Water Quality Analysis
of Eutrophication for
Lake Bernard Frank, Montgomery County, MD

FINAL

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List of Abbreviations

CEES	Center for Estuarine and Environmental Science
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
COMAR	Code of Maryland Regulation
CWA	Clean Water Act
DHMH	Department of Health and Mental Hygiene
DNR	Department of Natural Resources
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
m	Meters
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
mg/l	Milligrams Per Liter
mi^2	Square miles
NCHF	North Central Hardwood Forest
NGP	Northern Glaciated Plain
NLF	Northern Lakes and Forest
T	Temperature
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
WCBP	Western Corn Belt Plains
WQLS	Water Quality Limited Segment
*u*g/l	Micrograms Per Liter

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (the Act) directs States 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. 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.

Lake Bernard Frank in the Rock Creek watershed (02-14-02-06) was identified on Maryland's 1998 list of WQLSs as being impaired by nutrients. This report provides an analysis of recent monitoring data, which shows that the dissolved oxygen criterion and designated uses associated with nutrients are being met in Lake Bernard Frank. This analysis supports the conclusion that a TMDL for nutrients is not necessary to achieve water quality standards in this case. Barring the receipt of any contradictory data, this report will be used to support the removal of Lake Bernard Frank from Maryland's list of WQLSs when MDE proposes the revision of the 303(d) list for public review in the future. Although Lake Bernard Frank does not display signs of impairment, the State reserves the right to require additional pollution controls in the Lake Bernard Frank watershed if evidence suggests that 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 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.

A segment identified as a WQLS might not require the development and implementation of a TMDL if current information contradicts the previous finding of an impairment. Based on EPA's guidance, reasons obviating the need for a TMDL include the following: (1) 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 waterbody attains standards; (3) refinements to water quality standards or the interpretation of those standards, resulting in the attainment of the standard; and (4) correction to or errors made in the original listing. Scenarios 1, 2 and 3 all apply to the present case.

Lake Bernard Frank in the Rock Creek watershed (02-14-02-06) was identified on Maryland's 1998 303(d) list of WQLSs as being impaired by nutrients. The 1998 listing was prompted by an assessment of data associated with Lake Bernard Frank (Maryland Department of Natural Resources [DNR] 1991). This report provides more recent information that supports the removal of the Lake Bernard Frank listing when the 303(d) list is revised.

The remainder of this report describes the general setting of the Lake Bernard Frank watershed, presents a discussion of the water quality characterization process, and provides conclusions with regard to the characterization. The data establish that Lake Bernard Frank achieves water quality standards.

2.0 GENERAL SETTING

Lake Bernard Frank is an impoundment located near Rockville in Montgomery County, Maryland (Figure 1). The impoundment, which is owned by the Maryland-National Capital Park and Planning Commission, lies on the north branch of Rock Creek, just upstream of the confluence with Rock Creek. An earthen dam was installed in 1967 for the purpose of flood control, sediment control, and recreation.

Lake Bernard Frank lies in the Piedmont physiographic province. The soils immediately surrounding the lake are the Glenelg-Gaila-Occoquan association (Soil Conservation Service, 1994). These soils generally range from fine-loamy, mixed, mesic Ochreptic Hapludults to mesic Typic Hapludults. They are very deep and well drained. They form in material weathered from quartz muscovite schist, schist and gneiss. The outer watershed area is comprised of soils of the Urban Land-Wheaton-Glenelg association. These soils are very deep and well drained (USDA, 1994).

Lake Bernard Frank lies in the Piedmont ecoregion, which lies between the Appalachian Mountains to the West and the Atlantic Coastal Plain on the East Coast. The Piedmont has a rolling to moderately hilly topography with variable soils. Common Piedmont land use includes forest, agriculture, and development. There are few natural lakes in this ecoregion (none in Maryland).

The North Branch of Rock Creek is the primary inflow to the Lake Bernard Frank. Discharge from the lake is also to the North Branch of Rock Creek, which discharges to Rock Creek. The watershed map (Figure 2) shows that land use in the watershed draining to Lake Bernard Frank is predominantly developed. Land use distribution in the watershed is approximately 53% developed, 30% forested/herbaceous, 16% agricultural, and 1% open water (Figure 3) (Maryland Department of Planning, 2000).

Table 1 - Current Physical Characteristics of Lake Bernard Frank

Location:	Montgomery County, MD lat. 39^{o} 06' 15" long. 77^{o} 07' 00"
Surface Area:	56 acres = (2,439,360 ft^2) = (226,626 m^2)
Length:	0.85 mi
Maximum Width:	950 feet
Average Lake Depth:	12.8 feet
Maximum Depth:	26.5 feet
Purpose	flood control, sediment control, and recreation
Basin Code	02-14-02-06
Volume of Lake:	716 acre-feet = (883,186 m^3)
Drainage Area to Lake:	12.2 mi^2
Average Discharge:	15.7 cfs

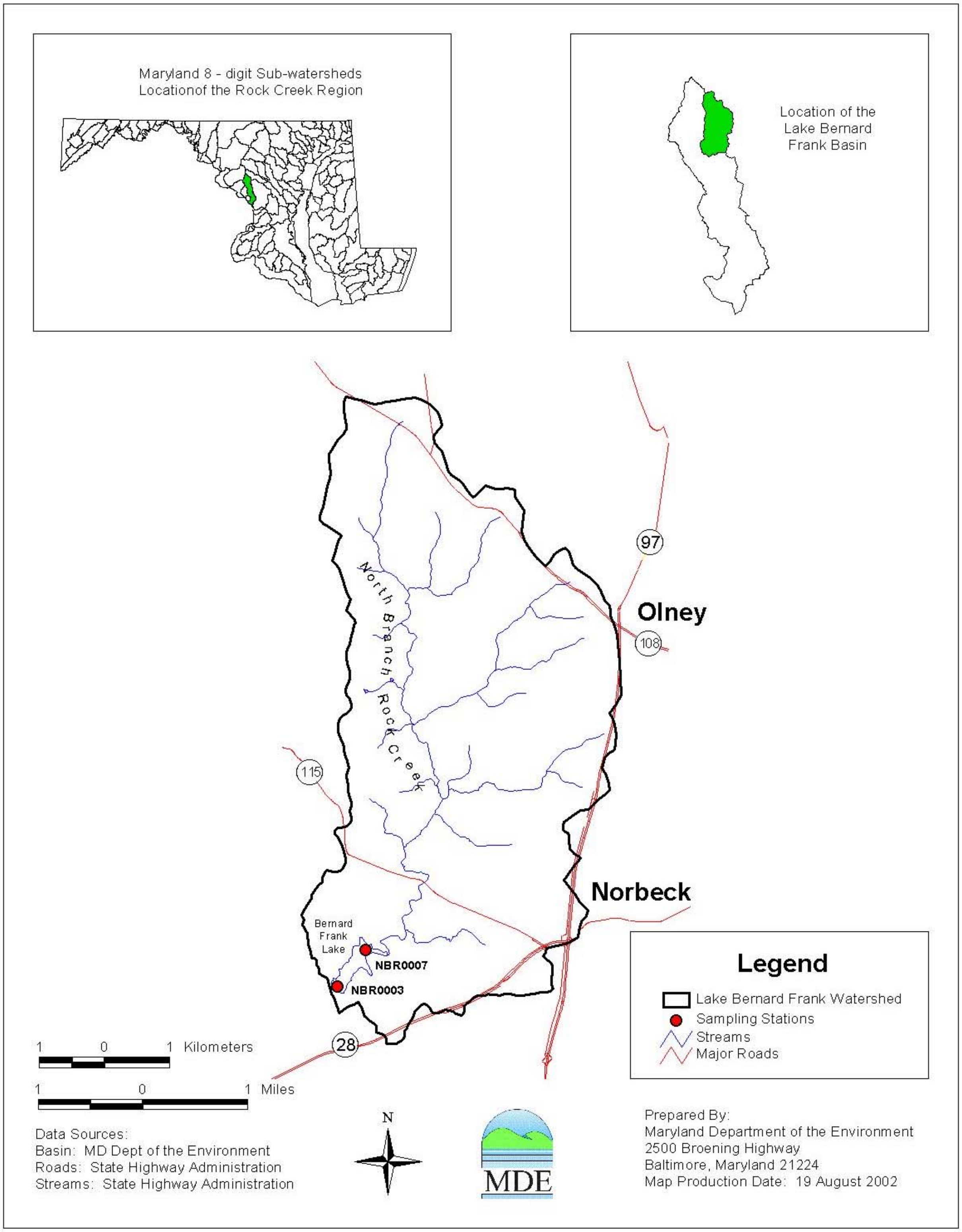

Figure 1 – Location Map of Lake Bernard Frank in Montgomery County, MD

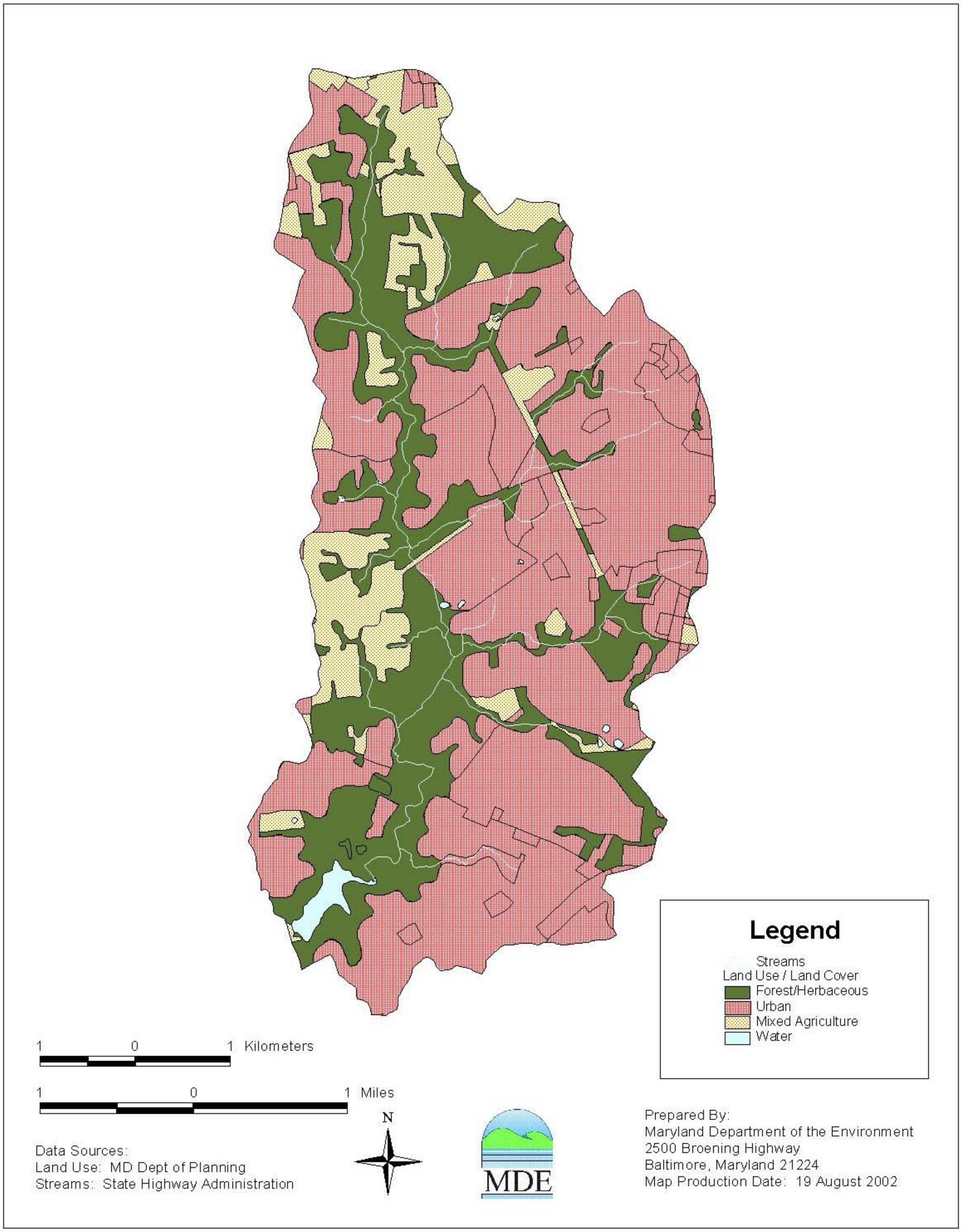

Figure 2 – Predominant Land Use in the Lake Bernard Frank Watershed

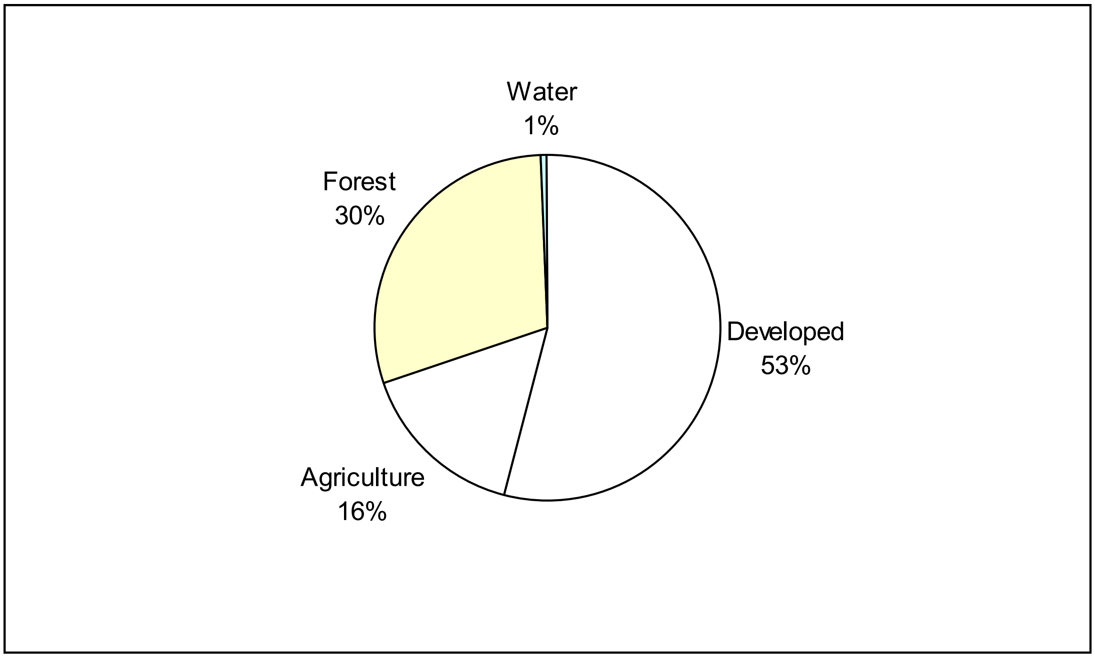

Figure 3 - Land Use in Drainage Basin of Lake Bernard Frank

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 established to protect that use. Designated uses include activities such as swimming, drinking water supply, and trout 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).

Lake Bernard Frank was identified in the *Maryland Lake Water Quality Assessment* (DNR, 1991) as having DO levels below the numeric criterion of 5.0 mg/l. As a result of this evaluation, Lake Bernard Frank was added to Maryland's 1998 303(d) list. DO levels below the applicable criterion were found to occur only in the subsurface waters.

Lake Bernard Frank has been designated a Use IV water body, pursuant to which it is protected for water contact recreation, fishing, aquatic life and wildlife, and holding and supporting adult trout for put-and-take fishing. See Code of Maryland Regulations (COMAR) 26.08.02.08(1). Use IV waters are subject to a DO criterion of not less than 5.0 mg/l at any time, unless natural

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

conditions result in lower levels of DO (COMAR 26.08.02.03A(2)). The DO concentration in the hypolimnion (subsurface waters) of Lake Bernard Frank occasionally falls below the criterion of 5.0 mg/l.

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. See 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 chlorophyll *a* endpoint selected for Lake Bernard Frank is a maximum concentration of 20 μg/l, or approximately 60 on the Carlson's Trophic State Index (TSI) (Carlson, 1977). This is in the lower range of eutrophy, which is an appropriate trophic state at which to manage this impoundment.

Other states have established their trophic-state for lakes or impoundments in a manner that is consistent with different uses. Minnesota, for example, uses an ecoregion-based approach. Heiskary (2000) reports that individuals utilizing lakes for recreational purposes (water contact, fishing) demanded relatively clear, less enriched lakes in the Northern Lakes and Forest (NLF) and North Central Hardwood Forest (NCHF) ecoregions. In the Western Corn Belt Plains (WCBP) and Northern Glaciated Plains (NGP) ecoregions; however, users accepted relatively greater enrichment and less clarity. Under Minnesota's classification system, lakes in the NLF and NCHF ecoregions are considered to fully meet use support with TSIs of about 53 and 57, respectively. Lakes in the other two ecoregions, both of which are largely agricultural, are considered to fully support use with TSIs of about 60 (Heiskary, 2000).

Because Lake Bernard Frank is not used as a drinking water source, the appropriate management goal is to protect the aquatic life and support recreational uses, *e.g.* fishing and boating. A moderate degree of eutrophication is compatible with these uses. A maximum chlorophyll *a* threshold of 20 μg/l represents an acceptable level at which nuisance algal blooms and excessive aquatic macrophyte growth will be kept in check.

Monitoring for the 1991 DNR lake assessment was conducted in June and August 1991. Physical measurements, including water temperature, pH, conductivity, and DO, were recorded at 0.3 m from the surface, at 0.3 m from the bottom, and at every whole meter in between. Secchi depth was recorded and water samples were collected 0.3 m from the water surface. The Maryland Department of Health and Mental Hygiene (DHMH) laboratory analyzed water samples for total phosphorus, total Kjeldahl nitrogen (TKN), and chlorophyll *a*. Detailed water quality data from the 1991 sampling events are presented in Table A1 of the Appendix.

MDE conducted additional monitoring of Lake Bernard Frank in July and August 2001. The monitoring included 3 in-lake stations in addition to 2 stream stations (inflow and outflow). In-lake physical measurements, including water temperature, pH, conductivity, and DO, were recorded at 0.5 m from the surface, at 1.0 m from the bottom, and at every whole meter in between. Secchi depth was recorded and water samples were collected 0.5 m from water surface. Measurements and samples from stream stations were conducted at the water surface. Flow measurements were also made at the stream stations. The University of Maryland Center for Estuarine and Environmental Science (CEES) laboratory conducted analyses on water samples for dissolved and particulate species of nitrogen, phosphorus, and carbon. The DHMH laboratory analyzed water samples for biological oxygen demand (BOD) and chlorophyll *a*. Detailed water quality data from the 2001 sampling events are presented in Table A2 through Table A4 of the Appendix.

3.1 Nutrients

Total phosphorus (TP) concentrations ranged from 0.02 mg/l to 0.04 mg/l in 1991, and 0.01 mg/l to 0.03 mg/l in 2001. TKN ranged from 0.50 mg/l to 0.55 mg/l in 1991, and 0.42 mg/l to 0.53 mg/l in 2001. Total nitrogen (TN) was not reported for the 1991 sampling event; TN in 2001 ranged from 0.46 mg/l to 0.80 mg/l in 2001.

3.2 Dissolved Oxygen

Water temperatures taken during the 1991 and 2001 decreased with depth, ranging from 29.4°C to 23.3°C in the 0.3 - 2 meter water column, and ranged from 26.7°C to 11.3°C in deep waters of the 3 - 6 meter water column. This wide range of water temperatures, and abrupt discontinuity at about 3 m, indicates that Lake Bernard Frank is thermally stratified and not well mixed. Thermal stratification is a natural phenomenon that occurs seasonally in deeper lakes. The stratification of lakes isolates the deep water from the surface water, preventing the exchange of oxygen. This results in some degree of low dissolved oxygen in the water below the layer of stratification.

DO concentrations ranged from 0.1 to over 13 mg/l along the vertical profile (Figures A1-A3 in Appendix I). Oxygen concentrations along the vertical profile decrease discontinuously, coincident with the depth at which thermal stratification was observed (*i.e*. about 3 m). Surface (0 - 2 m) DO concentrations between 7.2 and 13.8 mg/l are contrasted by DO concentrations as low as 0.1 mg/l at and below 3 m. Observed hypolimnetic DO concentrations fall below 10% saturation. Although this concentration is below 5.0 mg/l, it is consistent with natural conditions in the hypolimnia of stratified eutrophic lakes, which is documented in MDE's interim interpretation of the DO criterion for stratified lakes (see Appendix).

3.3 Chlorophyll *a*

A chlorophyll *a* concentration of 10 µg/l is typically associated with the boundary between eutrophic and mesotrophic states of a lake (Chapra, 1997). Instantaneous chlorophyll *a* concentrations ranging from 7.3 to 17.2 µg/l in 1991, and 5.8 to 12.8 µg/l in 2001, were observed in Lake Bernard Frank. The maximum observed values in Lake Bernard Frank, though associated with eutrophic conditions, are not extreme when compared to peak concentration of 275 µg/l in hyper-eutrophic lakes (Olem and Flock, 1990).

4.0 CONCLUSION

The data presented in this report suggest that there is no excessive algal growth in Lake Bernard Frank, as indicated by chlorophyll *a* concentrations below 20 ug/l. Similarly, dissolved oxygen concentrations meet standards for the surface of the lake, and is consistent with natural conditions in the hypolimnion. Barring any contradictory future data, this information provides sufficient justification to revise Maryland's 303(d) list to remove Lake Bernard Frank.

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Appendix
Lake Bernard Frank Water Quality Data

A study of Lake Bernard Frank was conducted in 1991 MDE Lake Water Quality Assessment Project. MDE also collected water data in 2001. A summary of the water quality data was provided in the main body of this report. Tables A1 through A4 provide the underlying data from which the summaries were derived.

Table A1. Table of 1991 DNR data.

Station	Date	Time	Depth	Secchi	w temp	pH	DO	TKN	TP	CHLA
NBR0003	6/11/91	1248	0.3		26.1	9.5	13.4			
NBR0003	6/11/91	1248	0.3					0.50	0.021	
NBR0003	6/11/91	1248	0.3							12.0
NBR0003	6/11/91	1248	0.3							8.8
NBR0003	6/11/91	1248	1.0		25.7	9.4	13.8			
NBR0003	6/11/91	1248	2.0		23.6	8.9	11.5			
NBR0003	6/11/91	1248	3.0		20.7	7.0	9.1			
NBR0003	6/11/91	1248	4.0		16.1	6.8	0.6			
NBR0003	6/11/91	1248	5.0		12.3	6.8	0.1			
NBR0003	6/11/91	1248	5.9		11.2	6.8	0.1			
NBR0003	6/11/91	1248		1.0						
NBR0007	6/11/91	1230	0.3		26.6	9.4	13.0			
NBR0007	6/11/91	1230	0.3					0.50	0.037	
NBR0007	6/11/91	1248	0.3							15.0
NBR0007	6/11/91	1248	0.3							17.2
NBR0007	6/11/91	1230	1.0		26.5	9.4	13.1			
NBR0007	6/11/91	1230	2.0		25.9	9.3	12.1			
NBR0007	6/11/91	1230	3.0		18.3	7.1	0.8			
NBR0007	6/11/91	1230		1.1						
NBR0003	8/14/91	1045	0.3		27.5	8.9	9.8			
NBR0003	8/14/91	1045	0.3					0.55	0.017	
NBR0003	8/14/91	1045	0.3							8.7
NBR0003	8/14/91	1045	0.3							9.7
NBR0003	8/14/91	1045	1.0		27.4	8.8	9.8			
NBR0003	8/14/91	1045	2.0		27.3	8.4	8.9			
NBR0003	8/14/91	1045	3.0		26.4	7.1	8.1			
NBR0003	8/14/91	1045	4.0		23.1	6.7	0.1			
NBR0003	8/14/91	1045	5.0		19.5	6.6	0.1			
NBR0003	8/14/91	1045	5.7		17.0	6.6	0.1			
NBR0003	8/14/91	1045		2.1						
NBR0007	8/14/91	1045	0.3							8.1
NBR0007	8/14/91	1045	0.3							7.3
NBR0007	8/14/91	1100	0.3		27.5	8.7	9.6			
NBR0007	8/14/91	1100	0.3					0.50	0.017	
NBR0007	8/14/91	1100	1.0		27.4	8.7	9.6			
NBR0007	8/14/91	1100	2.0		27.3	8.5	9.2			
NBR0007	8/14/91	1100	3.0		26.7	7.4	6.1			
NBR0007	8/14/91	1100		2.2						

Table A2. Table of 2001 MDE physical data.

Station ID	Date	Time	Depth	Secchi depth M	Dissolved oxygen MG/L	Conductivity µMHOS/CM	pH	water temperature °C
NBR0003	07/18/2001	11:35	0.5	1.4	10.8	131	9.3	27.2
NBR0003	07/18/2001	11:35	1	1.4	10.6	130	9.3	27.2
NBR0003	07/18/2001	11:35	2	1.4	13.7	127	9.3	23.3
NBR0003	07/18/2001	11:35	3	1.4	0.1	120	6.7	19.1
NBR0003	07/18/2001	11:35	4	1.4	0.1	172	6.8	15.5
NBR0003	07/18/2001	11:35	5	1.4	0.1	231	6.9	12.3
NBR0003	07/18/2001	11:35	5.5	1.4	0.1	253	6.9	11.3
NBR0005	07/18/2001	11:57	0.5	1.4	10.6	131	9.3	27.2
NBR0005	07/18/2001	11:57	1	1.4	10.7	131	9.3	27.1
NBR0005	07/18/2001	11:57	2	1.4	12.3	140	8.6	23.9
NBR0005	07/18/2001	11:57	3	1.4	0.1	131	6.8	18.8
NBR0005	07/18/2001	11:57	3.8	1.4	0.2	163	6.9	16.2
NBR0007	07/18/2001	11:50	0.5	1.4	10.5	131	9.2	27.1
NBR0007	07/18/2001	11:50	1	1.4	10.1	131	9.1	26.9
NBR0007	07/18/2001	11:50	2	1.4	8.9	146	7.7	24.5
NBR0003	07/23/2001	9:37	0.5	0.7	12.6	138	9.5	26.9
NBR0003	07/23/2001	9:37	1	0.7	12.2	138	9.4	26.8
NBR0003	07/23/2001	9:37	2	0.7	12	134	8.7	24.2
NBR0003	07/23/2001	9:37	3	0.7	0.4	124	6.6	19.6
NBR0003	07/23/2001	9:37	4	0.7	0.5	173	6.8	15.8
NBR0003	07/23/2001	9:37	5	0.7	0.6	244	6.8	12.3
NBR0003	07/23/2001	9:37	5.6	0.7	0.7	268	6.9	11.3
NBR0005	07/23/2001	10:00	0.5	0.9	12.5	139	9.5	27
NBR0005	07/23/2001	10:00	1	0.9	12	140	9.3	26.7
NBR0005	07/23/2001	10:00	2	0.9	9.6	145	7.9	24.7
NBR0005	07/23/2001	10:00	3	0.9	0.3	137	6.8	19.7
NBR0005	07/23/2001	10:00	3.7	0.9	0.4	168	7	16.6
NBR0007	07/23/2001	9:50	0.5	0.8	11.5	139	9.3	26.7
NBR0007	07/23/2001	9:50	1	0.8	10.9	140	9.2	26.6
NBR0007	07/23/2001	9:50	1.6	0.8	10.8	141	9.1	26.2
NBR0003	07/31/2001	9:50	0.5	1.4	7.9	136	8.4	24.8
NBR0003	07/31/2001	9:50	1	1.4	7.8	136	8.4	24.7
NBR0003	07/31/2001	9:50	2	1.4	7.2	136	8.1	24.6
NBR0003	07/31/2001	9:50	3	1.4	2.1	120	6.4	21.7
NBR0003	07/31/2001	9:50	4	1.4	0.6	159	6.4	16.4
NBR0003	07/31/2001	9:50	5	1.4	0.6	208	6.4	13.5
NBR0003	07/31/2001	9:50	5.7	1.4	0.7	249	6.4	11.7
NBR0005	07/31/2001	10:12	0.5	1.3	7.9	137	8.4	24.8
NBR0005	07/31/2001	10:12	1	1.3	7.9	137	8.4	24.8
NBR0005	07/31/2001	10:12	2	1.3	7.5	137	8.3	24.7
NBR0005	07/31/2001	10:12	3	1.3	3.9	150	6.7	21.9
NBR0005	07/31/2001	10:12	4.2	1.3	0.7	169	6.5	16.3

NBR0007	07/31/2001	10:05	0.5	1.1	7.8	137	8.3	24.8
NBR0007	07/31/2001	10:05	1	1.1	7.8	137	8.3	24.7
NBR0007	07/31/2001	10:05	2	1.1	7.3	138	7.8	24.5
NBR0003	08/08/2001	9:07	0.5	1.5	9.8	138	8.5	29.4
NBR0003	08/08/2001	9:07	1	1.5	9.7	138	8.5	29.3
NBR0003	08/08/2001	9:07	2	1.5	12.1	137	8.5	27.1
NBR0003	08/08/2001	9:07	3	1.5	5.7	126	6.1	22
NBR0003	08/08/2001	9:07	4	1.5	2.2	157	5.9	12.3
NBR0003	08/08/2001	9:07	5.3	1.5	2.7	234	6	12.7
NBR0005	08/08/2001	9:17	0.5	1.1	9.5	139	8.4	29.4
NBR0005	08/08/2001	9:17	1	1.1	9.6	139	8.4	29.1
NBR0005	08/08/2001	9:17	2	1.1	9	142	7.4	26.9
NBR0005	08/08/2001	9:17	3	1.1	3.7	138	6.1	22.3
NBR0005	08/08/2001	9:17	4	1.1	2.8	177	6.1	16.8
NBR0007	08/08/2001	9:25	0.5	1.2	9.4	140	8.4	29.2
NBR0007	08/08/2001	9:25	1	1.2	9	140	8.3	29.1
NBR0007	08/08/2001	9:25	2.1	1.2	4.8	146	6.4	26.4

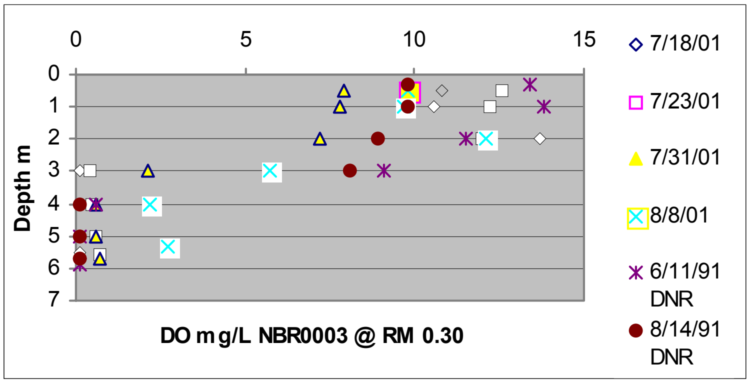
Table A3. 2001 MDE in-lake nutrient data.

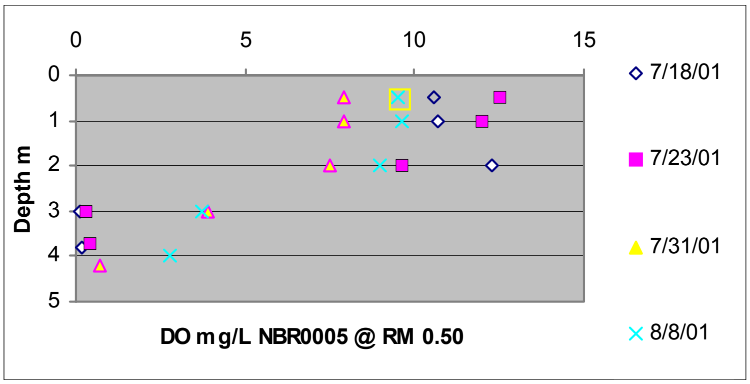
Station ID	Date	Time	BOD	NH4	NO2/ NO3	TKN	TN	PO4	TP	TSS	CHLA
NBR0003	7/18/01	11:35	2	0.007	0.229	0.519	0.762	0.0019	0.019	2.8	10.96
NBR0003	7/18/01										11.66
NBR0003	7/23/01	9:37									11.96
NBR0003	7/23/01										11.96
NBR0003	7/31/01	9:50	1.9	0.037	0.139	0.428	0.641	0.0031	0.0254	2.4	7.23
NBR0003	7/31/01										8.22
NBR0003	8/8/01	9:07	2.4	0.0103	0.0137	0.4218	0.4561	0.0007	0.0142	2.8	6.13
NBR0003	8/8/01										5.83
NBR0005	7/18/01										
NBR0005	7/23/01										
NBR0005	7/31/01										
NBR0005	8/8/01										
NBR0007	7/18/01	11:50	2.2	0.006	0.257	0.531	0.8	0.002	0.0221	3.6	11.46
NBR0007	7/18/01										12.86
NBR0007	7/23/01	9:50									13.46
NBR0007	7/23/01										14.95
NBR0007	7/31/01	10:05	2.7	0.03	0.148	0.467	0.675	0.0019	0.0245	2.4	8.97
NBR0007	7/31/01										9.72
NBR0007	8/8/01	9:25	1.8	0.0129	0.033	0.4549	0.5137	0.0007	0.0152	2	5.53
NBR0007	8/8/01										5.83

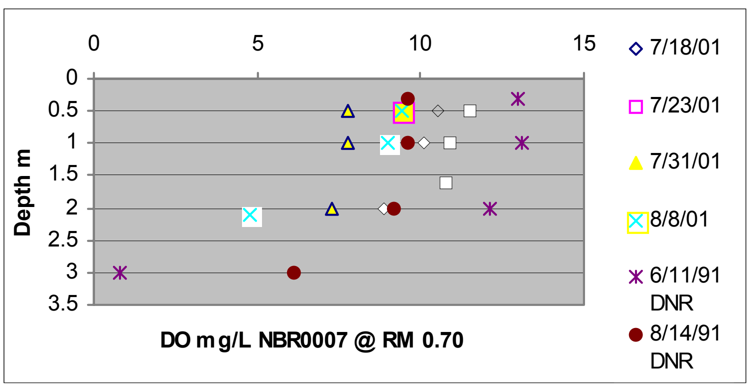
Table A4. 2001 MDE stream data.

Date	Time	Flow CFS	DO MG/L	Cond µMHO/ CM	pH	Water temp C	BOD	NH4 MG/L	NO2/ NO3 MG/L	TN MG/L	PO4 MG/L	TP MG/L	TSS MG/L	CLHA UG/L
Station NBR0002 below lake														
10/17/00	8:53	2.45	8.5	170	6.9	16.3	6	0.7409	0.3224	1.7251	0.0012	0.1015	4.3	21.38
11/15/00	9:40	3.93	9.7	165	7.5	10.3		0.2899	0.2607	1.1276	0.0038	0.0585	5.8	17.64
12/5/00	10:25		11.8	149	7.7	4.5	1	0.252	0.3918	1.1012	0.0076	0.0378	3.43	19.22
1/9/01	9:15	5.54	13.5	184	7.4	3		0.1112	0.838	1.3014	0.0153	0.0671	8	20.19
2/6/01	11:30	21.12	12.2	276	7.2	3.5	1	0.11	1.1063	1.6801	0.0026	0.0355	5	6.58
3/20/01	10:25	8.53	11.8	299	7.5	8.1		0.0536	1.1341	1.44905	0.0011	0.0223	4.2	9.42
4/17/01	8:50	4.36	10.9	180	7.5	12.7	8	0.0385	0.8957	1.5532	0.0077	0.0449	5.4	0.75
5/15/01	9:30	5.01	8.4	181	7.4	18.6		0.1586	0.7816	1.2591	0.0039	0.0186	2.14	3.14
6/19/01	9:55	5.26	7.9	132	8.4	24.4	2	0.1086	0.4405	1.0141	0.0045	0.0326	3.8	12.86
7/24/01	8:35	1.68	5.6	148	7.2	25.1		0.5507	0.1637	1.2117	0.009	0.042	4.33	10.47
8/7/01	8:45	1.38	5	165	7.1	24.9	3.5	1.0472	0.1056	1.7553	0.0051	0.0447	4.75	12.21
Station ZNB0016 above lake														
10/17/00	9:35	1.21	8.9	170	7.1	14	1	0.007	1.6713	1.8193	0.0007	0.0277	2.6	0.60
11/15/00	9:23	2.53	10.7	168	7.4	6.9		0.0024	1.1265	1.22495	0.0061	0.0207	1	1.20
12/5/00	9:40	2.54	13.6	144	7.6	0.4	1	0.0064	1.7708	1.8976	0.0247	0.0361	0.71	0.90
1/9/01	9:50	2.99	13.9	521	7.3	-0.1		0.0472	2.2182	2.3643	0.0055	0.0151	4.2	0.45
2/6/01	10:40	11.57	13	347	7.3	2.7	1	0.0204	1.1038	1.5359	0.0059	0.0381	8.75	2.49
3/20/01	10:05	6.22	12.5	168	7.4	5.4		0.0127	1.6689	1.76275	0.0033	0.0178	2.6	0.90
4/17/01	9:45	3.27	10.9	160	7.5	8.9	5	0.0056	1.2253	1.6161	0.0055	0.0303	5.6	2.99
5/15/01	9:05	3.05	9.8	165	7.3	12.2		0.0504	1.6768	1.9217	0.0095	0.0317	7.43	1.35
6/19/01	9:25	3.50	8.5	154	7.4	19.4	1	0.0289	1.5134	1.7667	0.0125	0.0414	10.8	0.90
7/24/01	9:25	0.84	7.9	162	7.2	21.6		0.0143	1.6072	1.696	0.013	0.0226	4	0.90
8/7/01	9:25	1.38	7.5	169	7.5	22.5	0.9	0.0164	1.2934	1.536	0.0134	0.0291	9.2	1.50

Figures A1-A3. DO profiles for 2001 MDE lake stations.







Supporting Determination of the Expected Minimum DO Below the Epilimnion

As noted in the main body of this document, observed DO concentrations in the surface waters currently meets State standards. The following analysis provides a linkage between the maximum allowable phosphorus load, as specified by the Vollenweider Relationship, and the assurance of meeting DO criteria in the lake's sub-epilimnetic waters.

During periods of thermal stratification in a lake, DO concentration below the epilimnion is largely determined by the relationship between trophic status and the saturation potential of oxygen. Because DO concentration is a function of temperature, the minimum allowable DO concentration cannot be specified *per se*, but can be determined graphically by reading the expected DO concentration at a specified percent saturation from a published nomogram.

Chapra (1997) presents ranges of hypolimnetic DO saturation as a function of trophic status in eutrophic, mesotrophic and oligotrophic lakes (Table A-5). MDE (1999) has adapted and extended this methodology to apply to the two additional trophic categories—oligo-mesotrophic and meso-eutrophic—used to classify Maryland's lakes (Table A-6).

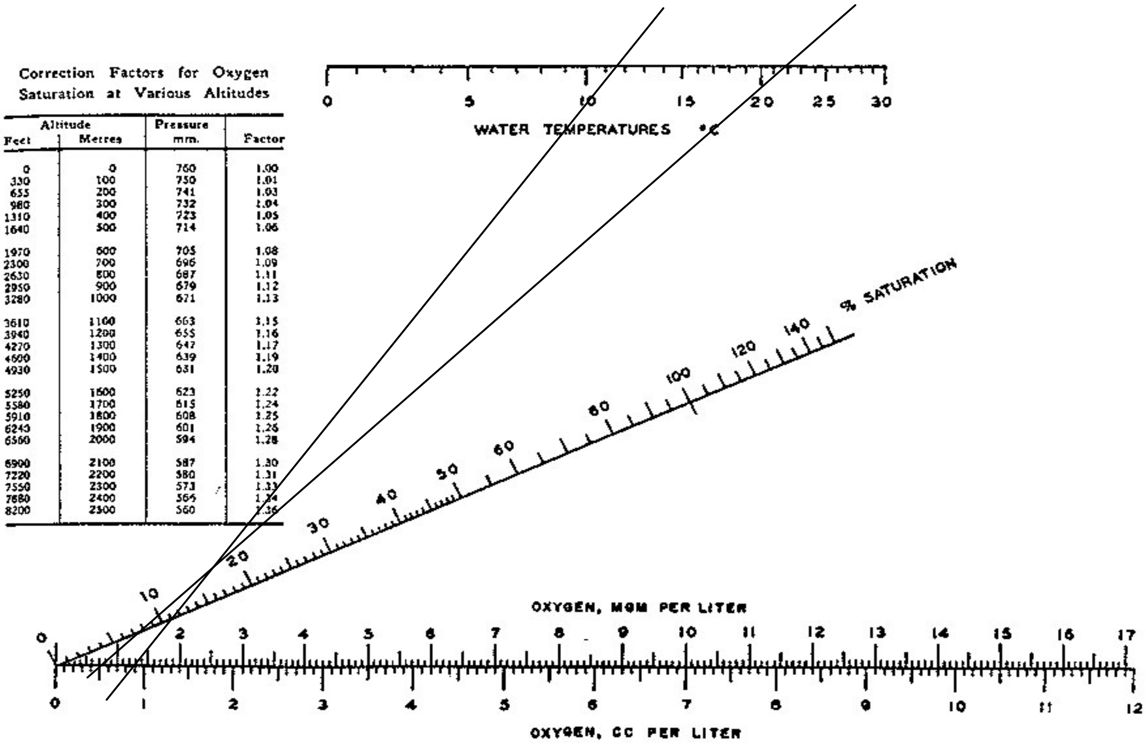
Table A-5

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)

Because DO concentration is a function of water temperature, a single expected DO concentration cannot be predicted. However, the nomogram in Figure A-4 may be used to determine a range of dissolved oxygen concentrations expected for a given temperature range. Equation (1) below presents an equivalent, computational method. The observed hypolimnetic DO concentrations in Lake Bernard Frank are consistent with the interim interpretation of Maryland's water quality criterion for dissolved oxygen in thermally stratified lakes (MDE, 1999).



Correction Factors for Oxygen Saturation at Various Altitudes

Altitude Feet	Altitude Metres	Pressure mm.	Factor
0	0	760	1.00
330	100	750	1.01
655	200	741	1.03
980	300	732	1.04
1310	400	723	1.05
1640	500	714	1.06
1970	600	705	1.08
2300	700	696	1.09
2630	800	687	1.11
2950	900	679	1.12
3280	1000	671	1.13
3610	1100	663	1.15
3940	1200	655	1.16
4270	1300	647	1.17
4600	1400	639	1.19
4930	1500	631	1.20
5250	1600	623	1.22
5580	1700	615	1.24
5910	1800	608	1.25
6240	1900	601	1.26
6560	2000	594	1.28
6900	2100	587	1.30
7220	2200	580	1.31
7550	2300	573	1.33
7880	2400	565	1.34
8200	2500	560	1.36

Figure A4. Nomogram (adapted from Reid 1961) showing expected sub-epilimnetic DO concentrations at ambient temperatures in Lake Bernard Frank during periods of stratification.

Equation (1) (Benson and Krause 1980, *in* Mortimer 1981).

$$\ln C^* = -139.34410 + (1.575701x10^5 / T) - (6.642308x10^7 / T^2) + (1.243800x10^{10} / T^3) - (8.621949x10^{11} / T^4)$$