The 2017 Survey of Oregon Lakes

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Abbreviations and Acronyms

ANC	Acid-neutralizing capacity
ANOVA	Analysis of variance
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DOC	Dissolved organic carbon
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
OAR	Oregon Administrative Rule
DEQ	Oregon Department of Environmental Quality
OHA	Oregon Health Authority
NARS	National Aquatic Resource Surveys
NALMS	National Association of Lake Management Society
NLA	National Lakes Assessment
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated diphenyl ethers
PCBs	Polychlorinated Biphenyls
PNW	Pacific Northwest (Idaho, Oregon, Washington)
RCA	Reference Condition Approach
TCEP	Tris(2-carboxyethyl)phosphine
Tukey’s HSD Test	Tukey’s Honestly Significant Difference Test

1. Introduction

Natural lakes and human-made reservoirs are important resources to all Oregon communities. They provide access to clean drinking water, irrigation water and recreational opportunities, such as fishing, swimming and boating, and are important culturally to Oregon's tribes. The natural diversity of lakes in Oregon ranges from coastal dune lakes to hyper-saline lakes in South Central Oregon, and the ultra-clear lakes of the high Cascades. While DEQ conducts some limited lake monitoring, participation in the National Lakes Assessment is currently the agency's only regular program for monitoring lake conditions throughout the state.

What is the National Lakes Assessment?

The National Lakes Assessment, or NLA, is a collaborative effort between the U.S. Environmental Protection Agency and tribal/state/local partners to monitor and assess the status and trends of ecological conditions in the nation's lakes and reservoirs. EPA provides the funding for survey designs, equipment, training and laboratory costs. However, tribes, states or private contractors oversee field sampling.

The NLA is one of four assessments included in the National Aquatic Resource Surveys program. Other surface waters sampled include rivers and streams, wetlands and coastal bays and estuaries. National Aquatic Resource Surveys rotate the sampling of water types over a five-year cycle. DEQ has participated in nearly all rounds of national survey sampling. Additionally, DEQ helped to develop the national survey program through participation in smaller scale regional surveys in the 1990s and the Wadeable Streams Assessment in the early 2000s.

What are the objectives of the NLA?

The NLA attempts to answer several key questions about lakes and reservoirs at the national scale.

- What percent of lakes and reservoirs support healthy ecosystems and recreation?
- What are the most common water quality problems?
- Is water quality improving or getting worse?
- Are investments in improving water quality focused appropriately?

What is special about 2017 NLA for Oregon?

2017 NLA saw DEQ utilize a partnership between two DEQ water quality monitoring programs. The Biomonitoring Program (which oversees NLA sampling) and the Toxics Monitoring Program combined their efforts to collect data simultaneously at Oregon lakes sampled as part of the NLA. This provided DEQ the opportunity to maximize resources and boost our sample size from 29 randomly selected lakes to 49 lakes. It also represents the first *statewide* assessment of toxic compounds in Oregon's lakes and reservoirs.

DEQ completed previous rounds of the NLA in 2007 and 2012, with DEQ sampling 30 and 29 sites, respectively. These sample sizes are too small to summarize statewide lakes conditions in a statistically valid manner, although a [summary report and individual lake summaries]() are available for the 2007 NLA. Unfortunately, unlike the national 2017 NLA report, our lower sample sizes in Oregon do not allow for change-over-time comparison estimates to be made from one NLA period to the previous. However, comparisons to other Pacific Northwest states may provide some insights into what is happening over time with Oregon's lakes (Figure 1).

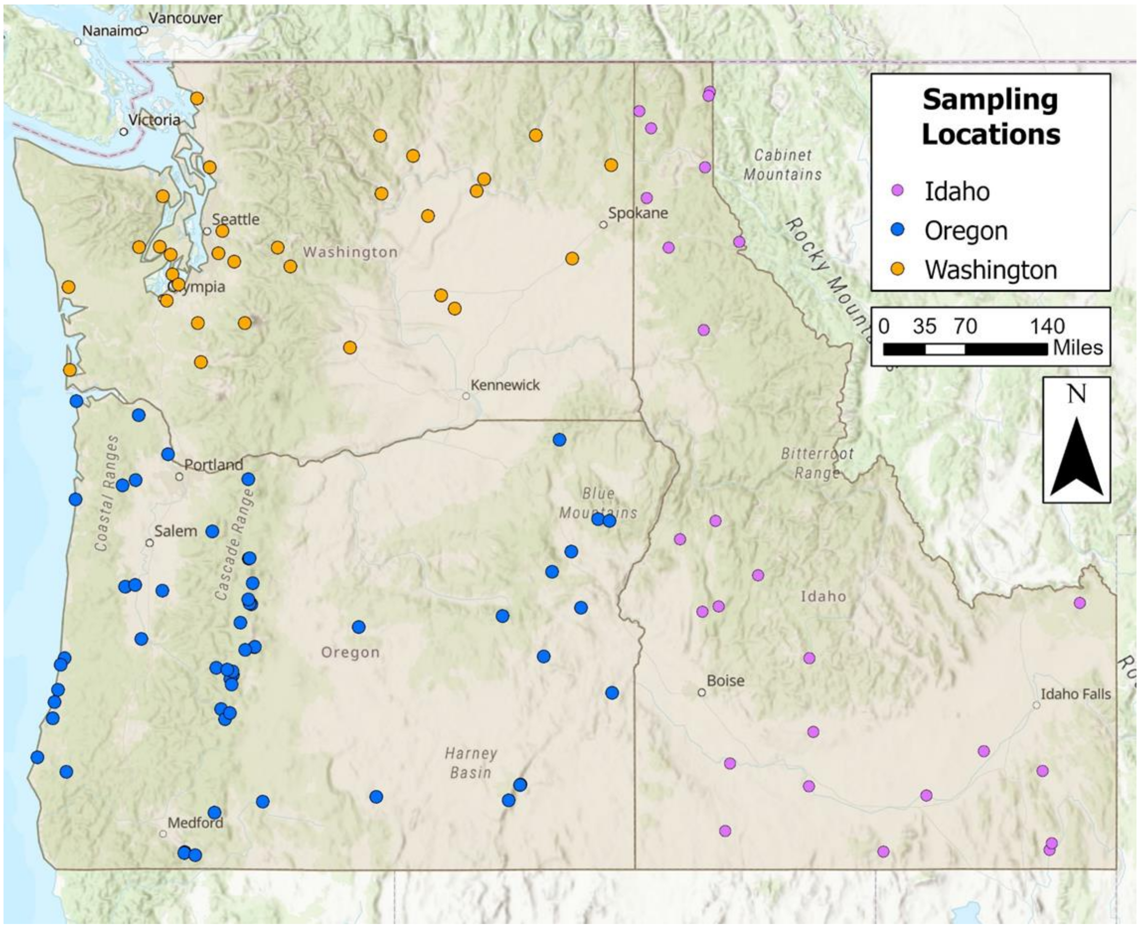

Figure 1. Pacific Northwest states used for comparison with the population of Oregon lakes. Circles represent the lakes sampled in each state.

DEQ also solicited input from stakeholders about lakes of concern that should be sampled in addition to the 49 NLA randomly selected lakes. DEQ fully funded the sampling and analysis for these targeted lake surveys. A total of four "targeted" (non-random) lakes were assessed, for a variety of reasons. Results for these non-randomly selected lakes can be found in Appendix A and are not included in the 2017 NLA survey findings, since lakes included in the NLA must be randomly selected.

This report summarizes the findings of the 2017 NLA surveys, with results presented at the statewide scale for Oregon. This report presents the differences between results observed in Oregon and those published by the EPA in the *National Lakes Assessment: The Third*

Collaborative Survey of Lakes in the United States (EPA 2022a). These regional comparisons are also addressed in the Oregon Lakes Interactive-Dashboard.

1.1 Key Findings

This section provides a high-level summary of results from the Oregon 2017 NLA. Estimates of lake conditions are provided here without the error associated with the estimates. See the main body of the report for a more complete view of the results.

Study overview

- The results presented in this report are estimates of conditions for all of Oregon's 4,819 lakes, based on sampling 49 randomly selected lakes.
- Each result presented is an estimate of true conditions with associated margins of error.
- At the national scale, with 1,005 lakes sampled, margins of error are approximately 5 - 10%.
- For Oregon, with 49 lakes sampled, margins of error typically range from 10 - 20%.
- We chose to follow convention with the national survey and use 95% confidence intervals, which may be considered too stringent for assessing ecological data with small sample sizes.
- For some indicators, there is a status of "Not Assessed." These represent instances where a sample could not be taken in the field, or the sample was compromised.

Increased monitoring offers insights into the conditions of Oregon's lakes.

- Additional funding by DEQ allowed for the first ever statewide assessment of toxics in Oregon's lakes.
- Oregon's population of lakes showed a high degree of similarity to conditions observed across Pacific Northwest states (Oregon, Washington and Idaho).
- Due to this similarity, changes observed at the Pacific Northwest scale may be useful to describe potential changes happening in Oregon's lakes, even when Oregon's future NLA sample sizes are too small for an adequate statewide assessment.

Biological conditions of Oregon's lakes were generally good, overall.

- Zooplankton communities were found to be in good condition for about 71% of Oregon lakes. With approximately 18% of lakes in fair condition and 7% in poor condition, this represents about 1,200 lakes with "at risk" zooplankton communities.
- Benthic macroinvertebrates were mostly observed to be in good condition (about 78% of lakes). However, approximately 21% of lakes were found to be in fair condition and about 1% in poor condition, meaning about 1,000 lakes in Oregon had "at risk" benthic macroinvertebrate communities.

Measures of eutrophication, or excess nutrients, were the most widespread indicators of poor conditions in Oregon's lakes. Nutrients were also identified as the most extensive stressor at the national scale.

- Chlorophyll *a* levels were estimated to be in poor condition for about 35% of Oregon lakes, or approximately 1,700 lakes, while about 46% were estimated to be in good condition.
- Phosphorus was estimated to be in poor condition for about 21% of Oregon's lakes, which represents approximately 1,000 lakes. The majority (about 74%) of Oregon lakes were estimated to be in good condition.
- Nitrogen was estimated to be in poor condition for about 13% of Oregon's lakes, or approximately 600 lakes, but the majority (about 60%) were estimated to be in good condition.

Lakeshore habitat represented the second highest class of stressors in poor condition.

- High levels of human disturbances in the riparian zone were observed in an estimated 11% of lakes, which represents about 500 lakes.
- About 44% of lakes were estimated to be in good condition for human disturbances in the riparian zone. This was the lowest percentage lakes in good condition for any of the stressors assessed.

All detected *E. coli* and microcystin concentrations occurred below recreational contact designations.

- *E. coli* was estimated to occur at concentrations within the safe level for recreational contact in 34% of Oregon lakes. No detectable concentration was found in the remaining lakes.
- Microcystin was estimated to occur in 2% of Oregon lakes, which represents 96 lakes. The Oregon Health Authority issued five cyanobacteria advisories for microcystin in 2017.
- The sampling protocol may underrepresent risk compared to targeted recreational use sampling at specific locations of high recreational use such as boat docks or beaches.

Most compounds included in the toxics assessment of Oregon lakes rarely exceed human health or aquatic life criteria.

- Only 21 of the 525 compounds of those included in the analysis of water and sediment samples occurred at concentrations above applicable criteria or benchmarks.

Lake sediment samples contained compounds that persist in sediment and bioaccumulate in fish and other aquatic life.

- Mercury (present in about 55% of Oregon lakes), DDT (present in around 44% of Oregon lakes) and PCBs (present in approximately 27% of Oregon lakes) were found at

concentrations over DEQ sediment bioaccumulation background or screening levels in some locations.
- OHA has fish consumption advisories in many reservoirs and lakes across the state for mercury.

PCBs detected in sediment samples, none detected in water samples.

- Analysis of both water and sediment samples included 172 different PCB compounds. None of the included compounds were detected in the water samples, while 72 of the compounds were detected in sediment samples.

2. Background

This section provides brief summaries of the 2017 NLA survey design and methods. Visit EPA's websites for detailed descriptions of the NLA survey design and field methods.

The NLA uses a probabilistic study design to randomly select many lakes, sample them for indicators of ecological and human health, and report on the ecological and human health conditions of lakes and reservoirs at various geographic scales. The random nature of this survey allows for reporting of conditions with known statistical confidence. Nationally, states, tribes, or other partners sampled 1,005 lakes in 2017, while DEQ sampled 49 lakes and reservoirs across Oregon. Figure 2 shows the lakes included in this report. Along with the 49 randomly selected lakes, DEQ collected water and sediment samples at four additional lakes targeted as lakes of interest. The results from the targeted lakes samples are included in Appendices A and B but are not included in the analysis of statewide conditions.

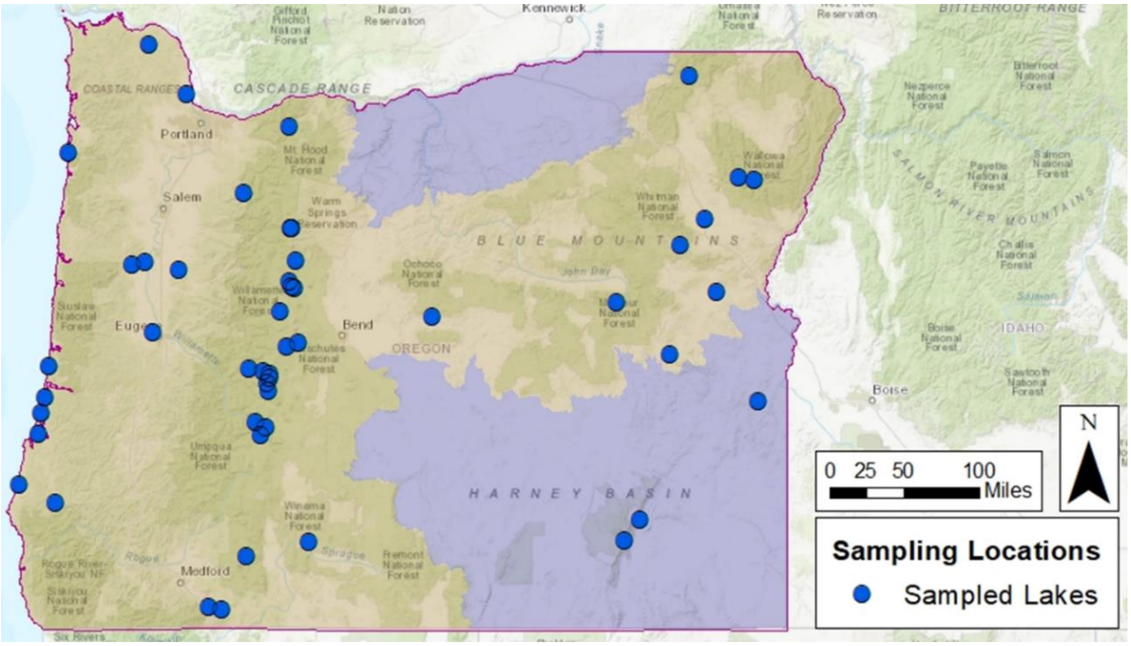

Figure 2. The population of Oregon lakes included in this report. The beige shading on the map indicates the western mountains ecoregion while the purple shading indicates the xeric ecoregion (Wilken, et al. 2011).

2.1 Choosing Indicators

DEQ's 2017 NLA addresses six types of indicators. The first five indicators were standard to all rounds of NLA sampling: trophic state, biological, chemical, physical and contact recreation. These five indicator categories allow direct comparisons to the results observed at national and regional scales. The sixth type of indicator, toxics, was unique to Oregon's 2017 NLA surveys. The only compound monitored in Oregon and at the national scale was the pesticide atrazine. DEQ included the atrazine samples collected by EPA in the analysis of Oregon lakes. The results are reported in the DEQ monitoring results section.

2.2 Selecting Lakes

What types of waterbodies are considered lakes?

The target population of lakes for 2017 NLA was derived from the National Hydrography Dataset (EPA 2022b). It includes any pond, lake, or reservoir with the following characteristics:

- At least 1 hectare (2.47 acres) in surface area
- At least 1 meter (3.3 feet) deep
- At least 0.1 hectare (0.25 acres) of open water
- A minimum residence time of one week

Waters excluded from this population include:

- The Great Lakes
- The Great Salt Lake
- Commercial treatment/disposal ponds
- Tidally influenced lakes
- Ephemeral lakes (those that dry completely, or to less than the depth/surface area requirements)

Interpreting results of the NLA

Based on the above criteria, results from the 49 randomly selected and sampled lakes represent the ecological conditions of the 4,819 Oregon lakes and reservoirs meeting the target population definitions. Stratified random sampling ensured that the lakes sampled had adequate representation across size classes. Each of the 49 sampled lakes was assigned a “weight”, representing a certain number of the total lakes in Oregon. Because there are many more small lakes (between 1-4 hectares) than large lakes (> 50 hectares), each small lake had a greater weight, meaning each small lake represents a greater number of the total lakes in Oregon (Table 1). See the 2017 NLA Technical Support Document for details (EPA 2022b).

Table 1. Sample size, actual number of lakes in Oregon and examples for each size class included in the study.

Lake Size	# of Lakes in Study	# of Lakes in Oregon	Example	County
1-4 hectares	13	3447	Chamberlain Lake	Tillamook
4-10 hectares	13	683	Timber Lake	Jefferson
10-20 hectares	9	369	Lake Edna	Douglas
20-50 hectares	5	92	Cheadle Lake	Linn
>50 hectares	9	227	Emigrant Lake	Jackson

2.3 Field Sampling

DEQ restricted sampling for the NLA to the summer growing season (June – September), prior to lake turnover. For each site, sampling occurred over a single day, and generally in three different zones (Figure 3):

<u>Mid-lake:</u> At the deepest point of the lake, crews collected the following near-surface water samples: chemistry, chlorophyll *a* and toxics (specific to DEQ’s study only). Additional samples at the deepest point include secchi depth, zooplankton tows and a vertical profile of temperature, conductivity, pH, dissolved oxygen and sediment for chemical analyses.

<u>Nearshore (littoral):</u> This zone represents the shallow-water transition zone between the lake’s shoreline and the deeper waters of the lake. The littoral zone is sampled within 10 meters from the shoreline and included 10 equally spaced littoral plots around the lake. Samples within the littoral zone include benthic macroinvertebrates and near-shore physical habitat features.

<u>Shoreline (riparian):</u> This zone represents the upland interface with the shoreline and littoral zones. Ten riparian zone plots, located on shore near the littoral plots, are sampled by

observation from the boat. Observations in the riparian zone include physical habitat features of riparian and shoreline vegetation, near-shore sediment composition, and human disturbances.

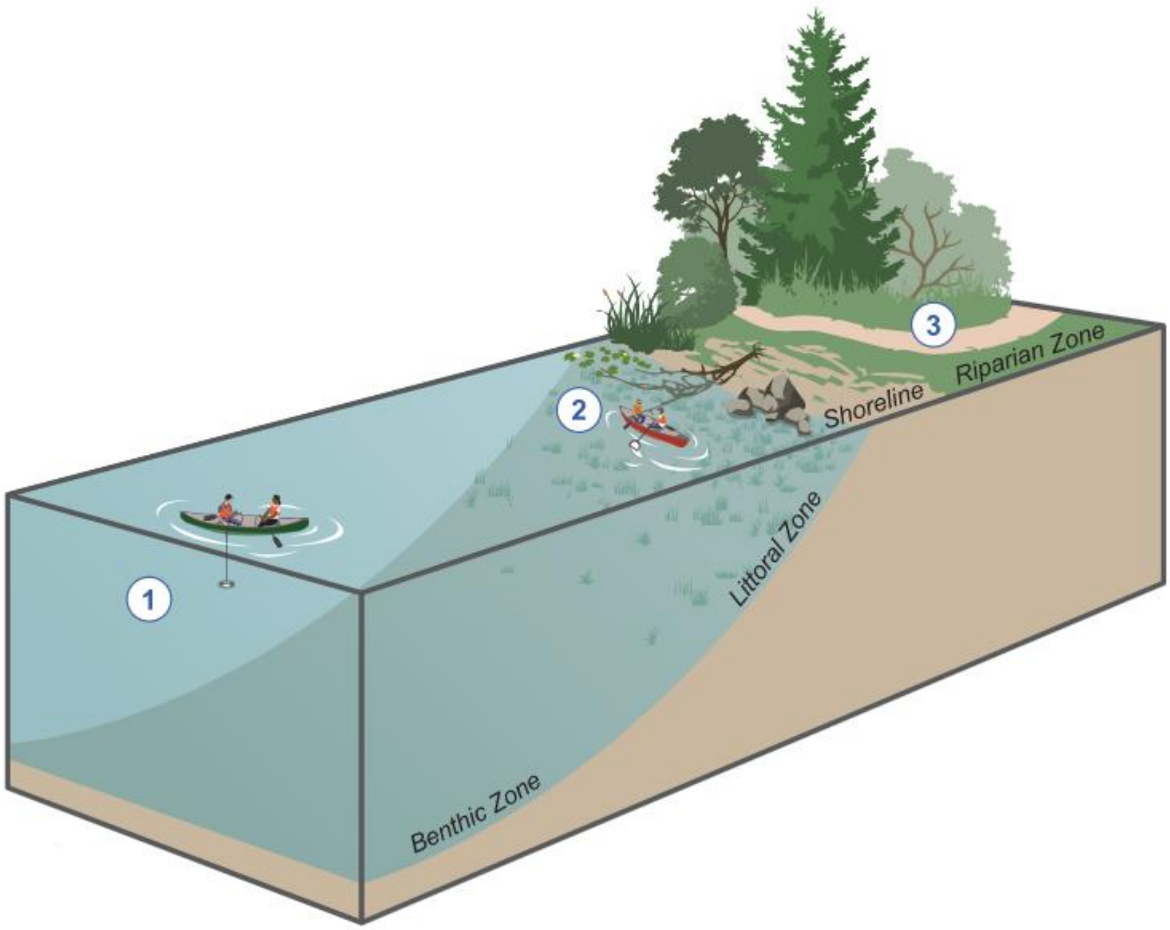

Figure 3. Lake zones sampled at each lake included in this study. The numbers represent the different zones sampled (1) mid-lake zone, or the deepest part of the lake, (2) the nearshore or the littoral zone and (3) shoreline, or riparian zone. Figure taken from EPA 2022a.

2.4 Assessment Benchmarks

DEQ's Biomonitoring Program typically uses a Reference Condition Approach (RCA) for assessing biological communities and parameters that do not have numeric water quality criteria (for example: sediment, nutrients, conductivity). However, DEQ does not have established reference thresholds for Oregon's lakes. For this report, assessment of all indicators, except for toxics data, used EPA's approach to evaluate lake conditions. A general overview of how NLA analysts assigned each lake into a condition class for each indicator can be found in the National NLA report (EPA 2022a). A more detailed description can be found in the 2017 NLA Technical Support Document (EPA 2022b).

DEQ uses two approaches to assess indicators in this report. The first approach, the EPA approach, compares sampling results to ecoregion-specific "reference sites". These reference sites represent the lakes with the lowest amounts of human disturbance and are used to set benchmarks for each indicator. Results from randomly selected lakes were compared to reference sites from the Western Mountains and Xeric ecoregions (Figure 4). EPA developed benchmarks based on the distributions of indicator values in the population of reference sites for each ecoregion to account for natural variation. After comparison with these benchmarks, DEQ assigned indicator values for each lake to one of three condition classes: “good” (< 75th percentile of reference observations), “fair” (between the 75th to 95th percentiles) and “poor” (> 95th percentile of reference observations).

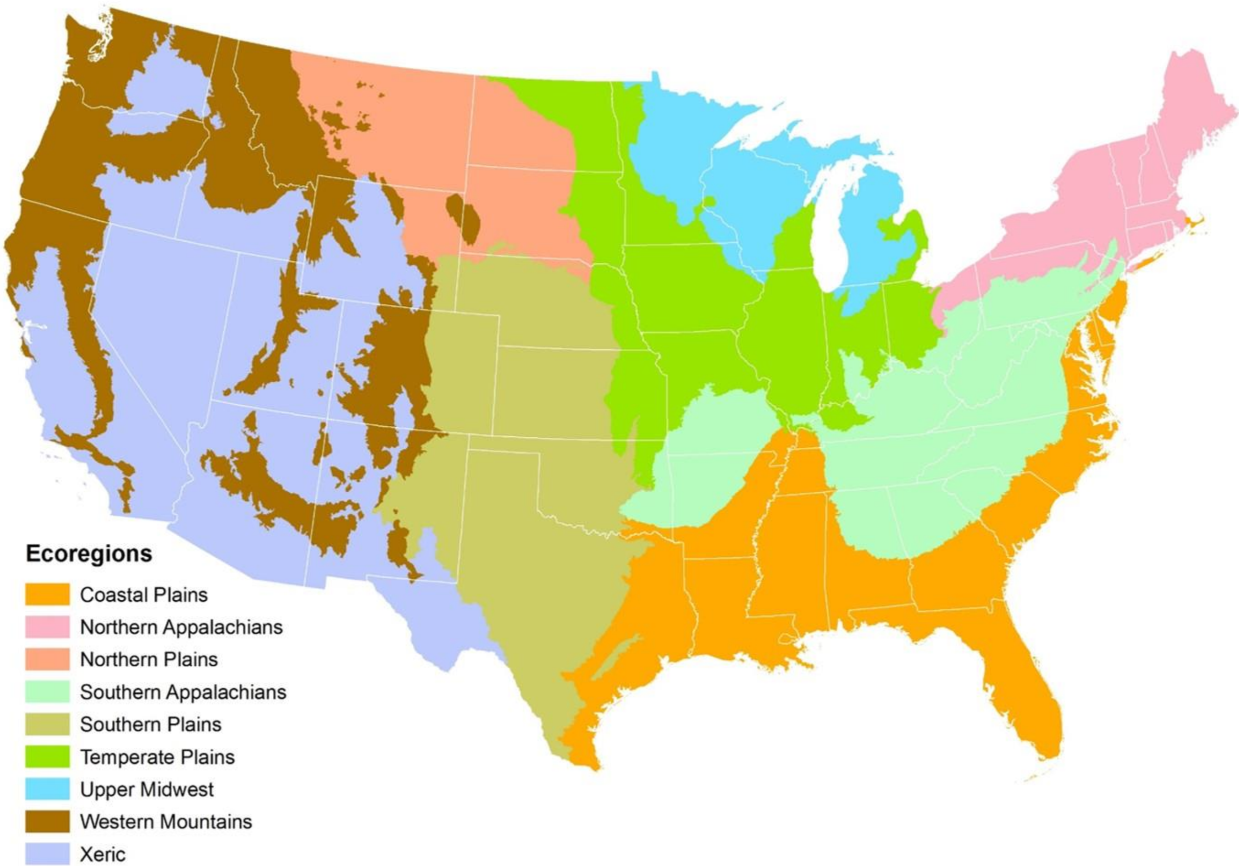

Figure 4. Map of the ecoregions used in EPA’s National Aquatic Resource Surveys. The ecoregions represent aggregations of the Level 3 ecoregions EPA delineated for the US. Figure from https://www.epa.gov/national-aquatic-resource-surveys/ecoregions-used-national-aquatic-resource-surveys

The second approach compares sampling results to fixed benchmarks for indicators with published ecological- or human health-risk values. Assessment of all toxic parameters used this approach. Assessment of toxic parameters included comparisons with Oregon human health and aquatic life criteria (DEQ 2014), EPA aquatic life benchmarks (EPA 2021) and DEQ sediment bioaccumulation screening levels (DEQ 2007). These benchmarks indicate the concentration below which the compound is not expected to have a health impact on humans or aquatic life, or to accumulate in fish or shellfish tissue. Detected concentrations were compared to the most sensitive of the applicable criteria, benchmark, or screening value for a given compound. This ensured that statements of risk to human health or aquatic life provided were conservative. Based on these benchmarks, parameter values for each lake were assigned to one of three condition classes: “above benchmark”, “at or below benchmark”, or “not detected”.

3. Statewide Results

This section contains information for each of the indicator groups (trophic state, biological, physical, contact recreation and toxics). Within each indicator section is a summary of the importance of each indicator, the status of Oregon lakes for that indicator and comparisons to results observed at the national-scale and in Pacific Northwest (PNW) states (Oregon, Washington and Idaho). Due to limited funding to routinely boost the sample size of lakes sampled in Oregon as part of the NLA, we have limited ability to draw conclusions about the status and trends of lakes at the statewide scale. However, due to a consistently larger sample size, as well as geographic proximity and similar ecoregions, the PNW population of lakes may provide regional results that are applicable to Oregon.

A nationwide assessment of toxics was not completed, so no comparisons to national or Pacific Northwest lakes are included in the toxics assessment section. A total of 49 randomly selected lakes were sampled in Oregon, 108 lakes were sampled in Pacific Northwest and 1,005 lakes sampled nationally.

The graphs below show the estimated percent of lakes in each condition class. Each estimate is accompanied by a 95% confidence interval, shown in the figures and the tables throughout, that conveys the level of certainty in the estimate. The 2017 NLA Technical Support Document (EPA 2022b) explains the underlying assumptions and analysis.

Unfortunately, due to low the low number of sites sampled in 2007 and 2012, “change analyses” (the difference in indicator condition status between two time periods) was not included.

3.1 Trophic State Indicator

The term trophic state is used to classify lake ecosystems according to their biological productivity based on oxygen content, algal biomass, plant material and clarity among others. The most common method for identifying a lake’s trophic state is to calculate its biomass, or the total mass of living organisms, typically measured by algal densities. Nutrient availability in a lake has a major influence on productivity and biomass. Higher nutrient concentrations promote more phytoplankton growth and a corresponding increase in the biomass of higher levels in the food chain.

Lakes with low nutrients and low biomass are termed oligotrophic. Eutrophic lakes have much higher levels of nutrients and consequently much higher biological productivity with hypereutrophic lakes having excessively high nutrients and plant life densities. Mesotrophic lakes fall in a middle ground in terms of productivity. Lakes generally transition through several stages over time depending on many factors, including their origin and subsequent events, including human disturbances. The National Association of Lake Management Society (NALMS) provides a high-level summary of lake types and life cycles (NALMS n.d.).

Progressive increases in nutrients, called eutrophication, can lead to decreased water clarity, increased harmful algal blooms and large swings in pH and dissolved oxygen that may ultimately result in fish kills. While eutrophication occurs naturally, it is often accelerated by human activity where nutrients are added to a water body from a wide variety of sources including partially treated sewage, fertilizers and increased runoff from land. In the extreme case beneficial uses, such as domestic water supply and fishing, are also negatively impacted.

The NLA uses chlorophyll *a* concentration as an indirect measurement of algal biomass to estimate trophic state, because all algae contain some amount of chlorophyll *a*. For more information on how EPA analysts link chlorophyll *a* and algal biomass, see the 2017 NLA Technical Support Document (EPA 2022b). The trophic state benchmark categories are as follows:

- Oligotrophic: Chlorophyll *a* levels ≤0.002 mg/L
- Mesotrophic: Chlorophyll *a* levels between 0.002 mg/L – 0.007 mg/L
- Eutrophic: Chlorophyll *a* levels between 0.007 mg/L – 0.030 mg/L
- Hypereutrophic: Chlorophyll *a* levels >0.030 mg/L.

What was the trophic status in 2017?

Most of Oregon’s lakes in 2017 were estimated to be oligotrophic (53%, Figure 5). Mesotrophic lakes accounted for 17% of Oregon’s lakes and 28% were estimated to be in the eutrophic range of chlorophyll *a* concentrations. Only 2% of Oregon lakes were classified as hypereutrophic, representing an estimated 100 lakes (Table 2).

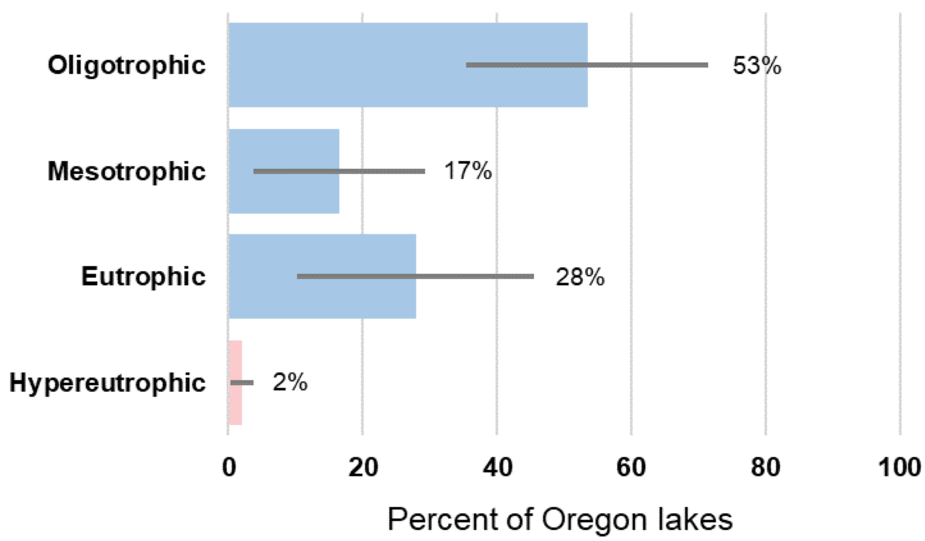

Figure 5. Estimated percentage of Oregon lakes in each of four trophic states. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Results in the Pacific Northwest are similar to Oregon's results. Oligotrophic lakes represented the highest percentage (44%), while hypereutrophic lakes accounted for the lowest percentage (3%, Table 2). Mesotrophic (30%) and eutrophic lakes (23%) rounded out the trophic status of the Pacific Northwest population of lakes.

The trophic status of Oregon's population of lakes was fairly similar to that of the PNW lake population, but quite different from the national population of lakes (Table 2). Oregon had a higher percentage of lakes in both oligotrophic and eutrophic status than the PNW lakes, but a lower percentage of mesotrophic lakes. None of these results were significantly different, though, at the 95% confidence level. On the other hand, Oregon had a significantly higher number of oligotrophic lakes compared to the national population (11%). Nationally, the greatest percentage of lakes were considered eutrophic (45%).

Table 2. Percent of Oregon, Pacific Northwest and National lakes by trophic status indicator (± 95% confidence interval).

Trophic state	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Oligotrophic	26	2575 ± 1240	53 ± 18	44 ± 14	11 ± 5
Mesotrophic	9	798 ± 609	17 ± 13	30 ± 14	20 ± 5
Eutrophic	9	1345 ± 943	28 ± 18	23 ± 11	45 ± 8
Hypereutrophic	5	100 ± 78	2 ± 2	3 ± 3	24 ± 6

3.2 Biological Indicators

Biological indicators, like diatoms, aquatic plants, insects, fish and amphibians, can offer some of the strongest signals of the overall conditions of natural ecosystems. The organisms that make up the biological communities complete most or all of their life cycles within the ecosystems being assessed. This means that many different stressors affect biological indicators (e.g., abundances, densities, cellular integrity, or overall health) over time. Thus, biological indicators can often be much more integrative of longer-term environmental conditions.

Chlorophyll *a*

Chlorophyll is the green pigment in plants, algae and cyanobacteria that is integral to photosynthesis, the capturing of light for use as an energy source. There are two types of chlorophyll, "a" and "b", with chlorophyll *a* being the primary form. All organisms that utilize photosynthesis require chlorophyll *a,* but chlorophyll *b* is an accessory pigment that is not utilized by all photosynthesizing organisms (thus, chlorophyll *b* is excluded from this analysis). As previously stated, chlorophyll *a* is often used as an indirect measure of biomass and trophic state. The amount of chlorophyll *a* is also used as a more direct measure of eutrophication, as increasing nutrients can lead to increasing cell densities of algae, which can lead to the formation of scums, unhealthy levels of dissolved oxygen, or blooms of nuisance algae capable of generating toxic compounds.

NLA analysts based the expected chlorophyll *a* values for any given lake in 2017 NLA on conditions observed in regional reference lakes. These values differ from the literature-based values used in assessing trophic state. For more information on how regional chlorophyll *a* values were established, see the 2017 NLA Technical Support document.

What was the chlorophyll *a* condition in 2017?

Nearly half of Oregon lakes are estimated to be in good condition for chlorophyll *a* (Figure 6). This is roughly the same as the percentage of oligotrophic lakes identified by the trophic status indicator, which uses chlorophyll *a* to determine status. The same pattern is shown in the percentage of lakes in the mesotrophic and eutrophic/hypereutrophic conditions compared to chlorophyll *a* condition. Chlorophyll *a* showed the highest percent of Oregon lakes in poor condition (35%) compared to any other indicator. This represents an estimated 1706 lakes throughout Oregon (Table 3).

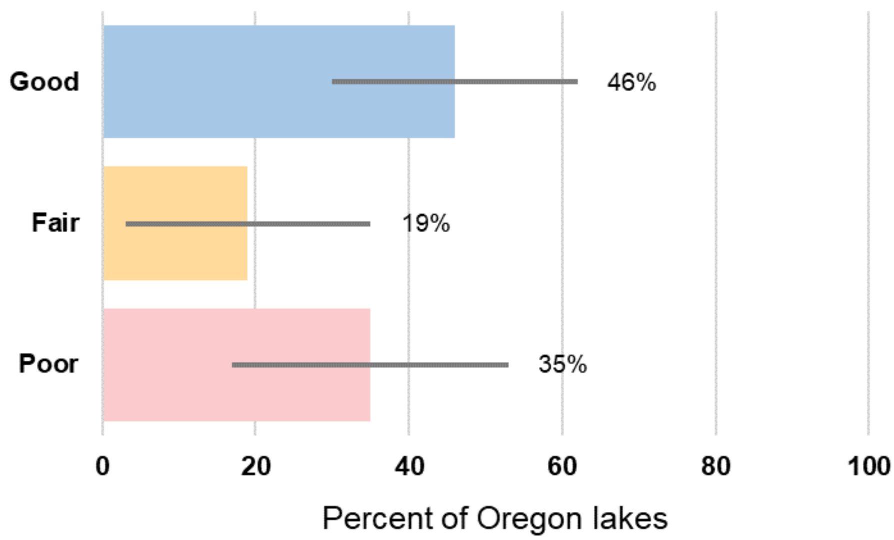

Figure 6. Condition estimates of chlorophyll *a* concentrations in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Chlorophyll *a* conditions were slightly better in Oregon than were estimated for both the Pacific Northwest and National lake populations (Table 3). None of the differences were statistically significant, with overlapping error ranges across all combinations of populations and condition classes (Table 3).

Table 3. Percent of Oregon, Pacific Northwest and National lakes by chlorophyll *a* status indicator (± 95% confidence interval).

Chlorophyll *a*	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	25	2195 ± 1069	46 ± 16	40 ± 13	34 ± 7
Fair	6	918 ± 771	19 ± 16	17 ± 12	20 ± 7
Poor	18	1706 ± 961	35 ± 18	43 ± 14	45 ± 8

Zooplankton

Zooplankton represent the group of small animals living in the water column. Like benthic macroinvertebrates they occupy the middle of lake food webs. They are frequently very small, including single-celled organisms, but may also be visible by the naked eye. They feed on algae and are eaten by larger animals, like fish. They also make good indicators of biological condition because they are sensitive to many different disturbances.

What was the zooplankton condition in 2017?

Like macroinvertebrate community conditions, the majority of Oregon lakes had zooplankton communities in good biological condition (71%, Figure 7). A slightly higher percentage of Oregon lakes were in poor condition for zooplankton (7%) than for benthic macroinvertebrates (<1%). While the percent of lakes in poor condition was low, this represents an estimated 376 lakes to be in poor biological condition across Oregon (Table 4).

Approximately 4% of lakes were unable to be assessed for zooplankton conditions.

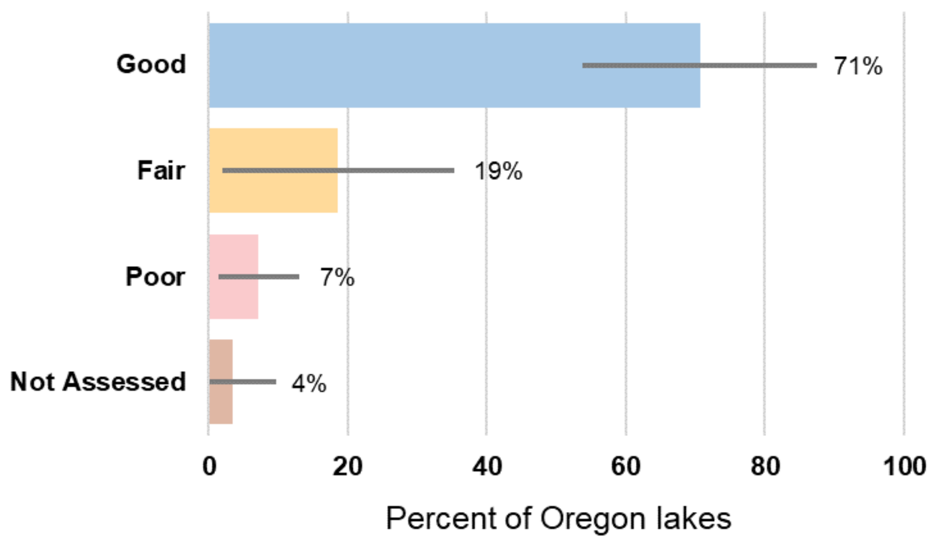

Figure 7. Condition estimates of zooplankton in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Zooplankton communities in Oregon were more often in good biological condition compared to the Pacific Northwest states (65%, Table 4) and national (51%) populations of lakes. Conversely, fewer Oregon lakes (7%) were found to have poor zooplankton communities than were observed in Pacific Northwest (10%) and national (19%) lakes. However, none of these results can be considered statistically significant, as all three geographic scales showed overlapping confidence intervals.

Table 4. Percent of Oregon, Pacific Northwest and National lakes by zooplankton status indicator (± 95% confidence interval).

Zooplankton	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	33	3406 ± 1410	71 ± 17	65 ± 13	53 ± 7
Fair	7	868 ± 861	19 ± 17	23 ± 13	23 ± 5
Poor	8	376 ± 255	7 ± 6	10 ± 5	22 ± 6
Not Assessed	1	169 ± 169	4 ± 4	2 ± 2	1 ± 1

Benthic Macroinvertebrates

Situated in the middle of most food webs and responding with a high degree of sensitivity to many stressors, benthic macroinvertebrates are a commonly used biological indicator of ecosystem conditions (Cairns and Pratt 1993). Benthic macroinvertebrates are organisms large enough to see without the aid of magnification, living in the bottom substrates and among submerged plants. Benthic macroinvertebrates are composed of insects, snails, clams and crustaceans.

To assess the condition of lakes across the nation, NLA scientists developed an index that included key aspects of macroinvertebrate community structure. Individual components of the benthic macroinvertebrate index included taxonomic composition, taxonomic diversity, taxonomic richness, feeding groups, habits, habitats and pollution tolerances. To learn more about the development of the benthic macroinvertebrate index, see the 2017 NLA Technical Support Document (EPA 2022b).

What was the benthic macroinvertebrate condition in 2017?

Most of Oregon's lakes (78%) had benthic macroinvertebrate communities in good condition. Less than a quarter (21%) of benthic macroinvertebrate communities in Oregon lakes were in fair condition (Figure 8). Less than 1% of lakes in Oregon had poor macroinvertebrate conditions, representing 19 lakes (Table 5).

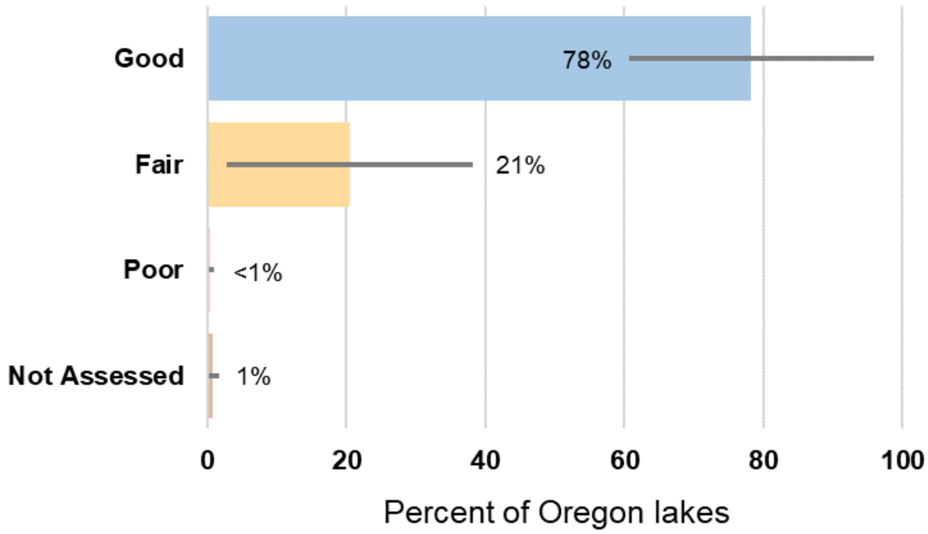

Figure 8. Condition estimates of benthic macroinvertebrate communities in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Oregon's lake macroinvertebrate communities showed conditions very similar to what was observed in other Pacific Northwest states. While more than three-quarters of Oregon lakes had benthic macroinvertebrate communities in good condition, less than half (43%) of lakes across the nation were in good condition (Table 5). Nationally, almost one-quarter (24%) of lakes had macroinvertebrate communities in poor condition, while less than 1% of Oregon lake macroinvertebrate communities were in poor condition.

Table 5. Percent of Oregon, Pacific Northwest and National lakes by benthic macroinvertebrate status indicator (± 95% confidence interval).

Benthic Macroinvertebrates	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	36	3774 ± 1340	78 ± 18	75 ± 12	43 ± 7
Fair	9	991 ± 921	21 ± 18	22 ± 12	29 ± 7
Poor	2	19 ± 19	<1 ± 1	3 ± 3	24 ± 7
Not Assessed	2	35 ± 35	<1 ± 1	<1 ± 1	4 ± 2

3.3 Chemical Indicators

Nationally and regionally, EPA assessed six chemical indicators of lake conditions. These indicators included acidification risk, dissolved oxygen, two nutrients (nitrogen and phosphorus) and two toxics (a pesticide, atrazine, and a cyanobacterial toxin, microcystin). For the assessment of Oregon lakes, DEQ chose to separately fund atrazine analysis and drop the analysis of microcystin. Atrazine results are included in the toxics monitoring section of this report. EPA's microcystin results are included in the contact recreation section of this report.

EPA and DEQ analysis of sediment samples, collected in the mid-lake zone at each lake, included combustion byproducts, legacy pesticides, PCBs and metals. The results for Oregon lakes are discussed in the toxics monitoring section. National and regional assessment of sediment results will be presented in a future EPA report.

Acidification

Deposition of acidic compounds into freshwaters became a well-known environmental issue by the 1980s (Menz and Seip, 2004). Severe ecological degradation can occur when acidic compounds enter freshwater, due to lowering pH values beyond ranges most aquatic organisms can tolerate. Acid rain is caused by the emissions of sulfur dioxide and nitrogen oxide from burning fossil fuels, which react with water molecules in the atmosphere to produce acids.

Acidification risk is measured in the NLA by acid-neutralizing capacity (ANC). ANC is a function of the soils and geology of an ecosystem and provides an indication of a waterbody's susceptibility to pH change. Oregon lakes are generally at lower risk for acidification due to relatively few major industrial centers burning fossil fuels (for example, coal fired power plants) and low rates of acid-mine discharges. However, there are several regions in the state with geologies that make their freshwater systems more susceptible to acidification, such as granitic mountain ranges in Northeastern Oregon. Sufficient ANC in surface waters buffers acid rain and prevents pH levels from straying outside of their natural range. In naturally acidic lakes, the ANC may be quite low, but the presence of natural organic compounds in the form of dissolved organic carbon (DOC) can mitigate the effects of pH fluctuations.

ANC is measured using concentration units of microequivalents per liter (µeq/L), which account for the charges of the ions dissolved in the water. To classify lakes for acidification, EPA considered ANC measurements along with DOC concentrations. Condition categories used in all ecoregions are defined below:

- Good — Lakes with ANC >50 µeq/L, or naturally acidic lakes with ANC ≤50 µeq/L and DOC ≥6 parts per million (ppm). Naturally acidic lakes are often associated with bog wetlands or certain types of swamps.
- Fair — Lakes with ANC >0 µeq/L but ≤50 µeq/L and DOC <6 ppm. These sites may become acidic occasionally, during periods of high precipitation.
- Poor — Lakes with ANC ≤0 µeq/L and DOC < 6 ppm.

See the 2017 NLA Technical Support Document for more on these benchmarks.

What was the ANC condition in 2017?

None of Oregon's lakes were classified as poor for acidification condition, as measured by ANC and DOC. Over three-quarters (83%) of Oregon's lakes were in good acidification condition, while 17% were in fair condition (Figure 9).

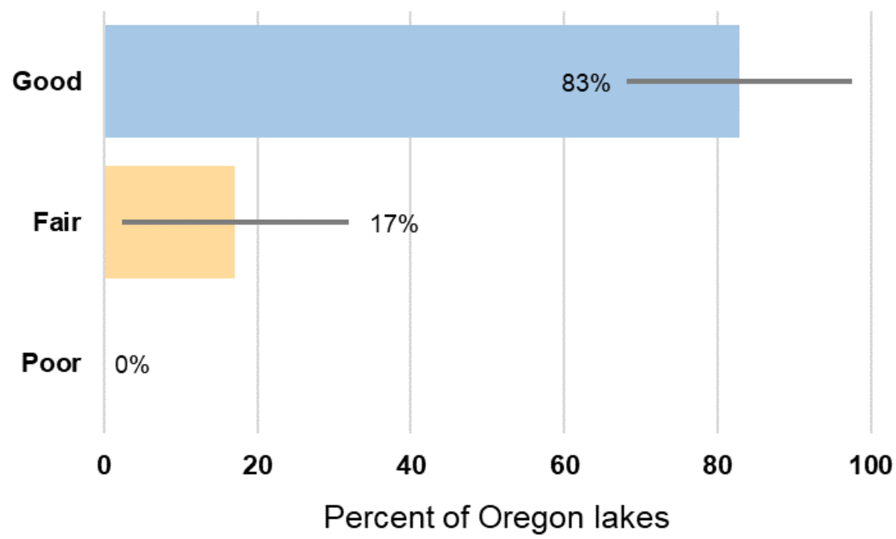

Figure 9. Condition estimates of acidification in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

As was true for Oregon lakes, none of the Pacific Northwest states had a lake population in poor acidification condition. Nationally, only 3% of the lake population was in poor condition. Almost all of the lakes at the national scale were in good acidification condition (96%, Table 6).

Table 6. Percent of Oregon, Pacific Northwest and National lakes by acidification status indicator (± 95% confidence interval).

Acidification	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	41	3993 ± 1240	83 ± 15	89 ± 9	96 ± 4
Fair	8	826 ± 789	17 ± 15	11 ± 9	2 ± 1
Poor	0	0	n/a	n/a	3 ± 4

Dissolved Oxygen

Dissolved oxygen is an essential measure of water quality, due to its direct role in respiration by living organisms. While there are naturally occurring low oxygen zones in lakes, most of the biomass in lake ecosystems requires oxygen. Many sensitive organisms require relatively high levels of oxygen to complete their metabolic cycles. Exceptionally low levels of oxygen can be natural in the deep waters of lakes, although this study only focused on oxygen levels in surface water. Shallow lakes with consistent and widespread low dissolved oxygen conditions can lead to fish kills and loss of sensitive benthic macroinvertebrates. Frequently, excessive algal and plant growth leads to low dissolved oxygen conditions through high respiration rates during the night, or through oxygen consumption during decomposition of organic materials.

NLA analysts used a single set of benchmarks to define dissolved oxygen conditions in the nation's lakes. These benchmarks were applied to the mean dissolved oxygen concentration in a lake's surface waters.

- Good — ≥5 mg/L.
- Fair — >3 mg/L but <5 mg/L.
- Poor — ≤3 mg/L.

What was the dissolved oxygen condition in 2017?

Nearly all of Oregon's lakes (96%) were in good condition for dissolved oxygen in surface waters (Figure 10). Only 4% of Oregon's lakes were in fair condition. None of Oregon's lakes were in poor condition for dissolved oxygen.

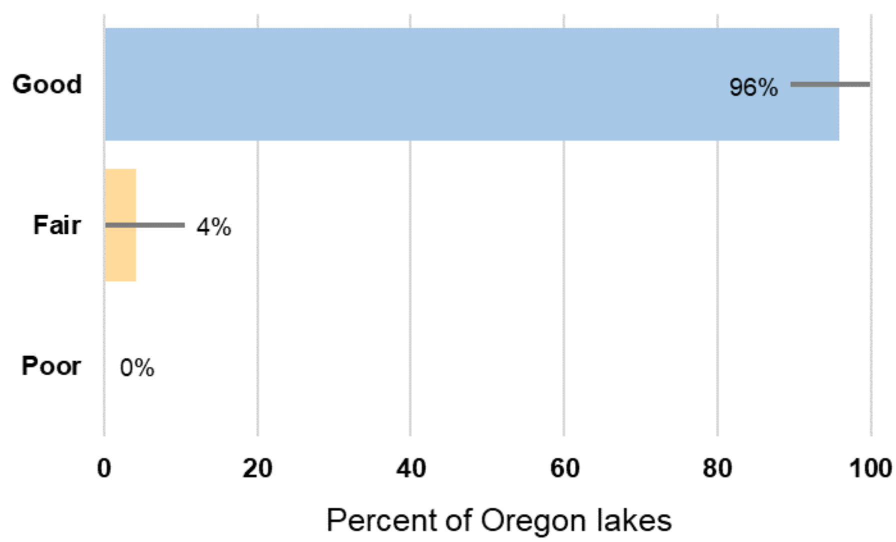

Figure 10. Condition estimates of dissolved oxygen in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

There are few differences in occurrences of dissolved oxygen between Oregon's lakes and the lakes of Pacific Northwest states (Table 7). While none of Oregon's lakes are in poor condition, 2% of Pacific Northwest lakes are in poor condition for dissolved oxygen. Nationally, 9% of lakes are in poor condition and 75% are in good condition.

Table 7. Percent of Oregon, Pacific Northwest and National lakes by dissolved oxygen status indicator (± 95% confidence interval).

Dissolved Oxygen	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	47	4617 ± 1477	96 ± 5	94 ± 5	75 ± 7
Fair	2	202 ± 202	4 ± 4	4 ± 4	16 ± 6
Poor	0	0	n/a	2 ± 2	9 ± 5
Not Assessed	0	0	n/a	<0.5 ± 0.5	<0.5 ± 0.5

Nutrients

Nitrogen and phosphorus are essential elements, which are frequently the drivers of lake food webs. They play a critical role in primary productivity by algae and plants and represent essential roles further up the food web. In many aquatic ecosystems, phosphorus is the limiting nutrient in algal productivity. However, in some regions, especially those with high amounts of volcanic soils, which are naturally high in phosphorus, nitrogen can be the limiting nutrient. Excess nutrients, above natural background levels, frequently come from sewage treatment plants, failing septic systems and use of fertilizers in agriculture for food production and urban landscapes for lawns. For more information, see EPA's nitrogen and phosphorus indicator pages.

While there are many different forms of nitrogen and phosphorus, the NLA uses total nitrogen and total phosphorus for the assessment of lakes. NLA analysts developed benchmarks from regional reference sites for assessing nutrient conditions.

What was the condition in 2017?

More of Oregon's lakes are in good condition for total phosphorus (75%) than total nitrogen (60%, Figure 11). On the other hand, more of Oregon's lakes are in poor condition for total phosphorus (21%) than for total nitrogen (13%). However, total nitrogen also has a relatively higher percentage of lakes in fair condition, compared to total phosphorus. Considering the poor and fair lakes together, 1,929 lakes are considered "at risk" for nitrogen, while 1,228 lakes are "at risk" for phosphorus (Tables 8 and 9).

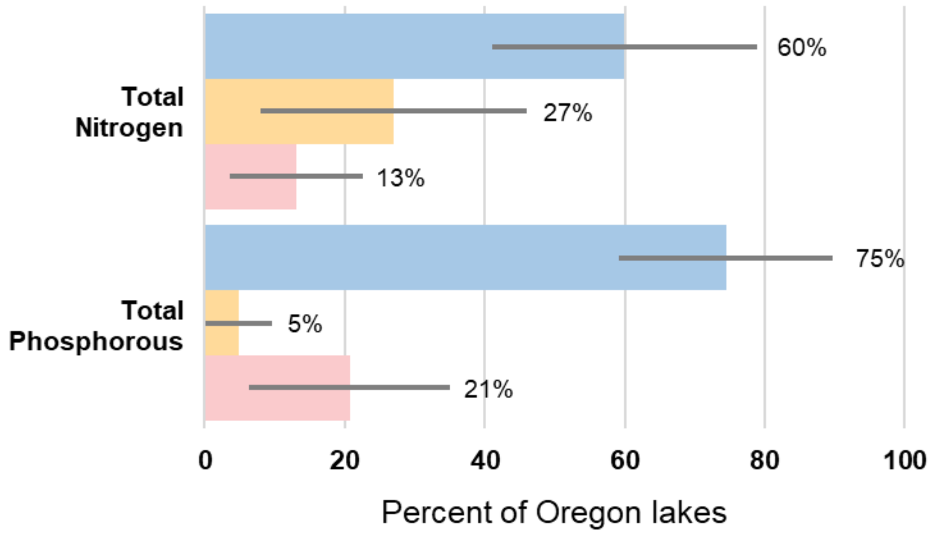

Figure 11. Condition estimates of total nitrogen and total phosphorous concentrations in Oregon lakes. Percentages indicate point estimates. Blue represents good condition, yellow represents fair condition and red represents poor condition. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Oregon's nutrient concentrations are lower and in better condition overall than the Pacific Northwest lakes population, although not statistically significant. However, for phosphorus, Oregon shows a statistically significant percentage of lakes in good condition and lower percentage of lakes in poor condition compared to the national population of lakes. The national population of lakes has statistically significant percentages of lakes in poorer nitrogen and phosphorus conditions than Oregon.

Table 8. Percent of Oregon, National and Pacific Northwest lakes by total nitrogen status indicator (± 95% confidence interval).

Total Nitrogen	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	28	2890 ± 1325	60 ± 19	44 ± 14	39 ± 8
Fair	8	1299 ± 1032	27 ± 19	28 ± 14	15 ± 4
Poor	13	630 ± 390	13 ± 10	28 ± 12	46 ± 8

Table 9. Percent of Oregon, National and Pacific Northwest lakes by total phosphorus status indicator (± 95% confidence interval).

Total Phosphorus	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	31	3591 ± 1520	74 ± 16	61 ± 14	41 ± 8
Fair	4	230 ± 226	5 ± 5	20 ± 12	14 ± 4
Poor	14	998 ± 626	21 ± 15	19 ± 11	45 ± 7

3.4 Physical Indicators

Physical indicators of lake ecological condition are important because they provide an insight into the quality of habitats for lake organisms, as well as indications of physical disturbances to lake environments that may be expressed in the biological communities, but not in the chemical stressors. The physical indicators in the NLA measure aspects near the lake-landscape interface: lake drawdown, near-shore human disturbances, riparian vegetative cover and shallow water (littoral) habitat.

Lake Drawdown Exposure

Lake water elevations typically peak during winter and/or spring and drop to their lowest levels during the summer period, coinciding with NLA sampling. This can be natural, due to evaporation and changing precipitation patterns within the seasons, or in more extreme cases due to drought or climate change. However, water drawdown can also be human-induced due to hydropower generation or irrigation withdrawals, most frequently observed in reservoirs. These changes, especially when water levels are lowered dramatically over a short time, can have significant impacts on water quality and biological communities.

What was the condition in 2017?

Most of Oregon's lakes (88%) do not show a large drawdown exposure (Figure 12). Only 10% of Oregon's lakes show a large drawdown exposure, but this represents an estimated 502 lakes (Table 10). DEQ did not have a large enough sample size to determine if any differences exist between natural lakes and constructed reservoirs. Of those lakes observed to have large drawdown exposure, three are of natural origin and four are constructed reservoirs.

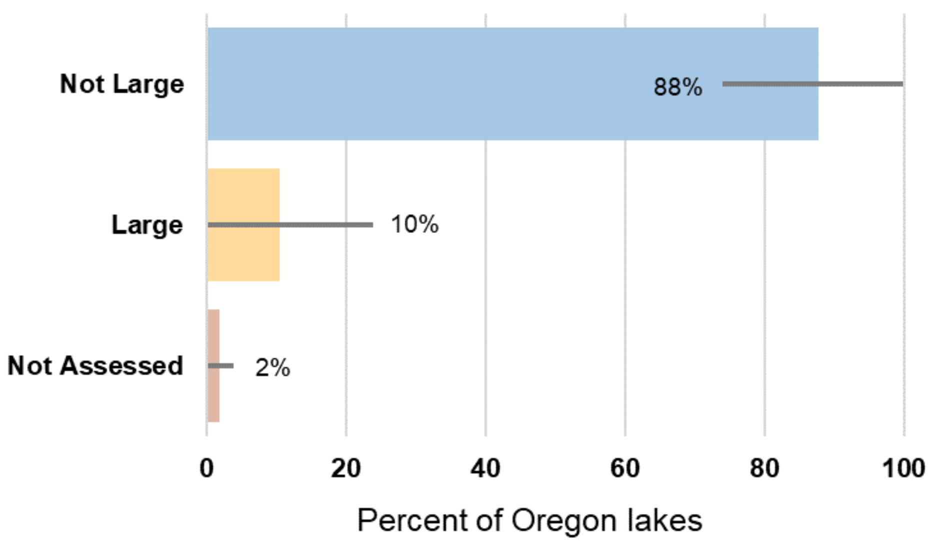

Figure 12. Condition estimates of lake drawdown exposure in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Compared to the national and Pacific Northwest populations, Oregon has a slightly greater percentage of lakes with a large drawdown exposure (Table 10). However, these percentages are small and not statistically significant.

Table 10. Percent of Oregon, Pacific Northwest and National lakes by lake drawdown exposure status indicator (± 95% confidence interval).

Lake Drawdown Exposure	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Not Large	39	4232 ± 1462	88 ± 13	91 ± 8	94 ± 2
Large	7	502 ± 502	10 ± 12	7 ± 8	3 ± 2
Not Assessed	3	85 ± 85	2 ± 2	1 ± 2	2 ± 2

Lakeshore Disturbance

This indicator measures the frequency and proximity of the direct alteration of lakeshore and nearshore habitats by human activities. The disturbances observed included roads, residences, agricultural activities (grazing, crops), logging, trash, etc. These disturbances can result in a variety of complex changes to lake conditions. For example, extensive removal of riparian vegetative cover can lead to increased erosion, which can lead to increased sedimentation or eutrophication through the delivery of nutrients otherwise isolated in the surrounding soils.

What was the condition in 2017?

Lakeshore disturbance showed the lowest percentage of Oregon lakes in good condition (44%, Figure 13), compared to any other indicator. While a relatively small percentage of Oregon lakes are in poor condition (11%) for lakeshore disturbance, this represents an estimated 533 lakes (Table 11). In addition, 45% of lakes are in fair condition, also the highest for any indicator. Less than 1% of Oregon lakes are unassessed for this indicator.

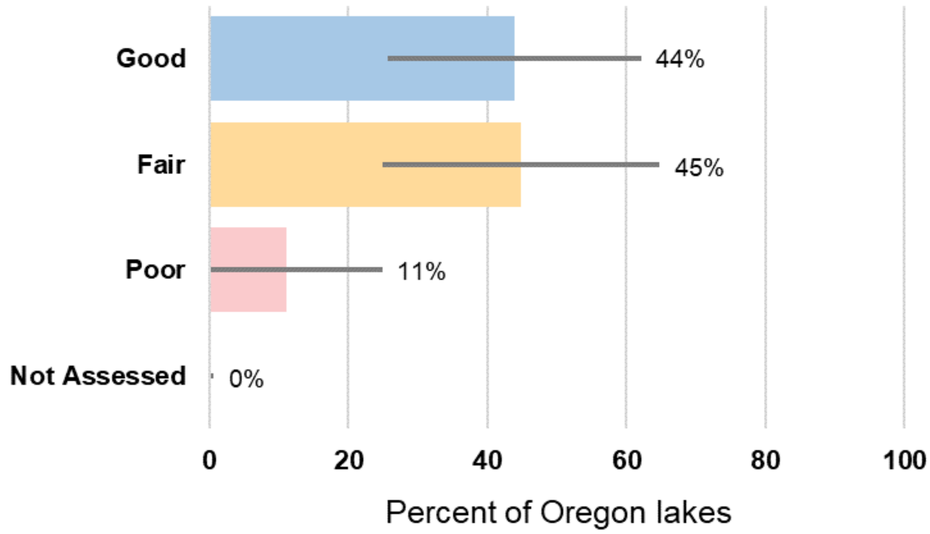

Figure 13. Condition estimates of lakeshore disturbance concentrations in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Lakeshore disturbance conditions in Oregon are similar to the conditions observed across Pacific Northwest states. Compared to the national lake population, Oregon has about twice as many lakes in good condition, and about half as many lakes in poor condition for lakeshore disturbance. None of these differences are statistically significant.

Table 11. Percent of Oregon, Pacific Northwest and National lakes by lakeshore disturbance status indicator (± 95% confidence interval).

Lakeshore Disturbance	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	21	2114 ± 1142	44 ± 18	45 ± 14	25 ± 8
Fair	23	2160 ± 1083	45 ± 20	46 ± 15	45 ± 7
Poor	4	533 ± 533	11 ± 11	9 ± 8	29 ± 7
Not Assessed	1	13 ± 13	<1 ± 1	<1 ± 1	1 ± 1

Riparian Vegetation Cover

The riparian vegetative cover indicator quantifies the amount of cover provided by nearshore vegetation in multiple vertical layers. While there is great variability in the types of cover naturally occurring in different regions, generally lakes with more vegetative cover and less bare dirt or soils will be in better ecological condition. NLA analysts set expectations for lakes based on the levels of cover observed in regionally appropriate reference sites.

What was the condition in 2017?

Riparian vegetative cover is in good condition for 81% of Oregon lakes (Figure 14). Only 6% of Oregon lakes are in fair condition. Poor riparian cover is observed for 13% of lakes, which represents an estimated 634 lakes across Oregon (Table 12). Less than 1% of Oregon lakes are unassessed for this indicator.

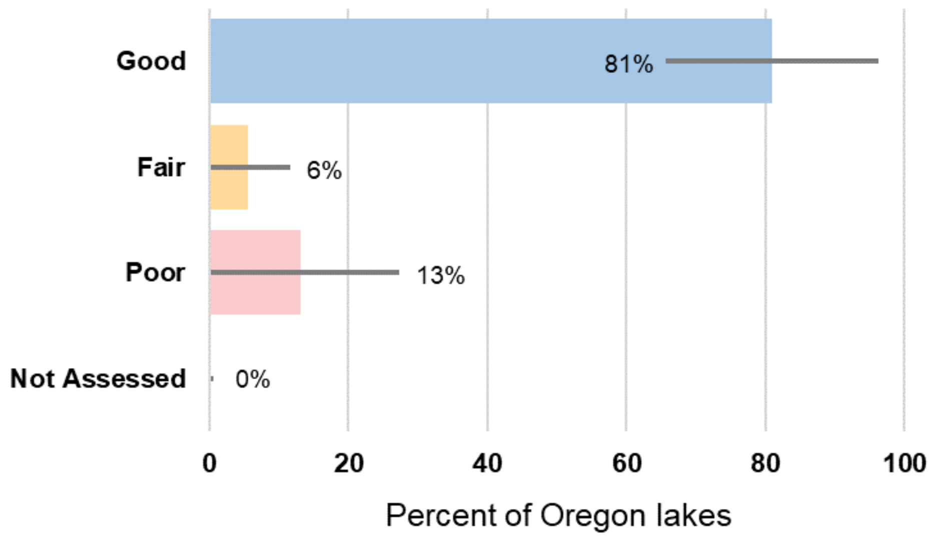

Figure 14. Condition estimates of riparian vegetative cover in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Riparian vegetation conditions across Pacific Northwest states are similar to Oregon, but there are fewer Pacific Northwest lakes in good condition (72%) and more lakes in poor condition (18%, Table 12). None of these differences are statistically significant.

Compared to the national population of lakes, the differences are greater. Only 51% of lakes nationally are in good condition, compared to 81% of Oregon lakes—a statistically significant difference. While the percentage of lakes nationally in poor condition (26%) is twice that of Oregon (13%), this difference is not statistically significant.

Table 12. Percent of Oregon, Pacific Northwest and National lakes by riparian vegetation cover status indicator (± 95% confidence interval).

Riparian vegetation cover	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	35	3899 ± 1463	81 ± 15	72 ± 13	51 ± 8
Fair	4	273 ± 273	6 ± 6	10 ± 10	22 ± 5
Poor	9	634 ± 634	13 ± 13	18 ± 10	26 ± 6
Not Assessed	1	13 ± 13	<1 ± 1	<1 ± 1	1 ± 1

Shallow Water Habitat

The shallow water habitat indicator measures the quantity and diversity of cover provided by natural and unnatural structures. These structures can be geological, such as large rocks or deep shelves; biological, such as weed beds or tree branches; or unnatural, such as docks. Generally, the more extensive and diverse the cover types are, the more diverse the biological communities are due to increased niches available for living organisms to occupy in the shallow water zone. NLA analysts sets expectations for individual lakes based on regional reference sites.

What was the condition in 2017?

Most of Oregon's lakes (87%) are in good condition for shallow water habitat (Figure 15). Only 9% of Oregon lakes are in poor condition, but this represents 431 lakes (Table 13). Less than 1% of Oregon lakes are unassessed for shallow water habitat condition.

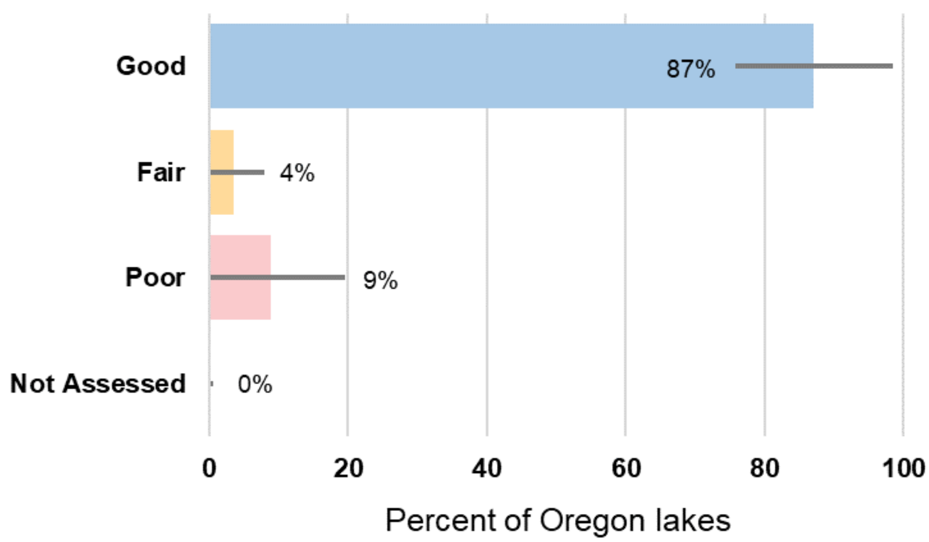

Figure 15. Condition estimates of shallow water habitat in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Shallow water habitat conditions across Pacific Northwest states are similar to conditions observed in Oregon. Nationally, 65% of lakes are in good condition, compared to 87% in Oregon, a statistically significant difference. The 16% of lakes nationally in poor condition for shallow water habitat is not significantly different from the Oregon population (9%).

Table 13. Percent of Oregon, National and Pacific Northwest lakes by shallow water habitat status indicator (± 95% confidence interval).

Shallow water habitat	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Good	40	4198 ± 1336	87 ± 11	88 ± 8	65 ± 7
Fair	4	177 ± 177	4 ± 4	5 ± 4	19 ± 5
Poor	4	431 ± 431	9 ± 9	6 ± 6	16 ± 4
Not Assessed	1	13 ± 13	<1 ± 1	<1 ± 1	1 ± 1

3.5 Contact Recreation Indicators

Contact recreation refers activities such as swimming, waterskiing, or tubing where ingestion of small quantities of water is likely to occur. The two indicators in this section – *Escherichia coli* and microcystin – are commonly detected in surface waters and may cause illness if ingested. Per the sampling protocol, the samples analyzed for both indicators were collected at the mid-lake location, not at the nearshore location. This may underrepresent risk compared to targeted recreational use sampling at specific locations of high recreational use such as boat docks or beaches.

Escherichia coli (E. coli)

E. coli is a type of bacteria normally found in the stomach and intestines of healthy humans and animals. Most strains of *E. coli* are harmless, but some can cause intestinal issues, urinary tract infections, respiratory illness and other types of illness. Exposure to *E. coli* can occur from eating contaminated foods, drinking contaminated water, or from touching your mouth with contaminated hands. Exposure to *E. coli* does not appear to affect aquatic organisms but represents an important indicator of recreational uses.

What was the *E. coli* condition in 2017?

The NLA found detectable concentrations of *E. coli* in the open waters of 34% of Oregon lakes representing about 1,638 lakes (Figure 16). All concentrations are below the numeric criterion for freshwater contact recreation of 406 MPN/100 mL outlined in Oregon Administrative Rule 340-041-0009.

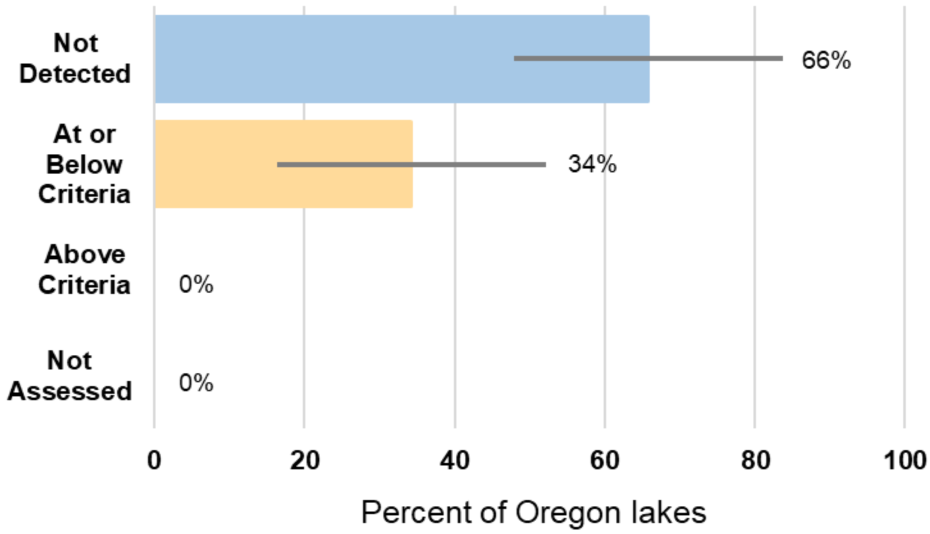

Figure 16. Condition estimates of *E. coli* in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Analysis of the *E. coli* results from the national and Pacific Northwest populations of lakes show that Oregon's detection rate is similar to the Pacific Northwest states, while both are substantially lower than the detection rate for the national population. Unlike other tables in this report, the condition classes in Table 14 do not match the corresponding figure. This is because *E. coli* criteria differ between Oregon, the other Pacific Northwest states, and nationally. Using the detect and not detected condition classes allows for a direct comparison between the different lake populations, which could otherwise be misleading.

Table 14. Percent of Oregon, National, and Pacific Northwest lakes by *E. coli* status indicator (± 95% confidence interval).

E. coli	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Detected	13	1651 ± 1095	34 ± 8	38 ± 13	69 ± 7
Not Detected	36	3168 ± 1144	66 ± 18	41 ± 13	30 ± 8
Not Assessed	N/A	N/A	N/A	21 ± 11	1 ± 1

Microcystin

Cyanobacteria are one-celled photosynthetic organisms that normally occur at low levels. Under eutrophic conditions, cyanobacteria can multiply rapidly, creating a bloom. Not all cyanobacterial blooms are toxic, but some may release toxins, such as microcystin. Recreational exposure is typically a result of inhalation, skin contact, or accidental ingestion. Health effects of exposure include skin rashes, eye irritation, respiratory symptoms, gastroenteritis, and in severe cases, liver or kidney failure and death. Per the sampling protocol, the samples analyzed were collected at the mid-lake location, not at the nearshore location. This may underrepresent risk compared to targeted recreational use sampling at specific locations of high recreational use such as boat docks or beaches.

What was the condition in 2017?

DEQ did not include microcystin in the analysis of water samples due to resource constraints at the laboratory, so the population of lakes included in this section is 26. This is indicated by the high percentage of lakes classified as not assessed. Detectable concentrations of microcystin in open water occur in 2% of Oregon lakes representing 96 lakes (Figure 17). All concentrations are below the Oregon Health Authority's (OHA) recreational use value of 8 µg/L (OHA 2019). OHA also developed regulations that require drinking water systems susceptible to hazardous algae blooms to routinely test for microcystins and notify the public of test results. The regulations are based on EPA health advisory levels and require public notification at levels of 1.6 µg/L for all drinking water users, and 0.3 µg/L for vulnerable populations (i.e., young children, pregnant mothers).

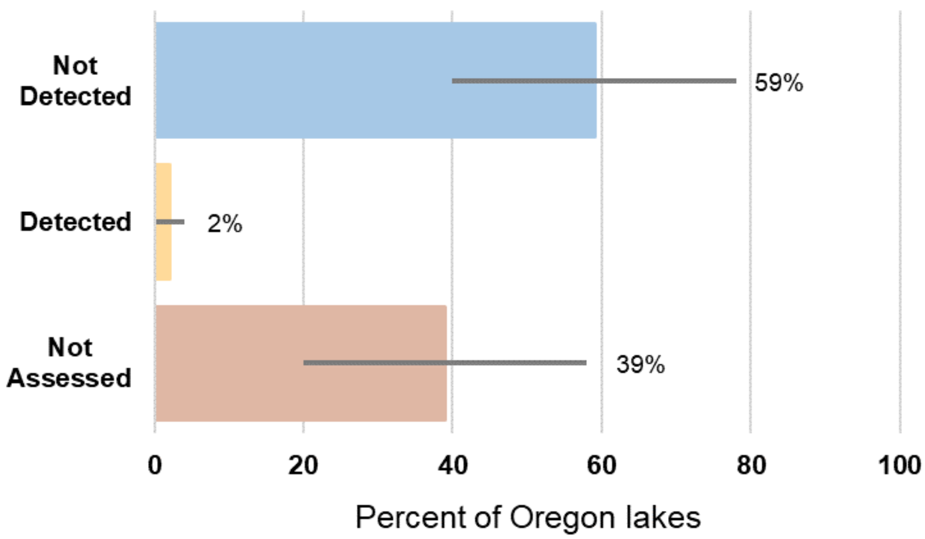

Figure 17. Condition estimates of microcystin in Oregon lakes. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Comparisons to National and Pacific Northwest lakes

Microcystin conditions in Oregon are similar to conditions observed across the Pacific Northwest. Nationally, 21% of lakes have detectable concentrations of microcystin, compared to 2% in Oregon (Table 15).

Table 15. Percent of Oregon, National, and Pacific Northwest lakes by microcystin status indicator (± 95% confidence interval).

Microcystin	# Oregon lakes sampled	Estimated # of Oregon lakes	% of Oregon lakes	% of PNW lakes	% of National lakes
Detected	4	96 ± 96	2 ± 2	3 ± 3	21 ± 5
Not Detected	22	2843 ± 916	59 ± 19	76 ± 12	77 ± 5
Not Assessed	23	1879 ± 916	39 ± 19	21 ± 11	2 ± 2

3.6 Toxics Assessment Results

The Toxics Monitoring program, which began in 2008, typically samples rivers and streams across Oregon. However, in conjunction with NLA sampling, DEQ staff collected additional water and sediment samples, which were analyzed for the same parameters the Toxics Monitoring Program typically assesses in rivers and streams. The goal of this effort was to create a more consistent dataset for all surface waters of the state and the results included in this report indicate DEQ's first comprehensive sampling effort completed on lakes and reservoirs for these contaminants. DEQ staff collected the additional water and sediment samples at the mid-lake site (Figure 2) using the same methods as the EPA samples.

DEQ included chemicals and contaminants from nine chemical groups (combustion byproducts, consumer use products, current use pesticides, dioxins and furans, flame retardants, industrial chemicals, legacy pesticides, metals, and PCBs) in this sampling effort. These chemical groups are consistent with those routinely sampled by DEQ's Statewide Toxics Monitoring Program. Some of the contaminants in these groups are naturally occurring; however, human activities can enrich or enhance concentrations through point and non-point source pollution, land use practices, fossil fuel burning, or wastewater effluent. Only a subset of these chemical groups was included in the analysis of sediment samples (combustion byproducts, legacy pesticides, metals, and PCBs). The remaining chemical groups do not readily bind to sediment, so no analysis was completed.

This section presents results analyzed in a manner consistent with the remainder of the report. DEQ staff reviewed the raw data for each contaminant and assigned values in each dataset to condition classes (e.g., "above criteria", "at or below criteria", or "not detected") based on the availability of DEQ human health or aquatic life criteria, EPA aquatic life benchmarks, or DEQ sediment bioaccumulation screening levels. In this section, select contaminant condition classes per chemical group are combined into one figure rather than depicting each condition class for each contaminant, or indicator, as in the previous section of the report. The toxics assessment was only completed in Oregon, so this section does not include comparisons to the populations of national or Pacific Northwest lakes. Appendix B contains a detection summary for comparison with other Toxics Monitoring Program reports. Appendix C contains the full analyte list include by parameter group and media type.

Combustion Byproducts

Combustion byproducts include polycyclic aromatic hydrocarbons (PAHs) and are associated with the incomplete combustion of organic matter from automobiles, fossil fuel burning, woodstoves, and cigarette smoke. They enter the waterways because of air deposition or stormwater run-off from impervious surfaces, such as roads and parking lots. Exposure to combustion byproducts can lead to kidney and liver damage, and in some cases cause cancer. Toxic health effects are not limited to humans. Aquatic organisms and birds exposed to PAHs have also shown negative health effects.

What was the condition in 2017?

DEQ analyzed water samples for 17 combustion byproducts and found detectable concentrations of nine of the included compounds. Three of the detected compounds do not have an established Oregon human health or aquatic life criteria or EPA aquatic life benchmark. However, the analysis estimated that two compounds, benz(a)anthracene and chrysene, occur at concentrations above their DEQ human health criteria in 2% and 8% of Oregon lakes representing 96 and 386 lakes, respectively (Figure 18). Four other compounds have established DEQ human health criteria; however, the detected concentrations did not exceed these criteria. A summary of detected concentrations can be found in Appendix B.

Due to resource limitations, DEQ did not include combustion byproducts in the analysis of sediment samples. Detection of combustion byproducts occurred more frequently in sediment samples than in water samples. EPA analyzed sediment samples for 25 combustion byproducts and detected each of them in at least one Oregon lake. Two compounds, pyrene and fluoranthene, have an DEQ sediment bioaccumulation screening level. Both were estimated to occur in 57% of Oregon lakes at concentrations below their sediment bioaccumulation screening levels. None of the detected combustion byproducts in sediment currently pose a threat to human health or aquatic life at the levels measured.

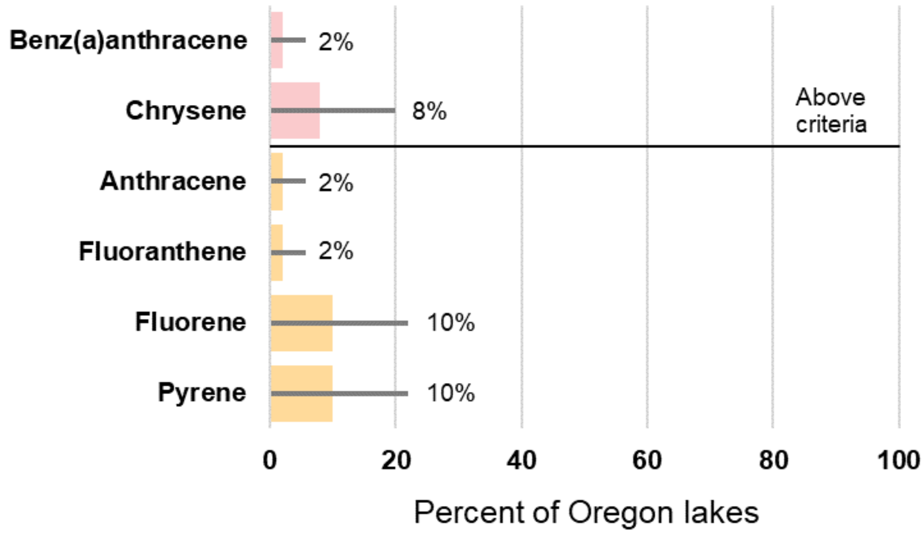

Figure 18. Estimated percentage of Oregon lakes with concentrations of combustion byproducts in water samples above (red) or below (yellow) Oregon human health criteria. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Consumer Use Products

Consumer use products include pharmaceuticals, bug sprays, and other products people use on a normal basis. These contaminants typically enter the waterways in wastewater effluent or from failing or leaching septic systems. Consumer use products included in DEQ analysis of water samples do not pose a threat to human health at the levels measured. However, studies show that some prescription drugs, like birth control, can feminize male fish and disrupt the male to female ratio of fish populations (Kidd 2007).

What was the condition in 2017?

DEQ analyzed water samples for 21 consumer use products, and found detectable concentrations of three—caffeine, cotinine, and DEET. Caffeine is a product of soda and coffee and ultimately indicates a wastewater influence. Cotinine is a product created when nicotine enters the body. Cotinine is more reliably measured than nicotine in aquatic environments. Caffeine and cotinine do not have Oregon human health or aquatic life criteria or EPA aquatic life benchmarks, and DEQ analysis estimated them to occur in 2% of Oregon lakes representing 96 lakes. DEET, an insect repellent, was the only detected compound with an EPA aquatic life benchmark, which DEQ analysis estimated to occur at concentrations at or below the benchmark in 52%, or 2,506 of Oregon's lakes. The remaining 48% are estimated to have no detectable concentration of DEET. (DEQ crews refrained from using DEET prior to collecting water samples, instead relying on clothing and netting for biting insect protection.)

This chemical group was not included in the analysis of sediment samples.

Current-Use Pesticides

Pesticides are a broad class of chemicals that include insecticides, herbicides, and fungicides. As the name implies, current-use pesticides are compounds currently available for legal use in the United States. Current-use pesticides are commonly applied on agricultural lands, public rights-of-way, managed forest areas, and residential properties to control unwanted organisms. Current-use pesticides can cause a variety of negative health effects in humans including issues with the skin, digestive tract, brain, lungs, reproductive system, hormones, and potentially cause cancer.

What was the condition in 2017?

The analysis of water samples included 110 compounds such as glyphosate (commonly sold as Roundup®), diuron, and atrazine. DEQ samples contained 15 of the included compounds. The highest estimated occurrence (13% of Oregon lakes) was for the herbicide, metsulfuron methyl. This pesticide is commonly sold as Escort® or Ally® and is used on weeds and annual grasses. Many of the detected pesticides have established Oregon human health criteria or EPA aquatic life benchmarks, but only one occurred at a concentration above its associated EPA aquatic life benchmark. DEQ analysis estimated that dichlorvos, an insecticide used for a wide range of insects including on flea collars, occurs above its benchmark in 2%, or 96 of the lakes in Oregon (Figure 19).

Few current-use pesticides reside in stream sediment, so this chemical group was not included in the analysis of sediment samples.

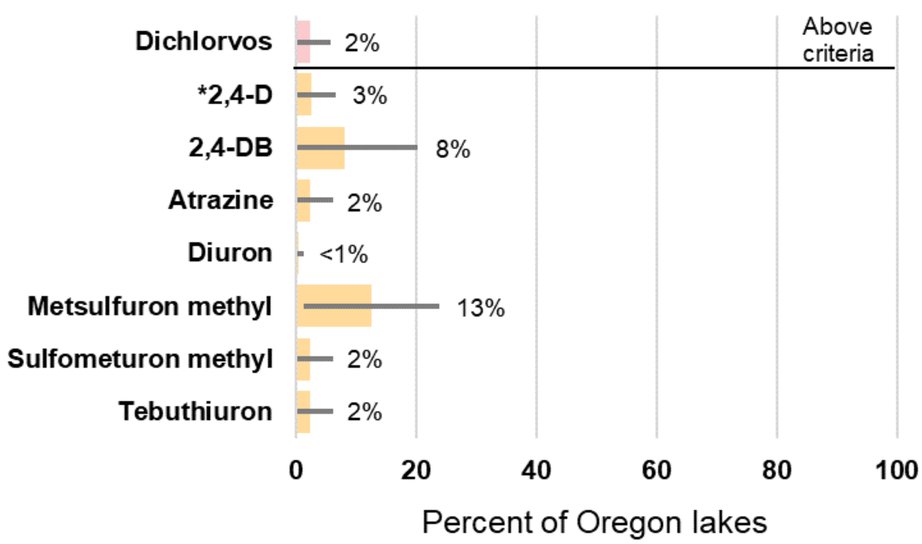

Figure 19. Estimated percentage of Oregon lakes with concentrations of current use pesticides above (red) or below (yellow) Oregon human health criteria (*) or EPA aquatic life benchmarks. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Dioxins and Furans

Dioxins and furans are two separate families of chemicals that share a similar chemical structure. These chemicals are not produced intentionally but rather are a byproduct of industrial activities (paper bleaching, industrial production, pesticide manufacture) and fossil fuel combustion from sources such as incineration, wood stoves and forest fires. Dioxins and furans can cause multiple negative health effects, including cancer, skin diseases and reproductive harm in humans and hormone disruption in humans and aquatic life.

What was the condition in 2017?

The analysis of this chemical group included 19 compounds. DEQ water samples contained detectable concentrations of 10 compounds including 2,3,7,8 tetrachlorodibenzo-p-dioxin, or TCDD, a constituent of Agent Orange and the most toxic compound of the chemical group. TCDD is the only dioxin or furan detected with an established Oregon human health criterion. DEQ analysis estimated its presence in less than 1%, or 48 of the lakes in Oregon at a concentration above the criterion. The analysis estimated that all other detected compounds in this group occur in less than 10% of Oregon lakes.

Chemicals in this group do tend to partition, or bind, to the sediment; however, due to resource constraints this chemical group was not included in the analysis of sediment samples.

Flame Retardants

Flame retardants are a group of chemicals added or applied to a variety of products, such as laptops, automobiles, furniture and textiles, to prevent the start or slow the growth of fires. There are many types of flame retardants, including polybrominated diphenyl ethers (PBDEs). Most of the compounds included in this chemical group are PBDEs. However, the analysis did include some chlorinated organophosphate flame retardants as well. None of the included flame retardants are those used to combat wildfires. Releases of these chemicals from products can enter the aquatic environment through air deposition, landfill leachate and wastewater discharges. Flame retardants can cause cancer and fertility issues in humans (NIEHS 2021) and can cause reproductive issues in aquatic organisms (Han 2013).

What was the condition in 2017?

DEQ analyzed water quality samples for 44 flame retardants and detected nine compounds. None of the detected compounds have established Oregon human health or aquatic life criteria or EPA aquatic life benchmarks. The highest estimated occurrence was 6% of Oregon lakes for TCEP, commonly found in polyurethane foam, furniture and baby products. All others were estimated to occur in less than 1-2% of Oregon lakes.

As with dioxins and furans, chemicals in this group also tend to partition to the sediment but were not included in the analysis of sediment samples due to resource constraints.

Industrial Chemicals

Industrial chemicals are used in the production of pesticides, pharmaceuticals, rubber, consumer products, etc. This group also includes ammonia; a naturally occurring compound commonly found in waste products that may be extremely toxic to aquatic organisms. Ammonia is included as an industrial compound because of its use in fertilizers and dyes. Negative health effects from exposure to industrial chemicals can include irritation or burning of the eyes, nose and throat, blood disorders, fatigue and cataracts in humans. In aquatic organisms, exposure to industrial chemicals can cause respiratory issues and lead to death (EPA 2013).

What was the condition in 2017?

The analysis of water samples includes 20 industrial chemicals. Samples contain detectable concentrations of three compounds including ammonia, isophorone and nitrobenzene. Isophorone is a widely used chemical solvent, while nitrobenzene is a chemical intermediate used to help create other chemicals. Ammonia has an established Oregon aquatic life criterion, while isophorone and nitrobenzene have established Oregon human health criteria. The analysis estimated that each occurs at concentrations below their criteria in less than 4%, or 193 of Oregon's lakes (Table 16).

This chemical group was not included in the analysis of sediment samples due to resource constraints.

Table 16. Estimated percentage of Oregon lakes with industrial chemical concentrations at or below DEQ human health criteria.

Legacy Pesticides	Category	% of Oregon lakes
Ammonia	At or below criterion	<1 ± 1
Isophorone	At or below criterion	3 ± 3
Nitrobenzene	At or below criterion	<1 ± 1

Legacy Pesticides

Legacy pesticides refer to chlorinated pesticides, such as DDT, banned from use in the United States. These compounds accumulate and persist in sediments, and runoff from agricultural fields may contain remnants of historical or illicit applications, a major pathway of these chemicals into streams and waterways. Like current-use pesticides, legacy pesticides also can cause a variety of negative health effects in humans including issues with the skin, digestive tract, brain, lungs, reproductive system, hormones, and potentially cause cancer. In aquatic organisms, negative health effect can reduce reproductive ability, interrupt food webs, and cause death (Beyond Pesticides n.d.).

What was the condition in 2017?

DEQ analyzed water quality samples for 32 legacy pesticides and detected eight compounds including two breakdown products of DDT. All the detected compounds have established Oregon human health or aquatic life criteria. Analysis of these samples estimated that three compounds, heptachlor epoxide, 4,4’-DDD, and 4,4’-DDE, occur at concentrations above their Oregon human health criteria in less than 1% of Oregon lakes. The analysis estimated that the other five compounds occur in a range of less than 1% to 8%, or between 48 and 386 of Oregon’s lakes (Figure 20) below their associated Oregon human health criteria.

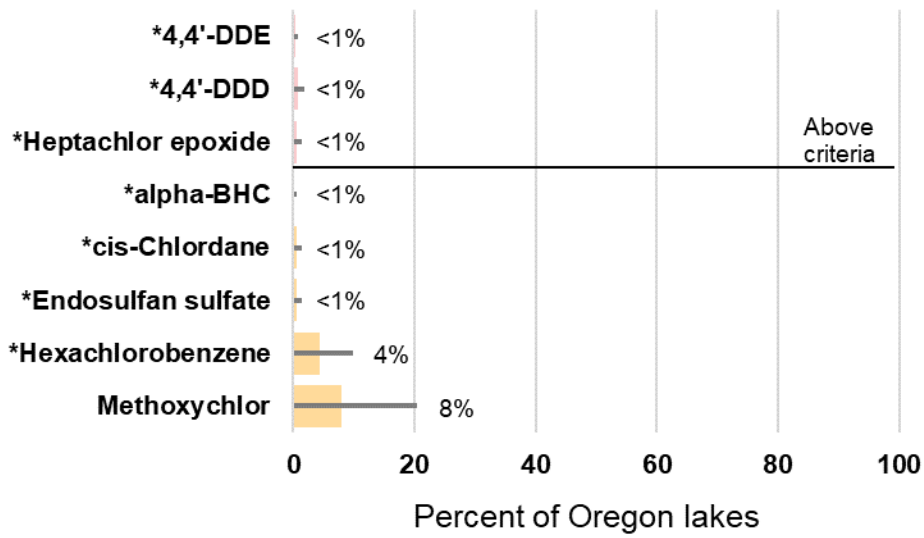

Figure 20. Estimated percentage of Oregon lakes with legacy pesticide concentrations in water above (red) or below (yellow) Oregon human health (*) or aquatic life criteria. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

The analysis of sediment samples includes 33 legacy pesticides, detecting 13 compounds. Two of the detected compounds have established sediment bioaccumulation screening levels and occurred at concentrations above these screening levels. DEQ analysis estimated that 4,4’-DDT, the primary form used as a pesticide, occurred above its screening level in 44%, or 2,120 lakes of Oregon’s lakes, while hexachlorobenzene occurred above its screening level in 8%, or 386 of Oregon’s lakes. Sediment samples also contained four breakdown products of DDT. These compounds do not have established screening levels, and the analysis estimated occurrence in 1-45% of Oregon lakes (Figure 21). Each of these compounds have different half-lives, affinities to stream sediments, and are impacted by sediment conditions differently (ATSDR 2019), which may help explain the wide range of estimated occurrence. None of the other detected compounds have established screening levels and the analysis estimated occurrence in less than 10% of Oregon lakes. A summary of detected concentrations can be found in Appendix B.

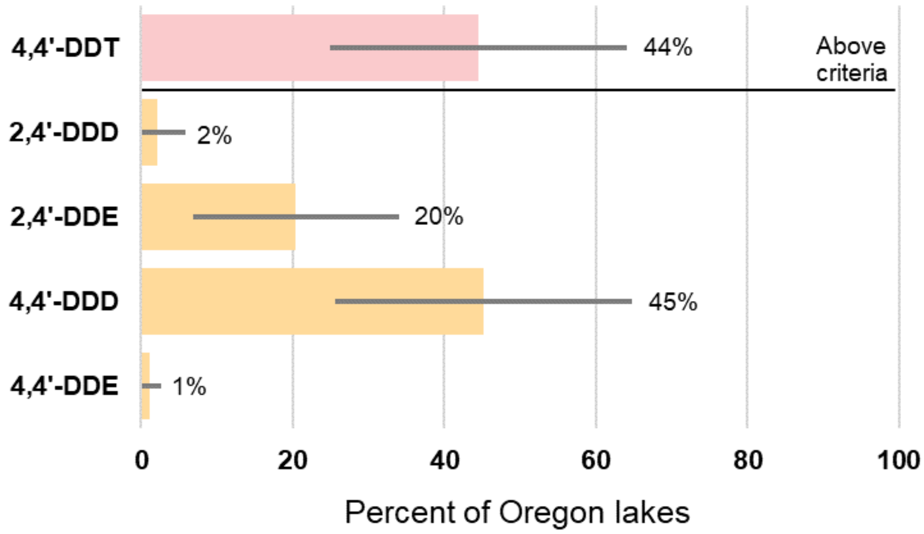

Figure 21. Estimated percentage of Oregon lakes with DDT concentrations in sediment detected (yellow) or above (red) an DEQ sediment bioaccumulation screening level. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Metals

Metals are naturally occurring in the environment and human activities can increase these concentrations. Detections of metals are common in water and most of the included metals have existing water quality criteria in Oregon. Consumption of metals in high concentrations can impair brain development and can cause liver, kidney and intestinal damage, anemia and cancer in humans (Martin and Griswold 2009). The list of negative health effects in aquatic organisms includes deformities, metabolic problems, tumors, reproductive loss and damage to liver and kidneys (EPA 2007; EPA 2016).

What was the condition in 2017?

DEQ detected concentrations of 14 of the 16 metals included in the analysis of water samples. Nearly all the included metals have established Oregon human health or aquatic life criteria. The detected concentrations are above these criteria for four metals: aluminum, chromium, iron and inorganic arsenic. DEQ chose to measure inorganic arsenic because of its high toxicity in the natural environment. The analysis estimated aluminum, chromium and inorganic arsenic to occur in 1% or less of Oregon lakes at concentrations above their criteria with iron estimated to occur in 4%, or 193 of Oregon's lakes (Figure 22). Estimated occurrence for manganese show it in over 80% of Oregon lakes. Manganese is an essential nutrient and does not have a criterion or benchmark.

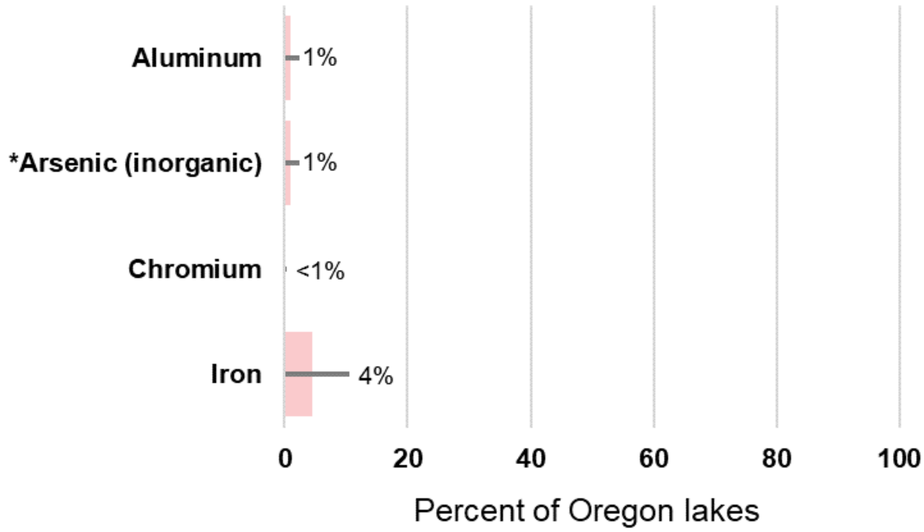

Figure 22. Estimated percentage of Oregon lakes with metals concentrations in water samples above Oregon human health (*) or aquatic life criteria. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

DEQ detected concentrations of all 19 metals included in the analysis of sediment samples. EPA analyzed three additional metals in sediment which accounts for the difference between water and sediment analytes. Due to the difficulty in associating concentrations of metals in animals and fish with concentrations in sediment, DEQ used background levels in place of sediment bioaccumulation screening levels for metals. Four metals have established background levels, and the analysis estimated arsenic, cadmium, lead and mercury to occur at concentrations above their background levels in Oregon lakes (Figure 23). Mercury is commonly detected across Oregon. This is due, in part, to the volcanic nature of the soil and sediment in many parts of the state but is also due to many other potential reasons such as atmospheric deposition and fossil fuel burning. OHA has statewide fish consumption advisory for mercury in place for bass along with location-based advisories for specific waterbodies and fish species across the state.

DEQ's analysis of sediment samples also estimated nine metals: aluminum, chromium, copper, iron, manganese, nickel, tin, vanadium and zinc, to occur in over 97% of Oregon lakes. Each of these metals are elements found in the earth's crust (Dodd 2020). However, none of them have established background levels. Iron, tin and vanadium were not included in the analysis of sediment samples from all 49 lakes. All three did occur in each of the 26 EPA sampled lakes. A summary of detected concentrations can be found in Appendix B.

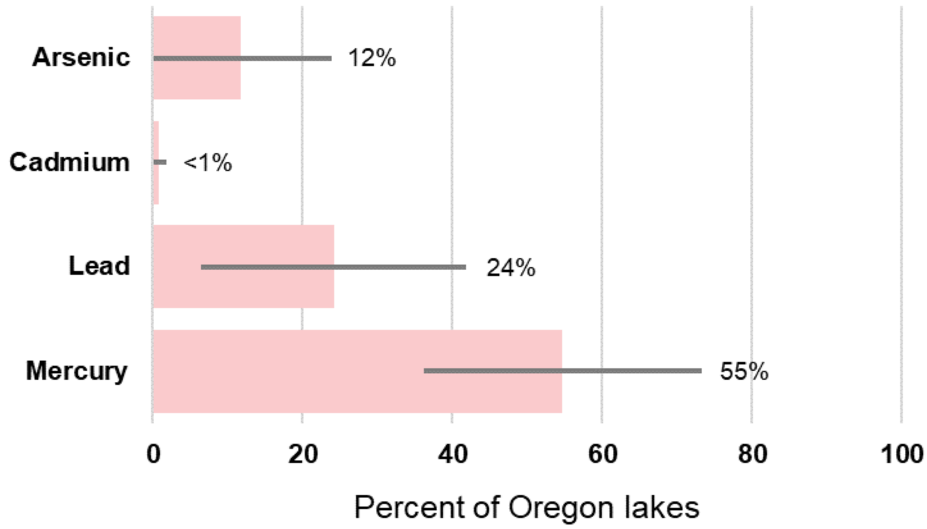

Figure 23. Estimated percentage of Oregon lakes with metals concentrations above DEQ background levels in sediment. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

Polychlorinated Biphenyls (PCBs)

PCBs are a class of industrial chemicals historically used as electrical insulating fluid in transformers and capacitors. The United States banned or limited the manufacture and use of PCBs due to their ability to persist in the environment and toxicity to humans and wildlife. However, no regulation exists for low levels (below 50 ppm) of PCBs in products, and PCBs can be inadvertent byproducts of some manufacturing processes, such as those associated with colorants. These historic and current uses of PCBs indicate a continued contamination risk to streams and rivers. PCBs can cause developmental abnormalities, cancer and impair immune function in aquatic organisms. PCBs accumulate in fat and organs of fish and other aquatic organisms with potential health impacts on the organisms that consume them, including humans. Negative health effects on humans include multiple types of cancer, weight loss and reproductive impairment among others (Carpenter 2006).

What was the condition in 2017?

DEQ's analysis of water samples included 172 of the 209 existing PCB compounds. However, the agency found no detectable concentrations in any of the sampled lakes. The analytical method DEQ's lab uses does not report the remaining PCBs because these compounds did not meet method validation criteria.

In sediment samples, DEQ detected 72 of the 172 compounds reported by the PCB method. Most PCB compounds do not have established sediment bioaccumulation screening levels. Of the 13 compounds that do, including total PCBs, which is the sum of all concentrations detected at a single lake, six exceeded their DEQ sediment bioaccumulation screening levels. DEQ analysis estimated that PCB-118 occurs in 27%, or 1,301 of Oregon's lakes, at a concentration above its screening level. This was the highest estimated occurrence of all PCB compounds (Figure 24).

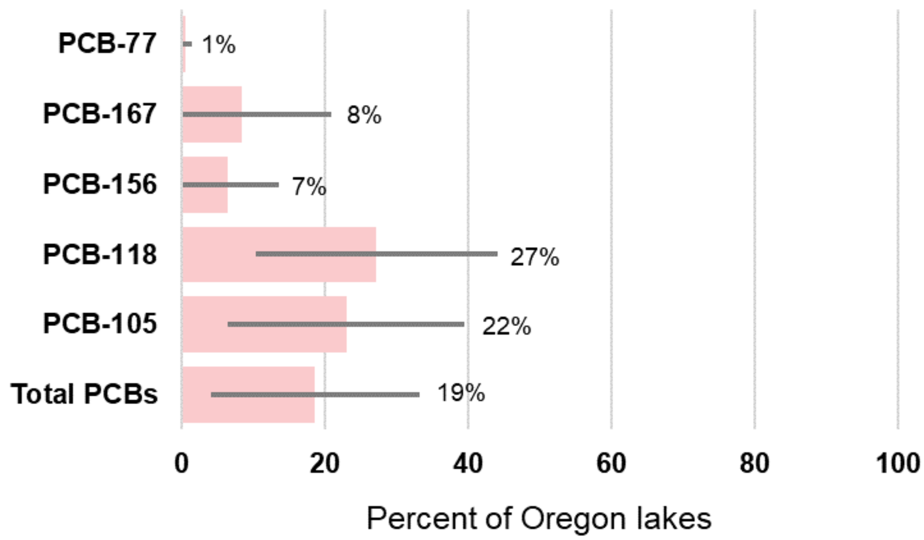

Figure 24. Estimated percentage of Oregon lakes with PCB concentrations above DEQ sediment bioaccumulation screening levels. Percentages indicate point estimates. Grey bars indicate 95% confidence intervals around the point estimate.

4. Indicator change and correlations

4.1 Change estimates

Due to small sample sizes in previous rounds of the NLA (2007 and 2012), DEQ was unable to make statewide assessments of the conditions in Oregon's lakes with known confidence. These small sample sizes (less than 30 lakes) also prevented DEQ from making estimates of change, which is a key component of the national report for NLA. However, by supplementing EPA funding with state funding in 2017, we learned that the condition of Oregon lakes is quite similar to that of the population of all lakes across the PNW. With this information we can infer that changes observed in the PNW population of lakes are likely to be similarly true for Oregon's population of lakes. This is an assumption and should be carefully considered before making policy decisions. Without increased funding to boost the monitoring of Oregon's lakes as part of the NLA, this inference provides the best data we have available to estimate change.

Comparing PNW results from 2012 to 2017, we observed statistically significant improvements in total phosphorous and shallow water habitat conditions across the population of PNW lakes (Table 17). Total phosphorous conditions shifted 27% to good condition and away from both fair and poor conditions. Shallow water habitat conditions significantly shifted away from fair condition with a large but not statistically significant increase in good condition.

Declining conditions were most notable in increasing chlorophyll *a*, with a significant increase (21%) in poor conditions (Table 17). Both lake habitat complexity and riparian vegetative cover also showed significant increases in poor conditions (9% and 12%, respectively). Benthic macroinvertebrates (14%) and total nitrogen (16%) showed significant increases in fair conditions, mostly due to insignificant declines in good conditions.

To see change analysis results for other indicators, please visit the [Oregon Lakes Interactive Dashboard](). (Change analysis is unavailable for toxics data.)

Table 17. Change estimates from 2012 to 2017 in the population of Pacific Northwest lakes (± 95% confidence interval). Statistically significant changes are shown in bold.

Indicator	% Good (CI range)	% Fair (CI range)	% Poor (CI range)
Improving Conditions			
Total Phosphorous	**27% (8 - 46%)**	-11% (-31 - 9%)	-16% (-36 - 4%)
Shallow Water Habitat	18% (-0.2 - 36%)	**-16% (-31 - -0.2%)**	-2% (-16 - 11%)
Declining Conditions			
Chlorophyll *a*	-13% (-32 - 6%)	-8% (-29 - 13%)	**21% (5 - 38%)**
Lake Habitat Complexity	0% (-16 - 17%)	-8% (-22 - 6%)	**9% (0 - 18%)**
Riparian Vegetative Cover	-9% (-22 - 5%)	-2% (-13 - 10%)	**12% (3 - 22%)**
Benthic Macroinvertebrates	-11% (-24 - 3%)	**14% (1 - 27%)**	-1% (-5 - 2%)
Total Nitrogen	-15% (-34 - 3%)	**16% (0 - 32%)**	-1% (-20 - 18%)

4.2 Correlations: Biological/Chemical/Physical

At the time of reporting, the raw data for physical habitat and biological indicators was not available for indicator correlation analysis. However, we can look to the results from the National survey to draw some general conclusions. Using a technique known as “relative risk”, EPA analysts determine the rate at which lake biological conditions are poor when a given stressor is also in poor condition. (Relative risk was not calculated for Oregon or PNW lakes due to the low number of poor biological conditions observed, which can give rise to misleading results.)

At the national scale, benthic macroinvertebrates are 2.3 times more likely to be in poor condition when total phosphorus is also in poor condition. Other stressors which result in high relative risks (>2.0) for macroinvertebrates include dissolved oxygen, shallow water habitat and total nitrogen. Similarly, there is a strong nutrients signal with relative risk for zooplankton. Zooplankton communities are greater than two times more likely to be in poor condition when either phosphorus (2.3) and nitrogen (2.1) are also in poor condition. Chlorophyll *a* also shows a significant relative risk (1.7). But the greatest relative risk to zooplankton is observed for dissolved oxygen, where zooplankton communities are 4.8 times more likely to be in poor condition. Dissolved oxygen concentrations are frequently related to primary productivity, which is also related to nutrient concentrations.

4.3 Correlations: Toxics Assessment

Based on the available toxics data, DEQ analysts compared indicator values with raw data from across the population of lakes in search of correlations. One-way ANOVAs were performed to compare the effect of lake origin on the detections of toxic compounds, lake setting on the detections of toxic compounds, physical habitat indicator condition class on nutrient values and on the detections of toxic compounds, chlorophyll *a* condition class on the total nitrogen and total phosphorous values, and trophic status condition class on the total nitrogen and total phosphorous values. Due to small sample sizes for some condition classes, sample variances did not meet the requirements for analysis using ANOVA. Those comparisons are not reported here. In cases where a significant difference occurred between at least two groups, DEQ used Tukey's HSD Test for multiple comparisons to determine which groups were significantly different.

From these comparisons, natural lakes have significantly fewer detections of compounds included in the toxics assessment than man-made lakes (ANOVA: $F(1, 47) = [15.65]$, $p = 0.00$; Tukey's: $p = 0.00$, 95% C. I. = [2.45, 7.53]). Similarly, lakes in a non-urban setting also have significantly fewer detections of compounds included in the toxics assessment than lakes in an urban setting (ANOVA: $F(1,47) = [5.19]$, $p = 0.03$; Tukey's: $p = 0.03$, 95% C. I. = [0.44, 7.08]). Each of the physical habitat indicators (shallow water habitat, riparian cover and lakeshore disturbance) have significantly fewer detections of compounds included in the toxics assessment in the good condition class than in the poor condition class (Table 18). This was also true for lakeshore disturbance between the good condition class and the fair condition class (Table 18). Lakes in the poor condition class for lakeshore disturbance also have significantly higher magnesium concentrations than those in the good condition class (ANOVA: $F(3, 37) = [4.88]$, $p = 0.01$; Tukey's: $p = 0.00$, 95% C. I. = [0.04, 0.25]). Finally, comparisons of trophic status indicator values with total phosphorous found that lakes considered oligotrophic have significantly lower concentrations of total phosphorous than lakes considered hypereutrophic (ANOVA: $F(3, 44) = [4.75]$, $p = 0.01$; Tukey's: $p = 0.01$, 95% C. I. = [1.85, 14.43]).

All other comparisons do not indicate a significant difference between the condition classes.

Table 18. Results of one-way ANOVA and post-hoc (Tukey's HSD) comparisons between physical habitat indicators toxics detection data.

Independent variable	Dependent variable	One-way ANOVA F-value	One-way ANOVA p-value	Condition class comparison	Tukey's HSD p-value	Tukey's HSD 95% C. I.
Shallow water habitat	# of toxics detected	F(3,45) = 3.11	p = 0.03	Good - Poor	p = 0.02	0.67, 12.38
Riparian veg. cover	# of toxics detected	F(3,45) = 6.06	p = 0.01	Good - Poor	p = 0.00	2.22, 9.96
Lakeshore disturbance	# of toxics detected	F(3,45) = 9.65	p = 0.00	Good - Poor	p = 0.00	2.37, 8.15
Lakeshore disturbance	# of toxics detected	F(3,45) = 9.65	p = 0.00	Good - Fair	p = 0.01	1.57, 12.02

5. Conclusion

The ecological condition of Oregon's lakes is largely good—especially when compared to results observed in the PNW region and nationally. Oregon's lakes are largely in good condition for biological communities (macroinvertebrates and zooplankton). The majority are clear, low productivity oligotrophic lakes, with excellent ecological and recreational value; however, there are several key stressors of concern.

Eutrophication, or increasing nutrients and changing trophic states, is of concern nationally (Stoddard et al. 2016) and globally (Smith and Schindler 2009). The leading chemical stressors observed at all scales we examined—Oregon, PNW, Nationally—were nutrients and chlorophyll *a*. Within PNW states, we observed a significant decline in conditions for total nitrogen and chlorophyll *a* between 2012 and 2017. This decline in chlorophyll *a* conditions in the PNW comes despite trends showing significant improvements in phosphorus conditions. Like Oregon, Vermont has a lot of oligotrophic lakes; yet oligotrophic lakes in Vermont are showing signs of eutrophication (Matthews et al. 2018). Without a consistent lake monitoring program in Oregon, we are unable to determine if Oregon's oligotrophic lakes are similarly at-risk of eutrophication. Establishing a smaller regional monitoring network to sample the oligotrophic lakes of the high Cascades and Northeastern Oregon may be more cost effective than a statewide assessment of lakes.

From a recreational indicator perspective, all detected concentrations of *E. coli* fell below OAR guidelines meaning that all lakes meet the requirements for safe freshwater contact recreation. Only 2% of the lakes sampled for microcystin contained detectable concentrations in open waters. This represents an estimated 96 lakes in Oregon; however, all detected concentrations fell below the OHA recreational use value. None of the lakes included in this study have had a hazardous algal bloom advisory for microcystin in the past 10 years. Again, NLA sampling protocols may underrepresent contact recreation risk, due to single-point sampling at the deepest point of the lake rather than targeting potential points of contact, like boat ramps.

Comparison of the toxics assessment results to fixed benchmarks rather than assignment to condition classes means that the toxics results cannot be viewed through the same lens. This approach does allow for the observation that most of the compounds detected in the toxics assessment do not pose an immediate risk to the health or safety of humans or aquatic life. This is because 96% of compounds included are detected at concentrations below applicable Oregon human health or aquatic life criteria or EPA aquatic life benchmarks, not detected, or do not have established benchmarks.

In sediment, 4,4'-DDT is estimated to occur at concentrations that could pose a risk to human health through the consumption of fish and shellfish in 2,120 of Oregon's lakes. The use and sale of DDT is banned in the United States making the most likely source of this contamination legacy applications. DDT also has a long residence time in sediment, which indicates the need for erosion control measures in places where previous DDT application occurred.

Mercury in sediment is estimated to occur at concentrations above background in 2,650 of Oregon’s lakes. Mercury contamination can occur through several processes. It is naturally occurring, but the burning of fossil fuels enhances contamination. Once in the environment, mercury does not breakdown or become less toxic. Mercury contamination is a focus of the Cleanup and Total Maximum Daily Load programs, a key component of the Toxics Reduction Strategy at DEQ, and the reason for a statewide consumption advisory for bass as well as local consumption advisories for other fish species.

PCBs were not detected in water samples; however, six PCB compounds were estimated to exceed their sediment bioaccumulation screening levels. Along with the fish consumption advisories for mercury, PCBs are another main reason for local consumption advisories put in place by OHA. Once compounds such as DDT, mercury and PCBs begin to accumulate in fish tissue there is little to no way to reduce the concentrations of these potentially harmful compounds, which could impact the health and reproductive ability of the fish and ultimately have a negative effect on the humans or wildlife that consumes the fish.

Comparing the EPA indicators to the number of toxic compounds detected indicates that lakes in poor condition are more likely to have detectable concentrations of toxic compounds. This could pose additional threat to the biological communities in those lakes because little is known about how persistent low-level detections or of how the synergistic effects of multiple chemicals in a lake might act in the environment or impact the aquatic community. The inclusion of additional lakes would make this analysis more robust and potentially indicate additional influences and impacts on Oregon’s lakes.

This assessment demonstrates that there is a need for continued statewide monitoring of lake conditions with a consistent set of indicators and sample sizes large enough to detect changes over time. The 2017 statewide assessment was made possible by including DEQ funding and partnerships among monitoring programs. This allowed for an increased sample size, large enough to make adequate population estimates and assess the overall ecological conditions of Oregon’s precious lakes resources. The results in this report also reflect the first statewide assessment of toxic compounds in Oregon’s lakes and reservoirs. The next iteration of the National Lakes Assessment will take place in the summer of 2022. DEQ will participate in that assessment; however, there are no plans to include Toxics Monitoring Program parameters or to boost the sample size to allow for a statistically-valid statewide assessment of lake conditions—leaving only 24 lakes to be surveyed. Considering that DEQ does not have an active statewide lakes program, the NLA offers the most cost-effective approach to monitoring Oregon’s lakes at the state scale.

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Appendix A. Targeted Lakes

This appendix contains sampling results from the “targeted” or non-random lakes (Figure 25). These data were not included in the EPA indicator analysis or toxics assessment because DEQ solicited input from stakeholders, which does not adhere to the EPA sampling protocols for the NLA.

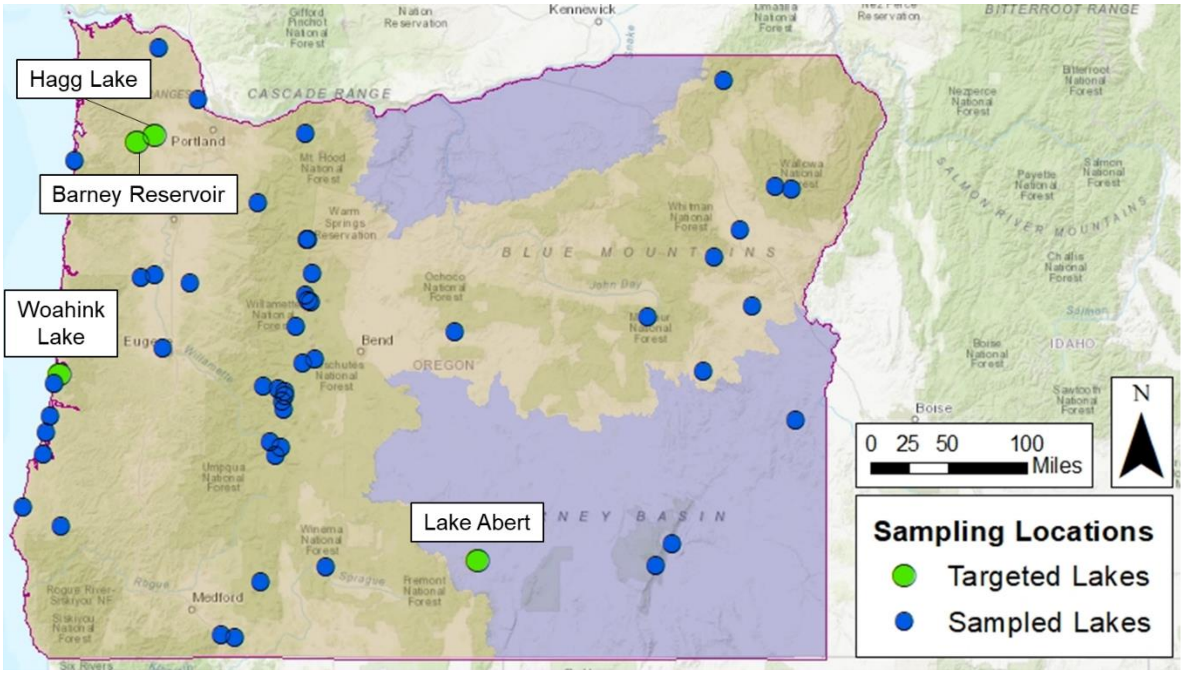

Figure 25. The location of the four targeted lakes DEQ sampled (green circles). The population of Oregon lakes included in the main part of this report are shown as blue circles.

Lake Abert

Lake Abert is a hypersaline (saltier than seawater) and alkaline (high pH, very low acidity) lake, located in south central Oregon in Lake County. For comparison, salinity has been measured in Lake Abert at 70-200 parts per thousand (salinity was not recorded during this study) while average seawater is 35 ppt. The average pH of the lakes included in this study was 7.6, while Lake Abert’s pH was 9.9. The average alkalinity of lakes included in this study was 21 mg/L while Lake Abert’s alkalinity was 20500 mg/L.

The lake is situated in a truly closed basin meaning that the basin has no connection to groundwater, has no drain or outlet and loses water almost entirely by evaporation. Further, this means that the lake does not flush, or cycle water in and out, like open basin lakes would. This leads to the concentration of natural metals (i.e., arsenic) and minerals (i.e., phosphorous) as well as pollutants from human sources (i.e., pesticides). Recent observations of Lake Abert have shown rapidly declining water levels and reductions in biological communities (OLA 2018). Lake Abert went dry in 2014, but in 2017, the year we sampled, water levels were up—although still below typical historic levels. Lake Abert went dry again in 2021. Periodic drying of the lake and general declining water levels likely influence the concentrations of metals and pollutants in the lake. Lake Abert was suggested for inclusion in this study by the Oregon Lakes Association (OLA) because it is one of only a few hypersaline lakes in the US, and an important stopover point for many migratory bird species.

As a hypersaline lake, comparisons to EPA indicators (biological, chemical, recreational) are limited. For this reason, saline lakes were excluded from NLA surveys. As such, it is not appropriate to assign condition classes to these indicators. However, the data collected is provided here and should be useful for comparisons to historic and future monitoring data.

For the toxics indicators, chemical measurements were compared against saltwater aquatic life criteria. Due to the unique nature of the lake and the limited aquatic species, the saltwater criteria may not be appropriate for naturally occurring parameters of geologic origin, such as arsenic and copper. Oregon has a toxics narrative criterion that applies to Lake Abert, but DEQ has not developed site-specific numeric criteria based on the unique water chemistry and species in the lake. Due to the limited species, fishing and fish consumption are not considered a beneficial use of the lake. The lake is not designated for domestic water supply either. Therefore, it is not appropriate to apply the human health toxics criteria to this lake. Similarly, due to the high alkalinity, water contact recreation is also not considered a beneficial use in the lake, so the *E.coli* criteria for freshwater water contact recreation is not applicable. Given Lake Abert's unique characteristics, the values measured in the lake and criteria are shown in this report for informational purposes only.

EPA indicators

Trophic status

Based on literature thresholds for chlorophyll *a*, the trophic status for Lake Abert was determined to be eutrophic (Figure 26).

Biological communities

Following is a brief summary of the results of biological communities sampled in Lake Abert. The lake has developed unique biological communities due to its unique chemical and physical characteristics. Only three benthic macroinvertebrate taxa were collected. All three of the taxa were "true flies" (Diptera), with Ephydridae (aka: shore flies, salt flies, brine flies) representing 97% of the sample.

Zooplankton samples showed five total taxa were collected. Dominance was very high, with two taxa dominating the counts. Three taxa were branchiopods (fairy shrimp, brine shrimp, water fleas, etc.) and two were rotifers. By a far margin, the two dominant taxa were Moina (a type of "water flea") and the rotifer Hexartha.

Chemical indicators

Total phosphorus in Lake Abert was 19.0 mg/L, much higher than any other value observed in this report (Figure 27). Phillips and Van Denburgh (1971) found a range of phosphorous concentrations between 17.9 and 32.9 mg/L. Few recent samples have been collected in the lake; however, samples collected from rivers across the basin rarely exceeded 0.8 mg/L.

Only a third of Oregon lakes were estimated to have a detectable concentration of *E. coli*. However, owing, in part, to its importance as a migratory stopover for birds, the *E. coli* concentration in Lake Abert was 613 MPN/100mL. This value was above the recreational contact criterion of 406 MPN/100mL (Figure 28). This comparison is made for informational purposes only because recreation is not a use supported by Lake Abert due to the high salinity and alkalinity concentrations.

Toxics Indicators

Analysis of water samples collected for the toxics assessment found detectable concentrations of 16 different compounds. The concentrations of 4,4'-DDE, arsenic (Figure 29) and copper represent the highest concentrations found across all lakes in this study and were above the chronic saltwater aquatic life criteria. The concentration of 4,4'-DDE is a potential concern as it is not a substance of natural origin and DDT, of which DDE is a breakdown produce, is known to effect reproductive ability in birds. Phillips and Van Denburgh (1971) found a range of aluminum concentrations between 76 and 270 µg/L well below the concentration found in 2017 of 4600 µg/L. Fluctuations in lake water levels could play a factor in the difference in concentrations.

The lake also had the highest concentrations of iron (Figure 30), phenanthrene and ammonia detected across the state. There are no saltwater aquatic life criteria for iron or phenanthrene. The Philips and Van Denburgh report also found iron concentrations of 84 and 90 µg/L. These concentrations are again well below the iron concentration found in 2017 of 4500 µg/L. Salinity was not recorded for this study; however, because Lake Abert is known to be hypersaline using the salinity of seawater is a conservative estimate of actual salinity in the lake. Per this assumption, the concentration of ammonia was above the DEQ ambient saltwater criterion. The ammonia concentration is likely influenced by the naturally high pH of the lake.

Glyphosate, AMPA, a breakdown product of glyphosate, and acetaminophen were detected at low levels in the lake. There are no benchmarks for these chemicals in saltwater or in highly saline and alkaline lakes. No flame retardants or dioxins and furans were detected in water samples.

The analysis of sediment samples for the toxics assessment found detectable concentrations of 11 different compounds. Only one, arsenic, was found at a concentration above DEQ sediment background levels (Figure 31). All other detections did not exceed applicable criteria. No legacy pesticides or PCBs were detected in sediment samples. No prior studies on lake sediment in Lake Abert could be found for comparison with these concentrations.

Barney Reservoir

Barney Reservoir is located in the northwest part of the state in Washington County. The reservoir serves as a drinking water source for nearby communities of Hillsboro and Beaverton.

Questions around contaminants and sedimentation lead DEQ's Northwest Region Office to suggest this lake be included in this study.

EPA Indicators

EPA indicators were not collected at Barney Reservoir.

Toxics Indicators

Just five of the compounds included in the toxics assessment of water samples were detected in Barney Reservoir. None of the detected concentrations exceeded applicable DEQ human health or aquatic life criteria. The reservoir was one of the only lakes in the study with a detectable concentration of atrazine and the dioxin OCDD. No combustion byproducts, consumer use products, flame retardants, industrial chemicals, or legacy pesticides were detected in the reservoir.

The analysis of sediment samples from Barney Reservoir contained detectable concentrations of 15 compounds included in the toxics assessment. Most of the detected compounds were metals and occurred below the DEQ sediment background levels. However, the concentration of aluminum found in Barney Reservoir was the highest concentration found across all lakes included in this study. The concentration of total PCBs did exceed the DEQ bioaccumulation screening level (Figure 32). This concentration is the sum of the three detected PCB compound concentrations detected in the sample collected.

Hagg Lake

Hagg Lake also located in the northwest part of the state in Washington County, was suggested for inclusion in this study by DEQ Land Quality personnel. The lake was included to serve as a reference location for toxic compounds such as PCBs as well as dioxins and furans. Previous DEQ studies found no detections of PCBs in either sediment (1988) or fish tissue (1993) samples.

EPA Indicators

EPA indicators were not collected at Hagg lake.

Toxics Indicators

Like Barney Reservoir, five compounds included in the toxics assessment of water samples were detected in Hagg Lake. The two lakes are closely located in northwestern Oregon. None of the detected compounds exceeded applicable criteria. Hagg Lake was the only lake included in this study with a detectable concentration of the furan 1,2,3,7,8,9-HxCDF. No combustion byproducts, consumer use products, current use pesticides, flame retardants, or industrial chemicals were detected in the lake.

Sediment samples from Hagg Lake contained 23 compounds included in the toxics assessment. Arsenic, total PCBs and total DDT occurred at concentrations above DEQ sediment screening values (Figures 31, 32, 33). The total PCB concentration is the sum of all PCB compound concentrations detected in the sample As noted above a previous study conducted in 1988, found no detectable concentrations of PCBs in sediment from the lake. The 2017 samples were analyzed using a different analytical method on equipment with higher resolution capabilities, which means smaller concentrations could be detected and quantified. Had the 2017 samples been analyzed using the same method as the 1988 samples, only the total PCB concentration from 2017 would have been detected.

Woahink Lake

Woahink Lake is located in the Coast Range in Lane County. The lake was suggested for inclusion in this study by the Oregon Lakes Association because it represents a type of lake not otherwise included in the study. Woahink Lake is a relatively deep lake with a small watershed. The lake serves as a drinking water supply for nearby communities. It is also an important recreational lake that provides aesthetic and economic benefits to shoreline homeowners as well as visitors.

EPA Indicators

Based on literature derived benchmarks for chlorophyll *a*, Woahink was observed to be mesotrophic (Figure 26).

Benthic macroinvertebrates were in good condition. A total of 37 distinct taxa were collected, well above the average observed in all Pacific Northwest lakes (28 taxa, n = 122 lakes). A total of 15 taxa deemed to be pollution tolerant were collected, representing 68.7% of all individuals. These numbers were above the averages observed for Pacific Northwest states (12.5 taxa, 50.2 % individuals).

Zooplankton were in good condition. A total of 13 taxa were collected, compared to an average of 14.4 total taxa for all Pacific Northwest lakes. The most dominant type of zooplankton were copepods (55%), followed by rotifers (42%). Water fleas (3%) made up a small portion of the zooplankton community.

For nutrients, both total phosphorus and total nitrogen were in good condition. However, chlorophyll *a* was in fair condition, based on Western Mountains ecoregion benchmarks.

Habitat conditions in Woahink Lake were mixed. Drawdown was not large. Littoral cover (shallow water habitat) was in good condition. However, riparian vegetation and riparian disturbances were in fair condition.

Toxics Indicators

Water samples from Woahink Lake contained the fewest number of compounds included in the toxics assessment with three compounds detected. Two of the detected compounds, barium and manganese, are naturally occurring and are very commonly detected across the state. The third detected compound, 2,6-dichlorobenzamide, is a breakdown product of the current use pesticide dichlobenil. The detected concentration was just above the detection limit and no human health or aquatic life criterion exists for this compound.

The sediment samples collected from Woahink Lake contained 14 of the compounds included in the toxics assessment. Arsenic, lead and mercury occurred at concentrations above DEQ sediment background levels (Figures 31, 34, 35). These concentrations do not pose an immediate risk to human health or aquatic life; however, the concentrations are above concentrations typically seen in the Pacific Northwest. Total DDT occurred at a concentration above the DEQ sediment bioaccumulation screening level (Figure 33). This concentration indicates the level where DDT could accumulate in tissues of fish or other aquatic life and pose a potential risk to humans or wildlife regularly consuming fish or other aquatic life from the lake.

Parameter Comparisons with Population of Oregon Lakes

The selected boxplots in this section depict the weighted percentiles from the population of Oregon lakes included in the main study. The letters indicate concentrations detected in the target lakes (Lake Abert = A, Barney Reservoir = B, Hagg Lake = H, Woahink Lake = W). The applicable freshwater criteria are included as a red dotted line while any applicable saltwater criteria are included as blue solid lines. Saltwater criteria are only applicable to Lake Abert. All boxplots are plotted on a logarithmic scale, so the axis scale may change between figures. Boxplots were not created for each parameter detected in the target lakes due to low numbers of detections; however, the detection data is available in Appendix B.

Water sample figures

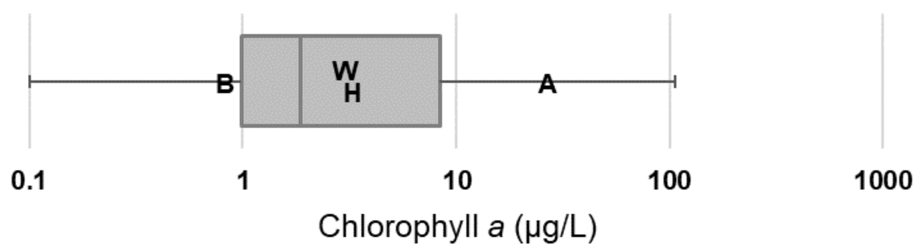

Figure 26. Boxplot of chlorophyll *a* detections in the population of lakes sampled for this study. Also depicted are the detections found in Lake Abert (A), Barney Reservoir (B), Hagg Lake (H) and Woahink Lake (W).

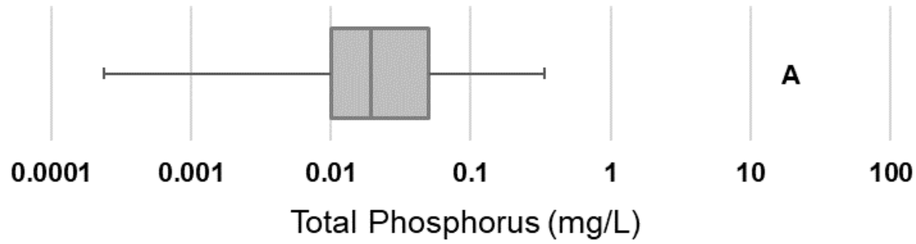

Figure 27. Boxplot of total phosphorous detections in the population of lakes sampled for this study. Also depicted is the detection found in Lake Abert (A).

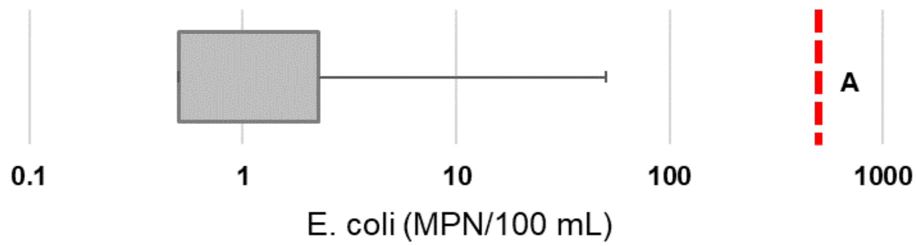

Figure 28. Boxplot of *E. coli* detections in the population of lakes sampled for this study. Also depicted is the detection found in Lake Abert (A), and the OAR recreational contact criterion of 406 MPN/100 mL (red dotted line). Including the criterion is intended for informational purposes only.

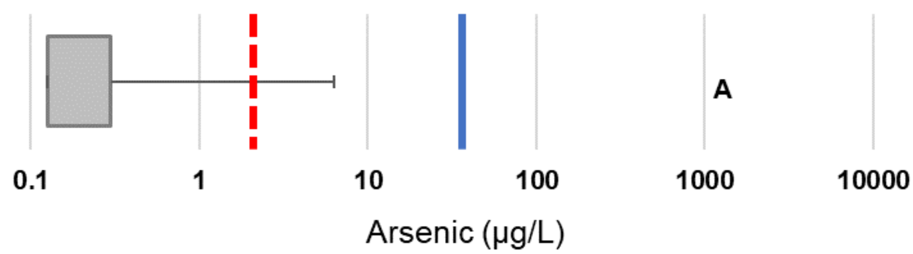

Figure 29. Boxplot of arsenic detections in the population of lakes sampled for this study. Also depicted is the detection found in Lake Abert (A), the Oregon Human Health freshwater criterion of 2.1 µg/L (red dotted line). Lake Abert is more appropriately compared to the saltwater chronic aquatic life criterion of 36 µg/L (blue solid line).

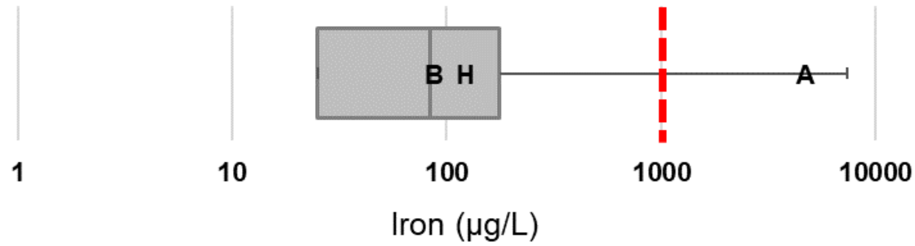

Figure 30. Boxplot of iron detections in the population of lakes sampled for this study. Also depicted are the detections found in Lake Abert (A), Barney Reservoir (B) and Hagg Lake (H), as well as the Oregon freshwater chronic aquatic life criterion of 1000 µg/L (red dotted line). Lake Abert is featured for informational purposes only, as Oregon has no saltwater aquatic life criterion for iron.

Sediment samples

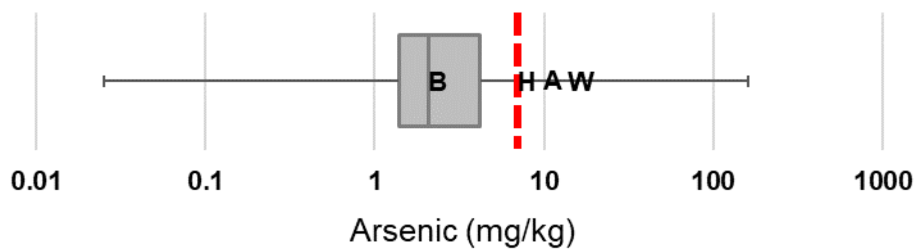

Figure 31. Boxplot of arsenic detections in the population of lakes sampled for this study. Also depicted are the detections found in Lake Abert (A), Barney Reservoir (B), Hagg Lake (H) and Woahink Lake (W), as well as the DEQ sediment background level of 7 mg/kg (red dotted line).

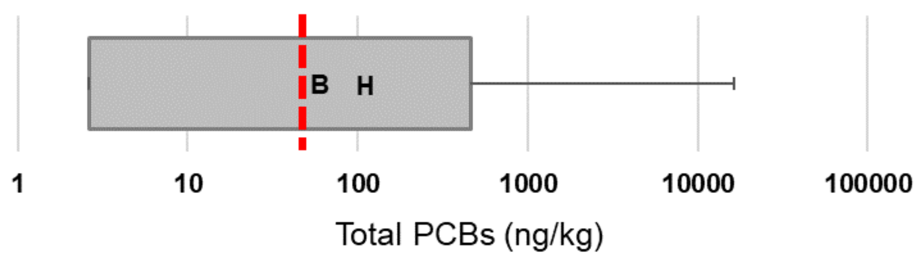

Figure 32. Boxplot of total PCB detections in the population of lakes sampled for this study. Also depicted are the detections found in Barney Reservoir (B) and Hagg Lake (H), as well as the DEQ sediment bioaccumulation screening level of 48 ng/kg (red dotted line).

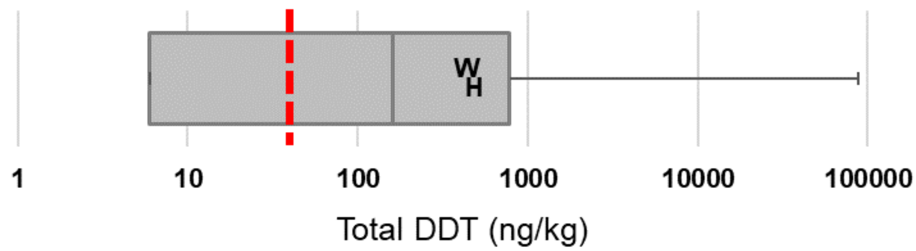

Figure 33. Boxplot of total DDT detections in the population of lakes sampled for this study. Also depicted are the detections found in Hagg Lake (H) and Woahink Lake (W), as well as the DEQ sediment bioaccumulation screening level of 40 ng/kg (red dotted line).

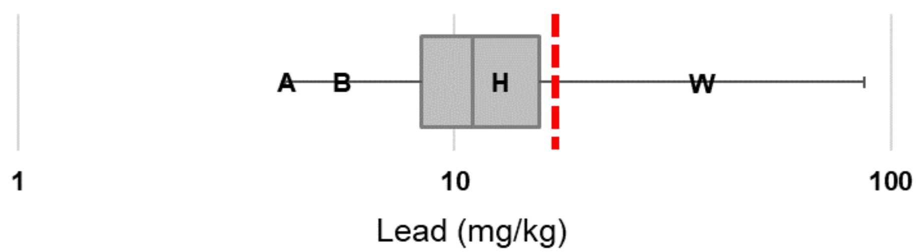

Figure 34. Boxplot of lead detections in the population of lakes sampled for this study. Also depicted are the detections found in Lake Abert (A), Barney Reservoir (B), Hagg Lake (H) and Woahink Lake (W), as well as the DEQ sediment background level of 17 mg/kg (red dotted line).

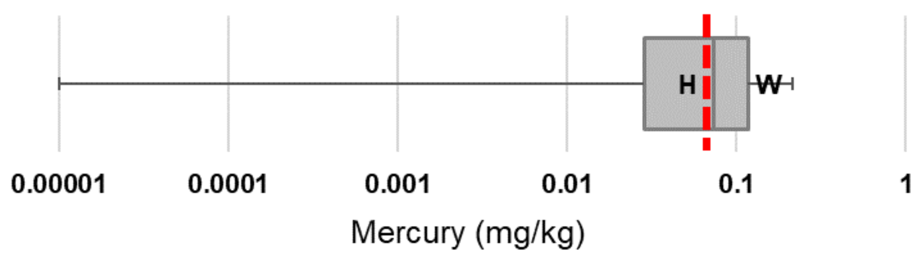

Figure 35. Boxplot of mercury detections in the population of lakes sampled for this study. Also depicted are the detections found in Hagg Lake (H) and Woahink Lake (W), as well as the DEQ sediment background level of 0.07 mg/kg (red dotted line).

Appendix B. Individual lake results

This appendix contains detailed detection summaries for each lake sampled during this study and the four targeted lakes described in Appendix A. The file also includes a key that contains references for all of the criteria, benchmarks and screening values used to evaluate the data, as well as individual tabs for the toxics sampling results in water, the toxics sampling results in sediment, and data collected for the EPA indicators.

All data included in the appendix adheres to DEQ data quality standards. The appendix is available for download on the DEQ National Aquatic Resource Survey webpage.

Appendix C. Full analyte list

This appendix contains an expandable table containing the full analyte list included in this study for both water and sediment samples. The appendix is available for download on the DEQ National Aquatic Resource Survey webpage.