Preliminary Review of Lahontan Reservoir Total Phosphorus Water Quality Standard

November 2012

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

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

Preliminary Review of Lahontan Reservoir Total Phosphorus Water Quality Standard

Table of Contents

List of Tables

List of Figures

Preliminary Review of Lahontan Reservoir Total Phosphorus Water Quality Standard

Introduction

In the early 1980s, extensive work by the Desert Research Institute on Lahontan Reservoir concluded that phosphorus loading was the major contributor to the eutrophic (highly productive) conditions in the reservoir. As a result, total phosphorus standards were set and served as the basis for estimating the needed load reductions (Cooper and Vigg, 1983).

The total phosphorus standard was based upon an assumed algae level in the reservoir that was deemed to be acceptable. As stated in the NDEP rationale (1984), *"[the] goal at Lahontan Reservoir will be to achieve a meso-eutrophic level of productivity that would be characterized by a summer mean chlorophyll-a*[1] *value of less than 10 µg/l."* According to the rationale, a chlorophyll-a threshold of 10 µg/l was selected as some research has shown that lakes and reservoirs with chlorophyll-a levels above this value usually have excessive growths of algae that significantly impair beneficial uses.

Cooper and Vigg (1983) found the lower basin near the dam to be more productive with summer chlorophyll-a levels about 4 to 5 time higher than in the upper basin of the reservoir. Therefore, conditions in the lower basin were used to derive the phosphorus standard. To achieve the chlorophyll-a goal of 10 µg/l in the lower basin, it was estimated that the total phosphorus levels needed to be at or below 0.06 mg/l (60 µg/l) based upon the following equation presented by Grieb et al. (1983):

$$\text{Mean Summer Chlorophyll-a } (\mu g/l) = 0.9 * (P)^{0.6} \qquad \text{[Eq. 1]}$$

Where:

P = mean summer in-lake total phosphorus concentration (µg/l)

While Grieb et al. developed 7 equations for various light and nutrient limiting conditions, the above equation produced the best predictions for the more productive lower basin. Empirical equations by other authors were evaluated but the above-Grieb et al. equation provided estimates that best approximated actual chlorophyll-a measurements. As a result of this work, the Lahontan Reservoir total phosphorus standard was set as a single value of 0.06 mg/l.

Development of Total Phosphorus Standard

Chlorophyll-a Target Selection

One of the first steps in developing the total phosphorus standard was to establish a desired maximum algae level. High algae levels decrease the aesthetic value of the reservoir for swimming, boating, and water skiing. While some algae is needed to provide food for aquatic life including fish, too much can be detrimental and can lead to depressed dissolved oxygen levels in the lower depths of the reservoir.

---

[1] Chlorophyll-a is a pigment within algae and is a common surrogate for characterizing algae biomass.

Based upon DRI recommendations, NDEP selected the a chlorophyll-a target of 10 µg/l. From the NDEP Water Quality Standards Rationale:

> *"Eutrophic conditions are generally associated with waterbodies having mean summer chlorophyll-a values exceeding 10 ug/l."* (Jones and Lee, 1979). *Lakes and reservoirs that fall into this category usually have excessive growths of algae that significantly impair beneficial uses* (Archibald and Lee, 1981). *The goal at Lahontan Reservoir will be to achieve a meso-eutrophic level of productivity that would be characterized by a summer mean chlorophyll-a value of less than 10 ug/l.*

Summary of Empirical Equations Evaluated by DRI

Once a chlorophyll-a target was selected, it became necessary to estimate the acceptable levels of phosphorus associated with the algae target. A number of empirical equations relating total phosphorus to chlorophyll-a levels were evaluated by DRI for their potential use in recommending phosphorus standards (Table 1). Of the 5 equations examined, one of the Grieb et al. equations produced estimates that most closely matched the observed values for 1980 and 1981. It was concluded that the Grieb et al. equations would serve as the best predictive tool in setting a total phosphorus standard (Cooper and Vigg, 1983).

Table 1. Empirical Equation Predictions for Summer Mean Chlorophyll-a Levels for Entire Reservoir

Description	Jun-Aug Mean Epilimnion Chlorophyll-a (ug/l)	
	1980	1981
Observed	13.0	12.5
Dillon and Rigler	204.8	217.3
Jones and Bachman	242.7	257.6
Rast and Lee	32.4	28.0
Smith and Shapiro	75.9	76.3
Grieb et al.[1]	10.7	10.9

[1] The equation for "Light and N Limited" systems was used ($1.2P^{0.4}$). See following section.

Grieb et al. Empirical Equations

Using nutrient, chlorophyll-a and Secchi depth data (June-August mean epilimnion values) for 34 lakes in the southeastern portion of the U.S.(Attachment A), Grieb et al. developed 7 different relationships for a variety of nutrient and/or light limited conditions (Table 3). To determine nutrient limitation, Grieb et al. developed ratios between the total nitrogen and total phosphorus concentrations. To determine light limitation, Grieb et al. estimated the proportion of light attenuation in the water column that was due to algae using Equation 2:

$$F = \frac{b*Chl}{a + b*Chl} \qquad \text{[Eq. 2]}$$

Where:

F = portion of light extinction due to algae
a = portion of light extinction due to non-algal causes
b = coefficient relating chlorophyll-a levels to algal-caused light extinction (estimated by Grieb et al. at 0.05)
Chl = chlorophyll-a (μg/l)

The resulting values for the 34 lakes ranged from 0.12 to 0.99. In other words, algal-caused light extinction ranged from 12% to 99% of the total light extinction due to all causes. Grieb et al. identified F < 0.5 (more than ½ of the light extinction was due to non-algal causes) as the criterion for considering a waterbody as light limited.

Using the N:P ratios and the F values, Grieb et al. categorizes the 34 waters according to the following criteria:

- If N:P > 8 (nitrogen to phosphorus ratio > 8), then the waterbody was considered to be phosphorus limited
- If N:P < 8, then the waterbody was considered to be nitrogen limited
- If $F \leq 0.5$, then the waterbody was considered to be light limited by non-algal causes
- If $F > 0.5$, then the waterbody was considered to not be light limited by non-algal causes

Using these conditions, Grieb et al. grouped the lakes into 7 different categories and developed 7 different regression equations between chlorophyll-a and total phosphorus data (Table 2). However, a number of problems with these equations have been identified (see Notes under Table 2).

Table 2. Grieb et al. Empirical Equations

Description	Criteria	No. of Lakes	R^2	Equation
Entire data set[1]	All data	34	0.45	$Chl\text{-}a = 0.2P^{0.6}$
Nutrient limited[2]	$F > 0.5$	18	0.61	$Chl\text{-}a = 0.9P^{0.6}$
Light limited	$F \leq 0.5$	16	0.17	$Chl\text{-}a = 1.4P^{0.4}$
P or light limited[3]	N:P > 8	27	0.48	$Chl\text{-}a = 0.5P^{0.8}$
Light and N limited[4]	N:P < 8; $F \leq 0.5$	14	0.27	$Chl\text{-}a = 1.2P^{0.4}$
P limited[5]	N:P > 8, $F > 0.5$	13	0.85	$Chl\text{-}a = 0.1P^{1.2}$
P limited[5]	N:P > 8; $F > 0.8$	5	0.98	$Chl\text{-}a = 0.3P^{1.1}$

Note: P, N and chl-a relationships developed using Jun-Aug mean values

[1] An analysis of the data provided in Grieb et al. indicates that the equation presented in the report appears to have a typo. The correct equation should be Chl-a = $0.8P^{0.6}$.

[2] Instead of calling this category "Nutrient limited", a more appropriate description would be "Not light limited". In generating this equation, those lakes with $F > 0.5$ (not light limited) were selected regardless of the nutrient limitation conditions.

[3] Instead of calling this category "P or light limited", a more appropriate description would be "P limited". In generating this equation, those lakes with $N:P > 8$ (P limited) were selected regardless of the light conditions.

[4] This category is incorrectly described as N limited and should be "Light Limited and P Limited". An analysis of the data provided in Grieb et al. indicates that the selection criteria had to have been "$N:P > 8$; $F \leq 0.5$" in order for 14 lakes to have been selected in generating the reported equation Chl-a = $1.2P^{0.4}$. Only 1 lake meets the criteria of both light limited ($F \leq 0.5$) and N limited ($N:P < 8$), so an equation could not be developed for "Light Limited and N Limited".

[5] Instead of calling these categories "P limited", a more appropriate description would be "P limited and not light limited". In generating this equation, only P limited, clearer lakes were selected.

Based upon Secchi depth and chlorophyll-a data, DRI concluded that the reservoir could be considered as "Light and N Limited" or "Nutrient Limited" depending upon which portion of the waterbody was evaluated. Using the appropriate Grieb et al. equations, predicted chlorophyll-a levels were similar to the 1980-81 observed levels (Table 3). However, the "Nutrient Limited" equation was selected as the most appropriate for setting the total phosphorus standard since it yielded the most restrictive P criteria. By setting a total phosphorus standard as needed to meet the chlorophyll-a target of 10 µg/l in the more productive and less turbid lower basin, it was believed that algae levels would be less than the target in the remainder of the reservoir.

Table 3. Light and Nutrient Limitation Status during 1980 and 1981 (from Cooper and Vigg, 1983)

Segment	**Conditions and Equation**	**1980**			**1981**		
		Observed TP (ug/l)	**Observed Chl-a (µg/l)**	**Predicted Chl-a (µg/l)**	**Observed TP (ug/l)**	**Observed Chl-a (µg/l)**	**Predicted Chl-a (µg/l)**
Whole Lake	Light and N limited; Chl-a = $1.2P^{0.4}$ (See Note)	0.24 (see Note 2)	13.0	10.7	0.25 (See Note 2)	12.5	10.9
Upper Basin			6.9	10.7		6.2	10.9
Lower Basin	Nutrient limited; Chl-a = $0.9P^{0.6}$		19.1	24.1		17.7	24.7

Note 1: The data used to derive this equation was found to be for "Light and P limited" lakes, not "Light and N limited" lakes.
Note 2: Authors used average for all basins rather than averages specific to each basin. Unfortunately, the report only provides water quality data combined for all monitoring sites, making it impossible to separate out the water quality by basin. Also, authors used March-May average TP levels even though the Grieb relationships called for June-August average TP values.

Therefore, DRI recommended using the "Nutrient Limited" equation for simulating the relationship between phosphorus and chlorophyll-a in the lower basin of Lahontan Reservoir:

$$\text{Mean Summer Chlorophyll-a } (\mu g/l) = 0.9*(P)^{0.6}$$

Where:
P = mean summer in-lake total phosphorus concentration (µg/l)

Based upon this equation, a total phosphorus concentration of 0.06 mg/l relates to a chlorophyll-a level of 10 µg/l.

Evaluation of Methods used in Setting Total Phosphorus Standard

Appropriateness of Using Grieb Equation

In developing their equations, Grieb et al. used nutrient, chlorophyll-a and Secchi depth data for 34 manmade lakes in south eastern U.S. The average morphologic characteristics of these reservoirs were somewhat higher than those of Lahontan Reservoir (Table 4). However, Lahontan Reservoir characteristics still fall within the range of characteristics for the 34 lakes. From that standpoint, the Grieb et al. dataset appears to be applicable to a study of Lahontan Reservoir.

Table 4. Morphologic Characteristics of Waters in Grieb et al. Dataset compared to Lahontan Reservoir

Characteristic	Grieb et al. (averages)	Lahontan Reservoir
Surface Area, km^2	77	44
Volume, 10^6 m^3	767	343
Mean depth, m	8.7	8.1

While the Grieb et al. equation seems to fit the 1980-81 dataset, the climate, geography and hydrology of the southeastern region of the U.S. is considerably different from that of the Carson River basin and Lahontan Reservoir. This raises significant concerns about the use of this equation from a regulatory standpoint. According to Grieb et al., *"[c]are should be taken in applying the model in dissimilar regions other than as a first approximation of the expected conditions in a warm water fishery."*

Of the 34 lakes in the dataset, Grieb et al. selected 18 waters to develop the "Nutrient Limited" equation. The water quality of Lahontan Reservoir in 1980-81 was similar to that of the 18 lakes used by Grieb et al. (Table 5). Additionally, the relative extinction coefficients (F) for these 18 waters and Lahontan Reservoir (lower basin) were greater than 0.5 (not light limited). Based upon these water quality conditions, the "Nutrient Limited" equation appears to be applicable to the lower basin of Lahontan Reservoir. However, a closer look at the information suggests there are some problems with the Grieb equation and its applicability to Lahontan Reservoir. In development of the "Nutrient Limited" equation, Grieb et al. used data for all the 18 lakes with F>0.5 (not light limited) regardless of the N:P ratios. Of these 18 lakes, only 4 had N:P ratios < 8 (N-limited; ranging from 5.7 to 7.5). N:P ratios for the other lakes ranged from 11.8 to 44.3 (P-limited). During the years 1980 and 1981, Lahontan N:P ratios were estimated at 4.7 and 3.4, respectively, making Lahontan Reservoir N-limited. From the N:P ratio standpoint, the Grieb et al. "Nutrient Limited" equation may not be appropriate for Lahontan Reservoir (with its nitrogen limitation).

Table 5. June-August Mean Epilimnion Water Quality for Nutrient Limited Waters (Grieb) Compared to Lower Basin of Lahontan Reservoir (1980 and 1981)

Parameter	Grieb et al. – Nutrient Limited Waters			Lahontan Reservoir – Lower Basin		
	Min	Max	Mean	Min	Max	Mean
Secchi Depth, m	0.6	6.4	2.0	0.8	1.4	1.1
Total Phosphorus, mg/l	0.01	0.71	0.09	0.12	0.24	0.20
Total Nitrogen, mg/l	0.30	1.20	0.70	0.75	0.81	0.80
N:P Ratio	5.7	44.5	22.6	3.4	4.4	3.9
Chlorophyll-a, µg/l	1.8	23.8	11.9	6.5	28.5	15.1
Relative extinction coeff. (F)	0.52	0.99	0.74	0.76	1.24	1.00

Appropriateness of How Grieb Equation Was Used

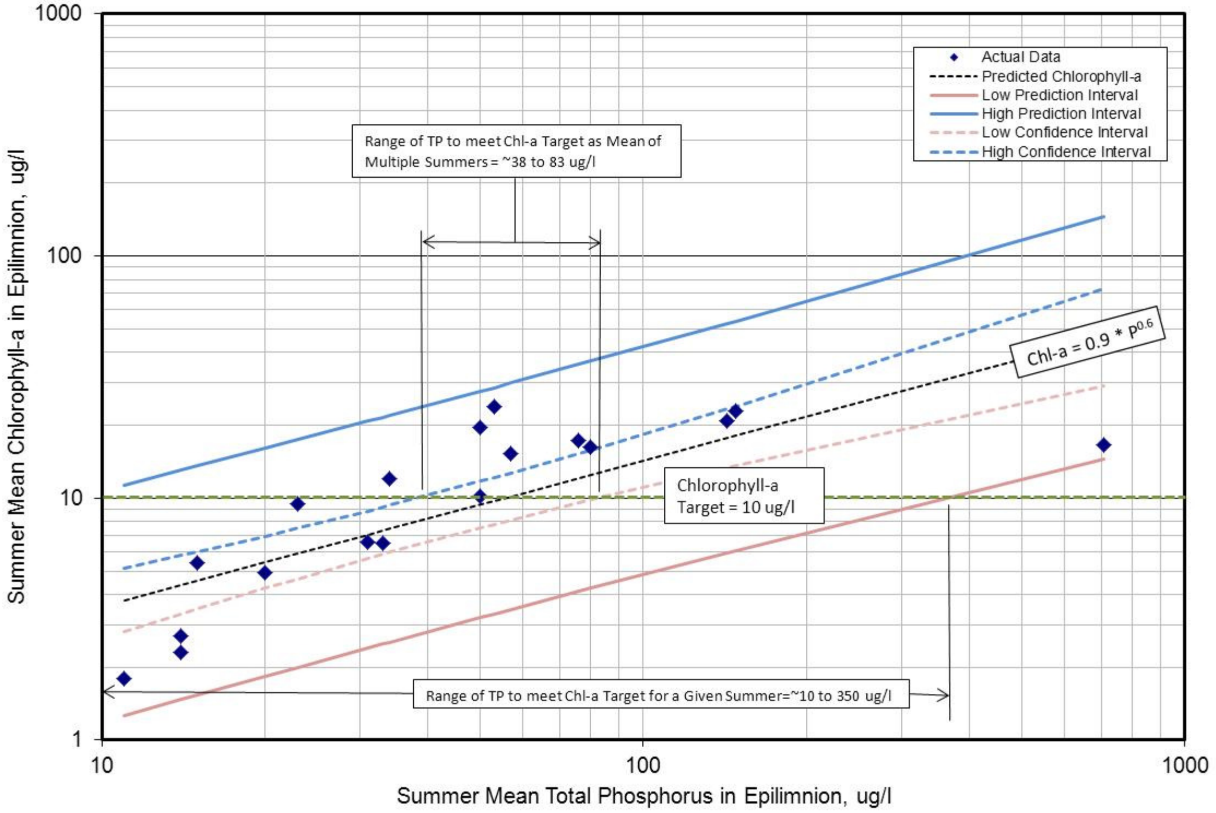
As discussed earlier, Grieb et al., developed a series of relationships between mean summer (June-August) epilimnetic chlorophyll-a levels and mean summer epilimnetic total phosphorus levels. When evaluating the appropriateness of these equations, Cooper and Vigg (1983) inappropriately used mean March-May epilimnetic total phosphorus values to predict mean June-August epilimnetic chlorophyll-a. However this error was not significant enough to have led the authors to a different conclusion.

In Cooper and Vigg's evaluation process, the mean March-May eplimnetic total phosphorus values were for the entire lake, while predicting chlorophyll-a levels by basin. Data has shown that the total phosphorus concentrations can vary significantly from the upper basin (near the Carson River inflow) to the lower basin (near the dam), with the highest levels typically in the upper basin. It may have been more appropriate for Cooper and Vigg to have used mean total phosphorus values specific to each basin when evaluating the performance of the Grieb equations.

Uncertainty of Grieb Predictions

The uncertainty in any prediction derived from the Grieb et al. equation is large. In order to meet the chlorophyll-a target of 10 ug/l (mean summer level in epilimnion), the Grieb et al. equation predicts that a mean summer total phosphorus level of 60 ug/l (0.06 mg/l) would be acceptable. However when uncertainty in the equation is accounted for, there is 95% confidence that the acceptable phosphorus levels for a given summer could be anywhere between 10 ug/l (0.01 mg/l) and 350 ug/l (0.35 mg/l) (Figure 1). For the mean of multiple summers, there is 95% confidence that the acceptable phosphorus levels could be between 38 ug/l (0.038 mg/l) and 83 ug/l (0.083 mg/l).

Figure 1. Grieb et al. Predictive Relationship for "Nutrient Limited" Waters

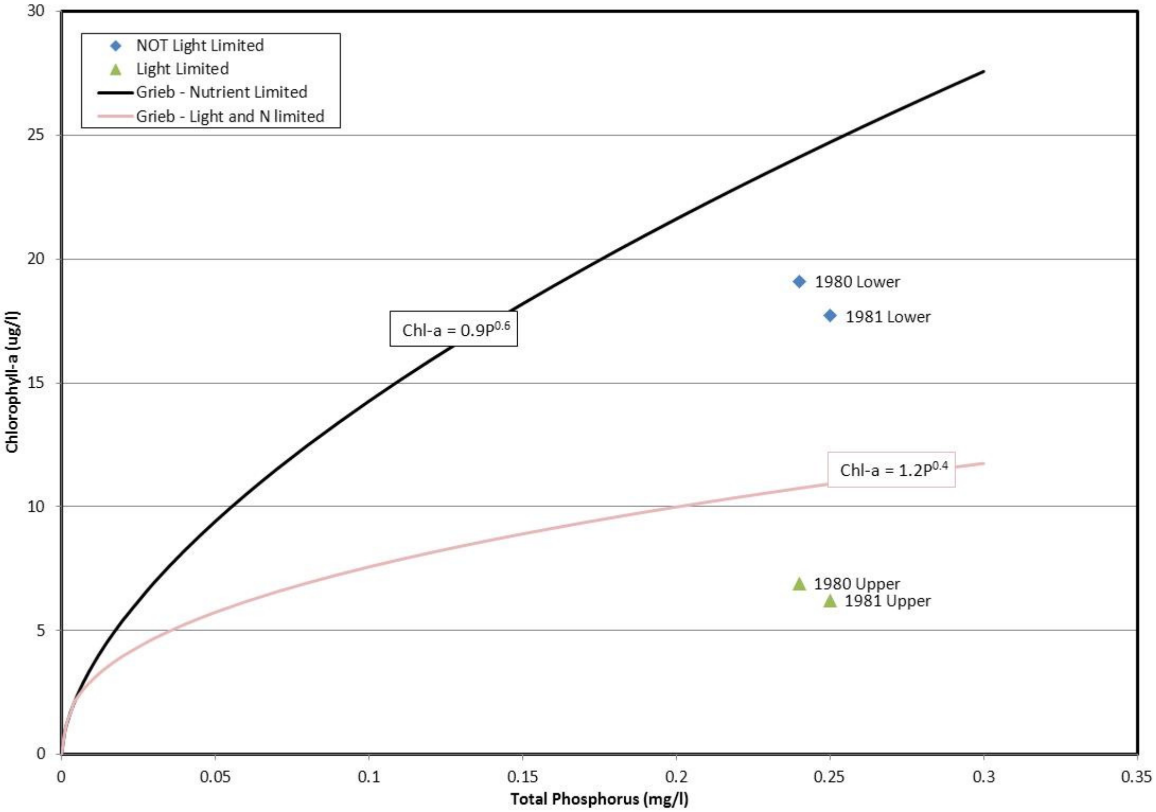


Limited Data to Conclude Grieb Appropriate

Limited data were relied upon to conclude that the Grieb et al. equation for “Nutrient Limited” conditions was applicable to Lahontan Reservoir. During the 3 years monitored by DRI (1980-81), only the lower basin experienced light conditions (F>0.5) applicable for the “Nutrient Limited” equation (Figure 2). The other summer values (1980 Upper, 1981 Upper) occurred during light limiting conditions. While close to the “Nutrient Limited” equation predictions, the 1980 Lower and 1981 Lower data points diverge from the predictions by a significant amount and more data were needed to evaluate the appropriateness of the equation.

It becomes difficult to fully evaluate the DRI findings because of the unavailability of any detailed water quality data. The report provides water chemistry data (1980-81) that are averages for the entire lake with no specific water chemistry data available for each monitoring stations.

Figure 2. 1980-81 Data Compared to Grieb Predictions



Issues with Light Limitation Assumptions

As discussed earlier, Grieb et al. used Equation 2 to calculate the percentage of light extinction (F) (or loss of clarity) caused by algae for the 34 lakes. High F values indicate that a majority of the loss of clarity is due to algae, while low F values indicate that a majority of the loss of clarity is the result of nonalgae sources. There are some problems with this approach. Two lakes with vastly different Secchi depths (thus different potentials for algae growth) could have the same F values, if both had 50% of their clarity loss due to nonalgal sources. The more appropriate measure is an estimate of lake clarity loss without the influence of algae. This is believed to be a more accurate depiction of maximum algal growth potential for a given waterbody. Walker (1999) has developed the following equation to estimate nonalgal turbidity based upon chlorophyll-a levels and Secchi readings:

$$NAT = \frac{1}{SD} - 0.025 * CHL \qquad \text{[Eq. 3]}$$

Where:

NAT = nonalgal turbidity (1/m)
Chl = chlorophyll-a (µg/l)
SD = Secchi disk depth (meters)

Based upon Equation 3, the NAT of 18 lakes Grieb et al. used in developing the "Nutrient Limited" equation ranged from 0.11 to 1.23 m^{-1}. In 1980 and 1981, NAT in lower basin of Lahontan Reservoir were 0.27 and 0.77 m^{-1}, respectively. While these 18 lakes have similar NAT levels to the 1980-81 levels in Lahontan Reservoir, several other lakes in the dataset of 34 also had NAT levels similar to Lahontan Reservoir and could have been used in Grieb's analysis.

Seasonality Consideration in Using Grieb et al. Predictions

The Grieb et al. equation was based upon June-August mean total phosphorus and chlorophyll-a levels. However, the current total phosphorus standard of 0.06 mg/l was set as a single value criterion. Based upon the Grieb methodology, some sort of average total phosphorus standard may have been more appropriate than a single value criterion.

Separate Standards for Each Basin

The Grieb et al. Nutrient Limited equation used in deriving the phosphorus standard was applicable only during times when light limitation did not exist ($F > 0.5$). During the 1980-81 and 1983 period studied by DRI, these conditions only occurred in the lower basin of the reservoir in 1980 and 1981. The upper portion of the reservoir was found to be light limited ($F<0.5$) in 1980 and 1981[2], and the lower basin was light limited in 1983. For light limiting conditions ($F<0.5$), DRI identified another Grieb et al. equation as a good predictor of chlorophyll-a levels:

$$\textit{Mean Summer Chlorophyll-a } (\mu g/l) = 1.2*(P)^{0.4} \qquad \text{[Eq. 4]}$$

Though there is no evidence in the report of NDEP pursuing a different standard for the upper basin, the available information suggests that this could have been feasible. Based upon the above equation, a total phosphorus standard for the upper basin of about 0.20 mg/l would be protective of the chlorophyll-a target during light limiting conditions.

Consideration of Nitrogen

The Grieb et al. equation used by Cooper and Vigg (1983) was based only upon total phosphorus even though the data shows Lahontan Reservoir to be nitrogen limited. Cooper and Vigg (1983) state numerous times that Lahontan Reservoir is N-limited, yet they relied on a phosphorus-algae relationship to develop water quality criteria. Given its potential for limiting the algae growth, nitrogen needs to be part of any prediction of chlorophyll-a levels. Future standards may need to include nitrogen criteria.

---

[2] Only the lower basin was monitored by DRI in 1983.

Consideration of More Recent Data

During 2003-05, NDEP collected extensive water quality on Lahontan Reservoir. From these data, mean June-August total phosphorus, total nitrogen, chlorophyll-a and Secchi depth values were determined for the upper, middle and lower basins of Lahontan Reservoir (Table 6). Additionally, each basin was evaluated to determine if it was experiencing light limitation conditions ($F<0.5$) or not ($F>0.5$) following the approach used by Grieb et al. All 3 basins were found to have F values <0.5 (light limited) in 2003 and 2004, but were >0.5 (not light limited) in 2005. A comparison of these results to the Grieb equation for "Nutrient Limited" conditions suggests that the Grieb equation is not appropriate and that updated equations may be needed (Figure 3). However, it must be remembered that use of the "F" values has issues and it may be more appropriate to use NAT values to characterize light limitation conditions.

There is no particular NAT threshold above which a water would be considered light limited. NAT values represent a gradient of nonalgal turbidity conditions with higher values indicating more nonalgal turbidity in the water column. When examining the 2003-05 data using NAT values (Figure 4), the relationship between phosphorus and chlorophyll-a for $NAT < 1.5$ is similar to the "not light limited" plot on Figure 3.

Table 6. Summary of Lahontan Reservoir Data, 2003-05

Year	**Basin**	**Mean Jun-Aug Secchi Depth (m)**	**Mean Jun-Aug Epilimnetic Nutrients**				**F (Relative light extinction)**	**NAT (nonalgal turbidity) (m^{-1})**
			Total Phosphorus (mg/l)	**Total Nitrogen (mg/l)[1]**	**Chlorophyll -a (ug/l)**	**N:P Ratio**		
2003	Upper	0.4	0.26	0.80	8.0	3.1	0.16	2.30
	Middle	0.8	0.17	0.55	2.0	3.2	0.08	1.20
	Lower	1.4	0.11	0.42	2.1	3.8	0.15	0.66
2004	Upper	0.4	0.27	1.06	13.4	3.9	0.27	2.17
	Middle	0.5	0.20	0.82	7.4	4.1	0.19	1.82
	Lower	0.9	0.14	0.69	3.7	4.9	0.17	1.02
2005	Upper	0.5	0.25	1.31	34.7	5.2	0.87	1.13
	Middle	0.9	0.18	1.02	24.5	5.7	1.10	0.50
	Lower	1.3	0.12	0.93	12.9	7.8	0.84	0.45

[1] As a result of accounting for values below the laboratory reporting limits, a range of TN values were calculated.

Figure 3. 1980-81, 2003-05 Data Compared to Grieb Predictions - using F

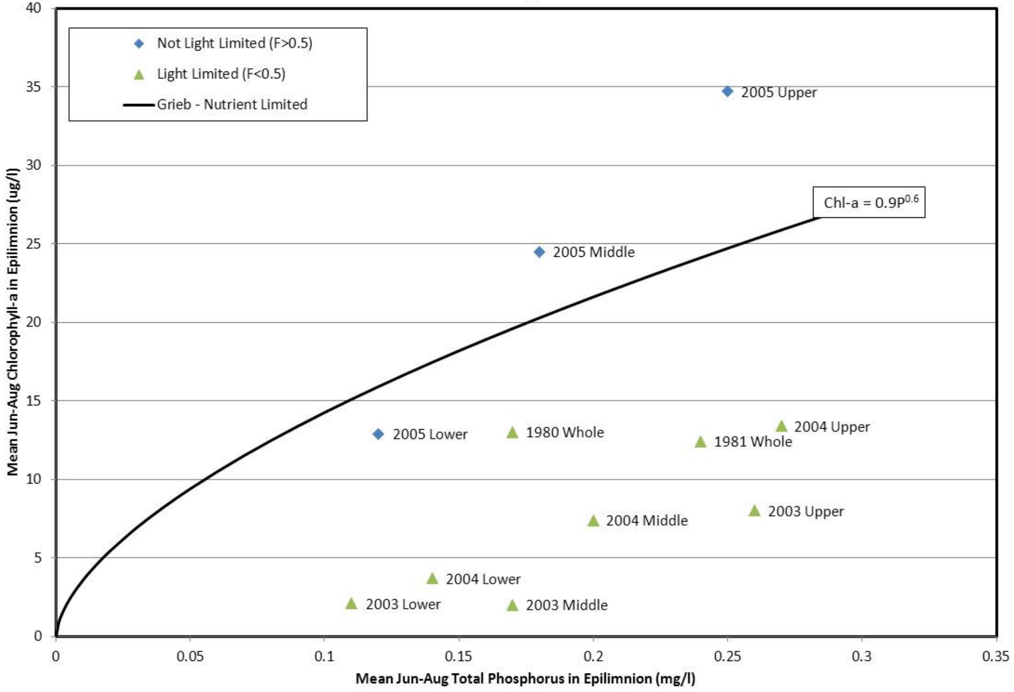
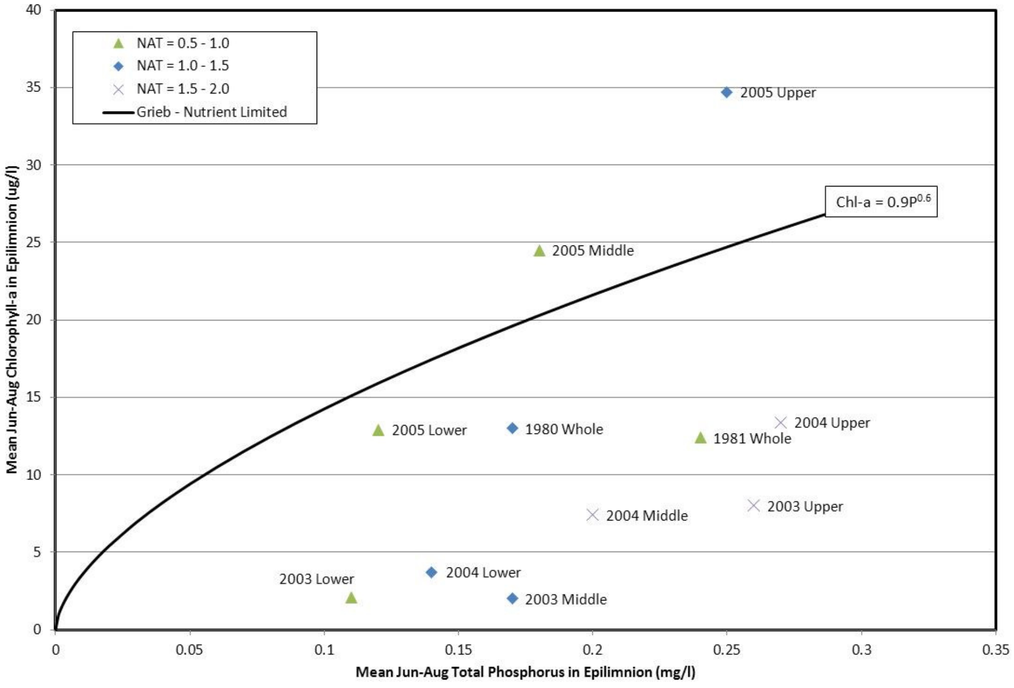
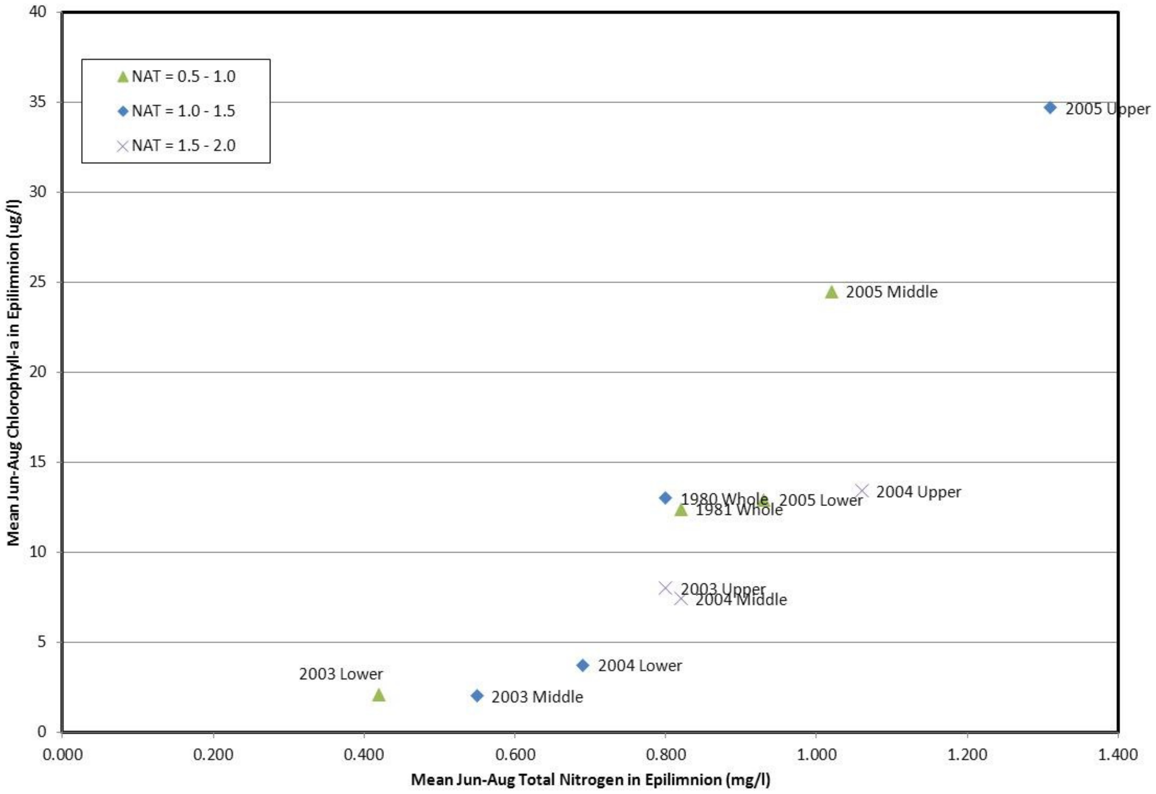


Figure 4. 1980-81, 2003-05 Data Compared to Grieb Predictions - Using NAT



Given that Lahontan Reservoir is nitrogen limited, there is interest in examining relationships between nitrogen and chlorophyll-a levels. As shown in Figure 5, there appears to be a fairly well defined relationship between chlorophyll-a and total nitrogen levels. Additionally, the 1980-81 and 1983 data seem to follow a similar relationship. According to this plot, NAT levels do not seem to affect algal levels since all of the data follow a similar pattern. The apparent strong relationship between nitrogen and and chlorophyll-a suggests that the system is truly N limited.

Figure 5. 1980-81, 2003-05 Data - Total Nitrogen v. Chl-a



It is not known if the 2003-05 nitrogen levels in the reservoir were solely the result of inflow loads, or include loads associated with nitrogen-fixing algae introducing nitrogen from the atmosphere into the water column. Cyanobacteria (nitrogen-fixing algae) are known to occur in Lahontan Reservoir, but limited data exists to characterize its historic extent. During the 2003-2005 NDEP investigation, algal species were only identified for the 2004 samples. In 2004, cyanobacteria (mostly *Aphanizomenon flos-aquae*) dominated the algal community at times.

According to Deas and Orlob (1999), algal cells contain 0.5-2.0 ug/l phosphorus and 7-10 ug/l nitrogen per ug/l chlorophyll-a. During 2005, average June-August total nitrogen levels in the epilimnion were nearly 1.30 mg/l in the upper basin. Based upon the ratios from Deas and Orlob, about 25% of the total nitrogen may have been tied up in the algae. If these algae were cyanobacteria, the most nitrogen they could have introduced to the system would have been 25% of the total.

Appropriateness of Chlorophyll-a Target

The total phosphorus standard was based upon an assumed algae level in the reservoir that was deemed to be acceptable. As stated in the NDEP rationale (1984), *"[the] goal at Lahontan Reservoir will be to achieve a meso-eutrophic level of productivity that would be characterized by a summer mean chlorophyll-a*[3] *value of less than 10 µg/l."* According to the rationale, a chlorophyll-a threshold of 10 µg/l was selected as some research has shown that lakes and reservoirs with chlorophyll-a levels above this value usually have excessive growths of algae that significantly impair beneficial uses.

Since the 1980s, significantly more information on appropriate chlorophyll-a thresholds has been developed. However, the choice of chlorophyll-a target is far from clean cut. The three main uses that are affected by algal levels – warmwater fisheries, recreation and municipal/domestic supply – often have desirable algal thresholds that are conflict with each other. While warmwater fisheries do well in more productive lakes with chlorophyll-a levels ranging from about 20 – 40 ug/l, contact recreation and drinking water typically require lower algae levels. In many states, appropriate chlorophyll-a levels to protect recreation uses have been based upon the results of user perception surveys. The results often vary depending upon the geographic region, the type of lake, and users expectations regarding a particular set of lakes. As an example, Minnesota relied on user surveys to set chlorophyll-a standards ranging from 9 ug/l in the northern forested areas to 22 ug/l in the southern cornbelt plains. While these different values all protect the same beneficial use of contact recreation, users have had different expectations for the lakes depending upon the region. As a result, the issue of setting a chlorophyll-a threshold becomes much more of a social question than a science question.

Currently, no Nevada waters have been assigned numeric chlorophyll-a criteria for the protection of beneficial uses. Chlorophyll-a criteria have been set for Lake Mead but have been established as part of the Nevada's antidegradation program. These criteria range from a growing season mean of 5 ug/l for open water areas of Lake Mead up to 45 ug/l in the Las Vegas Bay near the mouth of Las Vegas Wash.

Achievability of Current Phosphorus Standard

Nevada state law and the Clean Water Act and Nevada law provide justification for considering achievability when setting a water quality standard. According to Nevada Revised Statutes (NRS) 445A.520(2):

> "The commission shall base its water quality standards on water quality criteria which numerically or descriptively define the conditions necessary to maintain the designated beneficial use of uses of the water. The water quality standards must reflect water quality criteria which define the conditions necessary to support, protect and allow the propagation of fish, shellfish and other wildlife and to provide for recreation in and on the water **<u>if these objectives are reasonably attainable</u>**."

The NRS clearly states the need to have reasonably achievable standards, while the federal regulations take a slightly different approach. The Code of Federal Regulation (CFR) 131.10(d) states:

> "At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under sections 301(b) and 306 of the Act and cost-effective and reasonable best management practices for nonpoint source control."

---

[3] Chlorophyll-a is a pigment within algae and is a common surrogate for characterizing algae biomass.

The CFR differs from the NRS language in that it focuses on the achievability of beneficial uses and not the achievability of the numeric criteria to protect those uses. It could be argued each of the key beneficial uses (warmwater aquatic life, recreation, drinking water supply) actually could be defined at a location within a gradient ranging from adequate to high quality. The water quality that is reasonably achievable would dictate the reasonably achievable level of beneficial use that can be protected.

The question of achievability is an important one to consider in evaluating the Lahontan Reservoir standards. However the issue is extremely complex and difficult to answer. It is unknown whether or not the current TP standard of 0.06 mg/l is achievable, but the evidence suggest that reducing loads to Lahontan Reservoir to the necessary levels would be a daunting proposition. The total phosphorus levels in the Carson River are consistently much higher than 0.06 mg/l. Based upon loading estimates derived by Pahl (2007) for 1990-2005, TP concentrations of the Carson River inflow are below 0.06 mg/l only about 10% of the days. Pahl's estimates suggest that this typically occurs when flows are less than about 3 cfs. On a flow weighted basis, the average TP of the Carson River inflow ranges from 0.14 mg/l in low flow years to about 0.22 mg/l in high flow years. No amount of reasonable BMPs would be able to reduce TP in the Carson River to 0.06 mg/l.

References

Archibald, E.M. and G.F. Lee. 1981. Application of the OECD eutrophication modeling approach to Lake Ray Hubbard, Texas. Research and Technology. 73:590-599.

Cooper, J.J. and Steven Vigg. January 1983. Empirical Water Quality Modeling, Volume 5, The Lahontan Reservoir Water Quality Project. Desert Research Institute.

Deas, M.L. and G.T. Orlob. December 1999. Klamath River Modeling Project. Report No. 99-04. Sponsored by U.S. Fish and Wildlife Service.

Grieb, T.M., D.B. Porcella, T.C. Ginn, M.W. Lorenzen. February 1983. Assessment Methodology for New Cooling Lakes, Volume 2: Development of Empirical Multivariate Relationships for Evaluation Fish Communities in New Cooling Lakes. EA-2059, Research Project 1488-1. Tetra Tech, Inc. prepared for Electric Power Research Institute.

Jones, R.A., W. Rast and G.F. Lee. 1979. Relationship between summer mean and maximum chlorophyll-a concentrations in lakes. Environ. Sci. Technology 13:869-870.

Nevada Division of Environmental Protection. 1984. Water Quality Standard Review Rationale. Carson City, Nevada.

Pahl, R.A. December 2007. Trends in Nutrient Loads to Lahontan Reservoir. Nevada Division of Environmental Protection. Carson City, Nevada.

Walker, W.W. April 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. Prepared for Corps of Engineers.

Attachment A – Data Compiled by Grieb et al. (1983)

Table A-1. Mean Summer Epilimnetic Values from Grieb et al.

Light Criterion	Lake Name	Secchi (meters)	chl-a (µg/l	TP (mg/l)	TN (mg/l)	N:P
F > 0.8	Brauig Lake	0.74	23	0.148	0.990	6.7
	Calaveras Lake	0.81	23.8	0.053	0.820	15.5
	Caddo Lake	0.96	19.7	0.050	0.750	15.0
	Possum Kingdom	2.06	9.5	0.023	0.680	29.6
	Lake Tawakoni	0.95	20.8	0.143	0.820	5.7
	Gaston Res.	1.53	10.2	0.050	0.300	6.0
$0.7 < F \leq 0.8$	Lake Catherine	1.42	12	0.034	1.200	35.3
	Deep Creek Res.	3.35	5.4	0.015	0.640	42.7
	Lake Murray	1.93	6.5	0.033	0.620	18.8
$0.6 < F \leq 0.7$	Jackson Lake	0.96	15.2	0.057	0.680	11.9
	Old Hickory Res.	0.84	16.3	0.080	0.600	7.5
$0.5< F \leq 0.6$	Lake Stamford	0.6	17.3	0.076	0.900	11.8
	Lake Sinclair	1.58	6.6	0.031	0.670	21.6
	Dale Hollow Res.	6.4	1.8	0.011	0.490	44.5
	Woods Res.	2.32	4.9	0.020	0.680	34.0
	Beaver Res.	4.19	2.7	0.014	0.470	33.6
	Bull Shoals Res.	4.78	2.3	0.014	0.620	44.3
$0.4 < F \leq 0.5$	Lake Colorado City	0.56	13.4	0.020	0.830	41.5
	Lake Norman	1.06	8.5	0.032	0.370	11.6
	Mtn. Island Lake	1.12	7.4	0.017	0.350	20.6
$0.3 < F \leq 0.4$	Barnett Res.	1.05	8.2	0.043	0.890	20.7
	Lake Lavon	0.63	5.6	0.083	0.650	7.8
	Lake LBJ	1.3	5.2	0.035	0.960	27.4
	Eagle Mtn. Res.	1.18	3.9	0.025	0.400	16.0
	Keystone Res.	0.63	9.1	0.123	1.100	8.9
	Lake Wylie	0.89	8.1	0.034	0.420	12.4
$F \leq 0.3$	Lake Keowee	2.28	1.6	0.008	0.430	53.8
	Badin Res.	0.96	7.7	0.053	0.830	15.7
	Mitchell Res.	0.93	7.6	0.061	0.650	10.7
	Chickamauga	0.94	3.3	0.026	0.720	27.7
	Sardis Res.	1.38	5.1	0.048	0.580	12.1
	Thomas Hill Res.	0.78	3.1	0.032	0.700	21.9