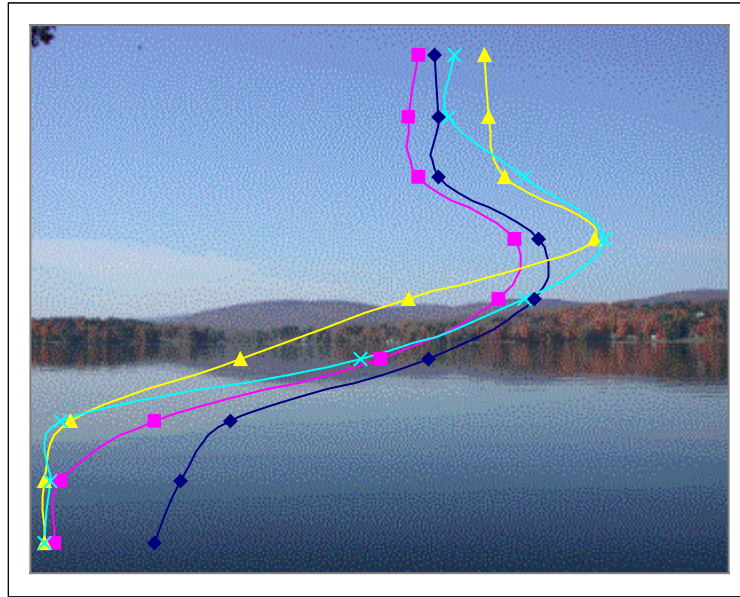


Massachusetts Water Watch Partnership

Data Interpretation Manual



For Volunteer Monitors

Jerry Schoen
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Data Interpretation

Jerry Schoen and Marie-Françoise Walk
Massachusetts Water Watch Partnership

Introduction

Turning data into useful information is one step in your monitoring program. Your program should begin with a clear study design, which describes the rationale and methods for your program. A part of the study design process is identifying the people who you expect to use your data, how you expect them to use it, and what specific questions you're trying to answer about the lake. If you've geared your monitoring to the needs of identified data users and conducted your monitoring to answer specific questions about your lake, you'll find that this data interpretation step is not as difficult as it might seem. For help on study designs, see the VEMN Merrimack River Watershed study design workbook (<http://www.umass.edu/tei/mwwp/acrobat/studydesign.PDF>). This was written for rivers, but covers many applicable concepts. Or consult "The Massachusetts Volunteer Monitor's Guidebook to Quality Assurance Project Plans" (see References).

The "data to information" process involves several steps:

Data entry and reconciliation

Get your raw data into a computer so that you can store it and retrieve it for analysis.

This is a two-part operation:

- a) Entry. Your data set should be entered into a computer data management application. The sooner you do this after data collection /analysis, the less chance of errors, lost data, and other catastrophes.
- b) Validation. The entered data must be checked against the field and lab sheets to assure that it has been entered correctly.

Assembling the information you'll need

You'll want to have your own data, along with supplementary data such as weather records or prior studies that others have conducted, at hand when you begin the interpretation process.

Summary

The data is put into a form that allows you to view it as a whole and examine relationships. You will want to generate simple statistics, tables, and graphs.

Making sense of it all

This is the part that requires your thinking cap. It involves asking a series of questions about your data that relate to your study question(s). Your answers to these questions are organized as findings and conclusions. Based on these, you may develop recommendations for action or for further study.

Presenting Your Results

Present your findings, conclusions, and recommendations in a form that best tells the story of your lake. This story can be told in text and selected tables and graphs that are organized into an oral presentation and/or a written report. Your presentation or report should be geared to the audience you are trying to reach.

Data entry, summarization, and presentation are discussed at length in other guidance documents. We will focus primarily on assembling the information and figuring out what it means – with some advice on generating graphs and statistics. Throughout the document, we will use examples from Lake Onota to illustrate our points.

Assemble the Information You'll Need

Consider these dictionary definitions of three important concepts:

Data: “Factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation.”

Information: “The communication or reception of knowledge or intelligence... knowledge obtained from investigation, study or instruction.”

Interpret: “To explain or tell the meaning of... to present in understandable terms.”

One way of thinking of it is that your sampling activities yield measurements. You then interpret these measurements in order to gain understanding of a water body’s health and how to preserve it. In most cases, the measurements alone (the numbers on your field or lab sheets) do not provide all the information needed to move from data to “knowledge.” For instance, suppose you are looking at a total phosphorus measurement of 60 parts per billion. What does that tell you? Is this an unhealthy level? Is it this high all the time, or only under certain conditions? Has the level been increasing over time? What causes these levels? To answer these types of questions, you may need access to a variety of supplementary information such as:

- Data from other studies – that you or others have conducted.
- Weather and other data that helps identify factors that influenced your results.
- Water quality standards and/or related scientific literature.
- Quality control data, to help you know if the reading is right in the first place.

The remainder of this section deals with how to determine what supplementary information is needed, where to find it and how to use it.

I - Start with the study design

A *study design* – or its more formal cousin the *Quality Assurance Project Plan* (QAPP)– is a good place to start. A study design states the issue(s) to be addressed, specifies information needed to address the issues, and then describes how that information will be obtained. The information need is often but not always expressed in the form of one or more questions.

Example study questions:

- Have nutrient levels in the lake changed since 1989 (i.e. when first monitored)?
- Are there any significant trends in macrophyte population density and/or in species composition since 1989?
- Do nutrient levels contribute to changes in macrophyte density?

Alternatively, the information need may be stated as a study objective rather than a question. Example study objectives:

- To identify trends in macrophyte population density and species composition in the lake.
- To determine if nutrients are changing and if they are contributing to accelerated macrophyte growth.

Once the study design has clearly articulated the information need, it will lay out a plan that shows how all the elements of a monitoring program (parameters, training, site selection, equipment, etc.) connect to help you meet that objective. When you interpret the results of your study, you trace your steps back to the project objectives. You check all the details of your work to see how well it answers your study questions. It is helpful to reacquaint yourself with the study design as you undertake this process, beginning with a review of the study objectives. All too often, groups will try to use their data set to answer every question under the sun, resulting in a lot more work for themselves and possibly generating some questionable conclusions not supported by the data. For instance, the above-mentioned study appears to limit its focus to macrophytes and nutrients. If you were trying to use the data from this study to make recommendations on the lake's fisheries, exercise caution. Work back from your proposed conclusions and recommendations. Check to see that the parameters sampled, sampling locations, and other study design elements would support your statements about the fisheries.

In addition to study objectives, there are other components of a study design that can point you in the right direction when assembling information that will be used as you interpret your data.

1. Project background

The study design should contain background information on watershed characteristics and history that have contributed to or documented the need for your study. This makes the study design an information repository that can reduce your research workload. In the total phosphorus example above, a study design might cite scientific literature that categorizes lake trophic states; previous studies that revealed high nutrient loads and land use data for the watershed; nonpoint pollution runoff models that estimate the amount of

nutrients coming off each category of land use; or even anecdotal reports of residents' complaints about how "Weeds are worse than they used to be." The study design will either summarize the information sufficiently for your data interpretation purposes, or tell you where to find the original documents, so you can have these referenced materials on hand when you and your Technical Advisory Committee (TAC) begin the interpretation process.

2. Project description - parameters, methods, sampling sites and schedules

As you will see below, we recommend an interpretation approach that subjects your data set to a series of questions that transform *results* into *findings* and *conclusions*, all of which are the basis for *recommendations* you make. Use the parameters and methods sections of your study design to convert the general questions we suggest below into specific ones. For instance, you might answer a general question such as "Does weather appear to influence your result?" by first obtaining weather data for your sampling dates (and 2 - 3 days beforehand), then comparing total phosphorus levels on the days with antecedent rain vs. levels on "dry" dates. If you were sampling multiple tributaries, you may be able to obtain a more sophisticated comparison by also comparing sampling sites that are downstream from forest land with those draining developed lands. For this comparison, the necessary information includes location of sampling sites, upstream land use, meteorological records, and the total phosphorus (TP) values themselves.

3. Quality control (QC)

A study design describes data quality objectives and activities that will be done to attain them – such as taking replicate samples and/or running lab QC samples. Use this part of your study design to translate generic "Does the data satisfy quality control objectives?" questions into "Were TP replicates within 20% of one another?" and so on.

If you haven't developed a study design, we recommend that at the very least you document the information objectives for your study, so you can frame your data interpretation questions appropriately. In the long run, it is wise to draft a full study design, as planning a study and interpreting the resulting data are activities that inform each other in a cyclical way. The information used to determine information needs and project objectives also helps you better understand the data you collect. And one product of most studies is a set of recommendations on additional monitoring needs. This becomes the basis for a new or updated study design. Consult Appendix 4 for sources of advice on how to develop a study design.

II - Review previous studies

When preparing to interpret data, be sure to check out any previous studies that have been conducted on your water body. These will indicate what is already known about its health, giving you something to compare your results with. Like a study design, they are also likely to be full of supplementary information that can help you make sense of your own data. However, gleaning useful information from these studies can be quite a chore. Before you can actually begin comparing the data from different studies, you have to answer all sorts of questions about consistency in selection of parameters, methods, sample sites and dates, weather conditions, etc. The case study below demonstrates how

one group tackled this opportunity / challenge.

Case Study: Onota Lake

Onota Lake is a 630 acre lake in the Housatonic Watershed. Residential development around the lake and immediate watershed is sparse; residences are found mostly along the northeastern and western shores. Numerous summer camps have been converted to year-round occupancy. The lake has a long history of recreational use, including swimming, boating, water skiing, fishing (winter and summer). Nuisance aquatic vegetation appears to have impaired water uses for decades. Drawdowns and mechanical harvesting were used to control the vegetation at different times. Several studies have been done since the 1980's. These include:

International Technology Corporation Diagnostic Feasibility Study (ITC).

(Study conducted 1986-1987, report completed 1991).

Purpose: "To identify factors which have contributed to the degradation of the lake, quantify their impact, and recommend strategies for their mitigation."

Fugro Incorporated Drawdown Study (Fugro). 1996.

Fugro was hired by Pittsfield to "review past documentation of lake features, define existing conditions, evaluate possible drawdown impacts, and provide a basis for management decisions, with emphasis on the efficacy of drawdown."

American Lake and Wetlands Services Incorporated Post Drawdown Study (ALWS). 1997.

The purpose of the study was to evaluate the drawdown done in 1996 and to provide data to help evaluate the on-going weed harvesting program.

Aquatic Control Technology (ACT). 1999 - 2000.

Purpose: To measure impacts of a Sonar treatment done by ACT in 1999.

Lake Onota Preservation Association monitoring program (LOPA). 1996 – 2001.

Purpose: To "provide consistent, long term database on water quality, macrophyte growth and reptile and amphibian status to support lake management decision-making."

Lake Onota Preservation Association (LOPA) used information from the previous studies to guide the design of their own program. After 5 years of sampling, they wished to review their own data along with the other studies to develop lake management recommendations and to see what changes if any should be made in their monitoring program.

We'll use this case study to demonstrate many concepts in this book – concentrating primarily on the macrophyte and water quality data.

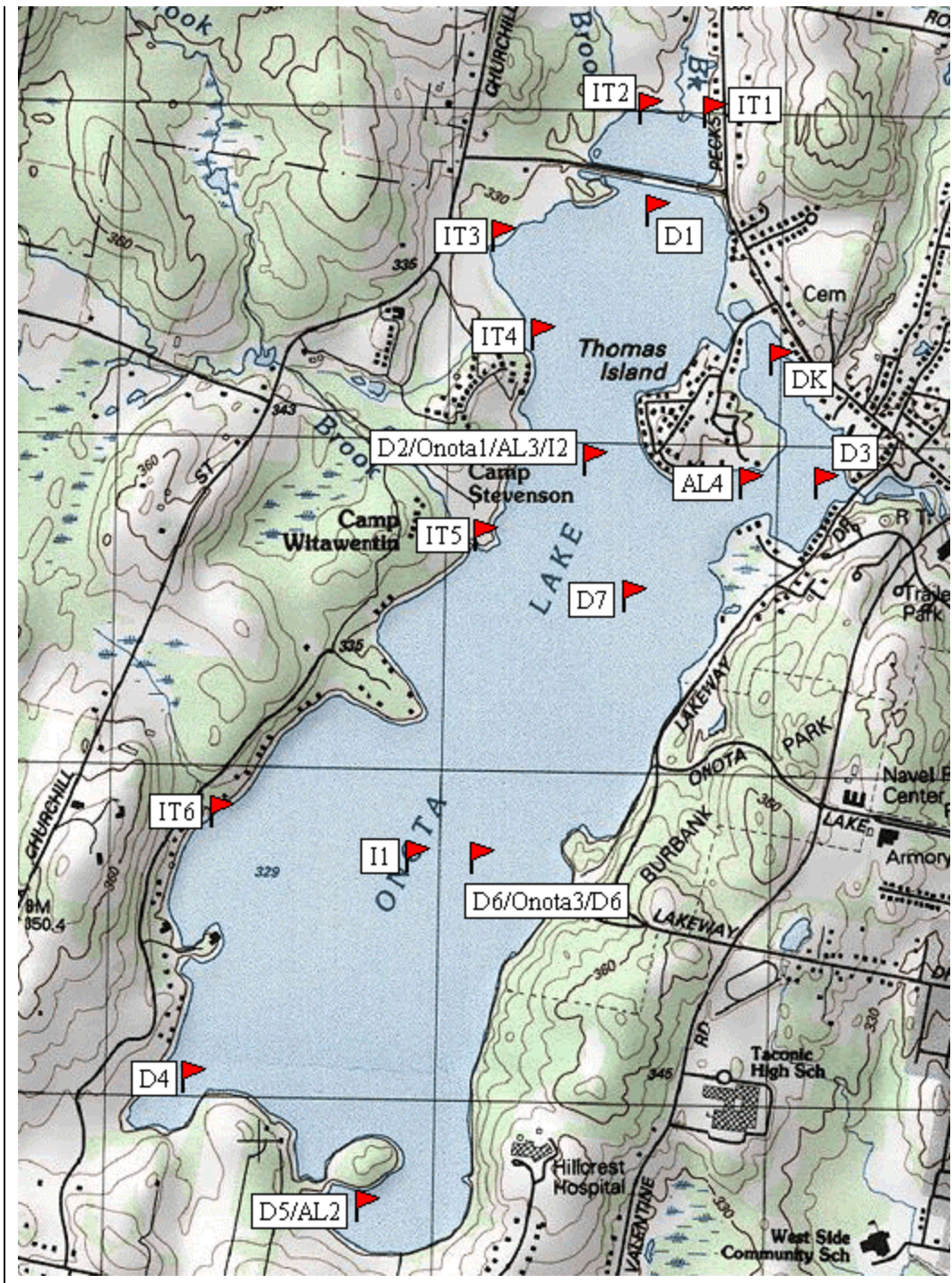


Figure 1: Lake Onota Sampling Site Locations

- AL = American Lake and Wetlands Services Incorporated Post Drawdown Study
- D = Lake Onota Preservation Association Monitoring Program
- I & IT = International Technology Corporation Diagnostic Feasibility Study
- Onota = Lake Onota Preservation Association Monitoring Program

As LOPA discovered, researching old data bases can be a daunting task. Relying on extant copies of reports from these studies, (including one draft report – the final could not be found), LOPA compiled a folder 3 inches thick. How would a monitoring group wade through such a pile? We have some suggestions on how to use existing studies:

III - Have reasonable expectations

For data interpretation purposes, there are four uses you might expect from existing studies:

- 1) *As an educational resource.* Reports from earlier studies may contain a wealth of information that can help the non-scientist understand how watersheds function. For instance, the ITC 1991 report begins with a narrative on watershed ecology, specifically the role that nutrients play, with some discussion of natural and cultural sources. Information like this can be used to teach volunteers how their watershed functions, and some TAC members may find it a useful refresher when they begin the interpretation work. When it comes time for a group to issue its own monitoring report or undertake other outreach work aimed at increasing public understanding of the watershed, such information can also provide valuable quotable material.
- 2) *To obtain complementary information* that provides context for a group's data set. Information such as lake bathymetry (lake map showing depth contours), nutrient budgets, and precipitation records can provide clues to why levels of various water quality parameters occur. For instance, one section of the above-mentioned ITC study includes a list of the soils found in the Onota watershed and describes the characteristics of the different soil types and how these might affect lake conditions: "The coarse nature of these deposits provides minimal filtering action and the aquifers underneath are especially susceptible to soluble pollutants from the surface (e.g. road salt and septic leachate)" (ITC, 1991). In a hypothetical situation where nutrient or bacteria levels were higher near one tributary than another, a check on soils information like this might point researchers in the right direction.
- 3) *Data comparison – advisory level.* Data from existing studies, when compared with a group's own results, can provide a broader picture of a water body's health. This happens three ways:
 - A longer timeline. For instance, LOPA can compare its 1997-2001 TP data with other results dating back to 1989.
 - A larger geographic scope. E.g. LOPA's two sites in the deep spots of the lake's two basins (one in each) are complemented by over half a dozen sites sampled in the earlier studies. These are located in tributaries, coves, and suspected hot spots.
 - Additional parameters. Sometimes one or more parameters can be used as surrogates for others. For instance, transparency (Secchi depth), total phosphorus (TP), and chlorophyll may roughly correlate with one another in a lake system. A group may be able to review historical records of one or more of these parameters and make some tentative assumptions about trophic trends in their lake, when compared with their own Secchi or TP data.

These kinds of extrapolation (either of time, space, or parameter) can be pretty risky, and we would advise caution when making them. Without a rigorous review of the validity of external data sets, it is better to treat them as useful for flagging possible problems or trends, not confirming them. As long as a group

keeps the comparisons advisory, the information sought can often be found in narrative form, in an executive summary or “conclusions” section – i.e. it is probably not necessary to engage in “data mining” (digging into the actual raw data).

- 4) *Data comparison - rigorous level.* In an ideal world, one could combine data from several studies into a single comprehensive data set that tracks trends extending years or miles beyond the scope of the study a group is currently engaged in.

IV - Proceed with caution

Combining several studies into a single database is the ideal, but it may be more trouble than it’s worth. If your group wishes to take this route, be aware of the pitfalls. There is a great deal of work involved (with no guarantee of success) in collecting all the quality assurance information needed to determine if another study is suitably compatible with your data. In addition to the raw data, you’ll probably need a copy of the study design or QAPP, and the Quality Control results for both field and lab data. Most of this will not be found in the project report itself, so it would be necessary to contact the report author or program manager. If you are successful to this point, you’ll then have to spend a lot of effort checking sample sites, dates, conditions, methods, and the QC results to filter out data that aren’t a good fit with yours. And you still have a lot of work ahead transcribing the resulting data set from the old study into your database. This will usually involve retyping data, because you don’t often find it available electronically.

Which is not to say it should never be done. Even without fully quality-assured data sets, combining data from multiple studies may work for you – particularly if:

- The earlier studies have clearly stated study objectives that are similar to your program’s objectives. The better the fit, the more valid your comparisons are likely to be.
- You have some confidence in an earlier study – because, for instance, the organization that conducted it has a solid reputation.
- You set reasonable limits on how you expect to use the data – e.g. for educational purposes or to influence local decisionmaking in a non-regulatory environment.

V - Don’t get lost in the details

To the extent possible, avoid getting bogged down in the raw data from previous studies. In most cases, the data will already be interpreted and reported in the form of narrative findings, conclusions and recommendations. You’ll save a lot of time if you read these and delve into the data only when questions arise. For instance, the ALWS study that evaluated the impacts of a lake drawdown reports that “a significant decrease has occurred in both percent cover and biomass rating for aquatic plants found in water less than 4 feet deep.” This sentence summarizes over 20 pages of graphs, statistical analyses and discussion.

How to use the information you assemble

Let's take a closer look at the information you can assemble to aid your interpretation efforts. Much of the information is available from other sources, but some you may have to collect yourself via field surveys. Along with advice on how to use the information, we offer some suggestions on where you might find some of it from other sources.

I - Lake and watershed setting

Geologic and landscape features are perhaps the most fundamental influences on the way a lake operates. They control, to a large degree, how and how much water, sediment, nutrients, and pollutants enter a lake, and how the lake responds. Most of these are slow to change. They can help you understand which phenomena are natural and which are caused by humans. This in turn helps you decide what management options are feasible (following the principle that 'you can't improve on nature').

Important features of lake and watershed setting include:

- Watershed topography, area and land use
- Lake morphology - surface area, bathymetry, shape of lake
- Soil types in the contributing watershed
- Climate
- Hydrology (contributing water bodies such as rivers and upstream ponds)

Table 1: Lake Onota Morphometric Data (ITC, 1991)

Lake Area	250 ha	Max Depth	20.6 m
Avg. Depth	6.4m	Max Volume	15.98x10 ⁶ m ³
Watershed Area	25.7 km ²	Shoreline Length	16.3 km
Max Width	3.4 km	Max Length	1.0 km

Some specific things to consider with lake and watershed setting:

1. Topography

This will affect erosion rates with consequent water quality impacts. All other factors being equal, what you consider "normal" levels of sediment, nutrients, etc. in a steep-terrain watershed will be higher than in watersheds that are relatively flat.

2. Watershed size to lake area

The larger this ratio, the more likely water quality will suffer, as runoff will be greater and will pass over or through a larger amount of land – and all the potential nonpoint pollution sources located on that land. Nutrient loads will likely be higher. It also means that changes in land use that produce a relatively small increase per acre of nutrients can still have a significant overall increase in the receiving water. This can have a major impact on the trophic status of a lake. Lakes with smaller watershed-to-lake size ratios are likely to be naturally oligotrophic (low nutrients, typically clear water); as the ratio grows, lakes tend towards eutrophic (high nutrient) status. This can help you determine whether nutrient levels found in your lake are caused by natural processes or are a case of "cultural eutrophication" (i.e. human-caused).

3. Lake size, shape, and orientation

Large lakes are likely to experience windy conditions more often and with more severity. This will increase the amount of “mixing” of lake water (more on this below). Similarly, shape and orientation of a lake can affect wind exposure and consequent mixing. A narrow lake that lies broadside to prevailing winds might experience less mixing than one where winds commonly blow the length of the lake. If the lake shoreline is forested, further protection from wind will also minimize mixing.

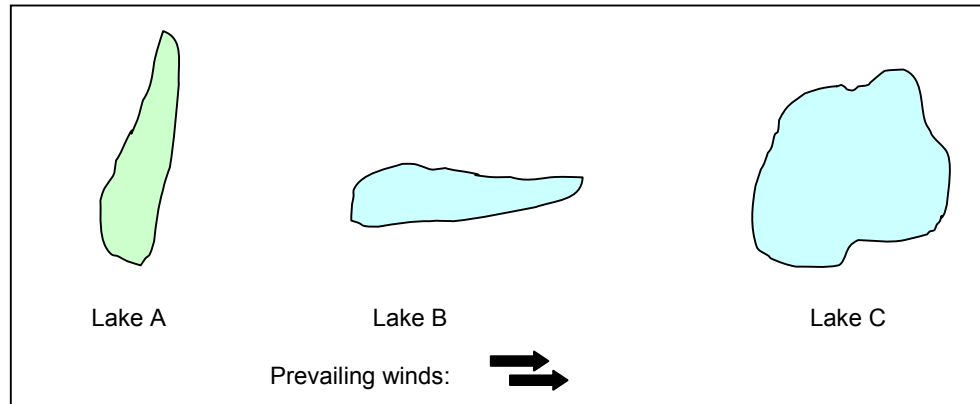


Figure 2: Lakes B and C are likely to experience more mixing than lake A

In general, the more uniform in shape a lake is (e.g. circular), the more valid it is to extrapolate a reading from one sample point (e.g. deep spot or center) to the entire lake.

4. Bathymetry

The depth of a lake is an important factor in how it functions. Shallow lakes tend to be more uniform than deep lakes, in terms of where plants and animals are found, temperature and oxygen levels, and the like. For instance, in those lakes that are shallow enough for light to penetrate to the bottom, rooted plants can cover large portions of the lake. This has obvious impacts on boating and swimming. It can also alter the dissolved oxygen dynamic considerably, as oxygen is usually available top to bottom. However, there are periods when oxygen can be depleted in shallow lakes:

- E.g. during warm cloudy periods in summer
- During cold winters when thick ice prevents oxygen exchange with the atmosphere. The oxygen contained in the relatively small volume of lake water can be used up by fish and other organisms.

During those periods, oxygen deprivation is likely to occur throughout the lake.

Deeper lakes, on the other hand, can have highly segregated zones, at least during parts of the year and under certain conditions. These zones are a factor of seasonal changes, the amount of light reaching different depths, wind and mixing patterns and the relationship between water temperature and density, and how plant and animal life react to variations in these constituents. Typically, in the summer there will be a layer of warm water overlaying a zone of colder and denser water. You will often find different species of fish inhabiting separate coldwater-warmwater zones; areas with high oxygen levels lying atop anoxic (without oxygen) layers; rooted plants on the (shallow) fringes of the lake, with floating algae throughout the upper layers of the entire lake, and virtually no plant life in deep waters. Deep lakes with a small surface area will generally exhibit better

clarity and water quality than will broad, shallow lakes.

Lake Onota behaves much as if it is two different lakes – one shallow and one deep. This is because the shallow north basin is separated by a submerged sand bar from the deeper south basin. In their 1991 study, ITC noted this bathymetric anomaly and recognized its significance to dissolved oxygen (DO) concentrations in the lake. They attributed low winter DO levels in the shallow basin to “the removal of oxygen by bacterial decomposition in the sediments and the slow diffusion of oxygen through the ice cover.” They went on to note that this might result in winter fish kills. By contrast, ITC observed no similar anoxia in the south basin in winter. Instead, the deeper south basin experienced a more pronounced and prolonged summer DO deprivation, as expected in a deep lake that stratifies (more on this topic below). ITC suggests that the difference in DO “behavior” is a natural product of the difference in depth between the basins.

Where to find bathymetric maps:

DFW web site: http://www.state.ma.us/dfwele/dfw/dfw_pond.htm

5. Land use

This is one watershed setting characteristic that *can* change relatively quickly; e.g. when development converts forested land to residential. This will affect the speed and type of runoff, often having a dramatic effect on nutrient inputs. ITC reports that Lake Onota contains ten subwatersheds, the three largest of which are predominantly forested and undeveloped. In general, the watershed is not highly developed, but three subwatersheds bear watching because of their degree of development.

Knowledge of land use types in a watershed can help you estimate nutrient loadings, or interpret the nutrient data you collected by comparing your results with expected values. Numerous models and formulae have been developed to estimate how different land use types will produce different stream flows, soil erosion rates, and contributions of nutrients and other constituents. Massachusetts DEP has created NSPLAKE, which estimates nutrient loads based on land use in the surrounding watershed (Mattson and Isaac, 1999). EPA has a similar model (Reckhow et al, 1980). For an example of a model relating land use and streamflow, see this Michigan Tech University website: <http://www.cs.mtu.edu/~mxue/epa/java/rainfall.html>. (The user enters rainfall amount, land use type, etc. and the model computes streamflow, then displays it with a diagram.)

Where to find land use information:

The best source is Geographic Information System (GIS) maps, available from your local planning agency, your watershed team leader, and from the web (<http://www.state.ma.us/mgis/>). Topographic maps will show some land uses such as forests vs. orchards, swamps and gravel pits, as well as built-up areas, but that information may not be up-to-date. Aerial photography is updated more frequently and is the basis for the state-generated land use maps. To obtain topographic maps and aerial photos, contact the University of Massachusetts Earth Science Information Office (<http://www.umass.edu/tei/esio/>).

You can also collect your own land use information through visual watershed and shoreline surveys. Because these will also document such things as leaking pipes,

farming and other operations that produce nutrients, bacteria, etc., they are useful to consult when doing data interpretation. Check such spots for proximity to sampling sites, to help suggest causes for high pollutant readings. They may also provide useful anecdotal information such as an observation of large transitory geese populations. There are two places you are likely to find existing visual surveys:

- Stream Team shoreline surveys conducted by Riverways-trained groups. Contact the Riverways program at: (http://www.state.ma.us/dfwele/river/riv_toc.htm).
- Any observations recorded on the field sheets from your own sampling program. It might be useful to set up a system whereby field sheets are checked by a supervisor after each sample event, and any unusual observations (e.g. “many geese observed” or “gray fluid leaking from pipe”) are recorded in a computer log, indicating date, site, and narrative comment. Check this computer file when data results indicate otherwise unexplained problems. At the same time, maintain all original field sheets in a file cabinet, in case you want to review them.

6. Climate and soils

These have a major influence on how much water goes through your lake, the route it takes to get there, and what it might pick up or filter out on the way. Earlier, we described how some soils around Lake Onota were likely to allow nutrients and bacteria to easily reach the lake from failing septic systems. Soil type can also determine how susceptible to acid rain a lake is. The ITC report states that carbonate rock formations and resulting soils in the Onota basin protect it against acid precipitation.

Where to find soils maps:

Check with your local Natural Resources Conservation Service: (http://www.ma.nrcs.usda.gov/conservation_prog.htm#soil).

Where to find bedrock and surficial geology maps:

<http://ma.water.usgs.gov/basins/> and click on your watershed.

Where to find weather data:

<http://205.156.54.206/er/box/clstns.htm> (Northeast Climate Data) lets you pick from 188 northeastern towns, month and year and gives you the daily climate data for that month. Other good sources are your local airport and your local waste water treatment plant.

II - How your lake functions

Landscape and lake morphology attributes determine how your lake functions in general. This in turn helps explain results you get when sampling specific parameters. Much of the information described in this section demonstrates the two-way nature of data interpretation. For instance, the data you collect may help you discover whether your lake stratifies or not. On the other hand, knowing that your lake stratifies helps you figure out why DO levels are high in certain parts of the lake or at certain times of year.

Hydrologic function of your lake includes such phenomena as:

- Major inputs
- Residence time
- Stratification

1. Inputs

We discussed watershed / lake size ratio, land use, and soils above. Assessment of their importance to lake health can be refined by taking a closer look at the hydrologic budget: How much water passes through the lake and where it comes from. For instance, we know that Lake Onota drains ten tributary watersheds; three of which are relatively pristine (i.e. forested), and three are fairly developed (with the remaining four somewhere in between, presumably). If the largest amount of water flows through the forested watersheds, Onota is likely to be healthier than if the developed areas contained the major tributaries.

But a lake doesn't live by tributaries alone. Groundwater is often a major source of lake water, via springs. Lakes that are primarily spring-fed tend to have small watersheds. If the watershed's geology is poor in alkalinity (also known as acid neutralizing capacity), the lake will be more sensitive to acid rain than stream-fed lakes. On the other hand, stream-fed lakes are more susceptible to adverse land-use practices.

ITC gives Onota's hydrologic budget as:

- Tributaries and surface runoff 7.36×10^6 cubic meters per year
- Precipitation on lake, minus evaporation $0.875 \text{ m}^3/\text{yr}$
- Direct groundwater seepage $8.7 \text{ m}^3/\text{yr}$

In other words, seepage accounts for about 51% of Onota's incoming water, tributaries and surface runoff about 43%.

Where to find above-mentioned information:

Existing studies such as Diagnostic Feasibility studies are always a good place to look. Also consider water quality assessment –305(b)– reports produced by DEP as well as reports from other agencies such as the U.S. Geologic Survey. Hydrologic information may be found in some 604(b) studies by Regional Planning Agencies. 305(b) reports can be found on the web at: <http://www.state.ma.us/dep/brp/wm/wqassess.htm>.

2. Residence time

Also called retention time, this is the amount of time a molecule of water resides in a lake before exiting through the outflow (or evaporation/groundwater loss in lakes with no stream outlets). Residence time is influenced by watershed size to lake size, lake morphology, land use, topography, and climate (which will affect evaporation rates). It is calculated by comparing the net input rate (i.e. inflow + precipitation – evaporation) with the lake volume.

For instance, water is piped through a container that holds 1000 gallons at a rate of 2 gallons per minute. Divide 1000 gallons by 2 gallons/minute: $1000 / 2 = 500$ minutes. A drop of water will reside in the container for 500 minutes.

Flushing rate, or the inverse of residence time, is often cited when discussing hydrologic

budgets. In the above example, divide the volume (1000 gallons) by the residence time (500 minutes) to get a flushing rate of 2 gallons per minute.

Residence time controls the significance of a chemical change in a water body. Residence times can range from a few days to hundreds of years. Lakes with long residence times will recycle nutrient inputs year after year while lakes with short residence times will flush nutrients faster than can be utilized. ITC calculates Lake Onota's residence time as 0.78 years (284 days). However, the north basin's is 0.116 years. It flushes eight times per year, or once every 45 days.

3. Stratification

In this part of the country, lakes with depths greater than 10 feet usually stratify at least once per year. This means they develop segregated temperature zones. As mentioned above, the degree of stratification is influenced by climate, lake morphology and orientation. Stratification in turn influences distribution of nutrients, gases (i.e. DO), and plant and animal life. Dissolved oxygen is often low or absent in deep layers of stratified lakes that are rich in nutrients. This can cause a chemical reaction between sediments and the water column, releasing phosphorus that was bound to iron, calcium, or aluminum in the sediments into the water column.

According to ITC, "Onota Lake can be classified as a temperature dimictic lake. Lakes are classified as dimictic if they circulate freely twice a year –in the spring and fall– and are directly stratified in summer and inversely stratified in winter." In other words, the warm water sits atop cold water in summer, and in the winter, the warm water is on the top due to physical properties of water, which is densest at 4 degrees Centigrade (water warmer or colder than 4°C will weigh less).

III - Contextual or reference information

In order for your data to have meaning, it must have context – you need to compare it to a value or values that indicate how "clean" or "healthy" your lake is. You can do relative comparisons: E.g. comparing a DO reading with last month's or last year's reading, against a 5 year average, against other sites or other lakes. Or you can make comparisons with known standards or indices that provide some reference. State water quality standards are perhaps the most widely used rating systems – in part because they carry such regulatory and management import, by guiding government programs and policies, and in some cases mandating restoration activities for impaired waters. Other means of *evaluation/classification* include national or regional nutrient criteria, Carlson's Trophic State Index (see below), the Index of Biological Integrity (which looks at macroinvertebrates and fish), or scientific literature that identifies the lethal temperature limit for different fish species, based on numerous studies of the different species. We discuss three of these that are pertinent to Lake Onota.

1. State water quality standards

The Federal Clean Water Act directs states to establish water quality standards that designate the uses that water bodies are supposed to support and the condition they should be in to support the uses. In Massachusetts, designated uses are:

- Aquatic life; suitable habitat for sustaining a native, naturally diverse

- community of aquatic flora and fauna
- Fish and shellfish consumption
- Drinking water
- Primary contact recreation: Swimming, wading, diving, surfing and water skiing
- Secondary contact recreation: Fishing, boating
- Aesthetics: Water shouldn't look, smell or taste too bad, or contain objectionable deposits or nuisance species of aquatic life
- Agricultural and industrial: Suitable for irrigation or other agricultural process water and for compatible industrial cooling and process water.

Each water body in the state is assigned a class. This determines which of the above uses it should support. The relevant classes and their designated uses:

Table 2: Massachusetts Surface Water Classification and Designated Uses

Class A (freshwater)	Class B	Class SA (saltwater)	Class SB
Public water supply source	Water supply with treatment (where designated)		
Excellent habitat	Habitat	Excellent habitat	Habitat
Primary and secondary recreation	Primary and secondary recreation	Primary and secondary recreation	Primary and secondary recreation
Excellent aesthetic value	Good aesthetic value	Excellent aesthetic Value	Good aesthetic value
		Shellfish harvesting without depuration (in approved areas)	Shellfish harvesting with depuration (in approved areas)
	Irrigation and other agricultural & industrial uses		

Note that these are *goals*, not necessarily current conditions. As you can see, they are pretty general. States provide *criteria* that provide more details on the condition a water body should be in to attain its use goals. These are represented as numeric or narrative values that define target (i.e. desired) levels of specific water quality indicators.

For instance, here are some criteria that are relevant to Lake Onota:

Table 3: State Criteria Relevant to Lake Onota

Indicator	Class A	Class B
DO	≥ 6.0 mg/l, ≥ 75% saturation unless background conditions are lower	Cold: ≥ 6.0 mg/l, ≥ 75% saturation Warm: ≥ 5.0 mg/l, ≥ 60% saturation. For either: unless background conditions are lower
pH	6.5 – 8.3 and no more than 0.5 change from ambient conditions	
Temperature (inland)	Coldwater: ≤ 68°F, no more than 3° change from ambient Warmwater: ≤ 83°F, ≤ 3°F change in lakes, 5°F change in rivers	
Aesthetics	All surface waters shall be free from pollutants in concentrations or combinations that settle to form objectionable deposits; float as debris, scum, or other matter to form nuisances; produce objectionable odor, color, taste or turbidity; or produce undesirable or nuisance species of aquatic life	
Secchi disk depth*	Lakes ≥ 1.2 meters	
Biocommunity*	Lakes – cover of macrophytes < 50% of lake area at maximum extent of growth	
Macrophytes**	Absence, presence, or dominance of non-native species	
Nutrients	Shall not exceed the site-specific limits necessary to control accelerated or cultural eutrophication	

* guidance used to assess whether waters support primary contact recreation

** guidance used to assess whether waters support aquatic life use

Massachusetts water quality standards regulations can be found at DEP’s web site:

<http://www.state.ma.us/dep/bwp/iww/files/314004.pdf>

They are also summarized nicely, with easy-to-read tables, in DEP’s 305(b) water quality assessment reports. Check section II of any of these reports. Also see Appendix 3 of this document for more information on criteria.

For some parameters, these standards and criteria provide some welcome definition to data interpretation: Comparing your results with the target ranges gives you an indication of whether your lake is impaired or not. For others the story is not so clear. Note the nutrients criterion in particular, which would require additional research to determine “site specific limits.” There may also be cases where a broad statewide limit or range doesn’t meet your specific needs. The Massachusetts criteria themselves acknowledge this situation in some cases; e.g. the DO allowance for circumstances where “background conditions are lower” than the stipulated number. In other cases, someone may wish to compare a seepage lake only with other seepage lakes, or a naturally high-alkaline lake with others with similar geology, or an urbanized lake with others in highly developed watersheds. Conversely, it is common to want to compare any water body with a “pristine” or “reference” water body, to get an idea of how far from the ideal one it is. There are a number of evaluation systems that use filters of varying type and degree to identify the “norm” for a particular water body type. We give two examples in the following paragraphs.

2. New England regional nutrient criteria

In 2000, the ENSR Corporation produced a draft set of regional nutrient criteria for the New England Interstate Pollution Control Commission (NEIWPCC). This effort was in response to EPA’s national Nutrient Strategy, which calls for EPA to develop numeric criteria for nutrients and to help states adopt “ecoregion-specific” standards based on the criteria.

ENSR reviewed data collected from over 7,000 New England waterbodies from “a variety of qualified sources including state and federal agencies, Tribal sources, academic institutes, watershed groups, and other sources” in their research. Most of the data was originally collected in 1990 or later. This database was subsequently refined to 1,155 New England waterbodies for which there was good quality data for nutrients and trophic responses (i.e., chlorophyll and Secchi disk transparency depth).

To make their New England data set more “ecoregion-specific”, ENSR sorted the waterbodies into 5 different ecoregions that EPA had previously identified. The regions are:

- New England Highland (a.k.a. North Eastern Highland)
- Laurentian Plains and Hills
- North Eastern Coastal Zone
- Atlantic Coastal Pine Barrens
- Eastern Great Lakes and Hudson Lowlands (a small portion of the area around Lake Champlain, Vermont).

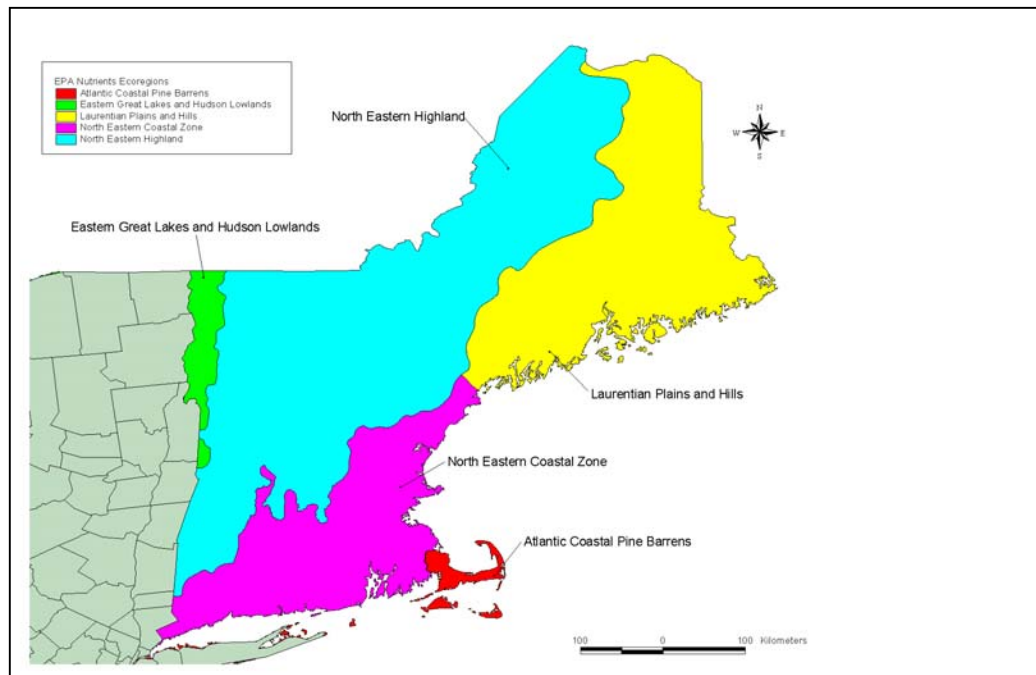


Figure 3: New England Ecoregions (ENSR, 2000)

According to the ENSR report (*“Collection and Evaluation of Ambient Nutrient Data for Lakes, Ponds, and Reservoirs in New England – Data Synthesis Report”*; ENSR, 2000), “an important facet of the development of regional nutrient criteria is the concept of ecoregion-specific criteria. Ecoregions are generally defined as relatively homogeneous areas with respect to geomorphology, climate, ecological systems and the interrelationships among organisms and their environment.”

This ecoregional classification system helps one to compare water bodies to those found in a similar environmental setting (see above). Lake Onota would be compared with others in the North Eastern Highland.

ENSR calculated median values for total phosphorus (TP), total nitrogen (TN), chlorophyll *a* (Chl *a*) and Secchi disk transparency (SDT) for lakes in four of the ecoregions where waterbody sample sizes were large.

Table 4: New England Ecoregions Median Parameter Values (ENSR, 2000)

Ecoregion	Median TP (µg/l)	Median TN (µg/l)	Median Chl <i>a</i> (µg/l)	Median SDT (m)
Laurentian Plains and Hills	10.8	300	4.0	4.5
North Eastern Highland	8.8	300	3.5	4.1
North Eastern Coastal Zone	14.4	448	4.1	2.3
New England Overall	10.0	370	3.7	3.9

After conferring with lake water quality experts from the six New England states and after further analysis of the data, ENSR identified preliminary draft nutrient criteria that estimate “what concentrations will be protective of waterbodies’ water quality as well as of their designated uses.”

Table 5: Ecoregional Preliminary Draft Nutrient Criteria (TP, TN) (ENSR, 2000)

Ecoregions	Total Phosphorus (µg/l)	Total Nitrogen (µg/l)
Laurentian Plain and Hills	9.8	262
North Eastern Highland	8.3	289
North Eastern Coastal Zone	9.9	383
All New England Lakes	9.3	311

These values were derived using a conservative, statistical approach similar to that being used by the United States Environmental Protection Agency (EPA) for larger ecoregions nationwide. The ENSR *Data Synthesis Report* describes alternative methods and decision-making to support criteria development. The criteria are preliminary and are subject to further development and implementation by the individual New England states. Hence, these preliminary values represent only one method to develop nutrient criteria, while states may opt to use several methods for a “weight-of-evidence” approach. When they are formally approved, the New England regional nutrient criteria will no doubt be widely used as an evaluation, management and regulatory tool. For the time being, both the preliminary criteria and the median values listed above for different parameters and ecoregions are useful as ballpark comparisons to LOPA’s results, or those of other New England lake monitoring groups. Further details are available in the ENSR *Data Synthesis Report* which can be found on the NEIWPC website at <http://www.neiwpc.org>.

The EPA has also developed regional nutrient criteria for rivers and lakes around the nation. These can be found at <http://www.epa.gov/ost/standards/nutrient.html>.

3. Carlson’s Trophic State Index

This well known index was one factor that ENSR considered in developing regional criteria. The EPA’s biodiversity web site

(<http://www.epa.gov/bioiweb1/aquatic/carlson.html>) describes the Carlson trophic state index (TSI) in this manner:

“The concept of trophic status is based on the fact that changes in nutrient levels (measured by total phosphorus) cause changes in algal biomass (measured by chlorophyll *a*) which in turn cause changes in lake clarity (measured by Secchi disk transparency). A trophic state index is a convenient way to quantify this relationship. One popular index was developed by Dr. Robert Carlson of Kent State University... The Carlson trophic state index was developed for use with lakes that have few rooted aquatic plants and little non-algal turbidity. Use of the index with lakes that do not have these characteristics is not appropriate.”

This suggests that the TSI has limited utility for Lake Onota, with its abundant macrophyte population. However, it is useful for other volunteer monitoring groups with algae problems, in part because the index can be calculated from any one of three different parameters: Chlorophyll *a*, Secchi transparency, or total phosphorus, according to the following formulae:

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

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

$$\text{TSI} = 14.42 \ln(\text{total phosphorus}) + 4.15$$

where:

TSI = Carlson trophic state index

ln = natural logarithm

Secchi transparency reported in meters

Total phosphorus reported in $\mu\text{g/l}$

Chlorophyll *a* reported in $\mu\text{g/l}$

“Ranges of trophic state index values are often grouped into trophic state classifications. The range between 40 and 50 is usually associated with mesotrophy (moderate productivity). Index values greater than 50 are associated with eutrophy (high productivity). Values less than 40 are associated with oligotrophy (low productivity)” (EPA, <http://www.epa.gov/bioiweb1/aquatic/carlson.html>).

ENSR used the TSI in its research. It cited trophic state thresholds that were slightly different from what EPA reports. ENSR’s TSI categories –and their equivalent TP, chlorophyll and Secchi transparency ranges– are given here:

Table 6: ENSR's Carlson Trophic State Index (ENSR, 2000)

Variables	Oligotrophic (TSI < 30)	Mesotrophic (30 < TSI < 50)	Eutrophic (TSI > 50)
TP (µg/l)	<10	10-24	>24
Chl <i>a</i> (µg/l)	<1.5	1.5-7.2	>7.2
SDT (m)	>6	2-6	<2

Remember that these are universal estimates/guidelines and not specific to New England or any of its ecoregions.

Screen the data set

Once you've gathered all the data and background information you think you'll need, you will want to filter out what's not usable. There are several things to watch out for when you are reviewing data sets – new or old, your own or others'.

How reliable is the data?

- Are sites, dates, time of day, depths suitable for your study questions?
- Is the data quality assured? (See quality control section in Appendix 1.)

Are different data sets describing the same thing?

- Check units of measure, especially for nutrients. Phosphorus and nitrogen are sometimes reported in milligrams per liter (mg/l – equivalent to parts per million), sometimes in micrograms per liter (µg/l, or parts per billion), sometimes in loadings (kg/m²).
- Make sure that forms of nutrients are the same, or convertible. For example if you require results for phosphorus but the test kit you use gives results as phosphate, it is important to convert the test kit value to phosphorus.
Atomic weight of oxygen (O) = 15.9994
Atomic weight of phosphorus (P) = 30.9738
Molecular weight of phosphate (PO₄) = 94.9714
To convert phosphate results to phosphorus results:
(atomic weight of P / molecular weight of PO₄) x (value of PO₄) = value of P.
I.e. to convert PO₄ to P, multiply value of PO₄ by 0.3261. But don't confuse P with TP (total phosphorus, which is a different analyte than phosphate).
- Keep in mind the sensitivity of the methods and equipment that were used. For example, if a color wheel was used to determine orthophosphate concentration, you should know that it can't detect concentrations below 0.1 mg/l (or 100 µg/l). When reporting values less than 0.1 mg/l, people sometimes write "0", or "<0.1 mg/l" (the preferred option). This can cause difficulties when you are trying to run statistics (e.g. averaging several samples). The situation gets complicated when you attempt to compare such results with another study that was able to measure levels down to 0.01 mg/l. In such a situation, our advice is to forget comparing results: Color wheels are just not sensitive enough to measure phosphorus in surface waters unless the pollution was huge.

- Another problem can occur when a program switches methods or instruments (or you compare two or more studies using different instruments). It's important to verify the accuracy (as opposed to precision) of the different methods. (For a discussion of accuracy and precision, see "The Volunteer Monitor's Guide to Quality Assurance Project Plans", EPA, 1996.) For example, suppose a group purchases a new pH meter, and after a period of sampling, data analysis reveals that at about that time, pH readings increased on the average by 0.5 units. Was there a change in the lake water, or was one of the instruments biased? Which one? To avoid this problem when instituting new procedures or using new equipment, it helps to run parallel tests with both instruments for a while, or in some other way document the accuracy of the old *and* the new.

By taking precautions like these, you may be able to 'filter' multiple data sets (including your own year-to-year studies) to a smaller composite that you can use for trend analysis.

Summarize the data

This involves three steps:

1. Identify logical categories within your data set that will help answer your study questions.
2. Run queries and filters of your data set to isolate those data that fall into the above categories.
3. Organize the query results into formats (usually graphs or charts) that facilitate analysis.

I - Identify categories

Refer back to your study questions to determine if there are any particular data subsets that help answer the questions. Identify the *indicators* of importance (e.g. dissolved oxygen, nutrients, etc.) as well as any *limiting conditions* that might help focus the question. These might relate to time (e.g. you want to look at spring pH results over the last 10 years); to space (e.g. comparing two sites or establishing trends at one site); or to weather or other natural or man-made phenomena (e.g. isolating and comparing wet weather and dry weather samples; or isolating and comparing pH values in the years before and after acid rain legislation was passed).

II - Run queries and filters

Now query the full data set to find out which records satisfy the conditions you've specified. You may also want to identify further statistical filters or summaries to apply to the data subset – e.g. highlight all values above or below a certain value, or capture average, mean, geometric mean, median, etc. values for the data subset.

Examples:

#1. This is a focus of recent Lake Onota studies:

Study question: "Have nutrient levels in the lake changed since 1986?"

Defining/limiting conditions: 1) Nutrients – i.e. phosphorus and nitrogen. You may also want to look at Secchi depth and chlorophyll as surrogates for nutrients, as discussed in the previous section; 2) Sampling sites and dates. Look for those sites that have records for several years for approximately the same dates. Total phosphorus data exists for Lake Onota, late July to mid August dates in 1986, 1997, 1999, and 2001.

Query: Retrieve and organize TP data to show results from each site (and/or an average of several sites) from 1986 – 2001.

Query result: (1986 results represent the average of 2 dates. All others were from single sample dates.)

Table 7: Result of Query of Lake Onota TP Data Set

Year	TP mg/l	Site #
1986	< 0.01	1 (deep basin)
1986	0.007	2 (shallow basin)
1997	< 0.01	1
1997	< 0.01	2
1999	0.040	1
1999	0.020	2
2001	0.008	1
2001	< 0.01	2

#2. This is a hypothetical example, fairly common in shallow northern lakes:

Study question: Are conditions likely to produce winter fish kills?

Indicators of importance: 1. Visual observations on field sheets (these would document any sightings of dead fish); 2. Dissolved oxygen (DO).

Defining/limiting conditions: 1. Sample dates (i.e. December through March); 2. Visual observations (i.e. those that document when a lake is ice and snow covered).

Query your data set to select all records that fall within these dates or that document dead fish or complete ice cover. The date query can probably be done by computer, but you'll probably have to do a manual search through the visual observations, unless you've designed a system that computerizes them.

Statistical filter / analysis: You might want to highlight or isolate all records where DO is less than, say, 3 parts per million. Because you are looking for specific instances of stressful conditions, be sure to retrieve and report individual values rather than a seasonal average.

III - Dealing with variability

The winter fish kill example mentioned above illustrates a problem associated with using statistics to summarize databases. Because it's unwieldy (cumbersome) to review every data point in a large data set, you will usually use some statistical summary (e.g. average, geometric mean, median, etc.) to obtain a clearer view of the data. As you are figuring out how to organize your data set, the question of variability will come up. Natural systems are inherently variable. How do you summarize and interpret a data set that displays a variety of high and low readings over time and space?

In some cases, a simple average of the individual readings will do: “Average total phosphorus levels for 2000 were 19.6 $\mu\text{g/l}$.” This is most useful when you are looking for effects of chronic exposure to a condition, or when a parameter accumulates in the environment (e.g. nutrients, PCBs, metals). A short-term spike of phosphorus input into a lake may not produce any noticeable immediate effect on the lake, but the phosphorus might well stick around, contribute to nutrient loading and pose subsequent disruptions in the plant community, etc. In this case, an average that includes the spike will suggest the total load produced and therefore might work well (of course, if the study objective is to “find the culprit” – the source of mysterious unexplained loadings, then average won’t help). In other cases, you want to observe high or low values. This is most important when results are highly variable and when the extremes –even if short-lived– can cause significant impacts, as in the DO example above.

In general, the more variation a parameter exhibits, the more careful you should be with a straight average. Two reasons:

- 1) The average value you obtain might itself be distorted by a few outliers – very high (or low) readings. This commonly happens with bacteria. For example: Daily coliform samples might show 9, 20, 29, 11, and 20,000 colonies/100ml (guess which day it rained). The average for that week is 4,014 colonies, clearly not representative of most of the week. To avoid this, calculate a geometric mean instead of an arithmetic mean. Geometric means are averages of values' logarithms, converted back to an antilogarithm, and are easily done with most spreadsheets. For the numbers above, the geometric mean is 65 colonies. This represents the “normal” days much better, but doesn’t do justice to the “bad” day. To capture that, we offer a second strategy:
- 2) As stated above, you may fail to see conditions that place temporary stress on the resource. To avoid this, identify the clusters where results are likely to be similar. Separate these out into groups and then scrutinize the groups directly (if there are only a few data points) or compute statistics on each group. But there should be an appropriate rationale for the categories that you do select. In the coliform example, if the 20,000 colony sample did occur after a rain, you might try separating out all wet weather from all dry weather samples in your data set, and compute the geometric mean for each group. Or compute the arithmetic mean if working with other more stable indicators. For instance, compute the average July water surface temperature, average August, October, etc. rather than a single average for the whole year.

Tip – to do this in Excel, you might want to add another column that computes the month number. Use the <i>month</i> function on the cell containing the date, and make sure that the cell containing the value returned is general or text format, rather than date. E.g. “month(A7)” where cell A7 contains “3/14/86” will return “3.”
--

Here’s a hypothetical table of monthly average monthly temperatures taken at lake surface and at 8 meters depth, sorted by month, then by year, to allow easy viewing or graphing of the monthly trend over several years.

Table 8: Result of Query Producing Monthly Temperature Averages for Several Years

Temperature (surface)	Temperature (8m)	Month	Year
19.5	15	6	1996
21.1	13	6	1997
22.9	9.5	6	1998
19.1	10.5	6	1999
20.6	8.8	6	2000
24.5	14.3	7	1996
23.5	14.5	7	1997
26.7	10.1	7	1998
21.3	10.8	7	1999
23.4	11.2	7	2000
24	14.3	8	1996
24.1	13.8	8	1997
24.6	10.2	8	1998
24.8	11.4	8	1999
26	13.6	8	2000
16.6	16.2	9	1996
22.7	14.4	9	1997
22.4	10.8	9	1998
21.4	11.9	9	1999
21.9	15.5	9	2000

Whenever the variability is predictable, it’s easier to separate out similar data subsets. For instance, DO readings tend to rise during the day as sunlight stimulates photosynthesis in aquatic plants and then drop after nightfall; pH readings are usually lowest in the spring after snowmelt; DO, temperature, Secchi depth and nutrients can change dramatically and quickly when spring or fall turnover occurs. These all suggest logical subsets to create –and then compare– with your queries.

Conversely it does not make sense in most cases to average surface-to-bottom DO and temperature readings in stratified lakes. Better to graph a profile of how these change with increasing depth. Here’s an example of representative June DO profiles taken at Lake Onota over the years:

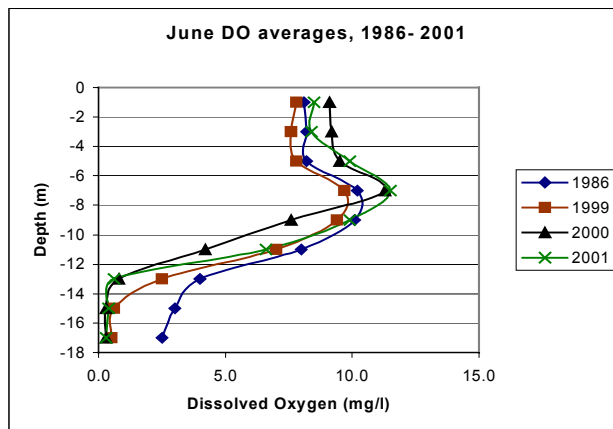


Figure 4: Lake Onota Dissolved Oxygen Profile Chart

Notice that June 1986 readings don't show quite as sharp a drop-off at depth, nor quite as high a spike near the thermocline as in the most recent years. This might possibly be an indication of the effects of increasing eutrophication.

Tip: To make similar depth profile charts in Excel: Select chart type "XY scatter" (with lines); select y value to equal the depths at which samples are taken, x value to equal the DO results.

Another case where annual averages may miss important fluctuations is with algae growth and Secchi or chlorophyll measurements intended to track the algae growth. Because different algae populations boom and crash throughout the season, retrieving regular (monthly or more frequent) readings and observing the highs and lows will be more useful than a single seasonal average. In this case, seasonal averages will still be useful for long term study, to see if the lake is getting more eutrophic on the whole. But you will also want to see how readings fluctuate throughout the "growing season."

The following chart, from the ITC 1986 study of Lake Onota, shows Secchi and chlorophyll data throughout the summer and fall. Seasonal or annual averages would clearly miss the several spikes that occurred in both parameters.

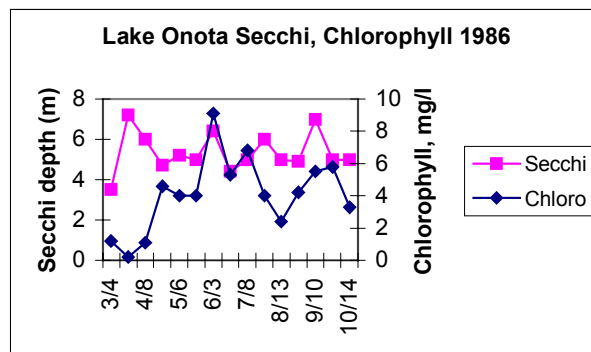


Figure 5: Lake Onota Secchi and chlorophyll results, 1986. (ITC, 1991)

A related question is the magnitude of variation: How much of a departure from "normal" is enough to set off warning flags for each indicator? This varies from indicator to indicator, and is a result of several factors, such as:

- How the indicator is measured. pH, for instance, is measured on a logarithmic scale, so a change of 1 unit represents a 10-fold change in ions found in the water. Hence, a seemingly small change from 6 to 5 in pH can be significant.
- How swift the change occurs, and the resulting impact on the biological community. For instance, fisheries managers know to take care when stocking fish. It is important to ensure that the temperature and pH of the receiving waters are not too different from what they've been living in at the hatchery. A large and sudden difference in temperature or pH –whatever the reason– can create a shock to their systems, sometimes killing them.
- The degree of natural variation in different parameters, as discussed above.

One place you can find information about what constitutes significant change –for some parameters, at least– are state water quality standards. For instance, here are some allowable limits for changes that discharges can cause to receiving class B waters in

Massachusetts, to protect aquatic life:

- pH: 0.5 units inland waters, 0.2 units coastal
- Temperature: Inland: 3°F coldwater, 3°F warmwater lakes, 5°F warmwater rivers; Coastal: 1.5°F July-September, 4°F October – June;
- Suspended Solids: 10 mg/l.

You may also want to run queries that capture the *frequency or duration* of stressful conditions: E.g. how many days (or how many days in a row) temperature exceeded the state criteria. This might help you get a better idea of the strain on fish populations. Another example is the length of time DO levels are very low at the bottom of the lake. This might tell you how long conditions favor nutrient resuspension (i.e. from the sediments to the water column). Or you might want to know how many days the lake was unfit for swimming. Knowledge of this sort has potentially useful political ramifications in addition to its scientific merit, for it may help you make your case for restoration efforts.

For a discussion of using statistics to analyze your data set, see the article “Variability Happens” from the spring 1995 issue of *The Volunteer Monitor* newsletter. It can be found on the web at <http://www.epa.gov/volunteer/spring95/mpdata13.htm>.

IV - Organize into graphs or charts

You’ll want to put some of this into easy-to-read tables, graphs, or maps to have available when looking at your data. Sometimes a picture is worth a thousand data points. We’ve already given some examples of graphs. For more information on using graphs for data interpretation or presentation, consult the MassWWP manuals on data management and data presentation (see References).

Put it all together into a data packet

When you’re done with all the assembling, screening, and summarizing, the final data set should have several parts. Consider making a packet of this information and distributing it to your TAC. This also constitutes a draft form of any reports you issue, so doing the work now saves you report-writing time later on:

- 1) A map of your watershed with the sites marked on it. If you are sampling several water bodies, or a river system that contains streams or reaches with different water quality classifications (i.e. A, B), it might help to indicate which classifications apply for each.
- 2) Data tables and graphs with correct units of measurement clearly reported.
- 3) General observations, such as habitat and weather information for each sampling date and site.
- 4) A list of the appropriate water quality criteria or reference conditions (either those you obtain from the literature or that your TAC sets, based on your organization’s goals for the lake).
- 5) Graphs, narrative summaries, or similar excerpts from other surveys that offer an

“advisory level” supplement to the view your ‘screened’ data set provides.

The makings of a Lake Onota packet are scattered through this manual. They include:

- Map of Lake Onota with sampling sites, page 8
- Excerpts from Lake Onota data set (Appendix 2).
- Excerpts from “Smart Charts” document (Appendix 3 – select portions that suit your needs).
- Narrative, map and data tables from ENSR New England Nutrient Criteria report, pages 18-20.
- Graphs such as those found on pages 26, 27 & 33.

Making sense of it all

The preceding activities (assembling and summarizing information) are preparation for the intellectual exercise of using sampling and related data to evaluate the health of your lake and watershed, and then deciding what subsequent actions are advisable. The process we describe below is intended to help you move in an orderly progression from results to findings to conclusions.

- Sampling *results* are the data – the numbers or values obtained from your field and lab sheets.
- *Findings* are observations about your data. These are pretty basic: You observed that on certain days, or under certain conditions, or at certain locations, values were particularly high or low.
- *Conclusions* are your explanation of why or how conditions occur: E.g. too many nutrients coming from residential runoff are responsible for excessive weed growth.

It is important that the logical path you trace from results to findings to conclusions is well documented, so that you as well as your audiences can be sure that you have made defensible claims and sound recommendations. We suggest a thorough exploration of each stage before moving on to the next. There’s value in deliberation – not jumping to conclusions. The following sections describe each step and suggest a set of questions you should answer at each step. The questions will help you cast a critical eye on your data – to weed out errors, identify causal connections, to isolate particularly high and low values and explain them.

The questions that are listed below are given in generic form. They can easily be modified to fit river or coastal situations or different study objectives. In many cases, the generic questions below are followed by an example specific to Lake Onota.

We suggest that you run through *the results to findings to conclusions* process in several iterations. This process, you will notice, produces a *preliminary*, then *provisional*, then *final* interpretation of your data.

- 1) Review and interpret the data “in-house” to develop *preliminary* findings, conclusions, and recommendations. Get 3-4 members of the program together to answer the questions – the program manager, one or two advisors and/or

volunteer samplers, possibly your lab specialist. Consider this your trial run. You will probably come up with several *provisional* findings and conclusions that will require additional research or fact-checking. The product of this exercise may simply be a printout of the questions with provisional answers typed in, and possibly a short narrative that summarizes your decisions.

- 2) Review the data and your initial interpretation of it with an advisory or technical group (i.e. your TAC). This group should involve local, regional, and state resource people who are familiar with monitoring and with your lake. They can verify, add to, or correct your interpretation of the results. You may want to do this with members of your Watershed Team, or a subcommittee of that group. After this review, you may be ready to prepare a project report complete with findings, conclusions and recommendations.
- 3) Review the data and your interpretation of it with the people who will use your data – for example, the public, lake users, and government officials. This might take place at a public meeting. This exercise is really a combination of data interpretation and data presentation. In a setting like this, you may want to present findings and conclusions only, and use the forum to get the assembled crowd to come up with recommended actions – or possibly just the findings only, and conduct a facilitated process of having the audience generate conclusions. This strategy can be useful when you need buy-in from various interests to proceed on any preservation/restoration projects. Commonly, when people come up with recommendations themselves, they are more likely to follow through with them than if they are just asked to implement recommendations that others have made. If this part of the process produces any changes in your findings, conclusions and recommendations, restate them in your *final* report on your data.

The Lake Onota Protection Association followed a similar process with their collected data set. LOPA members compiled several studies (including their own) and took an initial stab at identifying significant results. They recruited several experts in the field of limnology to review the compendium, apply the questions listed below, and discuss among themselves (primarily via email) what the data meant. They then held a symposium wherein each expert gave their perspective on the needs of the lake, and to proffer recommendations for lake or watershed management. The audience consisted of watershed residents and members of other lake organizations who were there to learn about the data interpretation process. Audience members were encouraged to ask questions and give their own views. The symposium produced a set of consensus recommendations. These would be considered draft recommendations, which LOPA is using to develop a set of potential management tasks to implement over a three year period.

I - Develop Findings

Findings are observations about your data. They are usually reported as narrative statements that summarize the important points found in the data. Findings often contain some reference to contextual information, such as how data compare with water quality standards or trophic status or how different sites or dates compare with others. By

carefully developing and explicitly stating your findings, you create a solid record that should strengthen your subsequent conclusions. Not only will you form a more thorough and accurate interpretation, but it will help you show your audiences how you arrived at your conclusions. It's quite common for people to look at data and come up with quick explanations before thoroughly observing and summarizing the trends, patterns, lack of patterns, or clues found in supplementary information such as weather or visual observations. Try to not move too fast or jump to conclusions – once you start down a path that leads to a particular interpretation, it can be difficult to see things objectively, to backtrack and throw out assumptions you've made. It's better to treat this part merely as a series of observations. Record as many as you can, *without attempting to explain them*. If an explanation occurs to you that you don't want to forget, record it as a *possible* explanation, to be subjected to scrutiny later on.

A lot of what you are doing is simply pulling out noteworthy nuggets from your data set and placing them under the spotlight. This process is analogous to separating out all the macroinvertebrates from the leaves and rocks in a sample net. You isolate and preserve them for later identification under a microscope using a dichotomous key. You may recognize a few particular species, but you're going to have to properly identify them later, so don't invest a lot of energy in on-the-spot IDs.

Here are some example findings that were reported by authors or reviewers of the various Lake Onota studies. Most of these are paraphrased – not exact quotes.

- Secchi reading at site 4 was greatly reduced and generally correlates with eutrophic lake conditions (from ALWS study, 1997). Turbidity readings tended to be higher in the north than the south basin (ALWS, 1997).
- Eurasian watermilfoil grew to nuisance densities in 1986 in the north basin, but was rare in the south basin (Fugro, 1996).
- Ten species with distinct nuisance potential were observed, including the two non-native species (Fugro, 1996).
- The trout layer (that volume of water colder than 71°F but containing at least 5 mg/l of dissolved oxygen) appears to have declined over the years. In 1947 this layer amounted to 42% of the lake's volume, but by 1972 it had declined to 18.5% – and to 13% by 1986 (ITC, 1991).

Developing findings is a process in which you compare your results with:

- Water quality criteria, reference conditions, or other desired ranges that you choose to compare with – e.g. the New England regional nutrient criteria discussed above. Or perhaps you would compare this year's total phosphorus data with a 10 year average for your lake.
- Other values within your data set – e.g. site to site, date to date, trends over time, etc.
- With other data sets – other studies of your water body or watershed, or with other water bodies or watersheds.

1. Questions that compare your data with criteria or reference conditions

- Are there *sites* that consistently exceeded (violated) the benchmarks you set? By how much? Ask this for each parameter. For example: “Did any sites exceed TP values

- of 8.8 $\mu\text{g/l}$ ” (8.8 $\mu\text{g/l}$ is ENSR’s draft TP criterion for the North Eastern Highland region). As the discussion above shows, this number is just one of several that could be used as a benchmark. Depending on your situation, you may decide to select a different value – such as 10 $\mu\text{g/l}$ (ENSR’s trophic status index (TSI) value separating oligotrophic from mesotrophic) or even 24 $\mu\text{g/l}$ (threshold of the eutrophic range).
- Are there sampling *dates* where most or all sites consistently exceeded the standards? By how much? This question can be useful to detect specific events that affect water quality, and are particularly helpful when your program involves sampling at several sites. If, for instance, you are sampling bacteria at seven sites along a river, it would be instructive to note that on a particular day, all sites had high levels. The question can also help you spot suspect dates. In Onota’s case, a primary interest is to detect trends in trophic status, and the data set primarily consists of two sites – the deep spots in the north and south basins. The question might be framed “Were there any dates when TP values at both sites exceeded 24 $\mu\text{g/l}$?”

These and other questions that compare data against a standard or against other data points are similar to the quality control questions you asked earlier about outliers when doing a QC check. As with the QC questions, organize your data to make it easier to find the answer. For example, on a question of which site had highest readings, organize the data so that it is sorted by site. Then create a chart that depicts your threshold or target values with a line, or background color, etc. Plot the data points to see which sites if any consistently fall above the threshold.

LOPA example:

- 1- Do any sites consistently produce total phosphorus levels that fall within eutrophic ranges (i.e. $\geq 24 \mu\text{g/l}$)?
- 2- Were there any dates when TP values at both sites exceeded 24 $\mu\text{g/l}$?
(Remember 24 $\mu\text{g/l}$ = 0.024 mg/l.)

A table of data values (showing only dates when both sites were sampled for TP), sorted by site, reveals:

Table 9: Onota Lake Data Sorted by Site

Date	Site#	Data source	TP (mg/l)
3/22/86	1 (North)	ITC	0.01
4/8/86	1	ITC	0.005
4/25/86	1	ITC	0.02
5/6/86	1	ITC	0.005
6/24/86	1	ITC	0.01
7/26/86	1	ITC	0.005
8/14/86	1	ITC	0.005
10/16/86	1	ITC	0.005
11/14/86	1	ITC	0.41
7/29/97	1	ALWS	0.005
7/29/99	1	ACT	0.04
6/25/01	1	Onota	0.008
8/18/01	1	Onota	0.008
3/22/86	2 (South)	ITC	0.01
4/8/86	2	ITC	0.005
4/25/86	2	ITC	0.005
5/6/86	2	ITC	0.02
6/24/86	2	ITC	0.01
7/26/86	2	ITC	0.01
8/14/86	2	ITC	0.005
10/16/86	2	ITC	0.005
11/14/86	2	ITC	0.02
7/29/97	2	ALWS	0.005
7/29/99	2	ACT	0.02
6/25/01	2	Onota	0.006
8/18/01	2	Onota	0.005

A graph of this data shows:

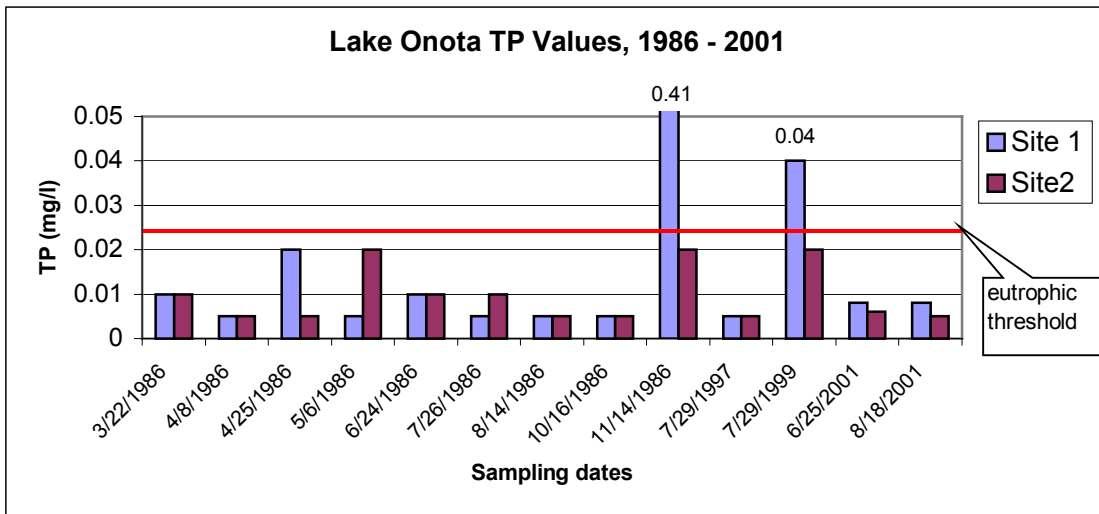


Figure 6: Onota Lake Total Phosphorus Values

From the table and the graph, you can see that site 1 exceeded the 24 µg/l threshold twice, and while there were no dates when both sites exceeded this level, there were two (November 14 1986 and July 29 1999) when site 2 came pretty close and site 1 exceeded it significantly. The November '86 level is so high that sampling or analysis error might be suspected.

2. Questions that compare your results within your data set:

These questions help you use your own data to focus on site-to-site comparisons and comparisons over time:

- Which *sites* had the highest or lowest readings?
- Which *dates* had the highest or lowest readings?
- Are there numbers which seem to be much higher or much lower than typical results (i.e. outliers)? See Appendix 1 on how to address outliers.

Any of the above questions can be asked on an individual level (e.g. which site had the highest single reading), or you might ask which had the highest (or lowest) average value.

- Do your results show a consistent pattern of change from one site to another? For streams, this is usually an upstream to downstream comparison. For lakes, you might be concerned with deep vs. shallow areas, sites in the lake center compared with those near tributary inlets, etc. In any case, do levels increase or decrease in a consistent manner? For instance, is Lake Onota’s site 1 consistently higher than site 2? The graph shows that site 1 was higher four times (twice significantly), while site 2 was higher twice (once significantly). Taking the average and median (which minimizes the effect of one or two extremely high or low values), we get:

Table 10: Comparing Summarizing Values for Two Sites at Lake Onota

mg/l	Site 1	Site 2
Average	0.041	0.010
Median	0.008	0.006

Because there were just two samples that raised the average so much – and one was from a very old data set, with no recoverable quality control data, it’s wisest to trust the median here more than the average. Looking at these data, it would be tempting to say that the shallow north basin (#1) has slightly higher TP values than the deeper south basin, but when one considers the minimum detection limit (about 0.005mg/l) the difference between 0.008 and 0.006 is not statistically significant.

- If you are monitoring the impact of a pollution source, are your results different above and below (for streams) or close to and far away from the impact (e.g. near a neighborhood of shoreline houses with suspect septic systems)? This can also be asked as a “before and after” question if you are monitoring a new or episodic source. For instance, if shoreline homes were converted from septic to sewer in 1998, you might ask “Were 1999 TP lower than 1998?” or “Are average TP levels from 1999-present lower than the pre-1999 average?”
- Do changes in one indicator coincide with changes in another? For example, there is frequently an inverse relationship between water temperature and dissolved oxygen,

since warm water can hold less oxygen than cold water. As mentioned above, this question is important in Lake Onota, where the interplay between temperature, oxygen and depth has an impact on the extent of the “trout layer” – that area of the lake that is cold enough and oxygenated enough to support trout. More on this below. Other parameter relationships found in lakes include plant activity, dissolved oxygen and pH. When there is a lot of photosynthesis occurring (usually in bright sunlight) oxygen levels increase, as can pH levels. The latter is because the algae are using CO₂ in excess of the rate that CO₂ can diffuse into water, in effect increasing pH. Also, very low oxygen levels near a lake bottom can cause phosphorous to re-enter the water column from lake bottom sediments.

- How do your results compare among tributaries? This can be a valuable question pertinent to lake health, if you are for instance trying to identify sources of high nutrient loads or estimate the contribution from different subwatersheds.

3. Questions that compare your results with other data sets:

Earlier sections of this manual include extensive discussion of how to sort through other data sets and (when appropriate) combine them with your data into a single composite set. If you do *not* make a composite data set, you may wish to compare your *interpreted* data (e.g. your narrative findings and conclusions) with the findings and conclusions of other studies. One example comparison:

- Did site 1 violate water quality criteria more consistently in your study than in the 1995 Diagnostic Feasibility study?

Remember also that “other data sets” may mean studies similar to yours –on your lake or on other waterbodies– or it may also mean supplementary data such as weather reports.

Some questions:

- What weather conditions prevailed on your sampling dates? Were there any sampling days where heavy rain (define this – e.g. ½ inch or more) occurred within 48 hours preceding any sample collection?
- If sampling tributaries, what were flow levels on sampling days? Was the flow rising or falling?
- How do your results compare with those of other waterbodies (similar or not)?

This last question is probably more valuable from a political or management perspective than it is as a scientific matter. There are any number of natural or anthropogenic differences between any two or more lakes (e.g. residence time, topography, % impervious surface in upstream watershed) to make meaningful data comparisons problematic. It might be appropriate, however, to compare your lake with other lakes in the same ecoregion – or with average values for that ecoregion. A comparison of this nature might give an indication of the relative health of your lake, as discussed previously in the section on the New England regional nutrient criteria.

Other examples of why you might want to compare with other lakes:

- You are collaborating with municipal government to prioritize lakes within city limits to target for restoration projects – or you are doing a similar exercise on a watershed level with the Watershed Team as you identify annual workplan priorities.
- You wish to nominate your lake for Outstanding Resource Water classification

- (which carries with it stricter criteria than the normal statewide standards); you want to document its outstanding ecological value.
- Conversely, you are applying for a grant and wish to use the comparison to show that the lake is one of the unhealthiest in the state, in great need of restoration funds.

4. Take a second look at your data set

There's another line of questioning that involves secondary considerations of your data set. These may be questions you ask after some manipulation of data, such as combining the effects of two or more indicators. For instance, you might ask:

- Is coldwater fishery habitat shrinking? For this, you would look at DO, temperature and lake bathymetry together. This question can be answered if you are taking DO and temperature depth profiles, preferably at several locations around the lake. This question is an issue for Lake Onota. In the 1991 ITC study, they identified the depths at which DO is at least 5 mg/l *and* temperature as no more than 71°F (you might choose 6 mg/l and 68°F, the state criteria). By finding the upper and lower limits of this combination zone, and using a bathymetric map, you can calculate the total lake volume available for coldwater fish. Presumably, with the help of a fisheries biologist, you could then estimate likely "carrying capacity" of the water – i.e. how many fish that zone could support.
- Are conditions favorable to nutrient uptake? For this, you would look at DO levels at sampling locations very near the lake bottom (because of the aforementioned relationship between low DO and nutrient uptake from the sediments). A follow-up question is "Did the expected nutrient uptake occur?" To answer this, you would review TP data for any dates when you found low DO near the lake bottom.

Both of these questions explore the *impact* of or *response* to exposure to different levels of various parameters. The first considers temperature and DO impact on certain fish species, the second looks at what happens to nutrients in the water column as a consequence of anoxic conditions. You might also want to ask other questions relating to either ecosystem or human impacts of various constituents. Some examples:

- "How many days was the swimming (bacteria) standard violated?" Or "How many days was the beach closed due to bacteria violations?"
- "How long do anoxic conditions prevail?" This might be asked for entirely different reasons. In one case, you may want to know how long conditions are stressful to fish and other wildlife. For this issue, it may also be important to ask *when* the anoxic conditions occur, and do they correspond with important times in the life cycle of the target species – e.g. when fish are spawning or eggs are hatching and they may have a particular need for well-oxygenated water. In a different circumstance, you may want to know how long conditions are favorable to nutrient release.

Questions of this nature –i.e. the duration of undesirable conditions– can be more important than simply documenting that such conditions do exist. The longer aquatic life is exposed to stressful conditions, the more likely mortality will occur. The longer conditions are favorable for nutrient release, the more nutrients are likely to return to the water column. And the more often conditions prevent human use of the resource, the greater the impact on quality of life, human health, property values, etc. So it's probably a good idea to construct some of these "impact" questions for your data set.

5. To develop findings from your data:

Notice that we provided a rather generic list of questions, along with several examples tailored to Lake Onota. In some cases, Onota-specific questions were obtained simply by specifying a parameter or other particular information: “Which sites had the highest or lowest *total phosphorus* readings?” In other cases, our LOPA examples required a bit more complicated modification of the generic/basic “Where are the high/low values?” type of question. The questions regarding DO and temperature curves are an example of this.

We suggest you follow a similar process to develop a list of questions specific to your study. Write down those parameters that you will want to ask questions about. For each parameter, write down the state criteria and/or any other threshold values you want to track. Then start writing down question sets for each parameter. Leave space for the answers, and you have a worksheet you can use year after year, study after study (with any modifications necessary to keep up with any study design changes).

No doubt you will need to make up additional questions not included in this manual. We have, for instance, not discussed macrophyte coverage or macroinvertebrate sampling. For either of these, you would ask questions about which sites had the most diversity, did certain species appear or disappear over time (from one study to the next) or did diversity rise or fall, etc. And any studies that key in on specific pollution sources or problems would feature questions on the location, timing, severity, and possible consequences of that pollution source or event; expanding on the before and after, upstream and down type of questions discussed above.

Bear in mind that these questions are all pretty much geared towards revealing ‘interesting’ or suspicious values: Dates, numbers, etc. that might be significant. These are straightforward questions: What, where, how much, how often? There are no “why” questions yet. Those are asked in the next section on *conclusions*. Hence these questions do not involve much in the way of conjecture or debate. You will pretty much know the answer or you won’t – and often if you don’t, it’s because a piece of information is missing... e.g. you don’t have the weather data, or you need more data points to establish a trend.

Once you’ve developed your list, go back to the start and answer each question in turn. In cases where you don’t know the answer, write down why you couldn’t answer and what must be done or what additional information is needed to answer the question.

Here’s an example of what a findings question worksheet might look like when filled out:

Table 11: Findings Questions Worksheet Example

Bacteria	Target Value	Answer
Which sites consistently exceeded the state swimming standard?	400 colonies/100ml	<i>Sites 1,3,4</i>
Which sites consistently exceeded the state boating standard?	2000 colonies/100ml	<i>Site 1</i>
On which dates was the state swimming standard exceeded at numerous sites?	400 colonies/100ml	<i>April 25, May 10, Sept 19</i>
Which sites had the highest single bacteria readings?	1000 colonies/ml	<i>April 25</i>
Which sites had the highest average bacteria readings over the summer?		<i>Sites 1,3</i>
Which sites had the highest wet weather bacteria readings?		<i>Site 1</i>
Total Phosphorus		
What sites consistently exceeded the trophic status index (TSI) oligotrophic limit?	10 µg/l	<i>Sites 1, 3, 9</i>
On which dates did numerous sites exceed 10 µg/l ?	10 µg/l	<i>April 25, Sept 19</i>
Which sites had the highest single TP readings?		<i>Site 1</i>
Which sites had the highest average TP readings over the summer?		<i>Site 1</i>
Which sites had the highest TP readings during spring runoff period?		<i>Sites 1,2</i>
Does weather affect results?		<i>Not sure... Need to find weather data for Aug-Sept 99-01</i>
Etc.		

At this point, you may be ready to write them up as your preliminary findings from the study, and prepare them for distribution to some data users (e.g. your Watershed Team, a state agency). Or you may wish to wait on this until you've reached your conclusions.

II - Develop Conclusions

Conclusions are your explanation of why the data look the way they do. For the most part, your conclusions will relate back to the questions you posed back when you were developing your study design. But you might also discover things you weren't originally looking for (i.e. Onota's shrinking trout layer as reported by ITC). You will want to develop conclusions about these.

A suggested process for developing conclusions:

- Gather your findings and your study questions/objectives together. Organize your findings so that all those related to a particular study question are grouped together.

Under each study question, note which findings appear to strengthen –or weaken– your hypotheses. You may also notice, particularly when reviewing studies others have done, that findings are often accompanied by explanatory or “qualifying” information. This was the case in several of the Lake Onota studies. We repeat here some of the findings reported in the previous section (develop findings), but this time with explanatory remarks provided by the report authors:

- “Secchi reading at site 4 was greatly reduced and generally correlates with eutrophic lake conditions...*It should be remembered however that the Secchi reading at site 4 was recorded only after the weed harvester had passed over that area... The resuspension of bottom sediments can increase turbidity thus influencing Secchi readings*” (ALWS, 1997).
- “Turbidity readings tended to be higher in the north than the south basin... *[this] likely reflected the effects of the weed harvester that had passed over that site only hours before sampling*” (ALWS, 1997).
- “The trout layer ... appears to have declined over the years... *This apparent decline in available trout waters is likely due to an increased sediment oxygen demand which has steadily increased the volume of water with an oxygen deficit*” (ITC, 1991).

Note any such explanatory remarks made by other researchers. You will be adding others as you continue to seek conclusions.

- From a quick look at findings and explanatory remarks, can you answer any of your study questions right off the bat? Jot down the answers. Consider these provisional conclusions.
- Now challenge your assumptions. Test them with the questions listed below – or a similar set that you develop specifically for your lake, as you did for your findings. At this stage, you are not focussing directly on your data as much as you are considering the narrative statements that comprise your findings. Based on the answers to these questions, restate your conclusions as necessary. When you state a conclusion, record what has occurred as well as the reason for it, if you know. Note that you may also find conclusions from other studies. Your challenge is to see if these hold up when viewed with additional data from your own or still other studies. For the time being, treat these “pre-existing” conclusions as provisional, to be tested along with your own preliminary conclusions.

Here are a couple of brief examples of how to move from findings to preliminary conclusions (examples based on Onota Lake):

Study Question # 1.

Have nutrient levels in the lake changed since 1986 (i.e. when first monitored)?
(See Appendix 2 for a review of relevant data.)

Related findings:

“Similar TP values were recorded in Aug 96 and July 1986”... “Nitrate levels were similar in 96 and 86” (ALWS study).

“Water clarity was slightly greater and chlorophyll levels were slightly lower in 1986, than in 1996” (ALWS study).

Qualifying remarks:

(About water clarity and chlorophyll) “It should be cautioned that differences are minor and well within the range of variability that may be expected to occur naturally” and “It is not possible to ascertain whether a true trend is being observed” (ALWS study).

Explanatory remarks:

Different analysis methods allow for lower detection limits in 2001 samples – otherwise most '86, '97 and '01 readings would be indistinguishable. Some samples in the 1986 study were considerably higher: E.g. 0.05 to 0.41 mg/l. But these were all either bottom samples or in different times of year (late fall or winter) – and QC data on these samples is not readily available.

Preliminary conclusion:

Comparing only similar situations, and based on the limiting nutrient (phosphorus) there was no significant difference in nutrient levels from 1986 to 2001.

Study Question # 2.

Are there any significant trends in macrophyte population density and/or in species composition since 1986?

Related findings:

“Macrophyte cover appears to have increased dramatically since the ITC 1986 survey, especially in the south basin, and both milfoil and curlyleaf pondweed have expanded their ranges substantially. Potamogeton ... has nearly been eliminated from the north basin, but is dense in several areas of the south basin and the outlet cove. Aquatic plant cover and biomass ranged from 75 to 100% in the north basin... [in the south basin] coverage approached 100% in many shallow areas” (Fugro, 1996).

Qualifying remarks:

“The increase in distribution and density of curlyleaf pondweed could be a function of seasonal differences in the surveys; this species is known to die back quickly by early July...” (Fugro, 1996). (Note that the 1986 macrophyte survey was done in August.)

Related findings:

“... far fewer species were encountered in the 1986 macrophyte survey than in 1996 or 1997.”

Qualifying remarks:

“In general, these tend to be the less common species and it is likely a consequence of sampling methodology” (ALWS, 1997).

Related findings:

“Of note, however, is the dramatic increase in macrophyte cover in 1997 compared to 1986... significant increases are noticed for *Myriophyllum spicatum* and to a lesser extent *Potamogeton crispus*” (ALWS, 1997). Other species changes, according to ALWS: “*Potamogeton richardsonni* and *Elodea canadensis* showed significant decline.”

Related findings:

“The most surprising finding of both (LOPA and ACT 2001) surveys was the widespread growth of the non-native *Najas minor*, one of 3 species of Bushy Pondweed.” “As for milfoil, its regrowth is significant and widespread” (LOPA, 2001, also reported by ACT 2001). These studies were done after an herbicide treatment the previous year.

Preliminary conclusions:

The macrophyte community has changed significantly. Plant coverage has increased. Non-native species, particularly milfoil and bushy pondweed, have significantly increased, changing the mix of species represented.

And so on for each study question.

The following are examples of questions that you can use to test your study questions and any preliminary conclusions. Many of these questions will look similar to questions or issues you considered earlier in the interpretation process. The difference is that in those earlier exercises you were trying to identify *what* possible influences were (i.e. when gathering background information on weather, topography, etc.) or trying to spot possible effects of those influences (e.g. looking for dates, locations, or conditions when levels were very high or low). You were just laying out all the evidence. Now you are trying to establish cause and effect by asking direct “whodunit” type questions. You’ll probably need the expertise of your TAC to answer many of these questions.

Does weather appear to influence your results?

For example:

- Do high levels regularly coincide with heavy rainfall? This is commonly asked for indicators such as bacteria, nutrients, turbidity, etc. Refine this question by considering the intensity and duration of any precipitation events.
- Alternatively, do high levels ever occur during prolonged hot, dry weather? This might happen with algae counts, or possibly dissolved oxygen if sampling in mid afternoon. Conversely, dissolved oxygen levels can be quite low during prolonged periods of hot, cloudy weather (when photosynthetic activity is low).

Do flaws in your field and/or laboratory techniques explain your results?

You should already have satisfied yourself on this point when you were developing findings. We include it here as a reminder that it doesn’t hurt to check again, especially if you have any particularly unusual findings.

If you are monitoring the impact of a pollution source, does the presence of this source explain your results?

This can be hard to determine in areas where numerous point or non-point pollution sources exist. Try this as a two-step process: First, did your data document a significant change either upstream and down, near to and far from, or before and after a suspected source (depending on the nature of the source)? If not, then you would have to answer no. If there was a notable difference, then ask:

Are there other impacts which might influence or confuse your results?

This can be anything from other nearby pollution sources to weather anomalies. To some extent, you should have resolved this in your study design, by selecting sites or dates that would isolate your primary suspects. However, in the interpretation process, it may be

wise to review visual surveys to identify any (particularly new) possible confusing sources, or to look for situations where you might be able to document or rule out other impacts. For instance, observing runoff from a farm after a fertilizer application when your primary concern is a treatment plant on the same tributary. See next question for similar examples.

For episodic discharges, did your sampling coincide with the discharge?

- For example, did you catch the storm-related polluted runoff you were trying to analyze?
- Some point source discharges are not constant. Did you catch the discharge? Suppose you are concerned about an industrial discharge. Are there times when the factory is not in operation (e.g. during a vacation week or scheduled maintenance shut-down)? In the case of the farm vs. treatment plant, can you find out when fertilizer is applied? Compare your up-down, near-far etc. results during these periods as well as at other times. See if the relationship shifts noticeably.

Might natural changes explain your results?

Here's where you look at some of the information you gathered such as watershed-to-lake size or the New England regional nutrient categories. Are the readings you've obtained normal for your type of waterbody? Another example might be the seasonal shift in populations of different algae species. Do fluctuations in your Secchi disk or chlorophyll data resemble what you would expect from that natural phenomenon?

Might man-made changes explain your results?

For example, was there a shift in population or from summer cottage to year-round shoreline homes during the study period? Enough to cause the changes in results you are finding? You might want to make a check-list of all visual observations you've made – for each “man-made” effect, what's the degree of likely influence? You will want to consider such things as the magnitude of the change, when it occurred, how suddenly, how close to or far from the waterbody or tributary streams, etc. Again, this might be tough to answer when aggregating a number of different changes that have occurred in your watershed. Another job for your TAC.

Did the time of day or season you sampled affect your results? For example:

- Dissolved oxygen is typically lowest at dawn and highest in the late afternoon.
- Did results show a big change around the time of lake turnover (spring or fall)?

Do changes in one of your indicators appear to explain changes in another? For example:

- As lake-bottom dissolved oxygen levels dropped in late summer, did you find a subsequent increase in TP levels?
- Can low DO levels be explained by high water temperatures?

Do your visual observations explain any of your results? For instance:

- Were a lot of geese observed around waters/during times you were sampling nutrients?
- What was the level of powerboat activity on days you measured Secchi depth?

- Were there a lot of dead, decaying plants observed when you recorded low surface DO levels?

For multiple years of data, what are some overall trends? For example:

- Have nutrient levels increased (or decreased) significantly over the study period?
- How do year-to-year fluctuations in nutrient levels compare with rainfall amounts for each year?
- Did any events occur during the study period that might have affected trends? For example, converting septic systems to a sewer line, implementation of a storm drain cleaning program, shifts in land use. Compare data before and after these events.

Important Note: Your data may be inconclusive, especially after only a year of monitoring. The complex relationship between physical, chemical, and biological components of aquatic ecosystems often produces different cycles that can complement, counteract, or follow upon one another. As a result, causes and effects of any particular influence can be more or less severe or prolonged, immediate or delayed, than what the scientific paradigm / literature might predict. For many surveys, you'll likely learn more by monitoring over a 5 - 10 year period than a single year. The moral? Don't be too quick to jump to conclusions.

What other information might you need in order to explain your results? For example:

- Shoreline survey
- Habitat assessment
- Additional indicators
- Documentation from the city regarding when sewer repair was done.

Are there any "new" conclusions you wish to state? I.e. any that are not related to your original study questions?

Occasionally, unexpected findings will crop up. For instance, ITC's finding that Lake Onota's coldwater fishery zone is shrinking. If you find any such nuggets, craft a hypothesis for them (for example "The coldwater fishery zone is shrinking"). Test your new hypothesis just as you did with your study questions. If it passes the test, you can add this to your list of conclusions (e.g., "The coldwater fishery zone appears to have declined over the years ... from 42% of the lake's volume in 1947 to 13% in 1986. The apparent decline ... is likely due to an increased sediment oxygen demand which has steadily increased the volume of water with an oxygen deficit" (paraphrased from ITC, 1991).

Other conclusions examples:

- Drainage from the farm barnyard appears to be causing elevated *E. coli* levels in the lake. The consistently high levels of *E. coli* at site X occur mostly during low flow in the feeder brook. This suggests a continuous source of fecal material entering the brook near this site. These bacteria levels indicate that swimming in the lake at this site is a health risk.
- The elevated phosphorus levels in tributary X are causing impacts to the lake in the form of excessive algal growth. We believe that residential fertilizers may be the cause.

- Erosion from a construction site upstream of site X appears to be causing excessive sediment deposition in the stream. This results in high embeddedness of cobble habitats, deep sediment deposits in pools, and lower abundance of benthic macroinvertebrates (especially the scraper functional feeding group which requires clean rock surfaces) compared with a site immediately upstream.

III. Develop Recommendations

Recommendations are based on your findings and conclusions. They can take two forms: *Action* that should be taken and *further information* that should be gathered.

Examples of recommendations for *action* (from the August 2001 panel that met to examine Onota data. Most of these relate to the issue of excessive weeds on the lake):

- Implement stormwater retention/detention program on major tributaries.
- Create stormwater management ordinance for new developments.
- Complete sewerage/infrastructure improvements.
- Consider macrophyte barriers in specific (small) areas, to create fishing/swimming lanes.
- Draw down lake in winter to 4 foot depth.

Examples of recommendations for *further information* (from ACT 2000 report):

- Institute a macrophyte monitoring program, including “visual inspection of the entire littoral zone of the lake, with specific transects and sampling stations for more detailed plant assessment.”
- An early season aquatic plant survey should be conducted each spring to finalize in-lake management needs for the upcoming season. A late season survey may also be appropriate to evaluate the effectiveness of management activities...
- Sampling stations should be established at the major tributaries, mid-lake, and outlet to evaluate how nutrients are reaching and being processed in the lake.
- A routine sampling program should include the following parameters: Phosphorus, nitrogen, pH, alkalinity, turbidity, color, chlorophyll, coliform bacteria. (A rationale is given for each.)

Recommendations thus conclude the data interpretation process by stating suggestions stemming from your conclusions, as well as by planning further monitoring if necessary.

In Conclusion

Making sense of collected data is obviously an easier task if a good study design was written in the first place, posing questions which then only need to be answered at data interpretation time. An important step necessary to data interpretation –collecting corollary information– should also have been completed at the study design stage.

Nevertheless, once the data is collected and checked for good quality, further research may be needed to fully complete the data interpretation steps: Developing findings, conclusions and recommendations.

Is this the end of the monitoring cycle? Not quite: You are now ready to present your data to your chosen audiences. But that's another story. See the MassWWP *Ready, Set, Present!* manual (Schoen et al, 1999) for advice on effective data presentations.

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Appendices

Appendix 1. Quality Control

Follow these steps to ensure quality control for any data you use – yours or others’.

1. Determine the Quality Control of external data

Use extreme caution when using external data for which there is no quality control available. Ideally you would have access to the study’s Quality Assurance Project Plan (QAPP). At a minimum, you should know what quality control measures were followed and what data passed those measures. You can feel confident using external data or comparing your own data to it if you know that the data set has been thoroughly examined by the researchers: Blank samples came out blank, replicates fell within a certain acceptable interval, data entry was checked and results were scrutinized for accuracy. Lacking this sort of information about an external data set, you should use it only to “flag” suspected problems or issues for further study or additional documentation with a more reliable data set.

2. Look at your own data Quality Control

Of course, you should do the same with your own data. The steps for reviewing quality control should be in your QAPP, but let’s review those steps briefly:

- Did your instruments perform as expected and passed calibration checks?
- Were holding times respected?
- Were the field and lab data sheets reviewed by the coordinator for completeness and logic, and questions resolved?
- Was the computer data entry checked by a second person and mistakes corrected?
- Was the data checked against your data quality objectives? In other words you want to make sure that blank samples resulted in zero concentrations; field and lab duplicates fell within your expected confidence interval, e.g. 10%; blind or audit samples were within your acceptable limits (again, given as a percent, e.g. 10%), or perhaps as an absolute \pm value, e.g. \pm 3mg/l); positive samples for bacteria had colony growth; spike samples result in the expected concentration range.

Then decide whether data that do not pass your data quality objectives will be deleted or flagged. In the latter case, you must make it clear to the data report reader or the data user which data are flagged, why, and what it means to the interpretation of results. Let’s assume for example, that for a particular collection, you passed all quality control benchmarks except that one of your two field blanks came out as near zero, but not zero. Say you decide to flag the data for that collection and to use them in your yearly computations. Clearly indicate that in your data analysis and explain that your results may be overly pessimistic as a result (higher fecal concentrations than in reality, for instance). You may also analyze your data without the failed data and present that alongside the other analysis.

3. Reports from QC officer

Ideally the data reviewer/interpreter does not need to do all of the above because there is a QC officer taking care of those tasks and writing a report on what s/he has found. It is the responsibility of the data analyzer to review the QC officer report(s) and discard or flag problem data accordingly.

4. Outliers

Sometimes all your data pass quality control and yet there will be a data point or two that just don't seem to make sense. For example a site consistently passes water quality standards except for one collection when nothing unusual can be found. Such data points are called outliers, because they often lie outside of the cluster of data points on a graph.

Your first task is to make sure you find all outliers. If you have a large data set, you may miss them if you are just poring over long lists of numbers. We suggest two methods:

- 1) Plot all data on a graph – the outliers will stick out well above or below the other data points.
- 2) If using a spreadsheet, create formatting instructions for the data that will highlight (by printing a different color or with bold type) all values outside of a range you stipulate. E.g. all DO values below 4 or above 13 mg/l will print red.

If you find outliers, you want to make sure that there hasn't been an error somewhere along the way. Review field and lab data sheets to double-check that there were no unusual circumstances that can explain the outlier: Perhaps the sample collector noticed a flock of geese (or cows!) just upstream of the sampling site. Or the chain of custody form shows a discrepancy in holding times. You might also discover a transcription or calculation error that escaped the quality control officer. If you uncover a method error that can't be fixed, you should discard the offending data point.

In the challenging situation where no logical explanation can be found for the outlier, you must keep it in your data set and include it in your analyses, but you can flag it. Alternatively, run the analyses without it but explain why you excluded the outlier.

Appendix 2. Lake Onota Data

The following data set is a partial compilation of all studies known to the Lake Onota Preservation Association. This table was created for use in this data interpretation manual. Only data from sites #1 (deep spot north basin) and #2 (deep spot south basin) were included. Note that when running any calculations on the data (e.g. means and averages), TP readings of “<0.01” were sometimes converted to “0.005” for convenience.

Lake Onota, common data – all sources, similar sites & indicators								
Date	Site#	Data source	TP mg/l	Chloro a mg/m3	Temp °C	Secchi meters	Surface DO mg/l	DO at depth mg/l
3/4/86	1	ITC	0.02	1.2				
3/4/86	2	ITC						
3/22/86	1	ITC	0.01	0.39				
3/22/86	2	ITC	0.01	0.39				
4/8/86	1	ITC	<0.01	0.93				
4/8/86	2	ITC	<0.01	1.7				
4/25/86	1	ITC	0.02	3.3				
4/25/86	2	ITC	<0.01	3				
5/6/86	1	ITC	<0.01					
5/6/86	2	ITC	0.02	2.1				
6/24/86	1	ITC	0.01	2.8	19.5		8.50	3.00
6/24/86	2	ITC	0.01		19.5		8.50	1.70
7/26/86	1	ITC	<0.01	1.52	24.5		8.50	1.70
7/26/86	2	ITC	0.01	0.9	24.5		9.50	3.00
8/14/86	1	ITC	<0.01	2	24		9.00	1.50
8/14/86	2	ITC	<0.01	2.1	24		8.50	1.00
10/16/86	1	ITC	<0.01	3.2	13.5		8.50	0.50
10/16/86	2	ITC	<0.01	3.3	12		10.00	7.00
11/14/86	1	ITC	0.41	1.9	7		9.00	9.50
11/14/86	2	ITC	0.02	1.5	2.5		10.50	11.00
8/30/96	1	Onota			22.9	5.3	6.40	
8/30/96	2	Onota				5.9	6.10	
7/29/97	1	ALWS	< 0.01	7.5	23.5	5	8.50	0.50
7/29/97	2	ALWS	< 0.01	7.7	23.5	4	8.60	6.00
8/1/97	1	Onota		1.1	24.1	4.8		
8/1/97	2	Onota			24.0	5.8		
8/4/98	1	Onota			24.6	4.3	6.40	0.10
8/4/98	2	Onota			24.6	6.4	6.10	0.10
7/28/99	1	Onota			26.7		6.81	0.29
7/28/99	2	Onota			26.8		7.22	0.35
7/29/99	1	ACT	0.04					
7/29/99	2	ACT	0.02					
8/4/99	1	Onota				1.3	6.70	
8/4/99	2	Onota						
6/13/00	1	Onota	0.006	6.5	18.3	3.2	9.80	0.75
7/28/00	1	Onota			21.3	2	7.30	0.38
7/28/00	2	Onota			22.1	3.6	8.33	0.26
6/25/01	1	Onota	0.008	5.0	22.6	3.6	8.24	0.35
6/25/01	2	Onota	0.006	2.9	22.3	6.8	8.46	0.28
8/18/01	1	Onota	0.008	5.1	24.8	3	7.57	0.20
8/18/01	2	Onota	0.005	4.0	25.3	5	7.93	0.16

Appendix 3. SMART Program Guidance

(Strategic Monitoring and Assessment for River Basin Teams Program guidance).

Author: Warren Kimball, MA DEP Central Office.

These are not official guidance for the State 305(b) report or water quality standards because they contain many simplifying assumptions.

See next 9 pages.

ENVIRONMENTAL INDICATORS FOR WATER USES

<u>INDICATOR GROUP</u>	ECOLOGICAL CONDITION			HUMAN HEALTH		
	Aquatic Life	Primary Recreation	Secondary Recreation	Fish Consumption	Drinking Water	Shellfishing
<u>Chemical Exposure</u>						
1. Dissolved Oxygen	X	X	X		(X)	
2. pH	X	X		(X)	X	
3. Nutrients	X	(X)	(X)			
4. Toxics						
A. Water	X	X		(X)	X	
B. Sediment	X					
C. Tissue	X			X		
<u>Physical Habitat</u>						
5. Water Quantity	X		(X)		X	(X)
6. Geomorphology	X	(X)	(X)			
7. Temperature	X	X	X		X	(X)
8. Suspended Solids/Turbidity/Color	X	X	(X)		X	
9. Substrate/Sediment	X	(X)	(X)			
10. Riparian Zone	X	X	X			
<u>Bioexposure</u>						
11. Pathogens/Indicators		X	X		X	X
<u>Bioresponse</u>						
12. Plankton/Periphyton	X	(X)	(X)		X	X
13. Macrophyton	(X)	X	X			
14. Macroinvertebrates	X				(X)	
15. Fish	X					
16. Semiaquatic Wildlife	X		X			

Legend X - Primary Indicator - criteria available and commonly used.

(X) - Secondary Indicator - criteria not always available or is site-specific; used to support primary indicators.

RATIONALE FOR ENVIRONMENTAL INDICATORS

INDICATOR GROUP	AQUATIC LIFE	PRIMARY RECREATION	SECONDARY RECREATION
1. Dissolved Oxygen (BOD, benthic demand, redox potential)	Required for respiration of aquatic life. Affects toxicity.	Anaerobic water is unaesthetic.	Anaerobic water is unaesthetic.
2. pH (Ionic strength, hardness, alkalinity, conductivity, salinity, total dissolved solids)	Affects life, toxicity and chemical processes, alters habitat suitability.	Extreme pH irritates eyes.	
3. Nutrients (phosphorus, ammonia, nitrate)	Affects productivity, toxicity and community structure.	Affects macrophyton and plankton growth (eutrophication).	Affects macrophyton and plankton growth.
4. Toxic Pollutants (ammonia, chlorine, priority pollutants, toxicity tests) A. Water B. Sediment C. Tissue	Toxic to aquatic life. Toxic to aquatic life. Shows exposure, potential toxicity to aquatic life, wildlife.	Toxic to swimmers.	
5. Water Quantity	Depth and flow needed for habitat.		Flow maintenance for boating, fisheries.
6. Geomorphology (slope, bank stability, channel morphology)	Type of habitat (erosive or depositional) controls biotic community.	Type of habitat governs recreation potential.	Type of habitat governs recreation potential.
7. Temperature	Affects life processes and community structure.	Affects deep body temperature of swimmers.	Fisheries are temperature dependent.
8. Suspended Solids (turbidity, color, Secchi disc depth)	Reduces habitat, light penetration, clogs gills, affects primary productivity, can trap and transport toxics.	Affects safety and aesthetic enjoyment.	Turbidity/color unaesthetic

RATIONALE FOR ENVIRONMENTAL INDICATORS (CONTINUED)

INDICATOR GROUP	AQUATIC LIFE	PRIMARY RECREATION	SECONDARY RECREATION
9. Substrate (sediment, embeddedness, size distribution)	Affects habitat, chemical availability.	Mud bottoms are unaesthetic.	Mud bottoms reduce fish availability.
10. Riparian Zone (shoreline vegetation, canopy, cover)	Affects habitat, temperature productivity, oxygen, inputs of organic matter.	Affects habitat, temperature, aesthetics.	Affects habitat, temperature, aesthetics.
11. Pathogens/Indicators		Potential pathogen exposure from ingestion.	Potential pathogen exposure from incidental contact.
12. Plankton/Periphyton	Biomass indicates primary production. Assemblage indicates trophic status, specific chemical effects, toxicity.	Biomass affects swimming, aesthetics.	Biomass affects boating, aesthetics.
13. Macrophyton	Biomass indicates habitat, food and trophic status.	Rooted and floating plants can entangle bathers.	Dense growths impair boating and fishing.
14. Macroinvertebrates	Assemblage reflects ecosystem health, structure and function.		
15. Fish	Assemblage reflects ecosystem, health structure and function.		
16. Semiaquatic Wildlife	Populations show system status, biomarkers show chemical exposure.		Harvestable populations.

WATER QUALITY CRITERIA FOR ENVIRONMENTAL INDICATORS (CONTINUED)

INDICATOR GROUP	AQUATIC LIFE	PRIMARY RECREATION	SECONDARY RECREATION
8. Suspended Solids Turbidity Transparency Aesthetics Oil & Grease	≤ 10.0 mg/l Suspended Solids	Δ5 N.T.U. ≥ 4.0 ft. Secchi disc depth	
		No Objectionable: 1. deposits 2. floating debris, scum other matter 3. color, odor, taste or turbidity 4. nuisance or undesirable species of aquatic life Free from visible sheen, oily taste in the water, objectionable despotism on banks or bottom.	
9. Substrate	US EPA RBP II and III Analysis		
10. Riparian Zone	MA DEP Habitat Assessment		
11. Pathogens/Indicators Fecal Coliform		< 5 samples ≤ 400/100 ml ≥ 5 samples ≤ 200/100 ml geometric mean and ≤10% of samples ≥ 400/100 ml	< 5 samples ≤ 2000/100 ml ≥ 5 samples ≤ 1000/100 ml geometric mean and ≤10% of samples ≥ 2000/100 ml
12. Plankton/Periphyton	BPJ	BPJ	
13. Macrophyton	BPJ	BPJ Lakes - cover of macrophytes < 50% of lake area at maximum extent of growth.	
14. Macroinvertebrates	RBP II - non impaired RBP III - non impaired or slightly impaired.		
15. Fish	BPJ		
16. Semiaquatic Wildlife	Site-Specific		Site-Specific

Δ = Change from ambient
BPJ = Best Professional Judgment
RBP = Rapid Bioassessment Protocol

WATER QUALITY ASSESSMENT REPORT CARD

<u>SUBJECT</u>	<u>INDICATOR GROUPS</u>	<u>RELEVANCE/REMEDIAL ACTIONS</u>
1. Water Quality A. Chemistry B. Nutrients C. Toxics	Dissolved Oxygen/pH/Temperature Phosphorus/Nitrogen Compounds Toxics in Water	Provides basic background for habitat and chemical reactions/secondary treatment. Enrichment potential, cultural eutrophication/tertiary treatment. Water column toxicity/source reduction, pretreatment, industry specific treatment.
2. Sediment	Toxics in Sediments	Accumulation of pollutants in sediments, historic pollution/dredging, capping, resuspension management.
3. Water Quantity	Depth and Flow Hydrologic Modification	Flow alterations/minimum flow requirements, hydrograph protection.
4. Habitat	Substrate/sediment/geomorphology riparian zone.	Habitat alterations/habitat restoration.
5. Bacteria	Pathogens Pathogen Indicators	Potential exposure to pathogens/chlorination ozonation, ultra-violet light.
6. Aesthetics	Suspended Solids/Turbidity/Color/ Aesthetics	Minimum requirements for freedom from pollution/primary treatment, enforcement.
7. Fish Tissue	Toxics in Tissue	Bioaccumulation, biomagnification/fish and shellfish advisories.
8. Biology	Macroinvertebrates/Fish/ Macrophyton/Plankton/Periphyton/ Semi-aquatic Wildlife	Bioresponse to other stressors (chemistry, nutrients, toxicity, habitat) short term cosmetic controls; long term controls require causal relationship with stressors.

MONITORING GOALS

QUESTION	MONITORING TYPES	ACTIVITY
1. What is the condition of the resource?	Status	Assess the condition of water uses or water quality.
2. Is the condition changing?	Trends	Determine how water uses or water quality is changing over time.
3. What are the stressors? (Activities that impact the Environment)	Causes	Determine specific physical/chemical/biological characteristics that impair uses.
4. What systems are vulnerable to human impacts?	Trends Loadings Critical Areas	- Downward trend - Determine concentrations or mass of individual pollutants. - Locate areas with greater pollution potential
5. How do we restore and enhance the resource?	Total Maximum Daily Loads (TMDL) Water Quality Standards (WQS) Permits Grants Non Point Source (NPS)	- Calibrate and validate math models to determine Water Quality based limits. - Collect ecoregion information needed to revise water quality standards. - Collect data necessary to issue/reissue permits. - Collect data necessary for the issuance or grants. - Collect data on nonpoint sources of pollution and performance of Best Management Practices (BMP).
6. Are our management strategies working?	Trends Loadings WQS	- Document improvements in water quality/or the protection of pristine areas. - Document decrease in pollutant loads. - Provide information for improved policies and criteria.

MONITORING TIME & SPACE SCALES

SPACE SCALE	DRAINAGE AREA	RELEVANCE
1. River Basins	1000 + sq. mi.	Statewide Trends 305(b)
2. Sub-Basins (27 Mass. Planning Units, 5 + order rivers).	100 – 1000 sq. mi.	Basin Planning
3. Watershed (3+4 order tributaries)	10 – 100 sq. mi.	Municipal Zoning
4. Subwatersheds (1+2 order streams, 75% of total stream miles).	0 – 10 sq. mi.	Stream Classification BMP's, site design
TIME SCALE	VARIABLES	RELEVANCE
1. Year	Climatic Changes Chronic Toxicity	Trends
2. Season	Annual hydrologic cycle snow melt, evapotranspiration	WQS Loadings (Rivers)
3. Month	Critical Periods, low flows/high flows	Permits Loadings (Point Source)
4. Week	Reaction rates, modeling Time of Travel	TMDLs (DO/BOD)
5. Day	Random Events Stormwater loadings	Compliance NPS, Grants
6. Hour	Diurnal variation Acute Toxicity	TMDLs (Nutrients/Toxicity)

**TIME & SPACE SCALES
FOR
INDICATORS**

SPACE SCALE	DISSOLVED SOLIDS	TOXICITY	NUTRIENTS	SUSPENDED SOLIDS	DISSOLVED OXYGEN	BACTERIA	HABITAT
1. Basin (50-5000 mi.)	X	Chronic	X	(X)	(X)		
2. Regional (1-500 mi.)	(X)		X	X	X	(X)	(X)
3. Local (0-5 mi.)		Acute		(X)	(X)	X	X
TIME SCALE							
1. Decade	X	Chronic	X				X
2. Year	X		X	X			X
3. Season			X	X	(X)		X
4. Month			X	X	X		
5. Week				X	X	X	
6. Day				X	X	X	
7. Hour		Acute				X	

Appendix 4. Useful information

This appendix lists useful web-based information cited in this report.

Aerial photographs, topographic maps

University of Massachusetts Earth Science Information Office:

<http://www.umass.edu/tei/esio/>

Bathymetric maps

Massachusetts Fisheries and Wildlife:

http://www.state.ma.us/dfwele/dfw/dfw_pond.htm

Bedrock and surficial geology maps

USGS: <http://ma.water.usgs.gov/basins/>

Carlson's Trophic State Index

EPA: <http://www.epa.gov/bioiweb1/aquatic/carlson.html>

GIS maps

Massachusetts GIS office: <http://www.state.ma.us/mgis/>

Land use information

The best source is GIS maps, available from your local planning agency, your watershed team leader, and from Massachusetts GIS office: <http://www.state.ma.us/mgis/>

Massachusetts Water Watch Partnership

<http://www.umass.edu/tei/mwwp/>

Rainfall-runoff computer model

Michigan Tech University: <http://www.cs.mtu.edu/~mxue/epa/java/rainfall.html>

Regional Nutrient Criteria

EPA: <http://www.epa.gov/ost/standards/nutrient.html>

Shoreline Surveys

Riverways Program:

http://www.state.ma.us/dfwele/dfw/dfw_pond.htm

Soils Maps

Natural Resources Conservation Service:

http://www.ma.nrcs.usda.gov/conservation_prog.htm#soil

Study Design Workbook

Volunteer Environmental Monitoring Network. Merrimack River Watershed Council:

<http://www.umass.edu/tei/mwwp/acrobat/studydesign.PDF>

Volunteer Monitor Newsletters:

<http://www.epa.gov/volunteer/spring95/mpdata13.htm> (Variability happens)

<http://www.epa.gov/volunteer/spring95/mpdata17.htm> (Interpreting your data)

Water quality assessment reports (MA State 305(b) reports)
MA DEP: <http://www.state.ma.us/dep/brp/wm/wqassess.htm>

Water quality standards (MA)
MA DEP: <http://www.state.ma.us/dep/bwp/iww/files/314004.pdf>

Weather data
Northeast Climatic Data Center: <http://205.156.54.206/er/box/clstns.htm>

Understanding lakes
<http://lakeaccess.org/understanding.html>