# Total Maximum Daily Loads of Phosphorus and Sediments to Urieville Community Lake, Kent County, MD

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# PREFACE

Section 303(d) of the federal Clean Water 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 establish a Total Maximum Daily Load (TMDL) of the specified substance that the water can receive without violating water quality standards.

On the basis of water quality problems associated with Urieville Lake, the Middle Chester River watershed was identified on Maryland's 1996 list of WQLSs as being impaired by nutrients and sediments. This report proposes the establishment of two TMDLs for Urieville Lake: one for excess sedimentation and one for phosphorus.

Once the TMDLs are approved by the United States Environmental Protection Agency (EPA), they will be incorporated into the State's Continuing Planning Process. In the future, the established TMDLs will support reservoir restoration and nonpoint source control measures needed to restore water quality in Urieville Lake.

## EXECUTIVE SUMMARY


On the basis of water quality problems associated with Urieville Lake, the Middle Chester River watershed (02130509) was identified on Maryland's 1996 list of WQLSs as being impaired by nutrients and sediments. This document establishes Total Maximum Daily Loads (TMDLs) for the nutrient phosphorus and sediments entering Urieville Lake.

Urieville Lake is an impoundment on Morgan Creek, a tributary of the Middle Chester River. The Chester River lies in the Upper Eastern Shore Tributary Strategy Basin, which drains to the Chesapeake Bay. Urieville Lake is impacted by a high sediment load, which has resulted in excessive sedimentation of the reservoir. The lake also experiences regular nuisance seasonal algae blooms, excessive plant growth, and foul odors, which interfere with direct contact and recreational uses of the lake. The death and decay of excessive algae can cause violations of the water quality standard for dissolved oxygen (DO), which can result in a disruption of the lake's ecosystem balance and cause fish kills. Phosphorus is most likely the limiting nutrient for the production of algae in freshwater lake systems such as Urieville Lake. Due to the propensity of phosphorus to bind to sediments, the overall strategy is to simultaneously address the water quality problems associated with phosphorus and sediments.

The water quality goal of this TMDL is to reduce long-term phosphorus loads to a permissible enrichment level consistent with the physical characteristics of Urieville Lake. This reduced loading rate is predicted to resolve excess algae problems and maintain dissolved oxygen concentration above the State water quality standard. The TMDL for phosphorus was determined using an empirical method known as the Vollenweider Relationship. Because the reduction of sediments is a component of controlling external phosphorus loads, a sediment loading rate, consistent with narrative water quality criteria, is predicted to be achieved.

The average annual TMDL for phosphorus is about 509 lb/yr. There are no point sources in the Urieville basin. Consequently, the allocation is partitioned between nonpoint sources and the Margin of Safety. For sediments, the TMDL is established to achieve a reasonable loading rate predicted to occur as a result of the proposed control of phosphorus. This loading rate is estimated to result in preserving 76% of the reservoir's design volume over a period of 40 years.

Preliminary estimations of the phosphorus controls necessary to achieve the load reduction were conducted to provide a reasonable assurance that the TMDLs could be implemented. Because this lake has significant loading rates, it is estimated that an 85 percent reduction in phosphorus loads would be necessary to meet the TMDL for phosphorus. This challenging goal can be put into perspective in two regards. First, the percentage of nutrient reduction associated with standard agricultural best management practices (BMPs) is greatest for easily erodible soils, which are present in the Urieville drainage basin. Second, if this goal is an overestimate of the necessary load reductions, it can be refined using better data and analysis tools, while initial steps are taken to reduce the loads.

# 1.0 INTRODUCTION

The Clean Water Act Section 303(d)(1)(C) and federal regulation 40 CFR 130.7(c)(1) direct each State to develop a Total Maximum Daily Load (TMDL) for all impaired waters on their Section 303(d) list. A TMDL reflects the maximum pollutant loading of the impairing substance a water body can receive and still meet water quality standards. A TMDL can be expressed in mass per time, toxicity, or any other appropriate measure (40 CFR 130.2(i)). TMDLs must take into account seasonal variations and a margin of safety (MOS) to allow for uncertainty. Maryland's 1996 303(d) list, submitted to EPA by the Maryland Department of the Environment (MDE), lists the Middle Chester River watershed segment (02130509) for nutrients and sediments. That 1996 listing was prompted by quantitative data associated with Urieville Lake (MDE, Lake Water Quality Assessment Project, 1993).

In 1996, the Maryland Department of Natural Resources (DNR) published a Phase I study of Urieville Lake to meet requirements of 40 CFR 35, Appendix A "Guidance for Diagnostic-Feasibility Studies." The goals of the study were "to document impaired use problems at Urieville Lake, determine the causes in the watershed and within the impoundment of impaired use, develop a lake management plan to alleviate problems and restore the lake to its full recreational potential." The results clearly indicate excessive sedimentation and severe algal blooms as a result of high nonpoint source loadings coming principally from agricultural land.

This document is not intended to replicate or update the 1996 DNR Phase I study of Urieville Lake. The reader is referred to the Phase I study for a more in-depth discussion of the chronology of activities and studies relating to Urieville Lake. The limited purpose of this document is to establish TMDLs for phosphorus and sediments entering Urieville Lake, as required by Section 303(d) of the Clean Water Act.

# 2.0 SETTING AND WATER QUALITY DESCRIPTION

## 2.1 General Setting and Source Assessment

Urieville Lake is a small, Y-shaped impoundment located near Kennedyville in Kent County, Maryland (Figure 1). The impoundment lies on Morgan Creek, a tributary of the Middle Chester River. The Chester River lies in the Upper Eastern Shore Tributary Strategy Basin, which drains to the Chesapeake Bay (MDE, May 1995). The impoundment, owned by the State of Maryland, was constructed prior to the Revolutionary War and originally served as a mill pond. The current concrete dam and earthen dike were constructed during 1955 to restore the impoundment and to function as a base for MD Route 213. The dam at Urieville Lake is the designated dividing line between tidal and non-tidal waters in Morgan Creek of the Chester River.

Inflow to the lake is primarily via three unnamed tributaries. Discharge from the lake is to Morgan Creek, which flows southwesterly to the Chester River. The watershed map, Figure 2, shows that land use in the watershed draining to Urieville Lake is primarily agricultural. Land use distribution in the watershed is approximately 80% agricultural, 18% forested, and 2%

developed (Figure 3). No point source discharge permits have been issued in the Urieville Lake Watershed.

Natural background sources of phosphorus and sediments are included in the assessment. The loads associated with each land use category include the naturally occurring as well as the human-induced contributions. The model uses water quality data to estimate the loading rates, which represent the cumulative impact from all sources—naturally-occurring and human-induced. Atmospheric sources of sediments and phosphorus due to wind erosion are considered insignificant because the ratio of the watershed area to the surface area of the lake is large (5200 acres/33.7 acres).

Soils in the watershed are of the Matapeake-Sassafras association, Mattapex-Matapeake-Butlertown association, and Sassafras-Bibb-Colts Neck association. These are well-drained alluvial soils with a high clay and silt content. The soils are easily eroded, having erosion factors in the range of 0.2 – 0.43 (DNR, October 1996).

Several relevant statistics for Urieville Lake are provided below in Table 1. Note that several of the lake's physical characteristics are described for both current and 1955 conditions, which differ due to the effects of significant sedimentation. Since a large volume of the lake has been lost to sedimentation, the TMDLs are developed under the assumption that the lake will be dredged to restore its approximate 1955 physical dimensions.

**Table 1**

**Current Physical Characteristics of Urieville Lake**

| | |
|---|---|
| Location: | Kent County, MD lat. 39$^{o}$ 16' 45" long. 76$^{o}$ 01' 30" |
| Surface Area: | 10.4 ha (25.6 acres)* 13.6 ha (33.7 acres)** |
| Length: | 0.8 miles (Lake is Y-shaped, See Figure 1) |
| Maximum Width: | 500 feet |
| Average Lake Depth: | 3.5 feet*, 3.6 feet** |
| Maximum Depth: | 6 feet |
| Permanent Pool Elevation: | 3.96 m (13 feet) above mean sea level |
| Drainage Area to Lake: | 5200 acres |
| Average Discharge: | 11.7 cfs |

* Current conditions
** Original Design Conditions (1955)

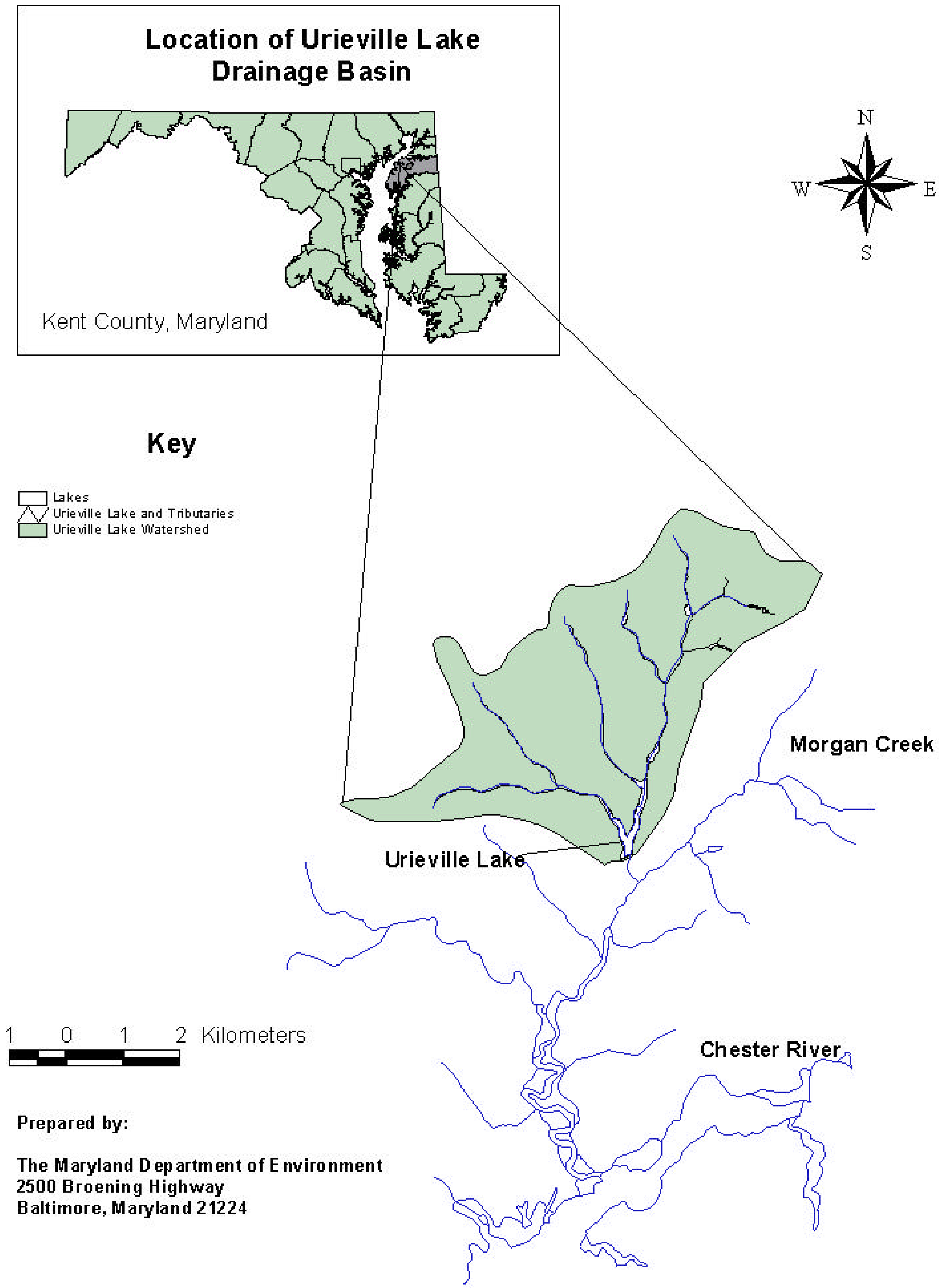
Location of Urieville Lake
Drainage Basin
Kent County, Maryland
N
W
E
S
Key
Lakes
Urieville Lake and Tributaries
Urieville Lake Watershed
Morgan Creek
Urieville Lake
Chester River
1 0 1 2 Kilometers
Prepared by:
The Maryland Department of Environment
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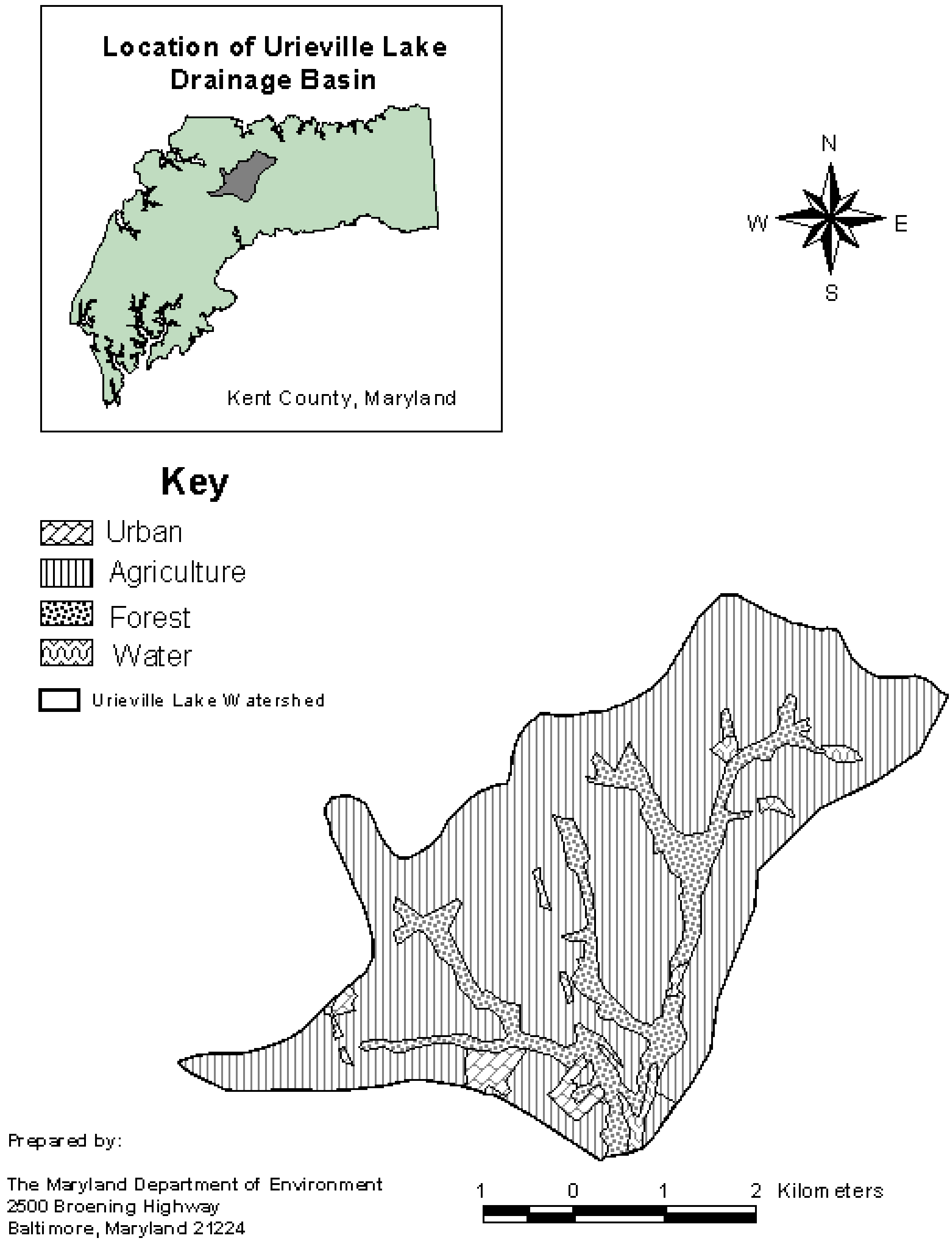
Figure 1


Location of Urieville Lake
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2500 Broening Highway
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1 0 1 2 Kilometers

Figure 2

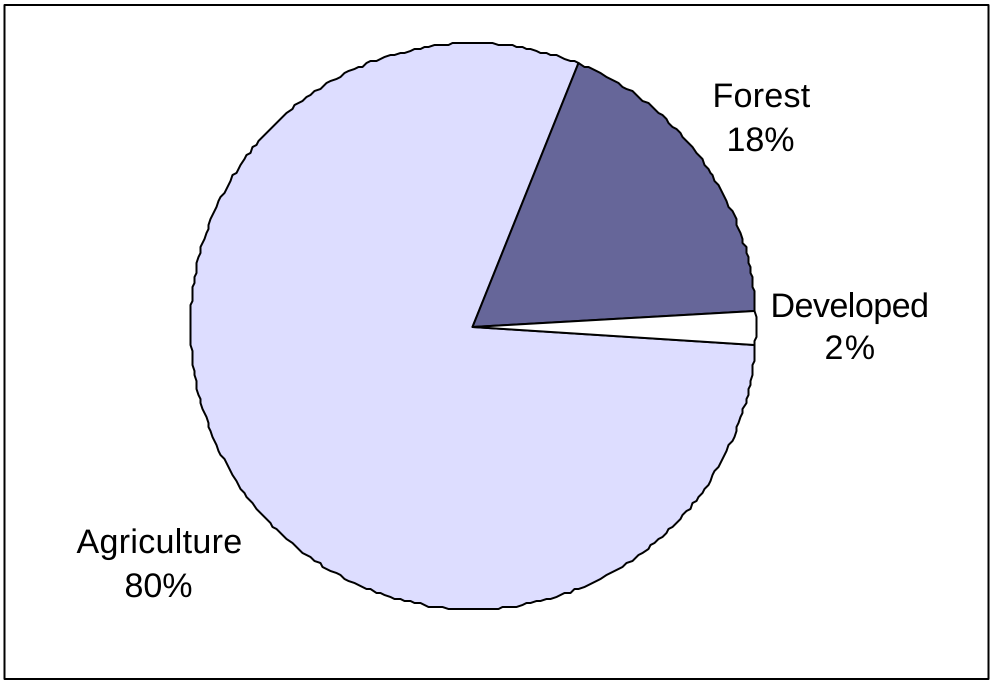


**Figure 3. Land Use in Drainage Basin of Urieville Lake**

### 2.2 Water Quality Characterization

Urieville Lake was identified as eutrophic and use-impaired in Maryland's 1994 biennial state water quality report (Clean Water Act Section 305 (b) Report) to the U. S. Environmental Protection Agency (EPA). Impaired usage stemmed from sedimentation and nutrient enrichment, causing excessive aquatic plant and algae growth. Water quality sampling was conducted at Urieville during 1993 by the MDE Lake Water Quality Assessment Project to update trophic status. Dissolved oxygen was depleted during the sampling period, and the lake's surface was completely covered with watermeal and duckweed, which is common each summer.

Urieville Lake was monitored in some detail for a period of one year during 1995-1996 (DNR, October 1996). Water quality samples were collected twice monthly from April through August and monthly from August through April except during December and January when ice covered the lake. Samples were collected from one station near the deepest part of the lake. Water samples were collected from the surface, middle, and bottom of the water column. Samples were analyzed by the Maryland Department of Health and Mental Hygiene for total phosphorus, soluble orthophosphorus, nitrate and nitrite N, ammonia nitrogen, total Kjeldahl nitrogen, total suspended solids, and alkalinity. Surface samples were analyzed for chlorophyll *a*. Physical measurements of Secchi disk transparency depths and dissolved oxygen were recorded in the field. A summary from the DNR October 1996 study follows. Detailed water quality data are presented in Appendix A.

Chlorophyll *a* concentrations (ranging from 1.1 to 11.0 µg/l) in Urieville Lake were low when compared to peak concentrations (10 to 275 µg/l) in other eutrophic lakes (Olem and Flock 1990). However, filament algae and algae mats are common nuisances in summer months.

Dissolved oxygen concentrations ranged from 0.1 to 12.7 mg/l, with depletion occurring from May through August. Lake waters do not show thermal stratification; however, dissolved oxygen depletion was more severe in the deeper waters during summer months.

Total phosphorus concentrations ranging from 0.023 mg/l to 2.377 mg/l exceeded the range of 0.01 mg/l to 0.03 mg/l for lakes that do not exhibit signs of over-enrichment (Reid 1961).

Total nitrogen ranged from 0.7 to 18.2 mg/l in Urieville Lake. High concentrations occurred during summer months above the tropholytic zone. Nitrate nitrogen can range from 0 to 10 mg/l in unpolluted waters, and increases under conditions of organic pollution and heavy runoff from agricultural lands (Oregon 1983). Urieville lake nitrate and nitrite remained in the unpolluted range of between 0.2 to 4.4 mg/l.

Ammonia was low (0.008 to 0.4 mg/l) in the lake's upper waters throughout the year. Ammonia levels as high as 11.7 mg/l in the tropholytic zone during the summer apparently resulted from the decomposition of aquatic vegetation, inasmuch as the lowest concentrations (0.008 mg/l) occurred immediately following mechanical harvest of vegetation. Ammonia levels toxic to fish (greater than 2.5 mg/l) were found only in the tropholytic zone.

### 2.3 Water Quality Impairment

The Maryland water quality standards Surface Water Use Designation (COMAR 26.08.02.07) for Urieville Lake is Use I - *Water Contact Recreation, and Protection of Aquatic Life.* The water quality impairments of Urieville Lake consist of a violation of the numeric water quality for dissolved oxygen, and violations of general narrative criteria applicable to Use I waters. The substances causing these water quality violations are phosphorus and sediments (see the discussion of the nitrogen/phosphorus ratio, under Section 4.2 "Analysis Framework," for an explanation of how phosphorus was determined to be the limiting nutrient associated with the eutrophication problems).

According to the numeric criteria for dissolved oxygen (DO), concentrations may not be less than 5.0 mg/l at any time (COMAR 26.08.02.03-3A(2)) unless resulting from naturally occurring conditions (COMAR 26.08.02.03.A(2)). In lake environments, low levels of dissolved oxygen are expected in bottom waters even under optimal natural conditions. However, achievement of 5.0 mg/l is expected in the well-mixed surface waters.

During summer months (June, July and August) of the 1995 sampling period, DO concentrations as low as 3.1 mg/l were observed at the surface (1 foot depth) of Urieville Lake, with DO values as low as 0.3 mg/l at a depth of 3 feet. Average summer DO at the surface was 4.5 mg/l, and 3.8 mg/l at the 3 foot depth. The observed numeric values fall short of the applicable numeric criterion.

In addition to the violation of the numeric criteria for DO, certain narrative criteria for meeting the Use I designation are violated. Specifically, excessive nutrient enrichment of Urieville Lake results in excessive plant and algae growth, which causes odors and physically impedes direct contact use, fishing, and boating. In addition, fish kill events due to low DO are common, indicating harm to aquatic life. Finally, in conjunction with excessive nutrients, Urieville Lake has experienced excessive sediment loads. In addition to carrying nutrients, the excessive sediment loads are filling in the reservoir at a high rate. Since 1955, sedimentation has reduced the lake's volume from 121 acre feet to 70 acre feet. The reduction in fish habitat and impediment to recreational use (e.g., fishing and boating) violate narrative water quality criteria.

## 3.0 TARGETED WATER QUALITY GOALS

The overall objective of the TMDLs established in this document is to reduce phosphorus and sediment loads to levels that are expected to result in meeting all water quality criteria that support the Use I designation. Specifically, one goal is to change the trophic status of Urieville Lake by reducing the phosphorus load. This is predicted in turn to reduce excessive plant and algae growth, which leads to violations of the numeric DO criteria, associated fish kills, and the violation of various narrative criteria associated with nuisances cited above (odors, and physical impedance of direct contact use).

Since phosphorus binds to sediments, sedimentation rates will be reduced as a component of reducing phosphorus loads. It is expected that this reduction will be sufficient to prevent violations of narrative sediment criteria.

In summary, the TMDLs for phosphorus and sediment are intended to:

1. Assure that a minimum dissolved oxygen concentration of 5 mg/l is maintained in the well-mixed surface waters of Urieville Lake;

2. Resolve violations of narrative criteria associated with excess phosphorus enrichment of Urieville Lake; and

3. Resolve violations of narrative criteria associated with excess sedimentation of Urieville Lake by reducing sedimentation to a reasonable rate.

## 4.0 TOTAL MAXIMUM DAILY LOADS AND ALLOCATION

### 4.1 Overview

This section describes how the nutrient TMDLs and loading allocations were developed for Urieville Lake. The second subsection describes the analysis for determining that phosphorus is likely to be the limiting nutrient in Urieville Lake, and the methodological framework for estimating a permissible phosphorus load. The third subsection summarizes the analysis used to establish the maximum allowable phosphorus load. The fourth subsection provides a discussion of the analytical results. The fifth and sixth subsections describe the translation of these results into statements of Total Maximum Daily Loads and allocations. The seventh subsection describes the margin of safety. The last section summarizes the TMDL, and allocations to nonpoint sources and the margin of safety.

### 4.2 Analytical Framework

Urieville Lake suffers from excessive sediment loads and associated nutrient enrichment. The TMDL for phosphorus is based on a widely accepted empirical method known as the Vollenwieder Relationship. The relationship predicts the degree of a lake's eutrophication as a function of the areal phosphorus loading. R. A. Vollenweider (1968) developed the relationship by assessing a large number of lakes. He established a linear relationship between the log of the phosphorus loading ($L_p$) and the log of the ratio of the lake's mean depth (• ) to hydraulic residence time ($\tau_w$) (Figure 4). This method is advantageous for a number of reasons: It is based on real data collected from a wide range of lakes; its application is conceptually simple and does not require the assumptions of many unknown parameters; and it is recognized by the scientific community as a reasonable method of predicting the trophic status of lakes.

There are other, more complex approaches (i.e., water quality models that simulate eutrophication processes) that can also yield acceptable results. However, such methods require extensive data and the investment of substantial resources to develop. In light of the data available for this TMDL and the small size of the watershed, the Vollenweider Relationship constitutes a sufficient, readily available tool.

Nitrogen and phosphorus are essential nutrients for algae growth. However, common types of algae require different amounts of these two nutrients. If one nutrient is available in great abundance relative to the other nutrient, then the nutrient that is less available restricts the amount of plant matter that can be produced, regardless of the amount of the other nutrient that is available. This latter nutrient is called the "limiting nutrient." Applying the Vollenweider Relationship necessitates that phosphorus be the limiting nutrient. Thus, before considering the application of the Vollenweider Relationship, it is necessary to examine the ratio of nitrogen to phosphorus to establish whether phosphorus is the limiting nutrient.

In general, an N:P ratio in the range of 5 to 10 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P ratio is greater than 10, phosphorus tends to be limiting, and if the N:P ratio is less than 5, nitrogen tends to be limiting (Chiandani et al., 1974). An N:P ratio of 18 was computed using stream inflow data (DNR, October 1996), which supports the use of the Vollenweider Relationship. Supporting data are provided in Appendix A.

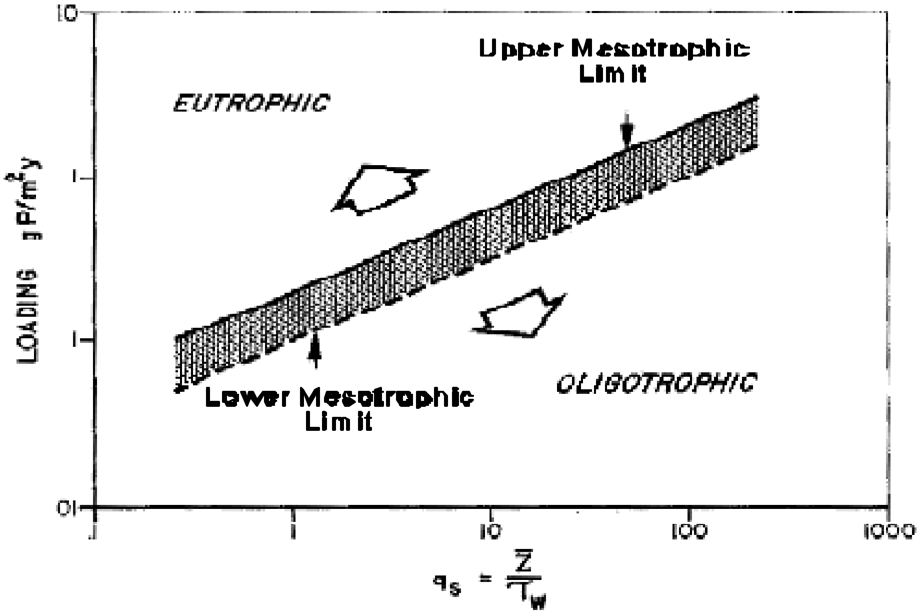


**Figure 4. Vollenweider Relationship**

### 4.3 Vollenweider Relationship Analysis

The Vollenweider Relationship establishes a linear relationship between the log of the phosphorus loading ($L_p$) and the log of the ratio of the lake's mean depth (• ) to hydraulic residence time ($\tau_w$). Thus, the Vollenweider Relationship requires the computation of three key values: (1) the average annual phosphorus loading ($L_p$), (2) the lake's mean depth (• ), and (3) the hydraulic residence time ($\tau_w$). The computations and results of the Vollenweider Relationship are summarized below. See Appendix A for details of the computations and supporting data.

Urieville Lake Mean Depth (• ):

The application of the Vollenweider assumes the lake's physical dimensions when the lake and dam underwent a major overhaul in 1955[1]. The mean lake depth was computed on the basis of an estimate of the lake volume and surface area in 1955. The 1955 surface area of Urieville Lake was 13.6 hectares or 136,000 $m^2$ (DNR, October 1996)[2]. The 1955 lake volume was estimated to be the sum of the 1995 lake volume plus the 1995 estimated sediment displacement since 1955. The 1995 lake volume was determined by sonar measurements to be 70 acre feet, or

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1 This assumption is in recognition that the natural tendency is for reservoirs to accumulate sediments, which eventually must be removed if the lake is to persist. Thus, the original design capacity is the most logical baseline upon which to establish the TMDLs.

2 It is recognized that several acres of wetlands have become established at the headwaters of the lake. Addressing these would be part of any future decisions on dredging the lake.

86,345 $m^3$. The volume of sediment displacement since 1955 was estimated to be 51 acre feet, or 62,909 $m^3$. The estimated 1955 lake volume is the sum of these:

Urieville Lake Volume: 86,345 $m^3$ + 62,909 $m^3$ = 149,254 $m^3$ = 5,270,860 $ft^3$
Urieville Lake Surface Area: 13.6 hectares or 136,000 $m^2$

- ***Urieville Lake Mean Depth (• ): (Volume)/(Surface Area) = 1.1 m***

Phosphorus Loading to Urieville Lake (Lp):

The total phosphorus loading is cited as 1.53 tons per year (3,060 lbs/year or 1,387,885 g/year) based on average precipitation and estimated concentrations (DNR, October 1996). Expressing this value as a loading per surface area of the lake gives:

- ***Annual Phosphorus Load ($L_p$) is: 10.2 g/$m^2$ yr***. Details are provided in Appendix A.

Urieville Lake Hydraulic Residence Time ($\tau_w$)

The hydraulic residence time is computed as volume/outflow; the time it would take to drain the lake. Assuming a volume of 121 acre feet, from above, and a discharge rate of 22.8 acre feet per day (DNR, October 1996) the hydraulic residence time would be 5.3 days.

- ***Urieville Lake Hydraulic Residence Time ($\tau_w$): 0.0145 years***

## 4.4 Vollenweider Relationship Results

The basic elements of the Vollenweider Relationship, established above, were combined to estimate both the current trophic status of Urieville Lake, and the maximum allowable unit loading. The current trophic status associated with a loading of 10.2 g/$m^2$ yr falls well into the eutrophic range, as indicated on figure 5 by a diamond "♦". The maximum allowable unit loading of 1.7 g/$m^2$ yr for a lake with mean depth of 1.1 m and hydraulic residence time of 0.014 years is indicated by the intersection of two segments. The TMDL implications are presented below in Section 4.5.

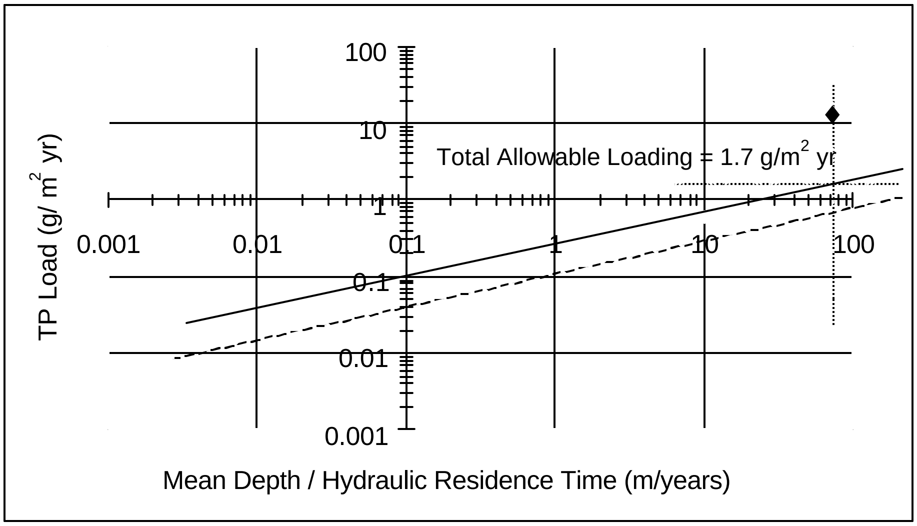


**Figure 5. Vollenweider Results for Urieville Lake**

### 4.5 Total Maximum Daily Loads

This TMDL appropriately considers seasonal variations by estimating loading rates over the entire year. This captures the dry weather loading rates, which generally occur during the warmer months when algae production is most prevalent. It also captures the wet-weather loading rates, which contribute significant sediment-bound sources of phosphorus. The Vollenweider Relationship specifically uses long-term loading estimates to avoid adopting a single transient loading pulse, which would yield erroneous results. The critical conditions are accounted for implicitly in the empirical Vollenweider Relationship. The resultant TMDL for phosphorus is based on the unit allowable loading indicated by the results of the Vollenweider Relationship. That is, the unit loading per square meter (1.7 g/m$^2$ year) times the total surface area of the lake (136,000 m$^2$) or 231,200 g/yr. This represents an 85% reduction in phosphorus loading.

The link between DO concentration and the lake's trophic status (as defined by the Vollenweider Relationship) is indirect, but may be inferred as described below. . Nutrient overenrichment causes excess algal blooms, which eventually die off and decompose, consuming DO.

Several computations are provided to account for the key processes that determine DO concentration in the well-mixed surface layer of a lake (see Appendix A). These processes, as they apply to Urieville Lake, are outlined below. This assessment is based on critical conditions and uses conservative assumptions.

- Dissolved oxygen saturation capacity as a function of water temperature.
- The diurnal variation in DO resulting from the shift between daytime net photosynthetic activity and nighttime net respiration of algae. This is calculated as a function of the

concentration of active chlorophyll-*a*, which is imputed from the lake's targeted mesotrophic status (defined by the Vollenweider Relationship) to range from 4 to 10 μg/l (Chapra 1997).

- Sediment Oxygen Demand (SOD).
- Carbonaceous Biochemical Oxygen Demand (CBOD).
- Water reaeration.

According to calculations presented in Appendix A, it is expected that an areal phosphorus load of 1.7 g/$m^2$ will result in minimum surface DO concentrations of about 5.7 mg/l.

No single critical period can be defined for the water quality impact of sedimentation. Sedimentation negatively impacts the lake regardless of when it occurs. In terms of sediment loading, the critical conditions occur during wet-weather events when the greatest amount of sediment is delivered to the lake.

To quantify the sediment reduction associated with this phosphorus reduction, the EPA Chesapeake Bay Program watershed modeling assumptions were consulted. For the agricultural best management practices (Ag. BMPs) that affect both phosphorus and sediments, EPA estimates a 1-to-1 reduction in sediments as a result of controlling phosphorus (EPA, CBPO 1998). However, this ratio does not account for phosphorus controls that do not remove sediments.

To estimate the applicable ratio, and hence the sediment load reduction, it is necessary to estimate the proportion of the phosphorus reductions that remove sediments versus those that do not. In general, soil conservation and water quality plans (SCWQPs) remove sediments along with the phosphorus removal, while nutrient management plans (NMPs) do not. It has been assumed that 50% of the phosphorus reduction will come from SCWQPs and 50% from NMPs. This results in a 0.5-to-1 ratio of sediment reduction to phosphorus reduction. The net sediment reduction associated with an 85% phosphorus reduction is about 43% (0.85 * 0.50 = 0.425). It is assumed that this reduced sediment loading rate would result in a similar reduction in the sediment accumulation rate. The sediment accumulation rate predicted to result from this reduced loading rate would allow for the retention of 76% of the impoundment's volume after 40 years. MDE believes that this volumetric retention will support the designated use of Urieville Lake. See Appendix A for further details concerning this estimate.

This estimate is reasonably consistent with technical guidance provided by EPA Region III of a 0.7-to-1.0 reduction in sediment in relation to the reduction in phosphorus. This rule-of-thumb would yield a 60% estimated reduction in sediment [100*(0.7 * 0.85) = 60].

| | |
|---|---|
| **PHOSPHORUS TMDL** | **231,200 g/*yr* = 509 lb/yr** |
| **SEDIMENT TMDL** | **An estimated 42.45% reduction in sediment loading rates. This translates to a sediment accumulation rate of about 24% of the storage capacity in 40 years, or an estimated load of 89.2 tons/yr (see footnote)[3]** |

[3] This estimated load is based on estimated "suspended solids," which include organic matter, but exclude materials transported in the bed load.

### 4.6 TMDL Allocation

The watershed that drains to Urieville Lake contains no permitted surface water discharges. Hence, the entire allocation will be made to nonpoint sources. The model uses water quality data to estimate the loading rates, which represent the cumulative impact from all sources—naturally-occurring and human-induced. Atmospheric sources of sediments and phosphorus due to wind erosion are considered insignificant because the ratio of the watershed area to the surface area of the lake is large (5200 acres/33.7 acres). All significant nonpoint sources are included in the allocation and are described further in the technical memorandum entitled *Significant Nonpoint Phosphorus and Sediment sources in the Urieville Lake Watershed, Kent County, Maryland*.

### 4.7 Margin of Safety

A margin of safety (MOS) is required as part of a TMDL in recognition of the fact that there are many uncertainties in scientific and technical understanding of water quality in natural systems. Specifically, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural water bodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Based on EPA guidance, the MOS can be achieved through one of two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = WLA + LA + MOS). The second approach is to incorporate the MOS as part of the design conditions for the WLA and the LA computations.

Maryland has adopted an explicit margin of safety for phosphorus. Following the first approach, the load allocated to the MOS was computed as 10% of the total allowable load. This value is considered reasonable in that it implies an additional 10% reduction in nonpoint source phosphorus loading beyond what would be expected to meet the goal.

Maryland has also incorporated conservative assumptions that effectively constitute an additional, implicit, margin of safety. In calculating minimum DO levels, MDE assumes a water temperature of $30^{o}$ C; the highest temperature observed during monitoring was $27.1^{o}$ C. Similarly, an active chlorophyll *a* concentration of 10 µg/l was assumed in calculating the diurnal DO fluctuation. This is at the upper limit of the mesotrophic range (Thomann and Mueller 1987) as predicted using the Vollenweider Relationship. The highest chlorophyll *a* concentration observed during the monitoring period was 11.0 µg/l.

In establishing a margin of safety for sediments, Maryland has adopted an implicit approach by incorporating conservative assumptions. First, because phosphorus binds to sediments, sediments will be controlled as a result of controlling phosphorus. This estimate of sediment reduction is based on the load allocation of phosphorus (458 lbs./yr), rather than the entire phosphorus TMDL including the MOS. Thus, the explicit 10% MOS for phosphorus will result in an implicit MOS for sediments. This conservative assumption results in a difference of about 1.3 T/yr (see Section 4.5 above for a discussion of the relationship between reductions in phosphorus and sediments). Secondly, MDE conservatively assumes a sediment-to-phosphorus reduction ratio of 0.5:1, rather than 0.7:1.

### 4.8 Summary of Total Maximum Daily Loads

The annual TMDL **for Phosphorus (*lb/yr*):**

| TMDL | = | WLA | + | LA | + | MOS |
|---|---|---|---|---|---|---|
| 509 | = | 0 | + | 458 | + | 51 |

On average, this TMDL represents a daily phosphorus load of 1.39 lbs/day.

Where:

LA = Nonpoint Source
WLA = Point Source
MOS = Margin of Safety

The annual TMDL **for Sediments (*tons/yr*):**

| TMDL | = | WLA | + | LA | + | MOS |
|---|---|---|---|---|---|---|
| 89.2 | = | 0 | + | 89.2 | + | Implicit |

On average, this TMDL represents a daily sediment load of 488 lbs/day.

## 5.0 ASSURANCE OF IMPLEMENTATION

Urieville Community Lake is located in a watershed in which the impairment is significantly dominated by nonpoint source contributions. As such, the implementation provisions will need to be more rigorous and iterative. Significant phosphorus reductions are required to meet the load allocation of this TMDL. The certainty of implementation of the phosphorus reduction plan in this watershed will be enhanced by three specific programs: the Water Quality Improvement Act of 1998 (WQIA), the EPA-sponsored Clean Water Action Plan of 1998 (CWAP), and the State's Chesapeake Bay Agreement's Tributary Strategies for Nutrient Reduction.

Maryland's WQIA requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout Maryland. This act specifically requires that these phosphorus nutrient management plans be developed and implemented by 2004. Thus, a specific milestone and benchmark, including a final expected attainment date have been established for this TMDL against which the adequacy of the initial load allocation and implementation plan can be measured. The water quality response accomplished by the date of this benchmark can be the basis for triggering appropriate load allocation revisions (either higher or lower). Additionally, as part of Maryland's Watershed Cycling Strategy, follow-up monitoring and assessments will be conducted to (1) determine the effect of the practices on water quality and related conditions, (2) determine the degree to which the selected practices are implemented, and (3) to the extent possible, determine the efficacy and impacts of the practices chosen. Based on this monitoring and assessment program, the TMDL will be evaluated as to whether additional practices must be employed in order to eliminate any remaining impairment.

Maryland's CWAP has been developed in a coordinated manner with the State's 303(d) process. All Category I watersheds identified in Maryland's Unified Watershed Assessment process are totally coincident with the impaired waters list for 1996 and 1998 approved by EPA. The State has given a high priority for funding assessment and restoration activities to these watersheds.

Maryland's Tributary Strategies have already established a voluntary program and an institutional framework in which to advance the goals of this TMDL. The findings of the TMDL analysis indicate that the implementation of the TMDL on the basis of external loading controls would require an 85% reduction of external phosphorus loadings. Taking actions to meet this reduction is estimated to result in a 43% reduction in sediment loads.

Because the watershed is 80% agricultural land, meeting these reductions will entail the implementation of agricultural best management practices (BMPs). Table 2 shows estimated reduction efficiencies for individual BMPs based on the "Technical Appendix for Maryland's Tributary Strategy" (Maryland, 1996). These efficiencies, when applied in combination, can be expected to have an ultimate nutrient reduction efficiency that is greater than any single BMP, but less than the sum of the BMPs. However, because the soils in the Urieville watershed are easily erodible, the efficiency of the soil conservation BMPs are expected to be toward the high end of the range.

**Table 2**

**Phosphorus Removal Efficiencies of Various Agricultural BMPs**

| Best Management Practice | Estimated Range of Phosphorus Removal |
|---|---|
| Soil Conservation & Water Quality Plan (SCWQP) | 11% - 35% |
| Treatment of Highly Erodible Land[1] | 3 x the result of SCWQP on typical soil |
| Conservation Tillage | 13% - 50% |
| Nutrient Management Plans | 9% - 30% |

Source: "Technical Appendix for Maryland's Tributary Strategy" (Maryland, 1995)
Notes:

1. The soils in the Urieville watershed are considered easily erodible (DNR, Oct. 1996).

The sedimentation reduction goal is reasonable and implementable. A number of best management practices—both structural and non-structural—can significantly reduce sediment loads. For instance, maintained vegetated buffer strips along stream channels (in this case, tributaries draining to Urieville Community Lake) have been shown to capture a significant amount of sediment and dissipate the energy of the surface runoff during storm events. The vegetation also helps to reduce stream bank erosion. Recent estimates of the trap efficiency of buffer strips range from 70% to 90% (Qui and Prato, 1998).

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# Appendix A: Technical Appendix

## Urieville Lake Water Quality

A number of studies of Urieville Lake have been conducted over the years in which water quality data have been collected (DNR, October 1996). A summary of the water quality data was provided in the main body of this report. Table A1 provides the underlying data from which the summaries were derived.

## Assessment of the N:P Ratio for Urieville Lake

Before considering the application of the Vollenweider Relationship, it is necessary to examine the ratio of nitrogen (N) to phosphorus (P) to establish whether phosphorus is the limiting nutrient. In general, an N:P ratio in the range of 5 to 10 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the N:P ratio is greater than 10, phosphorus tends to be limiting, and if the N:P ratio is less than 5, nitrogen tends to be limiting (Chiandani, et al., 1974).

The N:P ratio of 18 cited in the body of this report were drawn directly from the 1996 diagnostic study (DNR, October 1996). That assessment was based on data from the streams entering Urieville Lake and an estimated average annual precipitation of 44 inches in the vicinity (Calhoun 1982). Although this data set does not represent a multi-year annual average, the data was collected over a sufficient time period to avoid transient pulses, which could give misleading results (EPA, 1977).

Urieville Lake is fed by three unnamed tributaries of Morgan Creek, identified as the Eastern, Western, and Central branches. Although the exact computation used to arrive at the N:P ratio of 18 is not documented in the diagnostic study, the general approach used in-stream nutrient concentration and stream flow data from these three branches, combined with an estimation of the long-term annual average precipitation to calculate annual loads of N and P. The ratio of these annual N and P loads was then compared to yield an N:P = 18.

Nutrient concentrations from the three branches that feed Urieville Lake were measured for a subset of the field visits, and are shown in Table A2. Table A3 presents the complete set of stream flow data.

## Table A1
## Water Quality Data for Urieville Lake - 1995-96

| SITE (Depth, Ft) | DATE | DO (mg/l) | SS (mg/l) | NH3 (mg/l) | TKN (mg/l) | TN (mg/l) | NO23 (mg/l) | PO4 (mg/l) | TP (mg/l) | ALK (mg/l) | CHL (µg/l) | SECCHI (Meters) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2/29/96 | 11 | 3 | 0.089 | 0.9 | 0.989 | 4.1 | 0.015 | 0.037 | 36 | | 1.83 |
| 1 | 3/21/96 | 9.7 | 6 | 0.068 | 0.8 | 0.868 | 4.4 | 0.012 | 0.064 | 34 | | 1.14 |
| 1 | 4/17/95 | 12.7 | 2 | 0.2 | 0.7 | 0.9 | 1.9 | 0.2 | 0.2 | 50 | 1.3 | 0.89 |
| 1 | 5/8/95 | 10.6 | 11 | 0.2 | 0.7 | 0.9 | 1.3 | 0.2 | 0.2 | 52 | 2.2 | 1.48 |
| 1 | 5/25/95 | 9.3 | 10 | 0.2 | 1.3 | 1.5 | 0.7 | 0.015 | 1.07 | 49 | 8.3 | 1.31 |
| 1 | 6/6/95 | 7.6 | 6 | 0.037 | 0.8 | 0.837 | 0.6 | 0.012 | 0.038 | 57 | 5.8 | 1.18 |
| 1 | 6/19/95 | 6.5 | 11 | 0.025 | 0.7 | 0.725 | 0.2 | | 0.075 | 62 | 4.7 | 0.84 |
| 1 | 7/5/95 | 5.6 | 1 | 0.016 | 0.6 | 0.616 | 0.2 | 0.007 | 0.025 | 55 | 4.2 | 1.13 |
| 1 | 7/18/95 | 6.1 | 12 | 0.009 | 0.6 | 0.609 | 0.2 | 0.01 | 0.064 | 64 | 3 | 1.03 |
| 1 | 8/10/95 | 3.1 | 4 | 0.015 | 0.8 | 0.815 | 0.2 | 0.029 | 0.058 | 41 | 6.1 | 1.3 |
| 1 | 8/22/95 | 4.2 | 3 | 0.008 | 0.6 | 0.608 | 0.2 | 0.015 | 0.054 | 54 | | 1.26 |
| 1 | 9/13/95 | 7.1 | 6 | 0.01 | 0.8 | 0.81 | 0.2 | 0.01 | 0.033 | 65 | 11 | 1.42 |
| 1 | 10/19/95 | 9.4 | 2 | 0.018 | 0.812 | 0.83 | 0.2 | 0.011 | 0.023 | 48 | 5.2 | 2.13 |
| 1 | 11/16/95 | 8 | 28 | 0.109 | 1 | 1.109 | 1.8 | 0.045 | 0.209 | 27 | 2.3 | 2.13 |
| | | | | | | | | | | | | |
| 3 | 2/29/96 | 11.3 | 5 | 0.087 | 0.9 | 0.987 | 4.1 | 0.013 | 0.038 | 36 | 5.9 | |
| 3 | 3/21/96 | 10.1 | 7 | 0.072 | 0.7 | 0.772 | 4.4 | 0.011 | 0.048 | 34 | 6.5 | |
| 3 | 4/17/95 | 12.7 | 2 | 0.2 | 0.7 | 0.9 | 2 | 0.2 | 0.2 | 49 | 1.1 | |
| 3 | 5/8/95 | 10 | 10 | 0.2 | 0.9 | 1.1 | 1.8 | 0.2 | 0.2 | 51 | | |
| 3 | 5/25/95 | 6.1 | 10 | 0.4 | 1.8 | 2.2 | 0.3 | 0.012 | 1.643 | 71 | | |
| 3 | 6/6/95 | 6.5 | 17 | 0.091 | 1.8 | 1.891 | 0.3 | 0.018 | 0.133 | 68 | | |
| 3 | 6/19/95 | 2.5 | 15 | 0.097 | 0.7 | 0.797 | 0.2 | | 0.047 | 68 | | |
| 3 | 7/5/95 | 0.3 | 20 | 0.008 | 1 | 1.008 | 0.2 | 0.015 | 0.117 | 63 | | |
| 3 | 7/18/95 | 2.6 | 18 | 0.015 | 0.9 | 0.915 | 0.2 | 0.016 | 0.048 | 72 | 2.8 | |
| 3 | 8/10/95 | 2.7 | 26 | 0.028 | 0.9 | 0.928 | 0.2 | 0.036 | 0.15 | 41 | | |
| 3 | 8/22/95 | 4.1 | 9 | 0.008 | 0.7 | 0.708 | 0.2 | 0.016 | 0.065 | 55 | | |
| 3 | 9/13/95 | 7.2 | 12 | 0.017 | 0.7 | 0.717 | 0.2 | 0.008 | 0.036 | 66 | | |
| 3 | 10/19/95 | 9.4 | 3 | 0.017 | 0.861 | 0.878 | 0.2 | 0.012 | 0.023 | 48 | | |
| 3 | 11/16/95 | 8 | 29 | 0.117 | 1 | 1.117 | 1.7 | 0.048 | 0.227 | 27 | | |
| | | | | | | | | | | | | |
| 5 | 2/29/96 | 11.5 | 6 | 0.09 | 0.8 | 0.89 | 4.1 | 0.013 | 0.044 | 36 | | |
| 5 | 3/21/96 | 10 | 6 | 0.073 | 0.9 | 0.973 | 4.3 | 0.01 | 0.05 | 34 | | |
| 5 | 4/17/95 | 12.7 | 10 | 0.2 | 0.8 | 1 | 1.7 | 0.2 | 0.2 | 52 | | |
| 5 | 5/8/95 | 9.2 | 15 | 0.2 | 1.5 | 1.7 | 0.9 | 0.2 | 0.2 | 63 | | |

# Table A1
## Water Quality Data for Urieville Lake - 1995-96

| SITE (Depth, M) | DATE | DO (mg/l) | SS (mg/l) | NH3 (mg/l) | TKN (mg/l) | TN (mg/l) | NO23 (mg/l) | PO4 (mg/l) | TP (mg/l) | ALK (mg/l) | CHL (mg/l) | SECCHI (Meters) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 5/25/95 | 4.8 | 40 | 0.7 | 2.7 | 3.4 | 0.2 | 0.014 | 2.377 | 100 | | |
| 5 | 6/6/95 | 5.8 | 40 | 0.153 | 6.1 | 6.253 | 0.2 | 0.059 | 0.027 | 90 | | |
| 5 | 6/19/95 | 0.8 | 165 | 11.7 | 6.5 | 18.2 | 0.2 | | 0.261 | 122 | | |
| 5 | 7/5/95 | 0.1 | 160 | 5.53 | 6.2 | 11.73 | 0.2 | 0.006 | 0.177 | 120 | | |
| 5 | 7/18/95 | 0.2 | 175 | 1.3 | 5.8 | 7.1 | 0.2 | 0.007 | 0.218 | 118 | | |
| 5 | 8/10/95 | 0.1 | 60 | 0.149 | 1.4 | 1.549 | 0.2 | 0.031 | 0.177 | 44 | | |
| 5 | 8/22/95 | 0.1 | 58 | 0.296 | 1.9 | 2.196 | 0.2 | 0.056 | 0.302 | 73 | | |
| 5 | 9/13/95 | 6.5 | 10 | 0.031 | 0.8 | 0.831 | 0.2 | 0.01 | 0.058 | 66 | | |
| 5 | 10/19/95 | 9.4 | 2 | 0.017 | 0.783 | 0.8 | 0.2 | 0.01 | 0.026 | 48 | | |
| 5 | 11/16/95 | 8 | 27 | 0.179 | 1.2 | 1.379 | 1.7 | 0.047 | 0.237 | 27 | | |

**Table A2**

**Stream Inflow and Water Quality Data for Urieville Lake - 1995-96**

| Stream | DATE | flow | DO | SS | NH3 | TKN | ON | TN | NO23 | OP | PO4 | TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) |
| Eastern | 7/17/95 | 3.90 | 6.1 | 14 | 0.032 | 0.8 | 0.768 | 2.8 | 2 | 0.034 | 0.058 | 0.092 |
| Eastern | 8/3/95 | 3.66 | 5.5 | 8 | 0.09 | 1 | 0.91 | 2.5 | 1.5 | 0.036 | 0.033 | 0.069 |
| Eastern | 8/7/95 | 2.19 | 14.8 | 9 | 0.059 | 0.8 | 0.741 | 1.5 | 0.7 | 0.051 | 0.064 | 0.115 |
| Eastern | 8/31/95 | 2.21 | 6.7 | 3 | 0.061 | 0.5 | 0.439 | 2.8 | 2.3 | 0.025 | 0.017 | 0.042 |
| Eastern | 9/13/95 | 2.45 | 7.5 | 6 | 0.056 | 0.5 | 0.444 | 1.1 | 0.6 | 0.017 | 0.034 | 0.051 |
| Eastern | 9/27/95 | 3.93 | 8.1 | 10 | 0.05 | 0.4 | 0.35 | 0.7 | 0.3 | 0.026 | 0.035 | 0.061 |
| Eastern | 10/5/95 | 8.38 | 5.7 | 68 | 0.033 | 0.9 | 0.867 | 1.4 | 0.5 | 0.036 | 0.097 | 0.133 |
| Eastern | 11/8/95 | 8.95 | | 1 | 0.021 | 0.5 | 0.479 | 1.3 | 0.8 | 0.015 | 0.007 | 0.022 |
| Eastern | 3/21/96 | 9.89 | 11.2 | 8 | 0.053 | 1.9 | 1.847 | 4.2 | 2.3 | 0.017 | 0.059 | 0.076 |
| Averages: | | 5.06 | 7.289 | 14.111 | 0.051 | 0.811 | 0.761 | 2.033 | 1.222 | 0.029 | 0.045 | 0.073 |
| Western | 7/17/95 | 2.70 | 5.2 | 10 | 0.049 | 0.7 | 0.651 | 1.1 | 0.4 | 0.035 | 0.023 | 0.058 |
| Western | 8/3/95 | 1.90 | 4.8 | 13 | 0.054 | 1 | 0.946 | 1.5 | 0.5 | 0.023 | 0.042 | 0.065 |
| Western | 8/7/95 | 7.01 | 5.7 | 60 | 0.158 | 1 | 0.842 | 1.4 | 0.4 | 0.104 | 0.061 | 0.165 |
| Western | 8/31/95 | 2.86 | 6.9 | 8 | 0.061 | 0.6 | 0.539 | 1.2 | 0.6 | 0.041 | 0.02 | 0.061 |
| Western | 9/13/95 | 2.93 | 11.2 | 7 | 0.021 | 0.5 | 0.479 | 2.9 | 2.4 | 0.027 | 0.017 | 0.044 |
| Western | 9/27/95 | 4.91 | 6.8 | 4 | 0.015 | 0.3 | 0.285 | 2.2 | 1.9 | 0.855 | 0.025 | 0.88 |
| Western | 10/5/95 | 11.78 | 5.1 | 4 | 0.025 | 1.2 | 1.175 | 2.4 | 1.2 | 0.109 | 0.142 | 0.251 |
| Western | 11/8/95 | 8.98 | | 1 | 0.012 | 0.6 | 0.588 | 4.1 | 3.5 | 0.016 | 0.018 | 0.034 |
| Western | 3/21/96 | 8.22 | 11.2 | 8 | 1.102 | 2.4 | 1.298 | 9.6 | 7.2 | 0.16 | 0.15 | 0.31 |
| Averages: | | 5.70 | 6.322 | 12.778 | 0.166 | 0.922 | 0.756 | 2.933 | 2.011 | 0.152 | 0.055 | 0.208 |
| Central | 7/17/95 | 0.37 | 5.65 | | 0.0405 | | 0.7095 | 1.95 | 1.2 | 0.0465 | 0.0285 | 0.075 |
| Central | 8/3/95 | 0.30 | 5.15 | | 0.072 | | 0.928 | 2 | 1 | 0.028 | 0.039 | 0.067 |
| Central | 8/7/95 | 0.94 | 10.25 | | 0.1085 | | 0.7915 | 1.45 | 0.55 | 0.084 | 0.056 | 0.14 |
| Central | 8/31/95 | 0.18 | 6.8 | | 0.061 | | 0.489 | 2 | 1.45 | 0.029 | 0.0225 | 0.0515 |
| Central | 9/13/95 | 0.26 | 9.35 | | 0.0385 | | 0.4615 | 2 | 1.5 | 0.0305 | 0.017 | 0.0475 |
| Central | 9/27/95 | 0.65 | 7.45 | | 0.0325 | | 0.3175 | 1.45 | 1.1 | 0.445 | 0.0255 | 0.4705 |
| Central | 10/5/95 | 1.30 | 5.4 | | 0.029 | | 1.021 | 1.9 | 0.85 | 0.103 | 0.089 | 0.192 |
| Central | 11/8/95 | 1.65 | 0 | | 0.0165 | | 0.5335 | 2.7 | 2.15 | 0.0115 | 0.0165 | 0.028 |
| Central | 3/21/96 | 1.97 | 11.2 | | 0.5775 | | 1.5725 | 6.9 | 4.75 | 0.1095 | 0.0835 | 0.193 |
| Averages: | | 0.85 | 6.806 | | 0.108 | | 0.758 | 2.483 | 1.617 | 0.099 | 0.042 | 0.141 |

# Table A3

## Complete set of Inflow Data for the Three Branches Entering Urieville Lake - 1995-96

| Month | Western cfs | Central cfs | Eastern cfs |
|---|---|---|---|
| 6 | 3.91 | 0.47 | 4.04 |
| 6 | 3.54 | 0.40 | 5.13 |
| 6 | 2.90 | 0.24 | 4.53 |
| 6 | 4.02 | 0.41 | 5.15 |
| 7 | 3.38 | 0.51 | 4.83 |
| 7 | 3.18 | 0.41 | 6.80 |
| 7 | 2.70 | 0.37 | 3.90 |
| 7 | 2.48 | 0.53 | 4.54 |
| 8 | 1.90 | 0.30 | 3.66 |
| 8 | 7.01 | 0.94 | 13.16 |
| 8 | 2.82 | 0.47 | 2.98 |
| 8 | 3.31 | 0.47 | 2.55 |
| 8 | 2.56 | 0.29 | 2.05 |
| 8 | 2.52 | 0.18 | 2.21 |
| 9 | 2.26 | 0.19 | 2.31 |
| 9 | 2.93 | 0.26 | 2.45 |
| 9 | 4.16 | 0.27 | 3.12 |
| 9 | 4.91 | 0.65 | 3.93 |
| 10 | 11.78 | 1.30 | 8.38 |
| 10 | 2.97 | 0.42 | 3.04 |
| 10 | 3.67 | 0.60 | 3.31 |
| 10 | 3.41 | 0.56 | 3.97 |
| 11 | 8.98 | 1.65 | 8.95 |
| 11 | 7.01 | 2.25 | 14.18 |
| 11 | 6.61 | 1.42 | 5.58 |
| 12 | 5.35 | 0.95 | 5.74 |
| 12 | 6.15 | 1.14 | 4.08 |
| 12 | 6.13 | 1.14 | 4.44 |
| 1 | 6.51 | 1.42 | 6.59 |
| 2 | 7.82 | 1.85 | 4.89 |
| 2 | 9.35 | 2.14 | 7.01 |
| 2 | 9.69 | 2.61 | 9.06 |
| 3 | 8.82 | 1.96 | 9.12 |
| 3 | 8.11 | 2.14 | 11.49 |
| 3 | 8.22 | 1.97 | 9.89 |

## Supporting Calculations for the Vollenweider Analysis

Urieville Lake Mean Depth (• ):

The 1955 design volume was computed as the sum of the current volume plus displaced volume, that is,

(70 acre feet, current) + (51 acre feet, displaced) = 121 acre feet

121 acre feet x 1,233.5 $m^3$/ acre feet = 149,254 $m^3$

The mean depth of Urieville Lake is (Volume)/(Surface Area) is computed as:

149,254 $m^3$ ÷ 136,000 $m^2$ = **1.097 m**

Phosphorus Loading to Urieville Lake (Lp):

The total phosphorus loading was computed as 1.53 tons per year (DNR, October 1996).

1.53 tons/yr x 2,000 lbs/ton = 3,060 lbs/yr
3,060 lbs/yr x 453.59 g/lb = 1,387,885 g/yr

Using the estimated 1955 lake surface area (136,000 $m^2$), this value can be converted to grams per square meter per year as follows: 1,387,885 g/yr ÷ 136,000 $m^2$ = **10.2 g/$m^2$ yr**.

Urieville Lake Hydraulic Residence Time ($\tau_w$):

The hydraulic residence time is computed as volume/outflow; it is the time it would take to drain the lake.

The estimated hydraulic residence time of 3.1 days was estimated based on the current lake volume of 70 acre feet and an estimated 22.79 acre feet per day discharge rate (DNR, October 1996). That is, (70 acre feet) ÷ (22.79 acre feet per day) = 3.1 days.

For the 1955 lake design, the volume is the sum of the current volume plus displaced volume, that is,

(70 acre feet) + (51 acre feet) = 121 acre feet

The original hydraulic residence time is:

(121 acre feet) ÷ (22.79 acre feet per day) = 5.3 days.

5.3 days ÷ 365 days/yr = **0.01452 yr**

Ratio of Mean Depth to Hydraulic Residence Time (• $/\tau_w$)

From the computations above the mean depth of Urieville Lake (• ) is 1.1 m, and the hydraulic residence time ($\tau_w$) is 0.0145 yr. The ratio was computed as:

1.1 m / 0.0145 yr = **75.8 m/yr**

Graphing of Trophic Status of Urieville Lake using the Vollenweider Relationship

The intersection of the phosphorus loading rate ($L_p$) = 10.2 $g/m^2yr$ and the ratio (• $/\tau_w$) = 75.8 yr was plotted on log log paper to establish the trophic status of Urieville Lake (See Figure A1).

**Supporting Calculations for the TMDL Analysis**

Graphing of Maximum Allowable Unit Phosphorus loading of Urieville Lake using the Vollenweider Relationship

Figure A1 shows how the maximum allowable unit phosphorus loading can be read off of the log log paper. Point A represents the maximum allowable load, which includes the load allocation and the margin of safety (1.7 $g/m^2 yr$).

Computing the Phosphorus TMDL

The TMDL is computed from the maximum unit load read from Point A on Figure A1:

(Unit loading) x (Lake Surface Area) = Annual Loading
(1.7 $g/m^2 yr$) x (136,000 $m^2$) = **231,200 g/*yr***

Converted to pounds per year:
(231,200 g/yr) x (0.0022 lb/g) = **508.6 lbs/yr**

Computing the Phosphorus Margin of Safety

The Margin of Safety is computed as 10% of the total allowable unit loading:

0.10 x (Total allowable loading) = Annual Loading
(0.10) x (231,200) = **23,120 g/*yr***

Converted to pounds per year:
23,120 g/*yr* x (0.0022 lb/g) **= 50.9 lb/yr**

Computing the Percentage Phosphorus Reduction

The necessary reduction in phosphorus loads, as a percentage of the current estimated load was computed as follows:

$$\frac{\text{(current load)} - \text{(allowable load*)}}{\text{(current load)}} =$$

$$\frac{(1{,}378{,}885 \text{ g/yr}) - (208{,}080 \text{ g/yr})}{(1{,}378{,}885 \text{ g/yr})} = 84.9\% \text{ reduction}$$

* The allowable load does not include the margin of safety.

**Supporting Calculations of Expected Minimum DO in Mixed Surface Layer**

The dissolved oxygen concentration in the mixed surface waters is a balance between oxygen sources (ambient DO levels in water flowing into the lake, photosynthesis, reaeration) and oxygen sinks (cellular respiration, sediment oxygen demand, and biochemical oxygen demand). Saturation DO concentration is a function of temperature. Conceptually, this balance is represented by the following equation:

$$DO = f(T)\left[\left(DO_{AMBIENT} + DO_{PSN} + \mathrm{Re}\,aeration\right) - \left(Metabolic\,Demands + SOD + CBOD\right)\right]$$

Where:

$f$(T) = Function of temperature on the following term;
$DO_{AMBIENT}$ = [DO] in water entering the lake;
$DO_{PSN}$ = Photosynthetic DO contribution;
Reaeration = Diffusion of atmospheric $O_2$ into the water;
Metabolic demands = Metabolic oxygen consumption, including cellular respiration;
SOD = Sediment Oxygen Demand;
CBOD = Carbonaceous Biochemical Oxygen Demand.

Since we are especially concerned with minimum DO levels, a modification of this conceptual equation may be represented as:

$$DO_{MIN} = f(T)\left[(DO_{AMBIENT}) - (Max.Metabolic\,Depletion) - (SOD + CBOD)\right]$$

Where *Max. Metabolic Depletion* represents the maximum diurnal depletion of DO resulting from the calculated photosynthetic and respiratory fluctuation.

Following are two sets of computations. The first estimates the diurnal DO fluctuation resulting from photosynthesis and respiration, while the second addresses the effects of SOD and CBOD. Temperature and reaeration are implicit or explicit terms in both calculations.

**Calculations of Dissolved Oxygen Diurnal Fluctuation:**

Because the photosynthetic process is dependent on solar radiant energy, the production of oxygen proceeds only during daylight hours. Concurrently with this production, however, the algae (and other aquatic biota) require oxygen for respiration, which can be considered to proceed continuously. Minimum values of dissolved oxygen usually occur in the early morning predawn when the algae have been without light for the longest period of time. Maximum values of dissolved oxygen usually occur in the early afternoon. The diurnal range (maximum minus minimum) may be large, and if the daily mean level of dissolved oxygen is low, minimum values of dissolved oxygen during a day may approach zero and hence create a potential for fish kills.

The diurnal dissolved oxygen variation due to photosynthesis and respiration can be estimated based on the amount of chlorophyll *a* in the water. The phosphorus TMDL will result in a mesotrophic status for Urieville Lake. Chlorophyll *a* concentrations ranging from 4 – 10 µg/l are typical in mesotrophic lakes (Chapra 1997). In order best to simulate critical conditions, MDE has assumed a chlorophyll *a* concentration of 10 µg/l, at the high end of this range. The equations used to calculate the diurnal dissolved oxygen are shown below:

*Diurnal Dissolved Oxygen Calculations*

$$p_{av} = p_s G(I_a) \qquad \text{where}: p_s = 0.25P$$

$$\frac{\Delta}{P_{av}} = \frac{\left(1-e^{-K_a f T}\right)\left(1-e^{-K_a T(1-f)}\right)}{f\,K_a\left(1-e^{-K_a T}\right)} \qquad \text{where}: a_1 = \frac{I_a}{I_s}e^{-K_e z} \quad , \quad a_o = \frac{I_a}{I_s}$$

$$G(I_a) = \frac{2.718 f}{K_e H}\left[e^{-a_1} - e^{-a_0}\right]$$

Where:

$p_{av}$ = average gross photosynthetic production of dissolved oxygen (*mg* $O_2$*/l day*)
$p_s$ = light saturated rate of oxygen production (*mg* $O_2$*/l day*)
*P* = phytoplankton chlorophyll *a (mg/l)*
$G(I_a)$ = light attenuation factor
*f* = photoperiod (fraction of a day)
*H* = the maximum depth (*m*)
$K_e$ = the light extinction coefficient ($m^{-1}$)
$I_s$ = saturation light intensity for phytoplankton (*langly/day*)
$I_a$ = average solar radiation during the day (*langly/day*)
*z* = depth at which photosynthetic activity is calculated (*m*)
Δ = dissolved oxygen variation due to phytoplankton
$K_a$ = reaeration coefficient ($day^{-1}$)
*T* = period (Thomann and Mueller 1987)

Input variables for Urieville Lake diurnal DO swing calculations are shown below:

| | |
|---|---|
| $p_s$ | = 0.25 P |
| $P$ | = 10.0 *mg/l* |
| $f$ | = 0.6 day |
| $H$ | = 1.87 m |
| $K_e$ | = 1.04 $m^{-1}$ |
| $I_s$ | = 350 langley/day |
| $I_a$ | = 500 langley/day |
| $z$ | = 0.914 m (3 ft) |
| $K_a$ | = 0.5 $day^{-1}$ |
| $T$ | = 1 d |

Using these input parameters, a step-by-step breakdown of the diurnal DO variation computation is provided below:

1. Determination of the average gross photosynthetic production of dissolved oxygen ($p_a$)

   a. $G(I_a)$ (light attenuation factor):

$$G\left(I_a\right) = \frac{2.718\ (0.6d)}{1.04\ m\ (1.87\ m)}\left[e^{-0.55} - e^{-1.42}\right]$$

$$G\left(I_a\right) = 0.29$$

   b. $p_{sv}$ (light saturated D.O. production rate):

$$p_{av} = 2.5 mg0_2 / l - d(0.29)$$

$$p_{av} = 0.73 mg0_2 / l - d$$

2. Estimate of the diurnal dissolved oxygen range:

$$\frac{\Delta}{P_{av}} = \frac{\left(1-e^{-(0.5/d)(0.6d)(1d)}\right)\left(1-e^{--(0.5d)(1d)(0.4d)}\right)}{0.6d(0.5d)\left(1-e^{-(0.5d)(1d)}\right)}$$

$$\frac{\Delta}{0.73\, mg\ 0_2\ /\ l-d} = 0.39$$

$$\Delta = 0.29\, mg\ 0_2\ /\ l-d$$

For Urieville Lake, the diurnal variation in DO is calculated as a range of **0.58** mg/l—i.e., **0.29** mg/l in either direction from the average daily DO concentration.

**Calculations of Sediment Oxygen Demand (SOD):**

Sediment oxygen demand is included as a component of the overall DO concentration in the equation below (Thomann and Mueller 1987):

$$c = \left(\frac{Q}{Q + K_L A}\right) c_{in} + \left(\frac{K_L A}{Q + K_L A}\right) c_s - \left(\frac{VK_d}{Q + K_L A}\right) L - \left(\frac{S_B A}{Q + K_L A}\right)$$

where:

c = lakewide DO accounting for SOD and CBOD
Q = lake discharge = 28,624 $m^3$/d
$K_L$ = DO transfer rate = 0.87 m/d
$K_d$ = effective deoxygenation rate = 0.3/d*
L = ambient lake CBOD 2.0 mg/l (common value for Maryland waters)
A = area = 136,379 $m^2$
V = volume = 149,254 $m^3$
$S_B$ = SOD rate = 0.92 g/$m^2$/d** (Ambrose *et al*. 1988)
$c_{in}$ = ambient lake saturation DO level at T = 30$^o$ C = 6.78 mg/l (Thomann and Mueller 1987)

* $K_d$ is 0.2/d at 20$^o$ C. To account for the assumed critical ambient temperature of 30$^o$ C, the formula below was used to calculate $K_d$:

$$(K_d)_T = (K_d)_{20} 1.047^{T-20}$$

where $(K_d)_T$ and $(K_d)_{20}$ are deoxygenation rates at water temperature $T(^oC)$ and $20^o$ C, respectively (Thomann and Mueller 1987). Thus,

$$(k_d)_{30} = (0.2/d)1.047^{30-20}$$
$$(k_d)_{30} = 0.3/d$$

** $S_B$ is 0.5 g/m$^2$/d at $20^o$ C. To account for the assumed critical ambient temperature of $30^o$ C, the formula below was used to calculate $S_B$:

$$(S_B)_T = (S_B)_{20}(1.065)^{T-20}$$

where $(S_B)_T$ and $(S_B)_{20}$ are SOD rates at water temperature $T(^oC)$ and $20^o$ C, respectively (Thomann and Mueller 1987). Thus,

$$(S_B)_T = 0.5 \text{ g } O_2/m^2/day * 1.065^{10}$$
$$(S_B)_T = 0.92 \text{ g } O_2/m^2/day$$

Using these input parameters, a step-by-step breakdown of the in-lake DO computation (including SOD) is provided below:

$$c = \left(\frac{28624 \; m^3/d}{28624 \; m^3/d + (0.87 \; m/d)(136379 \; m^2)}\right) 6.78 \; mgO_2/l + \left(\frac{(0.87 \; m/d)(136379 \; m^2)}{28624 \; m^3/d + (0.87 \; m/d)(136379 \; m^2)}\right) 7.559 \; mgO_2/l -$$

$$\left(\frac{44776 \; m^3}{28624 \; m^3/d + (0.87 \; m/d)(136379 \; m^2)}\right) 2.0 \; mgO_2/l - \left(\frac{0.92 \; g/m^2/d \, (136379 \; m^2)}{28624 \; m^3/d + (0.87 \; m/d)(136379 \; m^2)}\right)$$

Thus, $\boldsymbol{c}$ = 5.948 mg$O_2$/l.

**Final Estimate of Minimum DO under Critical Conditions:**

Including SOD, an adjusted lakewide DO of **5.948 mg/l** is estimated for Urieville Lake. Incorporating the DO depletion estimated to result from diurnal variation (0.29 mg/l), the predicted theoretical minimum DO concentration under the assumed conditions is **5.658 mg/l.**

**Estimating the Sediment TMDL**

The EPA Chesapeake Bay Program watershed modeling assumptions were adopted to quantify the sediment reduction associated with this phosphorus reduction. For the agricultural best management practices (BMPs) that affect both phosphorus and sediments, EPA estimates a 1-to-1 reduction in sediments as a result of controlling phosphorus (EPA, CBPO 1998). The primary BMP in this category are the various land management practices that fall under Soil Conservation and Water Quality Plans (SCWQPs). The other broad category of phosphorus controls are nutrient management plans (NMPs), which manage fertilizer application, including animal waste. Thus, if nutrient management plans make up part of the control strategy, the ratio will be less than 1-to-1.

To estimate this ratio, and hence the sediment load reduction, it is necessary to estimate the proportion of the phosphorus reduction that is anticipated to result from SCWQPs versus NMPs. Table 2 of the report, which shows estimated ranges of phosphorus reduction, is reproduced below for convenience. Note that the range in reduction of phosphorus is about the same for NMPs and SCWQPs. Since these BMPs are applied on a per-acre basis, an initial assumption might be that half the reduction would come from NMPs and half from SCWQPs, making the ratio about 0.5-to-1. This ratio has been adopted for estimating the reduction in sediment loads.

This ratio is conservative (gives a low estimate of sediment reductions) for two reasons. First, because soils are easily erodible in the Urieville watershed, the NMP removal efficiency should be compared to the "treatment of highly erodible land," which is another term for a SCWQP in areas where soils are highly erodible. This interpretation of the BMPs gives a ratio of 1-to-0.75 or better. Second, the sediment reduction effects of conservation tillage have not been counted.

**Table 2**

**Phosphorus Removal Efficiencies of Various Agricultural BMPs**

| **Best Management Practice** | **Estimated Range of Phosphorus Reduction** |
|---|---|
| Soil Conservation & Water Quality Plan (SCWQP) | 11% - 35% |
| Treatment of Highly Erodible Land[1] | 3 x the result of SCWQP on typical soil |
| Conservation Tillage | 13% - 50% |
| Nutrient Management Plans | 9% - 30% |

Source: "Technical Appendix for Maryland's Tributary Strategy" (Maryland, 1995)
Notes:

1. The soils in the Urieville watershed are considered easily erodible (DNR, Oct. 1996).

To estimate the net sediment reduction associated with the 85 percent phosphorus reductions, we apply the ratio 0.5-to-1 ratio established above as follows:

100* (0.5 * 0.849) = **42.45 percent reduction in sediment loads**

Applying this reduction to the current estimation of 155 tons of sediments per year (DNR, October 1996), results in the estimated reduction, the converse of which is the estimated allowable load:

(0.4245 * 155) = 65.8 tons/year reduction
155 - (0.4245 * 155) = **89.2 tons/year allowable sediment load**

To estimate annual accumulation associated with this loading rate, we first considered the current accumulation rate. That is, 51 acre feet of 121 acre feet, or 42% of the volume, was displaced between 1955 and 1995 (40 years). Assuming a 42% reduction in sediment loading, the current rate of lake volume displacement will be reduced accordingly. Thus, rather than a 42% loss of volume over 40 years, we would expect a **24% loss of volume over 40 years**, computed as:

$$\frac{\text{42\% displacement in 40 years}}{\text{100\% of current loading}} = \frac{\text{X\% displacement in 40 years}}{\text{57.5\% of current loading}}$$

or, 0.42/1 = X/0.58
or, X = 0.575 * 0.42 = 0.24 (a 24% volume displacement over 40 years).