Total Maximum Daily Loads for Phosphorus To Address 9 Eutrophic Ponds in Rhode Island

Almy Pond, Newport
Brickyard Pond, Barrington
Gorton Pond, Warwick
North Easton Pond, Middletown, Newport
Roger Williams Park Ponds, Providence
Sand Pond, Warwick
Spectacle Pond, Cranston
Upper Dam Pond, Coventry
Warwick Pond, Warwick

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5.0 TMDL ANALYSIS

As described in EPA guidelines, a TMDL identifies the pollutant loading that a waterbody can assimilate per unit of time without violating water quality standards (40 C.F.R. 130.2). The TMDL is often defined as the sum of loads allocated to point sources (i.e. waste load allocation, WLA), loads allocated to nonpoint sources, including natural background sources (i.e. load allocation, LA), and a margin of safety (MOS). The loadings are required to be expressed as mass per time, toxicity, or other appropriate measures (40 C.F.R. 130.2[I]).

5.1 Margin of Safety (MOS)

The MOS may be incorporated into the TMDL in two ways. One can implicitly incorporate the MOS using conservative assumptions to develop the allocations or explicitly allocate a portion of the TMDL as the MOS. This TMDL uses the latter approach of allocating an additional 10 percent reduction in allowable total phosphorus loading as an adequate MOS.

5.2 Critical Conditions and Seasonal Variation

Critical conditions for phosphorus occur during the growing season, which in most waterbodies occurs from May though October, when the frequency and occurrence of nuisance algal blooms, low dissolved oxygen, and macrophyte growth are usually greatest. Since these TMDLs are based on information collected during the most environmentally sensitive period (i.e., the growing season) and were developed to be protective of this critical time period, they will also be protective of water quality during all other seasons.

5.3 Numeric Water Quality Target

The primary goal of this Total Phosphorus TMDL is to address the water quality impairments in the eutrophic ponds associated with excess phosphorus loadings including increased algal growth/chlorophyll a, and low dissolved oxygen. Reducing phosphorus is the most effective way to reduce algal abundance, because the growth of algae in freshwater environments is typically constrained by the availability of phosphorus. With algal abundance under control, the variability in dissolved oxygen levels (high daytime values, low nighttime values, and depressed oxygen levels following bloom crashes) will be reduced. As a consequence, dissolved oxygen and algae targets are not set explicitly by the TMDL. The Department believes that these impairments will be addressed by reducing phosphorus to an appropriate level.

RIDEM has set a total phosphorus concentration of 25 ug/l as the numeric target for most of the shallow ponds included in this study. These ponds are less than 5 meters deep and include Almy, North Easton, Roger Williams Park, and Upper Dam Ponds. This 25 ug/l numerical target is consistent with the State's water quality criteria for total phosphorus. Compliance points of shallow ponds are based on historic surface sampling stations.

A numerical target of 20 ug/l was set for deep ponds (> 5 meters deep) to address dissolved oxygen impairments in the hypolimnion. Deep ponds include Brickyard, Gorton, Sand, and Warwick Ponds. A separate TMDL conducted for Mashapaug Pond, located in Providence, concluded that in order to eliminate hypoxia (defined as a DO concentration <2 mg/l) in the hypolimnion of the pond, the mean total phosphorus concentration in the pond had to be reduced to 20 ug/l. Since Mashapaug pond is a deep eutrophic pond and has similar characteristics to the eutrophic ponds included in this study, a reduction of total phosphorus to the 20 ug/l target in the deep eutrophic ponds is expected to address the DO impairment to these ponds. The compliance points for the deep ponds (depth > 5 meters) are the simple averages of the historic surface and deep sampling stations. Although Spectacle Pond is classified as a shallow pond, its maximum depth exceeds 5 m and measurements by RIDEM staff indicated that dissolved oxygen concentration were low. For these reasons and the fact that Spectacle Pond is located immediately upstream of Mashapaug Pond, the target of 20 ug/l was also used for Spectacle Pond. Spectacle Pond was sampled for phosphorus at the surface only.

The URIWW data indicates that the primary water quality problem affecting most of the ponds is an overabundance of algae caused by elevated levels of phosphorus. Although many ponds had mean chlorophyll-a concentrations within an acceptable range, all exhibited extremely elevated maximum chorophyll-a concentrations ranging from 21 to 166 ug/l. The presence of algal blooms diminishes the value of the ponds for virtually all uses and aggravates hypoxic conditions in the bottom waters of the ponds in the summer months. Recreational use is made less appealing, aesthetic enjoyment is impaired, and habitat value is reduced. To support these designated uses, a chorophyll level of 9ug/l is set as an objective of this TMDL.

Dissolved oxygen concentrations are measured by URI Watershed Watch in deep (>5m) lakes only. The deep lakes among these eutrophic ponds include Brickyard, Gorton, Sand, and Warwick Ponds. All of these deep ponds are listed on the 303(d) list as impaired for DO. As previously discussed in sections 3.2, 3.3, 3.6, and 3.9, DO concentrations were measured 1 m from the bottom and typically fell below 3 mg/l (a critical level for most aquatic life) by May and remain below 3 mg/l through October. Dissolved oxygen concentrations were typically below the detection limit from mid-summer through October.

Data collected by RIDEM staff indicates that even shallow ponds can be characterized by low DO concentrations. Dissolved oxygen concentrations were measured on July 28, 2004 in Spectacle Pond. Although classified as shallow, temperature data indicates that the pond does become stratified. As discussed in section 3.7, the DO concentration in the hypolimnion of Spectacle Pond was 1-2 – 1.5 mg/l. Roger Williams Park Ponds, which is also classified as a shallow lake, is listed on the 303(d) list as impaired for DO based on historic data.

The dissolved oxygen condition that would be expected in the deep eutrophic ponds in the absence of human activities in its watershed was estimated from conditions in two similar ponds, Upper Schoolhouse Pond and Wakefield Pond (RIDEM, 2007). Data for these ponds was obtained from URI Watershed Watch Program. Both Upper Schoolhouse Pond and Wakefield Pond are located in rural areas and in the case of the latter, its watershed is primarily wooded. Data from URIWW were available for Schoolhouse Pond for the summer of 2001 and for Wakefield Pond for the summer of 1997. Both waterbodies are classified as deep ponds by URIWW. Vertical temperature differences in the ponds typically ranged from 3-8° C. (Figures 5.1 and 5.2). The naturally occurring stratification in these ponds lowered dissolved oxygen down to 2.5 mg/l in the hypolimnia. Hypolimnetic DO declines during the summer because it is cutoff from all sources of oxygen, while organisms continue to respire and decay, consuming oxygen.

The current Rhode Island water quality criteria for warm water fish habitat are an instantaneous DO concentration of at least 5.0 mg/L at any point in the water column except as naturally occurs and a 7-day mean water column concentration of at least 6.0 mg/L. As previously discussed, the natural process of density stratification due to a vertical temperature gradient can produce low dissolved oxygen concentrations in the hypolimnion (lower layer) of naturally stratifying deep lakes, and even shallower lakes and ponds. Low DO in the hypolimnion can be more distinct in eutrophic lakes (i.e., those having high nutrient and algae levels), but is present in healthy lakes as well.

Figure 5. 1 Upper Schoolhouse Pond Temperature and DO Profiles

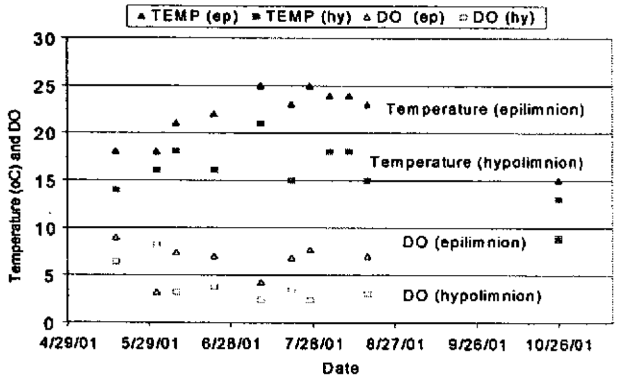
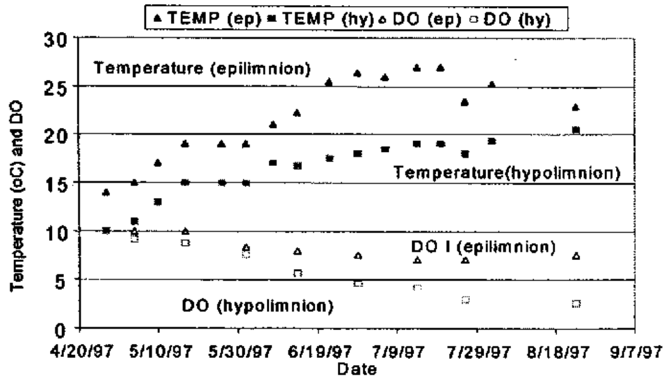


Figure 5. 2 Wakefield Pond Temperature and DO Profiles



DEM's Water Quality Regulations state in the definition for "low quality" or "degraded waters" that "*Waters in their natural hydraulic condition may fail to meet their assigned water quality criteria from time to time due to natural causes, without necessitating the modification of assigned water quality standard(s). Such waters will not be considered to be violating their water quality standards if violations of criteria are due solely to naturally occurring conditions unrelated to human activities.*" The clear intent of the definition is to state that a water body not meeting dissolved oxygen numeric criteria solely due to natural causes is not considered impaired. When a water body naturally does not meet the numeric criteria, as is the case with many freshwater lakes, the levels seen in the natural condition must then become the water quality target for those and similar bodies. The dissolved oxygen concentration measured along a vertical profile (which was greater than 2 mg/L in the hypolimnion) for the two unimpaired reference ponds is selected as the naturally occurring hypolimnetic condition for the deep stratified eutrophic ponds. Thus a DO concentration equal to or greater than 2 mg/l in the hypolimnion of deep eutrophic ponds is set as the goal for DO in these deep eutrophic ponds. For shallow ponds, it is recognized that DO levels of 4.0 mg/l or less may naturally occur. The objective of this TMDL is to restore the ponds to a condition that supports their designated uses and protects them from future degradation. In summary, the goals of this TMDL are to:

- Reduce total phosphorus levels in the ponds to an average level of 25 ug/L for shallow lakes (< 5 meters deep) and 20 ug/l for deep lakes;
- Reduce algal abundance to levels consistent with designated uses, targeting a chlorophyll level of approximately 9 ug/L;

- Improve instantaneous dissolved oxygen levels in the ponds to the maximum extent feasible consistent with naturally occurring conditions; and
- Eliminate hypoxia (defined as a DO concentration <2 mg/l) in the hypolimnion to support the propagation of fish and other animal life in the ponds.

5.4 Technical Analysis

The current annual mean phosphorus load was based on the average TP concentration and areal water loading (see below equation) using the Reckhow model (1979). The Reckhow model was developed from a database of lakes within a north temperate setting, thereby making it applicable for waterbodies within southern New England. The Reckhow model expresses phosphorus concentration (TP in mg/l) as a function of phosphorus loading (L, in g/m^2-yr), areal water loading (q_s, in m/yr), and apparent phosphorus settling velocity (v_s, in m/yr) in the form:

$$TP = L/(v_s + q_s)$$

Using a least squares regression, it was found that the apparent settling velocity could be fit using a weak function of q_s. This resulted in the fitted model:

$$TP = L/(11.6 + 1.2q_s)$$

Where:
L = Existing Load; and
q_s = Areal Water Load.

The existing annual load (*L*) for each pond was calculated by substituting the observed total phosphorus concentration, averaged over the sampling period, into the Reckhow equation. With the exception of North Easton Pond, the mean annual total phosphorus concentration was derived from URIWW data. All URIWW data available since 1993 was used. Generally three total phosphorus measurements were taken each year, typically in May, July, and October/November. The mean annual total phosphorus concentration of North Easton Pond was calculated from limited RIDEM data.

The estimation of Areal Water Load (q_s) was calculated in the following manner:

$$q_s = Q/Ao$$

Where:
Q = Inflow Water Volume; and
A_o = Lake Surface Area.

$$Q = (A_d \times r) + (A_o \times Pr)$$

Where:
q_s = Areal water loading (m/yr);
Q = Inflow water volume (m^3/yr);
A_d = Watershed area (m^2);
A_o = Waterbody surface area (m^2);
r = total annual unit runoff (m/yr); and
P_r = mean annual net precipitation (m/yr).

Ideally, Q should be determined from direct measurement of inflow or outflow. Since data for Q are not available, it was estimated by regressing mean annual inflows, based on long-term records of gauged streams in Rhode Island against drainage area. This resulted in a value of 2 cfs per square mile (18.9 m^3/d/ha), which was converted into the value Q in m^3/yr. This value was then divided by the waterbody area (A_o) in order to obtain values of q_s for each waterbody.

5.5 Existing Waterbody Loads

Estimated mean annual inflows, mean phosphorus concentrations, and annual current total phosphorus loads to the nine ponds are summarized in Table 5.1. The daily load is the annual load divided by 365. North Easton Pond had the highest estimated mean annual inflow in the study group, followed by Roger Williams Park Ponds, Warwick and Brickyard Ponds, Spectacle and Gorton Ponds, Almy Pond, and Upper Dam Pond. Sand Pond has the lowest estimated mean annual inflow in the study group.

Table 5. 1 Summary of estimated current total phosphorus loads, mean total phosphorus concentrations, and mean annual inflows.

Waterbody	Watershed Area (ha)	Estimated Mean Annual Inflow (m^3/yr)	Mean Annual Total Phosphorus Concentration (ug/l)	Current Load (kg/yr)
Almy Pond	135.4	9.35×10^5	152	526
Brickyard Pond	309.8	2.14×10^6	63	410
Gorton Pond	185.0	1.28×10^6	56	239
North Easton Pond	982.2	6.78×10^6	114	1470
Roger Williams Park Ponds	917.9	6.33×10^6	82	1027
Sand Pond	24.6	1.70×10^5	64	50
Spectacle Pond	237.6	1.64×10^6	57	216
Upper Dam Pond	87.2	6.02×10^5	42	71
Warwick Pond	346.2	2.39×10^6	27	185

At 152 ug/l, Almy Pond has the highest mean annual total phosphorus concentration in the study group. North Easton and Roger Williams Park Ponds have mean annual total phosphorus concentrations of 114 and 82 ug/l, respectively. Brickyard, Gorton, Sand, Spectacle, and Upper Dam Pond have mean annual total phosphorus concentrations in the 42-64 ug/l range. The mean annual phosphorus concentration for Warwick Pond was 27 ug/l.

At 1470 kg/yr, North Easton Pond has the highest current annual phosphorus load of any of the ponds in the study group. Roger Williams Park Ponds have a current mean annual phosphorus load of 1027 kg/yr. Almy Pond has a current mean annual phosphorous of 526 kg/yr. Brickyard Pond has a current mean annual phosphorus load of 410 kg/yr. The annual loads of Gorton, Spectacle and Warwick Pond are in the 180-240-kg/yr range. Upper Dam and Sand ponds both have annual phosphorus loads less than 75 kg/yr.

5.6 Loading Capacity and Allocation of Allowable Loading

In section 5.5, current loads were calculated from in-pond total phosphorus concentrations using the Reckhow model. Allowable loadings (TMDLs) were back-calculated using the Reckhow model and the 25 ug/l or 20 ug/l (0.025 or 0.020 mg/l) numeric water quality target as the load (L). A ten percent margin of safety was then subtracted from this value to determine the Target Load for each waterbody.

TMDL calculations for each of the eutrophic ponds are shown in Appendix C. The necessary load reductions are calculated as follows:

Percent Reduction (%) = [(Current Load – Target Load)/ Current Load] x 100

Allowable phosphorus loads, required load reductions in kg/yr and the percent reduction in loads for each pond are presented below in Table 5.2.

The allowable pollutant load, or TMDL for the ponds can be expressed as follows (EPA, 2002):

TMDL = WLA +LA + MOS

Where:

TMDL = Allowable Pollutant Load
WLA = Waste Load Allocation
LA = Load Allocation, and
MOS = 10% Margin of Safety.

Table 5. 2 Allowable Phosphorus Loads, Required Load Reductions & % Reductions to meet Water Quality Targets.

Waterbody	Current Load (kg/yr)	TMDL * (kg/yr)	Required Load Reduction (kg/yr)	Required Loading Reduction (% Present Value)
Almy Pond	526	78	448	85
Brickyard Pond	410	117	293	71
Gorton Pond	239	77	162	68
North Easton Pond	1470	301	1169	80
Roger Williams Park Ponds	1027	282	745	73
Sand Pond	50	14	36	72
Spectacle Pond	216	68	148	68
Upper Dam Pond	71	38	33	46
Warwick Pond	185	123	62	33

* Includes a 10% Margin of Safety.

The allocation of loads between stormwater WLAs (point sources) and LAs (non-point sources) was established according to estimates of percent impervious and pervious land cover within separate land use categories specified in Table 5.3. This separation between stormwater WLAs and LAs based on impervious area within land use categories represents the best estimate defined as narrowly as the data allow. For those ponds affected by birds and internal cycling of TP, this methodology of allocating between WLA and LA will over estimate the portion of the total load assigned to point sources. The values of percent impervious cover, assigned to each separate land use, were taken from a study conducted by the Center for Watershed Protection (CWP).

Table 5. 3 Impervious cover (%) for land uses within each waterbody.[1]

Land Use Category	IMPERVIOUS COVER (%)
High density residential	55
Medium density residential	36
Low density- rural residential	22
Commercial	85
Industrial	72
Mixed urban- other urban	46
Agriculture	2
Forest, wetland, water	0

1.Data taken from URI NEMO Program and the Center for Watershed Protection.

Percent impervious area within each of the land use categories was multiplied by the percent of each land use within the watershed in order to calculate a percent impervious value for each watershed. Table 5.4 presents the estimated percent impervious area for each watershed, and the allowable annual loads allocated between point (WLA) and non-point (LA) sources. The daily load is the annual load divided by 365.

Table 5. 4 Allocation of Phosphorus Loads for each Waterbody.

Water Body[1]	Percent Impervious Area in Watershed	TMDL[23] (kg/yr)	=	WLA (kg/yr)	+	LA (kg/yr)
Almy Pond	29	78	=	22.4	+	55.4
Brickyard Pond	33	117	=	38.1	+	79.1
Gorton Pond	39	77	=	29.7	+	47.2
North Easton Pond	34	301	=	101.0	+	199.6
Sand Pond	54	14	=	7.5	+	6.5
Spectacle Pond	57	68	=	38.6	+	29.6
Upper Dam Pond	32	38	=	12.1	+	25.8
Warwick Pond	39	123	=	47.8	+	75.4

1. Roger Williams Park Ponds allocations are presented separately.
2. Allowable loads (TMDL) are rounded to the nearest whole number and include a 10% explicit Margin of Safety.
3. The daily load is the annual load divided by 365.

As an example, for Spectacle Pond 57% of the total watershed area is impervious, so the required reductions are allocated between point and nonpoint sources such that 57% of the total reduction will be allocated to point sources (WLA), and 43% of the reduction to nonpoint sources (LA). The existing load for Spectacle Pond based on the Reckhow formula is 216 kg/yr, and the Reckhow formula predicts that the loading capacity is 76 kg/yr. An explicit 10% of the loading capacity is reserved for the MOS, so the TMDL becomes 68 kg/yr. The percent total load reduction is (216-68)/216 = 68%. From above, the WLA is 38.6 kg/yr, and the LA 29.6kg/yr. The fractional reduction assigned to point sources to meet the WLA will be equal to or greater (i.e. PS load reduction ≥ 57%) than that for LA reduction percentage (NPS reduction < or = 57%).

Mashapaug Pond discharges to Roger Williams Park Ponds via a 0.4 km subsurface conduit. Mashapaug Pond has been identified as a major source of phosphorus to Roger Williams Park Ponds. The existing or current load from Mashapaug Pond is 232 kg/yr (RIDEM, 2007), which comprises 23% of the total current load (1027 kg/yr) to Roger Williams Park Ponds (Table 5.5). The current load from the remaining portion of the watershed is 795 kg/yr. The existing point source and non-point source loads associated with the subwatershed that discharges directly to Roger Williams Park Ponds were determined using the estimate of the percent of impervious area within the subwatershed.

Table 5. 5 Current Phosphorus Loads for Roger Williams Park Ponds.

Total Current Load (kg/yr)	Current Load from Mashapaug Pond (kg/yr)	Current Load from Remaining Portion of Watershed (kg/yr)	Percent Impervious Area in Subwatershed	Subwatershed Point Source Current Load (kg/yr)	Subwatershed Nonpoint Source Load (kg/yr)
1027	232	795	39	310	485

The TMDL calculations associated with Roger Williams Ponds differs slightly from those of the remaining ponds. The TMDL assigned to Mashapaug Pond is 108 kg/yr (RIDEM, 2007), which comprises 38% of the entire TMDL of 282 kg/yr assigned to Roger Williams Park Ponds (Table 5.6). The remaining portion of the TMDL assigned to the subwatershed that discharges directly to Roger Williams Park Ponds is 174 kg/yr. The waste load and load allocations were assigned to the subwatershed that discharges directly to Roger Williams Park Ponds and were determined using the estimate of the percent of impervious area within the subwatershed.

Table 5. 6 Allocation of Phosphorus Loads for Roger Williams Park Ponds.

TMDL[12] for Roger Williams Park Ponds	TMDL Assigned to Mashapaug Pond (kg/yr)	Percent Impervious Area in Subwatershed[3]	TMDL Assigned to Subwatershed [3] (kg/yr)	=	WLA (kg/yr)	+	LA (kg/yr)
282	108	19	174	=	33.3	+	140.7

1. Allowable loads (TMDL) are rounded to the nearest whole number and include a 10% explicit Margin of Safety.
2. The daily load is the annual load divided by 365.
3. Subwatershed refers to that portion of the watershed that discharges directly to Roger Williams Park Ponds and excludes that portion that discharges to Mashapaug and Spectacle Ponds.