TARGETING IMPAIRED LAKES IN SOUTH DAKOTA

South Dakota Watershed Protection Program
Division of Financial and Technical Assistance
South Dakota Department of Environment and Natural Resources
Steven M. Pirner, Secretary

June 2005
SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

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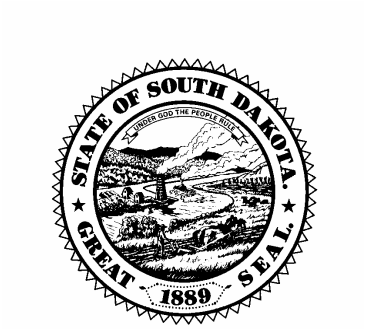
Prepared By

Paul B. Lorenzen, Environmental Project Scientist

Water Resource Assistance Program-Watershed Protection Staff



State of South Dakota
Michael M. Rounds, Governor

June, 2005

SECTION 319 NONPOINT SOURCE POLLUTION CONTROL PROGRAM

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Introduction

South Dakota is a rural, agricultural state with a surface area of 77,047 square miles. Rolling plains are the main feature of this prairie state. The most visible of South Dakota's geographic features are the Missouri River reservoirs which divide the state into glaciated 'east river' and unglaciated 'west river' and the Black Hills - an isolated area of granitic uplift in the far west. The maximum elevation of the state is 2,210 meters (7,242 feet), at Harney Peak in the Black Hills. The lowest elevation, 294 m (965 feet), is near Big Stone City in the bed of Big Stone Lake.

Past surveys by South Dakota Department of Game, Fish and Parks indicate there are approximately 800 publicly owned lakes in the state of which 260 are natural lakes formed primarily by glacial action. Most of the latter are concentrated in the northeast corner of the state within a glaciated plateau known as the Prairie Coteau. The South Dakota Department of Environment and Natural Resources (SDDENR) have classified 574 of the 800 lakes as fisheries.

Lakes in the unglaciated (west river) mixed grass prairie of South Dakota are primarily man-made impoundments ranging in size from small farm ponds to large reservoirs depending on the nature of the drainage basin. Three of four major drainage basins (Cheyenne, Moreau, and Grand) contain relatively large reservoirs. Most of the waterbodies within the Black Hills are also man-made reservoirs with the exception of a few small sinkholes.

South Dakota has a sub-humid (east) to semiarid (west) climate subject to periods of drought at roughly 20-year intervals. Due to the shallow nature of many natural lake basins, average water depth of eastern state lakes is less than eight feet and slightly higher in reservoirs. During prolonged periods of drought lakes in both climates may dry up completely while others are reduced to very low water levels which concentrate nutrient and other dissolved ions compounding water quality problems.

For this reason, many prairie lakes in South Dakota can be classified as semi-permanent. They respond quickly to changes in annual precipitation and the underlying water table with fluctuations in lake water levels and water quality. The majority of lakes in South Dakota tend to be turbid and well supplied with dissolved salts, nutrients, and organic matter. Although lakes by natural processes become more eutrophic through natural succession, most lakes in South Dakota have experienced accelerated eutrophication from non point source pollutants attributed to agriculture and domestic sources. The shallowness of the lakes together with the mixing action exerted by strong summer winds prevent the establishment of enduring thermal stratification in all but a few cases.

Intensive agricultural practices have contributed greatly to the cultural eutrophication process of lakes via soil loss and sedimentation. Fortunately, much of the cultural process can be prevented or impeded by the planned and timely application of the lake preservation and restoration measures adopted by the South Dakota Water Resources Assistance Program (WRAP).

Statement of Need

In May of 2000, the South Dakota Water Resource Assistance Program (SDWRAP) published narrative criteria for targeting impaired lakes for Total Maximum Daily Load (TMDL) development in accordance with Clean Water Act (CWA) section 303(d) (Stueven et.al, 2000). Mean growing season Trophic State Index (TSI) scores integrating chlorophyll-*a*, Secchi depth, and total phosphorus were used to quantify lake condition (Carlson, 1977). For trophic state comparison and impairment status, lakes were classified by Level III ecoregions (Omernik, 1987). Impairment or support categories were established independently with in each ecoregion based on natural breaks in mean TSI (Mann-Whitney-U). Lakes obtained full support, partial support and non-support status within their respective ecoregion based on these natural breaks. Ultimately lakes outside the full support category are listed on the 2000-2004 303 (d) list for non-supporting mean TSI.

Two **main** issues subsist with respect to the current targeting method; 1) variability in trophic state among lakes within ecoregion boundaries is contributing to unattainable impairment targets and 2) The phosphorus component of the mean TSI often deviates considerably skewing the cumulative measure above an attainable remediation level.

Lake TSI values within ecoregions typically exhibit a gradient from exceptional quality lakes to extremely poor quality lakes. Lakes vary within ecoregion boundaries in their beneficial uses from Coldwater permanent fisheries to warmwater marginal fisheries which by definition have major differences in physical structure and water quality. The current full support targets are bias towards the top quality lakes within each ecoregion making it difficult for the majority of lakes to reach recommended targets. Of the 119 assessed lakes between ecoregions only 19% were deemed fully supporting. A more refined classification system with attainable impairment targets are needed to best represent lake condition within a particular class of lakes.

The phosphorus TSI deviates more than $\pm$ 5 TSI points from the chlorophyll-a TSI (median = -11.3) in 82% of the assessed lakes. Carlson (1991) suggests that at this magnitude of deviation the phosphorus component of the TSI will often contribute to the misclassification of a lakes trophic state. In general, the phosphorus TSI exhibits a poor relationship with chlorophyll-a TSI (r^2=0.44, Figure 1). The Secchi TSI is better related to chlorophyll-a (median deviation = -2.3) with the exception of a few outliers typically associated with non-algal turbidity caused from windswept shallow lakes (r^2= 0.55, Figure 2).

As a function of the regression models all three TSI parameters are in theory interrelated though the chlorophyll-a component is the best indicator of biological productivity or algal biomass (Carlson 1977, 1991). Since many of the lakes are shallow and wind swept non-algal turbidity can best be determined with the Secchi component. Phosphorus concentrations in most prairie lakes and reservoirs exceed the level to produce nuisance algae blooms leading to reduced water clarity and overall polluted appearance. However

a suite of other micronutrients may also be limiting to nuisance algae species (Wetzel, 1983). The general public is mostly concerned with water clarity and not nutrient levels when it comes to using lakes for recreational activity. For this reason emphasis should be placed on Secchi depth and chlorophyll-a as the primary measure of a lakes trophic state. Phosphorus will remain the primary nutrient of concern however; it will not serve as the primary endpoint for listing.

After five years of using mean TSI and ecoregions as a classification tool for targeting impaired lakes, it was deemed necessary to revise the listing methodology and update the database. The current ecoregion method covers lakes up to the 2004 303(d) listing process. The SDDENR Watershed Protection has realized certain shortcomings with the ecoregion approach and has revised the protocol accordingly.

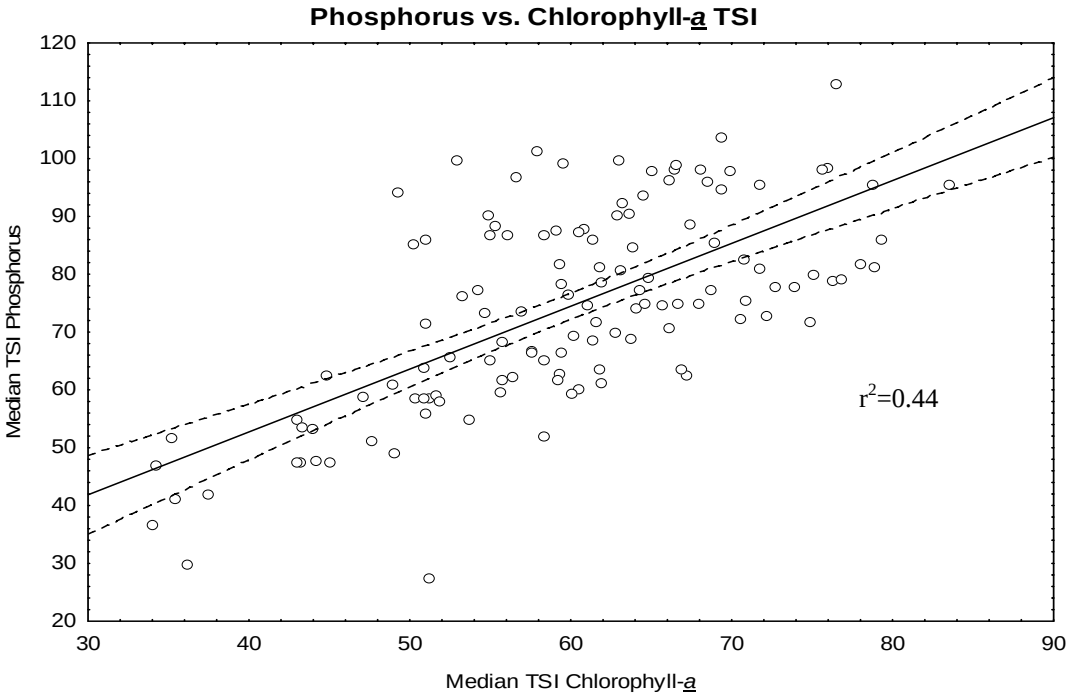

Figure 1. Linear relationship between median TSI phosphorus and chlorophyll-a from all assessed lake data.

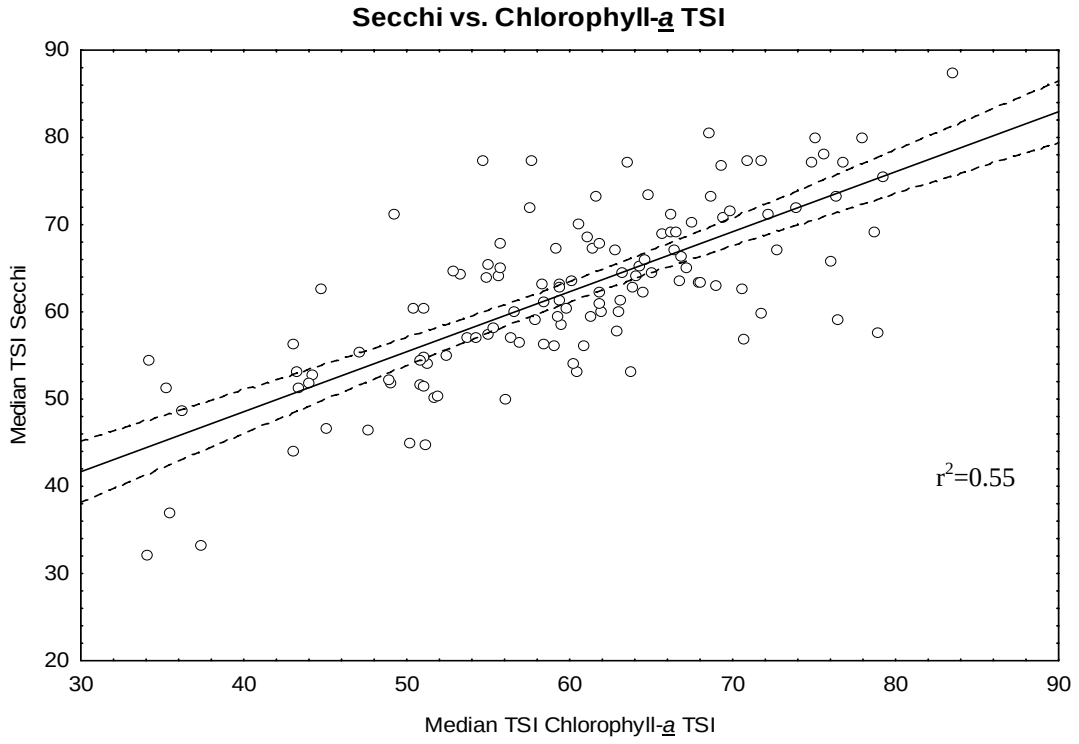

Figure 2. Linear relationship between median TSI Secchi and chlorophyll-a from all assessed lake data.

Fishery Classifications

Lakes (574) in the state are designated the beneficial use of fish life propagation. Five beneficial use categories for fisheries include 1) coldwater permanent, 2) coldwater marginal, 3) warmwater permanent, 4) warmwater semi-permanent and 5) warmwater marginal. Lakes were assigned to a particular fishery based on subjective criteria. Officials from SDDENR and Game Fish and Parks (GF&P) used best professional judgment (BPJ) based on physical attributes to assign lakes to a particular fishery use designation. Water quality standards are less stringent for warm water marginal fisheries progressing to the most stringent standards for a cold water permanent fishery (SDDENR, 1998). Lakes are protected by State water quality standards for each fish class and the narrative standards are not intended to provide a surrogate protective measure, but solely to provide a means of classifying trophic condition for lakes with similar physical, chemical and biological condition.

Fishery Definitions

"Coldwater permanent fish life propagation," a beneficial use assigned to surface waters of the state which are capable of supporting aquatic life and are suitable for supporting a permanent population of coldwater fish from natural reproduction or fingerling stocking. Warmwater fish may also be present.

"Coldwater marginal fish life propagation," a beneficial use assigned to surface waters of the state which are capable of supporting aquatic life and are suitable for stocked catchable-size coldwater fish during portions of the year, but which, because of critical natural conditions including low flows, siltation, or warm temperatures, are not suitable for permanent coldwater fish population. Warmwater fish may also be present.

"Warmwater permanent fish life propagation," a beneficial use assigned to surface waters of the state which are capable of supporting aquatic life and are suitable for the permanent propagation or maintenance, or both, of warmwater fish.

"Warmwater semi-permanent fish life propagation," a beneficial use assigned to surface waters of the state which are capable of supporting aquatic life and are suitable for the propagation or maintenance, or both, of warmwater fish but which may suffer occasional fish kills because of critical natural conditions.

"Warmwater marginal fish life propagation," a beneficial use assigned to surface waters of the state which will support aquatic life and more tolerant species of warmwater fish naturally or by frequent stocking and intensive management but which suffer frequent fish kills because of critical natural conditions.

Fishery classes provide an improved method for classifying trophic condition of lakes in respect to the ecoregion approach. By definition, lakes and reservoirs in the state are physically capable under natural conditions to support a range of fish life propagation. Lakes with coldwater designations should have considerably different trophic conditions then lakes with warmwater designations.

Data and Methods

Data used for trophic state comparison of lakes within and between fishery designations was compiled from all data available to the SDWRAP. Most of the available data was acquired from the South Dakota Statewide Lakes Assessment Program and individual lake assessment projects. Additional data from GF&P and citizens monitoring efforts was also included into the final dataset.

Carlson's Trophic State Index (TSI) was used to quantify trophic condition of each lake. The TSI provides an index score to quantify productivity in the context of algal biomass. Chlorophyll-*a* and Secchi depth measurements were subject to logarithmic transformation based on linear regression models to provide an independent index value

for both measures (Equations 1 and 2). The median (nonparametric data) of both measures was calculated to provide a single index score for each lake. Scores typically range from 0-100 with productivity increasing as the index score increases.

Due to spatial and temporal differences in data, SDWRAP set specific criteria to decrease variability and ensure data integrity. The following criteria were used:

Time Period: All available data since 1989.
Depth: Surface or water column composites.
Seasonality: Samples collected between May 15 and September 15.
Data points: Minimum of two separate years of TSI related data.

$$TSI\left(CHL\right)=10\left(6-\frac{2.04-\left(0.68\left(LN\,CHL\right)\right)}{LN\,2}\right)$$ **Equation 1.**

$$TSI\left(SD\right)=10\left(6-\left(\frac{LN\,SD}{LN\,2}\right)\right)$$ **Equation 2.**

CHL = Chlorophyll-*a* in mg/m^3
SD = Secchi depth in meters

A Shapiro-Wilks test was used to test median TSI values for normal distribution. In most cases data was not normally and independently distributed ($p=<0.05$) and subject to a non-parametric analysis of variance (ANOVA). A Kruskal Walis ANOVA (KWANOVA) was used to determine significant differences in median TSI between fishery classes. The median TSI for Secchi and chlorophyll-*a* was sorted by fishery beneficial use class and ranked in an increasing orientation. Figure 3 depicts median TSI values for lakes within each fishery class.

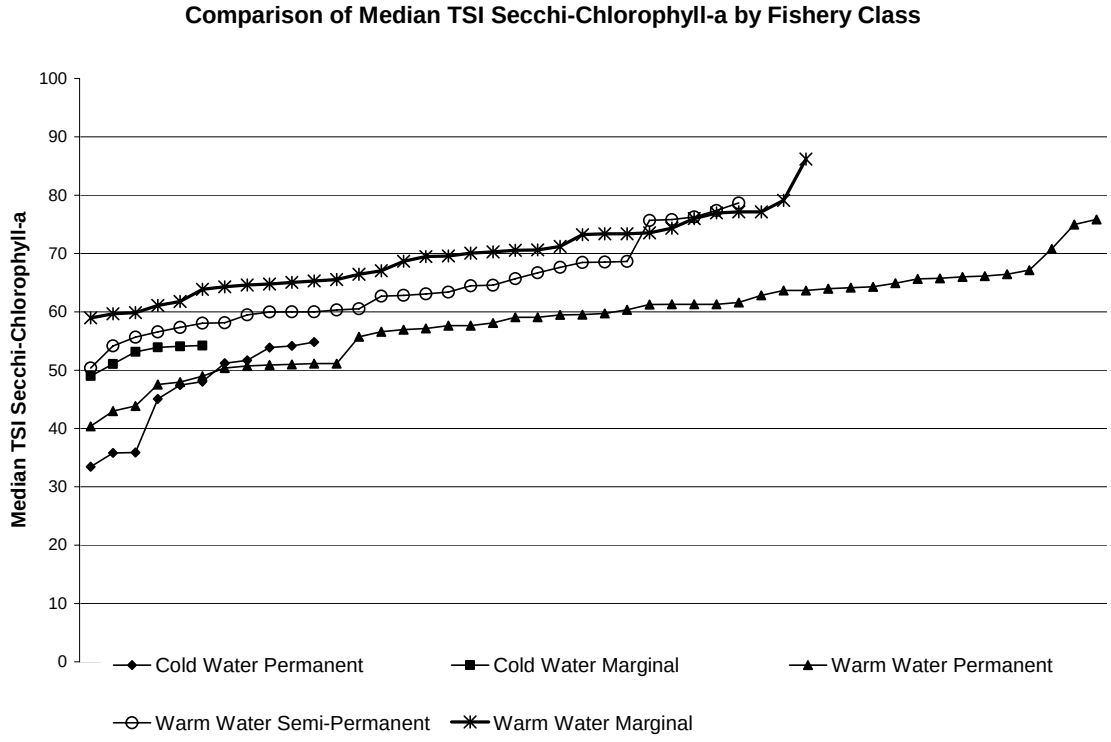

Figure 3. Median TSI values by fishery class sorted by increasing trophic states.

Carlson (1977) established numeric ranges to quantify the trophic condition of a given waterbody (Table 1). These trophic thresholds provided the basis for establishing long-term impairment targets. Impairment targets were established within each fishery class based on Best Professional Judgment (BPJ) in relation to the trophic condition expected for each fishery class.

Table 1. Trophic Index Ranges Carlson (1977).

Trophic State	Numeric Range
Oligotrophic	0-35
Mesotrophic	36-50
Eutrophic	51-65
Hyper-eutrophic	66-100

For the 2006 303(d) list, a decision was made to set attainable impairment targets that protect and/or improve lake trophic condition. Central tendency of the median TSI with in each fishery class was calculated and considered in the preliminary establishment of each impairment target (Table 2). However, central tendency was not used as the specific target due to potential fluctuations with added lake data over time. Impairment targets were subjectively based on narrative trophic state thresholds along the numeric scale

respective to expectations within each fishery class. If lakes fail to meet the assigned numeric standard they would be subject to TMDL development in accordance with CWA section 303(d).

Considerable variation was observed in median Secchi and Chlorophyll-a TSI within lakes and again within classes. Upon setting specific trophic criteria, a conservative measure of variability was estimated and incorporated into the final impairment target for each fishery classification. Variability within each classification was calculated by the following method. First, the standard deviation of Secchi and Chlorophyll-*a* TSI was independently calculated for each lake. This was done to provide an independent estimate of variability within each component. Second, the mean standard deviation of both measures was then calculated for each lake to provide an even weight estimation of variability. Third, the 25th percentile of the mean standard deviation within each class was then calculated to provide a conservative variability estimate for each fishery class. The 25th percentile of the mean standard deviation within each fishery class was roughly +/- 6 standard deviations around the mean (Table 2). Since number of samples with in the variability estimate for each lake varied significantly a conservative judgment was made to allow lakes to deviate 3 median TSI points above the established impairment target for all fishery classes respectively. Lakes within the 3 TSI point margin would not be listed however, WRAP would carefully monitor them to determine if they are increasing or decreasing in water quality.

Results

Statistically significant differences were observed in median TSI values between all fishery classes respectively (KWANOVA, p=<0.05). This strengthens the use of fishery beneficial use categories as a robust classification tool. In the ecoregion targeting document reservoirs and natural lakes were segregated due to reservoirs having significantly higher watershed to lake ratios (p=<0.05). The feeling was that reservoirs typically have a lower life expectancy (natural succession) then natural lakes and that trophic condition would deteriorate faster in reservoirs (Stueven et al. 2000). Median TSI was not found to be statistically significant between lakes and reservoirs (p=>0.105). Because both reservoirs and natural lakes were originally assigned to a particular fishery beneficial use they are assumed to provide equal services and were not segregated. Summary statistics by fishery classification are provided in Table 2.

Table 2. Summary statistics by fishery classification.

Fishery Classification	Median TSI	Median TSI Secchi	Median TSI Chlorophyll-a	25th percentile mean SD.
Coldwater permanent	48.0	46.7	45.0	5.7
Coldwater marginal	52.5	55.3	50.7	6.4
Warmwater permanent	59.6	60.8	57.6	6.6
Warmwater semi-permanent	62.9	63.7	61.4	6.3
Warmwater marginal	69.6	69.2	66.9	6.1

Support Determination for Coldwater Permanent

The median TSI value for lakes designated as a coldwater permanent fishery was 48.0 with a range of 33.4 to 54.8. Trophic conditions span a gradient from the upper end oligotrophic to mid-range eutrophic. All waterbodies in this class are reservoirs located in ecoregion (level III) 17 within the unique geography of the Black Hills. Only two assessed waterbodies were observed as oligotrophic, which is not common in the state of South Dakota even in the Black Hills. As a result, the impairment target was based on maintaining a mid-range mesotrophic state. The support target was established near the median and consistent with the original ecoregion support determination (Stueven et al., 2000). The full support target for lakes within the coldwater permanent classification is set at a median Secchi-chlorophyll-*a* TSI of $\leq$ 45 + 3 standard deviations or $\leq$ **48.4**. Those waterbodies $\geq$ 48.5 will be considered non-supporting. A graphical representation for the support determination of coldwater permanent fisheries including median values for both Secchi and chlorophyll-*a* TSI are found in figure 4.

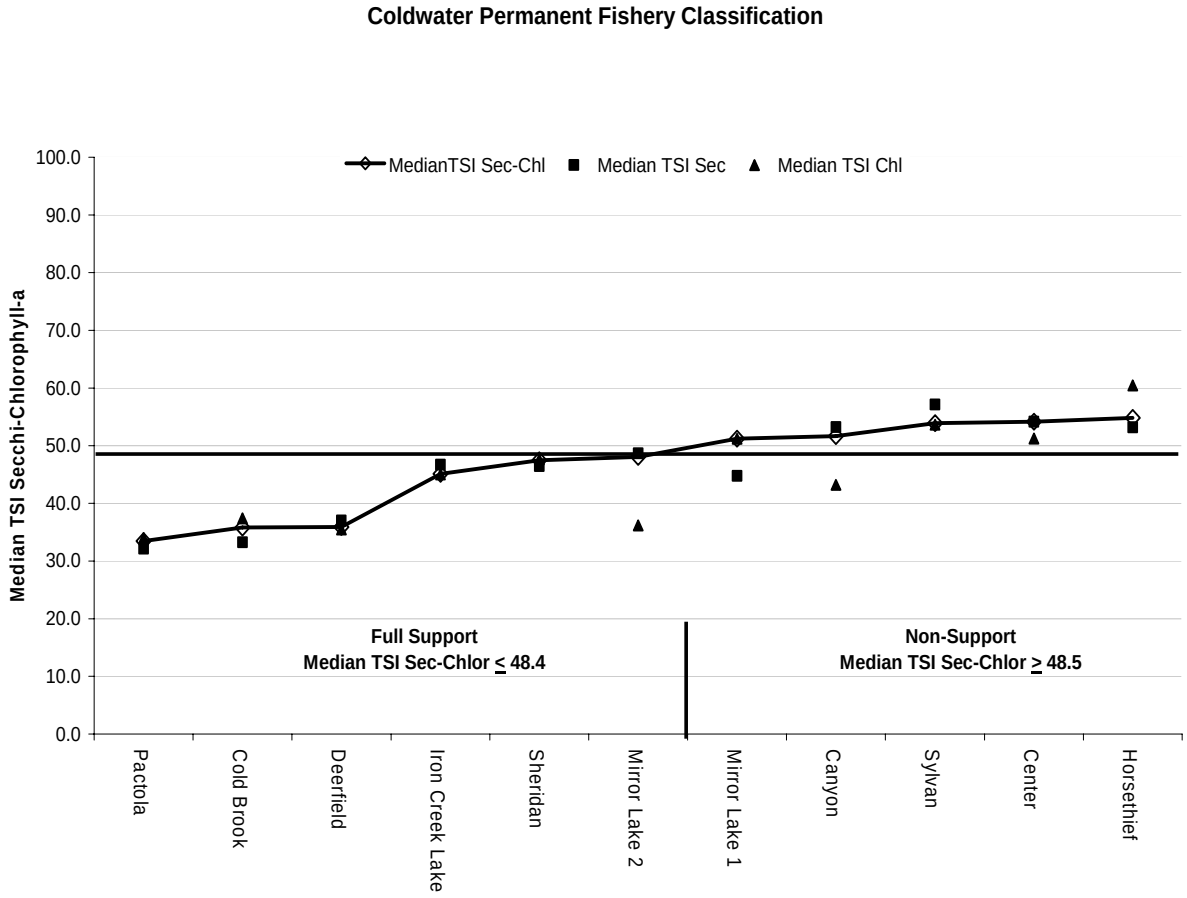

Figure 4. Median TSI values and support determination for coldwater permanent fisheries.

Support Determination for Coldwater Marginal

The median TSI value for lakes designated as a coldwater marginal fishery was 53.5 with a range of 49.0 to 54.2. Trophic status was relatively similar between lakes with conditions ranging from borderline mesotrophic to low range eutrophic. All waterbodies are reservoirs with the majority located in or near the Black Hills. The full support target for lakes within the coldwater marginal classification is set at a median TSI of $\leq 50 + 3$ standard deviations or $\leq$ **53.4**. Those waterbodies with a median TSI $\geq$ 53.5 are considered non-supporting. This target is designed to protect lakes at the upper end of mesotrophic to lower eutrophic condition. A graphical representation for the support determination of coldwater marginal fisheries including median values for both Secchi and chlorophyll-*a* TSI are found in figure 5.

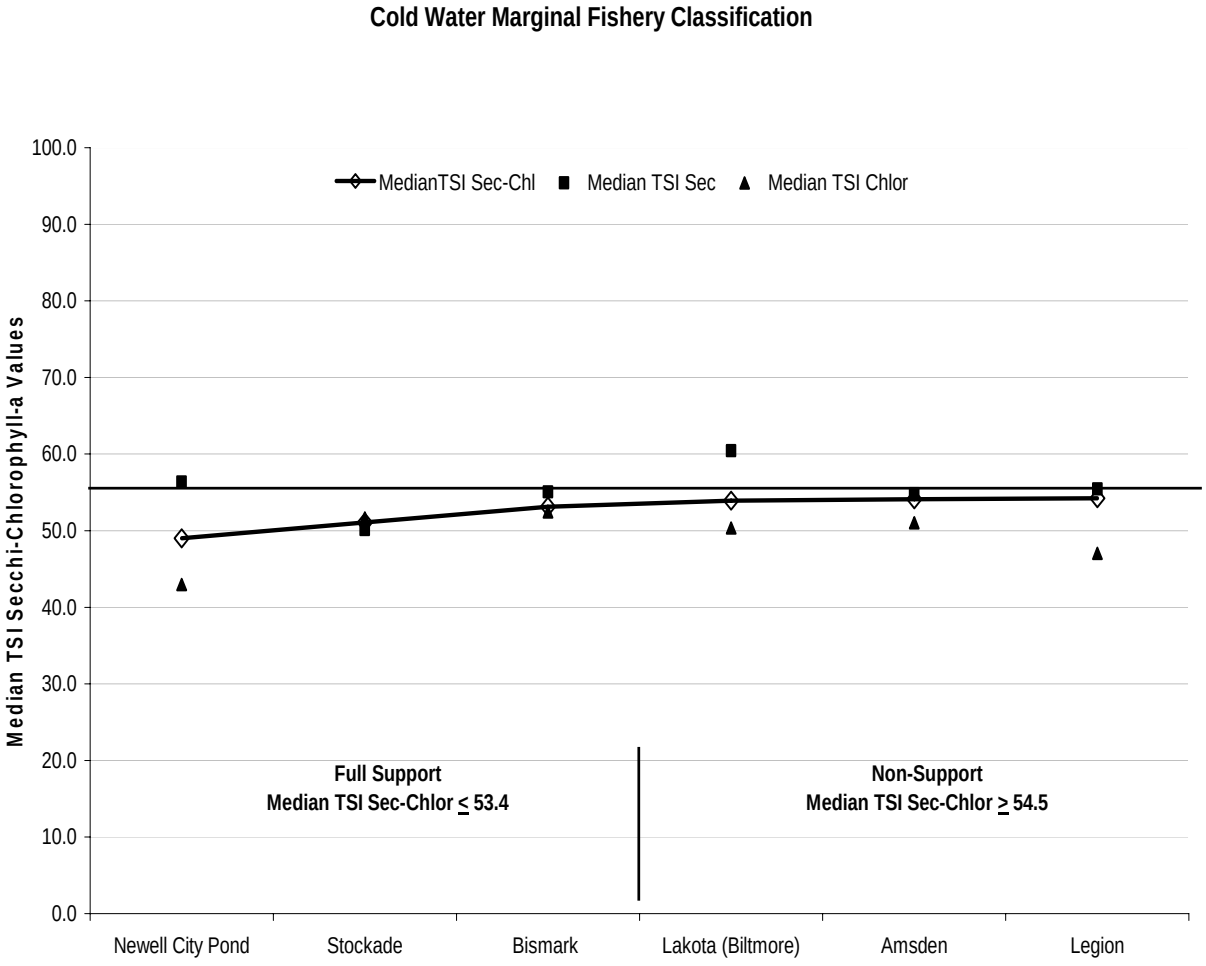

Figure 5. Median TSI values and support determination for coldwater marginal fisheries.

Support Determination for Warmwater Permanent

The median TSI value for lakes designated as a warmwater permanent fishery was 59.6 with a range of 40.4 to 75.8. Trophic conditions deviated considerably between lakes ranging from mid-range mesotrophic to moderately hypereutrophic. The full support target for lakes within the warmwater permanent classification is set at a median TSI of $\leq$ 55 + 3 standard deviations or $\leq$ **58.4**. Those waterbodies with a median TSI $\geq$ 58.5 are considered non-supporting. This target is designed to protect lakes at mid-range eutrophic. A graphical representation of the support determination for warmwater permanent fisheries including median values for both Secchi and chlorophyll-*a* TSI are found in figure 6.

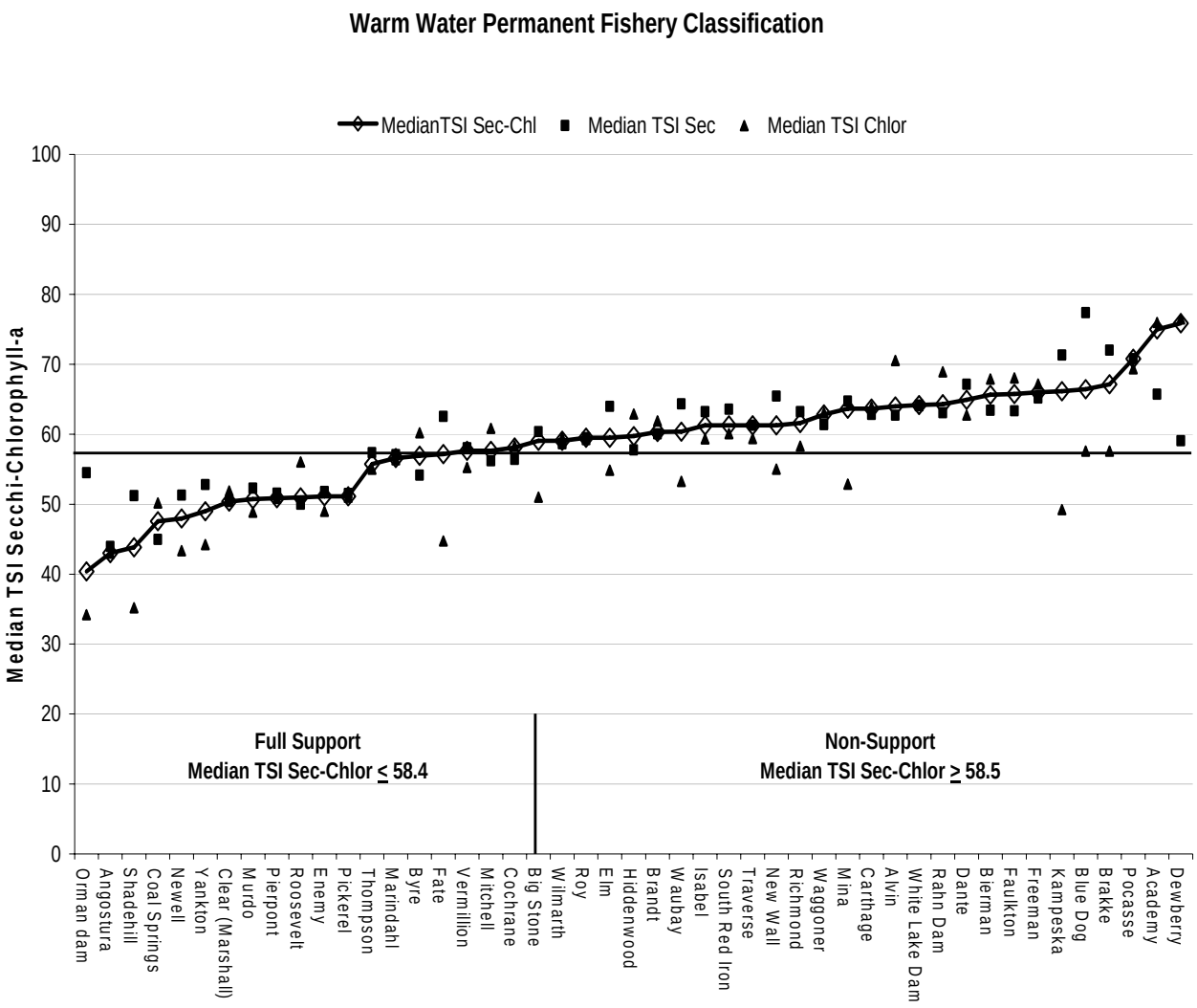

Figure 6. Median TSI values and support determination for warmwater permanent fisheries.

Support Determination for Warmwater Semi Permanent

The median TSI value for lakes designated as a warmwater semi permanent fishery was 62.9 with a range of 50.3 to 78.7. Trophic conditions deviated considerably between lakes ranging from upper mesotrophic to moderately hypereutrophic. The full support target for lakes within the warmwater semi permanent classification is set at a median TSI of $\leq$ 60 + 3 standard deviations or $\leq$ **63.4**. Those waterbodies with a median TSI $\geq$ 63.5 are considered non-supporting. This target is designed to protect lakes at the upper-range of the eutrophic scale. A graphical representation of the support determination for warmwater permanent fisheries including median values for both Secchi and chlorophyll-*a* TSI are found in figure 7.

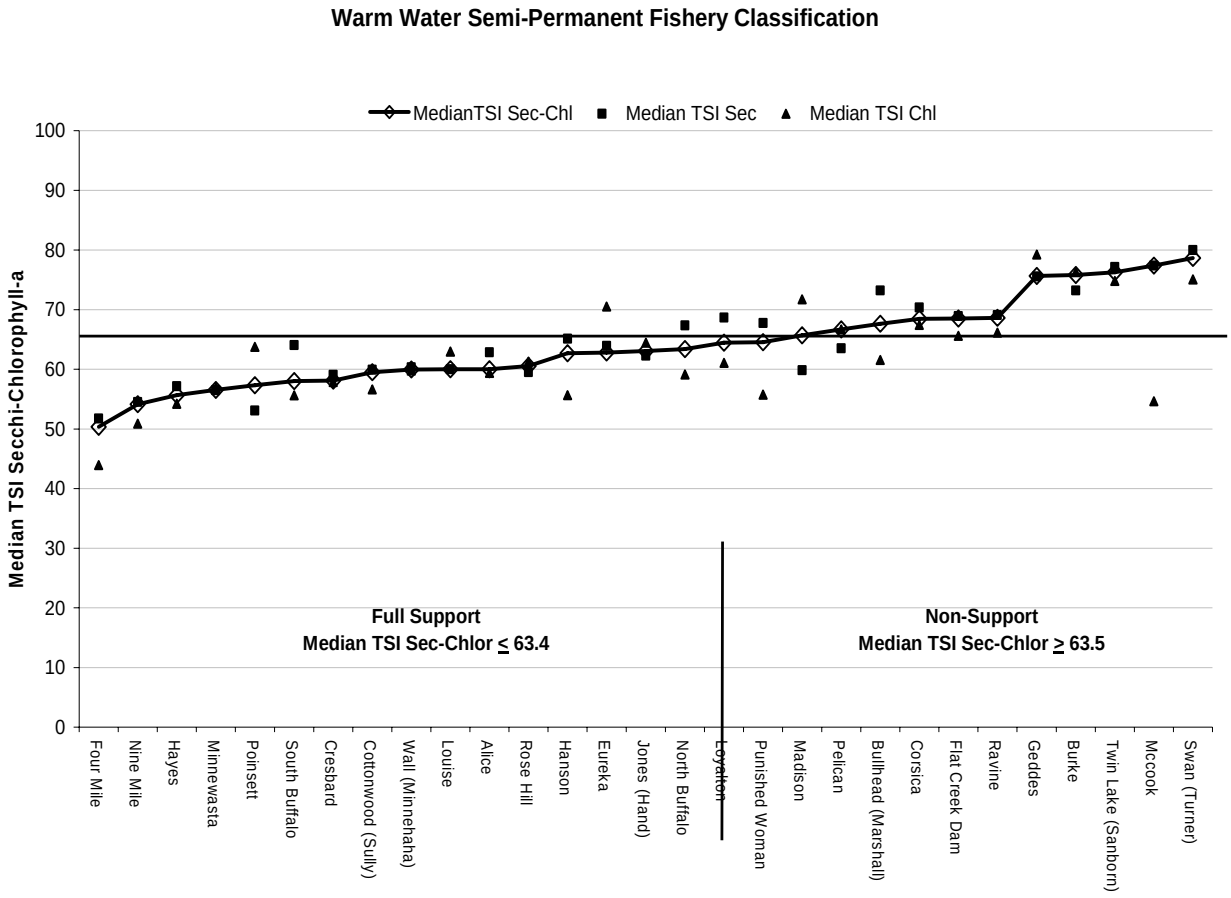

Figure 7. Median TSI values and support determination for warmwater semi permanent fisheries.

Support Determination for Warmwater Marginal

The median TSI value for lakes designated as a warmwater marginal fishery was 69.6 with a range of 58.9 to 86.2. Trophic conditions ranged considerably between lakes ranging from mid-range eutrophic to moderately hypereutrophic. The full support target for lakes within the warmwater marginal classification is set at a median TSI of $\leq 65 + 3$ standard deviations or $\leq$ **68.4**. Those waterbodies with a median TSI $\geq$ 68.5 are considered non-supporting. This target is designed to protect lakes at the low end of the hypereutrophic scale. A graphical representation of the support determination for warmwater marginal fisheries including median values for both Secchi and chlorophyll-*a* TSI are found in figure 8.

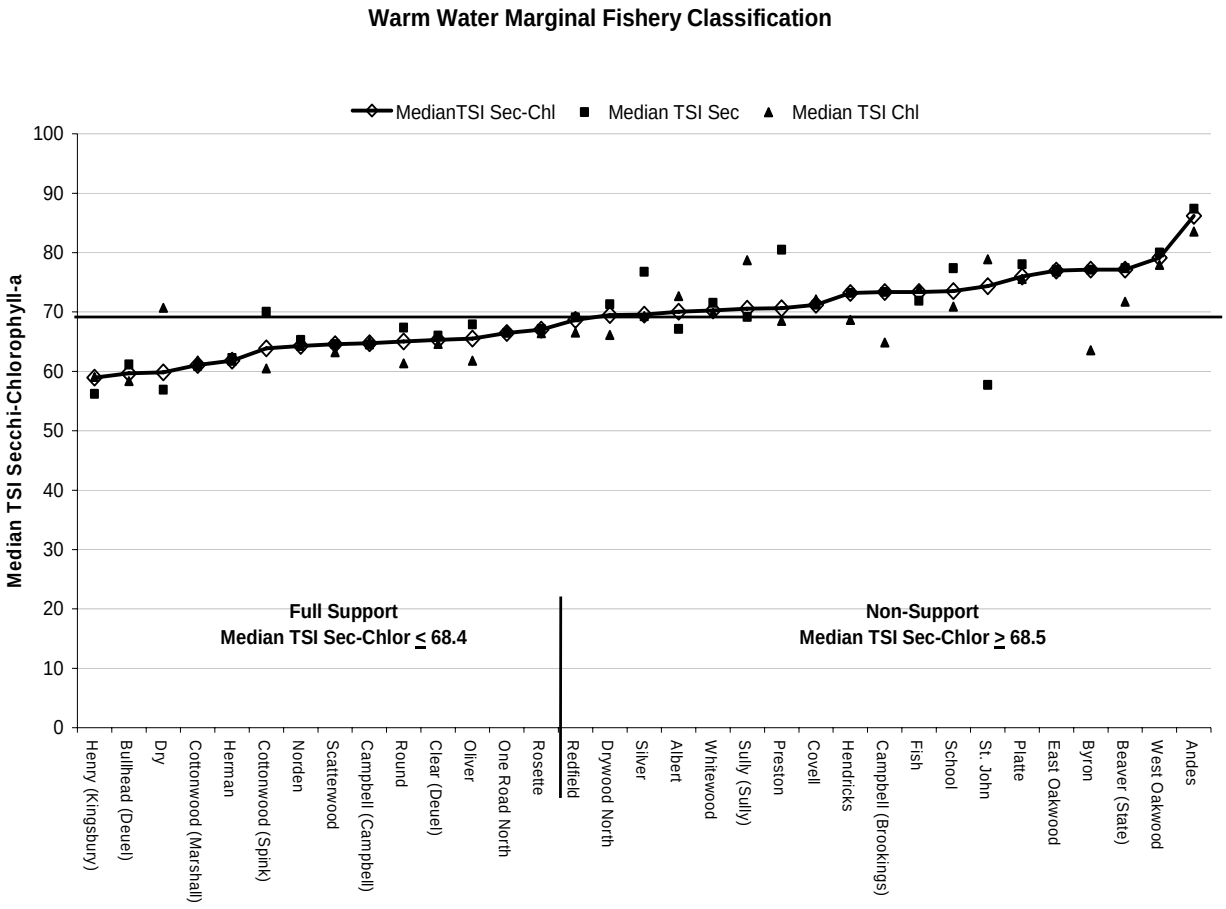

Figure 8. Median TSI values and support determination for warmwater marginal fisheries.

Conclusions

Fishery beneficial use designations as a classification tool should improve the comparison of lake trophic status among lakes with similar physical and biological potential. The narrative criteria presented in this document is not intended as a surrogate protection for the fishery beneficial use but, solely as a classification tool for targeting impaired lakes.

The elimination of phosphorus from the cumulative median TSI should alleviate misclassification of trophic state common in phosphorus rich systems. South Dakota lakes users relate trophic state in terms of water clarity and not nutrient limitation. The cumulative median Secchi and chlorophyll-*a* TSI index should provide managers with the tool for identifying and restoring impaired lakes statewide. SDWRAP realizes that a relationship between Secchi and chlorophyll-a TSI may not exist. In this case the component weighing heaviest on the median will be targeted for restoration efforts. An example would be shallow lakes suspending sediments, increasing Secchi TSI more than chlorophyll TSI. In addition, phosphorus will remain the primary nutrient of concern especially when statistically related to chlorophyll-*a*.

There may be a few lakes within each fishery class that may not be able to reach full support status. In those cases, attainable site specific targets may have to be established. Table 3 summarizes the support status of lakes within each fishery classification.

Table 3. Lakes fully and non-supporting by fishery classification.

Fishery Classification	Fully Supporting	Non Supporting	Total
Coldwater permanent	8	3	11
Coldwater marginal	4	2	6
Warmwater permanent	19	27	46
Warmwater semi-permanent	18	12	30
Warmwater marginal	16	17	33
Total	**65**	**61**	**126**

South Dakota DENR does not feel it appropriate to list lakes which do not have sufficient data to fit the criteria mentioned in the methods section of this document. Once sufficient and credible data are collected, the lakes may be entered in the proper fishery classification and support status determined.

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