GUIDELINES FOR INTERPRETING DISSOLVED OXYGEN AND CHLOROPHYLL *a* CRITERIA IN MARYLAND'S SEASONALLY STRATIFIED WATER-SUPPLY RESERVOIRS

I. DISSOLVED OXYGEN

A. Introduction.

Maryland's non-tidal water quality standards provide for a minimum dissolved oxygen (DO) criterion of 5.0 mg/l for all waters at all times (COMAR 26.08.02.03-3A(2)), except as resulting from natural conditions (COMAR 26.08.02.03A(2)). Bottom waters in thermally stratified lakes may naturally become depleted of DO during periods of stratification (Wetzel 2001).

New standards approved for the State's tidal waters, including the Chesapeake Bay, recognize the significance of thermal/salinity stratification, and the physical and natural impact thereof on deeper waters. The new standards for estuarine waters recognize three layers: (1) open water (surface); (2) deep water (below the upper pycnocline); and (3) deep channel (bottom waters).

All of Maryland's water-supply reservoirs undergo periods of seasonal thermal stratification similar to that in Chesapeake Bay. In the absence of a standard specifically addressing stratified lakes, MDE (1999) developed an interim interpretation of the existing standard, utilizing the percentage of oxygen saturation in the hypolimnion as a metric. This document updates that interim interpretation, providing a framework for additional technical analyses with respect to hypolimnetic DO in thermally stratified lakes.

B. Background

In idealized cases, lakes stratify into three distinct layers—the epilimnion, metalimnion and hypolimnion. The epilimnion is the well-mixed surface layer of relatively warm water. The metalimnion, the middle layer, is a zone of a distinct downward temperature gradient. The hypolimnion is the bottom layer of relatively cold and undisturbed water. Various analytical methods, typically involving measurement of temperature change over depth, exist to identify and define these layers. (Wetzel, 2001).

Thermal stratification is a seasonal phenomenon resulting from the lower density of warm surface waters, beginning in late spring or early summer, intensifying as summer progresses, decreasing in early fall, and finally ending with the fall turnover, as the lake becomes thermally uniform with depth. Therefore, data from May or June will generally show less stratification and higher hypolimnetic DO levels than data from August and September.

Often, stratified lakes do not exhibit this idealized separation into three distinct layers, but may still exhibit clear temperature gradients from surface to bottom. This phenomenon may be particularly true in the case of artificial impoundments, given the variability in basin and watershed morphometry and geometry. The formulaic determination of the exact point at which one layer grades into another may thus be difficult or impossible, and in such cases, managers may need to explore alternative methodologies or resort to professional judgment.

Various factors affect the 'natural' degree of oxygen depletion in a lake or impoundment. These include the degree or 'strength' of stratification; the morphometry of the water body itself (*i.e.*, the depth and geometry of the basin); and watershed characteristics, such as watershed size, land cover, and naturally occurring allochthonous loads of organic material.

Chapra (1997) describes hypolimnetic DO saturation as a function of lake trophic status[1]. This relationship, upon which Maryland based its interim interpretation, is summarized in Table 1 below.

Table 1

Relationship between Lake Trophic Status and Dissolved Oxygen Saturation in the Hypolimnion of a Thermally Stratified Lake

Trophic Status	Hypolimnetic Dissolved Oxygen Saturation
Eutrophic	0% - 10%
Mesotrophic	10% - 80%
Oligotrophic	80% - 100%

Adapted from Chapra (1997)

Maryland has no natural lakes; all are artificial impoundments—typically either larger, water-supply reservoirs, or smaller, recreational-use lakes. [In this document, the terms "lake" and "impoundment" are used interchangeably.] In impoundments, the factors outlined above (especially basin morphometry and watershed size) differ inherently from those in natural lakes. Natural lakes are typically deepest in the center with a gradual increase in depth to that point, while impoundments are usually deepest at the downstream extent—the point of impoundment—and exhibit an abrupt increase in depth at that point. Watershed size is also often proportionately greater in the case of impoundments, resulting in a correspondingly larger 'natural' load of watershed-derived materials (Wetzel 2001). For these reasons, Chapra's saturation-based method may not apply well to impoundments.

[1] When conducting analyses specifically to assess lake trophic status, Maryland generally uses other, more reliable, metrics (e.g., chlorophyll *a* concentration).

C. Dissolved Oxygen Guidance for Thermally Stratified Lakes in Maryland

MDE is adopting the following general approach to establish dissolved oxygen guidelines for lakes exhibiting seasonal thermal stratification:

- A minimum dissolved oxygen concentration of 5.0 mg/l will be maintained in the surface layer at all times, including during periods of thermal stratification, except during periods of overturn or other naturally-occurring disruption of stratification.

- A minimum dissolved oxygen concentration of 5.0 mg/l will be maintained throughout the water column during periods of complete and stable mixing.

- Hypolimnetic hypoxia will be addressed on a case-by-case basis. In the event of hypoxia observed in the deeper portions of lakes during stratification, Maryland will conduct an analysis to determine if current loading conditions result in a degree of hypoxia that significantly exceeds (in terms of frequency, magnitude and duration) that associated with natural conditions in the lake and its watershed. This analysis may vary from one lake to another in terms of type, approach and scope. Examples may include a review of setting, source assessment and land use, so as to assess current loads; a comparison of estimated current loads exported from the watershed with analogous load estimates under ‘natural’ land cover; and model scenario runs simulating natural conditions. This list is not exhaustive, and Maryland expressly reserves the right to determine and conduct the most appropriate type of analysis on a case-by-case basis.

The primary application of this approach is for use in conducting analyses to support development of Total Maximum Daily Loads (TMDLs) and Water Quality Analyses (WQAs), in satisfaction of the State’s obligations under Section 303[d] of the federal Clean Water Act (CWA). It is also envisioned that these guidelines, or natural outgrowths thereof, may be used in the context of listing and inventorying water bodies under Sections 303 and 305 of the CWA.

II. CHLOROPHYLL *a*

A. Introduction and Background.

Maryland’s General Water Quality Criteria prohibit pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses. Maryland’s water quality standards presently do not impose a limit on the concentration of nutrients in the water column.[2] Rather, Maryland manages nutrients indirectly by limiting their effects expressed in terms of excess algal

[2] Maryland does limit the ammonia form of nitrogen from wastewater treatment plants, due to its toxic effects on some aquatic organisms.

growth and low DO. In impoundments, chlorophyll *a* concentrations serve as a useful surrogate for quantifying the effects of excess nutrient loading.

In establishing chlorophyll *a* guidelines for water-supply reservoirs, Maryland has adopted a two-pronged approach. First, a chlorophyll *a* concentration of 10 µg/l is generally recognized as a boundary between mesotrophic and eutrophic conditions (Carlson, 1977). In water-supply reservoirs, preventing a shift to eutrophic conditions reduces the frequency, duration and magnitude of nuisance conditions—e.g., algal scums (Walker, 1984). Secondly, a mean concentration of chlorophyll a not to exceed 10 µg/l is correlated with an absence of instantaneous values exceeding 30 µg/l (see Figure 1). Exceedences of the 30 µg/l threshold are associated with a shift to cyanobacteria (blue-green algae) assemblages, and associated taste/odor treatment costs. Thus, maintaining chlorophyll a concentrations below these respective values ensures that the drinking water designated use will be supported.

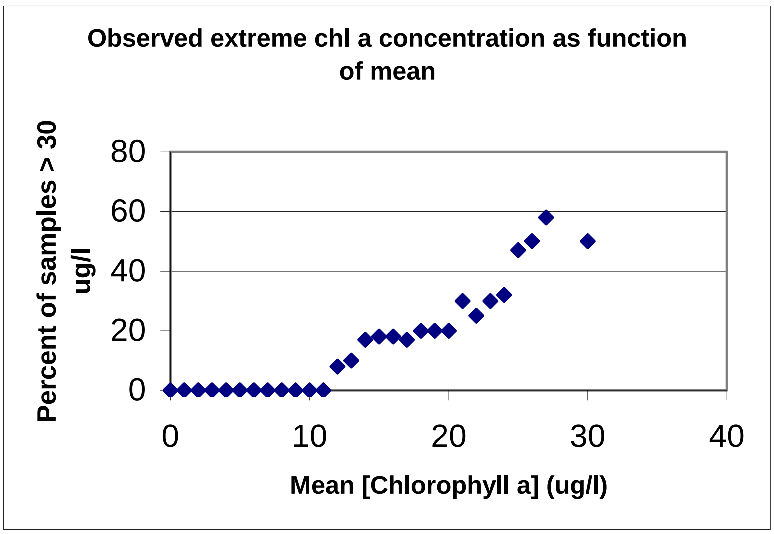

Figure 1. Correlation of instantaneous and growing season mean Chlorophyll *a* concentrations (adapted from Walker, 1984).

B. Chlorophyll *a* Guidelines for Water-Supply Reservoirs in Maryland.

MDE is adopting the following general approach to establish chlorophyll *a* guidelines for water-supply reservoirs:

- Mean concentrations of chlorophyll *a* in representative surface waters shall be maintained at 10 µg/l or less. This may be as measured over a growing season, as a 30-day moving average, or in any other period appropriate to the impoundment of interest.

- The 90th percentile of chlorophyll *a* in representative surface waters shall be maintained at 30 µg/l or less.

III. GEOGRAPHIC SCALE OF ASSESSMENT

For the purposes of the Integrated Report (IR), all water body assessments are georeferenced to graphically show the scale of the assessment. Whether a lake is assessed for dissolved oxygen or chlorophyll *a*, and regardless of the assessment result, only the lake water surface will be georeferenced for that assessment. MDE acknowledges that in many cases the sources for lake impairments originate in the upstream watershed. However, assessments for lakes will not be applied to the upstream waters unless it is determined that uses are also threatened in these upstream waters. In other words, assessments for lakes will be georeferenced to the polygonal water surface that represents a lake's area.

IV. REFERENCES

Carlson, R.E., 1977. A trophic state index for lakes. Limnology and Oceanography 22:361-369.

Chapra, Steven C. 1997. Surface Water Quality Modeling. McGraw – Hill, Inc. Boston, U.S.A.

Maryland Department of the Environment. 1999. Interpretation of Dissolved Oxygen Standards in Maryland's Thermally Stratified Lakes.

Walker, William W., 1985. Statistical bases for mean chlorophyll *a* criteria. Lake Reserv. Manage. 2:57-62.

Wetzel, R. G. 2001. Limnology: Lake and River Ecosystems. Academic Press, Inc., San Diego, U.S.A.