Addendum to the Total Maximum Daily Load Evaluation of pH for Reservoirs in the Black Hills Plateau Ecoregion of Custer and Pennington Counties, South Dakota

Introduction

This addendum addresses an addition to the Total Maximum Daily Load Evaluation of pH for Reservoirs in the Black Hills Plateau Ecoregion of Custer and Pennington Counties, South Dakota. Completed in November 2010, it is referred to as the "Ecoregion based TMDL" throughout this document. The addition consists of linking the pH impairment in Sylvan Lake to an existing nutrient TMDL developed for Sylvan Lake. The nutrient TMDL (Phase 1 Watershed Assessment Final Report and TMDL Sylvan Lake Watershed Custer County, South Dakota completed in November 2005) will be referenced as "Sylvan Lake TMDL" throughout this document. This document does not modify any aspect of the original TMDLs, which may be accessed on South Dakota DENR's TMDL web page: http://denr.sd.gov/dfta/wp/tmdlpage.aspx.

Sylvan Lake (AUID=SD-CH-L-SYLVAN_01) is located in Custer County, South Dakota. It was initially included in the 1998 South Dakota 303(d) list as impaired due to excessive chlorophyll *a* concentrations. The Sylvan Lake TMDL addressing the necessary nutrient reductions was approved by EPA in 2005. This addendum addresses pH impairments found during data analysis in 2016. It serves as the linkage between the reductions in the Sylvan Lake TMDL and the Ecoregion based TMDL approved by EPA for the Black Hills in 2010. The Ecoregion based TMDL was developed to address pH impairments in reservoirs found in Ecoregion 17b of the Black Hills. It found the correlation between chlorophyll *a* and pH impairments and indicated that a reduction in nutrient loadings would result in lower pH levels.

The majority of the information contained within this addendum is reprinted from the previously mentioned documents. The exceptions to this include the water quality standards and the TMDL expression. Since the Sylvan Lake TMDL was published, the water quality standards for permanent coldwater fisheries have been modified. Specifically, the range of acceptable pH values was adjusted from the previous standard of **6.6-8.6** su to the current standard of **6.5-9.0** su. The expression of the TMDL in the Sylvan Lake TMDL was in the form of an annual load. Since its publishing, requirements for expressing a TMDL have changed and now must include that it be expressed as a daily load. In the case of Sylvan Lake, the long term or annual loading is more important to the attainment of the TMDL. However, to comply with the daily expression requirement, the annual load has been converted to a daily load through the use of EPA's Technical Support Document (TSD) method.

Common Name	Sylvan Lake
County	Custer County
Waterbody Type:	Lake (Impoundment)
AUID	SD-CH-L-SYLVAN_01
Size of Impaired Waterbody:	18 acres
Size of Watershed:	565 acres
Water Quality Standards:	Narrative and Numeric
Analytical Approach:	Models including BATHTUB and FLUX
Location:	HUC Code: 10120109
Goal:	75% reduction of phosphorus load
Target:	Phsophorus TSI = 45 or concentration = 0.02 mg/L
Long Term Average Load	4.9 Kg/year Total Phosphorus
Total Maximum Daily Load:	0.026 Kg/day Total Phosphorus

Watershed Description

Sylvan Lake is an 18-acre impoundment located in the Spring Creek Basin in northern Custer County, South Dakota (Figure 1). The lake reaches a maximum depth of 34 feet (10.5 m) and holds a total water volume of 214 acre-ft (at spillway elevation). Two unnamed inlets are located on the south and east sides of the lake. Portions of the lake exhibit thermal stratification during spring and summer months. The 2004 South Dakota 303(d) Waterbody List identified Sylvan Lake for TMDL development due to elevated trophic state index (TSI) values. Information supporting this listing was derived from statewide lake assessment data.

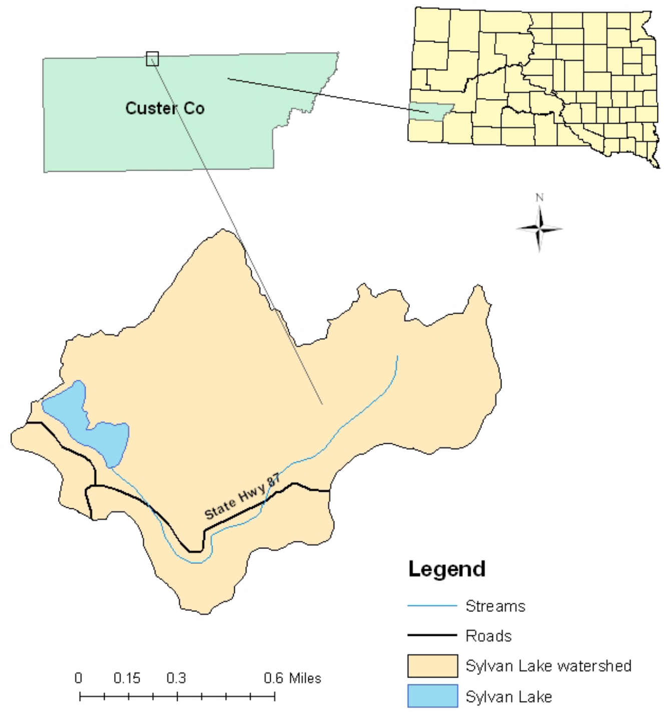

Figure 1. Location of the Sylvan Lake Watershed and Sylvan Lake, Custer County, South Dakota

Wetzel (2001) defines 'trophy' of a lake as "the rate at which organic matter is supplied by or to a lake per unit time." Trophic state is often measured as the amount of algal production in a lake, one source of organic material. Determinations of trophic state can be made from several different measures including oxygen levels, species composition of lake biota, concentrations of nutrients, and various measures of biomass or production. An index incorporating several of these parameters is best suited to determine trophic state.

Carlson's (1977) Trophic State Index (TSI) was used to determine the approximate trophic state of Sylvan Lake. This index incorporates measures of Secchi disk transparency, chlorophyll a, and total phosphorus into scores ranging from 0 to 100 with each 10-unit increase representing a doubling in algal biomass. TSI values were calculated for each of the index parameters individually (i.e. Secchi TSI, chlorophyll a TSI and TP TSI) and also combined into overall mean TSI value. In the 2005 Sylvan Lake TMDL, both the index value and phosphorus concentrations were used as TMDL targets and are considered numeric representations of the State's narrative biological integrity and nuisance aquatic life standards (ARSD 74:51:01:09 and 12).

The unnamed streams to Sylvan Lake Dam drain a watershed of 565 acres that predominantly consists of evergreen forest and state park camping areas. The streams carry sediment and nutrient loads, which degrade water quality in the lake and have caused increased eutrophication. An estimated 12.4 kg/year of phosphorus enter Sylvan Lake from watershed runoff.

The source of nonpoint source pollution loading from the Sylvan Lake watershed is likely a combination of recreational uses, forest management, as well as background sources (i.e. wildlife, natural weathering, etc.). However, degraded water quality in Sylvan Lake is primarily attributed to recreational activity within the watershed. According to (Wierenga & Payne, 1987), 5% of the total watershed area has been converted to commercial or developed recreational use. Approximately 90% of the watershed land area is managed by the SD Department of Game, Fish and Parks (Custer State Park), while the remaining 10% is managed by the US Forest Service. Although much of the watershed remains in its natural state, the intense usage of recreational facilities within Custer State Park has degraded the watershed condition. Sylvan Lake also experiences considerable internal phosphorus loading from lake-bottom sediment. An estimated 7.3 kg/yr of total phosphorus is delivered from the lake sediment.

Beneficial Uses and Water Quality Standards

South Dakota water quality standards establish 11 beneficial uses which are assigned to individual waters based on their characteristics. All waters (both lakes and streams) are assigned the beneficial use of fish and wildlife propagation, recreation, and stock watering (Use #9). All streams are assigned the beneficial use of irrigation (Use #10). Additional uses are assigned by the state based on a beneficial use analysis of each water body. Each beneficial use has a set of water quality standards to protect those uses. The Administrative Rules of South Dakota (ARSD) contain the water quality standards in Chapter 74:51. In instances where two beneficial uses have different requirements for a common standard, the more restrictive standard is applicable. Sylvan Lake has been assigned the beneficial uses of:

- Coldwater Permanent Fish Life Propagation (pH standard 6.5-9.0)
- Immersion Recreation (no pH standard)
- Limited Contact Recreation (no pH standard)
- Fish and Wildlife propagation, recreation, and stock watering (pH standard 6.0-9.5)

The pH standard for the coldwater permanent fish life propagation standard is the more restrictive and therefore the most applicable. It should be noted, that the coldwater fishery standard for pH has changed since the Sylvan Lake TMDL was written. The standard currently in use is the same as the standard which formed the basis for the Ecoregion based TMDL.

In addition to the numeric criteria established for pH, South Dakota has narrative criteria addressing acids and alkalis. South Dakota Administrative Rule 74:51:01:07 states “No materials may be discharged or caused to be discharged which affect the pH of the receiving waters by more than 0.5 pH unit. This does not apply to pH fluctuations of more than 0.5 pH unit contributable to natural influences.” Attainment of the more stringent numeric criteria will also result in the narrative criteria being attained.

Technical Analysis

pH Assessment Results

Data collected as a part of routine lake assessments during 2010 and 2015 indicated portions of the Sylvan Lake water column had elevated pH levels. Listed in Table 1, 27 of the 110 (25%) measurements were found to be above 9.0 su. Because greater than 10% of the pH measurements exceeded South Dakotas Integrated Report assessment methodology, a pH TMDL is required for Sylvan Lake. Elevated pH values were found near the surface of the water column (less than 2.5 meters of depth). Impairments were also tied to data collected later in the recreation season (July-August) while samples collected during June were found to fully support the standard.

Table 1. pH Data for Sylvan Lake

Date	StationID	Depth (m)	R_Depth	pH	Date	StationID	Depth (m)	R_Depth	pH
06/16/2010	SWLAZZZ2111A	0.4	Surface	7.56	06/23/2015	SWLAZZZ2111A	0.4	SURFACE	8.23
06/16/2010	SWLAZZZ2111A	1.1	Midwater	7.55	06/23/2015	SWLAZZZ2111A	1.5	MIDWATER	8.28
06/16/2010	SWLAZZZ2111A	2.1	Midwater	7.35	06/23/2015	SWLAZZZ2111A	2.4	MIDWATER	8.1
06/16/2010	SWLAZZZ2111A	2.5	Midwater	7.26	06/23/2015	SWLAZZZ2111A	3.5	MIDWATER	7.83
06/16/2010	SWLAZZZ2111A	3.2	Midwater	6.96	06/23/2015	SWLAZZZ2111A	3.5	MIDWATER	7.77
06/16/2010	SWLAZZZ2111A	3.6	Midwater	6.8	06/23/2015	SWLAZZZ2111A	4.3	MIDWATER	7.55
06/16/2010	SWLAZZZ2111A	4.1	Midwater	6.73	06/23/2015	SWLAZZZ2111A	5.4	MIDWATER	7.25
06/16/2010	SWLAZZZ2111A	5.0	Midwater	6.72	06/23/2015	SWLAZZZ2111A	6.4	MIDWATER	7.1
06/16/2010	SWLAZZZ2111A	6.0	Midwater	6.77	06/23/2015	SWLAZZZ2111A	7.4	MIDWATER	7.01
06/16/2010	SWLAZZZ2111A	7.0	Midwater	6.86	06/23/2015	SWLAZZZ2111A	7.7	BOTTOM	6.99
06/16/2010	SWLAZZZ2111A	7.2	Bottom	6.91	06/23/2015	SWLAZZZ2111B	0.3	SURFACE	8.2
06/16/2010	SWLAZZZ2111B	0.3	Surface	7.56	06/23/2015	SWLAZZZ2111B	1.3	MIDWATER	8.18
06/16/2010	SWLAZZZ2111B	1.1	Midwater	7.57	06/23/2015	SWLAZZZ2111B	2.4	MIDWATER	8.09
06/16/2010	SWLAZZZ2111B	1.6	Midwater	7.57	06/23/2015	SWLAZZZ2111B	3.3	MIDWATER	7.72
06/16/2010	SWLAZZZ2111B	2.0	Midwater	7.55	06/23/2015	SWLAZZZ2111B	4.3	MIDWATER	7.41
06/16/2010	SWLAZZZ2111B	2.6	Midwater	7.46	06/23/2015	SWLAZZZ2111B	5.0	BOTTOM	7.28
06/16/2010	SWLAZZZ2111B	3.0	Midwater	7.03	06/23/2015	SWLAZZZ2111C	0.4	SURFACE	8.31
06/16/2010	SWLAZZZ2111B	3.5	Midwater	6.81	06/23/2015	SWLAZZZ2111C	1.3	MIDWATER	8.21
06/16/2010	SWLAZZZ2111B	4.0	Midwater	6.78	06/23/2015	SWLAZZZ2111C	2.4	MIDWATER	8.02
06/16/2010	SWLAZZZ2111B	4.4	Bottom	6.77	06/23/2015	SWLAZZZ2111C	2.7	BOTTOM	7.73
06/16/2010	SWLAZZZ2111C	0.2	Surface	7.58					
06/16/2010	SWLAZZZ2111C	1.1	Midwater	7.56					
06/16/2010	SWLAZZZ2111C	1.5	Midwater	7.53					
06/16/2010	SWLAZZZ2111C	2.1	Bottom	7.55					
07/26/2010	SWLAZZZ2111A	0.5	Surface	9.1	08/04/2015	SWLAZZZ2111A	0.3	SURFACE	9.03
07/26/2010	SWLAZZZ2111A	0.5	Midwater	9.13	08/04/2015	SWLAZZZ2111A	0.9	MIDWATER	9.05
07/26/2010	SWLAZZZ2111A	1.0	Midwater	9.15	08/04/2015	SWLAZZZ2111A	1.4	MIDWATER	9.04
07/26/2010	SWLAZZZ2111A	1.5	Midwater	9.05	08/04/2015	SWLAZZZ2111A	2.1	MIDWATER	9.02
07/26/2010	SWLAZZZ2111A	2.1	Midwater	8.75	08/04/2015	SWLAZZZ2111A	2.5	MIDWATER	8.85
07/26/2010	SWLAZZZ2111A	2.5	Midwater	8.02	08/04/2015	SWLAZZZ2111A	3.0	MIDWATER	8.78
07/26/2010	SWLAZZZ2111A	3.0	Midwater	7.81	08/04/2015	SWLAZZZ2111A	3.5	MIDWATER	8.38
07/26/2010	SWLAZZZ2111A	3.5	Midwater	7.57	08/04/2015	SWLAZZZ2111A	4.0	MIDWATER	8.08
07/26/2010	SWLAZZZ2111A	4.1	Midwater	7.32	08/04/2015	SWLAZZZ2111A	4.5	MIDWATER	7.9
07/26/2010	SWLAZZZ2111A	4.6	Midwater	7.2	08/04/2015	SWLAZZZ2111A	5.1	MIDWATER	7.7
07/26/2010	SWLAZZZ2111A	5.1	Midwater	7.14	08/04/2015	SWLAZZZ2111A	5.5	MIDWATER	7.53
07/26/2010	SWLAZZZ2111A	5.5	Midwater	7.08	08/04/2015	SWLAZZZ2111A	6.1	MIDWATER	7.43
07/26/2010	SWLAZZZ2111A	6.0	Midwater	6.98	08/04/2015	SWLAZZZ2111A	6.5	MIDWATER	7.36
07/26/2010	SWLAZZZ2111A	6.6	Midwater	6.93	08/04/2015	SWLAZZZ2111A	7.1	MIDWATER	7.31
07/26/2010	SWLAZZZ2111A	7.0	Midwater	6.94	08/04/2015	SWLAZZZ2111A	7.6	MIDWATER	7.28
07/26/2010	SWLAZZZ2111A	7.0	Bottom	6.93	08/04/2015	SWLAZZZ2111A	8.0	BOTTOM	7.28
07/26/2010	SWLAZZZ2111B	0.5	Surface	9.06	08/04/2015	SWLAZZZ2111B	0.3	SURFACE	9.11
07/26/2010	SWLAZZZ2111B	1.0	Midwater	9.17	08/04/2015	SWLAZZZ2111B	0.9	MIDWATER	9.1
07/26/2010	SWLAZZZ2111B	1.6	Midwater	9.15	08/04/2015	SWLAZZZ2111B	1.4	MIDWATER	9.08
07/26/2010	SWLAZZZ2111B	2.1	Midwater	9.15	08/04/2015	SWLAZZZ2111B	1.9	MIDWATER	9.04
07/26/2010	SWLAZZZ2111B	2.5	Midwater	9.08	08/04/2015	SWLAZZZ2111B	2.4	MIDWATER	8.81
07/26/2010	SWLAZZZ2111B	2.6	Midwater	9.04	08/04/2015	SWLAZZZ2111B	3.0	MIDWATER	8.5
07/26/2010	SWLAZZZ2111B	2.7	Midwater	8.86	08/04/2015	SWLAZZZ2111B	3.5	MIDWATER	8.23
07/26/2010	SWLAZZZ2111B	3.1	Midwater	8.15	08/04/2015	SWLAZZZ2111B	4.1	MIDWATER	8.01
07/26/2010	SWLAZZZ2111B	3.5	Midwater	7.79	08/04/2015	SWLAZZZ2111B	4.5	MIDWATER	7.84
07/26/2010	SWLAZZZ2111B	4.0	Midwater	7.6	08/04/2015	SWLAZZZ2111B	5.0	MIDWATER	7.72
07/26/2010	SWLAZZZ2111B	4.5	Midwater	7.28	08/04/2015	SWLAZZZ2111B	5.9	BOTTOM	7.63
07/26/2010	SWLAZZZ2111B	5.2	Bottom	7.21	08/04/2015	SWLAZZZ2111C	0.3	SURFACE	9.11
07/26/2010	SWLAZZZ2111C	0.5	Surface	9.18	08/04/2015	SWLAZZZ2111C	1.3	MIDWATER	9.15
07/26/2010	SWLAZZZ2111C	1.1	Midwater	9.19	08/04/2015	SWLAZZZ2111C	2.0	MIDWATER	8.8
07/26/2010	SWLAZZZ2111C	1.6	Midwater	9.2	08/04/2015	SWLAZZZ2111C	2.7	BOTTOM	8.54
07/26/2010	SWLAZZZ2111C	2.1	Midwater	9.2					
07/26/2010	SWLAZZZ2111C	2.5	Midwater	9.17					
07/26/2010	SWLAZZZ2111C	2.5	Midwater	9.17					
07/26/2010	SWLAZZZ2111C	2.5	Bottom	9.16					

The primary focus of this report's analysis is a summary review of relevant sections found in the original TMDLs. Comprised of 90% state and 10% federal, land ownership in the watershed remained the same since the initial assessment. The watershed does not have any point sources of pollution. The primary remediation activity intended to address nutrient impairments in the lake is limited to the installation of a water circulating device in November of 2000. At this time, data is insufficient to determine the impacts this device may have had on the lake. Based on this information, it is expected that the assumptions made in the original Sylvan Lake TMDL during 2005 continue to hold true.

Linking Nutrients to pH

Phosphorus and nitrogen are nutrients that are essential to plant growth. While not directly linked to elevated pH concentrations, increased concentrations of either nutrient can result in excessive macrophyte and algae growth in the waterbody. Increased respiration from excessive macrophyte and algae growth results in processes that elevate the pH.

The ratio of nitrogen to phosphorus (N:P) considered optimal for plant growth is commonly accepted to be approximately 10:1. The ecoregion 17b reservoirs had an average N:P ratio of 17:1, suggesting that the limiting nutrient is phosphorus. Reducing the phosphorus entering the reservoirs is expected to result in a reduction of aquatic biomass.

Chlorophyll *a* is an indicator of primary production. Unlike many prairie lakes in South Dakota, reservoirs in the Black Hills tend to be phosphorus limited systems. The limiting nutrients section of Sylvan Lake TMDL found this to be true for Sylvan Lake with almost 90% of the samples collected indicating phosphorus limitation. As such, the most effective method for controlling primary production (chlorophyll *a* concentrations) is by reducing the available phosphorus load.

Section 4.0 pages 19-27 of the Ecoregion based TMDL address in greater depth the linkage between nutrients, chlorophyll *a*, and elevated pH concentrations. To summarize this linkage, the analysis found that there was a correlation between increasing chlorophyll *a* concentrations and rising pH levels for lakes in ecoregion 17b. Due to variability in the data, a range of concentrations were developed that were likely to meet the standard. That range suggests if chlorophyll *a* levels were kept at or below 9-12.5 ppb, pH levels should remain below the water quality standard of 9.0 su in at least 90% of the samples (i.e. factoring in the criterion's maximum 10% allowable exceedance rate).

Phosphorus

Sylvan Lake's chemistry is discussed in greater detail from pages 34-54 of the Sylvan Lake TMDL. The only new phosphorus data collected since the 2005 TMDL was written, includes 2 samples from 2015 (Figure 2). Although lower than many of the historic data points, they remained above the target in lake concentration of 0.02 mg/L total phosphorus identified in the 2005 Sylvan Lake TMDL. Considering variability observed in previous sampling seasons, little weight should be given to these two data points at this time. Phosphorus levels do appear to be lower in the 2000's than the 1980's. This may be due in part to the installation of a circulator which is discussed on pages 60-62 of the Sylvan Lake TMDL.

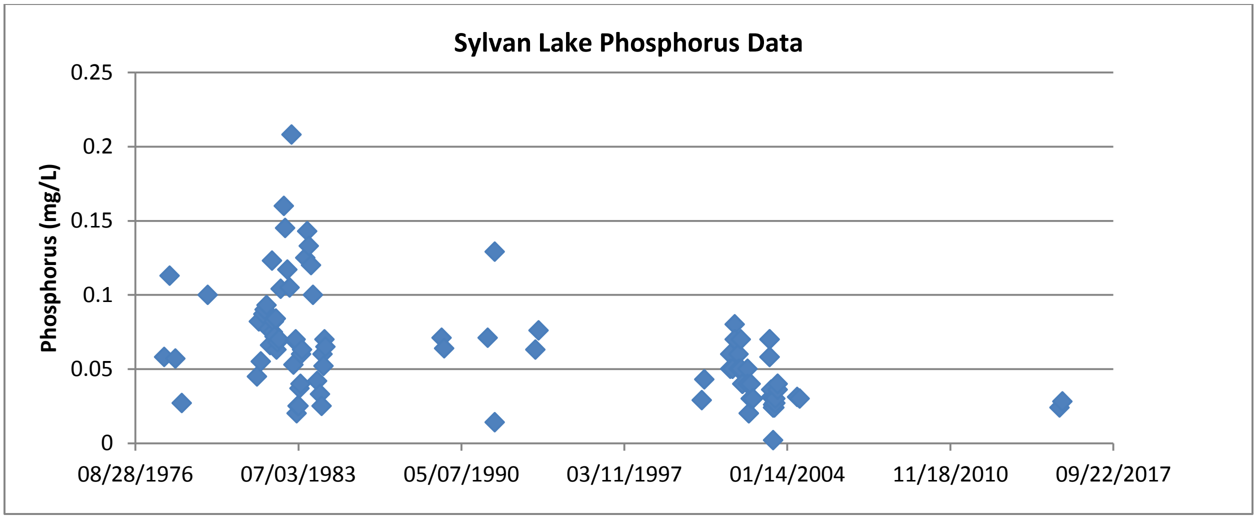

Figure 2. Sylvan Lake Phosphorus Data

Reduction Response Model

As part of the 2005 nutrient TMDL, reduction response modeling was conducted for external loading sources using BATHTUB, a eutrophication response model designed by the United States Army Corps of Engineers (USACE, 1999). The model predicts changes in water quality parameters related to eutrophication (phosphorus, nitrogen, chlorophyll *a*, and transparency) using empirical relationships previously developed and tested for reservoir applications. Lake and tributary sample data were used to calculate existing conditions in Sylvan Lake. Tributary loading data was obtained from the FLUX model output. Inlet phosphorus and nitrogen concentrations were reduced in increments of 10% and modeled to generate an in lake reduction curve.

The results of BATHTUB analysis for external nutrient source reductions are available in Figure 3. The ecoregion target called for a minimum chlorophyll *a* concentration of 9ppb, which translates into a TSI-Chlorophyll *a* value of 53. The targets from both the Ecoregion based TMDL and the Sylvan Lake TMDL are included in the graph. Achieving the 2005 TMDL goal of a TSI-TP of 45 or less required a greater than 90% reduction in nutrient loadings. In contrast, to achieve the 2010 ecoregion pH target, a much lower reduction of less than 40% is required. As a result, the more extensive reductions required to achieve the nutrient TMDL will be protective of the pH targets for the reservoir.

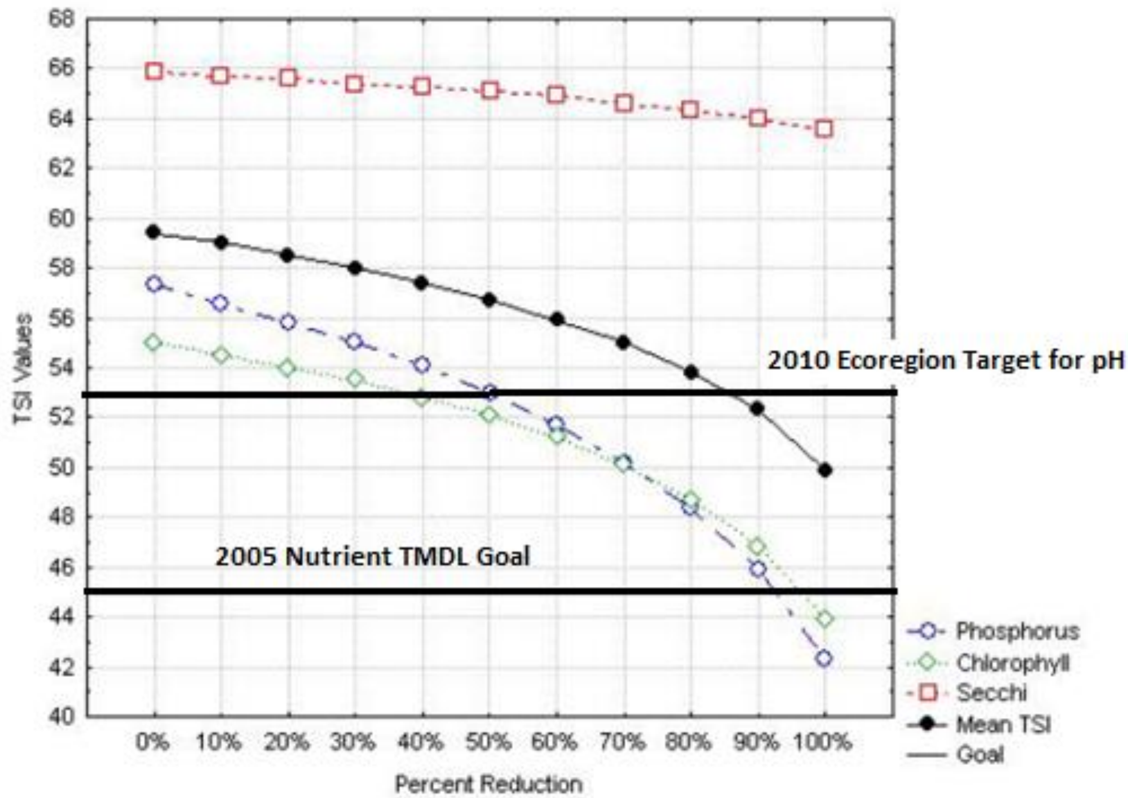

Figure 3. Sylvan Lake Reduction Response Modeling based on External Load Reductions and TMDL targets

Technical Analysis Summary

A summary of the conclusions of the various sections includes:

- Elevated pH concentrations in Black Hills reservoirs can be linked to eutrophication.
- Reducing eutrophication measured as chlorophyll *a* concentrations to less than 9ppb is expected to mitigate pH violations.
- Sylvan Lake is phosphorus limited, thus the most appropriate method for controlling eutrophication is phosphorus load reductions.
- Reduction response modeling indicated that a 92% reduction in external phosphorus loading could achieve a TSI-TP of 45.

Figure 4. 2005 Sylvan Lake Reduction Response BATHTUB Modeling Results

Percent Reduction	Total Phosphorus (ppb)	Total Nitrogen (ppb)	Predicted Phosphorus TSI value	Predicted Chlorophyll TSI value	Predicted Secchi Depth TSI value	Predicted Mean TSI value
0%	39.9	393.0	57.3	55.0	65.9	59.4
10%	38.0	386.6	56.6	54.5	65.7	59.0
20%	36.1	380.1	55.8	54.0	65.6	58.5
30%	34.0	373.6	55.0	53.5	65.4	58.0
40%	31.9	366.9	54.1	52.8	65.3	57.4
50%	29.6	360.1	53.0	52.1	65.1	56.7
60%	27.1	353.2	51.7	51.2	64.9	55.9
70%	24.4	346.2	50.2	50.1	64.6	55.0
80%	21.5	339.9	48.4	48.7	64.3	53.8
90%	18.1	331.8	45.9	46.8	64.0	52.3
100%	14.1	324.4	42.3	43.9	63.6	49.9

The Sylvan Lake TMDL called for a load of 4.9 kg/yr TP, which the BATHTUB model indicated would result in the TMDL goal of an in lake phosphorus concentration of 0.02mg/L (18.1 ppb) TP and a TSI-TP of 45. As shown above in Figure 4, the Sylvan Lake TMDL predicted that when the TSI-TP is reduced to 45, the TSI-chlorophyll *a* will fall below 46.8. Converting the TSI-Chlorophyll *a* to its base chlorophyll *a* concentration yields 5.2 ppb. Section 4.5 of the Ecoregion based TMDL found that maintaining chlorophyll *a* concentrations of less than 9-12.5 ppb would be adequate to meet pH criterion for the fishery. Since the 5.2 ppb chlorophyll *a* concentration is more conservative than the Ecoregion based TMDL, the Sylvan Lake TMDL expressed as a total phosphorus limit of 4.9 kg/yr will result in full attainment of the pH standard in Sylvan Lake.

TMDL Allocations

Wasteload Allocation

There are no point sources of pollutants of concern in this watershed. Therefore, the "wasteload allocation" component of this TMDL is considered a zero value. The TMDL is considered wholly included within the "load allocation" component.

Load Allocation (LA)

The 2005 Sylvan Lake TMDL estimated that 12.4 kg total phosphorus is currently being contributed into the lake annually from external sources while another 7.3 kg is being contributed annually from internal sources, such as lake sediments. As shown in Figure 3 above, if only external phosphorus loads originating from the watershed are managed, a 92% reduction would be required to meet the TSI-TP of 45 and the equivalent total phosphorus concentration of 0.02 mg/mL, both identified as TMDL targets. DENR estimates that a 90% reduction in external loading is possible through the construction of artificial wetlands. The remaining reduction necessary may come from internal sources. DENR estimates that in-lake management (i.e. alum treatment) could provide a 50% reduction of the lake's internal phosphorus load. A combination of the 90% reduction from the external load (from 12.4 to 1.2 kg/year) and the 50% reduction from the internal load (from 7.3 to 3.7 kg/yr) will provide approximately 75% reduction of the total load (from 19.7 to 4.9 kg/yr). Because there are no point sources, the entire 4.9 kg/yr total phosphorus loading capacity is allocated to the LA.

Table 2. Load allocation (kg/yr) summary for Sylvan Lake.

Load source	Current Load	BMP	Reduction	TMDL
External	12.4	Artificial wetlands	0.9	1.2
Internal	7.3	Alum Treatment	0.5	3.7
Total	19.7		0.75	4.9

To identify a maximum daily limit, a method from EPA's "Technical Support Document For Water Quality-Based Toxics Control," referred to as the TSD method, was used. This method, which is based on a long-term average load that considers variation in a dataset, is a recommended method in EPA's technical guidance "Options for expressing Daily Loads in TMDLs" (USEPA, 2007). The TSD method is represented by the following equation:

$$MDL = LTA * e^{[z\sigma - 0.5\sigma^2]}$$

where,
MDL = maximum daily limit
LTA = long-term average
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The daily load expression is identified as a static daily maximum load. A static daily load expression was deemed suitable because of the small watershed size, relatively constant loadings from nonpoint sources (e.g., septics, roads, in-stream sources), and the fact that a steady-state analysis was used. Assuming a probability of occurrence of 95% and a CV of 0.5 (assumed since the CV data used for modeling was not reported), the maximum daily load corresponding to an average annual load of 4.9 kg/yr is 0.026 kg/day.

Seasonal Variation

Different seasons of the year can yield differences in water quality due to changes in precipitation and landuse. To determine seasonal differences, Sylvan Lake sample data was graphed by month to facilitate viewing seasonal differences. Nearly all parameters assessed in this study displayed seasonal variation. For example, lake total phosphorus concentrations are highest in the early spring and late fall. Because much of the biologically available phosphorus is assimilated by algae, concentrations decrease during the early part of the growing season. Concentrations increase in the fall as algae assimilation decreases. Seasonal hydrologic loadings from the Sylvan Lake watershed were also calculated. Seasonality in the hydrologic loads appeared to vary by location. Approximately one-third of the hydrologic load from subwatershed SLT-4 occurred during the fall months, while approximately one-third of the hydrologic load from SLT-3 subwatershed occurred during the spring (see page 13 of the assessment report for seasonal hydrologic budget).

Margin of Safety

The margin of safety is implicit based on conservative estimations of lake model coefficients and a conservative estimation of the percent reduction of total phosphorus achieved with the alum treatment.

Critical Conditions

The impairments to Sylvan Lake are most severe during late summer. This is the result of warm water temperatures and peak algal growth. The TMDL load represents a measured load and may not represent the long term average load due to recent drought conditions.

Works Cited

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