# Oregon DEQ Harmful Algal Bloom (HAB) Strategy

## Appendix D

**June 2011**

State of Oregon
Department of Environmental Quality

This report prepared by:

Andy Schaedel
Oregon Department of Environmental Quality
811 SW 6th Avenue
Portland, OR 97204
1-800-452-4011
www.oregon.gov/deq

Contact:
Dan Turner
(503) 229-6682
turner.daniel@deq.state.or.us

# Appendix D
## Nutrients

The best way to control excessive algae is control the flow of nutrients into the waterbody. This appendix contains additional information regarding nutrients that was reviewed during the development of the DEQ HABs Strategy and is provided as additional background and reference material.

State of Oregon
Department of Environmental Quality

### Nutrients, In General

Algae, cyanobacteria, and other photosynthetic organisms require over 20 elements for growth and survival (Frausto da Silva and Williams, 1991). Nitrogen (N), and especially phosphorus (P), are often in shortest supply in relation to demand in lakes; thus their concentrations often limit phytoplankton growth (Schindler et al. 2008; Lewis and Wurtzbaugh 2008). The chemical forms of N and P also play a role in the competition between phytoplankton species in lakes. For example, most algae require N as ammonium ($NH_4^+$) or nitrate ($NO_3^-$) while some cyanobacteria species can utilize dissolved N gas ($N_2$). This gives cyanobacteria a competitive advantage when $NH_4^+$ and $NO_3^-$ concentrations are depleted and P is not limiting. Because of the central role of N and P in regulating algal production and competition in lakes, water quality management is often focused on reducing N and P delivery to lakes from watersheds and sediments.

A good review of the interactive physical, chemical and biotic factors implicated in the development, proliferation and expansion of HABs can be found in Hudnell (2008) – Chapter 10: Nutrient and other environmental controls of harmful cyanobacterial blooms along the freshwater-marine continuum by Hans Paerl[1]. **As discussed in the review, control of HABs is strongly dependent of phosphorus supply.** However, additional factors, such as molar N:P supply ratios, organic matter availability, light attenuation, flushing rates (residence time) and water column stability play interactive roles in determining HAB composition (nitrogen fixing vs non-nitrogen fixing taxa) and biomass. While single nutrient input constraints may be effective in some waters, **reductions of nitrogen and phosphorus are usually required for effective long-term control and management of blooms** (Hudnell, 2008).

### Phosphorus vs Nitrogen:

Much of the early understanding and modeling was based on the relationship of phosphorus loading to algal biomass, expressed as chlorophyll a (Vollenweider, 1968, Dillon and Rigler, 1975). Phosphorus was often found to be in the shortest supply relative to the nutritional needs of algae and therefore was limiting. Additionally, as many forms of cyanobacteria can fix nitrogen, phosphorus is also the more controllable nutrient.

A fair amount of variability existed in the earlier models and often the N:P ratio was used to explain some of the variability which brought more focus on the role of nitrogen and its role in modifying a lake's biological response to phosphorus (e.g. Smith, 1982).

The literature is full of much research and debate about relative importance and the role of the nitrogen to phosphorus ratio for predicting and controlling algae, particularly cyanobacteria, dominance in lakes. Particularly, much of the debate centers around if low N:P ratios lead to HAB blooms and could be used as predictors of the blooms.

[1] http://www.epa.gov/cyano_habs_symposium/monograph/Ch10.pdf

While the debate still continues, a few things stand out:

- Cyanobacteria blooms are more strongly correlated with variation in total P, total N or standing algae biomass than the ration N:P (Downing et al, 2001);
- The reduction of phosphorus loading is the most effective means of reducing phytoplankton biomass in eutrophic lakes, even if N is initially limiting (Lewis and Wurtsbaugh, 2008, Schindler et al, 2008).
- The ability to mechanistically model nutrients and phytoplankton, while improving, is still not very accurate (Arhonditsis and Brett, 2004)

State of Oregon Department of Environmental Quality

Schindler (2006) provides a good review of the advances in the science for understanding and management of eutrophication since 1967, which was the year when the U.S. National Academy of Sciences held an international symposium on the topic and provided a summary of earlier work. In his review, Schindler concludes:

> "during the past 40 years, the understanding of eutrophication and its management have evolved from rather unfocused studies of algal nutrition to a very narrow focus on controlling one, sometimes two elements. However, the focus has broadened in other ways, this time including the effects of increasing human activities on climate, land use, global nitrogen cycles and fisheries."… "Our understanding of eutrophication and its management has evolved from simple control of nutrient sources to recognition that it is often a cumulative effects problem that will require protection and restoration of many features of a lake's community and its catchment."

## More on N:P Ratios:

TN and TP are useful indicators of trophic state since they are often correlated with algal biomass (Smith 1982). Low ratios of TN to TP are indicative of conditions that favor $N_2$-fixing species of cyanobacteria. $N_2$-fixing cyanobacteria species such as *Anabaena spp.* and *Aphanzomenon flos-aquae* are thought to be more common in lakes with N:P values less than 30:1 or 22:1.

More on the background on calculating the N:P ratio and cautions in its usage[2]:

> "Since the observation of Redfield that marine phytoplankton contains a molecular C:N:P ratio of 106:16:1 (50:7:1 by weight), the use of elemental ratios has become widespread in marine and freshwater phytoplankton studies. A departure from this ratio has been assumed to imply nutrient deficiency. In such a case, there is not only sub-optimal growth of phytoplankton, but also substandard food resources for primary consumers of phytoplankton. For diatoms that need silicate for their frustules an optimal C:Si:N:P ratio of 106:15:16:1 has been suggested.
>
> However, the nutrient content of phytoplankton is not constant but varies according to species, season and environmental conditions. For example, Redfield ratios are the exception rather than the rule in freshwater. Therefore, a more accurate estimate of nutrient limitation is obtained when nutrient ratios are examined together with controlled biotests (bottle tests, mesocosms) with different levels of P and N amendments to natural phytoplankton community. Comparison of algal biotest results and chemical nutrient concentrations in lakes has suggested that a mass N:P ratio above 17 indicates P limitation, a ratio below 10 indicates N limitation and values between 10 and 17 indicate that either of the nutrients may be limiting. The corresponding molecular ratios are > 38, < 22 and 22–38, respectively.

[2] http://www.cost869.alterra.nl/FS/FS_NPratio.pdf

> The above values were calculated using concentrations of total nutrients, i.e. nutrients largely bound by phytoplankton and other particles ('seston'). Inorganic nutrient fractions have been used in estimating the potential for nutrient limitation, for example by calculating the ratio of dissolved inorganic N and P in water (DIN:DIP) and the combination of total and inorganic nutrients. The absolute concentration level also plays a crucial role: if the concentration of DIP exceeds ca. 5 µg/l and DIN ca. 300–500 µg/l neither P nor N may be limiting. Thus, the limiting factor may depend on the level of nutrient concentrations. In addition to a proxy of limiting nutrient, N:P ratio has been used in estimating the risk for cyanobacterial blooms. N-fixing cyanobacteria tend to dominate in lakes with a (total) mass N:P ratio below 22. Note that the growth of cyanobacteria is dependent on several other factors too, such as hydrodynamic and light conditions and the structure of food web."

State of Oregon Department of Environmental Quality

A few main points to take away from the above material are that: 1) there are a number of ways to calculate the N:P ratio and therefore the suggested breakpoint for indicating a limitation will vary based on how it was calculated; and 2) be careful on how the ratio is used as there is a great deal of debate in the literature.

### Trophic Classification (from Johnson et al, 1985):

"The classification system most widely applied to lakes and reservoirs is the trophic classification system. Surface waters are ranked according to their biological productivity: unproductive lakes are termed oligotrophic ("little-nourished") and productive lakes are termed eutrophic ("well-nourished"). The productivity of a lake is determined by a number of chemical and physical characteristics of which the most important are the availability of essential plant nutrients, primarily nitrogen and phosphorus, and the intensity of light through-out the surface water. Although the terms oligotrophic and eutrophic provide a scale against which lakes may be ranked, additional terms have been added to allow for a wider range of categories. These include "ultraoligotrophic" for lakes that are extremely unproductive, "mesotrophic" for lakes that are intermediate between oligotrophic and eutrophic, and "hypereutrophic" for lakes that are extremely eutrophic. Because of interrelationships between the chemical, physical, and biological characteristics of lakes, a number of chemical and physical factors correlate with the rate of biological production".

These factors and their correlations with trophic state are presented in Table D-1. These values were used as a general guide when the Atlas of Oregon Lakes (Johnson et al, 1985) was developed. Some of the material used in the Waterbody Summaries found in Appendix C of this report was from the Atlas and reference to high or low values refer to values in Table D-1.

**Table D-1 Trophic Classification System (from Johnson et al, 1985)**

| Trophic State | Phosphorus (ug/l) | Chlorophyll a (ug/l) | Secchi Depth (m) | Trophic State Index | Primary Productivity (mgC/m$^2$/day) |
|---|---|---|---|---|---|
| Ultraoligotrophic | <3 | <0.3 | >16 | <20 | <50 |
| Oligotrophic | 3-9 | 0.3-2 | 7-16 | 20-35 | 50-250 |
| Mesotrophic | 9-24 | 2-6 | 2-6 | 35-50 | 250-1000 |
| Eutrophic | 24-75 | 6-40 | 0.75-2 | 51-65 | 1000-2000 |
| Hypereutrophic | >75 | >40 | <0.75 | >65 | >2000 |

## Reference Conditions:

Reference condition benchmarks for water quality parameters were established by USEPA (USEPA, 2009; USEPA, 2010) as part of the National Lake Assessment (NLA) for the Western Mountains and Xeric Level II ecoregions which cover the State of Oregon and most of the western United States (Figure D-1). The Xeric ecoregion includes the: Columbia Plateau; Snake River Plain: and Northern Basin and Range Level III Ecoregions in Oregon. The Western Mountain ecoregion includes the: Coast Range; Willamette Valley; Cascades; Eastern Cascades, Slopes and Foothills; and Klamath Mountain Level III Ecoregions in Oregon.

State of Oregon Department of Environmental Quality

The reference condition benchmarks are shown in Table D-2. As shown, reference conditions differ significantly between these two regions of the west which, in part, reflect the vast differences in the landscapes (see USEPA, 2009). This information was not used in the development of the HAB Strategy but could be useful in the during the development of Nutrient Standard Issue Paper and for future lake studies, especially if enough data is collected in future NLA surveys to refine this analysis at the scale of Level III ecoregions.

**Table D-2 EPA Reference Condition Benchmarks for Ecoregions in Oregon**

| Water Quality – Western Mountains | Good | Fair | Poor |
|---|---|---|---|
| Total Nitrogen (ug/l) | ≤278 | >278 – 380 | >380 |
| Total Phosphorus (ug/l) | ≤15 | >15 - 19 | >19 |
| Chlorophyll a (ug/l) | ≤1.81 | >1.81 – 2.74 | >2.74 |
| Turbidity (NTU) | ≤1.44 | >1.44 – 5.47 | >5.47 |

| Water Quality – Xeric | Good | Fair | Poor |
|---|---|---|---|
| Total Nitrogen (ug/l) | ≤514 | >514 – 2,286 | >2,286 |
| Total Phosphorus (ug/l) | ≤48 | >48 - 130 | >130 |
| Chlorophyll a (ug/l) | ≤7.79 | >7.79 – 29.5 | >29.5 |
| Turbidity (NTU) | ≤3.69 | >3.69 – 24.9 | >24.9 |

**Figure D-1 Ecoregions and Nutrient Reference Sites in Oregon**

The following is background information on how these values were derived:

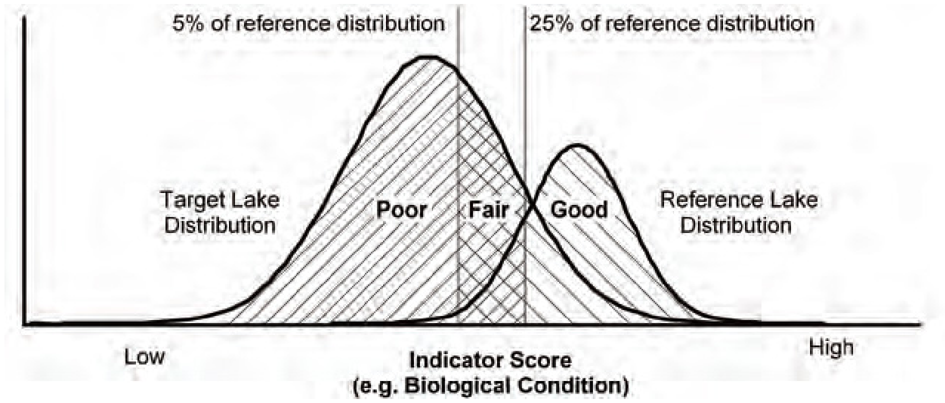
***Selecting Reference Lakes*** (USEPA, 2010): "In order to assess the condition of the country's lakes, results were compared to conditions in a suite of "reference lakes." A reference lake in the NLA is a lake (either natural or man-made) with attributes (such as biological or water quality) that come as close as practical to those expected in a natural state, *i.e.*, least-disturbed lake environment. NLA analysts used the reference distribution as a benchmark for setting thresholds for good, fair, and poor condition for each of the indicators.

EPA's experience with past surveys showed that only a small portion of the sampled population of lakes will be of reference quality. EPA used both identified lakes that were thought to be of high quality as well as high quality lakes from the random site selection process to serve as candidate reference lakes that might ultimately serve as "least-disturbed" benchmark reference sites. The candidate lakes were sampled identically to, and in addition, to the target lakes. Subsequently, data results from all sampled lakes were evaluated against the reference screening criteria to determine the final set of lakes that would be used to characterize the reference condition. NLA analysts used a number of independent variables reflecting human influence as classification and screening criteria, *e.g.*, limnological shoreline index, chloride content, total water column calcium, and others. Two parallel groups of reference lakes were set, one for biological condition, and another for nutrient stressors. The latter set of reference sites was developed so that nutrient levels could be used in screening reference lakes for biological condition.

When considering reference condition, it is important to remember that many areas in the United States have been altered – with natural landscapes transformed by cities, suburban sprawl, agricultural development, and resource extraction. To reflect the variability across the American landscape, these least-disturbed lakes diverge from the natural state by varying degrees. For example, highly remote lakes like those in the upper elevation wilderness areas of Montana may not have changed in centuries and are virtually pristine, while the highest quality, least-disturbed lakes in other parts of the country, especially in urban or agricultural areas, may exhibit different levels of human disturbance. The least-disturbed reference sites in these widely influenced watersheds display more variability in quality than those in watersheds with little human disturbance. Thus in reference conditions across the country, *i.e.,* the "bar" for expectations may be different. The resulting reference lakes represent the survey team's best effort at selecting lakes that are the least disturbed nationally and in specific regions across the country."

***Thresholds – Good, Fair, and Poor*** *(USEPA, 2010): "*After the reference lakes were selected and reference condition was determined, thresholds against which the target lakes are compared were set. For NLA, each indicator for a lake was classified as either "good," "fair," or "poor" relative to the conditions found in reference lakes. That is, "good" denotes an indicator value similar to that found in reference lakes, "poor" denotes conditions definitely different from reference conditions, and "fair" indicates conditions on the borderline of reference conditions. Specifically, these thresholds are then applied
to the results from the target lakes and are classified as follows: lake results above 25% of the reference range values are considered "good;" below the 5% of the reference range value are "poor;" and those between the 5% and 25% are "fair" (Figure D-2). These "good," "fair," "poor" designations however are not intended to be a replacement for the evaluation by states and tribes of the quality of lakes relative to specific water quality standards.

**Figure D-2. Reference condition thresholds used for good, fair, and poor assessment.**




State of Oregon Department of Environmental Quality