Nutrient Assessment Protocols for Lakes and Reservoirs in Nevada

Version 1
December 2008

Lahontan Dam and Reservoir (photograph by U.S. Bureau of Reclamation)

Prepared by:
Nevada Division of Environmental Protection
Bureau of Water Quality Planning

Nutrient Assessment Protocols
for Lakes and Reservoirs in Nevada

Table of Contents

List of Tables

List of Figures

Nutrient Assessment Protocols
for Lakes and Reservoirs in Nevada

Introduction

The purpose of this document is to provide some general guidance on possible steps for determining the nutrient impairment status of lakes and reservoirs in Nevada. These protocols will be useful in addressing a two key issues:

> **303(d) List and Appropriate Impairment Determinations:** The Draft 2006 303(d) Lists contains a number of lakes and reservoirs due to exceedances of the total phosphorus standards. However, NDEP is not confident that sole reliance on phosphorus levels is an appropriate approach for assessing lakes and reservoirs. Other factors such as nitrogen, chlorophyll-a, and secchi disk need to be evaluated before resources are devoted to developing TMDLs and control strategies.
>
> **Appropriate Nutrient Criteria:** As described in Nevada's Nutrient Criteria Strategy (NDEP, 2007), NDEP faces significant challenges in reviewing/revising existing nutrient criteria and establishing new criteria for new waters to be included in the regulations. Nutrient levels are believed to be a poor indicator of nutrient impairment. Rather parameters such as dissolved oxygen and algae density are much better measures of stream health as affected by nutrients. Assessments, such as described in this document, will increase the state's database on nutrients, algae levels and other factors. As a result, NDEP will be better equipped to move toward more appropriate nutrient criteria throughout Nevada.

This document is to be considered a living, changing report, which will be revised over time as NDEP obtains more data, tests these protocols, and gains more insight into Nevada's waters.

Background

Exceedances of total phosphorus standards are common in many of Nevada's waters. However in many cases, it is not known if the phosphorus levels are actually impacting the beneficial uses, e.g. aquatic life, recreation, etc. As discussed by TetraTech (2005), the use of nutrient concentrations alone are poor predictors of assessing eutrophication impacts. Given the problems of relying on nutrients concentrations to predict impairment, EPA Region IX RTAG (Regional Technical Advisory Group) has recommended the use of secondary indicators in determining impairment status (Tetra Tech 2006). Key indicators for lakes and reservoirs include: 1) algal biomass (measured as chlorophyll-a); and 2) Secchi disc depth. It is believed that these two parameters are more direct indicators of use support/impairment status than N and P concentrations.

Of these two indicators, algae is the primary driver. While some algae is a necessary component of the ecosystem, excessive algae can impact the beneficial uses in a variety of ways. According to EPA (2000):

> *"Algae are either the direct or indirect cause of most problems related to excessive nutrient enrichment, e.g. algae are directly responsible for excessive, unsightly periphyton mats or surface plankton scums, and may cause high turbidity* [low Secchi depths], *and algae are indirectly responsible for diurnal changes in DO and pH"*

The use of trophic classifications is a common practice for categorizing various waterbodies in terms of their algal productivity. Classifications represent a gradient of conditions from oligotrophic (little algal growth) to hypereutrophic (extreme algal growth), however there are no universally accepted threshold values for nutrients, chlorophyll-a and Secchi depths upon which one can classify a given waterbody. In 1998, EPA (1988) provided chlorophyll-a and Secchi ranges for oligotrophic, mesotrophic, eutrophic, and hypereutrophic classifications (Table 1). Wetzel (2001) has provided a more detailed presentation of nutrient, algal, and Secchi disc thresholds for trophic classifications (Table 2).

Table 1. Trophic Status by Chlorophyll-a and Secchi Depth (EPA, 1988)

Trophic Status	Chlorophyll-a (mean)	Secchi Depth (m)
Oligotrophic	<4	>4
Mesotrophic	4 – 10	2 – 4
Eutrophic	10 – 25	1 – 2
Hypereutrophic	>25	<1

Table 2. General Trophic Classification of Lakes and Reservoirs[a]

Parameter (annual mean values)	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
TP (ug/l)				
Mean	8.0	26.7	84.4	
Range	3.0 – 17.7	10.9 – 95.6	16 – 386	750 – 1200
TN (ug/l)				
Mean	661	753	1875	
Range	307 - 1630	361 - 1387	393 - 6100	
Chl-a (ug/l)				
Mean	1.7	4.7	14.3	
Range	0.3 – 4.5	3 - 11	3 - 78	100 – 150
Chl-a maxima (ug/l)				
Mean	4.2	16.1	42.6	
Range	1.3 – 10.6	4.9 – 49.5	9.5 - 275	
Secchi depth (m)				
Mean	9.9	4.2	2.45	
Range	5.4 – 28.3	1.5 – 8.1	.8 – 7.0	0.4 – 0.5

[a]From Wetzel (2001): Based on data of an international eutrophication program. Trophic status based on the opinions of the experienced investigators of each lake. (Modified from Vollenweider, 1979).

Response Variables and Appropriate Thresholds

Over the years, many regression equations relating nutrient (primarily phosphorus) levels to algal biomass (chlorophyll-a) have been developed, such as presented by Jones and Bachman (1976) (see Figure 1); Dillon and Rigler (1976). However, there is still considerable uncertainty in these equations with phosphorus concentrations explaining only a portion of the chlorophyll-a variability.

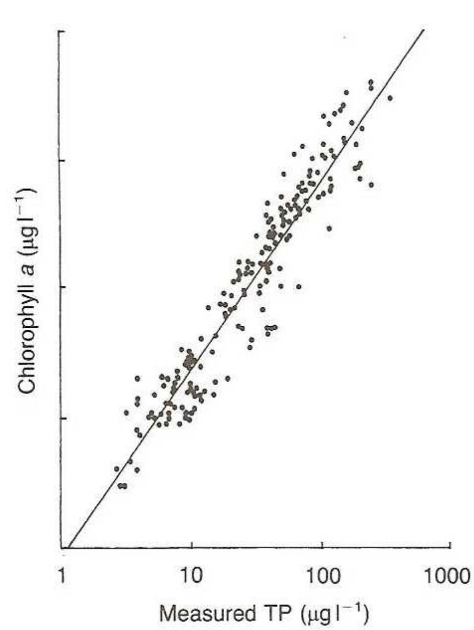

Figure 1. Chl-a vs. Total Phosphorus for 143 Lakes (Jones and Bachmann, 1976)

While good regression correlations between nutrients and chlorophyll-a have been identified in many cases, the fact that many of the relationships are derived on a log-log scale tends to mask the uncertainty. Welch and Jacoby (2004) concluded that for this reason many of these large dataset relationships are not very accurate for predictions for any single lake. Lake-specific chl-a vs. nutrient relationships may be possible but can require extensive data, be cost prohibitive, and still have considerable uncertainty.

It is recommended that chlorophyll-a levels be the primary metric upon which Nevada lakes are assessed for nutrient impairment. According to Walker (1985), chlorophyll-a "*is the most direct and practical measurement of algal productivity and eutrophication*" in lakes and reservoirs.

Secchi depths, in concert with chlorophyll-a levels, are another common measure for characterizing the trophic status of a waterbody. However, Secchi depths can be greatly impacted by suspended sediment levels depending upon the waterbody.

There are a number of states that already rely on chlorophyll-a and Secchi data for their assessments. For examples, Arizona (2007) has established assessment protocols that require exceedances of chl-a thresholds for 303(d) Listing purposes. To account for the natural gradient in their lake conditions, Arizona has provided a matrix of chlorophyll-a values depending upon the waterbody type.

While Nevada has set antidegradation chlorophyll-a values for Lake Mead, none of Nevada's lakes/reservoir have chlorophyll-a standards for the protection of beneficial. However in the development of the Lahontan Reservoir phosphorus standards (NDEP, 1984), total phosphorus standards were set "*to achieve a meso-eutrophic level of productivity that would be characterized by a summer mean chlorophyll-a value of less than 10 μg/l*." According to the documentation, a chlorophyll-a threshold of 10 μg/l was selected as some research had shown that lakes and reservoirs with chlorophyll-a levels above this value usually have excessive growths of algae that significantly impair beneficial uses.

Though it is believed that chlorophyll-a and Secchi targets are by far the best measure of the eutrophication status for our lakes and reservoirs, there is no clear consensus on appropriate targets for the support of the various beneficial uses. For this reason, TetraTech (2006) concluded that the "*selection of a target will need to combine both scientific and policy components*."

Aquatic Life

There is a significant range of algal and clarity thresholds that have been recommended in the literature and used by various states:

- According to Dillon et al. (1975) and McGhee (1983), coldwater fisheries are supported when chlorophyll-a does not exceed 10 to 15 ug/l. Dillon et al. (1975) also recommended a chlorophyll-a threshold of 25 ug/l for warmwater fisheries.

- Michigan has established summer mean chlorophyll-a criteria of 3 ug/l for coldwater fish lakes, and 40 ug/l for warmwater fish lakes (TetraTech, 2006). North Carolina has adopted chlorophyll-a standards of 15 ug/l and 40 ug/l for trout and non-trout waters respectively (EPA, 2003). Colorado (2006) has recommended chlorophyll-a (growing season means) thresholds for each of the three fishery types – cold water (6 ug/l), cool water (15 ug/l) and warm water (25 ug/l).

- TetraTech (2006) recommended chlorophyll-a thresholds from 5 to 10 ug/l for coldwater fisheries and 10 to 25 ug/l for warmwater fisheries.

- Following a review of literature values and available water quality data for their lakes/reservoirs, the State of Arizona adopted chlorophyll-a standards ranging from 5 to 15 for coldwater fisheries and from 25-40 for warmwater fisheries (except for urban lakes) depending upon the type of waterbody (Table 3). Arizona also set Secchi depth thresholds ranging from 0.9 to 2.0 meters dependent upon the waterbody type (Table 3).

Table 3. Summary of Arizona's Chlorophyll-a and Secchi Thresholds for Lakes and Reservoirs – Aquatic Life Uses (ADEQ, 2007)

Beneficial Use	Lake Category	Chl-a (ug/l) , growing season mean	Secchi Depth (m). growing season mean
Aquatic Life (cold)	All	5 - 15	1.5 – 2.0
Aquatic Life (warm)	All except urban	25 – 40	0.8 – 1.0
	Urban	30 – 50	0.7 – 1.0
Aquatic Life (effluent dependent)	All	30 - 50	0.7 – 1.0

- Researchers have shown fish yield increasing with increases in chlorophyll-a for warmwater systems (Jones and Hoyer, 1982; Maceina, 2001; Egertson and Downing, 2004). However, a study of Iowa lakes by Egertson and Downing (2004) showed that while the number of fish increased with increased algae, the species shifted from traditional sport fish to bottom feeding species like carp and black bullhead. Maceina et al. (1996) found that black bass and crappie fisheries increased with chlorophyll-a only up to about 20 ug/l.

Recreation Uses

Recreation uses include contact (swimming) and non-contact uses (boating, general aesthetic enjoyment). Some publications have attempted to define relationships between chlorophyll-a and Secchi depth with users visual perceptions. As shown in Figure 2, user perception surveys for lakes in Minnesota suggest that swimming uses become impaired when chlorophyll-a levels are at about 15 ug/l or higher; or when Secchi depths are about 1 meter or lower (Hieskary and Walker, 1988). However, there can be significant variation from region to region depending upon the waterbodies that are familiar to the users. For users in northern Minnesota, swimming was considered impaired when Secchi depths were less than 3 meters. However, swimming impairment in southern Minnesota (where most lakes have higher algal levels) may occur when Secchi depths are less than 1 meter (Heiskary and Walker, 1988).

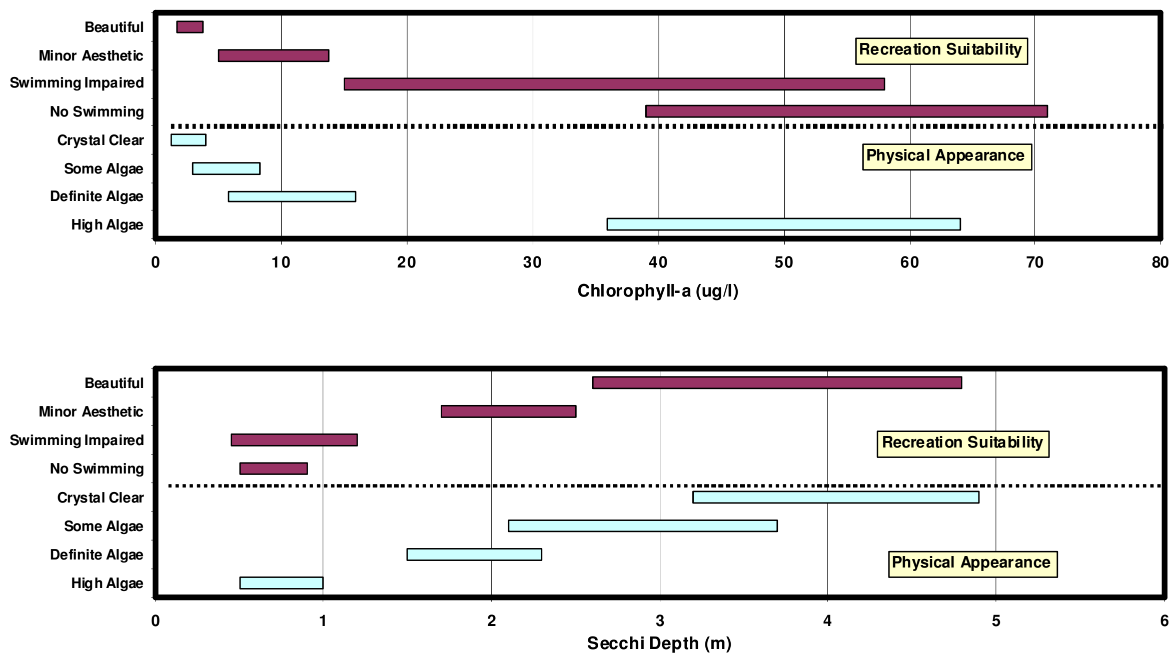

Figure 2. Chlorophyll-a and Secchi Values and Results of User Perception Surveys (Heiskary and Walker, 1988)

In a followup study, Smeltzer and Heiskary (1990) evaluated additional user perception survey data for lakes in both Minnesota and Vermont and again found significant variability between different regions. Users considered swimming uses to be slightly impaired when Secchi depths ranged from about 0.8 to about 3 meters, depending upon the region. For Secchi depths from about 0.5 to about 1.5 meters, users felt that swimming was substantially impaired.

Malcolm Pirnie (2005) compiled and evaluated chl-a thresholds from a number of publications and recommended chlorophyll-a targets ranging from 10 to 30 ug/l, and Secchi depth targets ranging from 0.5 to 2.5 meters for the protection of recreation uses in Arizona lakes and reservoirs (Table 4). As part of California nutrient strategy development process, TetraTech (2006) recommended similar targets with chlorophyll-a thresholds ranging from 10 to 20 ug/l for contact recreation and 10 to 25 for noncontact recreation; and Secchi depth thresholds ranging from 1 to 2 meters for both contact and noncontact recreation.

Table 4. Summary of Arizona's Chlorophyll-a and Secchi Thresholds for Lakes and Reservoirs – Recreation Uses (ADEQ, 2007)

Beneficial Use	Lake Category	Chl-a (ug/l), growing season mean	Secchi Depth (m). growing season mean
Contact Recreation	Deep	10 – 15	1.5 – 2.5
	Shallow	10 – 15	1.5 – 2.0
	Igneous	20 – 30	0.5 – 1.0
	Sedimentary	20 – 30	1.5 – 2.0
	Urban	20 – 30	0.5 – 1.0

Drinking Water Uses

Excessive algal growth can impairing drinking water supplies by creating taste and odor problems. Based upon recommendations from Malcolm Pirnie (2005), Arizona set chlorophyll-a thresholds ranging from 10 to 20 ug/l, and Secchi depth thresholds ranging from 0.5 to 1.5 meters for all lakes/reservoirs with drinking water uses. For lakes/reservoirs that include water intakes, TetraTech (2006) recommended chlorophyll-a thresholds from 5 to 10 ug/l. The State of Oregon has established similar chlorophyll-a standards of 10 ug/l for lakes that thermally stratify and 15 ug/l for lakes that do not thermally stratify (TetraTech 2006).

Nuisance Blooms

Since chlorophyll-a levels in a given waterbody can experience significant temporal variation over the course of a growing season[1], the selection of a mean chlorophyll-a threshold has implications for the frequency of possible nuisance algal blooms (TetraTech, 2006). Walmsley (1984) suggested that use impairment in lakes is more sensitive to the frequency and severity of algae bloom than to average algae conditions, and has recommended using chlorophyll-a thresholds of >20 and >30 ug/l for defining occurrences of nuisance blooms and severe nuisance blooms, respectively. In an attempt to address this issue from a statistical approach, Walker (1985) developed a series of curves relating mean algae levels in lakes and reservoir to the frequency of blooms (Figure 3). Walker's relationships suggest that severe nuisance blooms (chl-a > 30 ug/l) can become more likely when mean algal levels are at 10 ug/l or higher.

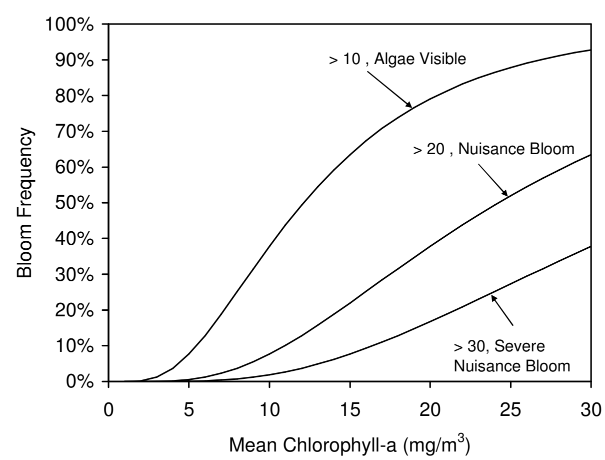

Figure 3. Bloom Frequency vs. Mean Chlorophyll-a Levels (Walker, 1985)

As part of Nevada's assessment approach, an option for dealing with nuisance blooms would be to use both a mean growing season chlorophyll-a threshold and a "single value" maximum threshold. This same

[1] In a 1982 study, the Organization for Economic Cooperative Development (OECD) found that maximum chlorophyll-a levels averaged over 3 time the annual means (Walker, 1985).

approach has been used by Colorado (2006) where a maximum chlorophyll-a threshold of 40 ug/l (not to be exceeded more than 20% of the time) was recommended, along with growing season mean values.

Cyanobacteria Considerations

Cyanobacteria (sometimes referred to as blue-green algae) are actually a form of bacteria that are photosynthetic like algae, but unlike algae, some cyanobacteria are able to utilize (fix) nitrogen from the atmosphere (Wetzel, 2001). There are a number of human health effects associated with cyanobacteria. Exposure to cyanobacteria can cause rashes, skin and eye irritation, allergic reactions, gastrointestinal upset, and other effects (Cal. Dept. of Public Health, 2008). At high levels, exposure can result in serious illness or death. Some cyanobacteria blooms produce toxins during growth or decay that kill aquatic animals (Downing et al., 2001).

As part of their nutrient implementation procedures, the State of Arizona (ADEQ, 2007) established cyanonbacteria thresholds. For full body contact recreation and drinking water uses, cyanobacteria is limited to 20,000 cells/milliliter as cited by the World Health Organization as protective against allergenic health effects. For aquatic life uses, cyanobacteria is limited to <50% of the total count of cells to prevent cyanobacteria dominance.

According to Downing et al. (2001), there is considerable controversy over the conditions needed for cyanobacteria dominance. It has been reasoned that cyanobacteria should dominate at low N:P ratios given that cyanobacteria can fish atmospheric nitrogen. This theory has largely been based upon work by Smith (1983), but more recent work has found that nutrient concentrations and algal biomass may be better predictors of cyanobacteria blooms. Downing et al. (2001) analyzed data from 99 temperate zone lakes and found that the risk of cyanobacteria dominance (>50% of biomass) seems to increase for phytoplankton chlorophyll-a levels above 10 ug/l (Figure 4). This compares well with work done recently in Arizona. In a review of data for Arizona lakes and reservoir, Malcolm Pirnie (2007) concluded that the probability of cyanobacteria dominance was higher when the chlorophyll-a levels exceeded 10-15 ug/l.

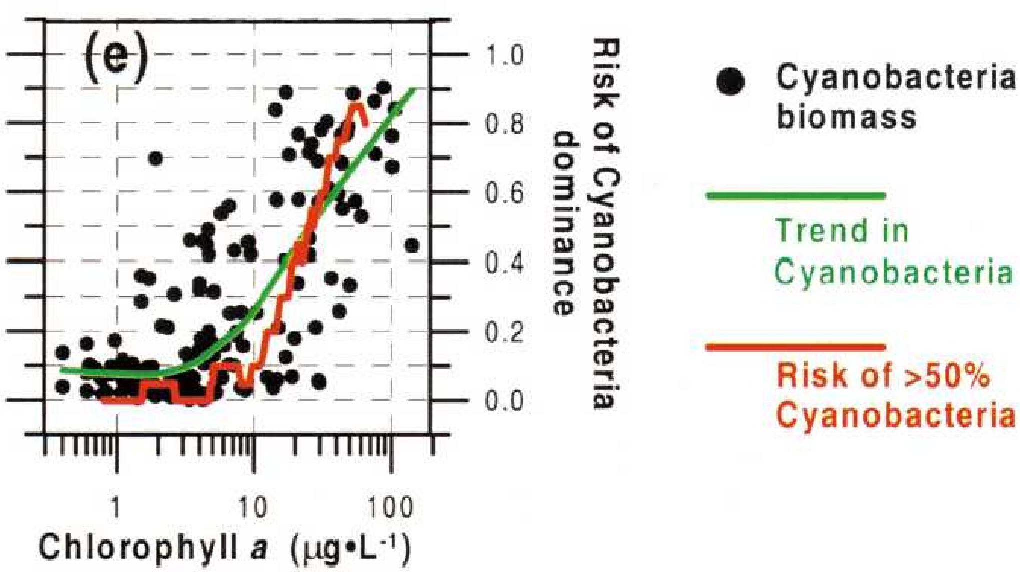

Figure 4. Risk of Cyanobacteria Dominance vs. Mean Chlorophyll-a (Downing et al., 2001)

Secchi Depth and Chlorophyll-a Relationships

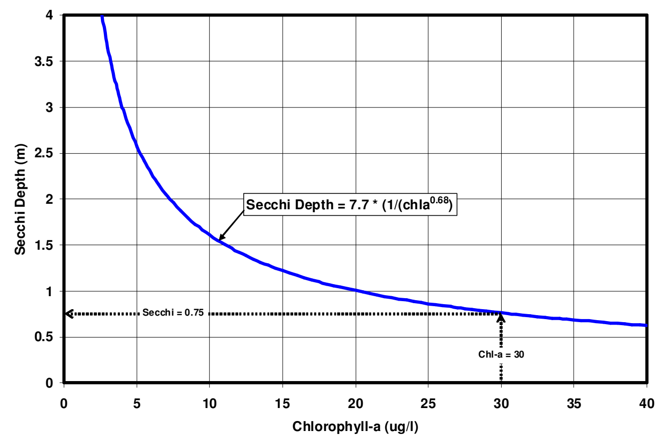

Figure 5. Relationship between Chlorophyll-a and Secchi Depth (Carlson, 1977)

As already discussed, Secchi disc depths along with chlorophyll-a levels are common metrics used to assess the trophic status of lake and reservoirs. When setting chlorophyll-a and Secchi depth targets for these assessments, it is important to recognize that a relationship exists between these 2 metrics (Figure 5), and that the selected targets should be relatively compatible. For example, it may not be appropriate to select a chlorophyll-a target of 30 ug/l and a Secchi depth of 2 meters, as a Secchi depth may be more achievable at this chlorophyll-a level (Figure 5).

When setting Secchi targets, the influence of suspended solids must be recognized. It could be possible to exceed a selected Secchi target with the cause being elevated suspended sediment and not a nutrient/algae problem.

Chlorophyll-a and Secchi Disc Data for Nevada Lakes and Reservoirs

Before establishing chlorophyll-a and Secchi disc targets, it is helpful to examine at current levels in Nevada's lakes and reservoirs. A variety of chlorophyll-a and Secchi disc data exist for lakes and reservoirs throughout Nevada. While much of these data are stored in NDEP-BWQP's water quality database, some additional information is available as a result of the National Eutrophication Study (EPA, 1978) and a study of high altitude reservoirs (UC Davis, 1994).

NDEP Data

Plots of chlorophyll-a (from epilimnion) and Secchi disc data from NDEP's database are shown in Figures 6 and 7, respectively. These data show that many of the waters have experienced chl-a levels less than 10 ug/l levels, however Lahontan Reservoir and Walker Lake have experienced some of the highest chlorophyll-a levels with some values greater than 100 ug/l. Some other waters have low Secchi depths, such as Nesbitt Lake and Rye Patch Reservoir, but rather low algal biomass. Suspended sediment is the likely cause of these low clarity levels.

1970s National Eutrophication Study

As part of a 1970s National Eutrophication Study (EPA, 1978), chlorophyll-a and Secchi depth data were collected at 8 lakes and reservoirs in Nevada. Field work consisted of 3 sampling events during 1975, however the report only presented median values for chlorophyll-a and Secchi depth. Based upon these data (Figure 8), Lake Tahoe experienced the best conditions with very low median chlorophyll-a and very high Secchi depth in comparison to the other waters. Wildhorse Reservoir showed the worst conditions with high chlorophyll-a and very low Secchi depths.

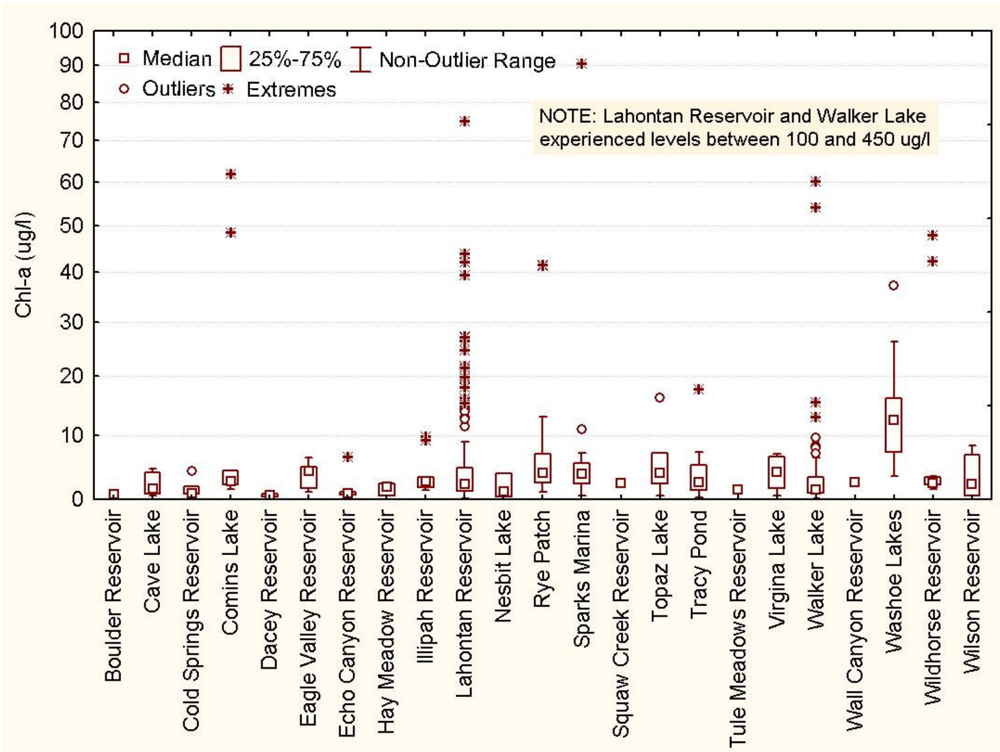

Figure 6. Chlorophyll-a Levels in Nevada's Lakes and Reservoirs based upon BWQP database

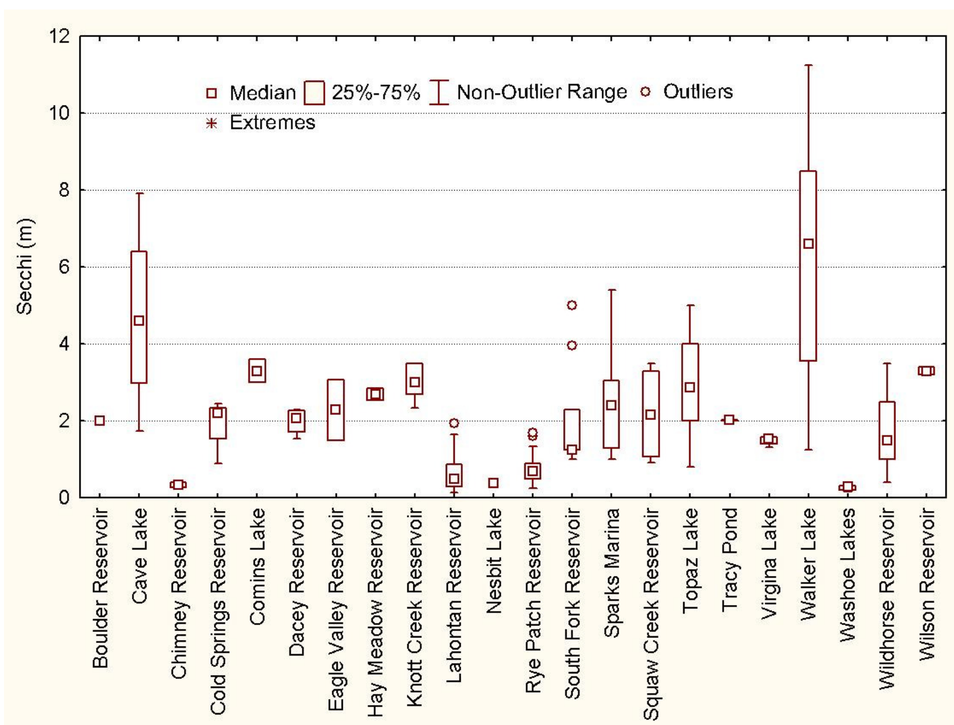

Figure 7. Secchi Disc Levels in Nevada's Lakes and Reservoirs based upon BWQP database

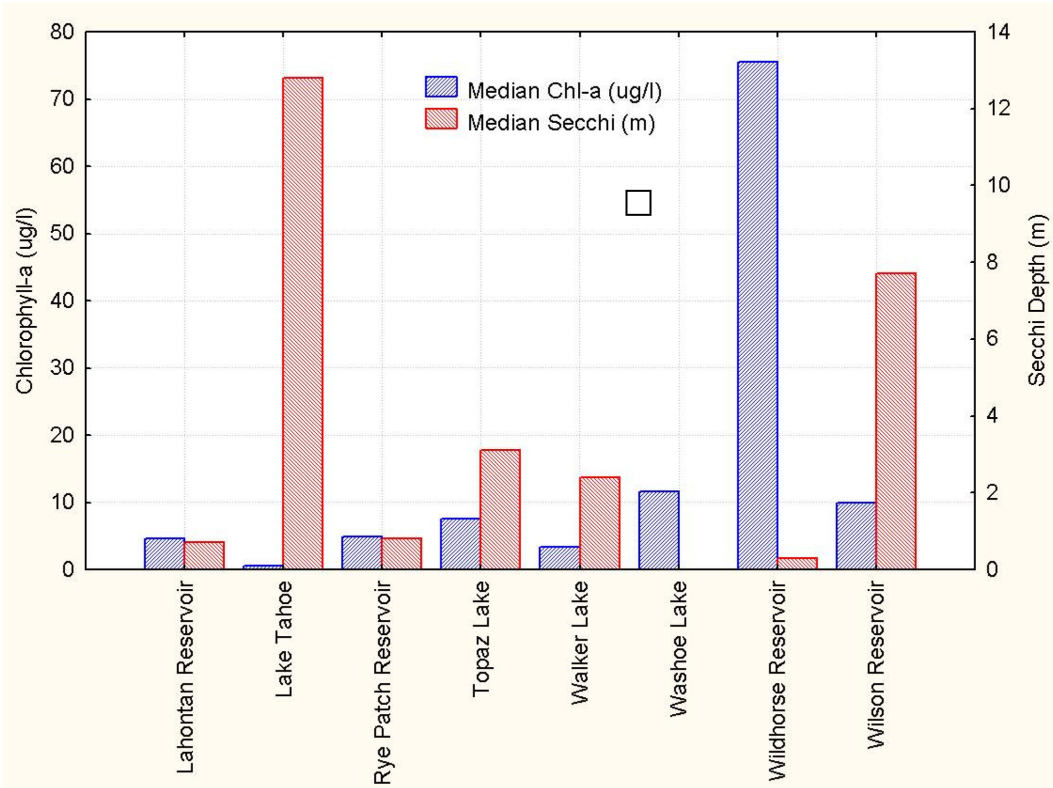

Figure 8. Median Chlorophyll-a and Secchi Depth Data from 1970s National Eutrophication Study (EPA, 1978)

1994 UC Davis Study

From late 1991 through 1993, UC Davis (1994) monitored water quality conditions at 4 selected lakes and reservoirs in Nevada, with the chlorophyll-a and Secchi depth results summarized in Figure 9. These data show the South Fork Reservoir with the higher chlorophyll-a levels and the lowest Secchi depths of the 4 waterbodies sampled.

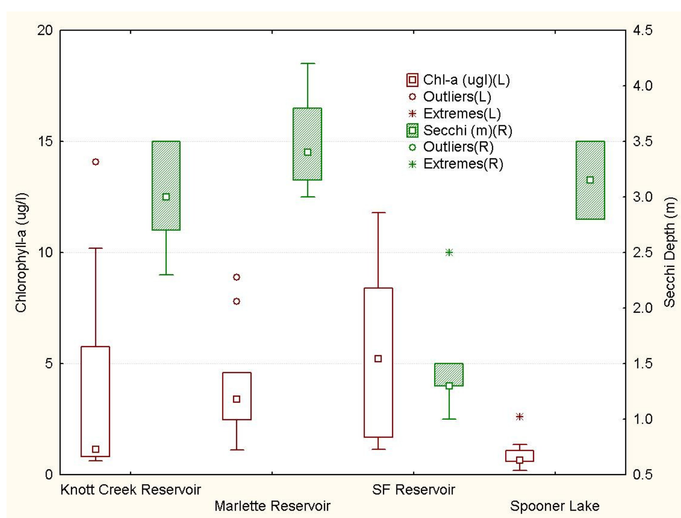

Figure 9. Chlorophyll-a Depth Data from 1994 UC Davis Study (UC Davis, 1994)

Suggested Nutrient Assessment Protocols for Lakes and Reservoirs

Table 5 presents suggested chlorophyll-a and Secchi disc targets that NDEP can begin using in assessing the trophic status of the lakes and reservoirs in Nevada.

Table 5. Initial Chlorophyll-a and Secchi Targets for Nevada's Assessments

Beneficial Use	Category	Chlorophyll-a		Secchi Depth - growing season mean (m)
		Growing Season Mean (ug/l)	Growing Season Maximum (ug/l)	
Aquatic Life	Cold water	10	30	1.5
	Cool water	15	30	1.2
	Warm water	25	40	0.8
Noncontact & Contact Recreation	Infrequent Use	20	40	1.0
	Frequent Use	10	30	1.5
Municipal & Domestic Supply	n/a	10	30	1.5

Number of Sample Sites

Arizona has developed a table of guideline for establishing sampling locations when evaluating lakes and reservoirs for eutrophic conditions (Table 6). The number of sites varies depending upon the size, shape and the mean depth of the waterbody. Following are definitions of the three waterbody shapes addressed in the guidelines:

- "Simple" waterbody is round to oblong with a bowl-like topography
- "Complex" waterbody has multiple arms or tributary inputs such that each arm may have individual characteristics
- "Linear" waterbody is typically a reservoir fed by one main tributary and has three sections: riverine, transition, and bay (by the dam)

It is suggested that Table 6 be used as a general guideline when implementing these protocols but assessments can still be acceptable with less or more monitoring sites. Algal levels can have great spatial variability throughout a lake or reservoir as shown in Figure 10. Additional sampling sites may be appropriate to characterize this variability.

Sample Depth

For comparison to the chlorophyll-a targets, algae samples should be collected within the upper portion of the photic zone of the waterbody. The photic zone could roughly be defined as that region from the water's surface to the Secchi disc depth. It is recommended that algae samples be collected from the upper 1 meter of the waterbody, and should not be taken from a depth greater than the Secchi depth.

Table 6. Arizona's Guidelines for Number of Lake Sampling Locations

Lake Size (acres)	Lake Shape	Mean Lake Depth (m)	Min. No. of Sample Sites
< 1,000	Simple	< 4	1
		> 4	2
	Complex	< 4	1
		> 4	2
	Linear	< 4	2
		> 4	3
1,000 – 10,000	Simple	> 4	2
	Complex	> 18	2
		> 18 with > 1 arm	3
	Linear	> 18	3
10,000 – 100,000	Complex	> 18	3
		> 18 with > 2 arms	4
	Linear	> 18	3
> 100,000	Linear/complex	> 18	5

Sample Frequency

Given the significant temporal variation that is possible in algal biomass, frequent (monthly or less, over multiple years) may ultimately be needed to accurately characterize algae conditions for a given lake or reservoir. However, this level of effort can be resource intensive and cost prohibitive. Initial sampling could consist of 2 samples taken during the summer for one season. Depending upon the results of that sampling, more extensive sampling could be undertaken in the future.

Low Water Level Considerations

Lake and reservoir nutrient assessments must account for low water conditions, which can lead to increased temperatures and higher algal biomass. Most of Nevada's lakes and reservoirs go through periods of low levels brought on by natural drought conditions. In addition, many Nevada reservoirs can experience low conditions each year due to water releases for irrigation. The guidelines in Table 5 are not intended to apply during periods of low water levels. However more work is needed to define appropriate thresholds.

Cyanobacteria

If resources allow, algae cell counts could be determined as part of the monitoring. Arizona's cyanobacteria thresholds could be used to evaluate:

- < 20,000 cells/milliliter of cyanobacteria
- < 50% of biomass attributed to cyanobacteria

Secchi Disc versus Chlorophyll-a

In evaluating Secchi data, it is important to consider the potential impact that suspended sediment can have on lake clarity. It is possible for lakes to have low Secchi depths with the problem being sediment and not algae. For this reason, it is recommended that the chlorophyll-a targets be the primary indicator for use support, with the Secchi disc serving as additional support for a trophic determination.

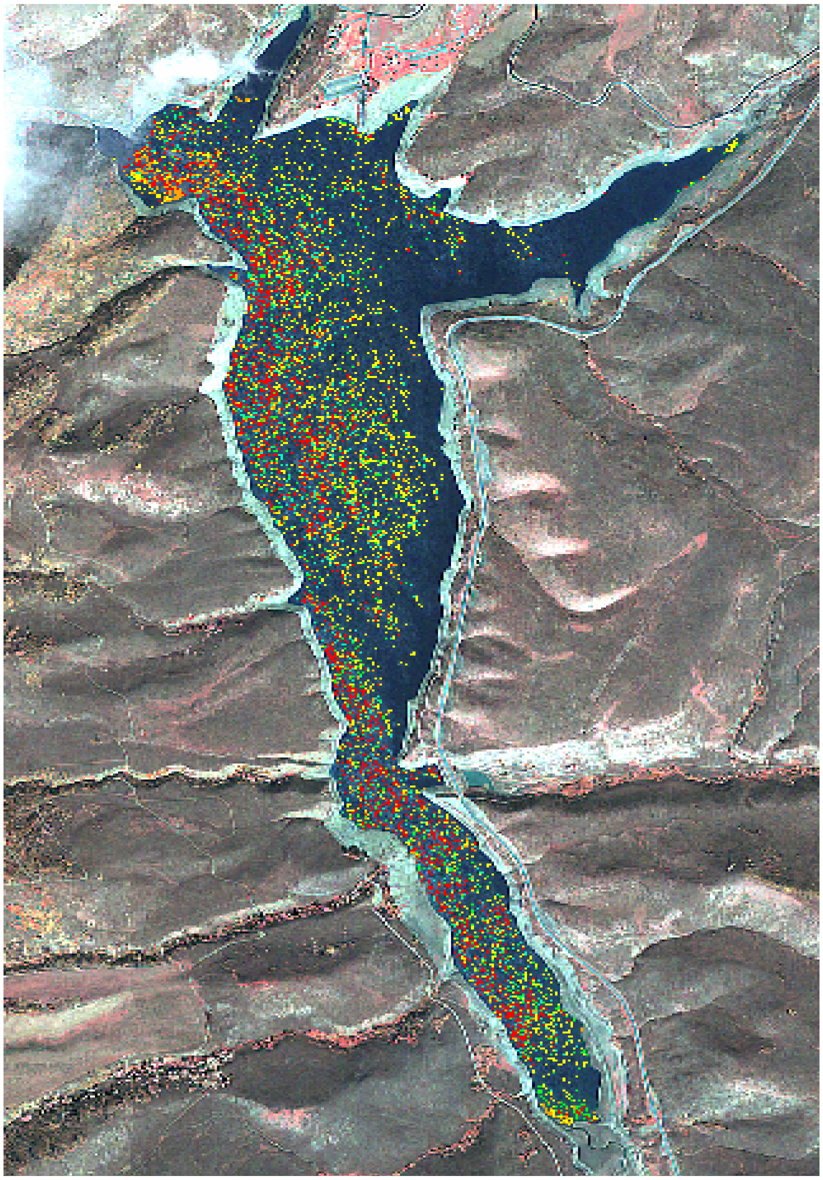

Figure 10. IKONOS Multispectral Imagery of East Canyon Reservoir (Utah). In-reservoir colors indicate qualitative derivation of algal biomass distribution for October 11, 2000. Red indicates high algal concentration (>20 ug chl-a/l); orange indicates medium-high (10-20 chl-a/l); green indicates medium(5-10 ug chl-a/l); and yellow indicates low (<5 ug chl-a/l), from Utah DEQ (2008).

Impairment Determinations

Initially, it is proposed that impairment determinations be based upon the criteria presented in Table7. Representative samples need to be collected during the growing season

Table 7. Conditions for Determining Nutrient/Algal Impairment

Chl-a Targets	Data Needs	Impairment Criteria
Growing Season Mean	2 independent sampling events from multiple sites for a given year	Water is considered impaired if the mean chl-a level of all samples for a given year is greater than the ***growing season mean targets***
Growing Season Maximum	1 or more independent sampling events from 1 or more sites for a given year	Water is considered impaired if any one of the samples contain chl-a levels greater than the ***growing season maximum targets***

References

Arizona Department of Environmental Quality. April 2007. Narrative Nutrient Standard Implementation Procedures for Lakes and Reservoir.

California Department of Public Health. 2008. Website - http://www.cdph.ca.gov/healthinfo/environhealth/water/Pages/bluegreenalgae.aspx.

Carlson, R.E. A trophic status index for lakes. Limnol. Oceanogr., 22:361-8.

Colorado Water Quality Control Division. October 2006. Colorado Lake Nutrient Criteria – A Rationale for Development.

Dillion, P.J. and R.F. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish Res. Board Can 32:1519-1531.

Downing, J.A., S.B. Watson, and E. McCauley. Predicting Cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci.: 58:1905-1908.

Heiskary, S.A., and Walker, W.W. Jr. 1988. Developing phosphorus criteria for Minnesota lakes. Lake and Reservoir Management. Volume 4(1):1-9.

Jones, J.R. and R.W. Bachman. 1976. Prediction of phosphorus and chlorophyll levels in lakes. Journal of the Water Pollution Control Federation 48: 2176-2182.

Jones, J.R. and M.V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll-a concentrations in Midwestern lakes and reservoirs. Transactions of the American Fisheries Society 111:176-179.

Maceina, M.J., D.R. Bayne, and A.S. Hendricks. 1996. Compatibility between water clarity and quality black bass and crappie fisheries in Alabama. American Fisheries Society Symposium 16:296-305.

Maceina, M.J. 2001. Trophic state and fish in Alabama reservoirs. NALMS Lakeline, Fall 2001. p. 16-19.

Malcolm Pirnie, Inc. April 2005. Potential Nutrient-Related Targets for Lakes and Reservoirs in Arizona. Prepared for Arizona Department of Environmental Quality.

McGhee, R.F. 1983. Experiences in developing a chlorophyll-a standard in the Southeast to protect lakes, reservoirs and estuaries. Lake Restoration Protection and Management. Proc. 2nd Annual Conference N. Am. Lake Management Society. EPA 440/5-83-001.

Nevada Division of Environmental Protection. 1984. Carson River Water Quality Standards Revisions Rationale.

Smeltzer, E. and S.A. Heiskary. 1990. Analysis and Application of Lake User Survey Data. Lake and Reservoir Management, 1990, 6(1): 109-118.

Smith, V.H. 1983. Lower nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science, 221: 669-671.

Tetra Tech, Inc. 2006. Technical Approach to Develop Nutrient Numeric Endpoints for California. Prepared for U.S. EPA Region IX.

University California Davis. September 1994. Seasonal Nutrient Limitation at Four High Altitude, Shallow Reservoirs of the Tahoe Basin and Northern Nevada. Prepared for Nevada Division of Environmental Protection and Tahoe Regional Planning Agency.

U.S. EPA. September 1978. A Compendium of Lake and Reservoir Data Collected by the National Eutrophication Survey in the Western United States, Working Paper No. 477.

U.S. EPA. February 1988. The Lake and Reservoir Restoration Guidance Manual. EPA 440/5-88-002.

U.S. EPA. April 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. EPA-822-B00-001.

U.S. EPA. April 2003. Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Cheasapeake Bay and its Tidal Tributaries, Appendix D. EPA 903-R-03-002

Utah Department of Environmental Quality. October 2008. East Canyon Reservoir and East Canyon Creek TMDLs – Public Review Draft.

Walker, W. Jr. 1985. Statistical Bases for Mean Chlorophyll A Criteria. Lake and Reservoir Management, 1:57-62.

Walmsley, R.D. 1984. A chlorophyll-a trophic status classification system for South African Reservoirs. J. Environ. Quality 13:97-104.

Welch, E.B. and J.M. Jacoby. 2004. Pollutant Effects in Freshwater: Applied Limnology.

Wetzel, R.G. 2001. Limnology – Lake and River Ecosystems, 3rd Edition. Academic Press.