Water Quality Analysis of Eutrophication for Greenbrier Lake, Washington County, Maryland

FINAL

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BOD	Biochemical Oxygen Demand
COMAR	Code of Maryland Regulation
CWA	Clean Water Act
DNR	Department of Natural Resources
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GIS	Geographic Information System
m	Meter
MDP	Maryland Department of Planning
MDE	Maryland Department of the Environment
mg/l	Milligrams Per Liter
mi^2	Square Miles
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Carlson's Trophic State Index
WQLS	Water Quality Limited Segment
μg/l	Micrograms Per Liter

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency (EPA)'s implementing regulations direct each State to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. This list of impaired waters is commonly referred to as the "303(d) list". For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met.

Greenbrier Lake in the Antietam Creek watershed (basin code 02-14-05-02) was identified on the State's 1998 list of WQLSs as impaired by nutrients. An analysis of recent monitoring data shows that the criteria associated with nutrients are being met, and the designated use in Greenbrier Lake is supported. This analysis supports the conclusion that a TMDL for nutrients is not necessary to achieve water quality in this case. Barring any contradictory future data, this report will be used as supporting material when Maryland Department of the Environment (MDE) proposes the revision of Maryland's 303(d) list for public review. Although the waters of Greenbrier Lake do not display signs of eutrophication, the State reserves the right to require future controls in the Greenbrier Lake watershed if evidence suggests nutrients from the basin are contributing to downstream water quality problems.

1.0 INTRODUCTION

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency (EPA)'s implementing regulations direct each State to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. This list of impaired waters is commonly referred to as the "303(d) list". For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met.

In addition to the successful implementation of a TMDL, there are four other scenarios that may be used to address an impaired waterbody: 1) more recent data indicate that the impairment no longer exists (*i.e.*, water quality standards are being met); 2) more recent and updated water quality modeling demonstrates that the segment is now attaining standards; 3) refinements have been made to water quality standards, or the interpretation of those standards, which result in standards being met; or 4) errors made in the initial listing have been corrected.

Greenbrier Lake (in the Antietam Creek watershed, basin code 02-14-05-02) was first identified on the 1998 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), as being impaired by nutrients on the basis of seasonally low oxygen levels in the deeper portion of the lake. This report provides an analysis of more recent information that supports the removal of the nutrients listing for Greenbrier Lake when the 303(d) list is revised; therefore, the aforementioned first scenario most closely applies. Additionally, the initial listing was based on the occurrence of low hypolimnetic dissolved oxygen (DO); analyses demonstrate that this condition in Greenbrier Lake is due to thermal stratification, a natural process in lakes. Thus, the second scenario also applies.

The remainder of this report lays out the general setting of the waterbody within the Greenbrier Lake watershed, presents a discussion of the water quality characteristics in the basin, and provides conclusions with regard to the current water quality characteristics and the current standards. The analysis establishes that Greenbrier Lake is achieving water quality standards.

2.0 GENERAL SETTING

Greenbrier Lake is located in Washington County, Maryland, in the Antietam Creek watershed. Greenbrier Lake is approximately one thousand feet in length and five hundred feet in width at its maximum extent. The lake's primary watershed covers an area of approximately 0.8 mi^2 (non-water) or about 512 acres. MDE's Geographic Information Systems (GIS) analyses revealed that a smaller, secondary watershed, draining via pipe under Interstate 70, covers an additional 164 acres, for a total watershed area of 675.7 acres (Figure 1). The land use in the overall watershed is primarily forested (approximately 650 acres or 92 %), with a small amount of urban land (about 26 acres or 3.7%) and no agricultural land. Refer to Figures 2 and 3 for a map and chart of these land uses (MDP, 2000).

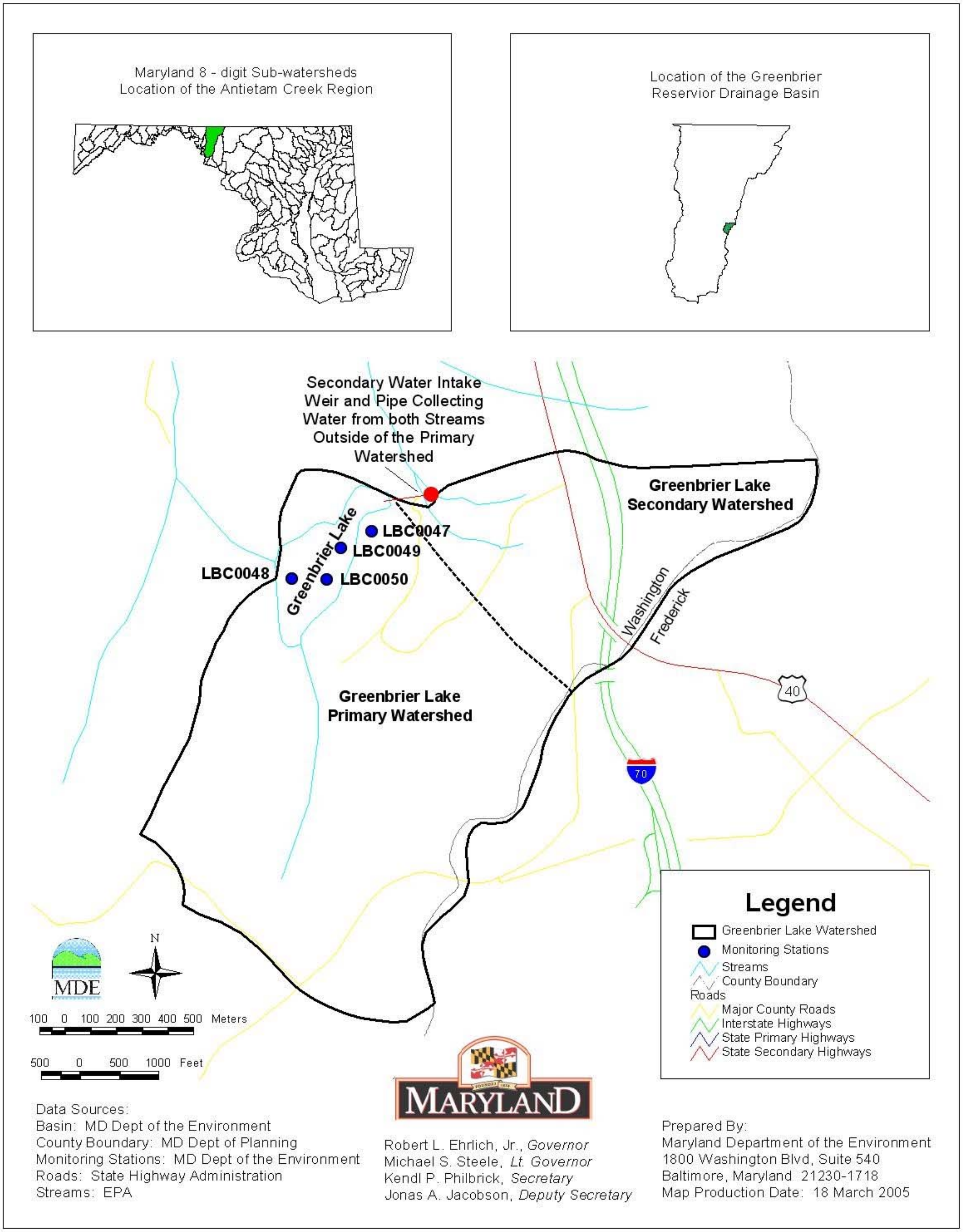

Figure 1: Greenbrier Lake Location Map and Monitoring Stations

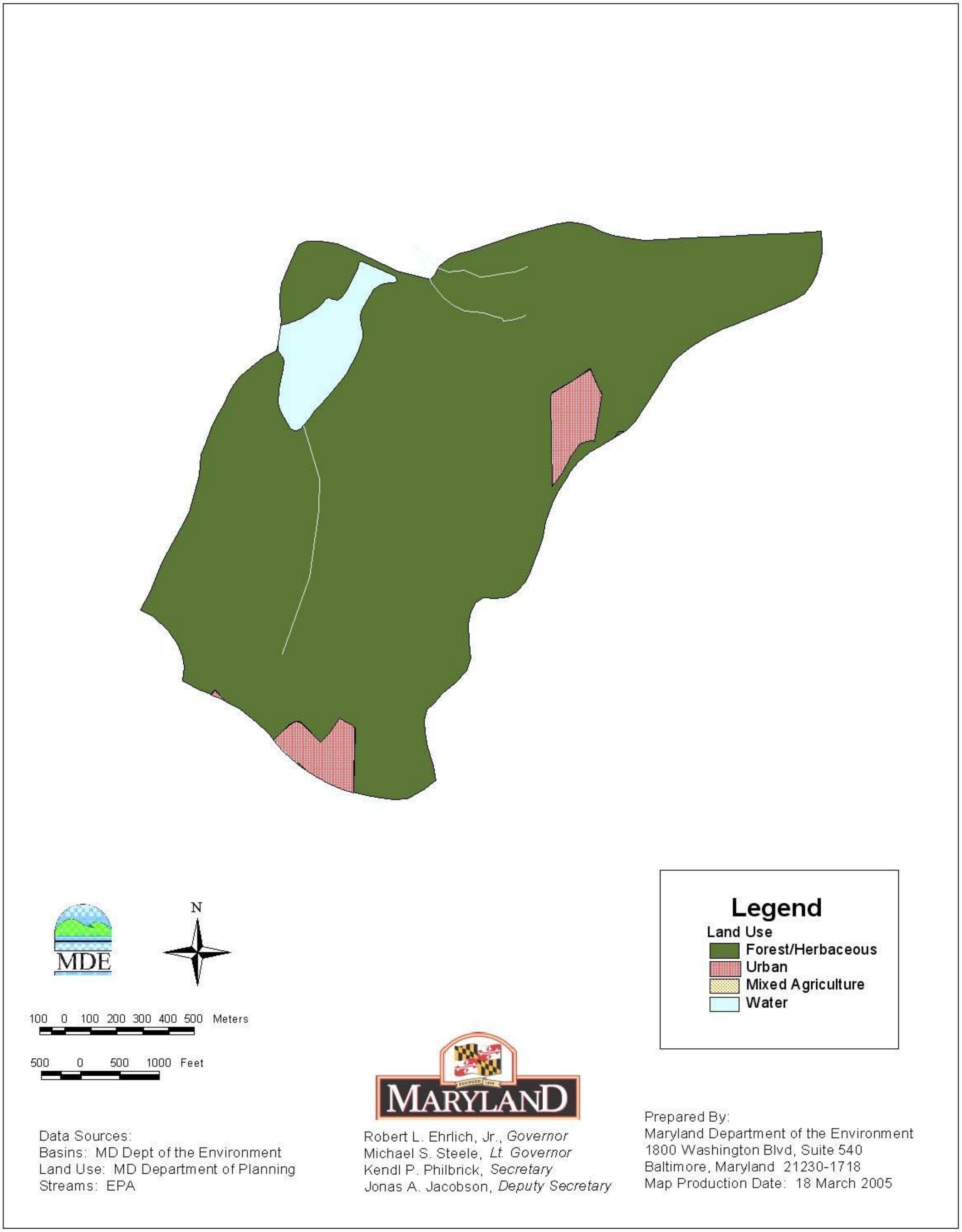

Figure 2: Land Use Map of the Greenbrier Lake Watershed

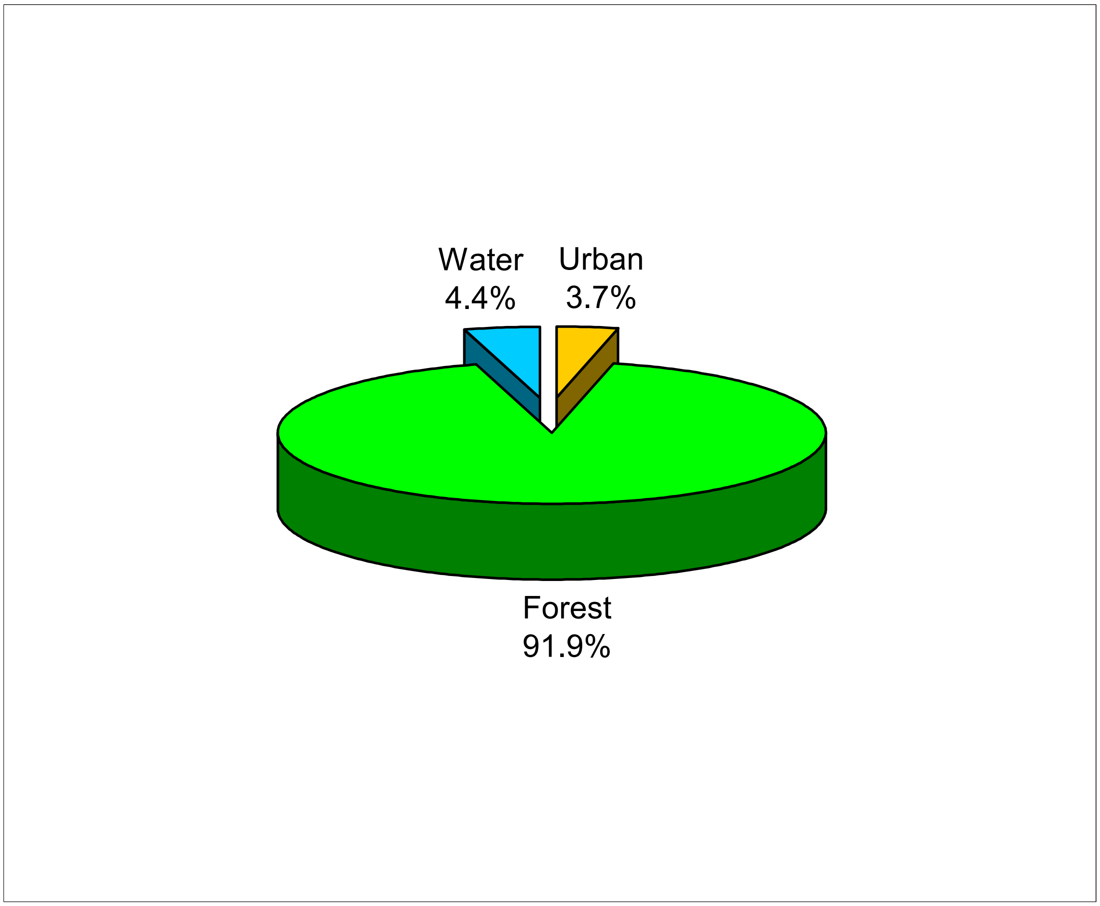

Figure 3: Land Use in Greenbrier Lake Watershed.

3.0 WATER QUALITY CHARACTERIZATION

A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

Maryland's water quality standards presently do not impose a limit on the concentration of nutrients in the water column[1]. Rather, Maryland manages nutrients indirectly by limiting their effects expressed in terms of excess algal growth and low dissolved oxygen (DO). Because biochemical

1 Maryland does limit the ammonia form of nitrogen from the Waste Water Treatment Plants due to its toxic effects on some aquatic organisms.

oxygen demand (BOD) also consumes DO, this potentially confounding factor must be considered in the analysis if low DO is observed.

The Maryland Surface Water Use Designation (Code of Maryland Regulations (COMAR) 26.08.02.07) for Greenbrier Lake is Use III-P—Natural Trout Waters and Public Water Supply. Use III-P waters are subject to a DO criterion of not less than 5.0 mg/l at any time, with minimum daily average of not less than 6 mg/l (COMAR 26.08.02.03-3E) unless natural conditions result in lower levels of DO (COMAR 26.08.02.03A).

Greenbrier Lake was listed in 1998 as impaired by nutrients on the basis of seasonally low oxygen levels in the lower portions of the lake. The DO concentration in the deeper portions of impoundments may fall below 5.0 mg/l in the summer months due to natural thermal stratification. The water quality data presented in this section will show that the designated use of this water body is being met as it relates to nutrients.

Maryland's general water quality criteria prohibit pollution of waters of the State by any material in amounts sufficient to create nuisance or interfere with designated uses (COMAR 26.08.02.03B(2)). Excessive eutrophication, indicated by elevated levels of chlorophyll *a*, can produce nuisance levels of algae and interfere with designated uses such as fishing and swimming. The Use III-P designation requires that Greenbrier Lake not become eutrophic. A maximum permissible chlorophyll *a* level of 10 µg/l will preserve and enhance the mesotrophic status of the impoundment. This corresponds approximately to a Carlson's Trophic State Index (TSI) of 53, which is at the boundary between mesotrophic and eutrophic condition (Carlson, 1977).

All readily available water quality data for the last five years pertaining to Greenbrier Lake were considered for this analysis. Water quality data from MDE surveys conducted at multiple depths at three stations within Greenbrier Lake during Summer 2001 were used to perform this analysis. This period encompasses the period of thermal stratification, a critical condition for Greenbrier Lake. Station LBC0048 lies approximately in the deepest part of the lake and is representative of conditions at various depths throughout the lake. Physical water quality parameters were assessed at all three stations, while nutrient and chlorophyll data were collected only at Station LBC0048.

3.1 Nutrients

During the sampling period, total phosphorus (TP) concentrations ranged from 0.0062 mg/l to 0.0097 mg/l, and total nitrogen (TN) concentrations ranged from 0.3660 mg/l to 0.3828 mg/l. The TN:TP ratio at Station LBC0048 ranged from 37.7 to 59.7, clearly indicating phosphorus limitation. The observed TP concentrations are associated with Carlson's TSI values in the range of 30 to 37, which is in the oligotrophic-mesotrophic region and well below the mesotrophic-eutrophic threshold at which the lake might be considered impaired. Tabular data are presented in Table A-1.

3.2 Dissolved Oxygen

Greenbrier Lake undergoes a period of distinct thermal stratification during summer months. This phenomenon is typical of lakes in the temperate region, where strong contrasts in seasonal conditions exist. During summer thermal stratification, the layers of the lake are highly resistant to mixing with each other. (Wetzel, 2001).

During the summer 2001 sampling period, DO concentrations measured at the surface ranged from 7.8 to 8.3 mg/l. DO concentrations in the deeper portions of the lake ranged as low as 0.4 mg/l. Figure 4 depicts a depth profile of temperature and DO at Station LBC0048 on August 7, 2001. These conditions are representative of maximum thermal stratification throughout the depth profile of the lake. Both temperature and DO decline discontinuously with depth, with an abrupt transition occurring between a depth of 3m and 6m. Above this region, both temperature and DO are relatively uniform (ranging respectively from 25.7 – 27.7 ^{o}C and 6.9 – 7.8 mg/l). Below 6m, these two parameters are similarly uniform, ranging from 8.5 – 13.4 ^{o}C and 0.5 – 1.0 mg/l, respectively. Within the 3 – 6m depth zone, temperature drops from 25.7 to 13.4^{o} C, and DO decreases from 6.9 to 0.5 mg/l. The temperature profile indicates a strong thermal stratification, which occurs naturally in many lakes and is often associated with natural hypolimnetic DO depletion. These observations are consistent with data collected at various times in the 1970s (Allison and Harman, 1979). Tabular data are presented in Table A-1.

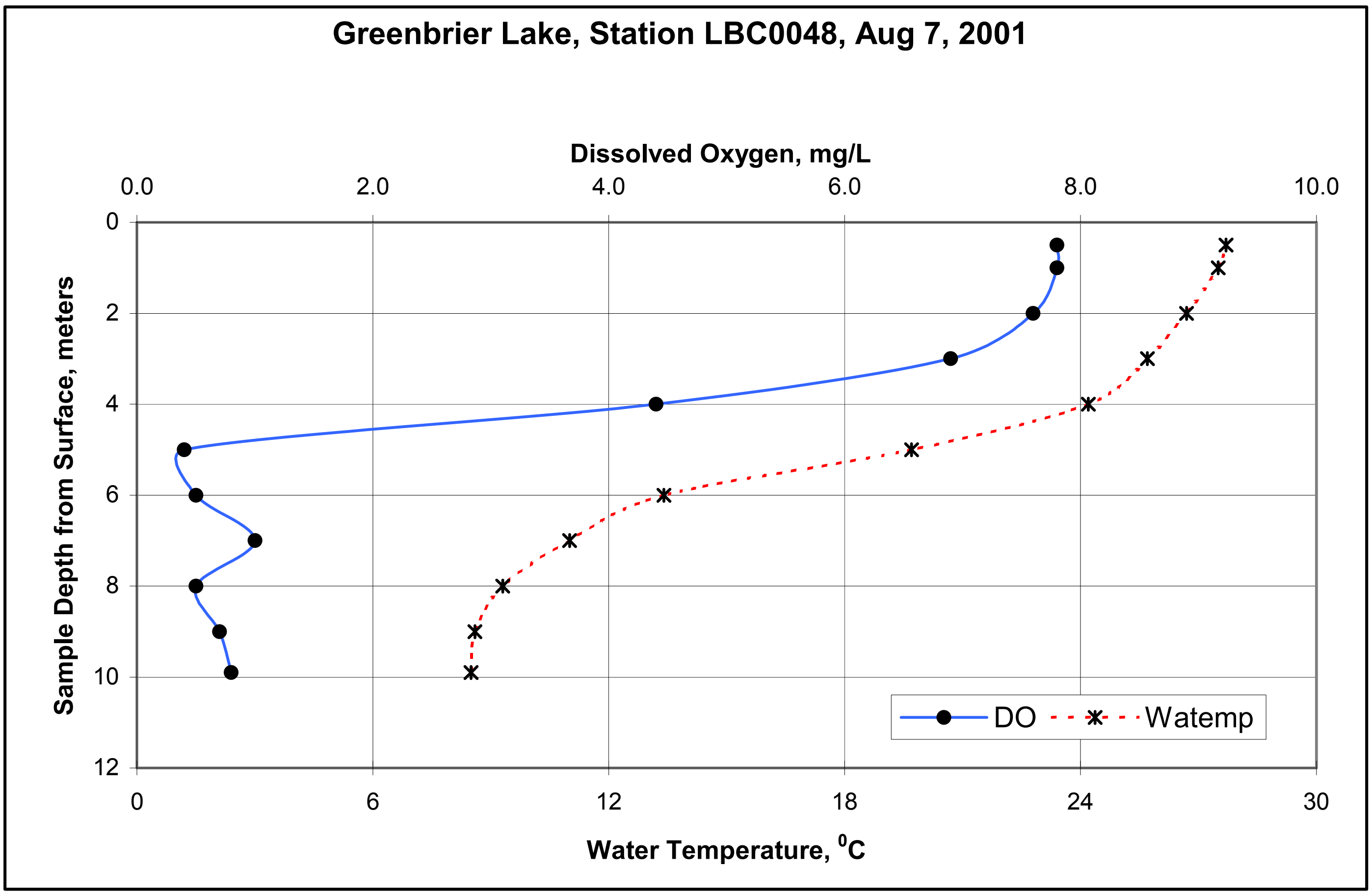

Figure 4: Depth Profile of Temperature and Dissolved Oxygen, Greenbrier Lake, August 7, 2001.

3.3 Chlorophyll *a*

Chlorophyll *a* data were collected at Station LBC0048 on July 19, July 24, August 2 and August 7, 2001. Chlorophyll *a* concentrations are typically at their peak in lakes during this time. Observed chlorophyll *a* concentrations are low, ranging from 1.35 – 2.14 µg/l, well below the water quality threshold of 10 µg/l associated with eutrophic conditions. These chlorophyll *a* concentrations are consistent with Carlson's TSI values ranging from 33.5 to 35.8, which are indicative of an oligotrophic to mesotrophic state.

3.4 Biochemical Oxygen Demand (BOD)

Because BOD also consumes DO, this potentially confounding factor must be considered in the analysis if low DO is observed. During the Summer 2001 sampling period, BOD concentrations were relatively low, ranging from 0.7 to 1.2. Given that over 90% of the lake's watershed is forested, such values could readily derive from natural organic inputs such as leaves and other forest detritus. Data are presented in Table A-1.

3.5 Water Clarity

During the sampling period in Summer 2001, Secchi depths at Station LBC0048 ranged from 3.8 to 5.1 m. These values correspond to Carlson's TSI values of 36.5 to 40.7, which are in the oligotrophic – mesotrophic range. The data are presented in Table A-2.

4.0 CONCLUSION

The data presented above clearly demonstrate that excessive algal growth does not exist in Greenbrier Lake, as indicated by low chlorophyll *a*. Measurements of TP concentrations, chlorophyll *a* levels, and Secchi depth are consistent in providing a trophic state assessment in the oligotrophic to mesotrophic range, which is compatible with the lake's designated use.

Low hypolimnetic DO concentrations are demonstrably the result of natural conditions, as evidenced by the occurrence of thermal stratification. The observed BOD concentrations are relatively low, and could indicate sufficient oxygen demand to result in the depletion of DO from the deepest regions of the lake only because the bottom waters are nearly completely cut off from any source of reoxygenation other than diffusion. More than 90% of the watershed is forested, with only a small amount (3.7%) of urban land and no agricultural land, minimizing the likelihood of anthropogenic nutrient loading. Hypoxia observed during the period of thermal stratification is thus not significantly different than what would occur under strictly natural conditions.

Based on the surveys conducted during 2001, the water quality data indicate that Greenbrier Lake has no eutrophication-related water quality impairments. Barring any contradictory future data, this information provides sufficient justification to revise Maryland's 303(d) list to remove nutrients as an impairing substance in relation to Greenbrier Lake.

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Appendix A: Tabular Water Quality Data

Table A-1: Physical and Chemical Water Quality Data at Greenbrier Lake.

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	SAMPLE DEPTH FROM SURFACE METERS	DEPTH WATER SAMPLE TAKEN METERS	DISSOLVED OXYGEN FIELD VALUE MG/L	WATER TEMPERATURE °C	BIOCHEMICAL OXYGEN DEMAND 5-DAY MG/L	TOTAL NITROGEN MG/L	TOTAL PHOSPHORUS MG/L	ACTIVE CHLOROPHYLL A µG/L
LBC0048	7/19/01	0.5	0.5	8.0	25.7	1.0	0.3828	0.0087	2.136
LBC0048	7/19/01	1		8.0	25.7				
LBC0048	7/19/01	2		8.0	25.6				
LBC0048	7/19/01	3		8.0	24.8				
LBC0048	7/19/01	4		6.2	19.9				
LBC0048	7/19/01	5		2.4	16				
LBC0048	7/19/01	6		1.3	12.1				
LBC0048	7/19/01	7		0.6	9.9				
LBC0048	7/19/01	8		0.7	8.7				
LBC0048	7/19/01	9		1.0	8.3				
LBC0048	7/19/01	9.6		1.8	8.3				
LBC0048	7/24/01	0.5	0.5	8.2	27.3				1.7088
LBC0048	7/24/01	1		8.2	27				
LBC0048	7/24/01	2		8.0	26.3				
LBC0048	7/24/01	3		7.3	25.9				
LBC0048	7/24/01	4		4.5	22.5				
LBC0048	7/24/01	5		1.1	16.3				
LBC0048	7/24/01	6		0.9	12.4				
LBC0048	7/24/01	7		1.0	9.4				
LBC0048	7/24/01	8.1		1.5	9				
LBC0048	8/2/01	0.5	0.5	8.3	25.6	1.2	0.366	0.0097	1.4952
LBC0048	8/2/01	1		8.4	25.2				
LBC0048	8/2/01	2		8.4	24.8				
LBC0048	8/2/01	3.2		8.1	24.2				
LBC0048	8/7/01	0.5	0.5	7.8	27.7	0.7	0.3698	0.0062	1.34568
LBC0048	8/7/01	1		7.8	27.5				
LBC0048	8/7/01	2		7.6	26.7				
LBC0048	8/7/01	3		6.9	25.7				
LBC0048	8/7/01	4		4.4	24.2				
LBC0048	8/7/01	5		0.4	19.7				
LBC0048	8/7/01	6		0.5	13.4				
LBC0048	8/7/01	7		1.0	11				
LBC0048	8/7/01	8		0.5	9.3				
LBC0048	8/7/01	9		0.7	8.6				
LBC0048	8/7/01	9.9		0.8	8.5				

LBC0049	7/19/01	0.5		7.9	25.7				
LBC0049	7/19/01	1		7.8	25.7				
LBC0049	7/19/01	2		7.8	25.6				
LBC0049	7/19/01	3.1		7.8	25.1				
LBC0049	7/24/01	0.5		8.4	27				
LBC0049	7/24/01	1		8.3	26.7				
LBC0049	7/24/01	2		8.0	26.3				
LBC0049	7/24/01	3		7.8	26.1				
LBC0049	7/24/01	4		5.9	23.7				
LBC0049	7/24/01	4.6		1.9	17.7				
LBC0049	8/2/01	0.5		8.2	25.3				
LBC0049	8/2/01	1		8.3	25.1				
LBC0049	8/2/01	2		8.4	24.9				
LBC0049	8/2/01	2.5		8.2	24.7				
LBC0049	8/7/01	0.5		7.9	27.8				
LBC0049	8/7/01	1		7.9	27.7				
LBC0049	8/7/01	2		7.6	27.2				
LBC0049	8/7/01	2.7		7.4	25.4				
LBC0050	7/19/01	0.5		8.1	25.6				
LBC0050	7/24/01	0.5		9.3	27.5				
LBC0050	8/2/01	0.5		9.2	25.6				
LBC0050	8/2/01	1		9.7	25.6				
LBC0050	8/7/01	0.5		9.2	28.1				

Table A-2: Secchi Depth at Greenbrier Lake.

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	SECCHI DEPTH METERS
LBC0048	07/19/2001	4
LBC0048	07/24/2001	5.1
LBC0048	08/02/2001	3.8
LBC0048	08/07/2001	4.3

Appendix B: Dissolved Oxygen Standards in Maryland's Thermally Stratified Lakes (Draft)

I. Introduction

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

New standards proposed 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 proposed standards for estuarine waters recognize three layers: (1) open water (surface); (2) deep water (below the upper pycnocline); and (3) deep channel (bottom waters).

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. The present document updates that interim interpretation, providing a framework for additional technical analyses with respect to hypolimnetic DO in thermally stratified lakes.

II. 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, 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; the temperature may decrease more or less continuously from the surface to the lake 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; 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 status2. 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 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.

III. Dissolved Oxygen Standards in Thermally Stratified Lakes in Maryland

MDE is adopting the following general approach to establish dissolved oxygen criteria 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 to stratification.

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

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

- Hypolimnetic hypoxia will be addressed on a case-by-case basis. In the event of observed hypoxia 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 inclusive, 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.

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