Bear Creek Reservoir Options for Defining Site-Specific Nutrient Criteria

Site-specific nutrient criteria have been adopted for Bear Creek Reservoir and for the other three reservoirs subject to control regulations. The form and substance of criteria for Bear Creek Reservoir are open to evaluation and possible alteration as part of the present technical review process. In preparation for discussions about suitable criteria, an exploration of options is helpful.

Water quality criteria for most pollutants are cast as numeric values that serve as thresholds for determining attainment and for deriving effluent permit limits. Three of the control regulation lakes have numeric standards for phosphorus or chlorophyll that serve as the basis for assessing attainment. In contrast, Bear Creek Reservoir has site-specific nutrient criteria constructed as a narrative statement.

> *Concentrations of total phosphorus in Bear Creek Reservoir shall be limited to the extent necessary to prevent stimulation of algal growth to protect beneficial uses. Sufficient dissolved oxygen shall be present in the upper half of the reservoir hypolimnion layer to provide for the survival and growth of cold water aquatic life species. Attainment of this standard shall, at a minimum, require shifting the reservoir trophic state from a eutrophic and hypertrophic condition to a eutrophic and mesotrophic condition.*

Narrative standards are possible through the Clean Water Act (CWA) and in Colorado's Basic Standards. The most common narrative criteria are the so-called "free from" standards, which are widely used for general water quality concerns like surface foam, odor, etc. The concept originated in the CWA where it states that "All waters…shall be free from substances attributable to wastewater discharges…." Narrative criteria can be used to supplement numeric criteria, as Arizona has done with nutrient criteria (see below).

The fundamental difficulty that must be confronted with a narrative standard is implementation. Determining attainment and deriving permit limits are implementation issues that must be addressed in any new proposal for any narrative standard. The attainment issue seems obvious in that all parties must be able to determine independently that a reservoir is, or is not, attaining the standard. The permits issue, which is perhaps less obvious, is related to choosing the target concentration that must be met in the lake. A permit writer derives water-quality based effluent limits using a mass balance approach. In the absence of numeric criteria, the permit writer will have to develop the rationale for the target concentration.

What EPA Recommends

EPA has developed a methodology for recommending nutrient criteria based on evaluation of existing water quality data from each eco-region across the country. It operates on the assumption that the 25th percentile concentration of chlorophyll or phosphorus represents "reference" or "least impacted" conditions that define expected water quality for all lakes in that eco-region.

The concept is attractive because it avoids the necessity of finding unimpacted sites, but it rests on assumptions that may not work well in Colorado. Almost all "lakes" in

Colorado are reservoirs that have been constructed for specific purposes. Moreover, many reservoirs (e.g., off-channel or transbasin projects) are filled with water that does originate in the natural watershed, undermining the basis for classification according to eco-region. Another concern is the independent determination of values for response and causal variables (i.e., chlorophyll and nutrients). The biological linkage between algae and nutrients is well-known, but unacknowledged when 25th percentiles are derived independently for each variable.

The numbers proposed by EPA for reference conditions in Colorado lakes and reservoirs are shown in Table 1. Chlorophyll values are uniformly very low, well below what is typically observed in high-elevation lakes and reservoirs that are thought to be relatively high quality (e.g., Grand Lake and Dillon Reservoir). In contrast, recommended phosphorus concentrations range almost an order of magnitude across the eco-regions.

Sub-ecoregion	Basin	TP, ug/L	NO3, ug/L	Chl, ug/L	Secchi, m
Southern Rockies	High elevation	14.8	10	1.7	4.2
Wyoming Basin	Yampa	10.0	50	1.4	3.0
Colorado Plateau	Colorado	3.0	10	1.4	3.2
AZ/NM Plateau	San Juan, Rio Grande	15.0	20	2.0	2.9
Western High Plains	South Platte, Arkansas	24.0	10	2.4	1.5
SW Tablelands	Arkansas	20.0	10	1.2	1.7
Bear Creek Reservoir	*South Platte*	*47*	*75*	*14*	*1.7*

Table 1. EPA recommendations for nutrient criteria in sub-eco-regions found in Colorado. Typical seasonal values are shown for Bear Creek Reservoir for perspective.

What Other States Have Done

Most states have chosen to pursue an alternative to the EPA recommendations. In some cases, the alternative involves application of EPA's statistical methodology to lakes aggregated according to different geographical criteria. For example, Florida is intending to use Level 4 eco-regions as the basis for defining lake types.

Other states, including Colorado, have voiced concern that the EPA methodology does not link criteria to uses. Colorado is working toward a scheme that associates chlorophyll thresholds with use protection. Minnesota and Virginia have developed criteria that are assigned on the basis of lake type within ecoregions (Tables 2-3). In this manner, the benefit of ecological zonation is combined with identified uses. Virginia has defined nutrient criteria based on maintenance of high quality fisheries.

Ecoregion	Lake trout	Stream trout	Deep	Shallow
Northern Lakes and Forests	3	6	9	9
North Central Hardwood Forest		6	14	20
Western Corn Belt/Northern Glaciated Plains			22	30

Table 2. Minnesota chlorophyll criteria (ug/L) for lake types within each eco-region.

Ecoregion	Cold	Cool	Warm	Fertilized
Southeastern Temperate Forested Plains and Hills		25	35	60
Central and Eastern Forested Uplands	10	25	35	
Eastern Coastal Plain		25	60	

Table 3. Virginia chlorophyll criteria (ug/L) for protection of high quality fisheries based on management strategy and eco-region.

Arizona has developed a more elaborate scheme based on use and lake type, with two thresholds for decisions (Table 4). The approach is novel in that it involves more than one threshold for chlorophyll. If concentrations remain less than the lower threshold, the lake is in attainment of the standard. If the concentration rises above the upper threshold, the lake should be listed (with some exceptions). In between, the listing decision relies on other constituents including nutrients, pH, DO, algal blooms, fish kills, or relative abundance of blue-green algae.

Use	Deep	Shallow	Igneous	Sedimentary	Urban
Full Body Contact	10/15	10/15	20/30	20/30	20/30
Aquatic & Wildlife Cold	5/15	5/15	5/15	5/15	5/15
Aquatic & Wildlife Warm	25/40	25/40	25/40	25/40	25/50
Aquatic & Wildlife effluent dependent	30/50	30/50	30/50	30/50	30/50
Drinking Water Source	10/20	10/20	10/20	10/20	10/20

Table 4. Arizona chlorophyll criteria (ug/L) for different lake types and designated uses. The scheme has lower and upper thresholds (e.g., 10/15) as explained in the text.

The purpose in describing approaches taken by other states is to show how they support implementation and not to point to one or another as a model for Bear Creek Reservoir.

What Bear Creek Has Now

The existing narrative standard for Bear Creek Reservoir specifies a water quality goal in terms of trophic status (see above). It does not specify what metric(s) should be used to determine trophic status, and there is no indication of a time table for attainment or an allowable frequency of exceedance. The present technical review process is a good opportunity to consider what attributes are appropriate for inclusion in a revised standard.

Schemes for classifying lakes according to productivity have been around for decades. The most common scheme uses nutrient concentrations and algal biomass as indicators of productivity (Table 5). A number of schemes have been proposed for trophic state indices that put the qualitative trophic states on numeric scales. These can be especially helpful for judging the importance of changes in trophic state, or in setting statewide criteria for attainment of water quality standards, as some states have done.

State	Average TP	Average Chl	Maximum Chl	Average Secchi
Oligotrophic	<10	<2.5	<8	>6
Mesotrophic	10-35	2.5-8	8-25	6-3
Eutrophic	35-100	8-25	25-75	3-1.5
Hypertrophic	>100	>25	>75	<1.5

Table 5. Fixed boundary scheme for trophic status definitions (OECD 1982). Phosphorus and chlorophyll boundaries are concentrations (ug/L), secchi depth is also given (meters).

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Indices of Trophic State

The most common scheme is the Trophic State Index (TSI) developed by Carlson (1977). It was designed to accommodate most lakes on a scale of 0-100, constructed such that every 10 units represents a doubling of phosphorus concentration, a 2.8-fold increase in chlorophyll, and a 50% decrease in transparency (secchi depth). The beauty of a scheme like this is that the three components are linked in biologically meaningful ways, making it possible to use any one of the metrics to evaluate trophic status, provided that the underlying assumptions are met. The problem is that the assumptions – phosphorus-limited lakes in which all turbidity is due to algal biomass –are not always met. When assumptions are not met, the three metrics may lead to conflicting conclusions about trophic status. To "resolve" the conflicts, many workers have averaged the three TSI values, but Carlson expressly discourages the practice (see http://dipin.kent.edu/tsi.htm).

Another index scheme was developed by Walker (1979), but it does not seem to have found practical application except in Bear Creek Reservoir. Walker's also consists of three components (chlorophyll, phosphorus, and secchi depth). In contrast to Carlson's stricture against averaging, Walker bases classification on the average of the three indices. At the same time, however, Walker makes clear that accepting the average value depends on the belief that a "given lake conforms to the index scheme." What he means is that differences among the three component indices are assumed to be the result of sampling and measurement errors, so that an average is a more robust estimate of the true trophic state.

There are several differences between the Carlson and Walker indices, and these can be summarized in terms of the scale for each constituent and the threshold concentrations associated with trophic states (Table 6). For the phosphorus component, a doubling of concentration adds 10 points to the Carlson TSI or 14 points to the Walker. For chlorophyll, a doubling of concentration adds about 7 points to the Carlson index or 10 points to the Walker. Doubling the secchi depth (transparency) reduces the Carlson index by 10 points; the Walker cannot be evaluated in the same way because the form of the function is different. In general, the two indices associate similar chlorophyll concentrations with trophic state ranges (see Table 5), except that the Carlson sets a much higher threshold for the hypertrophic category.

State	Carlson TSI	Chl, ug/L	Walker	Chl, ug/L
Oligotrophic	<30	<1	<25	1
Mesotrophic	40-50	3-7	30-45	2-6
Eutrophic	50-60	7-20	50-65	8-23
Hypertrophic	>70	>56	>70	>32

Table 6. Comparison of Carlson and Walker trophic indices as they relate to trophic state definitions and chlorophyll concentrations. Concentrations have been rounded to the nearest whole unit. Gaps in the ranges indicate transitions between adjacent trophic states.

The real indicator of trophic status is algal abundance (i.e., the chlorophyll TSI); it is an unequivocal and direct measure. The total phosphorus TSI could be considered an indication of potential trophic status if the underlying regression relationship holds true

DRAFT

for a particular lake. The secchi TSI may be a surrogate for chlorophyll, but only if transparency is governed exclusively by algal abundance.

Use of TSI in Bear Creek Reservoir

In annual reports, the BCWA has presented information on the trophic status of the reservoir based on both Carlson and Walker indices. Either could be proposed as the basis for evaluating attainment, but having information from both indices is difficult to interpret. A comparison of values for the indices can foster a better understanding of the differences among them that may be specific to Bear Creek Reservoir.

A time course of TSI values (Figure 1) illustrates temporal patterns in Bear Creek Reservoir. Three indices are compared on the graph – the Carlson chlorophyll TSI, the Walker chlorophyll TSI, and the Walker average TSI. Chlorophyll, which is the unequivocal measure of trophic status, shows that the reservoir is typically in the eutrophic range. Both chlorophyll indices dropped into the mesotrophic range in the late 1990s, and the Walker index shows several excursions into the hypertrophic range. The Walker average index suggests a more productive reservoir than either of the chlorophyll indices show.

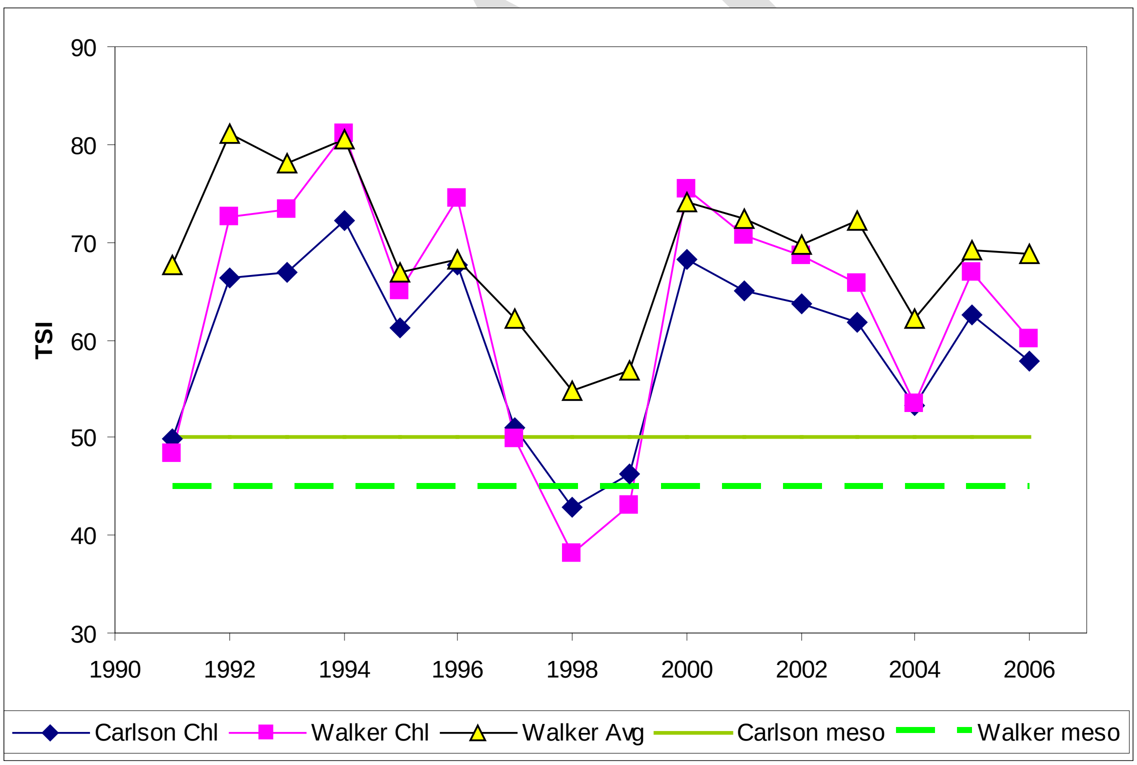

Figure 1. Comparison of TSI values from Bear Creek Reservoir. The Carlson chlorophyll, Walker chlorophyll and Walker average are shown along with the Carlson meso-eutrophic boundary (also the Walker lower eutrophic boundary), and the upper end of the Walker mesotrophic.

Summary and Recommendations
It is not clear that TSIs offer any advantage over concentration data for the narrow purpose of site-specific nutrient criteria development. Indices have great value in a comparative sense, and have been used by Minnesota as a framework for statewide development of nutrient criteria. Developing that framework required judgments about the linkages between water quality and trophic state, and those judgments may or may not be appropriate for Bear Creek Reservoir. What is more important for Bear Creek Reservoir is to determine how the relatively high productivity of the algal community affects uses directly or indirectly. This is a broader issue than can be addressed with a TSI.

1) Define numeric criteria for chlorophyll. This can be a single threshold value or a range of values supplemented with a narrative like the scheme developed by Arizona. The definition should be accompanied by a rationale describing how that threshold protects uses.
2) If there is continuing interest in using a TSI as a surrogate for productivity in the reservoir, pick one index preferably based on chlorophyll. It makes no sense to have dueling indices that lead to conflicting conclusions about status.
3) If a TSI is used, numeric targets should be proposed to enable implementation decisions (attainment and permitting).
4) If a narrative statement is retained, there must be a way for all parties to determine attainment independently, there must be a statement of the allowable exceedance frequency, and there should be a timetable for attainment if the water quality goal represents an expectation of improvement over the long term.

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