesotrophi	40-50	2-4 m (6.5-13 ft)	2.6-7.2 ppb	12-24 ppb
Eutrophic	50-110	<2 m (6.5 ft)	>7.2 ppb	>24 ppb

What *YOU* Can Do to Limit Phosphorus Inputs to Lakes (for more information see *Diet for a Small Lake...*)

* Maintain your septic system.
  —Have it inspected every year or two
  —Have it pumped regularly, usually every 1-3 years.
  —Old systems should be replaced to meet new standards.
  —Avoid using garbage disposals which add excessive solids and grease to septic systems.
* Don't pour chemicals (pesticides, disinfectants, acids, medicines, paint thinner, etc.) down the drain. These chemicals harm septic system bacteria and can contaminate groundwater.
* Manage lawn and garden fertilizer use. (Most fertilizers contain phosphorus)
  —Have your soil tested to determine exactly how much fertilizer your lawn needs.
  —Use a mulching lawnmower; grass clippings recycle nutrients to your lawn.
  —Avoid fertilizer application just before a heavy rain.
  —Use slow-release fertilizers.
  —Do not rinse spilled fertilizer off paved surfaces, but sweep excess up or onto lawn.
  —Use native and adapted plants with lower fertilizer needs.
  —Store fertilizer in a location with a concrete floor.
* Plant a buffer strip of plants or shrubs (a greenbelt) between your lawn and lake; this zone will absorb excess phosphorus before it can enter the lake. (Fig. 2)
* Rake and remove leaves from lakeside property in the fall (leaves contain phosphorus). Do <u>not</u> dispose of them in the lake.
* Use no-phosphate detergents (check labels). Most liquid laundry detergents do not contain phosphorus, but some powdered laundry detergents and dishwasher detergents still do.
* Support maintaining wetlands in their natural states. Wetland areas help to filter nutrients and many other pollutants.
* Do NOT feed the waterfowl. Waterfowl, along with all animals and humans, excrete phosphorus in their wastes. Feeding waterfowl encourages them to congregate in your lake.
* Direct roof downspouts to broad, grassy areas so the rain water has a chance to seep into the ground rather than run off, carrying sediments and nutrients with it.
* Conserve water. For example, use low-flow shower heads or place a brick in the toilet tank.
* Correct soil erosion problems immediately! Steep, sloping banks and exposed soil should be seeded or terraced to prevent erosion.
* Join your local lake, pond, or watershed association.

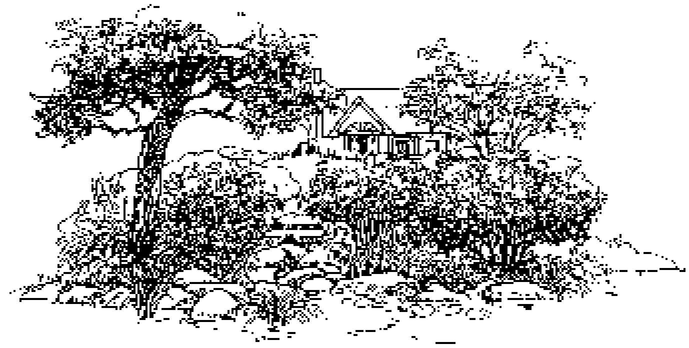


Fig. 2: A buffer zone of plants, shrubs, or trees between your property and your lake will help prevent phosphorus from entering the lake. This is just one way that **you** can help prevent cultural eutrophication in your lake.

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For more information:

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Jones, B. 1995. "Is oligotrophy bad?" *Lakeline*.15:12-13.

Monson, B.A. 1992. A Primer on Limnology. Second Edition. Water Resources Research Center. College of Natural Resources, University of Minnesota, Rm. 302, 1518 Cleveland Ave., N., St. Paul, MN 55108. Phone # (612) 624-9282.

Moore, L. and K. Thornton, ed. 1988. The Lake and Reservoir Restoration Guidance Manual. First Edition. EPA 440/5-88-002, US EPA, Office of Wetlands, Oceans, and Watersheds, Assessment & Watershed Protection Division, WH-553, 401 M Street, S.W., Washington, DC 20460. Phone # (904) 462-2554.

Natural Resources Facts, Fact Sheet No. 96-1, "Measuring Water Clarity," 1996. Cooperative Extension, URI.

Natural Resources Facts, Fact Sheet No. 96-3, "Dissolved Oxygen," 1996. Cooperative Extension, URI.

Natural Resources Facts, Fact Sheet No. 96-4, "Algae in Aquatic Ecosystems," 1996. Cooperative Extension, URI.

New York State Dept. of Environmental Conservation and the Federation of Lake Associations. *Diet for a Small Lake: A New Yorker's Guide to Lake Management*. 1990. Phone # (305) 655-4700.

Simpson, J.T. 1991. Volunteer Lake Monitoring: A Methods Manual. EPA 440/4-91-002. Phone # (202) 260-7018.

For more information on URI Watershed Watch:
Contact URI Watershed Watch at (401) 874-2905
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pH and Alkalinity

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UNIVERSITY OF Rhode Island

Kelly Addy, Linda Green, and Elizabeth Herron

URIWW-3, July 2004

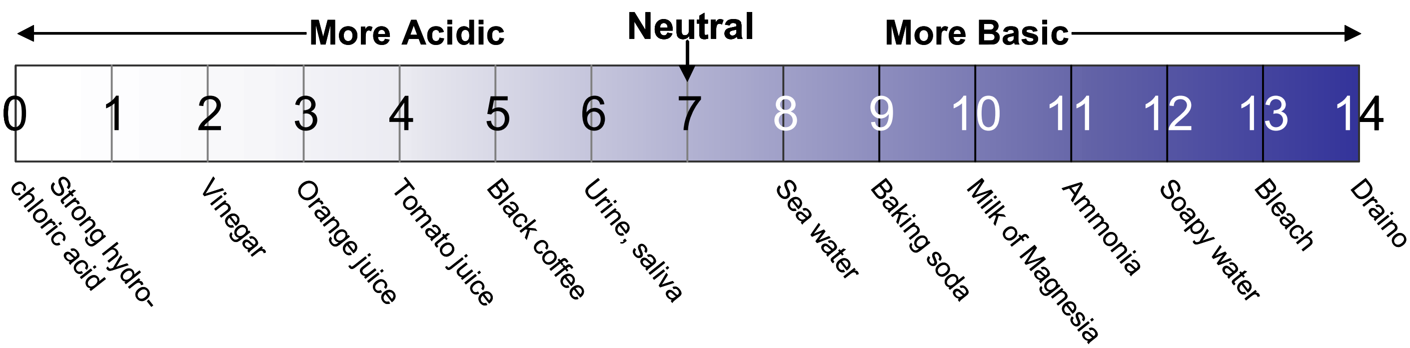


Figure 1: pH scale and examples of solutions at particular pH's.

What is pH?

pH, one of the most common analyses in soil and water testing, is the standard measure of how acidic or alkaline a solution is. It is measured on a scale from 0 – 14 (Figure 1). pH of 7 is neutral, pH less than 7 is acidic, and pH greater than 7 is basic. The closer pH gets to 1, the more acidic. The closer pH gets to 14, the more basic. Examples of the pH of some common items are listed in Figure 1. Acids and bases are two extremes like hot and cold. Mixing acids and bases together can even out the extreme effects much like mixing hot and cold water to even out water temperature.

The pH scale is logarithmic, which means that a unit *decrease* in pH equals a ten fold *increase* in acidity. For instance, tomato juice (pH 4) is ten times more acidic than black coffee (pH 5).

Hydrogen (H^+) ions (ions are atoms or groups of atoms with negative or positive charge) control acidity levels. pH measures the concentration of H^+ and hydroxide (OH^-) ions which make up water (H_2O):

$$H^+ + OH^- = H_2O$$

When the two ions are in equal concentration, the water is neutral, whereas the water is acidic if $H^+ > OH^-$ and basic when $OH^- > H^+$.

Why is pH important?

Aquatic organisms need the pH of their water body to be within a certain range for optimal growth and survival. Although each organism has an ideal pH, most aquatic organisms prefer pH of 6.5 – 8.0. Outside of this range, organisms become physiologically stressed. Reproduction can be impacted by out-of-range pH, and organisms may even die if the pH gets too far from their optimal range.

In addition to directly affecting the physiology of aquatic organisms, additional aspects of lake dynamics are influenced by pH. Low pH can cause the release of toxic elements and compounds from sediments into the water where they may be taken up by aquatic animals or plants. Changes in pH also influence the availability of plant nutrients, such as phosphate, ammonia, iron and trace metals, in the water.

Water quality standards for pH?

The U.S. E.P.A. considers lakes with pH less than 5 "acidified." Aquatic organisms may be stressed in such acidified lakes. The RI Department of Environmental Management (DEM) has a fresh water pH criteria of 6.5 – 9.0 or as what occurs naturally. The sea water pH criteria is 6.5 – 8.5, but not more than 0.2 units outside the normally occurring range.

What affects pH?

Some variables that influence pH include:

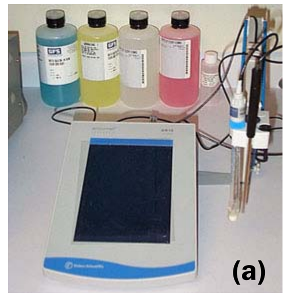
Bedrock (the solid rock underlying surface soils) of a location. Since we are in a glaciated area, our water generally has a lower pH (more acidic). However, areas with limestone bedrock, including areas in Lincoln, RI, generally have higher pH waters (more basic).

Acid rain (atmospheric deposition). The presence of acid rain can lower the pH in lakes making them more acidic. For more information on acid rain, please visit the U.S. Environmental Protection Agency (U.S. E.P.A.) web site at http://epa.gov/airmarkets/acidrain/

Water use. Municipal water suppliers often raise the pH of drinking water to prevent corrosion of pipes, often to pH 9.

Wastewater discharge. Materials added to water during domestic water use, such as detergents and soap-based products are often alkaline which can increase the pH of water (more basic). Wastewater treatment facilities are required to adjust the pH of wastewater that is outside of acceptable limits (U.S. E.P.A. range 5 – 10) prior to discharge into streams or estuaries. See the Narragansett Bay Commission's "P2 Facts: pH Control" http://www.narrabay.com/publications.asp for more information.

Carbon dioxide (CO_2). pH fluctuates throughout the day in a lake or pond largely in response to changing CO_2 levels. CO_2 dissolved in water forms a mild acid. When CO_2 is high, pH falls (more acidic). In the morning, CO_2 levels are high as a result of respiration that occurred in the pond overnight. As sun rises, plants and algae begin photosynthesis thereby consuming CO_2 and causing the pH to rise (more basic) as the day progresses. Algae blooms can significantly increase this effect.



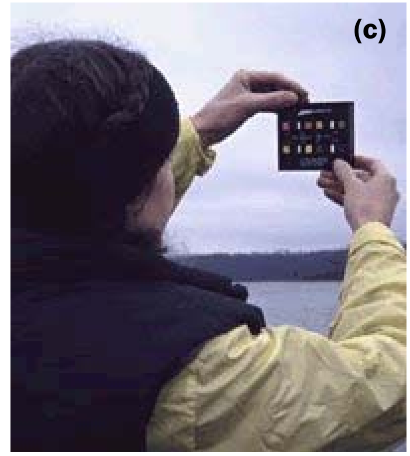


Fig. 2. (a) Laboratory quality pH meter and electrode with multiple reagents. (b) pH "pocket pal" for field monitoring of pH. (c) Volunteer uses a color comparator to assess pH (photo from EPA).

How is pH measured?

pH can be measured electronically or visually. There are three main methods routinely used in water quality monitoring (Figure 2):

1. Laboratory quality pH meter and electrode
2. pH "pocket pals" and multi-parameter probes
3. Color comparators / pH strips

The pH meter and electrode, generally restricted to laboratory analysis of field collected samples, offers the highest degree of accuracy and precision. This pH meter-electrode measures the electric potential which is a function of the H^+ activity in water samples. Calibration is completed with two buffer solutions. URI Watershed Watch (URIWW) uses a pH meter and electrode to measure the pH of lake and stream samples.

The latter two methods can be easily used in the field. pH "pocket pals" and multi-parameter probes are electronic hand-held testers that are dipped directly into the water body and provide digital read out of pH. Pocket pals are typically calibrated with one buffer.

With color comparators, you add a reagent to the water sample that colors the sample for a visual comparison. pH strips are dipped into water samples and then change color according to the pH. The intensity of the color is proportional to the pH in the sample, and colors are compared on a chart.

What is the pH of RI inland waterways?

pH in RI lakes and ponds generally increases as you move from south to north. In 2003, the pH range of inland waterways monitored by URIWW was 5.1 - 8.2 Visit the Monitoring Data page (parameter data) http://www.uri.edu/ce/wq/ww/html/ww_data.htm of the URIWW web site for site specific pH data.

pH of Drinking Water

The pH of drinking water generally is not a health concern. However, acidic water can leach metals from plumbing systems which can cause health problems. For more information on pH in private drinking water wells, please refer to “Healthy Drinking Waters for Rhode Islanders: pH-Acidity of Private Drinking Water Wells,” http://www.uri.edu/ce/wq/has/html/has_wellfacts.html a publication of the RI Department of Health and URI Cooperative Extension.

Table 1: U.S. E.P.A. Classification[1] of lakes and ponds based on alkalinity as measured in concentration of calcium carbonate ($CaCO_3$).

U.S. E.P.A. category	Concentration of $CaCO_3$ (mg/L)
Acidified	< 1 and pH < 5
Critical	< 2
Endangered	2 – 5
Highly Sensitive	5 – 10
Sensitive	10 – 20
Not Sensitive	> 20

What is Alkalinity?

Alkalinity is the buffering capacity of a water body. It measures the ability of water bodies to neutralize acids and bases thereby maintaining a fairly stable pH. Water that is a good buffer contains compounds, such as bicarbonates, carbonates, and hydroxides, which combine with H^+ ions from the water thereby raising the pH (more basic) of the water. Without this buffering capacity, any acid added to a lake would immediately change its pH.

Why is alkalinity important?

Aquatic organisms benefit from a stable pH value in their optimal range. To maintain a fairly constant pH in a water body, a higher alkalinity is preferable. High alkalinity means that the water body has the ability to neutralize acidic pollution from rainfall or basic inputs from wastewater. A well buffered lake also means that daily fluctuations of CO_2 concentrations (discussed above) result in only minor changes in pH throughout the course of a day.

What affects alkalinity?

Alkalinity comes from rocks and soils, salts, certain plant activities, and certain industrial wastewater discharges (detergents and soap-based products are alkaline). If an area’s geology contains large quantities of calcium carbonate ($CaCO_3$, limestone), water bodies tend to be more alkaline. Granite bedrock (much of RI) is deficient in alkaline materials to buffer acidic inputs. Addition of lime as a soil amendment to decrease acidity in home lawns can runoff into surface waters and increase alkalinity.

What are the water quality standards for alkalinity?

The U.S. E.P.A. developed 6 categories to describe alkalinity status of lakes and ponds (Table 1). As the concentration of $CaCO_3$ increases, the alkalinity increases and the risk of acidification decreases.

[1]Godfrey, P.J., M.D. Mattson, M.-F. Walk, P.A. Kerr, O.T. Zajicek, and A. Ruby III. 1996. *The Massachusetts Acid Rain Monitoring Project: Ten Years of Monitoring Massachusetts Lakes and Streams with Volunteers.* Publication No. 171. University of Massachusetts Water Resources Research Center.

How is alkalinity measured?

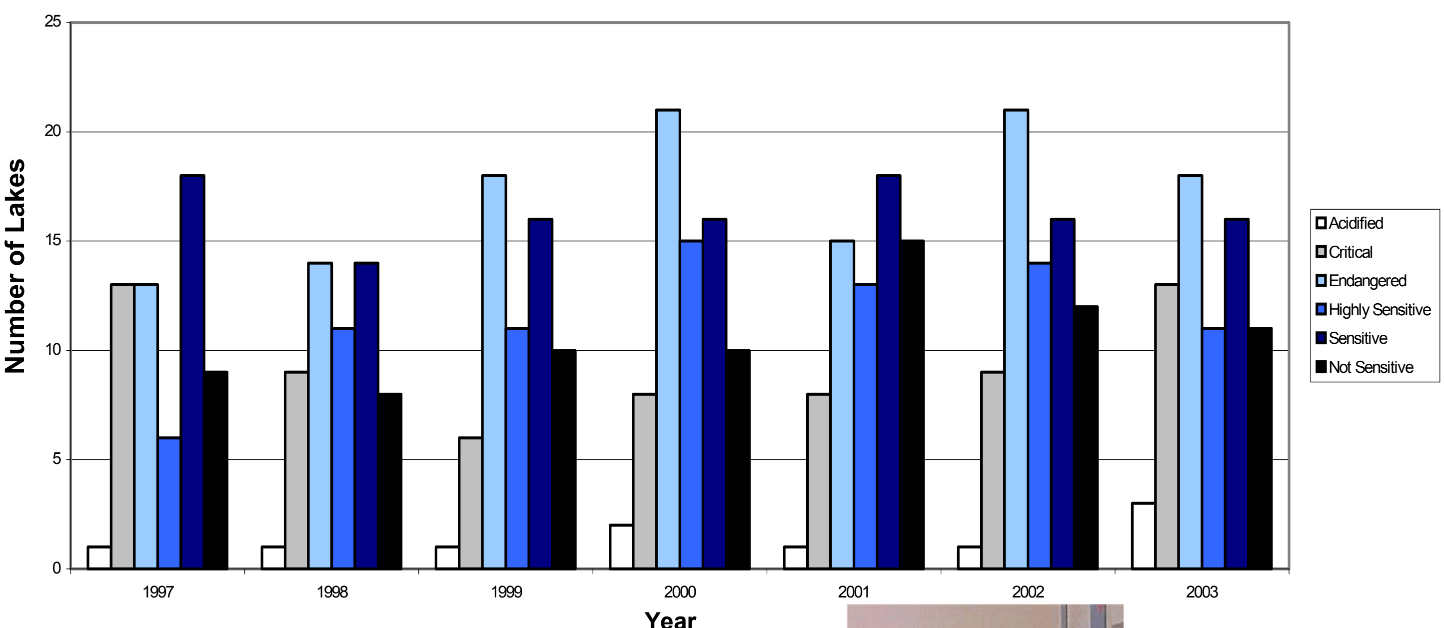
Alkalinity, reported as mg/L $CaCO_3$, is measured as the amount of acid (e.g., sulfuric acid) needed to bring the water sample to a pH of 4.2. At this pH, all the alkaline compounds of the sample are "used up." Laboratory technicians use a buret (a graduated glass tube with a small opening at its base and stopcock for delivering measured quantities of liquid) to dispense the sulfuric acid drop by drop into the water sample while continuously monitoring the change in pH with a pH meter and electrode or pH "pocket pal." Field kits are also available, but they typically target a higher range of alkalinity than in RI waterways.

What is the alkalinity of RI lakes and ponds?

Through its water collections, URIWW monitors alkalinity three times per year (Figures 3, 4). Only a few ponds have appeared in the acidified category. This appears to be a natural condition for these lakes. The more oligotrophic (low nutrient) lakes tend to have lower alkalinity while eutrophic (high nutrient) lakes tend to have higher alkalinity. In general, most locations stay within the same category from year to year. Visit the Monitoring Data page (parameter data) http://www.uri.edu/ce/wq/ww/html/ww_data.htm of the URIWW web site for more information.

Figure 3. Number of RI lakes monitored by URI Watershed Watch in each US E.P.A. category of alkalinity (Table 1) from 1997 to 2003.

RI Lakes: Alkalinity Distribution



To learn more about the URI Watershed Watch program or pH monitoring, please contact:
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Elizabeth Herron, Program Coordinator
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Figure 4. Measuring alkalinity in the URIWW laboratory.

Kelly Addy, M.S., Linda Green, M.S., and Elizabeth Herron, M.A. are members of the Dept. of Natural Resources Science, College of the Environment and Life Sciences, University of Rhode Island. Contribution #4059 of the RI Agricultural Experiment Station, with support from RI Cooperative Extension, RI Department of Environmental Management, and RI Seagrant.

Natural Resources Facts

University of Rhode Island • College of Resource Development
Department of Natural Resources Science • Cooperative Extension

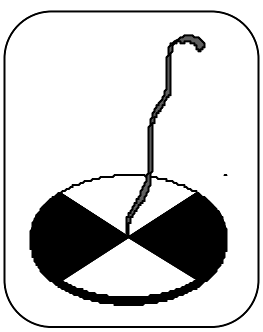
February, 1996 **Fact Sheet No.96-1**

MEASURING WATER CLARITY

Linda Green, Kelly Addy, and Natalie Sanbe

Whether or not we realize it, many of us judge the health of a waterbody by its clarity. Generally speaking, if we can see the bottom of a lake or some distance into its depths- it's clean; if we cannot see the bottom in even shallow water - it's dirty. However, the issue of water clarity is more than an aesthetic issue of "clean" or "dirty." Can water clarity objectively be used to measure water quality?

Although scientists have devised various complicated means to measure water clarity, a simple method was developed by Angelo Secchi, an astrophysicist and scientific advisor to the Pope. On April 20, 1865, Secchi lowered the first Secchi disk from the papal steam yacht and tested its utility in a series of experiments. The Secchi disk has become a universally accepted tool for monitoring water clarity on a long term basis. This fact sheet will describe water clarity, how to measure clarity using the Secchi disk, what these measurements indicate, and how to make a Secchi disk.



Water Clarity and the Secchi Disk

Water clarity is primarily affected by algae and suspended sediments. Algae are naturally occurring microscopic plant life found in most waterbodies. Algae, mostly growing as single cells or in colonies, are part of a healthy lake ecosystem. Their photosynthetic processes are a source of oxygen for the lake and its organisms. Also, many lake organisms depend on algae as a basic food source (Simpson 1991). However, too much algae growth, stimulated by nutrient inputs from watershed activities, can dramatically reduce water clarity and adversely affect a lake's ecological balance.

Sediment carried by streams and storm runoff also decreases water clarity. Additional factors reducing water clarity include "tea" colored staining from naturally occurring tannic acids and resuspension of bottom sediments in shallow waters due to wind, waves, and/or boating activities.

The measurement of water clarity using a Secchi disk is known as Secchi Depth Transparency. This is a direct measure of how deep sunlight penetrates the water column and an indirect measure of the amount of suspended material (algae, microscopic organisms, and sediment) in the water column. The standard Secchi disk consists of a weighted steel or heavy plastic disk, 20 centimeters (8 in.) in diameter either all white or with alternating black and white quadrants, attached to a calibrated line. Although 20 centimeters is the standard size of a Secchi disk for lake monitoring, they can range in size from 2.5 centimeters to 1.2 meters and are used to monitor all sizes of waterbodies from backyard ponds to oceans. The underlying assumption of Secchi disk methodology is that the greater the Secchi depth measurement, the clearer the water. Secchi depth measurements range from several centimeters (a few inches) for very turbid (cloudy) waters to more than 40 meters (130 ft.) for the clearest waterbodies. However, most measurements range from 2-10 meters (about 6-33 ft.).

How to Use a Secchi Disk

The basic procedure for using a Secchi disk is quite simple. The disk is slowly lowered into the water until it disappears from view. Then the calibrated line is marked at the water surface, often with a clothespin. Next, the disk is lowered several more feet and then slowly raised until it is again sighted. A second clothespin is used to mark this point. The Secchi depth measurement is determined by averaging the depths of disk disappearance and reappearance.

Sunlight variability can significantly influence Secchi depth measurements. To compensate for influences of the sun's angle in the sky, measurements should be taken between 10 am and 2 pm. Although usual prescription glasses should be worn, avoid wearing sunglasses.

To compensate for the sun's glare on the water, two variations have been developed for making Secchi depth measurements. The first variation is to take measurements on the shady side of the boat. On the shady side, there is less

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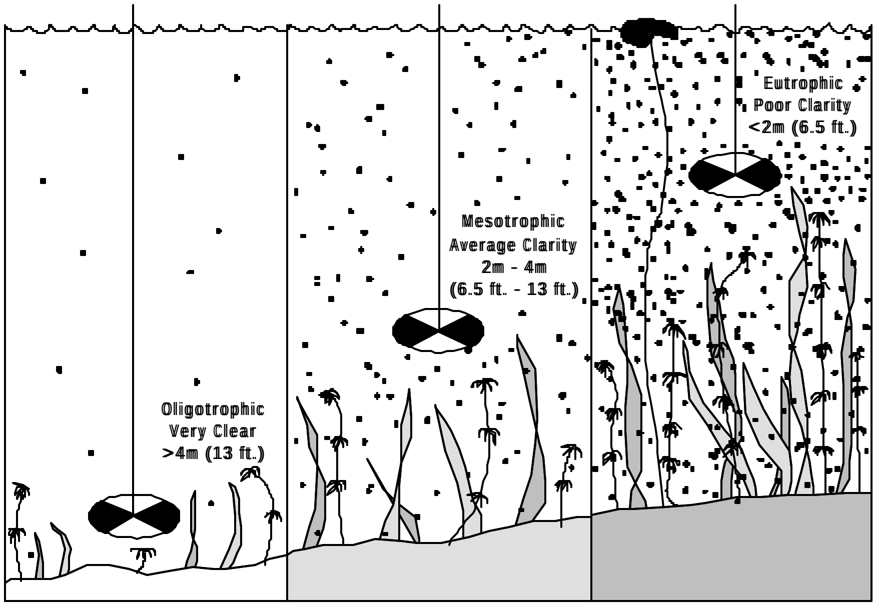


Figure 1:
Water Clarity and Secchi Depth Measurements
This diagram illustrates how Secchi depth measurements are influenced by algae, suspended sediments, and aquatic plants. Ranges of Secchi depth measurements are correlated with the appropriate trophic status.

sunlight variability to affect Secchi depth measurements. The second method, recommended by URI Watershed Watch and thought to be more accurate, is to observe the disk through a view tube on the sunny side of the boat. A view tube is a 2-3 foot long section of PVC pipe, preferably with a black interior and a handle attached near one end. The tube is held vertically, with four inches submerged in water. The view tube reduces interference from surface glare. Some view tubes come with a plexiglass "window" at one end to prevent water from entering the tube, like a scuba mask. Whichever variation you choose or your monitoring program recommends, you must follow it every time you take measurements to ensure consistency and reliability.

As with any water monitoring procedure, opportunities for human error exist when taking Secchi depth measurements. The visual acuity of the monitor can influence the depth to which the disk remains visible from the surface (Pseisendorfer 1986). To reduce chances of human error, some steps can be taken. For example, replicate measurements help to obtain more reliable results. URI Watershed Watch recommends that monitors lower their Secchi disks into the water at least two times, recording all disappearance and reappearance depths. In addition, if two people monitor the lake, the second person should take duplicate measurements at the same location. Under most circumstances, measurements that vary by even as much as 4 to 6 inches are still considered acceptable and useful data. All measurements are averaged for that particular day.

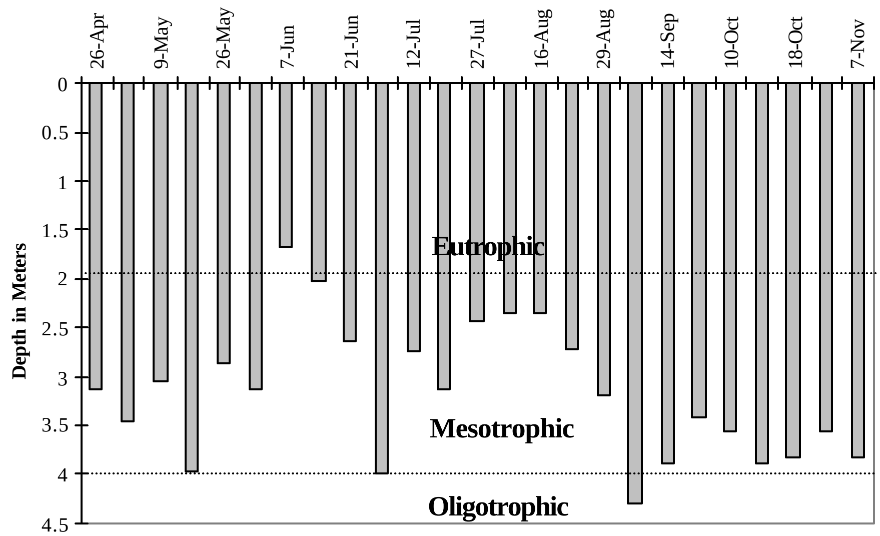
In order to compare water clarity measurements of a lake, it is critical for monitors to take Secchi depth measurements at the same location on the lake every time they monitor. This practice ensures consistency. The usual strategy is to take measurements at the deepest spot on the lake. However, monitors may wish to explore water clarity at other areas of concern. No matter how many locations are monitored, it is critical that replicate measurements be taken at the same location and recorded separately.

To obtain the best Secchi depth results, lakes or ponds ideally should be 50% deeper than the average Secchi depth measurement so that the disk is contrasted against the water and not bottom sediments (Carlson 1995). The biggest problem occurs when the disk is consistently visible at the bottom of the monitoring location. Under such circumstances, Secchi depth measurements are likely to misrepresent actual conditions. However, Secchi depth measurements on such lakes can be useful in identifying general trends in water clarity. For example, if the disk is seen at the bottom less frequently over the years, decreasing water clarity is evident. On the other hand, improving water clarity is indicated by seeing the disk at the bottom when it has not been seen there in the past. Despite these complications, studies have found no significant differences in precision between Secchi depth measurements and more sophisticated techniques (Carlson 1995).

What Do Secchi Depth Measurements Indicate?

Using Secchi depth measurements, lakes and ponds can be grouped into **trophic status** categories, which indicate their general level of clarity, nutrient enrichment, and algae and/or plant abundance (Fig.1). **Oligotrophic** waterbodies are what many people consider most desirable and pristine. Such lakes are clear to great depths and have low nutrient, or productivity levels. At the other end of the spectrum are **eutrophic** lakes, having low water clarity and high productivity levels. **Mesotrophic** lakes occupy the middle range. Lakes naturally progress from oligotrophic to eutrophic status over thousands of years in the process of **eutrophication**. However, human activities have greatly accelerated this process. This is known as **cultural eu-**

Figure 2:
1992 Secchi Depth Measurements Georgiaville Pond, Smithfield
The top of this graph can be viewed as the surface of the water, and the length of the bars represent how deep the Secchi disk was visible into its depths on that particular day. As can be seen in this graph, Secchi depth measurements can vary from week to week throughout a season. In 1992, Secchi depth measurements on Georgiaville Pond had a range of 2.6 meters.



trophication. (Simpson 1991, Wetzel 1993) For more information on trophic status, refer to Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging."

Secchi depth measurements can indicate the amount of algae in a waterbody. The more algae, the less clear the water and consequently, the less visible the Secchi disk. As algal populations fluctuate, individual Secchi depth measurements can also vary throughout a season (Fig. 2). This variation can be up to 2 meters. For example, in the summer, when the sunlight penetrating the lake is more intense, a summer algal bloom may occur if there is an abundance of available phosphorus. If a lake were characterized by only a single Secchi depth measurement during the summer, this could misrepresent the lake's water quality. The frequency and length of algal blooms are highly indicative of water quality problems and can be characterized by weekly Secchi depth measurements. Individual rainfall events may also carry a surge of nutrients to a waterbody. It is useful to examine seasonal variability in Secchi depth measurements on a particular waterbody to detect water clarity trends. Over 200 volunteers in the URI Watershed Watch program monitor more than 70 sites taking over 2000 Secchi depth measurements each year between April and November to detect any such water quality trends.

Secchi depth measurements can also indicate the turbidity (cloudiness) of a waterbody. Turbidity is caused by particulates, such as suspended sediments or algae, scattering the light passing through the water. The more suspended solids in a lake, the lower its clarity. Development greatly increases the amount of suspended sediments entering a waterbody in storm runoff. As vegetation is cleared, soil erosion increases while impervious surfaces increase the rate and volume of polluted runoff entering streams and lakes. Consequently, short term changes in Secchi depth measurements are often observed until the new influx of sediments settles to the lake bottom.

To distinguish between suspended sediment and algal influences on water clarity, chlorophyll *a* and total phosphorus concentrations are frequently measured in conjunction with Secchi depth measurements. Chlorophyll *a* is a green pigment found in algae and all other photosynthyzing plants. Chlorophyll *a* is considered a good indicator of the amount of algae in a waterbody (see Natural Resources Facts, Fact Sheet No. 96-4, "Algae..."). The amount of phosphorus controls the amount of algae and plant growth possible in freshwater lakes and ponds (see Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging"). Measuring total phosphorus can also predict the amount of chlorophyll *a*. Using these indicators, along with Secchi depth measurements, can lead to a more accurate portrait of the water quality of a given lake or pond.

Secchi depth measurements can also vary naturally over the long-term, responding to precipitation patterns. Depending on specific lake hydrology, droughts can reduce or improve water clarity. For example, if a lake has a low flushing rate (it takes a long time for water in a lake to be completely replaced by incoming water), drought may cause nutrients to accumulate in a lake resulting in high productivity and low water clarity for that particular year. On the other hand, droughts also suppress the transport of contaminants to a waterbody, which may improve water clarity. The timing of precipitation also influences Secchi depth measurements. For instance, if a heavy storm occurs in the early spring when many land surfaces remain uncovered, more runoff is generated. This additional runoff carries an early load of sediments and nutrients to a pond thereby decreasing water clarity. This illustrates the importance of long-term monitoring of lakes and ponds. If a lake is monitored for only one year, "normal" patterns and potential variation may be overlooked. Long-term monitoring of lakes is frequently supported by volunteer efforts, as with URI Watershed Watch. As of 1995, URI Watershed Watch volunteers have collected up to 8 years of data on some of its Rhode Island monitoring locations.

How to Make a Secchi Disk (Fig. 3)

From a plastics supply house (look under "Plastics" in your local Yellow Pages) order a 20-cm diameter, 1/4" thick, white opaque acrylic disk with a 3/8" hole drilled through the center. (The disk will have paper masking on both sides.) If possible, the plastic surface should have a non-glossy or "flat" finish.

1) On one side of the acrylic disk, divide masking paper into quarters and peel paper from opposing quadrants. A straight edge will be needed for use as a knife guide.

2) Rough up the exposed quadrants with fine sandpaper and warm the disk under bright lights. While the disk is still warm, paint exposed quadrants with flat black enamel paint. After applying a second coat of paint, peel off the remaining masking paper. The paint will take about two weeks to fully harden. If the disk is used during the hardening period, it must be treated gently to prevent chipping.

3) To weight the disk, use 1/4", 5" x 5" steel plate. The steel plate should be painted to avoid rusting. You could also use a series of washers, or even a brick or a sand-filled plastic bottle as a weight.

4) Assemble the disk with a 5/16" diameter stainless steel eyebolt. Use flat washers between the disk and nut, and between the steel plate and locking washer. Use one 5/16" nut at the top of the eyebolt, and another to bolt the steel plate onto the disk.

5) Attach the nylon line to the disk through the eye of the bolt. Measuring from the face of the disk, mark remaining length of line at meter and half meter (or foot and half foot) increments using an indelible pen or wire ties. The line should be calibrated periodically to ensure accurate measurements.

Pre-made Secchi disks and other water quality apparatus can be purchased from a number of commercial sources. Three sources are:

LaMotte Chemical Co. (1-800-344-3100)
Laurence Enterprises (1-207-276-5746)
Hach Chemical Co. (1-800-227-4224)

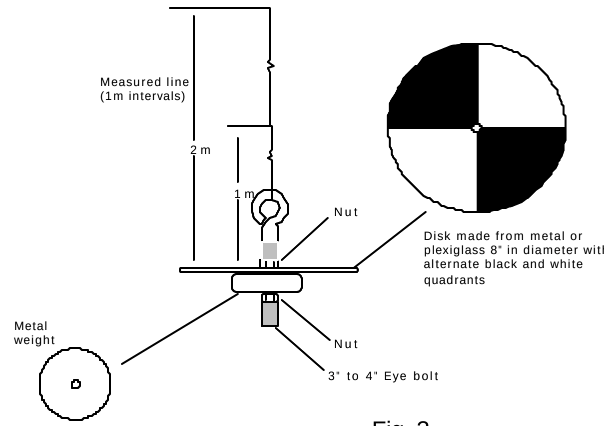


Fig. 3
Making a Secchi Disk

Special thanks to URI Natural Resources Professor Dr. Arthur Gold, and URI Research Associates Lorraine Joubert and Alyson McCann for commenting on and reviewing this fact sheet.

For more information:

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography. 22:361-369.

Carlson, R.E. 1995. The Secchi Disk and the Volunteer Monitor. *Lakeline*. 15:28-29,35-37.

Diet for a Small Lake: A New Yorker's Guide to Lake Management. 1990. Prepared by the New York State Department of Environmental Conservation and the Federation of Lake Associations, Inc. (315)655-4700.

The Lake and Reservoir Restoration Guidance Manual. Second Edition. 1990. EPA 440/5-88-002. (904)462-2554.

Manson, Bruce A. 1992. *A Primer on Limnology, Second Edition*. Water Resources Research Center, College of Natural Resources, University of Minnesota, Room 302, 1518 Cleveland Avenue, N., St. Paul, MN 55108. (612)624-9282.

Natural Resources Facts, Fact Sheet No. 96-2, "Phosphorus and Lake Aging," 1996. Cooperative Extension, URI.

Natural Resources Facts, Fact Sheet No. 96-4, "Algae in Aquatic Ecosystems," 1996. Cooperative Extension, URI.

Pseisendorfer, R.W. 1986. Secchi disk science: Visual optics of natural waters. *Limnology and Oceanography*. 31(5):909-926.

Simpson. 1991. Volunteer Lake Monitoring: A Methods Manual. EPA 440/4-91-002. (202)260-7018.

Wetzel, R. G. 1983. Limnology. Saunders College Publishing, Philadelphia, PA. pp. 48-68.

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A GLOSSARY OF TERMS

Anoxia:
A condition of no oxygen in the water. Often occurs near the bottom of eutrophic, stratified lakes in summer; under ice in winter.

Algae:
Green plants that occur as microscopic forms suspended in water (phytoplankton), and as unicellular or filamentous forms attached to rocks and other substrates. About 15,000 species of freshwater algae are known.

Algal bloom:
A sudden increase in the abundance of suspended (planktonic) algae, especially at or near the water surface, producing a green scum or a "pea-soup" appearance.

Biomass:
The weight of biological matter.

Brown water lakes:
Lakes which are naturally rich in humic (organic) materials derived from plants, giving the water a "tea" color; "stained" lakes.

Chlorophyll:
Green pigments found in plants which are necessary for photosynthesis; may be utilized as an indicator of algal population levels.

Cultural eutrophication:
The accelerated enrichment of waters due to the activities of man, such that they support a higher amount of plant and animal matter than they would naturally.

Ecosystem:
A community of plants and animals interacting within the physical and chemical environment.

Eutrophic:
A term used to describe very productive or enriched lakes. These lakes tend to exhibit some or all of the following characteristics: an abundance of rooted plants; turbidity due to high algal populations; loss of oxygen in bottom waters during the summer months; rapid accumulation of soft bottom sediments; and abundant fish, which may include stunted and/or rough species in the most fertile lakes.

Eutrophication:
A gradual increase in the productivity of a lake ecosystem due to enrichment with plant nutrients, leading to changes in the biological community as well as physical and chemical changes. This is a natural process, but can be greatly accelerated by man (see cultural eutrophication).

Flushing rate:
The number of times that the total volume of water in a lake is replaced in a year by inflowing streams, groundwater, precipitation, and overland runoff.

Epilimnion:

Uppermost, warmest, well mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.

Habitat:

The place where a plant or animal lives, which has all of the conditions necessary to support its life and reproduction.

Hypolimnion:

Lower cooler layer of a lake during summertime thermal stratification.

Mesotrophic:

A term used to describe lakes which are moderately productive. These lakes tend to exhibit some or all of the following characteristics: moderate growth of rooted plants and algae; some loss of oxygen from bottom waters during the summer months; some sediment accumulation; relatively good fish production of cool or warm water species, such as walleye, perch, bass, pike, and panfish. The majority of lakes are placed in this category.

Metalimnion:

The layer of rapidly changing temperature and density which separates the hypolimnion from the epilimnion.

Nitrogen:

An element necessary for the growth of the aquatic plants; may be found in several forms, including nitrates, nitrites, and ammonia.

Nutrient:

Any of a group of elements necessary for growth. Although over 15 elements have been identified as necessary for growth of aquatic plants, most are readily available in natural waters. Supplies of phosphorus or nitrogen may be depleted, however, thus limiting plant growth in surface waters.

Oligotrophic:

A term used to describe a relatively unproductive lake or one poorly supplied with plant nutrients. Because of low biological production, these lakes tend one poorly supplied with plant nutrients. Because of low biological production, these lakes tend to exhibit some or all of the following characteristics: clear waters; limited growth of algae or rooted plants; bottom waters well supplied with oxygen throughout the year; low rate of sediment accumulation; low fish production, but often of desirable species, such as trout, walleye, or perch.

Plankton:

The community of micro-organisms, consisting of plants (phytoplankton) and animals (zooplankton) inhabiting open-water regions of lakes and rivers.

Phosphorus:

An element necessary for the growth of aquatic plants. It is naturally present in low concentrations, and lack of phosphorus often limits plant growth. Thus the addition of phosphorus can affect water quality by increasing the production of algae and rooted plants.

Producers:
: Green plants that manufacture their own food through photosynthesis.

Productivity:
: The amount or mass of living things which can be supported by an ecosystem (e.g., a lake) over a specified period of time.

Photosynthesis:
: Conversion of water and carbon dioxide in the presence of sunlight to carbohydrates.

Residence Time:
: The average time required to completely renew a lake's water volume is called the hydraulic residence time. Short residence times are ten days or less, long residence times are greater than one hundred days.

Secchi disk:
: A simple device widely used to measure the transparency or clarity of water, consisting of a metal or plastic plate, usually 8" in diameter, painted black and white, on a calibrated line.

Secchi depth transparency:
: The depth at which a Secchi disc disappears from view when lowered into the water. A measure of water clarity.

Sediment:
: Solid material including both soil particles and organic matter which is suspended in the water and gradually deposited in the bottom of a lake.

Standard deviation:
: A statistical term used to describe the amount of variation in a set of data; 68% of all measurements are expected to fall within plus- or minus-one standard deviation from the mean (average).

Thermocline:
: A horizontal plane of water across the lake through the point of greatest temperature change. It is within the metalminion.

Trophic state:
: The level of productivity in a lake, or degree of eutrophication; generally described as eutrophic (very productive).

Trophic State Index (TSI):
: A numerical scale used to classify lakes according to productivity (the amount of living material supported by the lake). The TSI value (0-100) is calculated directly from Secchi depth transparency, phosphorus concentration, or chlorophyll a concentration.

Turbid:
: Cloudy, not clear.

Watershed:
: A drainage area or basin; all land and water areas which drain or flow toward a central collector, such as a stream or a lake, at a lower elevation.

UNITS OF MEASUREMENT

Acre (ac):

An area equal to 43,560 square feet, approximately 0.4 hectare. Acres / 2.5 = hectares.

Centimeter (cm):

One one-hundredth of a meter, equivalent approximately to two-fifths of an inch.

Concentration.:

The ratio of the amount of one substance in another substance. For example, in seawater, the amount of chloride dissolved in water is approximately 18,000 milligrams per liter.

Gram (g):

One one-thousandth of a kilogram.

Hectare (ha):

Metric measurement for area equivalent to 10,000 square meters or approximately 2.5 acres. Hectares X 2.5 = Acres.

Kilogram (kg):

The base unit for mass in the metric system; 1000 grams or approximately 2.2 pounds; a 150-pound person weights 68 kilograms.

Liter (L):

A unit of metric measurement for volume; roughly equivalent to 1 quart or 0.25 gallon.

Mass:

In common usage, mass is used synonymously with weight; the common English unit for mass is pounds (lb), whereas in the metric system the unit is the kilogram (kg).

Meter (m):

The basic metric unit for length; equivalent approximately to 3.25 feet; a 5-foot person is approximately 1.5 meters tall.

Metric System:

An international system of scientific measurements based on multiples of 10. The base unit for length is the meter and for mass, the kilogram.

Microgram (ug):

One one-millionth of a gram, one one-thousandth of a milligram.

Micrograms per liter (ug/L):

An expression for concentration, usually in reference to a liquid, roughly equivalent to parts per billion.

Milligram (mg):

One one-thousandth of a gram.

Milligrams per liter (mg/L):
An expression for concentration, usually in reference to a liquid, roughly equivalent to parts per million; for example, 1 gallon of food coloring placed in 1 million gallons of water would result in a concentration of food coloring in the water of 1 mg/L.

Millimeter (mm):
One one-thousandth of a meter; a dime is approximately 1 millimeter thick; 1 inch equals approximately 25 millimeters.

Parts per billion (ppb):
An expression for concentration (see Micrograms per Liter); one one-thousandth of a part per million; the quantity of one substance contained in 1 billion units of another substance when both are measured by identical terms. The magnitude of this quantity can be related to 8 ounces of a substance dissolved in 4 inches of water ponded on a 1 square mile area; roughly equivalent in scale to 2 seconds in a lifetime.

Parts per million (ppm):
An expression for concentration (see Milligrams per Liter); the quantity of one substance contained in 1 million units of another substance when both are measured by identical terms. For solutions (substances dissolved in liquids), it is the number of units of the substance contained in 1 million units of solution.

Meters to Feet Conversion

0.025 meters = 1 inch
0.1 meters = 4 inches
0.5 meters = 1.6 feet
1.0 meters = 3.3 feet
1.5 meters = 4.9 feet
2.0 meters = 6.6 feet
2.5 meters = 8.2 feet
3.0 meters = 9.8 feet
4.0 meters = 13.1 feet
5.0 meters = 16.4 feet
6.0 meters = 19.7 feet
7.0 meters = 23.0 feet
8.0 meters = 26.2 feet
9.0 meters = 29.5 feet
10.0 meters = 32.8 feet

Temperature Conversions

-18 C = 0 F
-12 C = 10 F
0 C = 32 F water freezes
10 C = 50 F
15 C = 59 F
20 C = 68 F
25 C = 77 F
30 C = 86 F
35 C = 95 F
40 C = 104 F
50 C = 122 F
100 C = 212 F water boils

F = [9/5 (C)] + 32
C = 5/9 (F - 32)