Water Quality Standards Review: South Fork Reservoir

Rationale Document

June 2014

Looking east toward South Fork Reservoir (photograph by G. Thomas)

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Introduction

Nevada state law (NRS 445A.520) requires the state to establish water quality standards at a level necessary to protect beneficial uses of the surface waters of the state. Additionally, Section 303 of the Clean Water Act and 40 Code of Federal Regulations (40CFR) Part 131 require that States and authorized tribes routinely review and, as appropriate, modify surface water quality standards that protect the designated uses of a water body and provide a basis for controlling discharges or releases of pollutants. This rationale discusses the revisions proposed by the Nevada Division of Environmental Protection, Bureau of Water Quality Planning (NDEP-BWQP) to the water quality regulations associated with South Fork Reservoir (NAC 445A.1432; 445A.1466). Currently, the reservoir is included in the NAC as part of a South Fork Humboldt River reach. Since streams and reservoirs have different water quality dynamics, they typically have a different set of water quality standards. The proposed action will break out South Fork Reservoir as separate waterbody with an associated set of water quality criteria.

Background

Under state law (NRS 445A.520), NDEP has the authority (through the State Environmental Commission) to establish water quality standards for surface waters of the state. Through section 303 of the Clean Water Act (CWA), U.S. Environmental Protection Agency (EPA) has delegated authority to Nevada to establish water quality standards for all water bodies or segments of water bodies that lie within the state. Standards are composed of three parts: designated beneficial uses, water quality criteria, and antidegradation considerations. This review evaluates all three of the standard components for South Fork Reservoir. In support of this review, the following background information has been developed.

Reservoir Operations

Located on the South Fork Humboldt River in Elko County (Figure 1), South Fork Reservoir was constructed in 1988-89. The reservoir area at full stage is about 3 miles long and 1 to 1.5 miles wide, with a maximum depth of about 67 feet, normal pool volume of 41,000 acre-feet, and surface area of about 1400 acres. Designed as a year round recreational facility, the reservoir is operated at relatively constant water level with most inflows being passed through for downstream uses (UC Davis, 1994; Nevada Div. State Parks, 2007). Since 2002, water surface elevations have varied by about 11 feet with a low of about 5224 feet (28,000 AF) in 2003 and a high of about 5235 feet (43,000 AF) in 2005 and 2006 (Figure 2). Typically, reservoir levels have peaked each year during June/July shortly after peak inflows have occurred.

Recreation Uses and Fisheries

The reservoir is part of the South Fork State Recreation Area which is owned and managed by the Nevada Division of State Parks. Primary recreation uses of the reservoir include fishing, boating, and swimming. With rather consistent water levels, South Fork Reservoir is a highly productive fishery. Game fish species include rainbow and brown trout, cut-bow trout, smallmouth and largemouth bass, wiper hybrid bass and channel catfish (Nevada Div. State Parks, 2007). Over 115,000 trout have been stocked annually since 2009 (http://www.ndow.org/Bodies_Of_Water/South_Fork_Reservoir/).

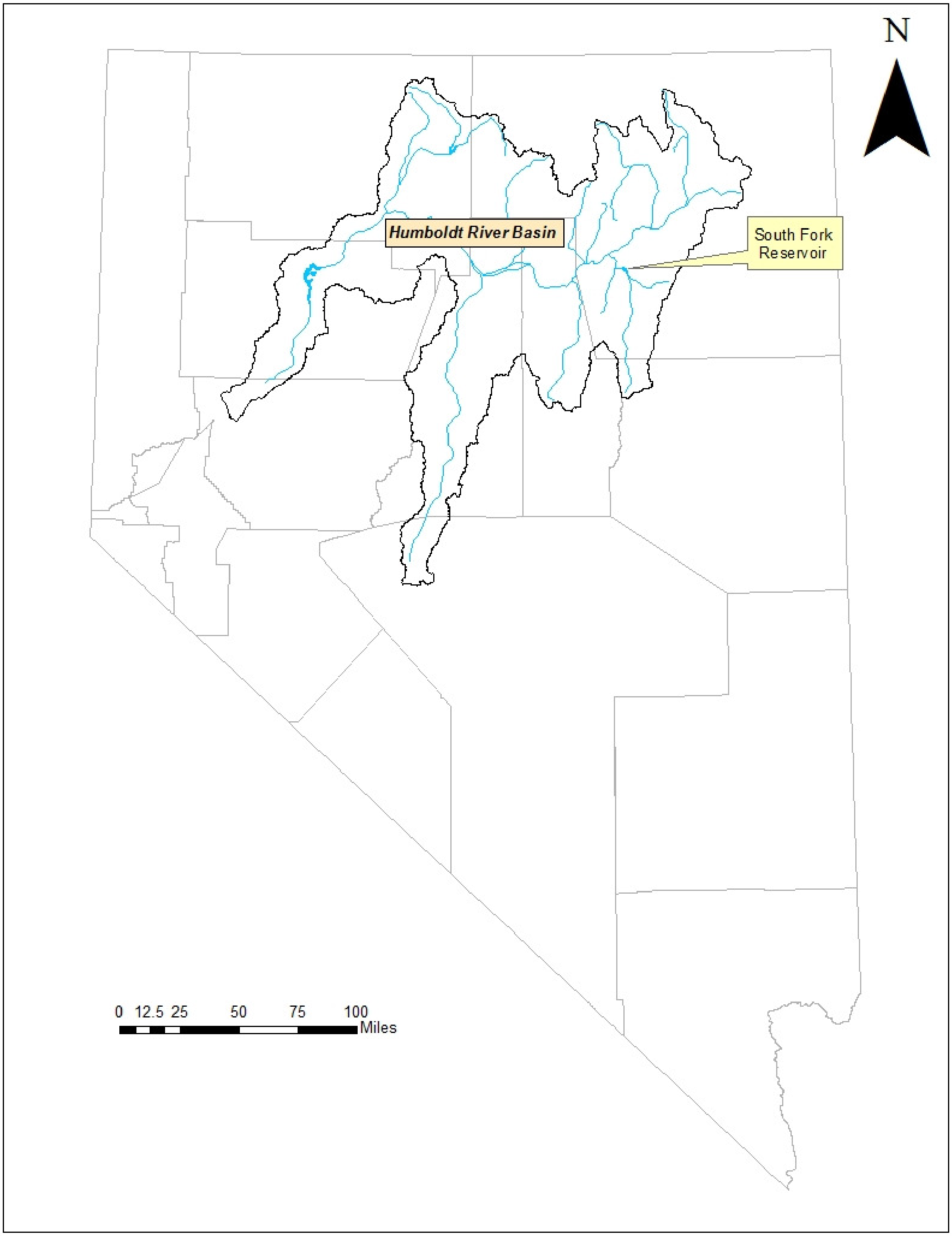


Figure 1. South Fork Reservoir Location Map

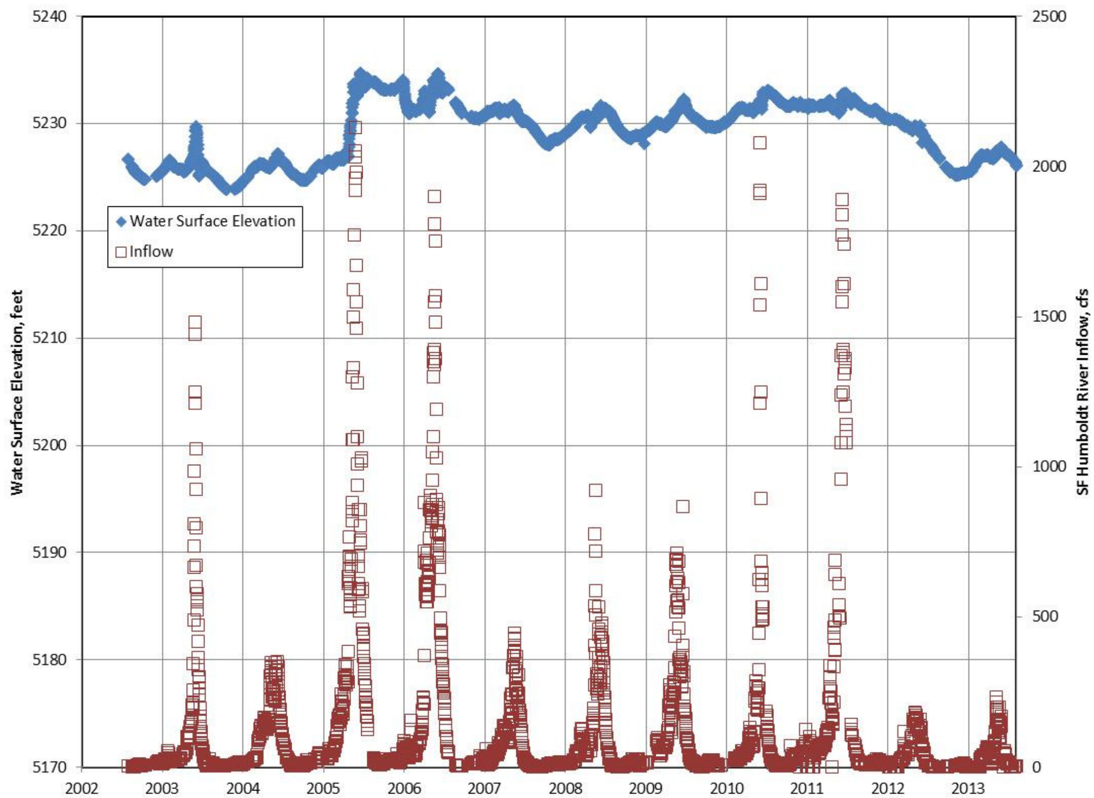


Figure 2. South Fork Reservoir Water Surface Elevations and Inflows, 2002-2013

Reservoir Stratification

Thermal stratification is an important consideration as it affects how water quality can vary throughout the water column. Thermal stratification exists in a reservoir when an upper layer is warmed (epilimnion) and essentially floats upon a colder undisturbed region (hypolimnion) (Figure 3). The transition zone is referred to as the metalimnion[1]. During periods of stratification, there is little to no water quality interaction between the epilimnion and hypolimnion. Once stratification ends, the water quality may become mixed throughout the water column.

Detailed temperature measurements taken in 2009 and 2010 show that the lake tends to stratify between May to August. By September, temperatures are relatively constant throughout the water column. Concurrent with these periods of thermal stratification are variations with depth in pH and dissolved oxygen.

[1] It is generally accepted that the metalimnion occurs in that area where the temperature changes at a rate > 1 °C per meter (Wetzel, 2001)

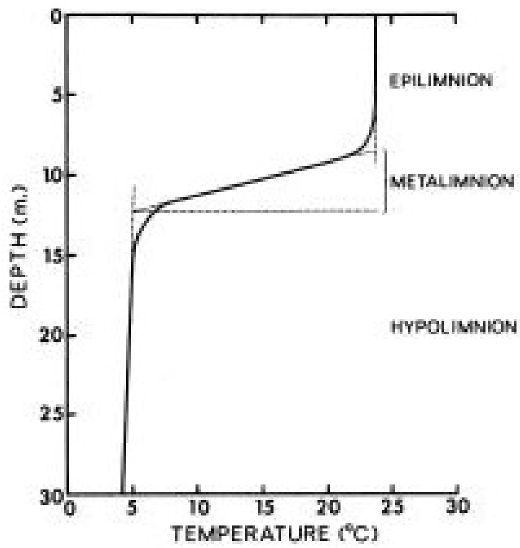


Figure 3. Typical thermal stratification of a lake (from Wetzel, 2001)

Water Quality Overview

Water quality monitoring of South Fork Reservoir has been sporadic since it first held water. Some limited monitoring occurred in the early 1990s and in 2006-08, but monitoring was typically at only one location. It is believed that the 1991-93 data are not that useful for purposes of this standards review as the reservoir was still being filled and had not yet reached equilibrium (UC Davis, 1994). Also, NDEP monitored from 1996-2004 taking samples from the pier, a location that is likely not very representative of overall lake conditions but provides some useful information nonetheless. Data collected in 2006-08 are not very useful as only 1 to 2 samples were collected each year. The most significant monitoring efforts took place by the Desert Research Institute in 2009 (Fritsen et al., 2010) and by NDEP in 2010, where monthly sampling occurred at 3 to 6 locations. Table 1 and Figure 4 display the key sampling locations since 1996. Average water quality conditions for several parameters are summarized in Table 2. Conditions in 2009 and 2010 were similar for several of the parameters.

Table 1. South Fork Reservoir Monitoring Sites, 1996-2010

Station ID	Station Name	UTM Coordinates, NAD 83		Date Range	Agency
		Northing	Easting		
NDEP SFR	South Fork Reservoir at Pier	4504449	604266	1996-2004	NDEP
NDEP SFR3	South Fork Reservoir near Dam	4504188	603039	2006, 2007, 2008, 2010	NDEP
NDEP SFR4	South Fork Reservoir near Center	4503061	604616	2006, 2007, 2008, 2010	NDEP
NDEP SFR5	South Fork Reservoir near Inlet	4502038	605688	2010	NDEP
DRI SFR1	South Fork Reservoir near Dam	4511098	596711	2009, 2010	DRI
DRI SFR2	South Fork Reservoir upgradient of Dam	4503940	603661	2009	DRI
DRI SFR3	South Fork Reservoir near Center (West)	4502844	604175	2009	DRI
DRI SFR4	South Fork Reservoir downgradient of Inlet	4501445	606217	2009	DRI
DRI SFR5	South Fork Reservoir near Inlet	4501093	606422	2009	DRI
DRI SFR6	South Fork Reservoir near Center (East)	4502706	605041	2009	DRI

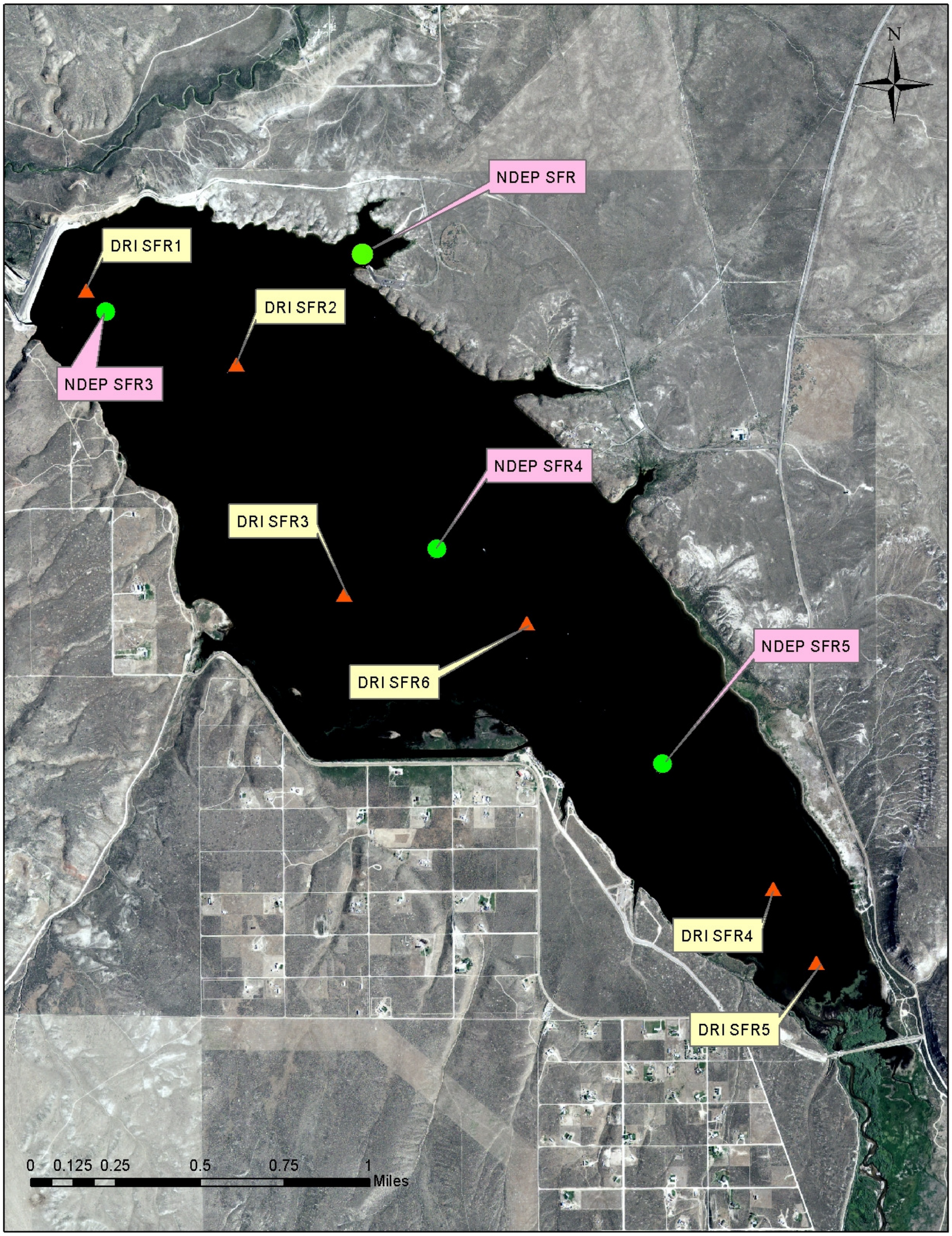


Figure 4. South Fork Reservoir Monitoring Sites, 1996-2010

Table 2. Mean Water Quality Conditions – 2009 and 2010

Parameter	2009	2010
Temperature (° C)	17.3	16.9
pH	8.3	8.3
Orthophosphates, as P (mg/l)	0.02	0.02
Total Phosphorus, as P (mg/l)	0.05	0.04
Total Kjeldahl Nitrogen, as N (mg/l)	0.50	0.54
Nitrate+Nitrite, as N (mg/l)	0.02	<0.1
Total Nitrogen, as N (mg/l)	0.52	0.55
Dissolved Oxygen (mg/l)	7.8	6.7
Sulfate (mg/l)	---	4.6
Chloride (mg/l)	---	<5
Total Dissolved Solids (mg/l)	---	128
E. Coli (no./100 ml)	---	<10
Fecal Coliform (no./100 ml)	---	<10
Color (PCU)	---	15.5
Turbidity (NTU)	---	2.7
Total Suspended Solids (mg/l)	---	<10
Chlorophyll-a (µg/l)	5.3	3.0
Secchi Depth (meters)	4.5	4.2

Nutrients: Nutrients are some of the key parameters that need to be evaluated when assessing reservoir health and the status of the beneficial uses. In most cases, nutrients of themselves do not impact beneficial uses. It is through the water's responses (algae blooms, lake clarity, dissolved oxygen) to the nutrients that beneficial uses can be affected. Based upon the limited detailed data available, total nitrogen, orthophosphates and total phosphorus levels were found to be similar in 2009 and 2010 (Table 3). In comparison to other northern Nevada reservoirs, South Fork Reservoir has nutrient levels on the lower end of the spectrum.

Table 3. Comparison of Average Nutrient Conditions (in mg/l) in Selected Reservoirs

Lake/Reservoir	TKN	TN	OP	TP
South Fork Reservoir	0.52	0.54	0.02	0.05
Lahontan Reservoir	0.68	0.8	0.14	0.24
Rye Patch Reservoir	0.62	0.65	0.06	0.11
Topaz Reservoir	0.45	0.50	0.02	0.04

For algae to grow in a reservoir, both nitrogen and phosphorus need to be available. However, algae growth may be limited if one or both of these nutrients are in limited supply. The nitrogen-phosphorus ratio (N:P) is a common measure used in evaluating which nutrient (or both) may potentially limit the algae growth. The literature suggests that a N:P ratio above 17 indicates potential P limitation, a ratio below 10 indicates potential N limitation, and values between 10 and 17 indicate that either N or P may be potentially limiting. Emphasis is on "potential" because the measured N and P concentrations may be so high that neither is currently limiting algae growth. N:P ratios for South Fork Reservoir in 2009-10 ranged from 6 to 35, with a median of about 15. Based upon this information, it would appear that the reservoir tends to fluctuate between potential nitrogen and phosphorus limitation. In this case, the N:P ratio can be used to predict which nutrient could be used up first during an algal bloom.

Another method to characterize nutrient limitation is through the examination of actual concentration levels of the more readily available forms of nitrogen (total inorganic nitrogen, TIN) and phosphorus (orthophosphates, OP). According to Jones-Lee and Lee (2005), growth rate limiting concentrations for phosphorus are about 5 µg/l (0.005 mg/l) available phosphorus (OP) and for nitrogen, about 20 µg/l (0.02 mg/l) available nitrogen (TIN). These concentrations are generally somewhat above the half saturation constant in the Michaelis-Menton-Monod equation commonly used to simulate algae uptake in modeling applications (Lee and Jones-Lee, 1998).

Surface OP and TIN concentrations (2009) in South Fork Reservoir ranged from 6 to 49 µg/l for OP and from 3 to 15 µg/l for TIN. Based upon thresholds identified by Jones-Lee and Lee (2005), TIN concentrations were typically low enough to be limiting algae growth. During 2010, surface OP concentrations were typically above 10 µg/l[2] and surface TIN concentrations typically reported as "<200 µg/l". These data suggest that OP was likely not limiting algae growth. However, the 2010 TIN reporting limit was too high to make any conclusions regarding the possibility of nitrogen limitation.

Algae Conditions: When evaluating reservoir health and beneficial use impacts, it is important to examine algae biomass levels. Since algae levels in a reservoir tend to vary throughout the waterbody, and over time, it is helpful to collect samples at multiple sites in the reservoir and for more than 1 year. One metric commonly used to quantify biomass is by measuring concentrations of chlorophll-a in the water column. Chlorophyll-a is a pigment that occurs in plants, such as algae, and aids in the photosynthesis process. As shown in Figures 5 and 6 and Table 4, chlorophyll-a levels in 2009 and 2010 were quite variable. Of the two years, 2009 experienced the highest algae levels. During a bloom in August 2009, chlorophyll-a levels were at a high of 163 µg/l at the surface at DRI SFR3 with an average in the upper meter of 82.9 µg/l. Based upon algae cell counts, the bloom was dominated by *Aphanizomenon* and *Synechococcus*, both cyanobacteria (commonly called blue green algae) that are capable of fixing nitrogen from the atmosphere. In terms of algae volume, *Aphanizomenon* accounted for about 96% of the algae in the upper meter at DRI SFR3 (Fritsen et al., 2010). During the August 2009 bloom at SFR3, total nitrogen levels at the surface increased to 2.63 mg/l (July 2009 levels were 0.43 mg/l) as a result of the algal nitrogen-fixing activity.

While DRI SFR3 algae levels were high, the other locations experienced much lower peaks in 2009 that ranged from 7.1 µg/l (DRI SFR5) to 24.2 µg/l (DRI SFR2). Overall, DRI found that cyanobacteria constituted a majority of phytoplankton abundance and biovolume in 2009. In addition to *Aphanizomenon* and *Synechococcus,* DRI found dominant levels of other cyanobacteria: *Anabaenopsis, Gloeotrichia, and Microcystis.* All of these cyanobacteria can potentially produce toxins which can affect the liver, the nervous system, and/or the skin. In general, toxin production by cyanobacteria is rare. Information is lacking as to when or why these toxins are produced.

The 2010 monitoring captured peak chlorophyll-a levels ranging from 7.5 to 13.0 µg/l at the surface. While these levels are considerably lower than in 2009, they are comparable to 2009 levels found at some of the nearby DRI sites. Given the potential patchiness of algae conditions in the reservoir, the smaller number of monitoring sites in 2010 may not have captured any isolated blooms similar to that in 2009.

[2] The laboratory reporting limit for 2010 OP samples was 10 µg/l (0.01 mg/l).

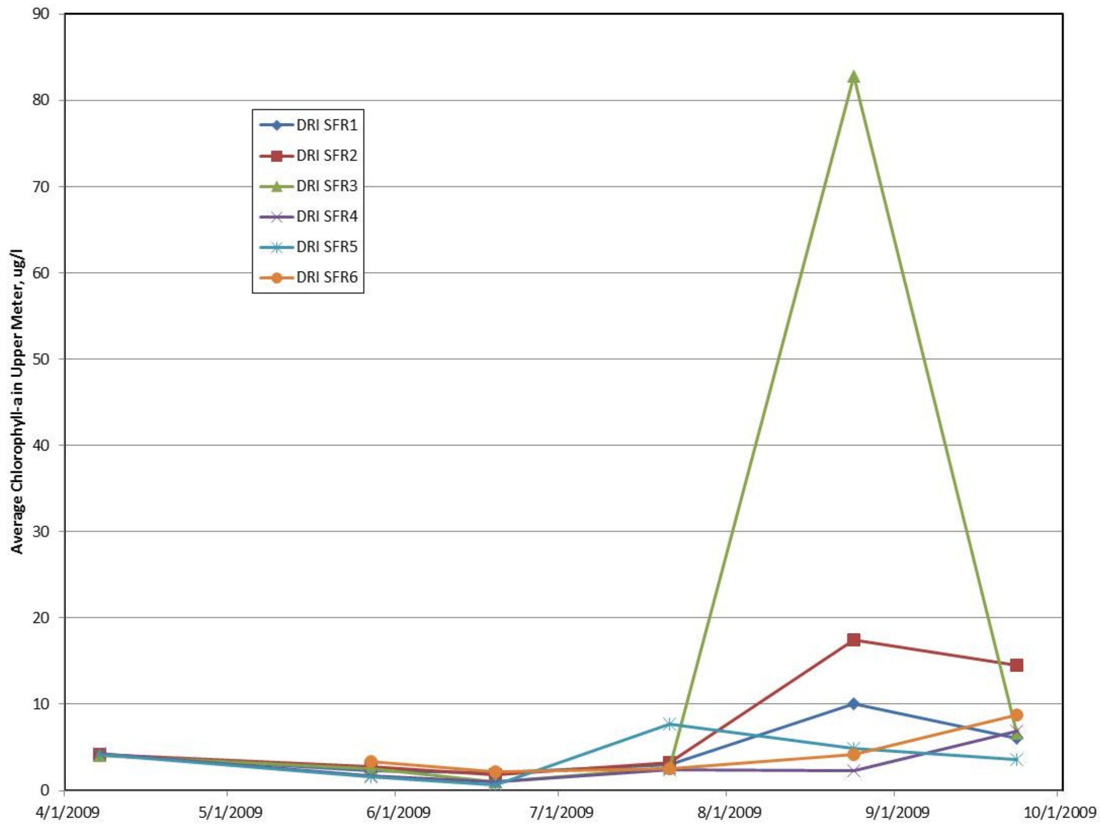


Figure 5. 2009 Average Chlorophyll-a Levels in Upper Meter

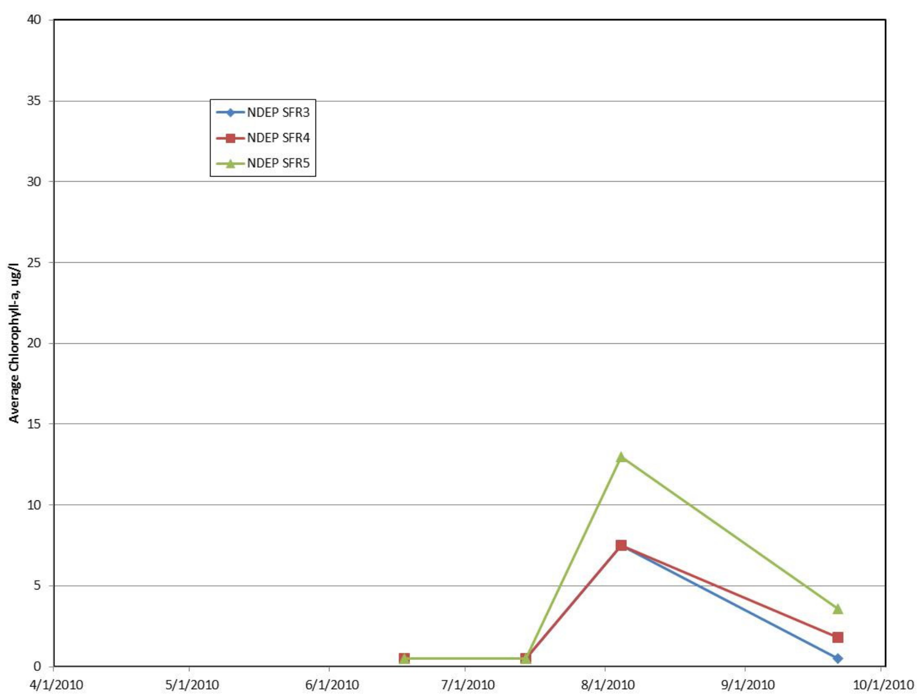
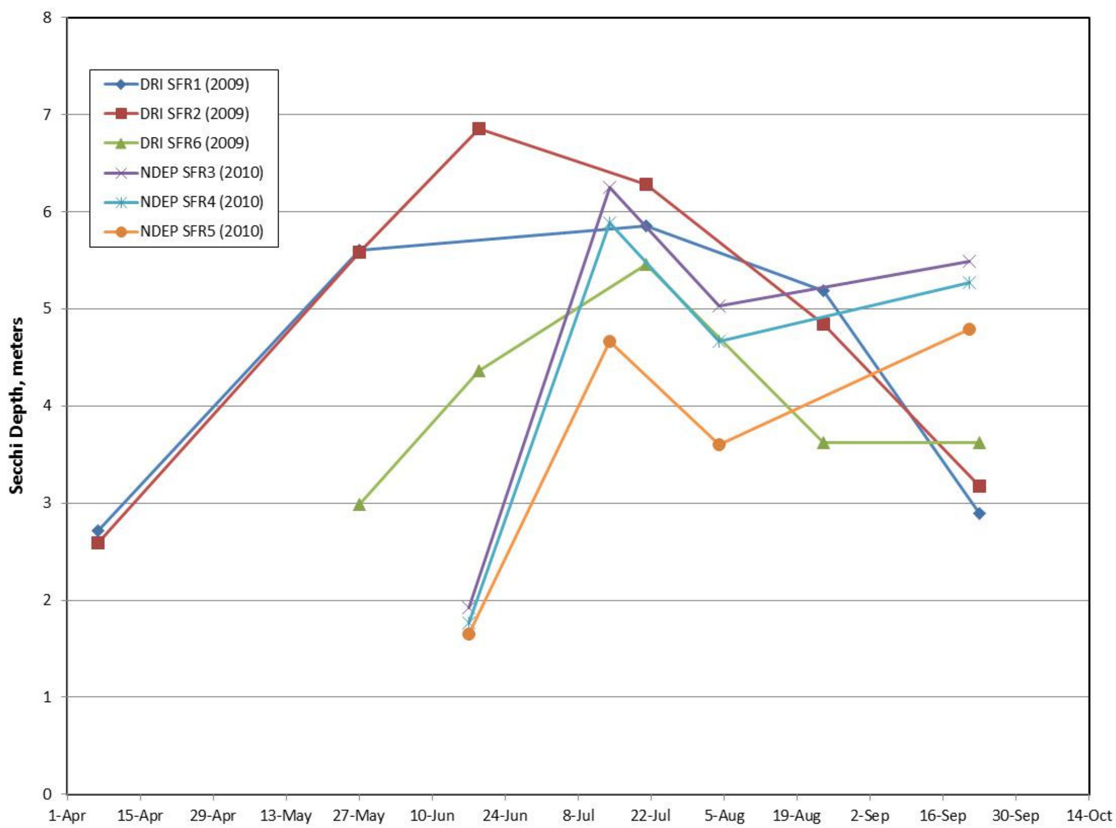


Figure 6. 2010 Average Chlorophyll-a Levels in Upper Meter

Table 4. Summary of Chlorophyll-a Levels in Upper Meter (in µg/l)

Parameter	2009							2010			
	SFR1-DRI	SFR2-DRI	SFR3-DRI	SFR4-DRI	SFR5-DRI	SFR6-DRI	Entire Lake	SFR3-NDEP	SFR4-NDEP	SFR5-NDEP	Entire Lake
Min	2.0	1.81	0.9	0.9	0.7	2.0	0.9	<0.5	<0.5	<0.5	<0.5
Max	13.6	24.2	162.7	8.3	7.1	11.0	162.7	7.5	7.5	13.0	13.0
June-September Mean	5.8	11.1	43.4	3.5	3.4	5.0	12.0	2.3	2.6	4.4	3.1

Water Clarity: Lake clarity is an important indicator of reservoir health and is often characterized in terms of Secchi depths[3]. South Fork Reservoir clarity varies depending upon location. The highest clarity levels tend to occur at sites closest to the dam (Figure 7 and Table 5) . Clarity also varies over time with the lowest Secchi readings in the spring, early summer and fall, and the highest Secchi readings in the summer. The Secchi readings in 2010 tended to fall below the 2009 levels, which may be the result of significantly higher spring inflows in 2010.



[3] A Secchi disk is a black and white disk that is lowered by hand into the water to the depth at which it vanishes from sight. The distance to vanishing is then recorded. The clearer the water, the greater the distance.

Figure 7. South Fork Reservoir Secchi Depths in 2009-10

Parameter	2009				2010			
	SFR1-DRI	SFR2-DRI	SFR6-DRI	Entire Lake	SFR3-NDEP	SFR4-NDEP	SFR5-NDEP	Entire Lake
Min	2.9	3.2	3.6	2.9	1.9	1.8	1.6	1.6
Max	5.9	6.9	5.5	6.9	6.3	5.9	4.8	6.3
Jun.-Sep. Mean	4.9	5.3	4.3	4.7	4.7	4.4	3.7	4.2

Table 5. Summary of Secchi Depths (in meters)

Review of Water Quality Standards and Proposed Changes

In the Nevada Administrative Code, water quality standards have been established for particular stream reaches, and lakes/reservoirs. The water quality standards for these reaches/waterbodies are composed of three parts: designated beneficial uses, beneficial use water quality criteria, and antidegradation water quality criteria. Following is a review of the existing reach description for the South Fork Humboldt River section from Lee to its confluence with the Humboldt River, and the associated beneficial uses, and water quality criteria.

Reach Description

Currently, the South Fork Humboldt River is divided into 2 reaches:

NAC 445A.1464: Humboldt River, South Fork and tributaries at Lee

> **Segment description:** From their origin to Lee, except for the lengths of the river and tributaries within the exterior borders of the South Fork Indian Reservation.

NAC 445A.1466: Humboldt River, South Fork at the Humboldt River

> **Segment description:** From Lee to its confluence with the Humboldt River, except for the lengths of the river and tributaries within the exterior borders of the South Fork Indian Reservation.

The section from Lee to its confluence with the Humboldt River is defined as a single reach. As a result, the reach includes both a free-flowing river section and a reservoir section (South Fork Reservoir). However since streams and reservoirs have different water quality dynamics, they typically have a different set of water quality standards. Therefore, it is proposed that the South Fork Humboldt River and South Fork Reservoir be segmented into 3 separate sections:

NAC 445A.1464: Humboldt River, South Fork at South Fork Reservoir, including tributaries above Lee

> **Segment description:** From their origin to South Fork Reservoir except for the lengths of the river and tributaries within the exterior borders of the South Fork Indian Reservation.

NAC 445A.1465: South Fork Reservoir

> **Segment description:** The entire reservoir

NAC 445A.1466: Humboldt River, South Fork at the Humboldt River

Segment description: From South Fork Reservoir to its confluence with the Humboldt River

Beneficial Uses

The current set of beneficial uses was assigned to the South Fork Humboldt River in the late 1970s and early 1980s. As with most other waters in Nevada, a suite of beneficial uses were assigned to the South Fork Humboldt River, including existing uses and potential future uses:

- Watering of livestock
- Irrigation
- Aquatic life
- Recreation involving contact with the water
- Recreation not involving contact with the water
- Municipal or domestic supply
- Industrial supply
- Propagation of wildlife

Following is a brief description of these beneficial uses. All of these uses have been found to be appropriate and should be protected. Therefore, no changes to these beneficial uses are proposed.

Watering of Livestock: While South Fork Reservoir water is not directly used for livestock watering, water released from the reservoir is applied to this use.

Irrigation: While South Fork Reservoir water is not directly used for irrigation, water released from the reservoir is applied to this use.

Aquatic Life: South Fork Reservoir is a highly productive fishery with a variety of game fish species including rainbow and brown trout, cut-bow trout, smallmouth and largemouth bass, wiper hybrid bass and channel catfish (Nevada Div. State Parks, 2007).

Recreation Involving Contact with the Water: Reservoir is frequently used for contact recreation activities, such as swimming and water skiing.

Recreation Not Involving Contact with the Water: Reservoir is frequently used for noncontact recreation activities such as boating and fishing.

Municipal or Domestic Supply: While the reservoir is not directly used as a drinking water supply, it potentially influences wells used by State Parks at the camping facilities and neighboring residences.

Industrial Supply: While not currently used for any industrial supply purposes, it is deemed appropriate to protect for the future potential for such uses.

Propagation of Wildlife: A variety of wildlife species utilize South Fork Reservoir and the subsequent releases in the South Fork Humboldt River.

Review of Beneficial Use Criteria

Water quality criteria are assigned as needed to protect the beneficial uses, including the most restrictive use. Generally, the criteria are derived from multiple sources: EPA recommendations, literature reviews, site specific studies, etc. Following are the beneficial use criteria recommendations for South Fork Reservoir.

NRS 445.253 requires that any surface waters of the state whose quality is higher than the applicable water quality must be maintained in their higher water quality. One method Nevada uses to implement these antidegradation requirements is through the establishment of RMHQs (**R**equirements to **M**aintain existing **H**igher **Q**uality). RMHQs are generally set for routine parameters where the existing water quality exceeds levels necessary to protect the beneficial uses. Currently, no RMHQs have been established for the South Fork Reservoir. NDEP is not proposing to establish any RMHQs at this time due to the lack of sufficient data.

Temperature: The beneficial use standards for temperature are directly related to the requirements of the aquatic species that exist in the waterbody. It is assumed that temperatures that are protective of the fish species in a reach will also be protective of other aquatic life forms. South Fork Reservoir supports a variety of coldwater/coolwater/warmwater fish such as rainbow and brown trout, cut-bow trout, smallmouth and largemouth bass, wiper hybrid bass and channel catfish

The current temperature standard is 20°C and was set in 1978. Unfortunately, no documentation is available which describes the rationale behind this criterion. In addition to the above criteria, a beneficial use temperature standard of $\Delta T \leq 0°C$ was established in 1978. This represents the maximum allowable increase in temperature at the boundary of an approved mixing zone, and is intended to limit degradation due to the potential discharge of heated effluent.

Temperature data collected during 2009-10 indicate that the reservoir is stratified during the summer, as shown in the sample temperature profile for NDEP SFR3 (Figure 8). The stratification then weakens by August/September and may even disappear. During 2009-10, the temperature standard (20°C) was frequently exceeded during July/August in the epilimnion, but was met during other months. As a result the higher summer temperatures, the South Fork Reservoir has been included on Nevada's 2012 303(d) list of impaired waters due to temperature exceedances.

No changes to the temperature criteria are proposed at this time. NDEP is in the process of developing updated recommendations for temperature criteria for the protection of coldwater fish. Once that process has been completed, changes may be proposed in the future.

pH: The pH of waters is a measure of the acid-base equilibrium, with low numbers being more acidic and high numbers being more basic. pH levels can affect a variety of beneficial uses. However, EPA guidance has identified aquatic life as the most sensitive to pH. Additionally, pH can impact water treatment process and distribution piping.

In 2004, the existing NAC pH standard of 6.5 – 9.0 was set for the protection freshwater fish and bottom dwelling invertebrates, as described in US EPA's "Quality Criteria for Water" (1986) – otherwise known as the Gold Book. Current EPA recommendations are still 6.5 – 9.0 for the protection of aquatic life. Therefore, no revisions are proposed for the pH criteria.

During 2009-10, no exceedances of the pH standard were observed at all sites except for DRI SFR5. DRI SFR5, located close to the mouth of the South Fork Humboldt River, experienced pH levels above 9.0 during the July and August monitoring events.

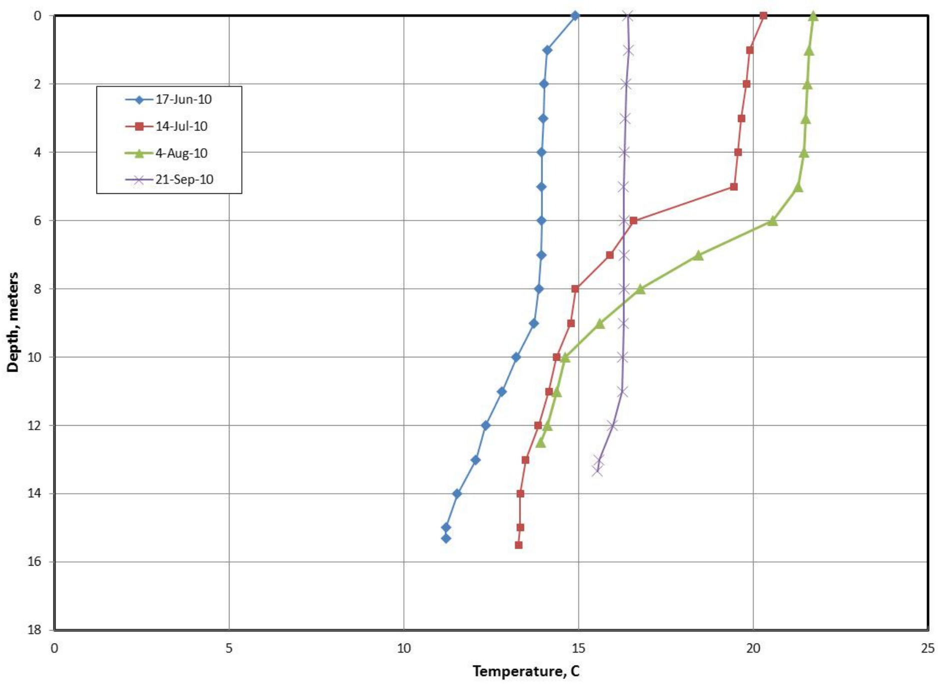


Figure 8. Temperature Profile for NDEP SFR3, 2010

Nutrients, Clarity and Algae: Nutrients, such as phosphorus and nitrogen, are essential for the health and diversity of our surface waters. However excessive levels can lead to overgrowth of algae, with an associated impact to aquatic life and recreational uses. Typical nutrient levels do not directly impair uses. It is through the responses (algae growth, depressed dissolved oxygen, reduced clarity) to the nutrient levels that the beneficial uses are generally impaired. EPA encourages the adoption of standards for both causal (both nitrogen and phosphorus) and response (chlorophyll-a and clarity) variables.

Currently, the only nutrient standard that has been set on South Fork Reservoir is a total phosphorus limit of 0.1 mg/l (Single Value). NDEP is proposing to revise this value and to add Secchi depth and algae biomass (chlorophyll-a) criteria to the regulations. The following summarizes the recommendations with more detailed discussions provided in Appendix A.

Secchi Depth: NDEP is proposing to establish a Secchi depth standard of $\geq$ 4.0 meters as a June-September average of all sites combined. This standard has been based upon literature values and other information and is designed to protect contact and noncontact recreation as the most restrictive uses in the reservoir. Historic data indicate that this proposed standard is being met.

Chlorophyll-a: NDEP is proposing to establish a chlorophyll-a standard of $\leq$10 µg/l as a June-September average of all sites combined in the upper 1 meter of the water column. This standard has been based upon literature values and other information and is designed to protect contact and noncontact recreation, and aquatic life as the most restrictive uses in the reservoir. The June-September period has been selected as this is the time of highest recreation use and highest algae levels. Historic data indicate that this proposed standard was exceeded in 2009 but was met in 2010.

Total Phosphorus and Total Nitrogen: NDEP is proposing to establish a total phosphorus standard of ≤0.04 mg/l as a June-September average of all sites combined in the upper 1 meter of the water column. The proposed standard has been designed to meet June-September average chlorophyll-a levels of 10 µg/l. As described in Appendix A, the total phosphorus standard has been developed based upon total phosphorus-algae relations provided in the literature, and as suggested by the historic data. Historic data indicate that this proposed standard was exceeded in 2009 but was met in 2010.

NDEP is proposing to establish a total nitrogen standard of ≤0.52 mg/l as a June-September average of all sites combined in the upper 1 meter of the water column. The proposed standard has been set at current total nitrogen levels which are deemed to be protective of the proposed June-September average chlorophyll-a levels of 10 µg/l. Due to concerns about the applicability of the nutrient-chlorophyll-a relationship approach during periods of N-fixation by cyanobacteria, NDEP is proposing that the reservoir TN levels be maintained at or below current levels (Appendix A). Historic data indicate that this proposed standard was exceeded in 2009 but was met in 2010.

Given that there is significant uncertainty in any relationship between TP, TN and chlorophyll-a, sole reliance on the TP and TN standard to determine the beneficial use support status of South Fork Reservoir could easily lead to false conclusions. As a response variable, chlorophyll-a levels are a more direct measure of use support/impairment than are total phosphorus and total nitrogen levels. Therefore, NDEP is recommending the incorporation of decision framework based upon TP, TN and chlorophyll-a, with an emphasis on chlorophyll-a conditions (Figure 9). Under this framework, South Fork Reservoir would be considered in attainment of the nutrient criteria if the chlorophyll-a criterion was met, regardless of total phosphorus or total nitrogen levels. If chlorophyll-a data are not available, the assessment is made solely on total phosphorus or total nitrogen levels.

Figure 9. Decision Framework for Attainment of Nutrient Criteria

	Jun-Sep Mean TP ≤ 0.04 mg/l AND Jun-Sep Mean TN ≤ 0.52 mg/l	**Jun-Sep Mean TP > 0.04 mg/l OR Jun-Sep Mean TN > 0.52 mg/l**
Jun-Sep Mean Chl-a ≤ 10 µg/l	Criteria met	Criteria met
Jun-Sep Mean Chl-a > 10 µg/l	Criteria NOT met	Criteria NOT met
Chl-a level is unknown	Criteria met	Criteria NOT met

This decision framework would be incorporated in the NAC by including the following footnote for the total phosphorus, total nitrogen and chlorophyll-a criteria:

The nutrient criteria are considered attained if:

1. *The chlorophyll-a criterion is met regardless of the level of total phosphorus or total nitrogen; or*

2. *If chlorophyll-a data are not available, both the total phosphorus and total nitrogen criteria are met*

<u>Nitrite:</u> Nitrites have the potential to be toxic to aquatic life. EPA (Gold Book, 1986) concludes that nitrite levels below 0.06 mg/l should be protective of coldwater fish. Therefore, NDEP is proposing to establish a nitrite standard of 0.06 mg/l for South Fork Reservoir. Historic data shows that 100% of the water quality samples meet this proposed standard.

Total Ammonia: The current total ammonia criteria for South Fork Reservoir were set in 2002 for the protection of aquatic life and are based upon 1999 EPA guidance. The criteria are based upon rather complicated calculations using water temperature and pH. In 2013, EPA released revised guidance which recommends calculations different from the 1999 guidance and Nevada's current regulations. NDEP will be re-evaluating the current total ammonia standards as part of a statewide activity.

Dissolved Oxygen: The amount of oxygen dissolved in a body of water serves as an indication of the health of the water and its ability to support a balanced aquatic ecosystem. Dissolved oxygen (DO) is essential for the survival of all aquatic organisms.

In 1978, Nevada adopted the current dissolved oxygen (DO) standard of $\geq$ 6.0 mg/L for many of the trout waters in Nevada, including the South Fork Little Humboldt River. During 2009-10, DO levels in the reservoir were mostly above the 6.0 mg/L criteria, except during stratification. During these times, DO levels in the hypolimnion were often less than 6.0 mg/L. (Figure 10). In 2009, Fritsen et al. reported hypolimnion DO levels less than 4 mg/l beginning in June with near anoxic conditions at the lowest depths of the reservoir. This phenomenon of low DO levels in the hypolimnion is common in lakes and reservoirs.

The current DO numeric criterion is consistent with our statewide approach and no changes are proposed. However, it is proposed that the regulations be revised so that the current DO standard of 6.0 mg/l criterion applies to the entire water column, except during times of stratification when the criterion apply only in the epilimnion. South Fork Reservoir is currently meeting the proposed DO water quality standard in over 95% of the measurements.

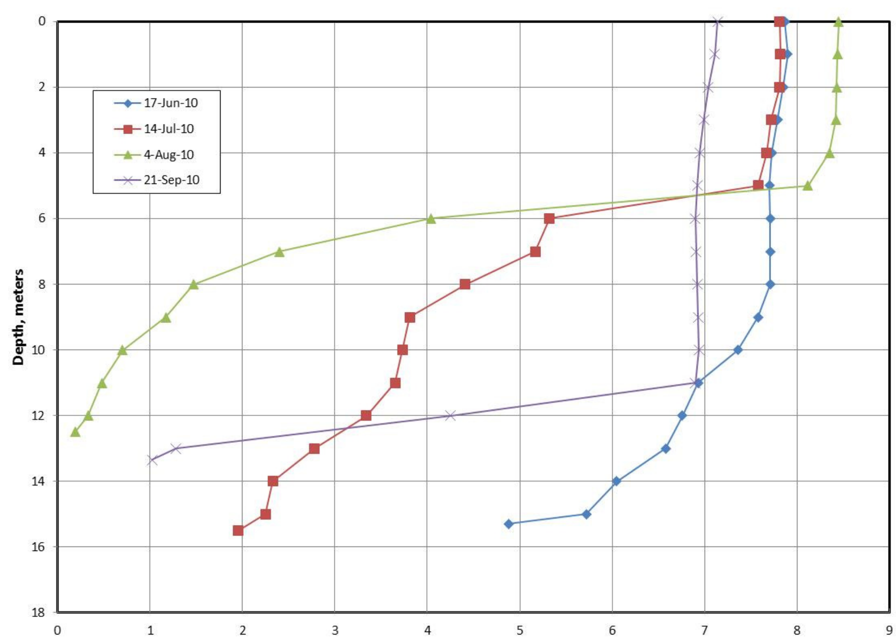


Figure 10. DO Profiles at NDEP SFR3 during 2010

Total Suspended Solids: Total Suspended Solids (TSS) are solid materials, including organic and inorganic, that are suspended in the water. Suspended solids affect aquatic life in a variety of ways. Excess TSS levels can clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. Particles that settle out can smother fish eggs and those of aquatic insects, as well as suffocate newly-hatched larvae.

Currently, there is no TSS standard for South Fork Reservoir. Other waterbodies throughout Nevada have been assigned TSS standards based upon EPA guidance (Blue Book, 1972) which recommends TSS levels of 25 mg/l for a high level of protection of aquatic communities and 80 mg/l for a moderate level of protection. A TSS standard of $\leq$25 mg/l (Single Value) is proposed for South Fork Reservoir. Historic data show that 100% of the samples have met the proposed standard (Table 6).

Table 6. Summary of TSS Conditions (in mg/L)

	NDEP SFR3 (2006-08, 2010)	**NDEP SFR4 (2010)**	**NDEP SFR5 (2010)**
No. of Samples	20	12	8
Minimum	<10	<10	<10
Maximum	<10	<10	<10
Average	<10	<10	<10

Turbidity: Turbidity is a measure of how particles suspended in water affect water clarity. Elevated turbidity can affect the productivity of a lake thereby reducing food availability for aquatic life, and can impair the ability of fish to feed. In general, coldwater fish are less tolerant of turbid conditions than are warmwater fish.

Currently, there is no turbidity standard for South Fork Reservoir. Other waterbodies throughout Nevada have been assigned turbidity standards based upon EPA guidance (Green Book, 1968). The Green Book (1968) recommends that turbidity values not exceed 10 NTU (nephlometric turbidity units) for coldwater lakes and 25 NTU for warmwater lakes. A turbidity standard of $\leq$10 NTU is proposed for South Fork Reservoir. Historic data show that only 1 sample (13 NTU at SFR5) since 2006 did not meet the proposed standard (Table 7).

Table 7. Summary of Turbidity Conditions (in Nephelometric Turbidity Units)

	NDEP SFR3 (2006-08, 2010)	**NDEP SFR4 (2010)**	**NDEP SFR5 (2010)**
No. of Samples	20	12	8
Minimum	0.75	0.9	1
Maximum	9.2	7.4	13
Average	2.8	2.6	3.8

Color: The most common cause of color in water is from the decomposition of naturally occurring organic matter. Of the beneficial uses, drinking water is considered to have the most restrictive color requirements.

Currently, color water quality standards are not in place for South Fork Reservoir. Existing EPA guidance (Gold Book, 1986) recommends a color standard of $\leq$75 PCU (platinum-cobalt color units) for the protection of municipal or domestic supplies. It is recommended that this criterion be established in the NAC for the reservoir. Historic data show that 100% of the samples have met the proposed standard (Table 8).

Table 8. Summary of Color Conditions (in Platinum-Cobalt Units)

	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2010)	NDEP SFR5 (2010)
No. of Samples	20	12	8
Minimum	5	5	10
Maximum	25	20	25
Average	13.3	12.9	18.1

Total Dissolved Solids: Total dissolved solids (TDS) consist of inorganic salts, small amounts of organic matter and dissolved materials. While the term salinity (used in oceanography) and TDS are not precisely equivalent, for most purposes the terms are generally the same. The principal inorganic anions and cations dissolved in water include carbonate, chloride, sulfate, sodium, potassium, calcium and magnesium. Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes, and higher costs for treatment systems because of corrosion or the necessity for additional treatment.

The current TDS criterion for the South Fork Reservoir is stated as follows: $\leq$500 mg/l or the 95th percentile (whichever is the less) and was set in 2008. Prior to that time, the standard read: 500 mg/l or 1/3 above that characteristic of natural conditions (whichever is less). The change was made from "natural conditions" to "95th percentile" as the first is not clearly defined making it difficult to apply.

The current standard was set in the late 1970s for the South Fork Humboldt River with the 500 mg/l value believed to have been based upon State of Nevada Drinking Water Standards that existed at the time. This value is consistent with current EPA guidance and no changes are proposed for this value. Historic data show that 100% of the samples have met the proposed standard (Table 9).

NDEP is in conversations with EPA to potentially move the "95th percentile" language from the Beneficial Use column in the regulations to the RMHQ column. The intent of the "95th percentile" language was to protect higher quality than that needed to support the beneficial uses. This action would likely be done for all the waters that have this language, not just the South Fork Reservoir.

Table 9. Summary of TDS Conditions (in mg/L)

	NDEP SFR (1996 – 2004)	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2006-08, 2010)	NDEP SFR5 (2010)
No. of Samples	46	22	12	9
Minimum	118	113	115	113
Maximum	237	159	157	140
Average	166	138	132	126

Chloride: As described above, chloride is one of the anions that make up TDS in waters. Chloride ions have been found to cause mineral tastes in drinking water at lower concentrations than other constituents. EPA recommends that chloride levels not exceed 250 mg/L for drinking water at the tap. However, EPA (1988 guidance) recommends a more restrictive chloride standard for the protection of aquatic life: one-hour average of 860 mg/l and a 96-hour average of 230 mg/ (not to be exceeded more than once in any three year period). Chloride levels in the reservoir is significantly lower than these recommendations (Table 10). NDEP proposes to incorporate these aquatic life chloride recommendations into the NAC for South Fork Reservoir. Historic data show that 100% of the samples met the proposed standard (Table 10).

Table 10. Summary of Chloride Conditions (in mg/L)

	NDEP SFR (1996 – 2004)	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2010)	NDEP SFR5 (2010)
No. of Samples	46	20	12	8
Minimum	<5	<5	<5	<5
Maximum	16	8	<5	<5
Average	7	<5	<5	<5

Sulfate: Sulfates are one of the anions that contribute to TDS concentrations. Elevated sulfate levels may have a laxative effect of drinking water users.

There are currently no sulfate standards set for the South Fork Reservoir. Based upon EPA guidance (Gold Book, 1986), NDEP proposes to set a sulfate standard of $\leq$250 mg/l for South Fork Reservoir for the protection of municipal or domestic supplies. Historic data show that 100% of the samples met the proposed standard (Table 11).

Table 11. Summary of Sulfate Conditions (in mg/L)

	NDEP SFR (1996 – 2004)	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2010)	NDEP SFR5 (2010)
No. of Samples	46	20	12	8
Minimum	6	5	5	5
Maximum	26	12	8	6
Average	11.8	7.2	6.1	5.4

Alkalinity: Alkalinity, often referred to as hardness, is the sum total of components in the water that tend to elevate the pH above a value of about 4.5. Alkalinity is important for aquatic life because it buffers pH changes, including those that occur naturally as a result of algal photosynthetic activity. Also, the main components of alkalinity will complex with some toxic heavy metals and reduce their toxicity.

There is currently no alkalinity standard for the South Fork Reservoir. It is proposed that South Fork Reservoir be assigned an alkalinity standard based upon current EPA guidance (Gold Book, 1986): alkalinity level of $\geq$20 mg/l as $CaCO_3$. Historic data show that 100% of the samples met the proposed standard (Table 12).

Table 12. Summary of Alkalinity Conditions (in mg/L)

	NDEP SFR (1996 – 2004)	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2010)	NDEP SFR5 (2010)
No. of Samples	46	20	12	8
Minimum	90	93	93	92
Maximum	152	122	100	100
Average	122	100	95	96

E. Coli: *E. coli* (*Escherichia coli)* is a bacteria that occurs in water and has been used as an indicator of fecal contamination. *E. coli* criteria are set to protect primary contact recreation, including swimming, bathing, water skiing, etc., where a high degree of body contact with the water, immersion and ingestion are likely.

In 2008, the current E. coli criteria were set for the South Fork Humboldt River as follows based upon EPA's "Ambient Water Quality Criteria for Bacteria" (1986):

Annual Geometric Mean $\leq$ 126 No./ml
Single Value $\leq$ 410 No./ml

All of the samples collected since 1996 have met these standards (Table 13).

Table 13. Summary of E. Coli Conditions (in Colony Forming Units per 100 mL)

	NDEP SFR (1996 – 2004)	NDEP SFR3 (2006-08, 2010)	NDEP SFR4 (2010)	NDEP SFR5 (2010)
No. of Samples	46	8	6	4
Minimum	<10	<10	<10	<10
Maximum	31	10	10	<10
Average	<10	<10	<10	<10

In 2012, EPA issued revised contact recreation criteria for *E. coli* that vary from the previous guidance. NDEP is in the process of working with EPA to resolve some issues associated with the revised guidance. Once these issues are resolved, NDEP anticipates reviewing all *E. coli* standards for all waters in the NAC, including South Fork Reservoir.

Fecal coliform: Fecal coliform is another bacteria that has been used as an indicator of fecal contamination of water. However since 1986, EPA has recommended E. coli as it has been found to be a better indicator for the protection of contact recreation uses. In 2012, NDEP revised the fecal coliform criterion to $\leq$1,000 No./100 ml for the protection of irrigation uses based upon EPA's Blue Book (1972). No additional changes are proposed at this time. All samples collected since 1996 have met these standards (Table 14).

Table 14. Summary of Fecal Coliform Conditions (in Colony Forming Units per 100 mL)

	NDEP SFR (1996 – 2004)	**NDEP SFR3 (2006-08, 2010)**	**NDEP SFR4 (2010)**	**NDEP SFR5 (2010)**
No. of Samples	28	8	6	4
Minimum	<10	<10	<10	<10
Maximum	10	10	<10	<10
Average	<10	<10	<10	<10

Summary of Proposed Revisions

Following is a summary of the proposed revisions for NAC 445A.1466 which covers the South Fork Humboldt River from Lee to the Humboldt River.

- The current river reach is to be segmented into 3 separate reaches:
  - NAC 445A.1464: Humboldt River, South Fork at South Fork Reservoir, including tributaries above Lee

    Segment description: From their origin to South Fork Reservoir except for the lengths of the river and tributaries within the exterior borders of the South Fork Indian Reservation.

  - NAC 445A.1465: South Fork Reservoir

    Segment description: The entire reservoir

  - NAC 445A.1466: Humboldt River, South Fork at the Humboldt River

    Segment description: From South Fork Reservoir to its confluence with the Humboldt River

- Revise Total Phosphorus criteria from "S.V. ≤ 0.10 mg/l" to "Jun.-Sep. Avg. ≤ 0.04 mg/l". Add Total Nitrogen criteria of "Jun.-Sep. Avg. ≤ 0.52 mg/l." Add chlorophyll-a standard of "Jun.-Sep. Avg. ≤ 10 µg/l". All three criteria will be based upon a June-September average for the entire reservoir measured in the upper 1 meter of the water column. Additionally, the following footnote will be included:

  The nutrient criteria are considered attained if:

  1. *The chlorophyll-a criterion is met regardless of the level of total phosphorus or total nitrogen; or*
  2. *If chlorophyll-a data are not available, both the total phosphorus and total nitrogen criteria are met.*

- Add Secchi depth criterion of "Jun-Sep Avg. ≥ 4.0 meters

- Add Nitrite criterion of "S.V. $\leq$ 0.06 mg/l"

- Revise Dissolved Oxygen criterion to include following footnote – "*When lake is stratified, the dissolved oxygen standard applies only to the epilimnion*."

- Add sulfate criterion of "S.V. $\leq$ 250 mg/l"

- Add TSS criterion of "S.V. $\leq$ 25 mg/l".

- Add turbidity criterion of "S.V. $\leq$ 10 NTU"
- Add color criterion of "S.V. $\leq$ 75 PCU"

- Add chloride criterion of "1-hour avg. $\leq$ 860 mg/l; 96-hour avg. $\leq$ 230 mg/l".

- Add alkalinity criterion of "S.V. $\geq$ 20 mg/l as $CaCO_3$".

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APPENDIX A

RECOMMENDED BENEFICIAL USE CRITERIA FOR NUTRIENTS, ALGAE AND CLARITY

Review of Beneficial Use Criteria for Nutrients, Algae and Clarity

Nutrients, such as phosphorus and nitrogen, are essential for the health and diversity of our surface waters. However excessive levels can lead to overgrowth of algae, with an associated impact to aquatic life and recreational uses. Typical nutrient levels do not directly impair uses. It is through the responses (algae growth, depressed dissolved oxygen, reduced clarity) that the beneficial uses are generally impaired.

The existing nutrient criterion for the South Fork Reservoir is the Total Phosphorus (TP) standard of 0.1 mg/l (single value). This criterion was established in 1978 for the South Fork Humboldt River and, with construction of the reservoir, became the standard for South Fork Reservoir. The basis of this value is unknown, but the current thinking is that this value may be appropriate for streams however not necessarily appropriate for lakes/reservoirs. In 1986, EPA's Gold Book suggested that entities consider a TP standard of 0.025 mg/l for lakes and reservoirs.

The development of nutrient criteria has become a significant undertaking by EPA, states and tribes. It has become well recognized that nutrients alone can be a poor predictor of eutrophic conditions in lakes or reservoirs and in a May 26, 2007 memorandum, Benjamin Grumbles, EPA Assistant Administrator, encouraged the adoption of standards for both causal (both nitrogen and phosphorus) and response (chlorophyll-a and clarity) variables. As a result, it has become common for states to set not just water chemistry standards for phosphorus and nitrogen, but states are also pairing these criteria with algae and clarity (Secchi depth) metrics.

As numeric nutrient criteria are developed by various states, EPA has defined three categories of approaches that could be used: (1) reference condition approach, (2) stressor-response analysis, and (3) process-based (mechanistic) modeling. In 2001, EPA published recommended water quality criteria for nutrients using the reference condition approach, with the intention that they serve as a **starting point.** EPA strongly encourages states and tribes to refine these recommendations using one of the three approaches listed above. The "starting point" nutrient criteria recommendations that may apply to the South Fork Reservoir region were developed for Subregion 13 within the Ecoregion III (Figure A-1). Simply stated, these criteria were calculated using the 25th percentile of the water quality parameters for waterbodies within Subregion 13 (Table A-1). It must be emphasized that these recommendations are based solely on a statistical calculation of a dataset, and are not based upon levels needed to support the beneficial uses. For this reason, NDEP has chosen to develop South Fork Reservoir standards that are driven by the beneficial use needs.

Figure A-1. Level III Ecoregions in Nevada

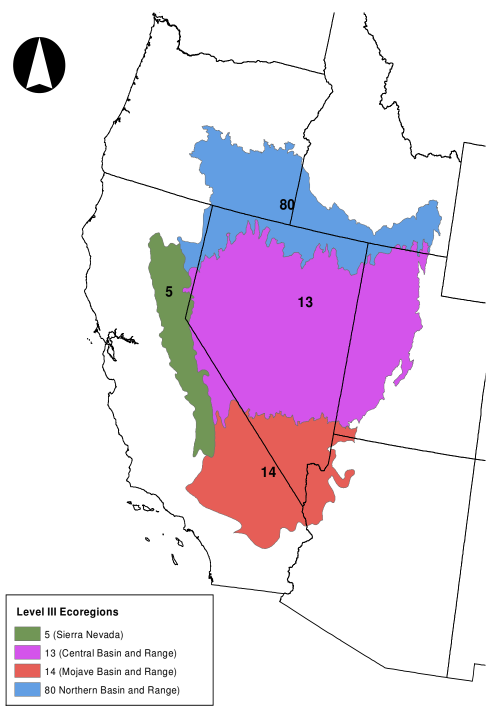


Table A-1. EPA's Recommended Nutrient Criteria for Subecoregion 13 Surrogate Reference Conditions for Level III Ecoregion Lakes and Reservoirs

Parameter	Value
TP (mg/l)	0.03
TN (mg/l	0.35 – 0.51
Chlorophyll-a (ug/l)	1.9 – 3.5
Secchi Depth (meters)	2.3

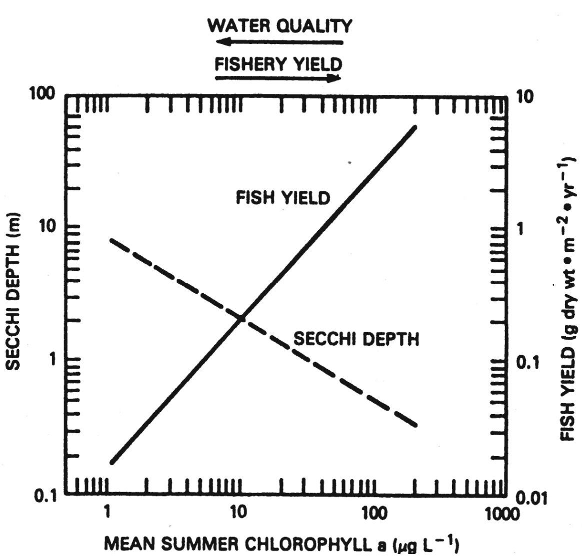
The common approach for establishing nutrient criteria for a reservoir is to first develop desired endpoints for the response variables, typically chlorophyll-a and Secchi depth, as needed to support beneficial uses. Once these criteria are identified, phosphorus and nitrogen can be derived based upon nutrient-chlorophyll-a relationships: 1) derived from data specific to the reservoir, and 2) from the literature.

Selecting Appropriate Chlorophyll-a and Secchi Depth Targets

As EPA has not recommended any particular chlorophyll-a or Secchi depth values as needed to protect beneficial uses, a thorough review of the literature and other states' regulations was undertaken to identify candidates values for South Fork Reservoir (Appendices B-E). The key beneficial uses for which chlorophyll-a and Secchi depth thresholds are usually set to protect are as follows:

- Contact and non-contact recreation
- Aquatic life
- Municipal and drinking waters

However, identification of appropriate chlorophyll-a and Secchi depth thresholds is not straight forward. One complicating factor is that the chlorophyll-a thresholds needed to support contact recreation may conflict with levels needed to support a productive fishery. A number of studies have shown that fish productivity can increase with increases in algae levels (Figure A-2), while recreational uses may be adversely impacted by these higher algae levels.



Following is a discussion of chlorophyll-a thresholds that have been identified for the protection of recreation, aquatic life and drinking water.

Figure A-2. Relationship between lake characteristics (e.g. Secchi depth, chlorophyll-a) and management objectives (e.g. water quality, fishery yield). Modified from Wagner and Oglesby (1984).

Recreation Use Considerations: Attainment of the contact and noncontact beneficial uses is largely subjective and dependent upon user familiarity with the waterbody and their expectations for the waterbody. Appendix B summarizes the key literature (Table B-1) and state standards (Table B-2) that were reviewed to identify appropriate chlorophyll-a criteria that would be protective of recreation uses.

In some instances, states have successfully relied on user perception survey results in setting nutrient and clarity water quality standards. Extensive user perception surveys have been performed in Minnesota by Heiskary and Walker (1988) and Smeltzer and Heiskary (1990). Heiskary and Walker (1988) reported that users considered swimming impaired when chlorophyll-a levels were above 15 µg/l or Secchi depths were below 1.2 meters. When evaluated on a regional basis, users in northern Minnesota users considered Secchi depths of <3.0 meters to be swimming impaired, while southern Minnesota users considered Secchi depths of <1.0 meter to be swimming impaired. Subsequent work by Smeltzer and Heiskary (1990) performed additional surveys and presented by the survey results by ecoregion, again with northern users having higher Secchi depth expectations than the southern users. Based upon these studies and other work, the State of Minnesota established chlorophyll-a and Secchi depth standards for five different waterbody classifications. Chlorophyll-a critieria range from 3-6 µg/l for trout waters to 22 µg/l for southern Minnesota waters. Secchi criteria range from 2.5-4.5 meters for trout waters to 0.9 meters for southern Minnesota waters.

Vermont users appear to have similar expectation to that of the northern Minnesotans. Smeltzer and Heiskary (1990) identified chlorophyll-a levels >6 µg/l and Secchi depths less than 3.0 meters as thresholds for use impairment perceptions in Vermont. Following that study, the State of Vermont established criteria similar to the Minnesota criteria. Chlorophyll-a criteria range from 5 µg/l for Class A1 (highest quality) waters to 16 µg/l for Class B (good to very good quality) waters. Secchi depth criteria range from 3.8 meters for Class A1 waters to 2.4 meters for Class B waters.

A number of professional papers have provided potential chlorophyll-a and Secchi depth thresholds not based upon user perception surveys like in Minnesota and Vermont, but based upon a classification system deemed appropriate by the investigators. For example, Dillon (1975) et al. used chlorophyll-a and Secchi depth thresholds of 5 µg/l and 2-5 meters, respectively, for "lakes to be used for water recreation but preservation of coldwater fishery is not imperative. For "lakes where body contact recreation is of little importance with emphasis on cool water and warm water fishery", Dillon used chlorophyll-a and Secchi depth thresholds or 10 µg/l and 1-2 meters, respectively. For Wisconsin lakes, Lillie and Mason (1983) considered "good" waters to have chlorophyll-a levels of 5-10 µg/l and Secchi depths of 2-3 meters. However in Louisiana, Burden et al. (1985) considered "excellent to good waters" to have higher chlorophyll-a levels up to 14 µg/l and lower Secchi depths of 1.2 meters.

In the western U.S., some states/tribes have established (or are under review) chlorophyll-a and Secchi depth standards. The Pyramid Lake Paiute Tribe established a chlorophyll-a standard of 5 µg/l for recreation uses. In the upper Carson River watershed in California, Indian Creek Reservoir was assigned a chlorophyll-a standard of 10 ug/l. The State of Arizona (2007) has developed criteria which have yet to be approved by EPA. Arizona has proposed chlorophyll-a (10-15 µg/l) and Secchi depth (1.5-2.5 meters) for deep (mean depth > 18 m) and shallow (mean depth < 4 m) lakes, and chlorophyll-a (20-30 µg/l) and Secchi depth (0.5-2.0 m) standards for other lakes.

Overall, the literature and other information suggest that chlorophyll-a levels of 10 to 15 µg/l and Secchi depths of 2 to 3 meters are common thresholds beyond which recreation use could be considered impaired for waters such as South Fork Reservoir. June-September mean surface chlorophyll-a levels (entire lake) in 2009 and 2010 were 11.0 µg/l and 3.1 µg/l, respectively. Assuming that these values are typical for the reservoir, summer mean chlorophyll-a levels of about 10 µg/l may be comparable to multi-year average conditions that the users have come to expect.

Lakewide June-September mean Secchi depths in 2009 and 2010 were 4.8 meters and 4.3 meters, respectively. Based upon these data, it is likely that the users have come to expect Secchi levels (>4 meters) close to those levels assigned by Minnesota and Vermont to their highest quality waters (3.8 – 4.8 meters).

Aquatic Life Use Considerations: According to NDOW, South Fork Reservoir is managed for a variety of coldwater (bowcut, brown trout and rainbow trout), and coolwater/warmwater (smallmouth and largemouth bass, and channel catfish) species. The success of these different fish is dependent upon the productivity of the water, with algae making up a part of the food chain. Appendix B summarizes the key literature (Table B-1) and state standards (Table B-2) that were reviewed to identify appropriate chlorophyll-a criteria that would be protective of aquatic life uses.

Since coldwater fish prefer clearer waters with lower chlorophyll-a than do the warmwater fish (EPA, 2000), the following discussion breaks out coldwater fisheries thresholds from coolwater/warmwater thresholds.

Coldwater Fisheries

In Lake Windmere, United Kingdom, brown trout abundance more than doubled when chlorophyll-a declined from 30 to 14 µg/l (Elliott et al., 1996). As part of a fertilization experiment in small mountain lake in British Columbia, Johnston et al. (1999) found increased rainbow trout growth while raising chlorophyll-a levels from 1 to 6 µg/l. Coldwater fisheries are believed to be supported when chlorophyll-a levels do not exceed 2 µg/l (Dillon et al., 1975) to 15 µg/l (McGhee, 1983). Dillon et al. (1975) also considered a Secchi depth of 5 meters to limit algae production and potential dissolved oxygen problems in the hypolimnion.

Several states have set chlorophyll-a and Secchi depth water quality standards for the protection of coldwater fish. Chlorophyll-a standards for coldwater lakes range from 3 µg/l (Minnesota – lake trout) to 15 µg/l (Arizona), and Secchi standards for coldwater lakes range from 1.5 meters (Arizona) to 4.8 meters (Minnesota – lake trout).

Coolwater and Warmwater Fisheries

The optimal chlorophyll-a concentrations for coolwater and warmwater fisheries is typically higher than desired for other beneficial uses such as contact and noncontact recreation, and coldwater fisheries (Malcolm Pirnie, Inc., 2005). In a study of 30 large Alabama reservoirs, Maceina et al. (1996) found that the growth of largemouth bass increased with chlorophyll-a levels up to 20 µg/l., with the potential to catch a trophy (> 5 pounds) about 3 times greater in eutrophic (chl-a >10 µg/l) lakes than mesotrophic (chl-a <10 µg/l) lakes. A similar finding made by Bachmann et al. (1996) for natural Florida lakes where largemouth bass were more abundant in lakes with chlorophyll-a levels >40 µg/l.

Several states have set chlorophyll-a and Secchi depth water quality standards for the protection of coolwater and warmwater fish. Chlorophyll-a standards for coolwater lakes range from 9 µg/l (Minnesota) to 25 µg/l (Virginia), and Secchi standards for coolwater lakes range from 0.9 meters (Minnesota) to 2.0 meters (Minnesota). For warmwater lakes, chlorophyll-a standards range from 20 µg/l (Colorado, W. Virginia) to 35 µg/l (Virginia) and Secchi standards range from 0.7 meters (Arizona) to 1.0 meters (Arizona).

The literature and other information suggest that chlorophyll-a levels of 10 to 15 µg/l and Secchi depths of 2 to 3 meters may be a good compromise between the needs of the coldwater, coolwater and warmwater fish.

Drinking Water Considerations: Excess algae in a reservoir can affect drinking water supplies by creating taste and odor problems and introducing algal toxins into the water (Malcolm Pirnie, Inc., 2005). Excessive algae levels are also linked the creation of carcinogenic trihalomethanes (THMs) during a drinking water system's disinfection process. Many of these problems can be caused by cyanobacteria (often referred to as blue-green algae) (Welch and others, 2004). Unfortunately, there is minimal literature available characterize correlations between chlorophyll-a thresholds with taste/odor or toxic problems in public water supplies. Appendix C summarizes the key literature (Table C-1) and state standards (Table C-2) that were reviewed to identify appropriate chlorophyll-a criteria that would be protective of drinking water uses.

Heath et al. (1988) found that algal-related health problems were more likely to occur when chlorophyll-a levels in a South African reservoir exceeded 30 µg/l. Raschke (1994) identified a chlorophyll-a threshold of 15 µg/l for water supply impoundments of the Piedmont region of southeastern U.S. In a study of Cheney Reservoir which supplies drinking water to Witchita, Kansas, Smith et al. (2002) recommended that chlorophyll-a levels be reduced to 10 µg/l to reduce taste and odor problems that were being caused by cyanobacteria.

Few examples of drinking water chlorophyll-a and Secchi criteria were found in our research of state regulations. Arizona has proposed chlorophyll-a criteria of 10-20 µg/l and Secchi depth criteria of 0.5 – 1.5 meters. Oklahoma has a number of lakes and reservoirs that are assigned the beneficial use of "Public and Private Water Supply (PPWS)." A subset of these waters has been provided additional protection by being identified as "Sensitive Public and Private Water Supply" waters. These are waters that are currently being used as a drinking water supply, and where additional protection from new point sources and additional loading from existing point sources is desired (OWRB, 2005). Oklahoma has adopted a chlorophyll-a criterion of 10 µg/l (long term average) for these sensitive waters. For the other PPWS waters, no chlorophyll-a criterion has been assigned.

Colorado has the most restrictive chlorophyll-a criterion (5 µg/l) of the values found in our research. However, this criterion was set for "Direct Use Water Supplies", waterbodies from which water is directly piped to a plant for treatment and subsequent distribution to customers. This criterion would not apply to reservoirs which release water into a stream for later diversion to a water treatment plant. Colorado recognizes that less restrictive chlorophyll-a criterion would be appropriate for these situation, but has yet to establish any regulatory values.

It should be noted that when Nevada assigns municipal and domestic supply as a use to a waterbody, it does not require that the must meet drinking water standards. The goal is that the water be treatable with conventional methods to meet the drinking water standards. Other states have taken a similar approach.

Overall, the literature suggests that a chlorophyll-a threshold of 5-10 µg/l may be an appropriate threshold where water is piped/pumped directly from a lake/reservoir (or from a nearby downstream location) to a water treatment plant. In the case where drinking water supplies are not directly removed from a waterbody, less restrictive criteria are appropriate. As far as South Fork Reservoir is concerned, water is not directly removed for any drinking water supply. However, reservoir water likely recharges regional groundwater systems that are used for domestic wells. Given that any reservoir water would be naturally filtered through the area geology with algal matter being removed, it is deemed unnecessary to assign a chlorophyll-a criterion for the protection of the municipal or domestic supply beneficial use. Criteria to protect recreation and aquatic life should provide adequate protection for drinking water uses.

Other Considerations: Some states have identified lake chlorophyll-a criteria that are not tied to any particular beneficial use. Maine has set chlorophyll-a criteria ranging from 5 – 10 µg/l, while Oregon has set slightly higher criteria ranging from 10 – 15 µg/l. Nevada has established antidegradation criteria for Lake Mead ranging from 40 µg/l near the mouth of Las Vegas Wash to 5 µg/l for the open waters. These criteria are set to protect water quality that is deemed higher than needed to support the beneficial uses.

Chlorophyll-a and Secchi Depth Recommendations: Table A-2 provides a summary of the chlorophyll-a and Secchi depth criteria suggested by the literature and other state regulations for the beneficial uses. For South Fork Reservoir, it is recommended that the chlorophyll-a criterion be established at 10 µg/l, as a June-September mean value calculated from surface samples from all sites. Secchi criterion is recommended to be set at 4 meters as a June-September mean from all sites.

Table A-2. Summary of Chlorophyll-a and Secch Criteria by Beneficial Use

Beneficial Use	**Chlorophyll-a (µg/l)**	**Secchi (meters)**
Contact and Noncontact Recreation	10 - 15	4
Aquatic Life	10 - 15	2 - 3
Municipal or Domestic Supply	None needed	None needed
Recommended Criteria	≤10	≥4

Research of other states' regulations show a multitude of approaches in how Secchi depth, chlorophyll-a (and associated phosphorus) standards are applied to a lake or reservoir from depth, spatial and temporal perspectives. Some states have established chlorophyll-a standards for a variety of depths, such as:

- Mean of levels in the entire water column
- Mean of levels in the epilimnion
- Mean of levels in the upper meter
- Mean in the euphotic zone

To deal with spatial considerations, states may evaluate:

- Secchi depth and chlorophyll-a levels based upon the mean of all sites for the entire lake/reservoir
- Secchi depth and chlorophyll-a levels based upon the mean for a segment of the lake/reservoir (such as a distinct bays, or zones)

States use a variety of time periods upon which mean Secchi depth and chlorophyll-a levels are calculated:

- Annual mean
- Summer mean

- July 1 – September 30 mean
- May – October mean

It is recommended that a Secchi depth standard of $\geq$4.0 meters and a chlorophyll-a standardsof $\leq$10 µg/l be applied as a June-September average over the entire reservoir area. June-September is recommended as the averaging period as this the time during which most of the recreation occurs and the highest algae levels are observed. It is recommended that the chlorophyll-a standard be applied to the upper 1 meter of the water column, as this is the zone in which most of the recreation occurs.

Phosphorus and Nitrogen Criteria

EPA encourages the adoption of standards for both causal (both nitrogen and phosphorus) and response (chlorophyll-a and clarity) variables. As described earlier, a common approach for establishing nutrient criteria for a reservoir is to first develop a desired endpoint for a response variables, such as chlorophyll-a, and then identify phosphorus and nitrogen criteria based upon nutrient-chlorophyll-a relationships. Unfortunately, insufficient data exist to develop site specific nutrient-chlorophyll-a relationships for the South Fork Reservoir. Therefore, relationships developed by others were examined for possible application to the South Fork Reservoir. Over the last 70 years, numerous empirical relationships have been developed between nutrients and chlorophyll-a (Brown et al., 2000). Typically, large datasets covering numerous lakes have been used in developing these equations.

Phosphorus Criteria

Following is a summary of the phosphorus-algal relationships examined as part of the standards review. In all equations, chl-a and TP concentrations are in µg/l.

1) Mazumber et al. (1998) – used data from a range of temperate lakes in North America and Europe. Authors identified different relationships depending upon the dominance of small-bodied zooplankton versus large-bodied zooplankton (specifically *Daphnia*, a filter-feeding zooplankton). In general, the relationships show that for given nutrient levels, less algae occurs for waters dominated by large-bodied zooplankton due to their grazing activity. Mazumber et al. (1998) classified as large-bodied zooplankton dominant if >20% of the zooplankton consisted of *Daphnia*. According to Fritsen et al. (2010), *Daphnia* (large-bodied) comprised 20 – 40% of the zooplankton population in South Fork Reservoir from April-September 2009.

   ALL DATA

   $$\text{Chl-a (summer mean)} = 0.45*(\text{summer mean TP})^{0.94}$$

   Large-bodied zooplankton dominance

   $$\text{Chl-a (summer mean)} = 0.25*(\text{summer mean TP})^{0.87}$$

   Small-bodied zooplankton dominance

   $$\text{Chl-a (summer mean)} = 0.62*(\text{summer mean TP})^{0.97}$$

2) Phillips et al. (2008) – used data for wide range of lakes (over 1,000 lakes) in Europe.

   $$\text{Chl-a (summer mean)} = 0.351 * (\text{summer mean TP}^{1.026})$$

3) Prairie et al. (1989) – used data for wide range of lakes from the literature.

$$\text{Chl-a (summer mean)} = 0.407 * (\text{summer mean TP}^{0.874})$$

Of the 5 equations evaluated, Prairie et al. provides the best prediction of the higher 2009 algae levels while Mazumber et al. – large-bodied zooplankton is the closest to the observed 2010 algae levels (Table A-3, Figure A-3). The Prairie et al. equation was selected for deriving the total phosphorus standard as it captures the highest observed chlorophyll-a response to total phosphorus.

Table A-3. Observed and Predicted June-September Average Chlorophyll-a (upper 1 meter) based upon Total Phosphorus, 2009-10

Source	2009			2010		
	Average TP (µg/l)	Observed Avg. chl-a (µg/l)	Predicted Average chl-a (µg/l)	Average TP (µg/l)	Observed Avg. chl-a (µg/l)	Predicted Avg. chl-a (µg/l)
Mazumber and Havens – all lakes	48	11.0	17.0	34	3.1	12.3
Mazumber and Havens – large-bodied zooplankton			7.3			5.4
Mazumber and Havens – small-bodied zooplankton			26.5			19.0
Phillips et al.			18.6			13.1
Prairie et al.			12.1			8.9

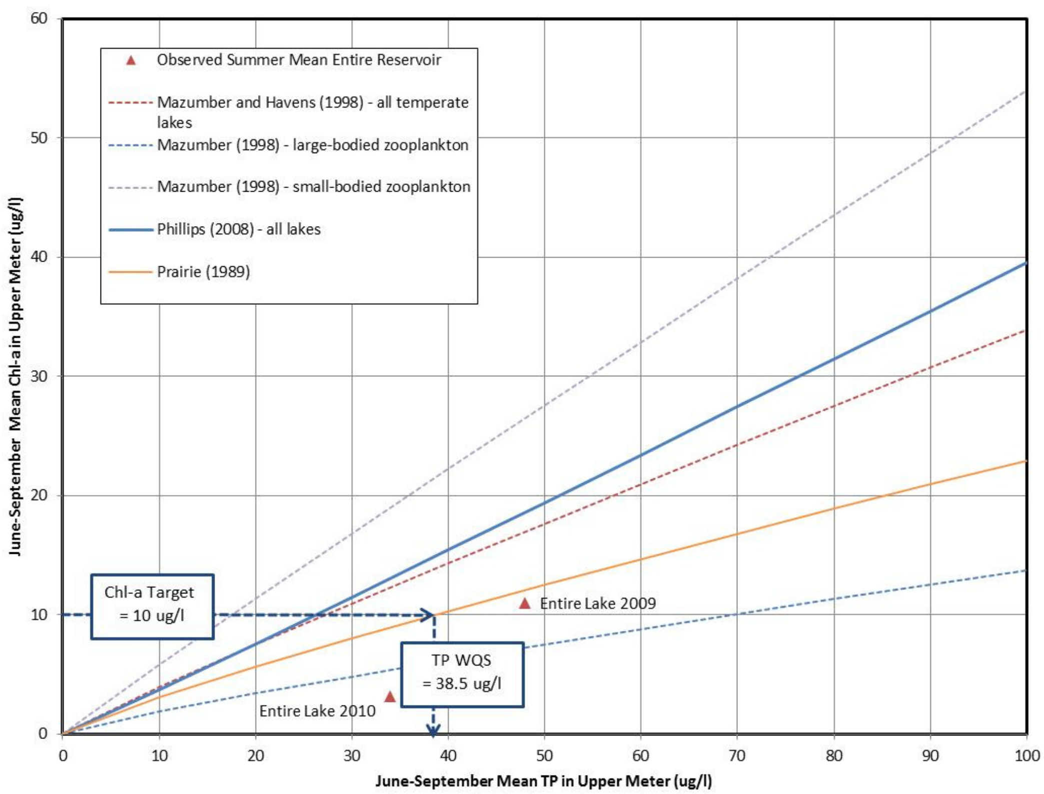


Figure A-3. Mean June-September Total Phosphorus and Chlorophyll-a Relationships

Based upon a desired chl-a level of 10 µg/l, the Prairie et al. equation yields an acceptable TP concentration of 38.5 µg/l (rounded to 0.04 mg/l). It is recommended that the total phosphorus criterion be established at $\leq$ 0.04 mg/l, as a June-September mean value calculated from upper 1 meter samples. This value is slightly higher than the 0.03 mg/l recommended by EPA (2001) as a starting point for lakes/reservoirs in Subregion 13 (Level III Ecoregion).

Nitrogen Criteria

Following is a summary of the nutrient-algal relationships examined as part of the standards review. **In all equations, chl-a and TN concentrations are in µg/l.**

1) Mazumber et al. (1998) – used data from a range of temperate lakes in North America and Europe. Authors identified different relationships depending upon the dominance of small-bodied zooplankton versus large-bodied zooplankton (specifically *Daphnia*, a filter-feeding zooplankton). In general, the relationships show that for given nutrient levels, less algae occurs for waters dominated by large-bodied zooplankton due to their grazing activity. According to Fritsen et al. (2010), *Daphnia* comprised 20 – 40% of the zooplankton population in South Fork Reservoir from April-September 2009, and therefore did not dominate the zooplankton community.

   Large-bodied zooplankton dominance

   $$\text{Chl-a (summer mean)} = 4.07\text{x}10^{-3}*(\text{summer mean TN})^{1.15}$$

   Small-bodied zooplankton dominance

   $$\text{Chl-a (summer summer)} = 4.27\text{x}10^{-4}*(\text{summer mean TN})^{1.66}$$

2) Phillips et al. (2008) – used data for wide range of lakes (over 1,000 lakes) in Europe. The chl-a:TN relationship is for lakes with N:P ratios of 10-17.

   $$\text{Chl-a (summer mean)} = 0.017 * (\text{summer mean TN}^{1.034})$$

3) Prairie et al. (1989) – used data for wide range of lakes from the literature.

   $$\text{Chl-a (summer mean)} = 7.40\text{x}10^{-4} * (\text{summer mean TN}^{1.445})$$

Of the 4 equations evaluated, Philips et al. provides the best prediction of the higher 2009 algae levels while Mazumber et al. – large-bodied zooplankton is the closest to the observed 2010 algae levels (Table A-4, Figure A-4). If the total nitrogen standard were to be based upon the highest chlorophyll-a response to total nitrogen (represented by the Philips et al. equation), then a total nitrogen criteria of 480 µg/l (0.48 mg/l) would be selected. This value is within the range of 0.35 to 0.51 mg/l recommended by EPA (2001) as a starting point for lakes/reservoirs in Subregion 13 (Level III Ecoregion).

Table A-4. Observed and Predicted June-September Average Chlorophyll-a (upper 1 meter) based upon Total Nitrogen, 2009-10

Source	2009			2010		
	Average TN (µg/l)	Observed Avg. chl-a (µg/l)	Predicted Average chl-a (µg/l)	Average TN (µg/l)	Observed Avg. chl-a (µg/l)	Predicted Avg. chl-a (µg/l)
Mazumber and Havens – large-bodied zooplankton	533	11.0	5.6	517	3.1	5.4
Mazumber and Havens – small-bodied zooplankton			14.3			13.6
Phillips et al.			11.2			10.9
Prairie et al.			6.4			6.2

It must be noted that nitrogen fixation by cyanobacteria elevated the 2009 total nitrogen levels. During the August 2009 bloom at SFR3, total nitrogen levels increased to 2.63 mg/l[4] (July 2009 levels were 0.43 mg/l) as a result of the algal nitrogen-fixing activity (Figure A-5). A purpose of the nutrient-algae relationships is to characterize the algae response to the changes in a cause (nutrients). In cases where cyanobacteria are fixing nitrogen from the atmosphere, this approach tends to fall apart. As a result of cyanobacteria blooms, nitrogen levels in the water column can increase. At this point, nitrogen concentrations in the water are no longer the cause of the algae growth, but are a response to the algae. This seems to invalidate the use of the nutrient-algae relationship in Figure A-5 for nitrogen criteria development.

An alternative approach is to calculate average total nitrogen and chlorophyll-a concentrations without the Station SFR3 data (Figure A-6). Under this approach, the Mazumber et al. – large-bodied zooplankton performs the best. Based upon this equation and a chlorophyll-a criteria of 10 µg/l, a total nitrogen criteria of 890 µg/l (0.89 mg/l) would be calculated. One problem with this approach is that it ignores any role water column nitrogen levels may have played in the cyanobacteria bloom.

The third (and preferred) approach is to establish the TN water quality standard at current TN levels, 0.52 mg/l (approximate average of 2009 and 2010 levels). It can be argued that maintenance of these TN levels is protective of the chlorophyll-a standard of 10 µg/l, excluding times of cyanobacteria blooms. A more restrictive nitrogen standard is not believed to reduce the severity of cyanobacteria blooms. In fact, lower nitrogen levels may encourage more cyanobacteria blooms. Therefore, NDEP is proposing a TN standard of 0.52 mg/l, as a June-September mean values calculated from upper 1 meter samples.

[4] While this possible increase in TN (~2 mg/l) due to nitrogen fixation may appear to be large, it is not uncommon in productive waterbodies. The best example is Upper Klamath Lake which experiences frequent blooms of *Aphanizomenon* (the same cyanobacteria that typically appears in Lahontan Reservoir). According to the Upper Klamath Lake TMDL (Oregon DEQ, 2002), algal nitrogen fixation increased TN loads by a factor of 3.5. In a dissertation by Kann (1997), TN increases of about 1.0 to 4.0 mg/l were identified for the Upper Klamath Lake. In a recent USGS study (Hoilman et al., 2008), 2006 Upper Klamath Lake data showed TN increased by about 12 mg/l during a cyanobacteria bloom with chl-a levels very high (9,000 ug/l).

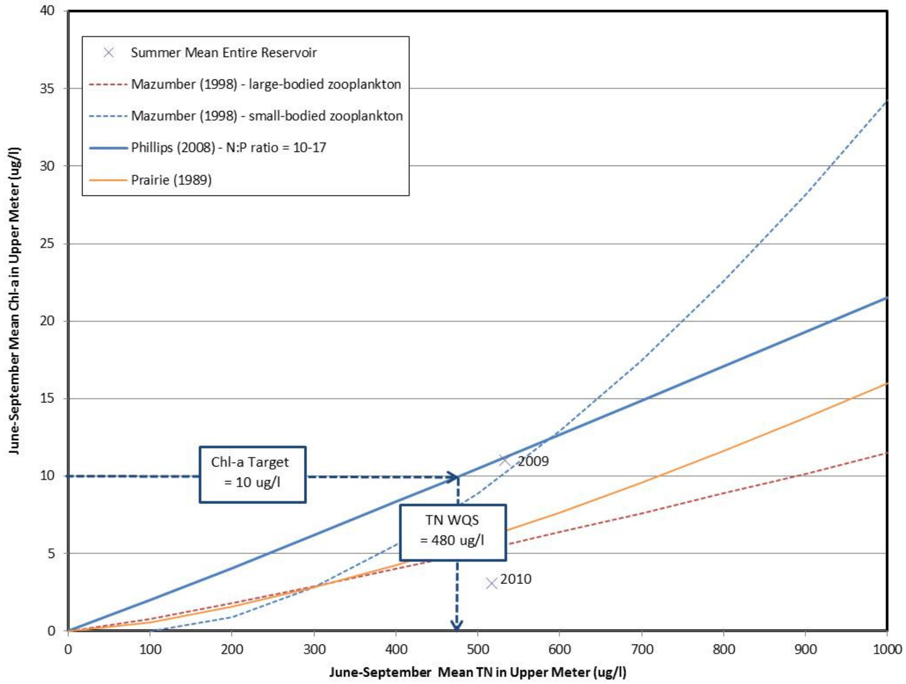


Figure A-4. Mean June-September Total Nitrogen and Chlorophyll-a Relationships

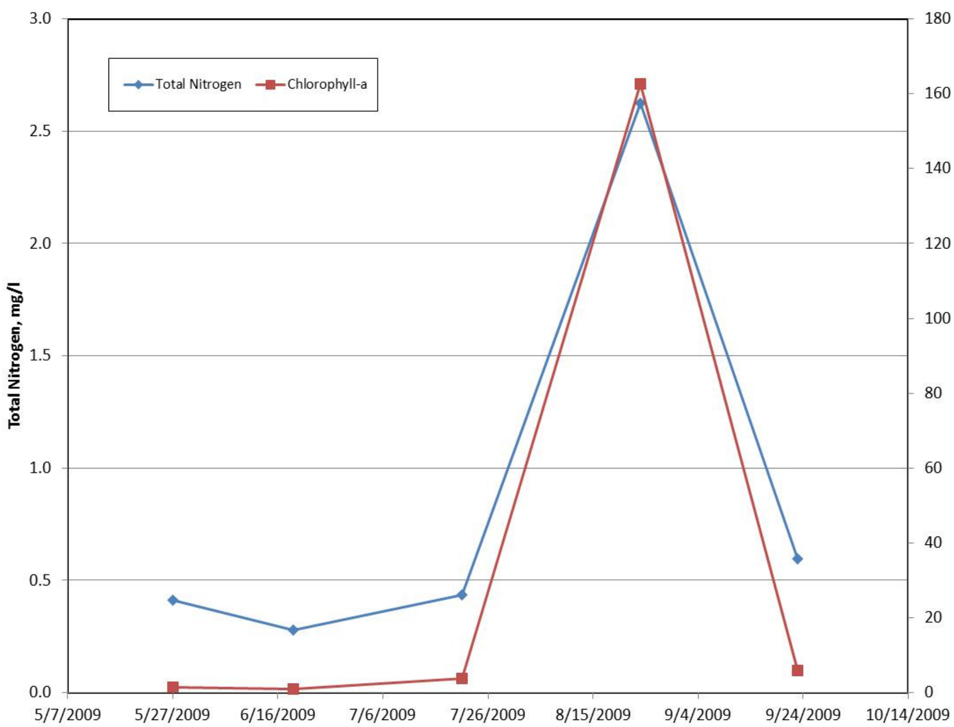


Figure A-5. Total Nitrogen and Chlorophyll-a in Upper Meter at SFR3-DRI

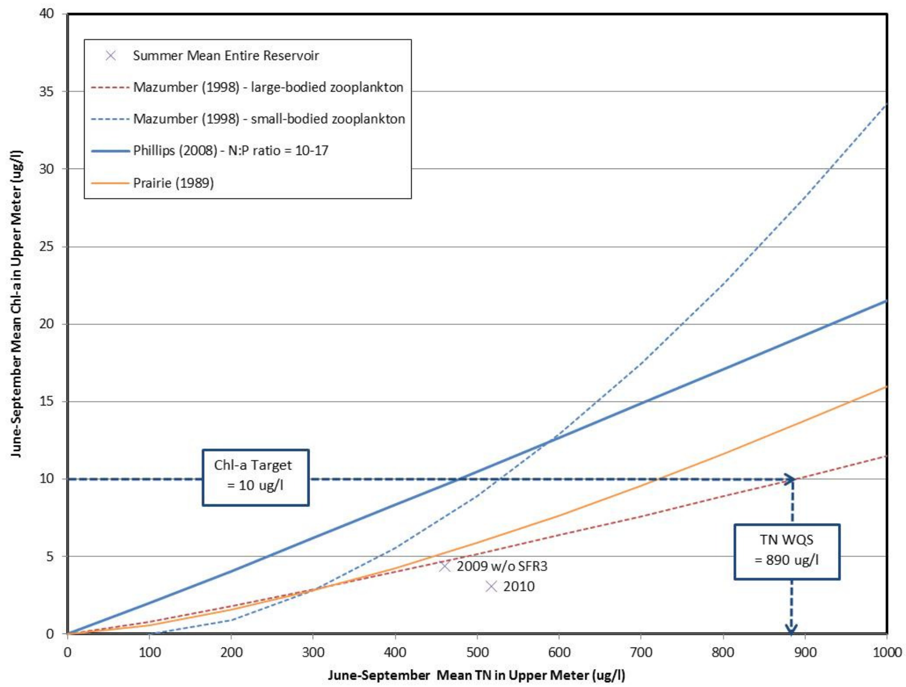


Figure A-6. Mean June-September Total Nitrogen and Chlorophyll-a Relationships without SFR3

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APPENDIX B

SUMMARY OF RECREATION THRESHOLD VALUES FOR ALGAE AND SECCHI DEPTH

Table B-1. Recreation Use Threshold Values from Literature

Source	Location	Chl-a (µg/l)	Secchi Depth (m)	Notes
Burden et al. (1985)	Louisiana	14	1.2	Excellent to good
		30	0.8	Good to acceptable
		32	0.7	Acceptable to marginal
Dillon et al. (1975)		2	5	Lake will be clear but will not support a highly productive fishery
		5	2 – 5	Lake to be used for water recreation but preservation of coldwater fishery is not imperative
		10	1 – 2	Lake where body contact recreation is of little importance with emphasis on cool water and warm water fishery
		25	< 1.5	Lake suitable only for warm water fishery
Heiskary and Walker (1988)	Minnesota Lakes	<2	2.6 – 4.8	Beautiful
		5 - 14	1.7 – 2.5	Minor aesthetic
		15 - 58	0.5 – 1.2	Swimming impaired
		39 – 71	0.5 – 0.9	No swimming
Heiskary and Walker (1995)	Lake Pepin (Minnesota)	30		Based upon user perception surveys
Lillie and Mason (1983)	Wisconsin	<1	>6	Excellent
		1 – 5	3 – 6	Very good
		5 – 10	2 – 3	Good
		10 – 15	1.5 – 2	Fair
		15 – 30	1 – 1.5	Poor
		>30	< 1	Very poor
Raschke (1994)	Piedmont impoundments in southeastern U.S.	<25 (a)		Maintain minimal aesthetic environment for viewing, safe swimming, good fishing and boating

Source	Location	Chl-a (µg/l)	Secchi Depth (m)	Notes
Smeltzer and Heiskary (1990)	Vermont	>6	3.0 – 6.0	Frequently produces perceptions of use impairment
	Minnesota – Northern Glaciated Plains and Western Corn Belt Plains		0.5 – 1.0	Use slightly impaired
	Minnesota – Central Hardwood Forests		1.0 – 3.0	Use slightly impaired
	Minnesota – Northern Lakes and Forests		2.0 – 4.2	Use slightly impaired

(a) Growing season mean

Table A-2. Recreation Use Threshold Values from State Regulations

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Arizona				
Deep Lakes – mean depth >18 m	10-15 (a)	1.5-2.5 (a)	Full Body Contact	Under EPA review
Shallow Lakes – mean depth <4 m		1.5-2.0 (a)		
Igneous Lakes	20-30 (a)	0.5-1.0 (a)		
Sedimentary Lakes		1.5-2.0 (a)		
Urban Lakes		0.5-1.0 (a)		
California				
Indian Creek Reservoir	10 (c)	2 (d)	**Recreation**, cold water fishery	Targets for TMDL
Kansas				
Eutrophication TMDLs	12		Primary contact recreation (i.e., **swimming** and domestic water supply)	
	20		Secondary contact recreation (i.e., fishing)	

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Minnesota				
Lake Trout waters in all ecoregions	3 (d)	4.8 (d)	Class 2A – Coldwater fishery, **recreation**, drinking water supply	
Other trout waters in all ecoregions	6 (d)	2.5 (d)		
N. Lakes and Forest Ecoregion	9 (d)	2.0 (d)	Class 2B - Cool and warm water fishery, **recreation**; Class 2Bd – Cool and warm water fishery, **recreation**, drinking water supply	
Central Hardwood Forest Ecoregion	14 (d)	1.4 (d)		
W. Cornbelt Plains and N. Glaciated Plains Ecoregions	22 (d)	0.9 (d)		
Nevada				
Pyramid Lake	5 (e)		Primarily aquatic and **recreation** uses	Pyramid Lake Paiute Tribe standards
Vermont				
Class A1 – waters are to be maintained in their natural condition	5 (f)	3.8 (f)	Aesthetics	Criteria primarily based upon user perception surveys
Class A2, B1 – excellent aesthetics	9 (f)	3.8 (f)	Aesthetics	
Class B, B2, B3 – good to very good aesthetics	16 (f)	2.4 (f)	Aesthetics	

(a) Growing season mean
(b) Annual mean in water column
(c) Summer mean in epilimnion
(d) Summer (July 1 – September 30) mean in water column
(e) Depth average in the upper 20 meters
(f) May-October mean in the euphotic zone

APPENDIX C

SUMMARY OF AQUATIC LIFE THRESHOLD VALUES FOR ALGAE AND SECCHI DEPTH

Table C-1. Aquatic Life Use Threshold Values from Literature

Source	Location	Chl-a (µg/l)	Secchi Depth (m)	Notes
Coldwater				
Dillon et al. (1975)		2	5	Lake will be clear and hypolimnetic oxygen levels will be adequate for coldwater fishery
		5	2 – 5	Lake to be used for water recreation but preservation of coldwater fishery is not imperative
		10	1 – 2	Lake where body contact recreation is of little importance with emphasis on cool water and warm water fishery
		25	< 1.5	Lake suitable only for warm water fishery
Elliott et al. (1996)	United Kingdom	14		Brown trout abundance much higher
Johnston et al. (1999)		6		Increased trout growth and survival
McGhee (1983)	N. Carolina	15		Trout waters
Warmwater				
Bachmann et al. (1996)	Florida	40		Largemouth bass more abundant
Maceina et al. (1996)		20		Growth of largemouth bass increased
Raschke (1994)	Piedmont impoundments in southeastern U.S.	<25 (a)		Maintain minimal aesthetic environment for viewing, safe swimming, good fishing and boating

(a) Growing season mean

Table C-2. Aquatic Life Use Threshold Values from State Regulations

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Arizona				
All Lakes	5-15 (a)	1.5-2.0 (a)	Coldwater aquatic life	Under EPA review
All Lakes (except urban)	25-40 (a)	0.8-1.0 (a)	Warmwater aquatic life	
Urban Lakes	30-50 (a)	0.7-1.0 (a)		
Effluent Dominated Waters	30-50 (a)	0.7-1.0 (a)	Effluent dominated warmwater	
California				
Indian Creek Reservoir	10 (c)	2 (d)	Recreation, cold water fishery	Targets for TMDL

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Colorado				
Lakes and reservoirs > 25 acres surface area	8 (d)		Coldwater fishery	
	20 (d)		Warmwater fishery (while being respectful of recreation uses)	
Minnesota				
Lake Trout waters in all ecoregions	3 (d)	4.8 (d)	Class 2A – **Coldwater fishery**, recreation, drinking water supply	
Other trout waters in all ecoregions	6 (d)	2.5 (d)		
N. Lakes and Forest Ecoregion	9 (d)	2.0 (d)	Class 2B - **Cool and warm water fishery**, recreation; Class 2Bd – **Cool and warm water fishery**, recreation, drinking water supply	
Central Hardwood Forest Ecoregion	14 (d)	1.4 (d)		
W. Cornbelt Plains and N. Glaciated Plains Ecoregions	22 (d)	0.9 (d)		
Nevada				
Pyramid Lake	5 (e)		Primarily **aquatic** and recreation uses	Pyramid Lake Paiute Tribe standards
Virginia				
Virginia	10 (g)		Cold water	Protect fishery recreation and aquatic life
	25 (g)		Cool water	
	35 (g)		Warm water	
W. Virginia				
W. Virginia	10 (h)		Cool water	
	20 (h)		Warm water	

(a) Growing season mean
(b) Annual mean in water column
(c) Summer mean in epilimnion
(d) Summer (July 1 – September 30) mean in water column
(e) Depth average in the upper 20 meters
(f) April-October median at one meter or less
(g) April-October 90th percentile at one meter or less
(h) Average of four or more samples collected May-October

APPENDIX D

SUMMARY OF DRINKING WATER THRESHOLD VALUES FOR ALGAE AND SECCHI DEPTH

Table D-1. Drinking Water Use Threshold Values from Literature

Source	Location	Chl-a ((µg/l)	Notes
Heath et al. (1988)	South Africa	30	Levels should be below 30 µg/l to be to efficiently treat the raw water for drinking; Algal related health problems more likely to occur at levels above 30 µg/l
Raschke (1994)	Piedmont impoundments in southeastern U.S.	<15 (a)	Water supply impoundments
Smith et al. (2002)	Cheney Reservoir, Kansas, USA	10	Recommended level to control taste and odor problems for Witchita water system customers

(a) Growing season mean

Table D-2. Drinking Water Use Threshold Values from State Regulations

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Arizona				
All Lakes	10-20 (a)	0.5-1.5 (a)	Drinking water supply	Under EPA review
Colorado				
Lakes and reservoirs > 25 acres surface area	5 (b)		Direct use drinking water	Drinking water intake located in the lake or reservoir
Oklahoma				
Lakes designated as SWS	10 (c)		Sensitive public and private water supply (SWS)	

(b) Growing season mean
(c) Summer (July 1 – September 30) mean in water column
(d) Long term average at 0.5 meters below the surface

APPENDIX E

SUMMARY OF THRESHOLD VALUES FOR ALGAE AND SECCHI DEPTH NOT ASSOCIATED WITH SPECIFIC BENEFICIAL USE

Table E-1. Other State Regulatory Values Not Specific to a Beneficial Use

State/Waterbody/Region	Chl-a (µg/l)	Secchi Depth (m)	Key Protected Uses	Notes
Maine				
All Lakes	8 (a)	2	No specific beneficial uses identified	
Impounded Class A	5 (a)	2		
Impounded Class B and C	8 (b), 10 (c)	2		
Nevada				
Lahontan Reservoir	10 (see note)			While not identified in the regulations, this value was used to derive the TP standard
Lake Mead	40 (e)		Antidegradation criteria	At 1.85 miles from mouth of Las Vegas Wash
	16 (e)			At 2.7 miles from mouth of Las Vegas Wash
	5 (e)			In open water
Oregon				
Natural lakes that thermally stratify	10 (f)		No specific beneficial uses are identified as being protected under these criteria	
Natural lakes that do not thermally stratify, reservoirs, rivers and estuaries	15 (f)			

(a) Depth integrated sample from epilimnion
(b) Spatial mean of depth integrated samples from epilimnion
(c) Maximum of all depth integrated samples from epilimnion
(d) No spatial or temporal averaging mentioned in regulations
(e) Growing season average
(f) Mean of a minimum of three samples collected over any three consecutive months at a minimum of one representative location (e.g., above the deepest point of a lake or reservoir) from samples integrated from the surface to a depth equal to twice the secchi depth or the bottom (the lesser of the two depths)