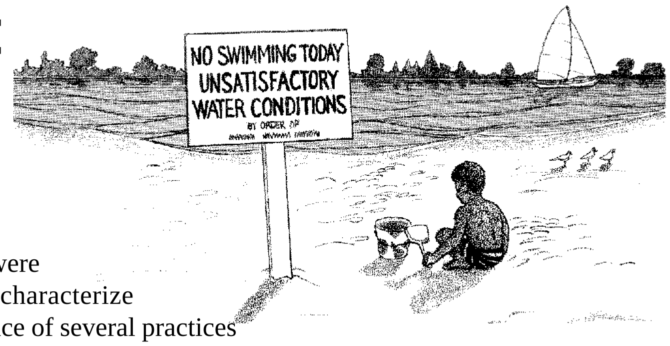
Managing Phosphorus Inputs Into Lakes

III. Evaluating the Impact of Watershed Treatment



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Introduction

A major challenge for lake managers facing watershed growth is to choose the most effective practices to reduce phosphorus loads, in order to maintain current lake uses into the future. This article focuses on the potential for treating nonpoint sources of phosphorus; however, lake managers should also keep in mind that point sources, such as wastewater treatment plants, should also be examined if they represent a major component of a lake's total phosphorus budget.

Lake managers possess a number of tools to reduce phosphorus loadings from new watershed development, the most notable of which are stormwater treatment practices (STPs) and Better Site Design (BSD). In addition, they can apply a series of practices to reduce phosphorus loads after development has occurred. These "post development" watershed practices include lawn care education, stormwater retrofits, rehabilitation of failing septic systems, pet and waterfowl control, and elimination of illicit discharges. This article outlines what is currently known about the ability of each of these practices to reduce phosphorus loads, as a thorough understanding of the capabilities and limitations of each kind of watershed treatment practice is critical to crafting an effective lake watershed protection plan.

Phosphorus Removal of Stormwater Treatment Practices

Table 1 summarizes the removal capabilities of several common STPs, as derived from the Center's pollutant removal database (Winer, 2000). While most lake eutrophication models utilize total phosphorus, soluble phosphorus is of particular interest to the lake manager, since this form of phosphorus is most readily available for uptake by algae (i.e., phytoplankton). Therefore, lake managers will want to emphasize STPs that have high removal capability for both total and soluble phosphorus. Table 2 summarizes the pollutant removal of five major groups of STPs (i.e., ponds, wetlands, filters, infiltration, and open channels).

The performance data contained in Tables 1 and 2 represent median values derived from 145 monitoring studies conducted throughout the United States and Canada (Winer, 2000). It is important to note that limited data were available to characterize the performance of several practices (these are designated by an asterisk). Therefore, the STP removal data should be viewed as a general indicator of achievable performance for different practices. As a general rule, the median total phosphorus removal achieved by the typical stormwater treatment practice is about 50%. However, this removal represents an ideal efficiency, and should probably be discounted to account for practice age, imperfect application, and partial runoff capture.

Not surprisingly, infiltration practices were found to be the most effective treatment practice for phosphorus removal. An added benefit of infiltration practices

Table 1. Median Phosphorus Removal Efficiencies for Selected Stormwater Treatment Practices (Winer, 2000)

Stormwater Treatment Practice	TP	Soluble P
Infiltration Trench*	>90%**	>90%**
Dry Swale*	83	70
Multiple Pond System*	76	69
Porous Pavement*	65	10
Bioretention*	65	N/A
Submerged Gravel Wetland*	64	-10
Organic Filter*	61	30
Surface Sand Filter	59	-17
Pond/Wetland System	56	43
Wet Extended Detention Pond	55	67
Wet Pond	49	62
Vertical Sand Filter*	45	21
Shallow Marsh	43	29
Perimeter Sand Filter*	41	68
Extended Detention Wetland*	39	32
Grass Channel*	29	40
Wet Swale*	28	-31
Dry Extended Detention Pond	20	-11

**Data based on fewer than five performance studies.*
*** Insufficient data to reliably report a median.*

is that they reduce the amount of surface runoff. Unfortunately, infiltration practices may not always be feasible due to soil constraints or poor longevity. Pond systems were also found to be a reliable removal option for both soluble and total phosphorus. Filters were fairly effective at removing total phosphorus, but exhibited little or no capability to remove soluble phosphorus. This phenomenon can be explained by the fact that most sand filters have no biological or chemical processes to bind soluble phosphorus. The addition of organic matter or binding agents to sand filters may show promise in boosting removal, but early monitoring of experimental filters have yet to demonstrate this result conclusively (Schueler, 2000a).

Wetlands were found to have highly variable capability to remove both soluble and particulate forms of phosphorus. The variability can be explained in part by internal phosphorus cycling within the wetland, sediment release, and vegetative dieback during the non-growing season (Schueler, 1992). As might be expected, the best overall performers in the stormwater wetland group were pond-wetland systems (i.e., wetlands with a relatively large portion of their storage devoted to a deep pool).

Lake managers should also be aware of irreducible phosphorus concentrations when assessing the potential removal capability of stormwater treatment practices. Irreducible phosphorus concentrations represent minimum achievable concentrations discharged by a stormwater treatment practice. In other words, they represent the current limit of treatment with respect to outflow phosphorus concentrations. Table 3 presents the mean total phosphorus and soluble phosphorus outflow concentrations from each of the stormwater treatment practice groups (Winer, 2000), and compares them to runoff from forested watersheds and uncontrolled stormwater runoff. Irreducible concentrations have important implications for the watershed manager. They suggest that, even if stormwater treatment practices are widely spread across a watershed, the treated stormwater runoff may still exceed background concentrations, potentially leading to a shift in lake trophic status. In addition, they imply that stormwater regulations that require "no increase in P load" may be extremely difficult to meet at the site level.

Table 2. Median Phosphorus Removal Efficiencies for Stormwater Treatment Practice Groups

Practice Group	TP [%]	Soluble P [%]
Infiltration Practices	80	85*
Filtering Practices	59	3
Stormwater Wet Ponds	51	66
Stormwater Wetlands	49	36
Water Quality Swales	34	38
Stormwater Dry Ponds	19	-6.0*

**Data based on fewer than five performance studies.*

Table 3. Mean Total and Soluble Phosphorus Effluent Concentrations (mg/l)

Practice Group	TP	Soluble P
Typical Untreated Urban Runoff	**0.30**	**0.16**
Infiltration Practices	0.18	0.01
Filtering Practices	0.16–0.06[c]	0.06
Stormwater Wet Ponds	0.13–0.03	0.06–0.02
Stormwater Dry Ponds	0.19	0.13
Water Quality Swales	0.21–0.11	0.09–0.05
Stormwater Wetlands	0.17–0.04	0.09–0.03
Typical Concentrations for Forested Watersheds	**0.05[a]**	**0.01[b]**

a: TP concentrations (USGS, 1999)
b: Orthophosphorus for >90% forested watersheds (Omerink, 1977)
c: – indicates 90% confidence intervals assuming a normal distribution. This value is not calculated for sample sizes smaller than 5.

Stormwater Design for Enhanced Phosphorus Removal

Given the range of phosphorus removal that can be achieved by STPs, lake managers may want to provide more detailed guidance on how to maximize phosphorus removal by STPs. Some recommendations for selecting, sizing, and designing STPs for greater phosphorus removal are provided in Table 4. Lake managers should also seriously consider revising current STP design manuals to eliminate stormwater practices with poor phosphorus removal capabilities.

Better Site Design

Better site design (BSD) refers to a series of practices that minimize impervious cover, conserve natural areas, and improve stormwater treatment on individual development sites. These practices have become much more accepted in recent years, and go by many names such as low impact development, zero discharge, green infrastructure, conservation development, environmentally sensitive design, and sustainable urban drainage systems. While the brand names are different, most rely on a mix of a few dozen simple design practices. BSD is very important in both the shoreland protection zone and the watershed as a whole.

Redesign analyses have shown that the careful application of BSD at a development site can be an important element of a lake protection strategy. In general, the phosphorus reduction is achieved by minimizing or disconnecting impervious cover, reducing turf area, and conserving natural areas. For example, Zielinski *et al.* (1998) reported that intensive application of BSD techniques could result in phosphorus removal equivalent to STPs over a range of residential development sites. Zielinski also concluded that the combination of STPs and BSD could approach, but not quite attain, predevelopment phosphorus loading rates.

In general, BSD produces the greatest phosphorus reduction for low density residential development, since clustering or open space subdivisions can be utilized. Some estimates of the potential phosphorus reduction that can be achieved through BSD for different zoning categories are presented in Table 5. However, it is important to note that many communities will need to revise their current development codes and ordinances to realize these benefits.

The combined benefit of applying STPs and BSD is shown in Figure 1. The figure was derived using the Simple Method (Schueler, 1987), with the assumptions of a discounted, watershed-wide phosphorus removal rate of 38.5%, BSD load reductions as shown in Table 5, and the very conservative assumption that no secondary phosphorus loads, such as wastewater loading, are present.

As can be seen, stormwater runoff starts to exceed phosphorus loads at 4%, 17%, and 40% impervious cover for forested, rural, and agricultural watersheds, respectively. If STPs and BSD are effectively applied across the watershed, however, these impervious cover thresholds can be roughly doubled.

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Table 4. Design Tips for Stormwater Treatment Practices to Remove Phosphorus

- In the shoreland protection zone, use environmentally sensitive shoreline development techniques in lieu of stormwater treatment practices.
- Infiltration practices are preferable in watersheds where they are widely feasible.
- Wet ponds are also recommended, particularly if they have a large permanent pool (up to one to two watershed inches of storage).
- Design wet ponds with a depth no greater than eight feet to prevent stratification, and potential release of phosphorus from bottom sediments. Also consider a surface or mid-depth release from the pond. Landscape ponds to discourage geese.
- Avoid the use of dry or dry extended detention ponds, which have very limited phosphorus removal capabilities.
- Use stormwater wetlands sparingly, given their variable phosphorus removal and potential loss of removal capacity over time (Oberts, 1999). Promote the pond/wetland system where possible.
- Submerged gravel wetlands show promise for phosphorus removal, but more experience is needed to develop sound design criteria (VANR, 2001).
- In northern areas, designers should explicitly consider the snowmelt runoff volume and phosphorus concentrations, which Oberts (1994) has shown can deliver a large fraction of the annual P load. Designers may wish to consider seasonal operation for ponds, and provide pervious areas on-site for meltwater treatment. For design guidance, consult Caraco and Claytor (1997).
- Bioretention areas show greater promise than sand filters to remove phosphorus, and are a preferred option for small sites.
- Any practice can release phosphorus over time if improperly maintained. A stormwater management program should include specific maintenance requirements, as well as a mechanism to ensure that these actions are completed.
- Although open channels are a preferred method of stormwater conveyance, they cannot be relied on as the only practice to remove phosphorus at a development site, with the exception of an engineered dry swale.
- Most practices require a vigorous vegetative cover to function properly (e.g., grass swales, filter strips). Landscaping plans for these practices should specify minimal use of phosphorus fertilizer.

Phosphorus Removal Associated with Post-Development Watershed Practices

Significant opportunities exist to reduce phosphorus loads from existing development in a lake watershed. Many of these practices involve treating secondary sources of phosphorus to urban lakes, and include the following:

- Education to reduce phosphorus runoff from turf and lawns
- Stormwater retrofit ponds to serve uncontrolled development
- Repair of failing septic systems and septic system maintenance
- Pet waste cleanup
- Street sweeping and improved leaf collection
- Discouraging waterfowl populations
- Eliminating illegal discharges, sanitary sewer overflows, and combined sewer overflows
- Catch basin cleaning
- Impervious cover disconnection

A common feature of most of these watershed practices is that they reduce phosphorus loadings at their source to protect or restore lake quality. As a result, they require considerable changes in individual behaviors that generate phosphorus loadings, and require intensive outreach and/or enforcement programs on the part of a municipality or lake association to be effective.

As one might expect, lake managers are often challenged to precisely estimate how much these programs will influence a lake's phosphorus budget. An analytical approach to estimates of the likely phosphorus reduction achieved at the watershed level has recently been developed (Caraco, 2001). This model, known as the Watershed Treatment Model, emphasizes the concepts of "treatability" and performance discounts.

Using lawn care education as an example, *treatability* is defined based on the fraction of watershed population that can be effectively reached, and the corresponding acreage of fertilized turf in the watershed that could be treated. Often, a lake manager must improvise as to the phosphorus reduction that can be achieved by lawn care education on this "treated" area. Whatever phosphorus reduction is assumed to occur must then be discounted to account for real world implementation factors. For example, in the lawn care example, not all homeowners in the watershed who actually hear the education message will be compelled to change their ways. While many of these discount factors are not well understood, they can be estimated from watershed behavior surveys (Schueler, 2000b). An example of how the Watershed Treatment Model evaluates the effect of post-development watershed practices can be found in Box 1.

As the foregoing suggests, lake managers need to clearly acknowledge the limits of watershed treatment, whether applied to new or existing development. In most watersheds, stormwater treatment and better site design can only partially offset the increase in phosphorus loadings generated by watershed development. If a lake is extremely sensitive to phosphorus inputs (e.g., an oligotrophic or mesotrophic lake), the application of stormwater treatment and better site design practices may be inadequate to prevent an upward shift in a lake's trophic status. In these situations, lake managers will need to rely on land use controls to limit the overall amount of development in the watershed.

Table 5. Potential Reduction in Site Impervious Cover Using Better Site Design

Zoning Category	Base Impervious Cover (%)	Expected Reduction in Impervious Cover From Better Site Design (%)	Potential Resulting Load Reduction (%)
2-Acre Residential	11	50	33
1 Acre Residential	14	40	29
‰Acre Residential	21	30	24
…Acre Residential	28	20	17
1/8 Acre Residential	33	20	17
Townhouse	41	15	13
Multifamily	44	15	13
Light Industrial	53	10	9
Commercial	72	10	9

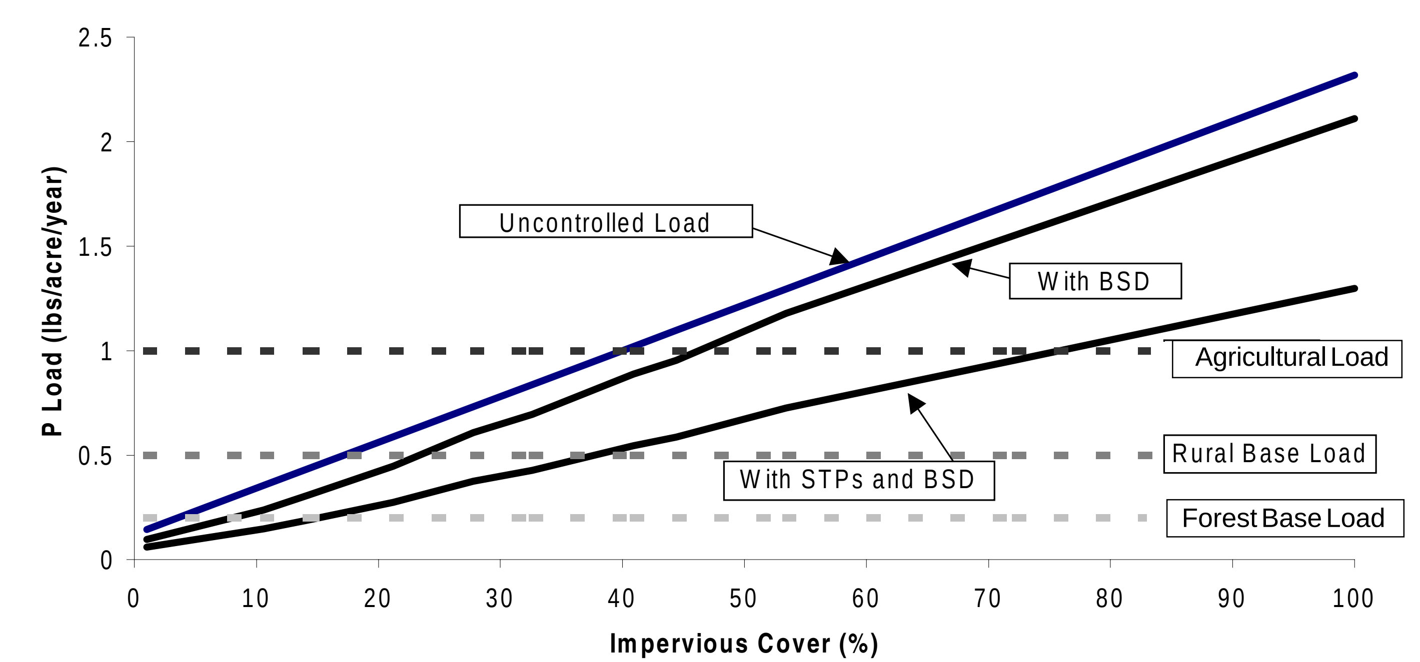

Figure 1. Phosphorus Export for Various Levels of Development and Stormwater Control

This graph shows how phosphorus loads in a watershed increase in response to more impervious cover. Note the impact of better site design and stormwater treatment on reducing phosphorus loads. Typical phosphorus loads for forest, rural and agricultural watersheds are shown for comparison purposes.

The exact combination of watershed practices will be different for each lake, given its projected phosphorus budget, vulnerability to phosphorus inputs and, most importantly, the water quality goals for the lake. In most urban lakes, however, managers will need to educate the community on both their role in preserving lake quality, and the need for land use controls. In order to retain the very qualities that attract people to live in or near a lake, individuals will need to change their behavior, and the overall level of development in the watershed may need to be restricted.

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Box 1. Example Scenario: Effect of Lake Watershed Controls

A hypothetical management plan is being developed for Green Lake (see example in Article I for existing lake conditions and land use). The current phosphorus load to the lake is approximately 130,000 lbs/year (lake areal loading rate of approximately 20 lbs/acre/year). The lake has an average depth of twenty feet, a surface area ten square miles, and a drainage area of 250 square miles. Located in the mid-Atlantic region, the lake receives about 22 inches of annual runoff (this includes baseflow). Therefore, the flushing rate of the lake times the lake depth is determined as:

$$pZ = (22\ \text{in/year})(250\ \text{mi}^2)/[(12\ \text{in/ft})(10\ \text{mi}^2)(20\ \text{ft})] \times 20\ \text{ft} = 46\ \text{ft/yr}$$

Using Vollenweider's model as illustrated in Article 1, we determine that the lake is hypereutrophic.

The lake management plan focuses on four programs designed to reduce existing phosphorus loads, including lawn care education, stormwater retrofits, illicit connection removal, and septic system repair. The benefits of each of these practices are summarized below. With the new net load of 90,800 lbs/year (30% reduction), the areal loading rate is 14 lbs/acre/year. Assuming the same runoff volume and using Vollenweider's model as illustrated in Article 1, Figure 2, we can estimate the trophic state. Even with these aggressive treatment measures, the lake remains in a hypereutrophic state. However, this reduction in phosphorus load will likely improve the overall lake condition. Lake managers will need to monitor the lake to assess whether desired uses are being met or whether additional management measures, such as in-lake management measures, are warranted to reduce algal blooms.

Impacts of Management Practices for Phosphorus Reduction

Practice	Description	Load Reduction (lbs/year)
Lawn Care Education	Assumes an aggressive mixed media campaign that reaches 40% of the population. Of those reached, 50% currently overfertilize, and 70% are willing to change their behavior. Those individuals will cut fertilizer use by 50%.	3,400
Stormwater Retrofits	Application of a 50% efficient design over 75% of the developed area. Discount factors include 0.8 for bypass, and 0.9 for long-term maintenance and design.	20,000
Illicit Connection Removal	Removal of all illicit connections.	11,200
Septic System Repair	Repair of 90% of all failing septic systems.	4,600
	Total Reduction	**39,200**
	Net Load (130,060-39,200)	**90,860**