Watershed Protection Techniques

# Urban Lake Management

SPECIAL ISSUE
Urban Lake Management

A Periodic Bulletin on Urban Watershed Restoration and Protection Tools

Vol. 3, No. 4 — December 2001

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# Watershed Protection Techniques

***Special Urban Lake Management Edition***

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# From the Editor's Desk

Who doesn't like a lake? Most of us find the placid and tranquil waters of lakes strongly appealing, and jump at the chance to spend leisure time in, on, or around them. Many of us also depend on lakes and reservoirs as the source of our drinking water. However, it is this very attraction to lakes that can greatly diminish both their scenic and recreational values and the purity of the water we drink, as our collective enchantment inexorably leads to extensive development and increased pollutant loads. Quite simply, lake quality usually declines when its contributing watershed is developed.

**In This Issue**

This special issue of *Techniques* is devoted to defining how development impacts lakes and reservoirs, and examining ways to reduce these impacts with watershed management practices. The issue has been literally years in the making, which is not surprising given the scope and magnitude of the topic. And certainly, the tools of watershed management change radically when the focus is shifted from protecting streams and rivers to lake quality.

Since we tend to be lotic rather than lentic in our thinking at the Center, we had a lot to learn and synthesize. What we learned first, and argue in our first article, *Why Urban Lakes are Different,* is that urban lakes behave quite differently than other lakes, and deserve a special watershed management approach. A key element of this approach is outlined in *Managing Phosphorus Inputs Into Lakes*, a series of three articles designed to help lake managers forecast how their lake will respond to these inputs, craft realistic phosphorus budgets, and predict how much watershed treatment practices can help. Phosphorus has always been the main currency of lake managers, and urban watersheds usually generate excessive loads of this element, which normally controls lake productivity. Consequently, lake managers need to aggressively manage all sources of phosphorus at the watershed level if they are to prevent a blue lake from turning green, or a green lake from getting even greener.

Shoreline development around lakes is often intense, and requires special oversight. With this in mind, *Crafting A Lake Protection Ordinance* provides practical insights on how to regulate development along the shoreline and in the contributing watershed of a lake. Watershed management becomes absolutely essential when a lake or reservoir serves as a source of drinking water. *Managing Watersheds for Pure Drinking Water* details the many ways that watershed development can threaten drinking water quality, and reports on the extraordinary watershed protection practices that communities have undertaken to preserve their water supplies.

Past development has already rendered many urban lakes highly eutrophic, forcing lake managers to directly confront the symptoms of eutrophication in the form of algal blooms, aquatic weeds and reduced water clarity. Techniques to combat these problems are profiled in the article *In-lake Treatment to Restore Urban Lakes.* As septic systems are major potential pollutants of both lakes, water supplies and coastal waters as well, the most recent research data on this enigmatic pollutant source are reported in the *Influence of Septic Systems at the Watershed Level*. Finally, *Land Use/Impervious Cover Relationships in the Chesapeake Bay* describes simple tools watershed managers can use to forecast current and future impervious cover in small watersheds.

**The Future of *Techniques***

This publication constitutes the last issue of the third volume of *Watershed Protection Techniques.* Beginning next year, *Techniques* will shift from a subscriber-based journal to an occasional monograph that is published once every 12 to 15 months or so. Our goal is to sharpen our focus and report on specific techniques to protect special watersheds such as estuaries, trout streams and degraded urban streams. While less frequent, *Techniques* will continue to feature the latest research on urban watersheds and the performance of techniques to protect and restore them. For those of you who need a more frequent Center fix, our free e-newsletter *Runoff Rundown* will continue to be transmitted every three or four months and will contain watershed news, Center project and research updates, and a few short articles or

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technical notes. If you want to subscribe, please forward your e-mail address to us at center@cwp.org and we will add you to our list of e-mail subscribers. Lastly, I would like to invite you to become a Friend of the Center, and directly support our watershed protection efforts. Details on how you can become a Friend of the Center and the benefits of being a Friend can be found on our website at www.cwp.org.

On a personal note, I have immensely enjoyed my job as editor of *Techniques*, and am grateful for both your patience and support as we produced 12 issues over the last eight years (at the stunning rate of one and a half issues per year). In my first "From the Editors Desk" message in 1994, I remarked that a new practice of protecting and restoring urban watersheds was just emerging out of the research and experience of more than a dozen different professional disciplines. Last year, we managed to distill the vast body of knowledge that we've gained since then into the *Practice of Watershed Protection*, a comprehensive reference that compiles nearly 150 of the best feature articles and technical notes that appeared in the first eleven issues of *Techniques*.

Looking over this mammoth chronicle, it's clear to me that our profession has evolved from its infancy, and is now headed towards a healthy and perhaps tumultuous adolescence. We may not be fully grown up, but we are recognizing the important dynamics of urban watersheds and are gaining confidence in applying the tools of watershed protection (although I wouldn't necessarily hand over the car keys, yet). *Techniques* has played an influential role in the maturation of our practice, due in no small part to the talents and hard work of our contributors, editorial board and the hundreds of researchers and practitioners over the past eight years.

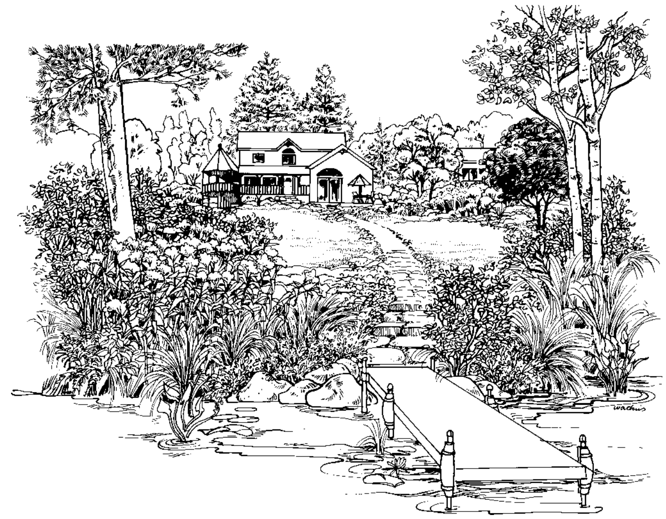
By the way, if you're missing back issues of *Techniques*, or need to find a specific article or technical note, you can now download all 150 articles compiled in *The Practice of Watershed Protection* for free from our special stormwater management website at www.stormwatercenter.net. If you prefer a hard copy as a desktop reference, you can order *The Practice* directly online from our homepage at www.cwp.org.

Special thanks are due to many people for getting this issue to press. First, thanks are extended to Anne Weinberg from EPA for keeping the faith, and waiting nearly two years to get the special issue that she was promised. I'm also grateful to my personal lake mentor, Jon Simpson of TetraTech, Inc., for his insights and contributions to the issue. Tom Davenport, of EPA, provided his customary thorough review, as well as the article on lake restoration techniques. I also want to recognize the hard work and diligent research performed by Center staff, most notably Ted Brown, Karen Cappiella, Deb Caraco, Anne Kitchell, Paul Sturm and Chris Swan. Lastly, I would be remiss without thanking Heather Holland for her talents in producing the issue.

–TRS

# Introduction:
# Why Urban Lakes Are Different

*by Tom Schueler and Jon Simpson*



**What Exactly Are Urban Lakes?**

For the purposes of watershed management, urban lakes are defined by six operational criteria. First, they tend to be rather small, and generally have a surface area of 10 square miles or less (this excludes larger lakes). Second, they tend to be shallow, with an average depth of 20 feet or less. Third, they have a watershed area/drainage area ratio of at least 10:1, meaning that their watersheds exert a strong influence on the lake. Fourth, the lake watershed must contain at least 5% impervious cover as an overall index of development. Fifth, whether natural or man-made, the lake must be managed for recreation, water supply, flood control or some other direct human use. Finally, our definition excludes several types of lakes with unique hydrology or nutrient cycling. These include solution lakes that are strongly influenced by groundwater, the rare nitrogen-limited lakes, saline lakes and playa lakes. While these lake types can be found in urban areas, it is not clear whether they share the same water quality response to watershed development as other freshwater lakes.

Curiously, the unique problems and conditions of urban lakes have received little attention in the limnological and watershed management literature. This is particularly surprising given that many of our management efforts are devoted to lakes and reservoirs that are distinctly urban in character. While the watershed management literature is replete with phosphorus budgets and watershed models, it is very unusual to find generalizations about the influence of watershed development on lake quality. Instead, urban land use is generally confined to a line item in a phosphorus budget, and it is exceptionally rare to find studies that have tracked changes in lake quality as a function of watershed development over time.

Similarly, limnologists tend to treat the influence of a watershed on its lake as a constant, and devote most of their attention to the internal dynamics within each individual lake. From their perspective, lakes, as a group, defy easy classification. For example, Hutchinson (1957) described some 76 types of lakes, simply based on their geomorphic origin. Other have classified lakes primarily on the basis of their trophic state. Indeed, lakes differ so much in their size, depth, drainage area/surface ratio, water balance, nutrient cycling and trophic state that there is a tendency to treat each individual lake as unique. Consequently, urban lakes are seldom viewed as a distinct class, much less as a special watershed management category.

While the diversity of lakes is great, we argue that the impact of watershed development on lake quality is so pervasive that it is worth treating urban lakes as a distinct group, particularly from an applied watershed management perspective. Certainly urban lakes do share some common characteristics, which are profiled below.

**Many Urban Lakes Are Man-made**

The number of natural lakes in the continental United States has been estimated at more than 100,000 (NALMS, 2001). By contrast, Van der Leeden *et. al* (1990) report that precisely 2,654 reservoirs exist in the U.S. While this number is small relative to the number of natural lakes, reservoirs occupy more than 30,000 square miles in surface area. A significant proportion of these constructed reservoirs meet our urban lake definition, particularly east of the Mississippi. The key differences between natural lakes and constructed reservoirs have been extensively studied by Wetzel (1990), Thornton (1984), and Kimmel and Groeger (1984), and these differences are profiled in Table 1.

> The impact of watershed development on lake quality is so pervasive that it is worth treating urban lakes as a distinct group.

Reservoirs have several striking geometrical differences from lakes. First, reservoir watersheds are often much greater in area in relation to their water surface area, which means that their watersheds often exert a greater influence over the lake. One direct consequence of this expanded area is that reservoirs tend to have a shorter hydraulic residence time. Furthermore, since most reservoirs are formed by placing a dam across a stream network, they tend to have much longer shorelines, and tend to be deeper than natural lakes as well.

**Urban Lakes are Greener Than Non-urban lakes**

According to the US EPA (1986), half of all U.S. lakes are classified as either eutrophic or hyper-eutrophic. However, of the 3,700 urban lakes evaluated by the US EPA (1980), the percentage that are eutrophic or hyper-eutrophic exceeds 80%. Quite simply, urban lakes tend to receive higher phosphorus loads, and all other factors being the same, become more eutrophic than non-urban lakes. This is due to the fact that urban watersheds produce higher unit area phosphorus loads from stormwater runoff, compared to other watersheds (see Caraco and Brown, this issue). In addition, most urban watersheds produce significant secondary phosphorus loads from a diverse range of sources including municipal wastewater discharges, failing septic systems and sewage overflows. Urban lakes also have many unique internal phosphorus sources such as geese droppings, boat sewage and sediment release.

Watershed treatment is an indispensable element of effective drinking water strategy.

Given such high phosphorus loads, it does not take much uncontrolled development in the watershed of an urban lake to quickly accelerate the eutrophication process. For example, stormwater runoff from watershed development begins to exceed background phosphorus loads at 4%, 17% and 40% impervious cover for forested, rural and agricultural watersheds, respectively (Caraco, this issue). However, these thresholds can be approximately doubled if stormwater treatment practices and better site design are effectively applied across the watershed.

**Algal Blooms or Aquatic Weeds**?

Urban lake managers should carefully diagnose the ecology of their urban lakes to determine if they are primarily dominated by algae or aquatic weeds. Many urban lakes are dominated by dense growths of aquatic weeds, because they are quite shallow, and influenced by nutrient rich bottom sediments. In recent years, an increasing number of invasive, non-native species have spread into these littoral habitats, including Eurasian watermilfoil, hydrilla, and water hyacinth to name but a few of the successful invaders. These species create dense beds of aquatic weeds that cause nuisance conditions for lake users, making it unpleasant to swim, hard to operate boats, and difficult to maintain open water areas.

Aquatic weeds present a great challenge to the lake manager, since they are often more resistant to traditional phosphorus therapies. This is due to the fact that they derive their nutrients from bottom sediments and not the water column. As a result, aquatic weeds thrive on past phosphorus inputs but not current ones. As Cooke *et. al* (1993) notes, increased phosphorus levels in the water column are not directly linked to nuisance growths of aquatic weeds. Indeed, the density of aquatic weeds is often controlled by physical factors

**Table 1. A Comparison of the Physical Properties of Natural Lakes and Reservoirs (Thornton,1984 and Walker, 1984)**

| Variable | Units | Natural Lakes | Reservoirs |
|---|---|---|---|
| Number Sampled | | 309 | 107 |
| **Mean Drainage Area** | acres | 54,834 | 797,316 |
| **Mean Surface Area** | acres | 1383 | 8,251 |
| **DA/SA Ratio** | -- | 33 | 93 |
| **Mean Depth** | feet | 13.5 | 20.7 |
| **Shoreline Development Ratio** | ratio of the length of the shoreline to the length of the circumference of area equal to that of the lake | 2.9 | 19 |
| **Hydraulic Residence Time** | years | 0.74 | 0.37 |
| **Secchi Depth** | feet | 5.1 | 3.3 |
| **Chlorophyll a** | ug/l | 10.2 | 9.1 |

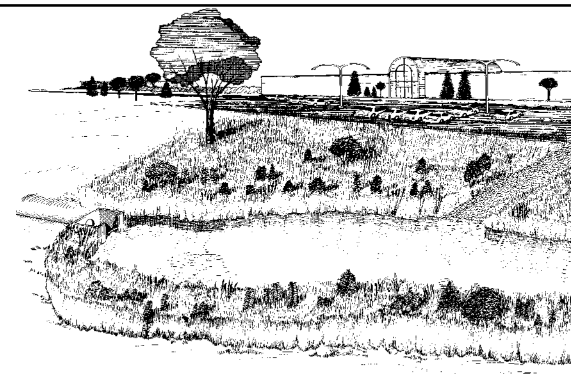
such as the composition and texture of bottom sediments, water depths, lake levels, and most importantly, the availability of light. Once beds of aquatic weeds become established, a series of ecological factors help to sustain and reinforce their presence for many years.

Many current models used to manage lakes were originally developed for deeper, open-water lakes that are dominated by algal biomass. These tools may not be applicable to shallow lakes that are dominated by aquatic weeds (see Simpson, this issue). In particular, the basic tenet of eutrophication management for open water lakes may not always hold, namely that an external reduction in phosphorus load will reduce in-lake phosphorus concentrations, and ultimately reduce algal biomass levels.

When aquatic weeds dominate an urban lake, it is doubtful whether a phosphorus "diet" alone will achieve desired lake management goals. In these settings, lake managers may want to acquire more data on lake ecology before deciding on the next course of treatment. In particular, managers should study the ecological factors that sustain and reinforce dense populations of aquatic weeds. In most cases, lake managers must resort to in-lake treatment practices such as harvesting, dredging, water level manipulations or applications of herbicides (see Davenport and Kaynor, this issue). These practices often need to be combined with emerging "biomanipulation" practices, and the more traditional watershed treatment practices that can reduce phosphorus inputs to lake sediments (see Simpson, this issue).

**Extensive Shoreline Development Pressures**

As lakefront property is highly desirable, it is quite common to have intense shoreline development even in lightly developed urban watersheds. Unregulated shoreline development often clears vegetation to the waterline, replaces natural vegetation with turf, and artificially stabilizes the shoreline. This extensive alteration of the littoral zone and its natural shoreline vegetation can adversely impact both fish and wildlife (see Cappiella and Schueler, this issue). In addition, shoreline development is often served by septic systems, which under certain conditions can become secondary phosphorus loading sources. It is also difficult to treat stormwater runoff from lakefront development sites, given their close proximity to the lake. Consequently, communities often need to adopt a lake protection ordinance (LPO) to regulate how and where shoreline development can occur (see Cappiella and Schueler, this issue).



**High Water Quality Standards for Drinking Water**

Many urban lakes function as a source of drinking water for downstream communities. However, urban watersheds produce pathogens, DBP precursors, turbidity and chemical pollutants that tend to degrade the quality of these same source waters. Given that drinking water utilities are working under increasingly stringent water quality standards, they have discovered that watershed treatment is an indispensable element of effective drinking water treatment strategy. Simply put, urban lakes that serve as a source of drinking water require extensive watershed practices to protect public health even for filtered water supplies. Recent surveys indicate that communities have adopted very stringent watershed development regulations to ensure that these practices are implemented (see Kitchell, this issue).

**Higher Turbidity Levels**

Urban watersheds produce considerable sediment loads from stormwater runoff, construction sites and active channel enlargement. Consequently, urban lakes typically have higher turbidity levels than their natural counterparts (see Kimmel and Kroeger, 1984 and Table 1). The combination of higher algal levels and turbidity often reduces water clarity in urban lakes, as measured by secchi depth and other measures of water transparency. High turbidity levels are often associated with run-of-the-river reservoirs.

**Diagnostic Sediment Signature**

Perhaps the best way to identify an urban lake is to examine its sediments. Urban lakes tend to have bottom sediments that are enriched with nutrients, trace metals, and polycyclic aromatic hydrocarbons (PAHs). Some indication of the phosphorus-rich nature of urban lake sediments can be gleaned by looking at the quality of stormwater pond sediments. Schueler (1994) reviewed 23 studies of stormwater pond sediment chemistry and derived a median phosphorus value of 583 mg/kg. Zinc is also fairly diagnostic of urban lake sediments, which is not surprising given its high concentration in urban stormwater runoff. In fact, Callender and Rice (2000) reported that zinc levels in southeastern reservoir sediments were highly correlated with both watershed population density and vehicle miles traveled. Koppen and

Souza (1984) and Schueler (1994) also reported zinc enrichment in the bottom sediments of suburban lakes and stormwater ponds, respectively.

Van Metre *et. al* (2000) recently analyzed sediment cores from 10 urban lakes and reservoirs across the country and found that PAH levels were one to two orders of magnitude higher than pre- development sediments in the same cores. While PAH levels were only loosely correlated with watershed urbanization, they are closely related to the amount of vehicle traffic in the watershed. Indeed, Van Metre and his colleagues indicated that the majority of PAHs were created during the internal combustion process, and noted that a handful of PAH compounds routinely exceeded interim freshwater sediment quality criteria.

**Focus on In-Lake Treatment to Control Symptoms of Eutrophication**

Because highly urban lakes have high phosphorus loads and many concerned shoreline owners, they are often the subject of intensive in-lake management efforts to control the symptoms of eutrophication, such as nuisance algal blooms. In-lake treatment techniques include dredging, aeration, alum treatment, copper sulfate applications, hypolimnetic withdrawal or, more rarely, herbicide treatment (McComas, 1993; Payne *et. al*, 1991 and Davenport and Kaynor, this issue). While these in-lake measures are mostly palliative in nature, they often represent the only feasible and cost-effective way to manage our most urbanized lakes. The continuous cost of in-lake management techniques should serve as a powerful reminder that eutrophication is best managed at the watershed level, through preventative practices.

**Each Urban Lake Is Unique**

Having made the case that urban lakes merit special attention from a watershed management perspective, it should be stressed that no two urban lakes are the same. Every urban lake will experience a different level of watershed development, and will exhibit a different response to phosphorus loads based on its internal geometry and contributing watershed area. In addition, the water quality goals for each urban lake will differ based on its intended uses (recreation, water supply, flood control, etc.) and its current trophic state. Consequently, lake managers will need to develop a unique watershed plan for each urban lake.

The remainder of this special issue provides detailed information to guide lake managers in formulating plans to protect or restore urban lakes. The following articles set forth a comprehensive approach for regulating new development in lake watersheds, and provide practical methods and tools that can be adapted to meet the unique conditions of each urban lake.

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# Crafting a Lake Protection Ordinance

by Karen Cappiella and Tom Schueler

**Introduction**

Lake protection ordinances are an essential tool for protecting the quality of the 41 million acres of lakes and reservoirs in the United States that are under increasing development pressure. This article describes how to craft an ordinance to protect and maintain the quality of lakes from the pressures of both shoreline and watershed development. An effective lake protection ordinance extends over four major zones: the actual shoreline, a forested buffer extending landward, a shoreland protection area that extends further, and finally, a watershed-wide zone used to control pollutant loadings to the lake or reservoir as a whole.

A lake protection ordinance (LPO) is particularly critical around urban lakes, to guide how and where new development will occur. Historically, there has been limited guidance on how to craft an effective LPO that protects lake resources, maintains the quality of the recreational experience, and accommodates the property rights of landowners. Traditionally, most LPOs have primarily focused on a relatively narrow ring of land around the shoreline where development is most visible. However, given that lakes are so strongly influenced by runoff from their watersheds, they often need to be managed from a watershed perspective.

**Key Factors to Consider in Lake Protection**

Techniques for protecting lakes are markedly different from those used to protect streams. A watershed manager must account for nine factors that are unique to the ecology of lakes and the nature of development that occurs around them:

*Shoreline development is a unique form of development.*

Lake shorelines are a valuable piece of real estate, and command premium land prices. Purchasers often use these lots to build summer homes or cottages, and seek both good access to the water and an unobstructed view of the lake. Consequently, individual homes are oriented toward the lake. Over time, a ring of development is formed around the lake, with the greatest density of homes within 500 feet of the lake, and less density further away (Figure 1).

Lake shorelines also tend to be developed incrementally over time. It is rare that the lakefront is developed as a single subdivision (which would be much easier to regulate). Rather, shoreline development often happens on a "lot-by-lot" basis, whereby individual lakefront lots are sold and subdivided to build second homes or cottages, often on a custom basis. In addition, each home and its accessory structures tend to be continuously "improved" or expanded by successive owners, to meet their changing tastes and recreational needs. Consequently, an LPO should be written to provide continuous regulation of the shoreline development process.

Techniques for protecting lakes are markedly different from those used to protect streams.

Since lakefront property is so desirable, it is quite common to have intense lakefront development in otherwise lightly developed watersheds. This presents a real challenge for protecting lakes in rural areas, since these communities typically have limited staff and development review experience.

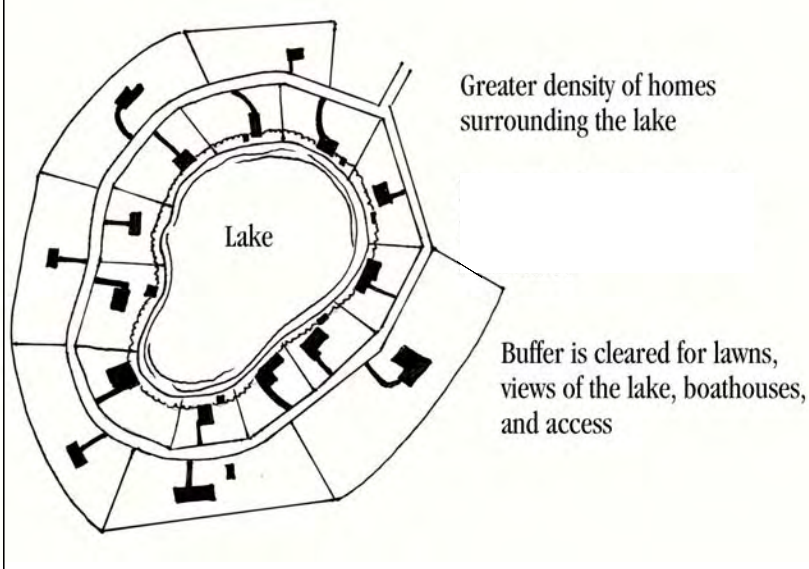


**Figure 1. Typical Development Pattern Around a Lake**

*Lake protection focuses on phosphorus reduction.*

An explicit goal of many LPOs is to maintain the trophic state of the lake, which usually means preventing or reducing phosphorus inputs. Most lakes are extremely sensitive to additional phosphorus inputs from future waterfront or watershed development. Consequently, the overall development density in these watersheds should generally be very low.

Shoreline buffers can be justified based on a common economic interest as much as an environmental one.

Lake managers have several tools to reduce phosphorus inputs from new development in a lake watershed. They include limits on the total amount of new development, shoreline and stream buffers, and the use of stormwater treatment practices designed to remove phosphorus from stormwater runoff. In practice, most managers elect to use all of these tools, and to apply them across the entire watershed draining to the lake. In particular, stormwater treatment practices are often designed to achieve a specific target for phosphorus removal. The LPO often provides very specific instructions to engineers on which stormwater treatment practices to use, how much runoff they need to treat, and how they should be designed to promote greater phosphorus removal. A handful of communities have adopted stormwater performance criteria that call for no increase in phosphorus loading from new development sites (MDEP, 1992; Kitchell, this issue).

*Importance of a natural shoreline.*

The natural beauty of a lake's shoreline, with its ever-changing panorama of water, light and wildlife, is a prime attraction for lakefront development. Lake property owners as well as lake users consistently report that their primary use of the lake or reason for visiting is to view the scenery (Warbach *et al.*, 1990; Anderson *et al.*, 1998). This is why lakefront properties nearly always command a considerable premium in terms of land prices. To the extent that a LPO will preserve the natural look of the shorelines, they can maintain or enhance the value of property (CBP, 1998). In one Maine case study, increased water clarity due to the addition of lake buffers increased property values by $11 to $200 per foot of shoreline property (Michael *et al.*, 1996). Consequently, shoreline buffers can be justified based on a common economic interest as much as an environmental one.

*Direct influence of shoreline vegetation on fish and wildlife.*

Natural shoreline vegetation has a direct influence on the ecological integrity of a lake, as it provides shade, leaf litter, woody debris, protection from erosion, and littoral habitat. These benefits are extensively reviewed in Engel and Pederson (1998), and selected research is profiled in Table 1.

Studies in a variety of lake settings have demonstrated a strong relationship between declining fish abundance or diversity and increasing shoreline development, as measured by several indices (Hinch and Collins, 1993; Hinch *et al.*, 1994; Bryan and Scarnecchia, 1992; Chick and McIvor, 1994). Fish foraging and spawning have also been shown to decline as a direct function of cottage or home density around the lakeshore (Engel and Pederson, 1998). Most fish species spend at least part of their lifecycle in the littoral zone of the shoreline. Emergent and submergent plants and coarse woody debris are critical habitat elements in the littoral zone, and each of these is highly vulnerable to shoreline development (Christensen *et al.*, 1995).

Many birds, such as eagles, loons and songbirds, tend to avoid developed lakes, and several researchers have noted that they depart at a relatively low rate of cottage development (Johnson and Brown, 1990; Voight and Broadfoot, 1995; Heimberger *et al.*, 1983). In some cases, the avoidance is due to a loss of nesting sites or perches to spot prey, while in others it reflects a lack of tolerance for noise or disturbance within or along the lakeshore. In contrast, some bird species favor a densely developed shoreline, such as mallards, geese and gulls.

Similar relationships have been discovered for amphibians and reptiles, which utilize the lakeshore to bask, feed, nest and overwinter (Engel and Pederson, 1998). Natural lakeshore habitat has also been found to be important for deer and other mammals (Buehler *et al.*, 1991). Conversely, many species suffer from increased predation and harassment by pets along more developed shorelines.

*Intense pressures for shoreline improvement and clearing.*

A lake shoreline is unique in that it remains under continuous pressure for shoreline "improvements" well after the initial development has been completed. Many lakefront property owners install docks, piers, stairs, gazebos, boathouses, boat ramps, bulkheads and other structures on or near the shoreline. At the same time, the forest buffer is under relentless pressure to be converted into a tidier lawn or an unobstructed view.

Figures 2 and 3 are examples of shoreline lots with unregulated and regulated "improvements."

While the individual effect of each of these improvements is relatively minor, their cumulative impact on the integrity and attractiveness of a shoreline buffer can be severe. For example, a survey of users in a Minnesota lake found that a majority of the respondents felt that multiple shoreline structures and lawns had a negative impact on the lake (Warbach *et al.*, 1990).

When a person is on a lake, he wants to see a natural shoreline. Yet, when the same person is on the shore, he wants to see a lake. This can create a lot of pressure on the buffer, as property owners clear trees and remove vegetation to promote a better view of the lake. However, one individual's quest for a better view of the lake diminishes the quality of the view for another. Thus, all property owners share a common interest in limiting clearing along the shoreline to screen their neighbors, while still getting at least a decent glimpse of the lake themselves. Consequently, an LPO needs to carefully prescribe how and where view corridors can be created, and include realistic measures to inform land owners on what uses, structures and activities are restricted or prohibited in the shoreline buffer zone.

*Recreational issues are paramount management concern.*

Lakes that are actively used for fishing, boating, swimming and other forms of recreation require direct access to the shoreline and across the buffer. While some lakes do have public access and central facilities (such as boat ramps, swimming beaches, etc.), many do not. In these lakes, each waterfront owner creates his or her own recreational access. This can create an inherent conflict between the property owners and outside users of the lakes. Therefore, although the shoreline buffer usually remains in private ownership, it is important to address issues of both public and private recreational access in an LPO.

**Table 1. Recent Research Documenting Ecological Benefits of Shoreline Buffers**

| Key Finding | Reference | Location |
|---|---|---|
| Coarse woody debris positively correlated with riparian tree density and negatively correlated with lakeshore cabin density | Christensen *et al.*, 1996 | 17 north temperate lakes in northern Wisconsin and the Upper Peninsula of Michigan |
| Less fish activity, less fish feeding, and increased wave disturbance in fringe zones adjacent to lawns versus undeveloped shorelines | Collins *et al.*, no date | 2 sites on Lake Rosseau, Ontario, an oligotrophic lake |
| Increase in development and decrease in vegetative cover is correlated with decrease in lakeside populations of white-tailed deer | Voight and Broadfoot, 1995 | Lake Muskoka, Ontario |
| Increase in development and decrease in vegetative cover is correlated with decrease in shoreline populations of nesting bald eagles | Buehler *et al.*, 1991 | Chesapeake Bay Shorelines |
| Increase in development and decrease in vegetative cover is correlated with decrease in lakeside populations of loons | Heimberger *et al.*, 1983 | Northern Ontario lake |
| Increase in development and decrease in vegetative cover is correlated with decrease in lakeside populations of songbirds | Johnson and Brown, 1990 | Eastern Maine lake |
| Species richness and abundance of fish were greater along undeveloped shorelines versus developed shorelines in nearshore and intermediate depth zones | Bryan and Scarnecchia, 1992 | Spirit Lake, Iowa 2266 hectare glacial lake |
| Decrease in plant cover from human activity is correlated with a decrease in fish abundance | Chick and McIvor, 1994 | Lake Okeechobee, Florida |
| Decrease in plant cover from human activity is correlated with a decrease in fish abundance | Hinch and Collins, 1993 | Ontario |

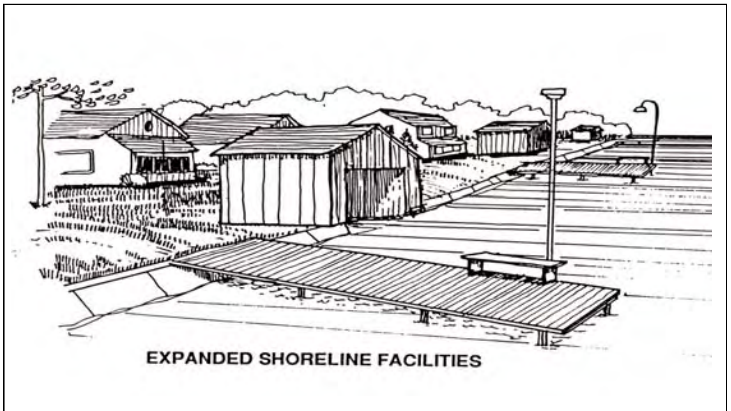


**Figure 2. Typical Shoreline With Unregulated "Improvements" (PZC, 1992)**

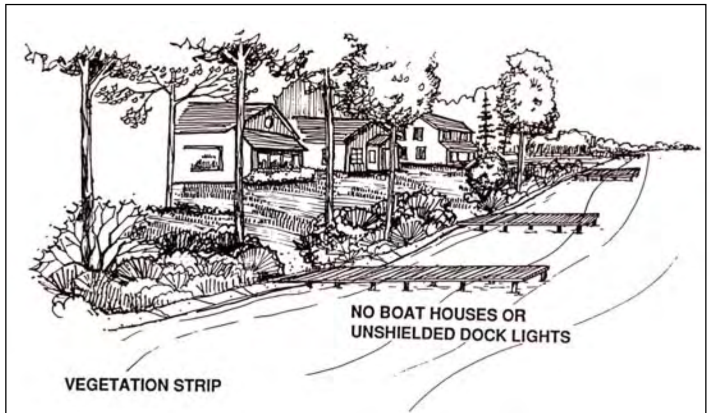


**Figure 3. A Shoreline With Limited "Improvements" Is More Attractive and Ecologically Beneficial (PZC, 1992)**

Recreational conflicts are not only confined to the shoreline buffer, but often extend into the lake itself. A recurring conflict involves whether or not motorized water craft will be allowed on the lake, either because of concerns over noise, safety, wakes or potential pollutant sources. Many water utilities restrict or prohibit motorized watercraft on water supply lakes, since two-stroke engines can be a significant source of hydrocarbons, lead and phosphorus to the lake. In recent years, conflicts have erupted over the noise, wakes and safety of personal watercraft, such as jet skis. Figure 4 is an example of how conflicts over lake recreational use can be managed by designating specific areas of the lake to each activity. Consequently, residents or local agencies may want to address these issues as part of the LPO or a lake management plan.

*Prominence of septic systems.*

Lakefront developments are often serviced by septic systems because of their seasonal use or distance from wastewater treatment plants. Because of their proximity to the lake, septic systems can become a potential source of subsurface phosphorus seepage to a lake. Indeed, many researchers have identified failing or poorly functioning waterfront septic systems as an important and controllable source of phosphorus and nitrogen in a wide range of lake systems (Harper, 1995; Childs *et al*., 1974; Gilliam and Patmont, 1983; Grant, no date; Kerfoot and Skinner, 1981; Robertson and Harman, 1999; and Arnade, 1999). One of the primary functions of the shoreline buffer is to create distance from the leach field and the shoreline, thereby providing as much soil treatment as possible in such a confined area. Watershed-wide septic system regulations may also be a key element of an LPO, particularly in watersheds that have potentially high septic system density or unsuitable soils. More information about septic system impacts on lakes can be found in Swann (this issue).

*Lake associations available for enforcement or education.*

The lake and its shorelines are a classic case example of the "commons," where the actions of one user or owner can diminish the quality of life for another. Often lakefront property owners recognize that they share a common interest in some form of self-regulation. This has led to the formation of hundreds of lake associations across the country to promote better local lake management. In many lakes, these associations are similar to homeowners associations, in that they are self-governing and self-financing. As such, a lake association can play a pivotal role in education and enforcement of the LPO, through legally binding covenants on individual properties. The North American Lake Management Society (NALMS) has excellent materials on its website on how to establish a new lake management association or energize an older one (www.nalms.org). Lake associations are particularly valuable in educating shoreline landowners about LPO provisions that directly affect them.

*Lake protection ordinances must be customized for unique lake conditions and water quality goals.*

While this article presents an overall framework for crafting an LPO, it is important to keep in mind that the actual details of each ordinance will differ for every lake. For example, more stringent criteria are often applied to lakes that are a primary water supply, as compared to a reservoir used for recreation or flood control. Similarly, managers will usually adopt more stringent criteria in order to maintain the character of a phosphorus-sensitive lake in a wilderness setting, as compared to a highly eutrophic lake in a more urban setting. In some lakes, the LPO is primarily used to regulate competing recreational or shoreline interests, while others may be driven more by the need to reduce phosphorus loads.

In nearly all lakes, the ability to achieve management goals for a lake is heavily influenced by the amount and type of prior development along the shoreline or within the watershed. Thus, lake managers should engage both lake users and watershed residents to set realistic goals for lake protection very early in the ordinance process. In addition, communities that have many lakes and reservoirs may want to classify them in order to manage them better. An example is the state of Minnesota's lake classification system shown in Table 2.

**Table 2. Example of Lake Classification System (Bernthal and Jones, 1998)**

| Lake Class | acres water per shoreline mile | # homes per shoreline mile | lake depth |
|---|---|---|---|
| Natural Environment | < 60 | < 3 | <15 feet |
| Recreational Development | 60 - 225 | 3 - 25 | > 15 feet |
| General Development | > 225 | > 25 | > 15 feet |

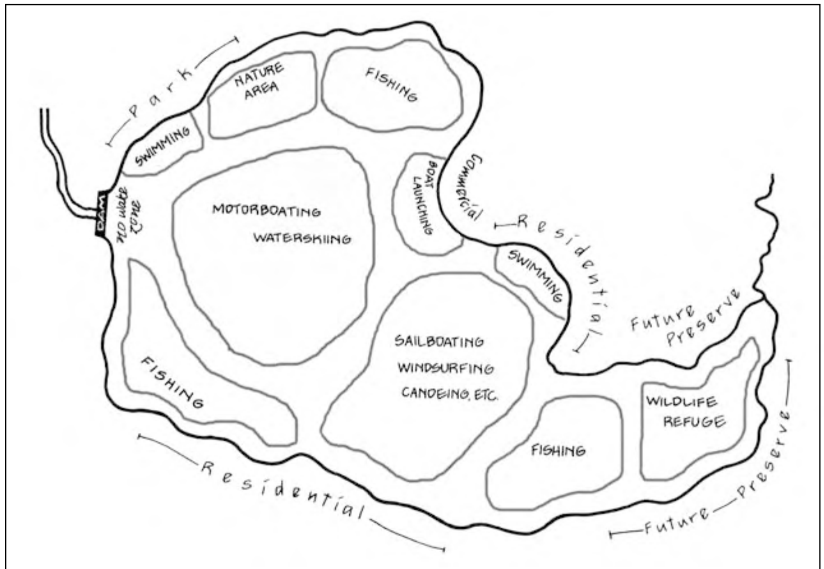


**Figure 4. A Lake Use Plan Can Resolve Conflict Over Recreational Use (NIPC, 1995)**

### The Four Zones of Lake Protection

The four primary zones of lake protection are the shoreline, shoreline buffer, shoreland protection area, and the lake's contributing watershed (see Figure 5). The development criteria within each of the four zones are often different and include the following:

1. Zone geometry
2. Vegetative target
3. Allowable uses
4. Restricted uses
5. Septic system siting
6. Stormwater treatment practice design
7. Residential lot design requirements
8. Zoning
9. Enforcement
10. Education

The key development criteria for the four zones of an LPO are compared in a condensed fashion in Table 3.

In general, the four-zone approach to lake protection is most restrictive at the shoreline, and is more flexible as one progresses further up into the watershed. Greater detail on the key criteria for a lake protection ordinance is provided in the following pages.

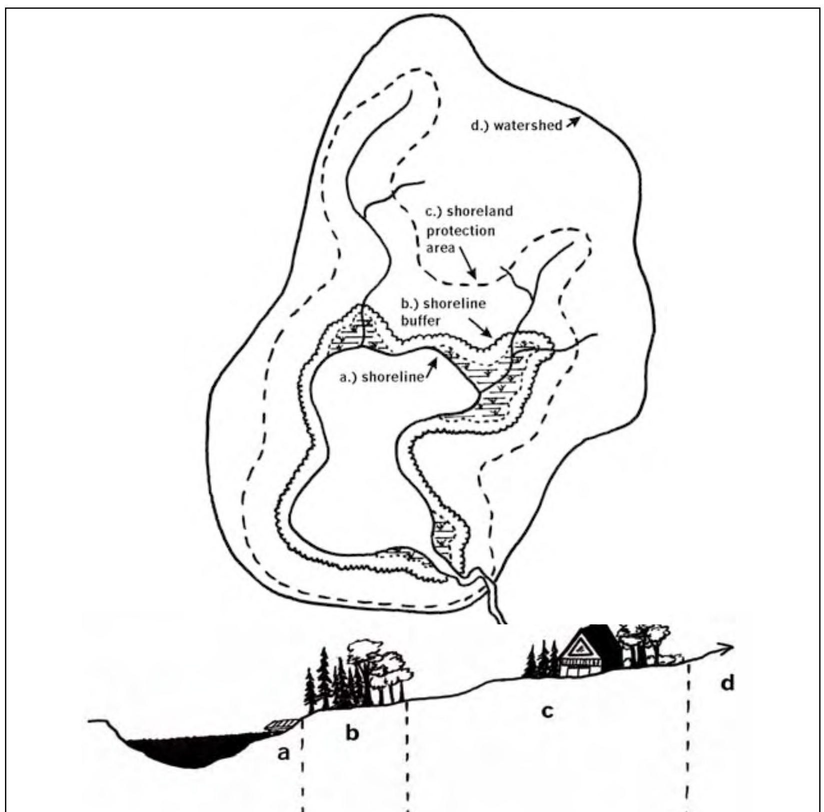


**Figure 5. The Four Zones of Lake Protection**

## Zone 1: Shoreline

The shoreline begins as the point where the mean high water mark meets the land. Given the importance of the shoreline to lake ecology and screening, it is essential that this zone be retained in a natural state, with minimal disturbance of native vegetation. A common approach to manage the shoreline is to require shoreline permits for any activity that modifies, alters, clears or otherwise disturbs the natural shoreline. Permits, which can be required by a local or state agency, place limits on tree clearing, bulkheading and rip-rapping. Exceptions may be granted to clear small areas for allowable uses, as defined later. The permit process should require the applicant to demonstrate that natural methods of shoreline stabilization, such as bioengineering, are not feasible before retaining walls, riprap or bulkheads are allowed to stabilize the shoreline. Some communities may also specify low or no wake areas, set boat speed limits and exclude motorized watercraft in their LPOs in order to prevent shoreline erosion (Standing *et al*., 1997).

***Allowable Uses***

Most communities allow minor alterations along the shoreline to provide reasonable access and recreational use. For example, most typically allow only one pier or dock on each frontage lot, along with a limitation on its total length and extension into the lake (50 feet is common; Standing *et al*., 1997). This provision prevents the proliferation of docks from detracting from the scenic character of the natural shoreline. Most communities also permit a single stairway or ramp down to the water, but may restrict its

**Table 3. Development Criteria for the Four Zones of an LPO**

| Criteria: | Shoreline | Shoreline Buffer | Shoreland Protection Area | Watershed |
|---|---|---|---|---|
| **Defined as:** | high water mark (HWM) | 50 to 150 feet from HWM, 300 feet for source water | 250 to 1000 feet from HWM | divide of contributing watershed |
| **Vegetation target for the zone** | maintain natural shoreline, no disturbance without permit | forest or native vegetation, maximum view corridor of 30 feet | maximum clearing limits on individual lots of 25 to 50% | forested buffers for tributary streams |
| **Allowable Uses** | Bioengineering, 1 pier or dock per frontage, 1 stairway | walkways, boathouses within the view corridor | residential homes, septic systems | most are allowed |
| **Restricted Uses** | boathouses and other accessory structures, rip rap, bulkheads | no permanent structures, no impervious cover or other land disturbing activity | commercial or industrial zones, uses with hazmat spill risk | uses with hazmat spill risk |
| **Septic Systems** | n/a | not allowed | setback 100 to 200 feet from HWM | design, feasibility or inspection criteria to reduce failure |
| **Stormwater** | no new pipe outfalls to lake | no stormwater practices allowed (except for practices at boat launching) | presumed to be achieved by environmentally sensitive site design | stormwater treatment practices required to remove target phosphorus levels |
| **Lot Requirements** | n/a | n/a | minimum lot size, minimum frontage, max impervious cover, limit rooftop runoff | open space subdivisions and better site design to reduce impervious cover |
| **Zoning** | establish requirements and density in a lake protection overlay district or a comprehensive plan | | | |
| **Enforcement** | local or state permit | local development review process | | |
| **Education** | lake association and/or resource agency | | | lake association or watershed organization |

width to six feet or less. Normally, pre-existing structures are exempted from the shoreline permit process, but they may not be significantly expanded without one (Bernthal and Jones, 1998).

***Restricted Uses***

Many communities prohibit tree clearing or grading along the shoreline, although individual trees can be removed for safety purposes. Boathouses and other accessory structures are generally prohibited within the narrow shoreline zone. In addition, no new stormwater outfalls should be allowed that discharge to the shoreline.

**Zone 2: Shoreline Buffer**

When natural shoreline buffers are maintained, they protect the integrity of the shoreline, provide habitat for wildlife and fish, reduce the likelihood of erosion, and help to reduce runoff and pollutant loads (Engel and Pederson, 1998; Wenger, 1999; Fuller, 1995). In addition, natural shoreline buffers support the aesthetic and recreational values that make lakefront development so desirable and economically attractive. Natural shoreline buffers also protect the physical and ecological integrity of lakes by providing shade, leaf litter, woody debris, erosion protection, and habitat.

A common base width for a shoreline buffer is 75 feet (Heraty, 1993), although widths typically range from 50 to 150 feet. If a lake is used as a source of drinking water or is very pristine, buffer widths of 200 to 300 feet are often used (RICRMC, 1994; Standing *et al*., 1997; Kitchell, this issue). The base width of a shoreline buffer should be expanded to include steep slopes or wetlands, or contracted when pre-existing development is located close to the shoreline. Some communities set the base width of the shoreline buffer based on the surface area of the individual lake, and require wider buffers around their larger lakes. Most communities now clearly prescribe how the buffer will be delineated within the LPO. For natural lakes, the natural mean high water level is a good benchmark, whereas the water line at "full pond" is often used for reservoirs.

***Vegetation Management***

The vegetative target for the shoreline buffer is mature forest or native vegetation. This may involve actively re-vegetating areas or letting them gradually return to their natural state. Depending on the region, the natural state will not always be a forest. The use of native plants within the buffer usually requires less maintenance, and these plants are easier to establish. Some communities set specific restoration goals for the shoreline buffer. For example, New Hampshire requires that a plan be submitted that describes the species, number, and basal area of trees proposed for replanting a natural woodland buffer (Springs, 1999).

Tree clearing for view corridors or access trails is inevitable, so many LPOs do allow for some clearing, or have guidelines for thinning or removing of dead trees. For example, Rhode Island Coastal Zone Buffer Program and Maine Shoreland Protection Standards indicate that shoreline access paths can be no more than six feet wide and follow a winding path that does not promote erosion (see Figure 6).

In addition, clearing for a view corridor is generally limited to no more than 25% of the length of the shoreline for residential lots of two acres or less (RICRMC, 1994). Other communities have opted for a more operational criteria, allowing a single view corridor per lot, and no opening greater than 250 square feet in the forest canopy

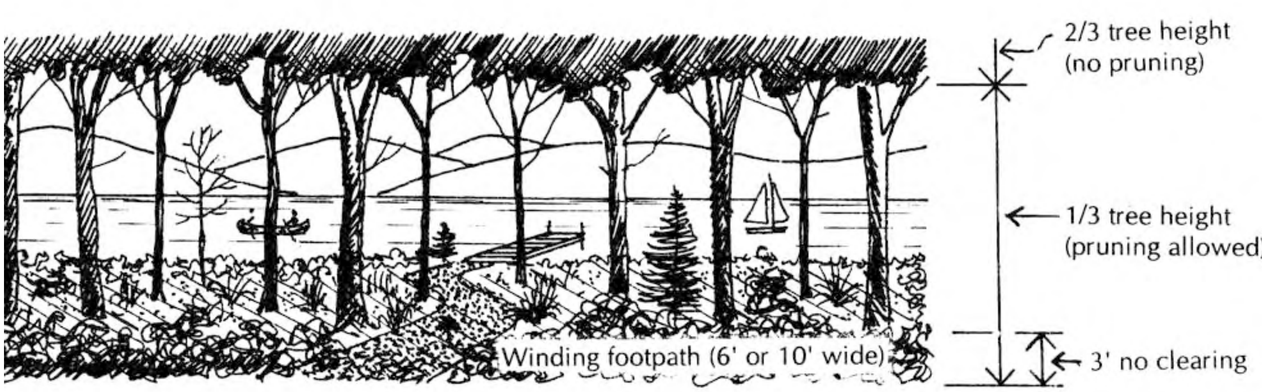


**Figure 6. Example of Guidelines for Vegetation Thinning in the Shoreline Buffer for View Corridors and Footpaths (Illustration by Brian Kent)**

as measured from the outer limits of the tree crown (MDEP, 1999). Still others allow clearing of no more than 40% of the basal area of trees within 100 feet of the shoreline (Bernthal and Jones, 1998).

***Allowable Uses***

Allowable uses in the shoreline buffer should be limited to clearing for shoreline access paths and view corridors. Many communities also permit trails and passive recreation within the buffer zone. In addition, boathouses and other accessory structures may be allowed within the buffer, but must be set back at least 25 feet from the shoreline. Some shoreline zoning ordinances also place limits on the number and square foot area of boathouses and other structures (Bernthal and Jones, 1998). An exemption is usually provided for public recreation facilities such as boat ramps and public beaches. Careful planning is needed to develop public facilities in a manner that minimizes clearing of the shoreline. In some cases, stormwater practices such as perimeter sand filters can be installed to treat direct runoff from boat ramps and associated parking lots.

The LPO should specify who is responsible for enforcing and maintaining the shoreline buffer.

***Restricted Uses***

Many land uses and activities are restricted or excluded from the shoreline buffer zone. These include paved surfaces, primary structures, grading, pesticide application, mowing, motorized vehicles, or any other activity that causes soil disturbance or contributes to pollution. In addition, septic tanks and drain fields are excluded from the shoreline buffer, and often must be set back an even greater distance into the shoreland protection zone.

***Stormwater Treatment***

The natural vegetation of the shoreline buffer acts to slow down and spread out runoff and promotes infiltration in the soil, thereby reducing the need to treat the quality of stormwater runoff. In this sense, the natural shoreline buffer is the last line of defense for treating stormwater. More importantly, stormwater treatment practices designed to treat stormwater from upland sources should not be located within the buffer. Many communities also prescribe that no new pipes or channels be constructed to convey stormwater across the shoreline buffer (i.e., sheetflow conditions must be maintained).

***Enforcement and Education***

The LPO should specify who is responsible for enforcing and managing the shoreline buffer during and after construction. A lake association can be a good candidate to perform this role, since the shoreline buffer often falls within the boundaries of most lake associations. In addition, lake associations may have the authority to extend covenants from their members to establish shoreline buffers on existing waterfront lots that otherwise might be grandfathered. The North American Lake Management Society publishes several useful lake management references (www.nalms.org). The Terrene Institute also publishes *The Lake Pocket Book* as a useful guide.

Regardless of whether the shoreline buffer is enforced by a lake association or a local agency, it is important that the LPO contain provisions to notify owners and contractors about the boundaries and restrictions of the buffer. Some useful techniques include marking buffer boundaries with permanent signs that describe allowable uses; clearly delimiting the buffer boundaries on all construction plans, maps, deeds and property surveys; and verifying that new owners are fully informed about uses/limits when waterfront property is sold.

The LPO should contain a series of progressively tougher enforcement actions for owners and contractors who violate the provisions of the buffer, beginning with a notice of violation with time to correct. If these administrative remedies fail, then fines, property liens, stop work orders, restoration liability and other sanctions should be available.

Enforcement measures can and will create needless conflict with many waterfront owners if they are not accompanied by strong and continuous programs to educate residents about the value of shoreline buffers, and the limits that they impose on their land. Lake managers should strive to reach every landowner with a mailing, meeting or visit to ensure they understand the rules. The enforcement agency can directly educate owners during annual buffer walks to check on encroachment, and provide information on how residents can become better stewards through reforestation and shoreline bufferscaping programs. Lake managers should strive to integrate buffer education with other water quality and recreation messages they want to deliver, whether they are boating or fishing regulations, septic system cleanouts or lake management issues. Waterfront owners may also want to know about techniques to slow the spread of invasive species such as zebra mussels and Eurasian water milfoil, which are an increasing problem in many lakes (Klessig *et al.*, 1993). Techniques to prevent the spread of invasive species may include boat cleaning or boat pumpout facilities at centralized locations.

## Zone 3: Shoreland Protection Area

The shoreland protection area extends beyond the shoreline buffer and is primarily intended to regulate the geometry and nature of development on lots adjacent to a lake. In a way, the shoreland protection area is a special overlay zone for residential development, and includes various setbacks, impervious cover limits and forest conservation requirements.

The width for a shoreland protection area typically ranges from 250 to 1,000 feet, as measured from the shoreline. The state of Minnesota has a similar zone where shoreland standards apply to all land within 1,000 feet of the lake (ILCC, 1996). The actual width depends on the underlying lot size or zoning category in the area. In general, as lot size increases, the width of the shoreland protection area increases. At a minimum, the shoreland protection area should extend at least two lot lengths outward from the lake. Often, the exact boundaries of the shoreland protection area are expanded to account for bluffs, wetlands, steep slopes, erodible soils, or other sensitive natural features around the lake.

***Vegetation***

Since development will occur in the shoreland protection area, vegetative targets are much less restrictive than along the shoreline or in the shoreline buffer zones. Maximum clearing limits are imposed in this zone to keep the building footprints as small as possible and conserve natural areas. A typical example is prescribed under the Maine Shoreland Zoning guidelines, which limit clearing during construction to no more than 25% of total lot area or 10,000 square feet, whichever is less (MDEP, 1999, see Figure 7). In Waupaca County, Wisconsin, no more than 50% of each shoreland lot or 25,000 square feet, whichever is less, may be disturbed for residential or commercial construction (Standing *et al.*, 1997).

***Restricted Uses***

A primary reason for establishing the shoreland protection area as a zoning district is to exclude or set back uses or activities that have the potential to degrade the water quality of the lake or detract from its scenic character. Consequently, a long list of uses and activities are often excluded from the shoreland protection area.

Examples of land uses that are frequently considered to be non-conforming include livestock operations; facilities that generate, store or dispose of hazardous materials; landfills; junkyards; surface discharges from sewage treatment plants; golf courses (unless they have an approved integrated pest management plan); above or below ground storage tanks; stormwater hotspots (MDE, 2000); and non-residential roads.

In addition, most communities consider the shoreland protection area to be an exclusively residential zone, with exceptions for water-dependent operations (such as boat launching areas, private campgrounds, and the like). Consequently, industrial, commercial, or institutional developments are often excluded from this zone, particularly if the lake is a primary drinking water supply.

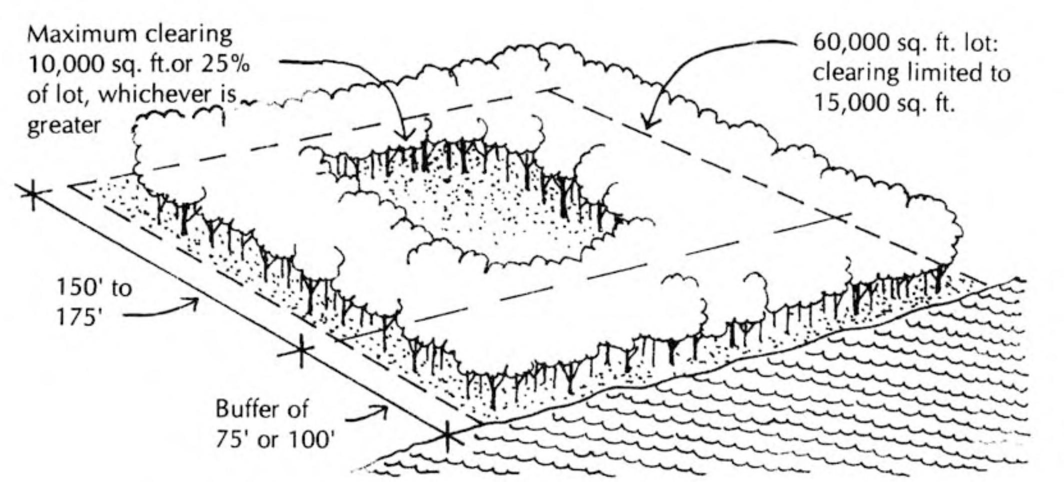


**Figure 7. An Example of Limits on Clearing for a Shoreline Lot (Illustration by Brian Kent)**

Shoreland protection areas frequently require setbacks, the most common being a 100 to 200 foot setback for septic tanks and drain fields, as measured from the shoreline. From a practical standpoint, this means that septic systems need to be located well beyond the outward boundary of the shoreline buffer. Figure 8 illustrates this concept.

Setbacks for septic systems may vary depending on the lake's use and watershed characteristics. For example, the state of Virginia requires a 100 foot septic system setback from a stream; New Hampshire requires a 125 foot septic system setback for areas with porous soils; the New York City reservoir system has a 300 foot setback for absorption fields, and a 500 foot setback for septic systems; and the state of Maine prohibits septic systems in Resource Protection Districts (CWP, 1995a; Spring, 1999; NRC, 2000; MDEP, 1999).

It is very difficult to effectively treat the quality of stormwater runoff within the shoreland protection area with conventional stormwater practices.

A few LPOs regulate the use of fertilizer or pesticides in the shoreland protection area. For example, the New Hampshire Comprehensive Shoreline Protection Act limits the use of any fertilizer in protected areas, and limits fertilizer use outside these areas to low phosphate, slow release nitrogen fertilizer or limestone (Springs, 1999). In other watersheds, the use of pesticides is prohibited in this zone. For example, the herbicide atrazine may not be applied within 200 feet of natural lakes or reservoirs in the New York City reservoir watersheds (NRC, 2000). While these restrictions are admirable from an environmental standpoint, they are often difficult or impossible to enforce with individual property owners.

***Environmentally-Sensitive Shoreland Design***

In practice, it is very difficult to effectively treat the quality of stormwater runoff generated by development within the shoreland protection area with conventional stormwater practices such as ponds, wetlands, or filters. Constraints such as the proximity to the lake, small drainage area, poor conveyance and the need to stay out of the shoreline buffer make it a major challenge to engineer treatment practices in the zone. Therefore, the stormwater strategy in the shoreland protection area is to minimize the creation and concentration of stormwater runoff through environmentally sensitive shoreland development techniques. These development techniques include site fingerprinting, impervious cover limits, minimum lot sizes and natural conveyance. As a practical matter, then, stormwater treatment is achieved through site design requirements within the shoreland protection area. Lots that meet the design requirements are presumed to automatically comply with any stormwater requirements. Figure 9 illustrates how environmentally sensitive shoreland design can be applied in a typical lakefront residential lot.

Environmentally sensitive shoreland design techniques for residential lots include the following:

*Minimum Lot Sizes and Minimum Shoreline Frontages*

Since the shoreline is a finite resource, many communities have sought to limit the intensity of lakefront development through minimum lot sizes and shoreline frontage distances. Minimum lot sizes tend to range from slightly less than one acre to five acres or more. For Maine lakes, minimum lot size for residential development in the shoreland zone is 60,000 square feet, with a corresponding minimum shoreline frontage of 300 feet (MDEP, 1999), while Minnesota lots adjacent to Natural Environment lakes have a minimum lot size of 80,000 square feet (Bernthal and Jones, 1998). Once again, lakes or reservoirs that are a primary source of drinking water or undeveloped lakes that are being protected because of their natural beauty tend to use very large lot zoning typically greater than five acres (Standing, 1997; Kitchell, 2001, this issue).

*A Maximum Limit for Impervious Cover on the Lot*

The LPO often specifies a maximum amount of imperviousness for the shoreland zone. We generally recommend a 10 to 15% as an impervious cover limit

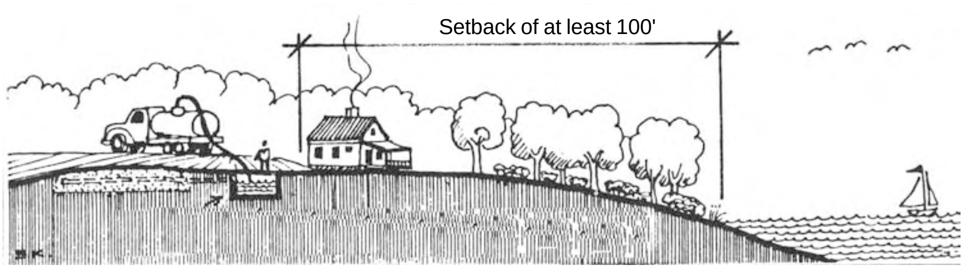


**Figure 8. A Septic System Setback in Relation to the Shoreline Buffer (Illustration by Brian Kent)**

for residential lots in the shoreland protection area. However, this percentage can vary depending on land use, lot size, and the desired level of development around a lake. For example, Shawano County, Wisconsin has a limit of 8% impervious cover on lots within 300 feet of the lake's ordinary high water mark (Standing, 1997), while the state of New Hampshire has a 20% impervious cover limit for alternative developments such as PUDs, which incorporate residential and commercial areas in a planned community (Bernthal and Jones, 1998).

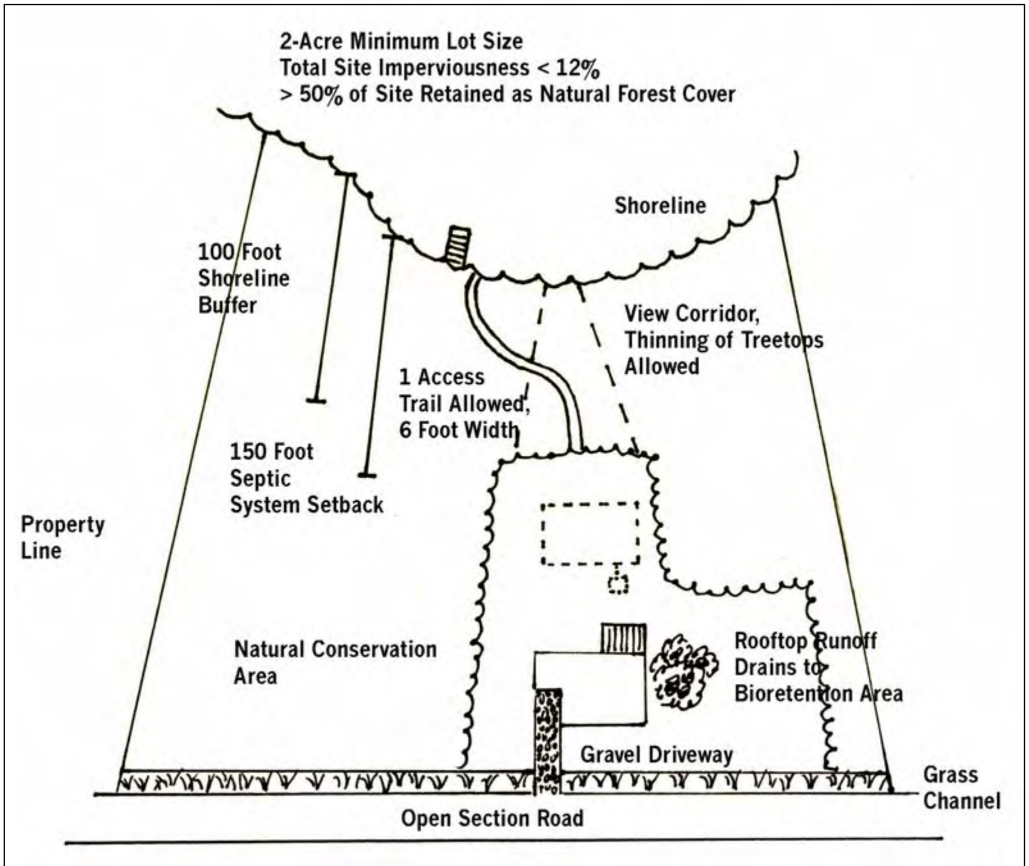


**Figure 9. Example of Environmentally Sensitive Design for a Residential Shoreline Lot**

*Site Fingerprinting*

Many communities specify that a minimum fraction of the lot be conserved in natural cover, and mandate that the lot cannot be cleared or otherwise disturbed during site construction, nor converted to lawn afterwards. Normally, area that must be conserved includes the shoreline buffer and additional areas within the shoreland protection area. For the lot as a whole, the target for natural cover conservation will vary according to zoning category, but typically ranges 40 from 75%. Figures 10 and 11 contrast conventional and alternative techniques for clearing a site for development.

*Grading Limits*

Any grading at the site should promote sheetflow, and avoid concentrating runoff. Often, driveways comprise much of the grading in the shoreland protection zone. In this respect, driveways should be graded to follow contours and avoid the need for ditches. Otherwise, driveways should be constructed of more permeable material, such as river rock, blue stone, gravel or grass pavers. If the lot has a slope greater than 10%, or is less than one acre in size, berms, depressions or terraces may be required to capture runoff and encourage infiltration at the outer boundary of the shoreline buffer.

*Rooftop Disconnection*

Residential rooftop runoff can be easily disconnected and conveyed as sheetflow across vegetated areas or into the buffer. In practical terms, this means that downspouts should not be connected to any conveyance system. If soils are not suitable, then dry wells, french drains or rain barrels can be used to store rooftop runoff. Figure 12 illustrates how to use a rain barrel to store rooftop runoff.

*Limitations on Back Lot Development*

Lake managers constantly struggle with the issue of backlot development, which drives up the overall density of shoreline development. Backlot development allows off-water lots to share a narrow strip of waterfront land that provides access to the water. This often results in over-development of the lakeshore to accommodate docks and access points for a large number of people. Several zoning techniques can limit backlot development. First, zoning regulations can prohibit the development of shore lots with more than one owner or establish limits on the number of off-water lots served by one access lot (Standing, 1997). Alternatively, minimum lot sizes can be established for off-water lots by extending the width of the shoreland protection area further from the lake. Figure 13 illustrates the backlot or "keyhole" development concept.

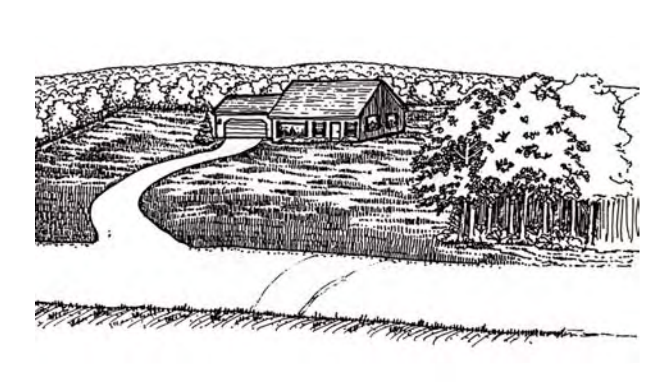

**Figure 10. Conventional Clearing and Grading Techniques Leave the Majority of This Residential Lot Bare (PZC, 1992)**

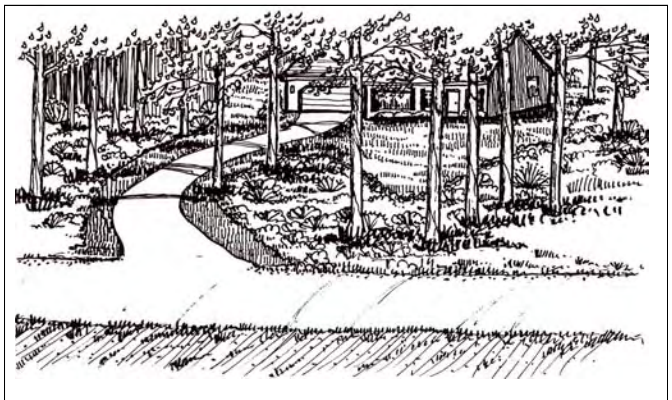

**Figure 11. Site Fingerprinting Was Used on This Residential Lot to Reduce Clearing and Preserve Trees (PZC, 1992)**

## Zone 4: Watershed

Establishing shoreline buffer zones may not always be enough to protect a lake from the impact of land development, particularly if it is sensitive to increased phosphorus inputs. If significant land development is expected in a lake watershed, the LPO must be designed to create a fourth management zone that encompasses the watershed as a whole.

From a watershed perspective, it may be necessary to control all sources of phosphorus to the lake in order to meet water quality goals. In this case, the LPO should define how and where the eight tools of watershed protection should be applied (CWP, 1998). Often, this may require a watershed plan that estimates current and future impervious cover, and investigates major (and controllable) phosphorus sources. Still, some generalizations can be made on how the eight tools can be applied to protect lakes, as discussed in the following paragraphs.

**Watershed Zoning/Land Use Planning**

Given the current limits of stormwater treatment described by Caraco (this issue), it is evident that the water quality of many lakes can only be maintained if limits are set on the cumulative amount of watershed development. While the exact development threshold often depends on the combined geometry of each individual lake and its watershed, most lakes can sustain only a rather low density of development, as measured by indicators such as impervious cover or lot size. The notion that a carrying capacity for development exists for many lakes has long been advanced by many limnologists (Wetzel, 1975; Wetzel, 1990; Vollenweider, 1968 and 1975).

Consequently, one of the first tasks of a lake manager is to compute current and future phosphorus budgets for the watershed as a whole. These budgets help determine how much extra phosphorus load can be expected in the future, and how much this load can be reduced by stormwater treatment practices in the watershed. If the budget indicates that phosphorus loads will still exceed desired targets even if stormwater treatment practices are widely applied across the watershed, then additional land use controls may be needed. Lake managers have typically relied on three complementary land use strategies to minimize development density in lake watersheds.

*Large-lot Zoning*

Residential land in the watershed is often zoned for large-lot development, with minimum lot sizes of one, two, five or even 20 acres. The basic reasoning is that large lots have comparatively low impervious cover, even if it spreads development over a potentially greater area than would otherwise occur. In addition, communities may allow developers the option to cluster development within these large lot zones, if shared septic systems are allowed.

*Land Use Exclusion*

Commercial and industrial zones are often minimized or excluded from the watershed in order to minimize spill risk, and to reduce impervious cover. Often these zones are not feasible for development if a community elects not to extend sewer into the watershed, given the larger volumes of wastewater that they generate.

*Reliance on Septic Systems*

Communities often choose to rely on septic systems for wastewater disposal within lake watersheds for two reasons. First, most communities find that it is not economical to service large lot development with sewers. Second, the presence of sewers can often induce more development density than originally intended. Therefore, a lack of sewer capacity acts as a secondary growth control, and can reduce pressures to rezone land to a higher density in the future.

While these land use strategies have been widely applied, they may not be appropriate for every lake watershed. For example, it may not be desirable to extend large lot zoning or exclude commercial development when a lake has a very large watershed, or has already experienced a great deal of past development. The strategy can also backfire if unsuitable soils or site conditions make widespread septic system failure likely, or if the community has no capacity to inspect and manage septic systems over time. These situations call for a more sophisticated land use strategy that may involve down-zoning, transferable development rights, or watershed-based zoning (CWP, 1998).

Another important component of zoning is a careful assessment of existing water pollution hazards in the watershed, with a strong emphasis on land uses or activities that may pose a risk of spills or accidental discharges. In particular, the potential risk of spills from existing or planned roadways should be assessed, and contingency response plans prepared.

**Land Conservation**

Land conservation is a critical tool for limiting where land development takes place in a lake watershed. Many communities have secured easements or acquired land in the watershed for the express purpose of lake protection. Generally, shorelines, shoreline buffers, and tributary streams are the key land acquisition priorities, although large wetlands and public access areas may also be preferred.

**Stream Buffers**

Stream buffers are an integral part of any watershed protection strategy, and an LPO should strongly recommend establishing them throughout the watershed. The buffer should apply to all perennial streams that drain to the lake. The basic design of stream buffers is described in Schueler (1995), and model ordinances can be found at the Stormwater Manager's Resource Center (www.stormwatercenter.net). In some cases, stream buffers in lake watersheds have a variable width depending on the distance of the stream from the primary water intake. A good example of this concept can be found in Georgia's reservoir protection standards, which require a 150 foot buffer around the reservoir, a 100 foot buffer along streams within a seven mile radius of the reservoir, and a 50 foot buffer along streams outside the seven mile radius for watersheds less than 100 square miles (Burnett and Ashley, 1992).

**Better Site Design**

Communities may also want to encourage open space designs for residential subdivisions located outside of the shoreland protection area, since clustering has been shown to reduce the phosphorus loadings (Zielinski, 2000). Narrower road standards and the use of roadside swales are also particularly appropriate in most lake watersheds.

**Figure 12. Rooftop Runoff is Collected in a Rain Barrel and Stored for Later Use**

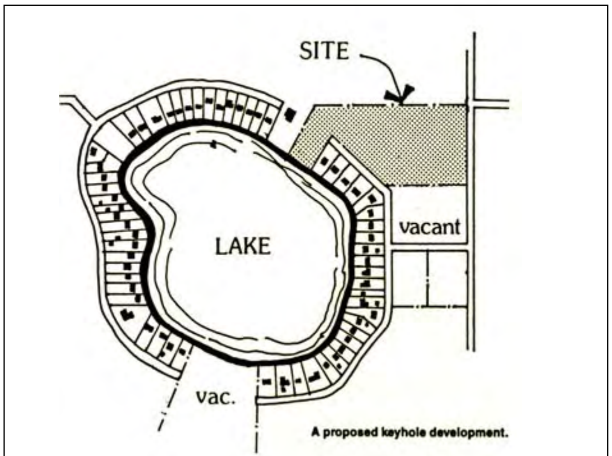


**Figure 13. An Example of a "Keyhole" or Backlot Development (Warbach *et al.*, 1990)**

**Erosion and Sediment Control**

Lakes are especially vulnerable to the impacts of sedimentation and turbidity generated from upstream construction sites. Consequently, erosion and sediment control (ESC) plans are normally required at new development sites in lake watersheds. ESC requirements need to be adjusted to reflect the prevailing development conditions around lakes. For example, if most of the development will be constructed on large lots or by individual contractors working on a single lot, it may be important to have both a low area threshold for triggering ESC plans, as well as a simple checklist approach for preparing ESC plans for individual lots.

Lakes are especially vulnerable to the impacts of sedimentation and turbidity generated from upstream construction sites.

**Stormwater Treatment Practices**

Stormwater treatment practices in the watershed are often designed to achieve a specific target for phosphorus removal. Local ordinance and design manuals often give very specific instructions to engineers on what stormwater treatment practices to use, how much runoff they need to treat, and how they should be designed to promote greater phosphorus removal. Depending on the phosphorus sensitivity of the lake and the amount of future development forecasted, lake managers may elect to establish specific stormwater phosphorus removal targets in the LPO.

A number of communities have adopted stormwater performance criteria that set forth specific phosphorus load reductions from new development sites. Typically, they require an engineer to calculate the phosphorus load before and after the site is developed, and then design a stormwater treatment system that can eliminate the difference (MDEP, 1992; Kitchell, this issue). Most communities prescribe the Simple Method (Schueler, 1987) to compute post development loads, and provide tables that indicate the estimated phosphorus removal capability associated with each practice (see Caraco, this issue). Depending on the site, the engineer may need to choose a stormwater practice with a higher phosphorus removal capability, reduce the impervious cover of the site, capture a greater volume of stormwater runoff, or install more than one practice on the site. If a designer still cannot meet their phosphorus load reduction target, they may have the option of providing an offset or a fee in-lieu for phosphorus reduction elsewhere in the watershed.

**Wastewater Discharges in Lake Watersheds**

Communities are often sharply divided on how to manage and dispose of wastewater in lake watersheds, given that treated wastewater is often a major component of a lake's phosphorus budget. Most have adopted one of three broad strategies to manage wastewater, depending on the degree to which they wish to limit development and their confidence in septic systems:

*Reliance on Septic Systems*

This strategy prohibits any surface discharges of treated wastewater within a lake watershed, and relies instead on septic systems to dispose of wastewater on individual sites. The strategy is frequently employed in drinking water reservoirs and to maintain low residential density in other lake watersheds. The success of this strategy requires effective phosphorus removal by septic systems, which in turn may require stringent requirements throughout the watershed, particularly if the overall density of tanks is high (Swann, this issue). Regulations in the watershed typically establish criteria for soil suitability, minimum lot size and drainfield area and a greater shoreline setback from the lake during initial construction. Of equal importance is the establishment of a management authority to inspect, maintain and rehabilitate septic systems after they are built.

*Limited Sewer Relief*

Failing septic systems are sometimes found to be a major water quality problem along the shoreline, and a common remedy is to extend a sewer to connect to clusters of failing units. Sewers may also be needed to accommodate denser development elsewhere in the watershed. In either case, while wastewater is collected by sewers, it is pumped out of the lake watershed for subsequent treatment and discharge.

*Reliance on Sewer*

In some watersheds, communities have had such poor experience with septic systems that they rely instead on sewers to dispose of wastewater. Often, these communities are concerned with bacteria and phosphorus discharges from failing septic systems or package plants, or have large areas of the watershed that are simply not suitable for septic treatment. Some communities pump the sewage out of the watershed for treatment, while others rely on advanced wastewater treatment within the watershed.

In phosphorus-sensitive lakes, it is important to deal with all sources of phosphorus in the watershed. Many developing watersheds still have active agricultural operations that can contribute significant nonpoint phosphorus loads. Consequently, lake managers should carefully evaluate agricultural sources, such as row crops, confined animal feeding operations, dairies, hobby farms and grazing livestock, and cooperate with farmers and ranchers to implement needed best management practices.

**Watershed Stewardship**

The watershed is often the best scale at which to perform public education and outreach. In lake watersheds, the outreach effort strives to meet two broad objectives. The first objective is to create an awareness among all watershed residents that they are connected to the lake downstream. Once residents become more connected to the lake, the next objective is to educate them about specific ways they can have a positive influence on lake quality through their daily actions. These include activities such as lawn fertilization, car washing, septic cleanouts, fall leaf disposal, and pet waste disposal (CWP, 2000). Indeed, many of the most progressive watershed education programs have been created for lake watersheds. Examples include Lake Sammamish, Washington, and Lake Harriet, Minnesota (PCP, 1998; MDA, 1998). Figure 14 shows a graphic used on a billboard for the Lake Harriet Watershed Awareness Project.

Lawn care has traditionally been the primary focus of many lake education efforts, which is not surprising given the potential phosphorus inputs from careless fertilization (CWP, 1995b). A handful of communities have gone as far as to place restrictions on the use of fertilizer/pesticide applications throughout the watershed (Springs, 1999; NRC, 2000). Other communities promote fertilizer formulations that do not include phosphorus. Most communities have stressed direct technical assistance to homeowners on how to reduce or eliminate the use of fertilizer and pesticides. Several excellent fact sheets have been developed to educate lake residents about environmentally friendly shoreline landscaping techniques (PWD, 1995; UWEX, 1994).

**Summary: The Lake as a Commons**

Garret Hardin, in his famous essay on the tragedy of the commons, observed that the quality of a shared resource will always be degraded when everyone has access, but no one has control or ownership. Resource degradation can only be averted, he argued, if the parties agree to some form of self-regulation in order to minimize their collective impact on the resource (Hardin, 1968).

In this sense, a lake is a classic example of a commons. Most of the residents in the watershed use the lake in some way, and all residents influence it directly through their impact on the watershed. The very qualities that attracted current residents to a lake are likely to lure new ones. As a consequence, most lakes will expe-


**Figure 14. Graphic used for Lake Harriet Watershed Awareness Project (MDA, 1998)**

rience constant growth pressures along their shorelines and in their watersheds. An LPO is an effective framework for regulating the nature of development within the lake "commons."

The quality of a shared resource will always be degraded when everyone has access, but no one has control or ownership.

While lake communities often face tough choices about which precise criteria to apply within each of the four lake protection zones, they possess an inherent advantage when it comes to watershed protection. Most residents already place a high value on lake quality, whether it means natural scenery, good fishing, pure drinking water or a place to float. These shared values provide a strong foundation to reach a consensus for greater lake protection.

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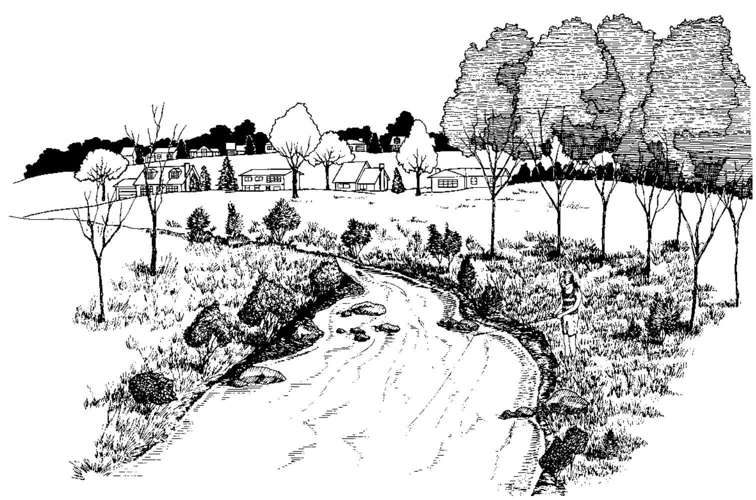

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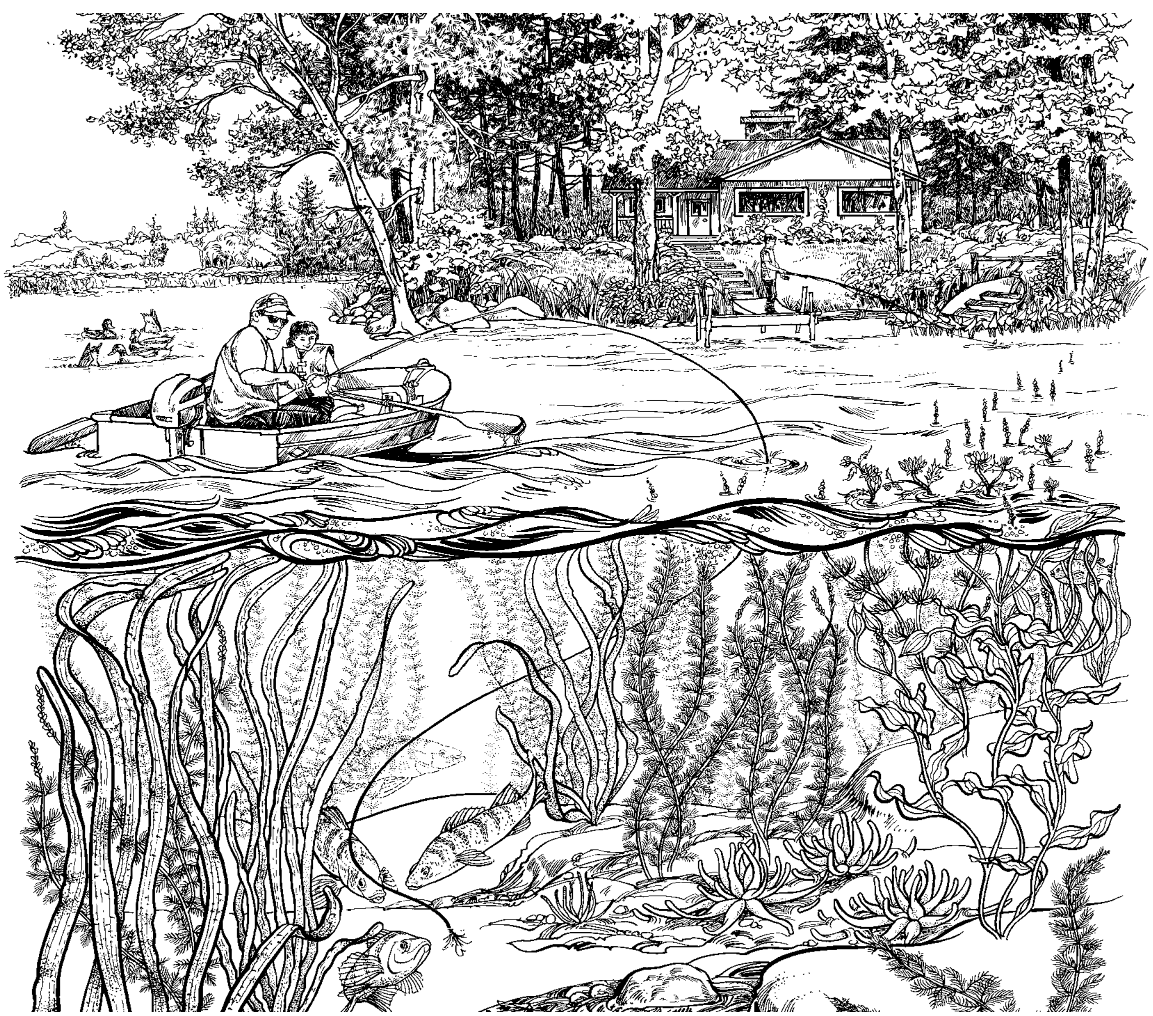
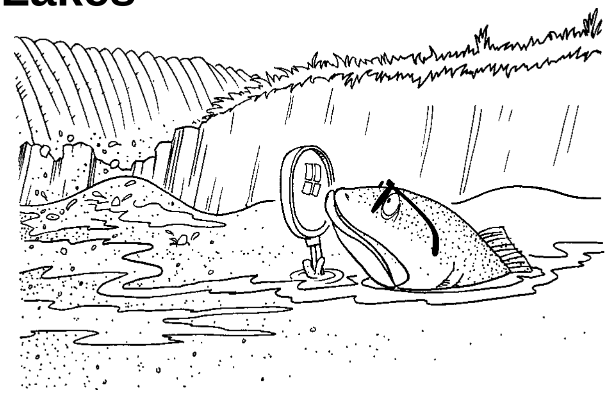


# Managing Phosphorus Inputs Into Lakes

# Introduction



**The Phosphorus Diet**

For the urban lake manager, managing phosphorus is a lot like trying to lose a few pounds. The first step is calculate an ideal weight based on our individual combination of height and body type, and determine the caloric intake needed to maintain that weight. Next, we get on the scales and find that, lo and behold, we slightly exceed this ideal weight. Well, to be honest, we really exceed it. Our next step is to add up our total daily calorie intake from meals, snacks, and the occasional indulgence in beer or chocolate. This rather dismal count almost invariably reveals why we are overweight: more calories are coming in than are being burned off. And, even more depressing, we realize that it is likely that we will get fatter and not slimmer in the future. If we want to shed the extra pounds, then, we need to discipline ourselves to consume fewer calories, and burn more off through exercise.

The diet analogy is particularly appropriate for urban lakes, given the essential similarity between phosphorus and calories. Most urban lakes are receiving more phosphorus than they need, and are projected to get even more in the future. Even worse, urban lakes tend to accumulate excess phosphorus over time in their bottom sediments. Thus, even if a manager is able to get the lake on a phosphorus diet, visible improvement may not be detected very soon, given the poor dietary habits of the past. Quite simply, the pounds are hard to take off without a major and sustained commitment to eat less and exercise more. In many cases, such discipline is beyond us, and we must simply accept the notion that we are pleasantly plump or a "plus-size." (It would be stretching this analogy well beyond the breaking point to note the similarity between dredging and liposuction).

At any rate, urban lake managers need to count phosphorus, and this series of articles provides mind-numbing detail on how to do so. In the first article, *Determining the Trophic State of Your Lake,* we present some simple methods to predict how your lake will respond to increased phosphorus loads. If your lake is unusual (i.e., is exceptionally deep or has a small drainage area to surface area ratio), it may be possible to maintain its trophic state, even when phosphorus loads increase (just like those annoying people that can eat cheesecake every day with no noticeable effect on their waistline). But in most urban lakes, increased phosphorus inputs signal a higher trophic state, so that a blue lake turns green and a green lake goes lime. In the second article, *Crafting an Accurate Phosphorus Budget for Your Lake,* we document the primary, secondary and internal phosphorus sources to urban lakes, and indicate how each can be rapidly counted to produce a phosphorus budget for your lake that will be reasonably accurate both now and the future.

In the third article, *Evaluating the Impact of Watershed Treatment,* we review the capability of various watershed treatment practices to reduce phosphorus inputs to lakes. Included is an examination of the influence of stormwater treatment practices, better site design, and other watershed practices in reducing phosphorus loads to urban lakes, based on the most recent performance research. The basic conclusion is that these practices can be very useful, as long as the increase in phosphorus inputs as a result of watershed development are rather modest. If watershed development is expected to be substantial, watershed treatment practices may not be able to achieve phosphorus reduction goals when used individually or even in combination. In these situations, lake managers can only deal with the symptoms of eutrophication, either through in-lake treatment (see Davenport and Kaynor, this issue) or by tempering expectations about achievable lake quality.

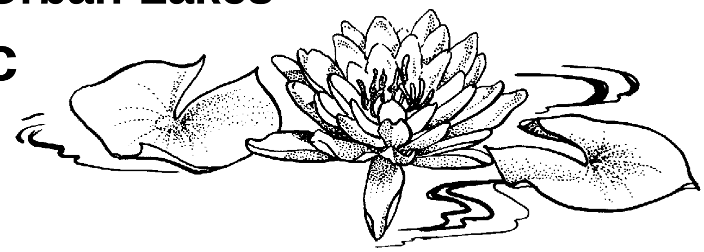
Most urban lakes are receiving more phosphorus than they need, and are projected to get even more in the future.

Watershed managers need to accurately forecast current and future phosphorus inputs when they craft lake management plans. As a result, they often must deliver an unpopular message to their patients: if they want to be slim, they must embrace a strict regime of diet and exercise.

–TRS

## Managing Phosphorus Inputs to Urban Lakes

# I. Determining the Trophic State of Your Lake



*by Ted Brown and Jon Simpson*

### Trophic State Classification

Lakes are commonly classified according to their *trophic state,* a term that describes how "green" the lake is as measured by the amount of algae biomass in the water. Three trophic state categories are used to describe lakes as they grow progressively greener: *oligotrophic*, *mesotrophic*, and *eutrophic*. Watershed managers typically do not determine trophic state by directly measuring algae biomass, however. Instead, they indirectly assess it by doing the following:

(1) Measuring the levels of nutrients and chlorophyll *a* in the lake (the primary photosynthetic pigment found in plant cells)
(2) Measuring lake water clarity using a Secchi disk

Using these measurements, lake managers can classify the lake based on typical ranges for phosphorus, nitrogen, chlorophyll *a* and Secchi depth values reported in the lifecycle (Table 1).

*Eutrophication* is a term used to describe a directional movement over time towards the eutrophic trophic state from a lower trophic state (US EPA, 2000) (see Table 2 for more lake terminology). Note that a lake does not have to reach the eutrophic state to undergo eutrophication; rather, use of the term indicates a trend toward a more eutrophic state (e.g., higher phosphorus, nitrogen, and chlorophyll concentrations and lower Secchi depth readings over time). For example, a lake is undergoing eutrophication if trophic state indicators show that it was once oligotrophic but is now mesotrophic. In general, the primary concern of most lake managers is slowing down, halting, or even reversing eutrophication.

### Determining the Trophic State of Your Lake

In general, trophic state measurements serve as benchmarks for measuring the success of a lake management program. Initial determinations about the trophic state of a lake can be made by simply observing the lake's basic characteristics (Table 3). However, more sophisticated approaches to assessing trophic state require analysis of key variables such as phosphorus, nitrogen, chlorophyll, and Secchi depth. Lake managers can learn about setting up a sampling program to measure these variables from several sources, including US EPA (1990; 1991), Carlson and Simpson (1996), and US EPA (2000).

**Table 1. Ranges of Variable Values Associated with Trophic Levels in Lakes (adapted from Vollenweider and Kerekes, 1980)**

| Water Quality Variable | Oligotrophic | Mesotrophic | Eutrophic |
|---|---|---|---|
| Total Phosphorus | | | |
| Mean | 8 | 27 | 84 |
| Range | 3-18 | 11-96 | 16-390 |
| Total Nitrogen | | | |
| Mean | 660 | 750 | 1,900 |
| Range | 310-11600 | 360-1400 | 390-6100 |
| Chlorophyll *a* | | | |
| Mean | 1.7 | 4.7 | 14 |
| Range | 0.3-4.5 | 3-11 | 2.7-78 |
| Peak Chlorophyll *a* | | | |
| Mean | 4.2 | 16 | 43 |
| Range | 1.3-11 | 5-50 | 10-280 |
| Secchi Depth (m) | | | |
| Mean | 9.9 | 4.2 | 2.4 |
| Range | 5.4-28 | 1.5-8.1 | 0.8-7.0 |

*Note: Units are Ug/l (or mg/m$^3$), except Secchi depth; means are geometric annual means (log 10), except peak chlorophyll* a.

**Table 2. A Primer on Lake Terminology**

**Areal phosphorus load:** Total watershed phosphorus load delivered to the lake divided by the lake surface area.

**Chlorophyll *a:*** A type of photosynthetic element present in all types of algae which is used to indicate the biomass of algae in a lake.

**Epilimnion**: Uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification. The epilimnion extends from the surface to the thermocline.

**Eutrophication**: The process of physical, chemical, and biological changes associated with nutrient enrichment of a lake or reservoir.

**Flushing rate**: The rate at which water enters and leaves a lake relative to lake volume, usually expressed as time needed to replace the lake volume with inflowing water.

**Hypolimnion**: Lower, cooler layer of a lake during summertime thermal stratification.

**In-lake phosphorus concentration:** Phosphorus concentration measured in the water column of a lake that is representative of well-mixed lake conditions. Frequently used as a trophic state indicator.

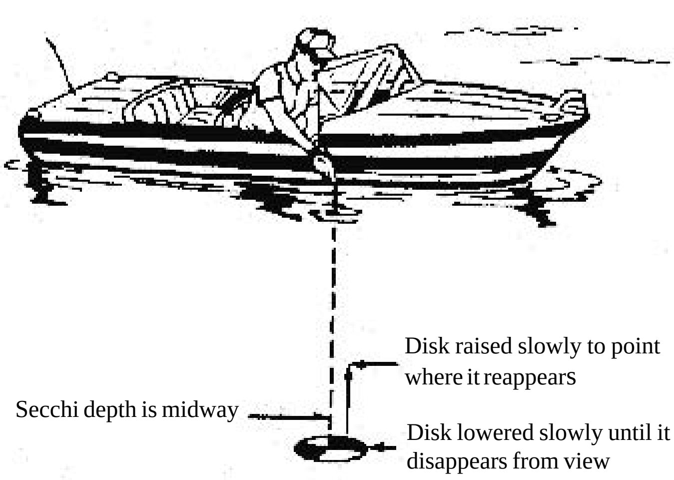
**Phosphorus budget**: Quantitative assessment of phosphorus moving into, being retained in, and moving out of a lake.

**Production**: The mass of new organic material formed over a period of time, plus any losses during that period. A lake's productivity is then the rate of production divided by a period of time.

**Secchi depth:** (See graphic below.) A measure of transparency of water obtained by lowering a black and white, or all white, disk (Secchi disk, 8 inches in diameter) into water until it is no longer visible. Measured in units of meters or feet.

**Trophic state:** The degree of eutrophication of a lake, based on an index of water clarity, chlorophyll *a* levels, and nutrient levels.

**The Secchi Disk**




*(graphic courtesy Sebago Lake Association)*

A Secchi disk is a weighted 8-inch diameter disk with alternating black and white quadrants. Named after Pietro Angelo Secchi, a papal scientific advisor and head of the Roman Observatory in the 1800's, it is the oldest tool in a lake manager's toolbox. The disk is lowered into the water by a measured cord or rope until it cannot be seen. The depth (i.e., the length of the rope from the disk to the water surface) is recorded. Then the disk is raised until it can be seen again. The average between the depth of disappearance and the depth of appearance is called the Secchi depth (US EPA, 2000). The relationship between this measurement and algae biomass in the water column is strongly correlated in lakes where clarity is not affected by sediments, silts, or other materials that stain or make the water cloudy or muddy.

| Table 3. Trophic State Classification Based on Simple Lake Characteristics (adapted from Rast and Lee, 1987) | | |
|---|---|---|
| | General Characteristics | |
| **Variable** | **Oligotrophic** | **Eutrophic** |
| Total aquatic plant production | Low | High |
| Number of algal species | Many | Few |
| Characteristic algal groups | Greens, diatoms | Blue-greens |
| Rooted aquatic plants | Sparse | Abundant |
| Oxygen in hypolimnion | Present | Absent |
| Characteristic fish | Deep-dwelling cold water fish such as trout, salmon, and cisco | Surface-dwelling, warm water fish such as pike, perch, and bass; also bottom-dwellers such as catfish and carp |
| Secchi depth | 25 feet or none | 6 feet or less |

Lake managers should have an understanding of the many forms of phosphorus that can be found in a lake. The two most important forms to consider are soluble reactive phosphorus (SRP) and particulate phosphorus (PP) (Rigler, 1974). Soluble and particulate phosphorus are differentiated by whether or not they pass through a 0.45-micron membrane filter. The sum of these two components is known as total phosphorus (TP). TP is the parameter generally used in trophic assessments and in a wide variety of empirical lake and watershed models.

In some instances managers may also want to measure the soluble concentration of phosphorus. This fraction consists largely of inorganic orthophosphate, which can be taken up by algae. Consequently, if the concentrations in a lake are low (e.g., <5 µg/l), phosphorus is likely to be the limiting element for algae growth.

**Carlson Trophic State Index**

A popular method for examining algal biomass as it relates to trophic state is through the use of the Trophic State Index (TSI) developed by Carlson (1977). A watershed manager can use measurements of three variables - chlorophyll *a*, TP, and Secchi depth - to calculate a TSI value within a numerical trophic continuum. The continuum is divided into units based on a base-2 logarithmic transformation of Secchi depth, each 10-unit division of the index representing a halving or doubling of Secchi depth. The TSI index ranges from zero to 100 and can be used to assign a trophic state "grade" to a lake.

When classifying lakes, priority is often given to the TSI value associated with chlorophyll, since it is the most accurate of the three parameters for predicting algal biomass. Any of the three variables, however, can theoretically be used to classify a lake (an especially useful attribute if only one variable was measured in historical monitoring). The formulas for calculating the TSI values for Secchi disk, TP, and chlorophyll *a* are as follows:

Secchi disk: $TSI(SD) = 60 - 14.41 \ln(SD)$

Chlorophyll *a*: $TSI(CHL) = 9.81 \ln(CHL) + 30.6$

Total phosphorus: $TSI(TP) = 14.42 \ln(TP) + 4.15$

Where ln = natural log

Table 4 lists TSI values and corresponding measurements of the three lake parameters. Ranges of TSI values can by grouped into the traditional trophic state categories. Lakes with TSI values less than 40 are usually classified as oligotrophic. TSI values greater than 50 are generally defined as eutrophic lakes. Mesotrophic lakes have TSI values between 40 and 50.

The TSI formulas are interrelated by linear regression models and should produce the same TSI value for a given combination of variable values. In cases where they do not agree, managers can possibly gain some greater insight about their lakes. Table 5 presents some possible interpretations associated with various combinations of TSI results.

**Cautions**

Lake managers need to keep in mind that the TSI classification scheme is a simple tool to provide benchmark information about the trophic state of a lake. Just like there are no absolutes when categorizing people by age (e.g. young, middle-aged, or elderly), there are also no absolutes when classifying lakes into oligotrophic, mesotrophic, or eutrophic states. When trophic state is

| Table 4. TSI Values Associated With Variable Measurements | | | |
|---|---|---|---|
| **TSI** | **Secchi Disk (meters)** | **Surface total Phosphorus (ug/L)** | **Surface Chlorophyll *a* (ug/L)** |
| **0** | 64 | 0.75 | 0.04 |
| **10** | 32 | 1.5 | 0.12 |
| **20** | 16 | 3 | 0.34 |
| **30** | 8 | 6 | 0.94 |
| **40** | 4 | 12 | 2.6 |
| **50** | 2 | 24 | 6.4 |
| **60** | 1 | 48 | 20 |
| **70** | 0.5 | 96 | 56 |
| **80** | 0.25 | 192 | 154 |
| **90** | 0.12 | 384 | 427 |
| **100** | 0.062 | 768 | 1,183 |

used to classify a lake, lake managers are implying that algal biomass is the key parameter defining lake quality.

For many urban lakes, the assumption that algal biomass is the primary management concern is entirely appropriate, given the host of problems that algal blooms can create (see Table 6). However, some shallow urban lakes may not fit this mold. These shallow urban lakes suffer from an overgrowth of emergent and/or submergent aquatic weeds, not algae. In these lakes, control of algal biomass might not be the primary concern. Lake managers must therefore understand the dynamic nature of their lake and prepare management strategies based on current and anticipated conditions.

### Tracking Trophic State and Phosphorus

Understanding phosphorus is often the key to slowing down, stopping, or even reversing eutrophication. Lake managers need to answer many questions about phosphorus: Where are sources of phosphorus in my watershed? How it is transported to the lake and in what amounts? Do loading amounts vary seasonally? What forms does phosphorus take once it gets there? How is it transported out of the lake?

It is important to keep in mind that not all lakes start out with the same lake phosphorus concentration. Indeed, even lakes with identical watershed geometry can have dramatically different phosphorus concentrations depending on their geologic regions, land use and climatic settings. Lake managers should understand how these differences can influence the trophic status of their lakes. For example, Table 7 compares the reported in-lake total phosphorus concentrations for lakes and reservoirs over a broad range of ecoregions in North America. As can be seen, in-lake phosphorus concentrations range from 6.4 to 170 µg/l, spanning the full range of trophic conditions. Trophic state can be extremely variable even within an ecoregion: Figure 1 illustrates how in-lake phosphorus concentrations vary across the state of Ohio (Fulmer and Cooke, 1990).

These regional variations often constrain the trophic state target for an individual lake. For example, it may not be possible to attain an oligotrophic or mesotrophic state in certain regions of the country, such as Florida, or the corn-belt, or, in some cases, reservoirs. A knowledge of the expected in-lake phosphorus concentration helps to set attainable goals for lake management and establish what is an acceptable level of eutrophication, given existing uses. In fact, Fulmer and Cooke (1990) and Heiskary (1989) have proposed an ecoregion-based approach to establish

| Table 5. Interpretations of Deviations From Typical Conditions Associated With TSI Values | |
|---|---|
| **TSI Relationship** | **Possible Interpretation** |
| TSI (CHL) = TSI (SD) | Algae dominate light attenuation |
| TSI (CHL) > TSI (SD) | Large particulates, such as Aphanizomenon flakes, dominate |
| TSI (TP) = TSI (SD) > TSI (CHL) | Non-algal particulate or dissolved color dominate light attenuation |
| TSI (SD) = TSI (CHL) >= TSI (TP) | Phosphorus limits algal biomass (TN/TP ratio greater than 33:1) |
| TSI (TP) > TSI (CHL) = TSI (SD) | Zooplankton grazing, nitrogen, or some factor other than phosphorus limits algal biomass |

lake management goals and standards in Ohio and Minnesota, respectively, that reflect attainable lake trophic status and user expectations. The approach proposed by Heiskary was ultimately adopted in Minnesota (NALMS, 1992).

**1. How can in-lake total phosphorus concentration be measured or estimated?**

In-lake total phosphorus concentration is probably the most common and useful indicator of trophic state, since it can be directly measured or empirically derived. It can be directly measured by collecting water quality samples in the lake over time. When appropriate sampling protocols are followed, lake monitoring provides an accurate measure of trophic conditions in a lake (US EPA, 1988). However, the effort and cost to properly mobilize, collect and analyze samples can be significant. For example, due to thermal stratification that can occur in lakes, samples may need to be collected at several depths. US EPA guidance (1990) recommends that three points be sampled for deep lakes (i.e., lakes that stratify). One sample should be collected from the epilimnion at the center of the lake one foot below the surface. The other two samples should be collected from the hypolimnion: one near the top of the hypolimnion and the other just above the lake sediments. For shallow lakes (i.e., lakes with fairly uniform oxygen concentrations in the surface-to-bottom profile that do not stratify), a single sample from the center of the lake at a depth of one foot below the surface is adequate.

In-lake phosphorus concentrations can also be estimated using empirical lake response models. These models have the advantage of being fairly easy and quick to apply; however, their accuracy depends on the quality of the input data. Well-established empirical models by Vollenweider (1968 and 1975) and Walker (1977) can be used to quickly estimate lake trophic status, assuming some basic input parameters are known, such as areal phosphorus load, hydraulic residence time, and lake depth. Chapra and Tarapchuk (1976) and Rast and Lee (1987) advanced Vollenweider's original work to include additional data and mechanisms that allow for refined estimates of phosphorus concentrations as well as chlorophyll *a*. While this article focuses on Vollenweider's model, other models can just as easily be used. It should be noted that most of the simple lake response models (such as Vollenweider's) do not take into account the potentially significant effect of internal phosphorus loading from lake sediments.

Mathematically, the Vollenweider model can be expressed in the following form:

Eq. (1) $$P = 0.368 \times \frac{L}{Zp} \times \frac{1}{1 + 1/\sqrt{p}}$$

where:

0.368 = conversion factor
P = in-lake total phosphorus concentration (mg/l)
L = areal phosphorus load (lbs/ac/yr)
Z = mean depth of lake (feet), and
p = the flushing rate in times (per year)

A common graphical representation of the Vollenweider model is shown in Figure 2, which shows the analytical solution to Equation 1 for in-lake total phosphorus concentrations of 10, 20, and 50 µg/l, respectively. The product of mean lake depth and flushing rate is shown on the x-axis, while the areal phosphorus load is shown on the y-axis. The Vollenweider relationship is most sensitive to changes in areal phosphorus load, which is implicitly a function of the drainage area to surface area ratio. As watershed development occurs, the areal phosphorus load increases, as shown in Figure 3. The effect of urbanization can potentially increase lake areal loading by a full order of magnitude. It should be noted that Figure 3 is based on extremely conservative assumptions, since it only considers the increase in primary phosphorus loads due to impervious cover, and does not consider secondary or internal sources, which can boost the areal load significantly during watershed development.

It is important to keep in mind that not all lakes start out with the same lake phosphorus concentration.

**Table 6. Why it Matters: Impacts of Eutrophication on Lake and Reservoir Quality**

- Nuisance algal blooms in the summer
- Reduced dissolved oxygen in the bottom of the lake
- Fish kills due to low dissolved oxygen
- Taste and odor problems with drinking water
- Formation of THMs and other disinfection byproducts in water supplies
- Increased cost to treat drinking water
- Reduced water clarity
- Decline in fish community (more rough fish, fewer game fish)
- Blockage of intake screens by algal mats
- Reduced quality of boating, fishing and swimming experience
- Decline in lakefront property values
- Floating algal mats and/or decaying algal clumps
- Increased density of aquatic weeds in shallow areas

The Vollenweider model is less sensitive to changes in lake depth and flushing rate, since for a constant drainage area to surface area ratio, flushing rate generally decreases as depth increases, effectively canceling each other out. However, deep lakes tend to be less eutrophic than shallow lakes, given the same areal phosphorus load and flushing rate.

To establish the existing trophic condition of a lake, one needs to solve the Vollenweider equation for in-lake total phosphorus concentration. This requires the lake manager to know what the areal loading, mean depth, and lake flushing rate are. Given some basic data on lake geometry (e.g., surface area and mean depth) and watershed area, these unknowns can be quickly estimated.

Areal phosphorus loading, L, can be computed by dividing the total watershed phosphorus budget by the surface area of the lake. Mean depth, Z, can be determined from bathymetric maps, direct sampling, or as-built drawings (for reservoirs).

**Table 7. Regional Differences in In-Lake Total Phosphorus Concentrations for Lakes and Reservoirs (ug/l)**

| State | Region | TP [ug/L] | Notes | Reference |
|---|---|---|---|---|
| Alaska | Southeastern and South-central Coastal Region | 6.4 | 52 clear lakes | Edmundson and Carlson, 1998 |
| | Southeastern and South-central Coastal Region | 8.4 | 21 organically stained lakes | |
| | Southeastern and South-central Coastal Region | 22.3 | 14 glacial turbid lakes | |
| Connecticut | Eastern Uplands | 27 | 26 lakes | Canavan and Siver, 1994 |
| | Coastal Slope | 19 | 7 lakes | |
| | Central Valley | 52 | 8 lakes | |
| | Western Uplands | 33 | 14 lakes | |
| | Marble Valley | 31 | 5 lakes | |
| Florida | Entire State | 32 | 209 lakes | Brown *et al*., 1998 |
| Iowa | Entire State | 91 | 12 lakes and reservoirs | Knowlton and Jones, 1993 |
| Kansas | Entire State | 62 | 4 reservoirs | Knowlton and Jones, 1993 |
| Missouri | Ozark Highlands | 28 | 25 reservoirs | Jones and Knowlton, 1993 |
| | Ozark Border | 40 | 14 reservoirs | |
| | Great Plains | 48 | 32 reservoirs | |
| | Osage Plains | 65 | 22 reservoirs | |
| Minnesota | Northern Lakes and Forests | 20 | Reference Lake | Heiskary, 1989 |
| | North Central Hardwood Forests | 30 | Reference Lake | |
| | Western Corn Belt Plains | 105 | Reference Lake | |
| | Northern Glaciated Plains | 170 | Reference Lake | |
| Ohio | Huron/Erie Lake Plain | 142 | 1 reservoir | Fulmer and Cooke, 1990 |
| | Eastern Corn Belt Plain and Erie/Ontario Lake Plain | 54.8 | 10 reservoirs | |
| | Western Allegheny Plateau | 17.2 | 8 reservoirs | |
| Oklahoma | | 73 | 12 reservoirs | Knowlton and Jones, 1993 |
| Texas | West | 50 | 15 reservoirs | Ground and Groeger, 1994 |
| | Central | 44 | 44 reservoirs | |
| | East | 64 | 21 reservoirs | |
| Washington | Mountain Region | 15 | 6 mountain lakes | Larson *et al*., 1998 |
| Southwest US | CO, TX, UT, NM,.and OK | 36 | 56 reservoirs | Thornton and Rast, 1989 |

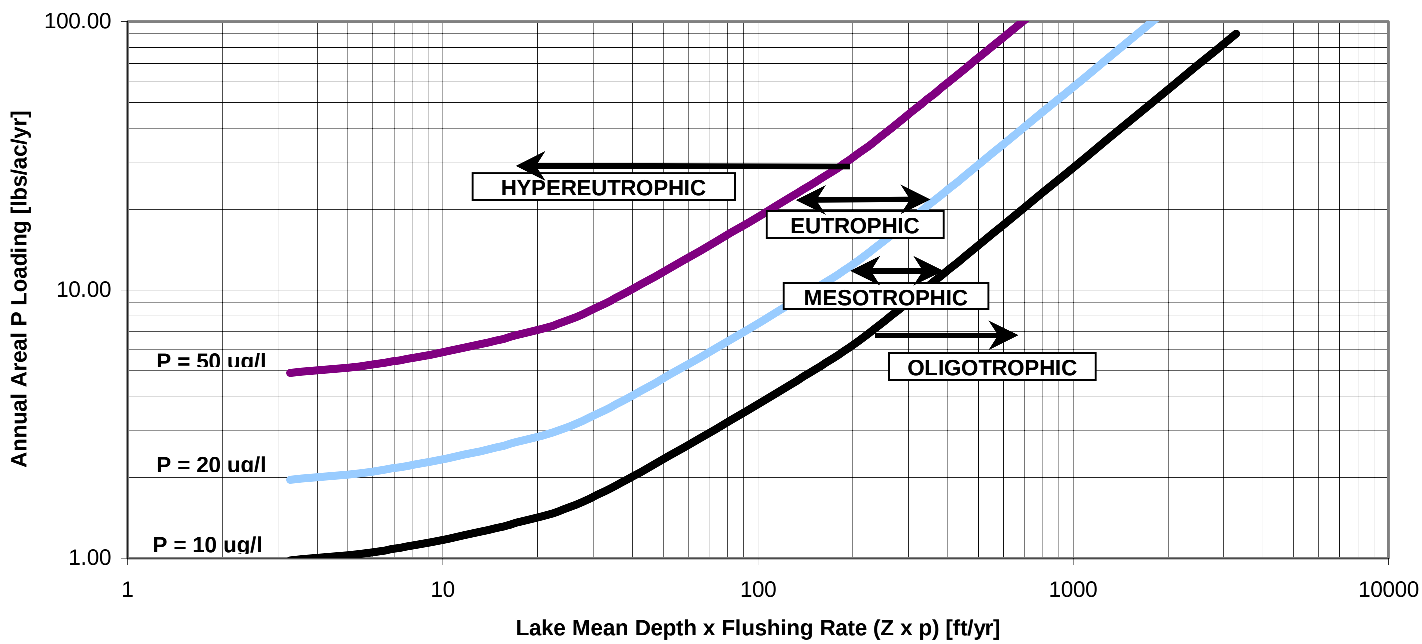



**Figure 2. Phosphorus Loading vs. Lake Trophic Condition (Vollenweider, 1975)**

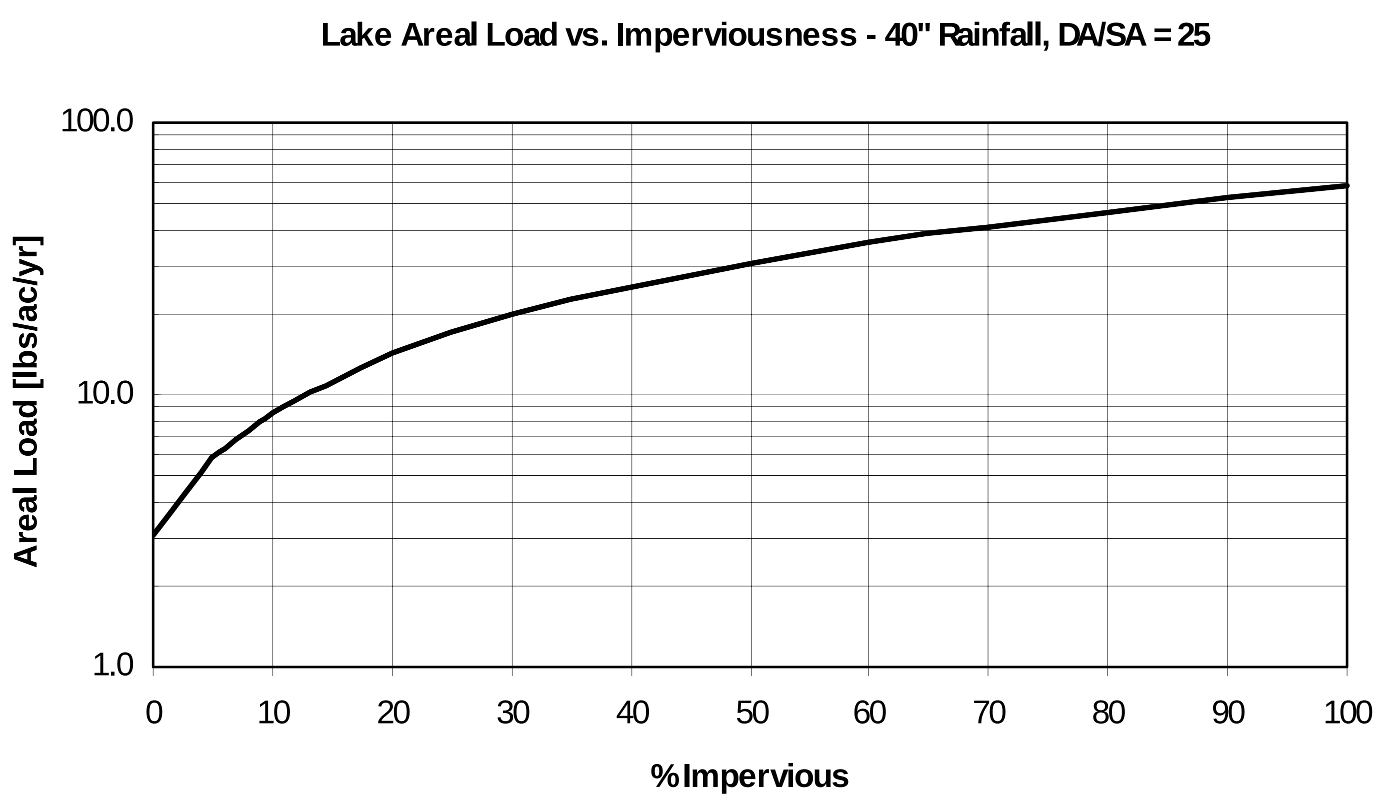



**Figure 3. Areal Phosphorus Loads as a Function of Watershed Imperviousness**
***(loads calculated using the Simple Method, assuming a total phosphorus concentration of 0.3 mg/l for the full range of impervious cover and without considering secondary sources such as wastewater discharges)***

Flushing rate, p, is the lake outflow rate divided by the lake volume, and is computed as follows:

$$P = \frac{(R)(A)}{[(SA)(Z)]}$$

where:

| | | |
|---|---|---|
| p | = | Flushing rate (times per year) |
| R | = | Watershed unit runoff (feet/year) |
| A | = | Watershed area (acres) |
| SA | = | Lake surface area (acres), and |
| Z | = | Lake mean depth (feet) |

Even relatively minor changes in land use can have a profound effect on the trophic state of a lake.

Annual runoff, R, is best derived from hydrologic models for the lake, but can be estimated from regional runoff maps, such as the one depicted in Figure 4. It is important to note that the runoff includes both storm event surface runoff volume and the annual baseflow volume.

Armed with estimates of the areal loading, depth, and flushing rate, it is possible to solve the Vollenweider model directly for in-lake total phosphorus concentration (Equation 1). An example scenario is provided in Box 1.

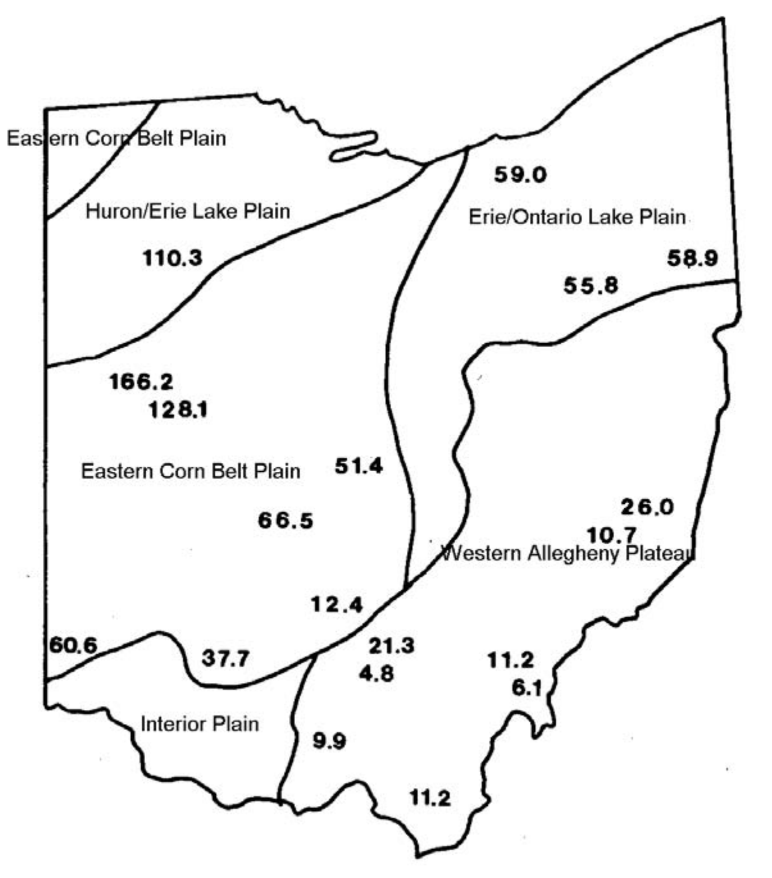



**Figure 1. Total Phosphorus Concentrations (ug/l) in 19 Ohio Lakes by Ecoregion (Fulmer and Cooke, 1990)**

**2. Will the lake trophic state shift because of future growth, and if so, by how much?**

Once the current trophic state has been established, the next step is to determine how much additional phosphorus load could occur, while still maintaining the same trophic state. This sensitivity analysis helps to ultimately shape the phosphorus loading targets for the lake watershed management. Lake areal loading changes that can be expected as a result of future watershed development can be estimated by deriving current and future phosphorus budgets. An example calculation of the impact of future growth in a lake watershed is presented in Box 1, which illustrates how even relatively minor changes in land use can have a profound effect on the trophic state of a lake.

**3. How much areal load reduction is necessary to maintain current trophic status?**

If an urban lake is expected to shift to a higher trophic state, a lake manager must evaluate whether watershed treatment strategies can reduce enough phosphorus load to maintain desired lake uses. There are two approaches lake managers can take to make this evaluation. First, it is possible to calculate the areal phosphorus load reduction necessary to maintain the current trophic state. This is accomplished by subtracting the predicted future areal load by the maximum allowable areal load associated with the current trophic state. Using our Lake Mesotroph example, a quick inspection of Figure 2 indicates that the necessary phosphorus reduction is approximately 2.5 lbs/ac/yr (i.e., 6 lbs/ac/yr minus 3.5 lbs/ac/yr). A second approach is to set forth a management goal of no net increase in areal phosphorus load, which simply translates to reducing the increase in phosphorus load quantified from the projected watershed growth. Either approach will require a fairly high level of treatment for both existing and new development.

**Lake Sensitivity: Implications for the Lake Manager**

Most urban lakes are very sensitive to increases in phosphorus load caused by watershed development. Exceptions to this general rule can occur where lakes are unusually deep and/or have very small drainage area to surface area ratios. In general, uncontrolled watershed development will likely shift a lake's trophic status upward, even under relatively low density development scenarios.

Consequently, aggressive phosphorus reduction programs will be needed for most lakes that are forecasted to experience watershed growth. The next articles

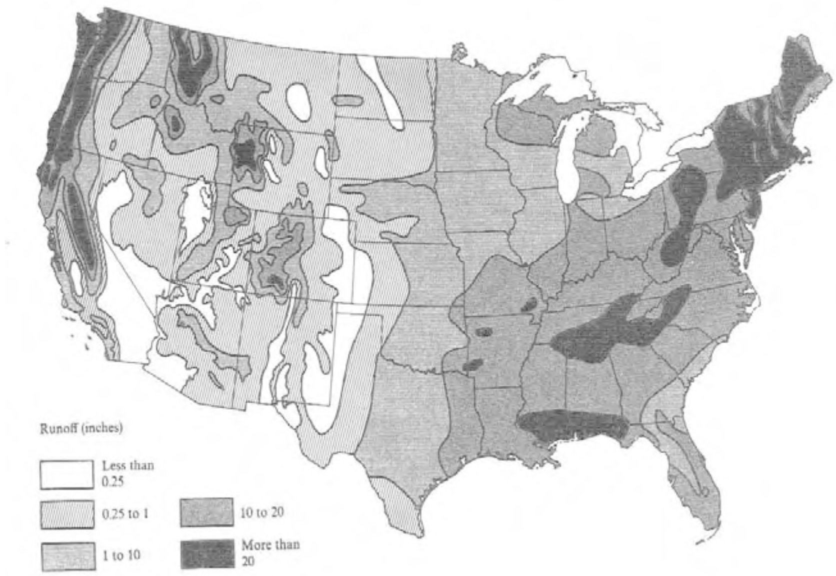



**Figure 4. Average Annual Runoff in the United States (Leopold *et al.*, 1964)**

## Box 1. Example Scenario: Determining Existing Trophic State

Lake Mesotroph is a pristine Mid-Atlantic Piedmont lake. The lake surface area is 10 square miles, and has an average depth of 20 feet. Its 250 square mile watershed is entirely forested. The county government and the state jointly own much of the land in this watershed. In order to stimulate the local economy, these governments are considering a sale of the property, to be developed as two-acre lots over approximately 90 square miles of the watershed (watershed imperviousness of about 5%). These homes would be seasonal, primarily operating during half of the year, and served by septic systems. A study is being conducted to estimate the impacts of this potential development, and in particular whether the change would shift the lake trophic status.

**Existing Conditions**

Monitoring in the area suggests that the forested land use exports only 0.1 lbs/acre of phosphorus per year, and that total streamflow represents approximately 15 watershed inches of runoff per year. The flushing rate, p, of the lake is determined as:

$$p = (15 \text{ in/year})(250 \text{ mi}^2)/[(12 \text{ in/ft})(10 \text{ mi}^2)(20 \text{ ft})] = 1.55/\text{yr}$$

and the flushing rate times lake mean depth, pZ, is determined as:

$$pZ = 1.55/\text{yr} \times 20 \text{ ft} = 31 \text{ft/yr}$$

With the current land use, and including atmospheric deposition, the total annual load to the lake is 19,200 lbs/year. With the lake area of 10 square miles (6,400 acres), the current lake areal load is 3 lbs/acre/year. Using Vollenweider's model as illustrated in Figure 2, we can see that the lake is mesotrophic.

**Projected Future Conditions**

The future land use plan will convert 90 square miles of the 250 square mile Lake Mesotroph watershed to two-acre lots (i.e., 11% imperviousness for the land use, 5% imperviousness for the watershed), and assuming seasonal septic operation, it is calculated that the external load to the lake will increase to 38,400 lbs/year (up from 19,200 lbs/year), or an areal loading rate of 6 lbs/acre/year.

To determine the resulting trophic state from the projected growth, the same approach that is used in the example above is followed. However, the total annual runoff volume also increases from 15 inches/year to 17 inches/year as a result of the increased impervious cover and loss of evapotranspiration. So the flushing rate multiplied by lake mean depth, pZ, is determined as:

$$pZ = (17 \text{ in/year})(250 \text{ mi}^2)/[(12 \text{ in/ft})(10 \text{ mi}^2)(20 \text{ ft})] \times 20 \text{ ft} = 35 \text{ ft/yr}$$

Again, using Vollenweider's model as illustrated in Figure 2, we can see that the change in land use would result in a trophic shift from mesotrophic to eutrophic.

will provide guidance on developing phosphorus budgets, and evaluate the degree to which watershed treatment practices can reduce phosphorus inputs.

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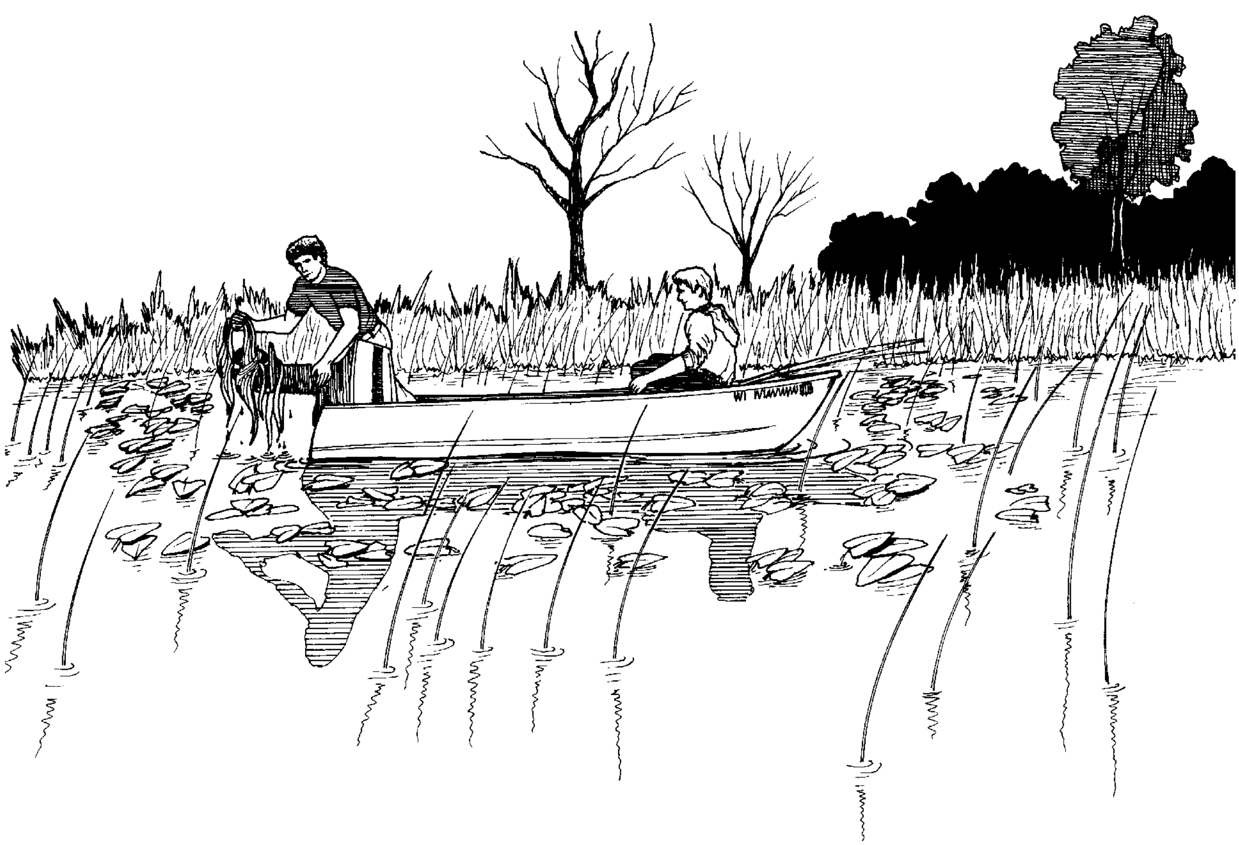


# Managing Phosphorus Inputs Into Lakes
# II. Crafting an Accurate Phosphorus Budget for Your Lake

*by Deb Caraco and Ted Brown*

**Introduction**

This article presents simple, practical advice on how to derive a lake phosphorus budget for current and future land use in the watershed. Included are the most recent data on primary, secondary and internal phosphorus sources to urban lakes, which can be used to quickly develop a phosphorus budget to assess the risk of eutrophication due to watershed growth. By carefully tracking the individual sources of phosphorus to a lake, managers can forecast the impact of phosphorus loads on the current or future trophic condition of a lake. Such estimates are essential for developing effective and realistic watershed management plans.

Each lake has its own phosphorus budget, depending on its unique mix of phosphorus sources. Caraco (2001) identifies three broad categories of phosphorus sources to track: *primary* sources, *secondary* sources, and *internal* sources (e.g., sediment release, waterfowl droppings, and atmospheric deposition on the lake itself). A lake manager needs to carefully account for each of these major phosphorus sources when constructing a phosphorus budget for an urban lake (see Figure 1).

*Primary* phosphorus sources are defined as nonpoint source loads that are derived from individual land use categories in the watershed. Phosphorus loads can be quickly estimated by calculating an annual runoff volume and phosphorus concentration for each land use category, or by using export coefficients derived from the literature (expressed in terms of pounds of phosphorus per acre per year, lbs/ac/yr). *Secondary* sources are defined as human or animal wastewater flows produced in the watershed. These flows can take the form of an outfall pipe from a sewage treatment plant, a failing septic system, a sanitary sewer overflow, or runoff from a confined animal feedlot operation. With the exception of wastewater discharges, secondary sources tend to be more scattered throughout a watershed and occur more sporadically, which often makes it difficult to estimate them with precision. In addition, the units used to calculate secondary source flows are frequently difficult to compile and may require many simplifying assumptions.

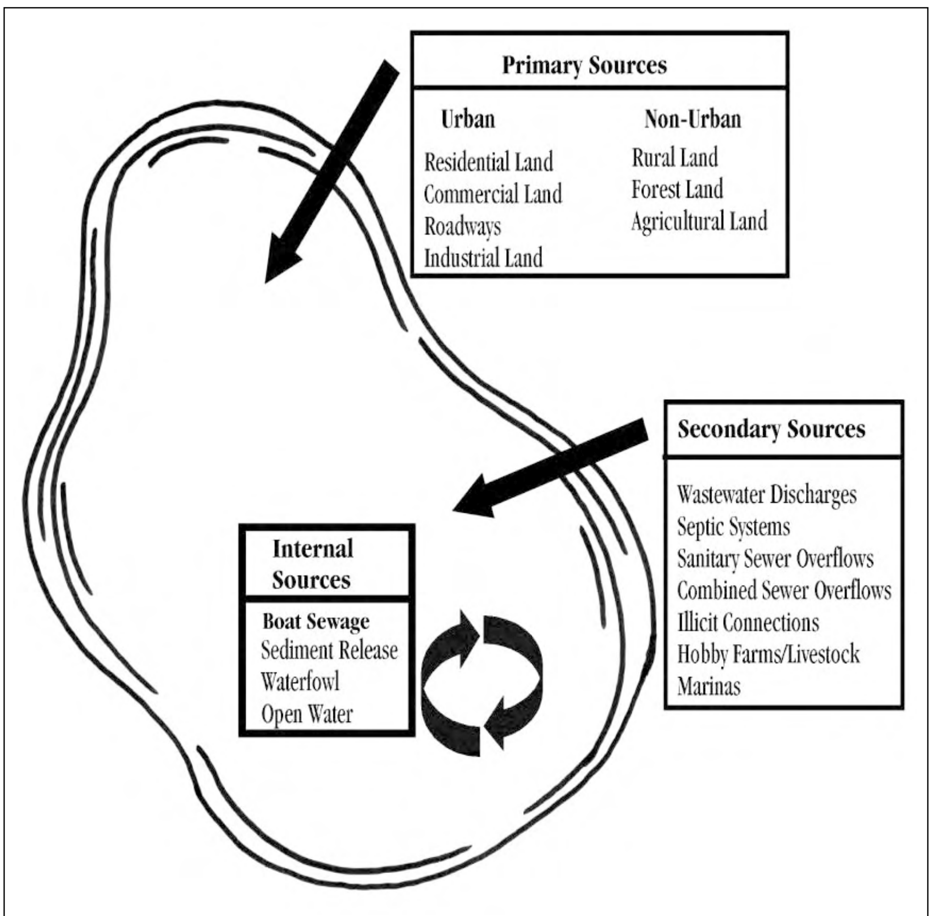



**Figure 1. Three Categories of Phosphorus Sources To Lakes**

The remainder of this article presents simple and rapid methods to estimate primary, secondary and internal phosphorus sources to urban lakes. These methods can be used to define a representative phosphorus budget for a lake, and more importantly, identify which phosphorus sources can be most easily controlled. In some cases, more complex simulation models may be needed to construct a phosphorus budget for an urban lake; detailed guidance on choosing the most appropriate model can be found in US EPA (1999).

**Estimating Primary Phosphorus Sources in Urban Watersheds**

Hundreds of monitoring studies have been conducted to characterize average phosphorus concentrations and runoff volumes associated with urban and non-urban land uses. Export coefficients are frequently used to express total phosphorus loads for non-urban land uses, such as forest, rural, and agriculture (see Table 1). Event mean concentrations (EMCs) are often used to characterize total phosphorus concentrations in the runoff from specific urban land uses, such as residential, commercial, roadway, and industrial (see Table 2). By way of comparison, the USGS (1999) recently summarized median in-stream total phosphorus concentrations for watersheds of different land uses, and concluded that urban streams had higher phosphorus concentrations than forested and agricultural streams (Figure 2).

**Table 1. Total Phosphorus Export Coefficients Associated with Non-Urban Land Uses (lbs/ac/yr)**

| Source | Forest | Rural | Ag | Open Water | Notes |
|---|---|---|---|---|---|
| Horner *et al.*, 1994 | 0.1 | 0.12 | - | - | These data represent median values from literature, and from data collected in the Pacific Northwest. The rural values represent a pastureland use. |
| LizÆraga, J., 1997 | 0.14 | 0.75 | - | - | These values are estimated 1994-1995 export coefficients for several sub-basins within the Potomac River Basin, ranging in size from 15 to 1,500 square miles. Flow was monitored at all stations, and concentration data were extrapolated from a few stations using a USGS regression method based on basin characteristics. |
| Smith *et al.*, 1991 | 0.20 | 0.21 | - | - | These values are export coefficients derived from government monitoring programs conducted between 1980 and 1989. |
| Reckhow *et al.*, 1980 | 0.18 | 0.72 | - | - | These values are medians of export coefficients from 23 studies of forested watersheds, and 14 studies of pasture (grazing) land. |
| Frink, 1991 | 0.11 | 0.4 | 1.62 | - | Average of up to 14 studies summarized. |
| Scarborough and Peters, 1996 | 0.15 | - | 0.96 | 0.44 | Average of up to 8 studies summarized. |
| MWCOG, 1983 | - | - | - | 0.5 | Based on dryfall NURP data from Washington D.C. |

**Table 2. Total Phosphorus EMCs Associated with Urban Land Uses (mg/l)**

| Source | Land Use | | | | |
|---|---|---|---|---|---|
| | Urban (Arid) | Residential | Commercial | Roadway | Industrial |
| Barrett and Malina, 1998 | - | - | - | 0.4 | - |
| Caraco, 2000, mean | 0.78 | - | - | - | - |
| Gibb *et al.*, 1991 mean | - | 0.33 | - | 0.59 | - |
| Schueler, 1987 mean | - | 0.26 | - | 0.59 | - |
| Schueler, 2001 mean | - | 0.30 | - | - | - |
| US EPA, 1983 median | - | 0.38 | 0.20 | - | - |
| Whalen and Cullum, 1988 | - | 0.62 | 0.29 | - | 0.42 |

The concentration of total phosphorus in urban stormwater is quite high, averaging about 0.3 mg/l in most studies. To put this in perspective, this figure is three times greater than the in-stream concentration recommended by US EPA to prevent nuisance plant growth in streams (0.1 mg/l), and roughly six times the recommended concentration for urban lakes (USGS, 1999). Roadway runoff tends to have the highest total phosphorus concentrations of all urban land area (Table 2).

Creativity and resourcefulness are needed to develop good estimates of phosphorus loads from secondary sources.

Urban streams in the west and southwest also exhibit higher average total phosphorus concentrations, which reflects the influence of wastewater return flows that often dominate the baseflow of streams in these regions. The phosphorus concentration in stormwater runoff also tends to be higher in arid and semi-arid regions compared to other regions of the country (Table 2). This phenomenon is caused by longer periods between rainfall events, which lets phosphorus accumulate on impervious surfaces prior to washoff (Caraco, 2000).

Recent research has focused on isolating the phosphorus concentrations from urban source areas such as parking lots, rooftops, driveways, and lawns. Bannerman *et al*. (1992), Steuer *et al.* (1997), and Waschbusch *et al*. (2000) have all conducted source area monitoring studies; some of their results are presented in Table 3. This research has helped to define phosphorus "hotspots" in the urban landscape that may be of particular interest to the lake manager. For example, lawn runoff consistently has the highest phosphorus concentrations of any urban source area, giving lake managers justification for seeking to minimize total lawn area in a watershed or reduce phosphorus fertilization on lawns. The source area monitoring also pinpoints street runoff as a significant source of phosphorus (Waschbusch *et. al* (2000) note that leaves are the source of more than half of the total phosphorus found in street runoff. In addition, they discovered that phosphorus concentrations in street runoff were positively correlated with the percentage of tree canopy over the street. This suggests that street sweeping, storm drain inlet cleanouts, and improved leaf collection may be useful in some lake watersheds.

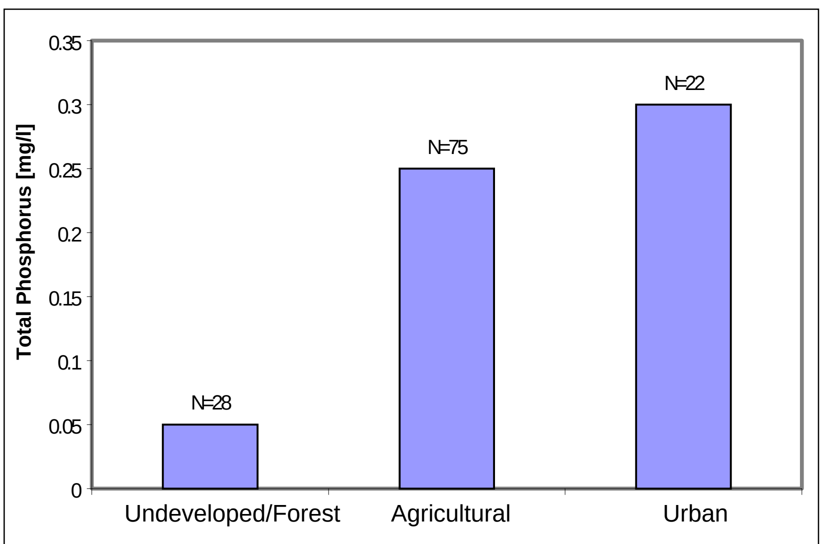



**Figure 2. Median In-Stream Total Phosphorus Concentration by Dominant Land Use (USGS, 1999)**

The average annual phosphorus load from primary land uses can be quickly calculated using the Simple Method (Schueler, 1987) or some other comparable loading model (see US EPA, 1999, for a comparative review of nutrient loading models). Average annual phosphorus loads are presented for four rainfall regimes and 11 urban land use categories over a wide range of impervious cover in Table 4. For the purpose of the Simple Method, a uniform total phosphorus EMC of 0.3 mg/l was applied for all rainfall categories, except for the 20-inch annual rainfall category (i.e., arid and semi-arid climates), where an EMC of 0.78 mg/l was used (Table 2). For lake managers who require a higher level of detail, separate Simple Method calculations can be made for each urban source area by applying the stormwater EMC data presented in either Table 2 or 3.

### Estimating Secondary Phosphorus Sources in Urban Watersheds

Creativity and resourcefulness are needed to develop good estimates of phosphorus loads associated with secondary sources. In general, secondary phosphorus loads can be calculated as a product of flow and concentration; however, unconventional units of measurement are required to estimate flows from many secondary sources, such as miles of sewer, number of septic systems, or number of building permits. Furthermore, because secondary source flows are often scattered across the watershed and episodic in nature, calculating load estimates using local data will greatly improve their accuracy. Secondary source concentrations are much easier to estimate, since they are often associated with wastewater streams, which have been extensively characterized in the literature (Caraco, 2001). Table 5 provides a summary of methods that can be used to estimate secondary source total phosphorus loadings for an urban lake.

Lake managers should be particularly alert to any direct wastewater treatment plant discharges in the lake watershed, as the phosphorus discharged from this source can comprise a significant portion of lake phosphorus loading. Depending on the level of sewage treatment provided (e.g., tertiary versus secondary), the phosphorus effluent concentrations from sewage treatment plants can range from 0.5 to 5 mg/l. Currently, only an estimated 7% of all municipal sewage treatment plants provide tertiary treatment, which suggests that improved sewage treatment may be an effective option to reduce phosphorus loads in lakes where sewage treatment plant effluent comprises a substantial portion of the total phosphorus budget (Litke, 1999).

| Table 3. Total Phosphorus Geometric Mean Concentrations Associated with Urban Source Areas (mg/l) | | | |
|---|---|---|---|
| **Source Area** | **Bannerman *et al.*, 1992** | **Steuer *et al.*, 1997** | **Waschbusch *et al.*, 2000** |
| Commercial Parking Lot | 0.19 | 0.20 | 0.10 |
| High Traffic Street | 0.47 | 0.31 | 0.18 |
| Medium Traffic Street | 1.07 | 0.23 | 0.22 |
| Low Traffic Street | 1.31 | 0.14 | 0.40 |
| Commercial Rooftop | 0.20 | 0.09 | 0.13 |
| Residential Rooftop | 0.15 | 0.06 | 0.07 |
| Residential Driveways | 1.16 | 0.35 | - |
| Residential Lawns | 2.67 | 2.33 | 0.79 |

**Estimating Internal Phosphorus Sources to Urban Lakes**

While external phosphorus sources are critical, lake managers should not ignore internal sources when constructing their phosphorus budgets. Key internal phosphorus sources include sediment release, waterfowl droppings, atmospheric deposition, and boat sewage.

The sediments of many urban lakes can become a source of phosphorus, particularly when the bottom of the lake becomes anoxic. The phosphorus released back into the lake under these conditions can become a major and even dominant component of a lake's phosphorus budget, particularly for shallow urban lakes. US EPA (1988) contains a thorough discussion on how to predict and manage internal phosphorus loads.

Releases from the sediments to the water column are a function of several physical, chemical, and biological reactions. Under aerobic conditions, the exchange is almost exclusively from the water column to the sediments; however, under low or zero oxygen conditions, the exchange is reversed, largely due to the redox conditions (Wetzel, 1975). The net result is a significant release of sediment phosphorus to the water column. For example, Nürnberg (1984) reported average sediment phosphorus release rates under anoxic conditions of 0.14 lbs/ac/day for a population of 20 eutrophic lakes. For a lake that is anoxic for a period of between one to two months per year, this might translate to an annual loading of four to eight lbs/ac/yr. Methods to reduce the internal sediment phosphorus release include dredging of bottom sediments, aeration of the hypolimnion, or alum injection (see Davenport, this issue, for a review).

| Table 4. Total Phosphorus Unit Area Loads Associated with Different Urban Zoning Categories and Annual Rainfall Ranges | | | | | |
|---|---|---|---|---|---|
| **Zoning Category** | **% Impervious[1]** | **lbs/ac/yr** | | | |
| | | **20[2] inches** | **30 inches** | **40 inches** | **50 inches** |
| Open Urban Land | 8.6% | 0.41 | 0.23 | 0.31 | 0.39 |
| 2 Acre Lot Residential | 10.6% | 0.46 | 0.27 | 0.36 | 0.45 |
| 1 Acre Lot Residential | 14.3% | 0.57 | 0.33 | 0.44 | 0.55 |
| 1/2 Acre Lot Residential | 21.2% | 0.77 | 0.44 | 0.59 | 0.74 |
| 1/4 Acre Lot Residential | 27.8% | 0.96 | 0.55 | 0.74 | 0.92 |
| 1/8 Acre Lot Residential | 32.6% | 1.09 | 0.63 | 0.84 | 1.05 |
| Townhome Residential | 40.9% | 1.33 | 0.77 | 1.03 | 1.28 |
| Multifamily Residential | 44.4% | 1.43 | 0.83 | 1.10 | 1.38 |
| Institutional | 34.4% | 1.15 | 0.66 | 0.88 | 1.10 |
| Light Industrial | 53.4% | 1.69 | 0.98 | 1.30 | 1.63 |
| Commercial | 72.2% | 2.23 | 1.29 | 1.72 | 2.14 |

*Notes:*
1 *Data from Cappiella and Brown, (2001), this issue*
2 *Total phosphorus concentration of 0.78 mg/l assumed for 20 of annual runoff; all other rainfall categories assumed total phosphorus concentration of 0.3 mg/l*

As many urban lakes have high resident populations of geese, ducks, and other birds, waterfowl droppings can become another significant internal phosphorus source. For example, Scherer *et al.* (1995) reported that bird droppings constituted between 25% and 34% of the total phosphorus budget of an urban lake in Seattle, WA. Another study on a suburban Boston lake by Moore *et al.* (1998) estimated that during drought years, phosphorus loads from geese droppings were up to seven times greater than all other external phosphorus loads combined. Controlling phosphorus loads from waterfowl is challenging, since they generally don't want to leave favorable habitat conditions. Several innovative approaches to discourage waterfowl have been devised, including the use of border collies or motion-sensing sprinkler units to harass waterfowl, planting dense vegetation or low-lying fence around the shoreline to screen access to open water, and using noisemakers to discourage birds.

Waterfowl droppings can become another significant internal phosphorus source.

Direct atmospheric deposition of phosphorus on the surface of a lake is usually only a minor component of the phosphorus budget for an urban lake. Exceptions include lakes that have small drainage area to surface area ratios (less than five). The concentration of phosphorus in rainfall generally ranges from 0.03 mg/l in rural areas to 0.5 mg/l in arid metropolitan areas (Litke, 1999). The annual phosphorus loading from direct atmospheric deposition to lakes has been estimated to range from 0.4 to 0.5 lbs/lake acre/yr (Table 1).

**Deriving a Current and Future Phosphorus Budget**

Given good data on land use and wastewater streams, it is relatively easy to compute a phosphorus budget for a lake that will be applicable both now and in the future. The budget allows a lake manager to determine the

**Table 5. Methods to Estimate Secondary Source Total Phosphorus Loadings (Caraco, 2001)**

| Secondary Source Area | Preferred Unit | Suggested Method for Defining Flow | Suggested Concentration |
|---|---|---|---|
| **Failing Septic Systems** | Population | Multiply daily water use times unsewered population draining to failing septic systems. | 1 mg/l |
| **Sanitary Sewer Overflows** | Miles of Sewer | Assume 140 overflows/1,000 miles of pipe (AMSA, 1994). Volume based on best local estimate per overflow. | 10 mg/l |
| **Combined Sewer Overflows** | CSO-Shed Characteristics | Complete a simple hydrologic and rainfall analysis of combined sewershed to determine CSO volume. | 2 mg/l |
| **Household Illicit Connections** | Population | Site-specific info on number and size of illicit connections is preferable. As a default, assume that a fraction of individuals have illicit connections to the sewer system. | 10 mg/l |
| **Business Illicit Connections** | Number of Businesses | Assume that a fraction of businesses have illicit connections, and that some fraction of these are wash water, while others are complete connections. | 10 mg/l |
| **Hobby Farms/Livestock** | Animal Density | Calculate based on the TP loading rates for various animals. | |
| **Wastewater Discharges** | Average daily flow (MGD) | NPDES Discharge Monitoring Report | 0.5 to 5 mg/l depending on treatment level |

sensitivity of the lake to watershed development, and is essential for targeting the phosphorus sources that are the best candidates for watershed treatment. A common convention used is to characterize annual loads in terms of areal loading to the lake, or pounds per unit surface area of lake per year (see Box 1).

While lake managers have an interest in the current phosphorus budget, they are often more concerned about how it will change in response to future watershed development. Computing a future phosphorus budget is a relatively straightforward process if the change in impervious cover can be forecast reliably. To forecast future imperviousness, the lake manager typically chooses a time horizon of 15 to 25 years, and analyzes future zoning, master plans, and growth trends to determine how many non-urban land uses will be converted into urban ones. Zielinski (2001) provides practical guidance on how to calculate these changes in terms of impervious cover.

Once the changes in watershed land use are calculated, it is a simple matter to recompute primary loadings for the future phosphorus budget. It is also likely that several secondary loading sources may need to be recomputed as well, since the added population growth in the watershed will normally generate greater wastewater flows of one kind or another.

**Phosphorus Budgets: Implications for the Watershed Manager**

The phosphorus source data presented in this article have several important implications for lake managers as they develop phosphorus budgets and lake management plans. First, lake managers should recognize that increased watershed development will normally increase areal phosphorus loads to a lake, with the possible exception of the conversion of row crop agriculture to low density residential development.

Phosphorus export steadily increases as impervious cover increases in the lake watershed. However, the precise amount of watershed development that causes eutrophication problems is unique to each individual lake. With a little effort, it is possible to calculate a specific impervious cover limit for a lake, given its internal geometry, watershed characteristics, current in-lake phosphorus concentrations, and degree of watershed treatment.

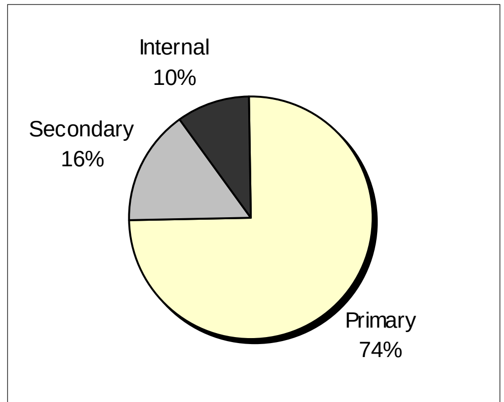
In general, a wide range of phosphorus sources needs to be considered when preparing a phosphorus budget for any urban lake. Lawns and streets appear to be the two areas of the urban landscape that generate the highest phosphorus concentrations and merit special attention by lake managers. Managers should not only calculate phosphorus loads from primary sources, but also investigate secondary and internal sources. If wastewater discharges exist in the watershed, they may still be a significant and controllable element of a lake phosphorus budget.

Clearly, given a basic Geographic Information System (GIS) and some sleuthing, it is possible to develop a rapid phosphorus budget for an urban lake that will be applicable both now and in the future. These budgets allow lake managers to determine the sensitivity of their lake to watershed development, and are essential for targeting which phosphorus sources are the best candidates for watershed treatment.

Lake managers should recognize that increased watershed development will normally increase areal phosphorus loads to a lake.

**Box 1. Example Scenario: Phosphorus Sources and External Phosphorus Budget**

Green Lake is a 10 square mile lake with an average depth of 20 feet located in the Mid-Atlantic region (i.e., average annual rainfall of approximately 40 inches). Over the past 40 years, the 250 square mile watershed has been developed with a mix of residential and commercial uses. Current watershed impervious cover is 16%, and no stormwater treatment practices have been used in the watershed. While about 25% of the residential development is served by septic systems, the remainder is served by a treatment plant which discharges to a location downstream of the lake. Algal blooms occur frequently, and the historically robust fishery in the lake has steadily declined. Lake secchi depths are less than six feet. The community has become concerned about eutrophication, and has decided to construct a phosphorus budget for the lake. The table below summarizes how the phosphorus budget was derived for the lake. The total phosphorus load is approximately 130,000 lbs/year, which translates into an areal loading rate of 20 lbs/acre/year for the lake. In a later phase, the community plans to evaluate possible control measures (see Article III).




**Distribution of Phosphorus Sources**

| **Primary Sources** | | | | **Secondary Sources** | | |
|---|---|---|---|---|---|---|
| **Land Use** | **Area (mi$^2$)** | **TP Loading Rate (lbs/acre)** | **TP Load (lbs/year)** | **Source** | **Description** | **TP Load (lbs/year)** |
| Residential (0.5 du/acre) | 50.0 | 0.36 | 11,600 | Septic Systems | Assumes 25% of homes on septic, 20% failure rate. | 5,100 |
| Residential (1 du/acre) | 62.5 | 0.43 | 17,200 | SSOs | Assumes 100 miles of sanitary sewer, with 140 overflows/1000 miles | 100 |
| Residential (2 du/acre) | 31.3 | 0.58 | 11,700 | Illicit Connect-ions | Assumes complete connections in 1 in 1000 residences. Assumes connections in 10% of businesses, with 90% only washwater, and 10% complete connections. | 11,200 |
| Commercial | 25.0 | 1.70 | 27,300 | Lawns | Subsurface flow from lawns, assuming 0.03 mg/L. | 4,100 |
| Roadway | 5.0 | 1.88 | 6,000 | **Total** | | **20,500** |
| Forest | 25.0 | 0.20 | 3,200 | | | |
| Rural | 51.3 | 0.50 | 16,400 | | | |
| Lake Surface | 10 | 0.50 | 3,200 | | | |
| **Total** | **260** | **--** | **96,600** | | | |
| **Internal Sources** | | | | | | |
| Atmospheric | 10 | 0.5 | 3,200 | | | |
| Sediment | 10 | 0.15 | 960 | | | |
| Waterfowl | 10 | 1.37* | 8,800 | | | |
| **Total** | **--** | **--** | **12,960** | | | |

**Primary = 96,600**
**+ Secondary = 20,500**
**+ Internal = 12,960**

**Total Current P Load = 130,060 lbs/year**

** Waterfowl loading rate is dependent upon resident bird population. For this example, 0.5 million bird-days/year was assumed.*

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# Managing Phosphorus Inputs Into Lakes
# III. Evaluating the Impact of Watershed Treatment

*by Deb Caraco*


**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.

If STPs and BSD are effectively applied across the watershed, impervious cover thresholds can be roughly doubled.

**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 |

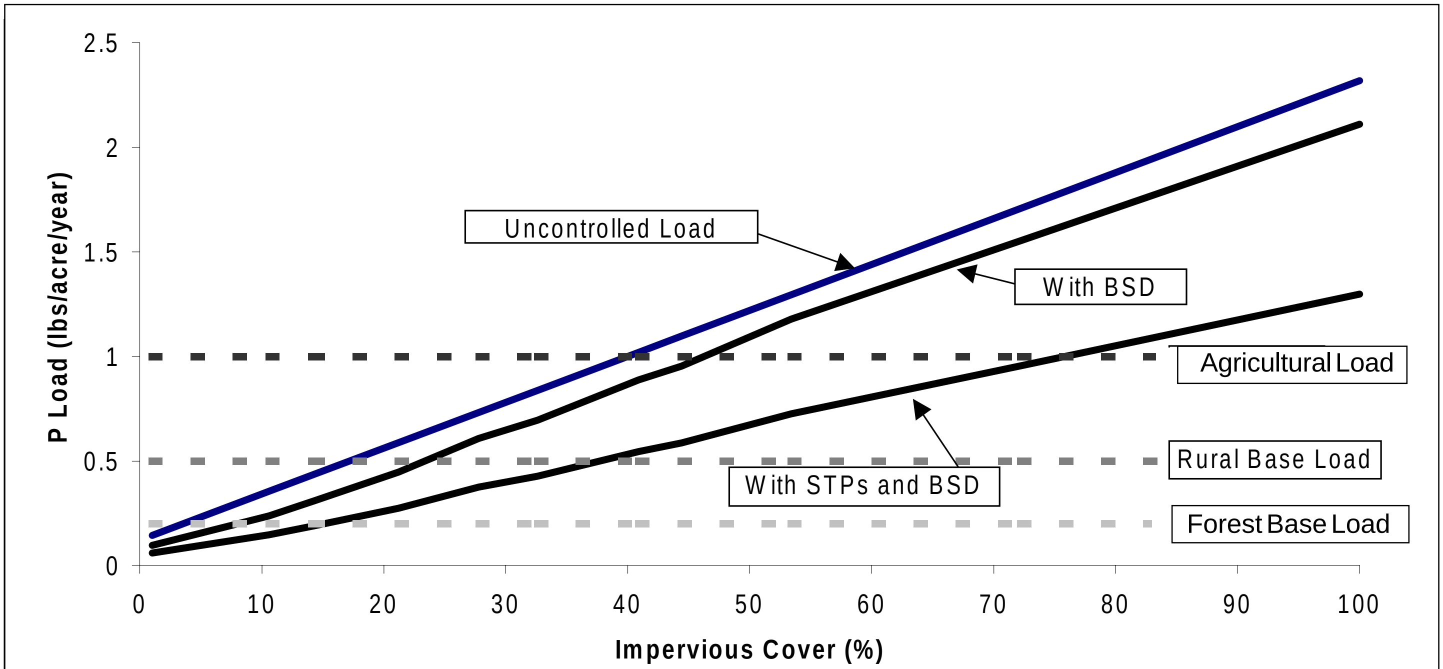


**Figure 1. Phosphorus Export for Various Levels of Development and Stormwater Control**

**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.

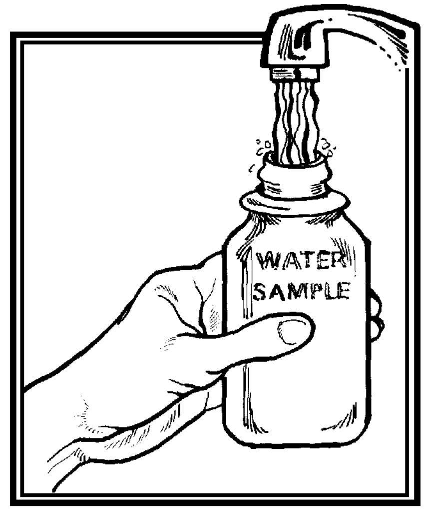
The lake management plan focuses on four programs designed to reduce existing phosphorus loads, including lawn care education, stormwater retrofits, illicit connection removal, and septic system repair. The benefits of each of these practices are summarized below. With the new net load of 90,800 lbs/year (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** |

# Managing Lakes for Pure Drinking Water

*by Anne Kitchell*




*"Lakes are the reservoirs into which rivers and other streams empty, and their waters are not widely different from their sources of water supply. They are the receptacles of all the waste products of the inhabitants of the district; they receive the contents of sewers, cess pools, and privies; the offal of the distilleries, slaughter-houses and tanneries, and the refuse of factories."*

Willis Tucker, 1885a

"*In the United States, 30,000 people die annually from typhoid fever. The mortality from typhoid fever in many of the eastern cities is proportional to the quantity of sewage which enters the water supplies*."

Floyd Davis, 1889

"*In the absence of positive knowledge, we had best err, if err we must, on the safe side, and avoid the use of polluted waters*."

Willis Tucker, 1885b

As these historical quotes remind us, public health authorities have always had an acute interest in the purity of their drinking water, an intuitive understanding of the watershed concept, and an aggressive pursuit of ever-cleaner source waters. Over the past hundred years, these trends have continued. If any threat to source waters can be established, even imperfectly, and a reasonable remedy to treat or eliminate the threat found, it will usually be undertaken. Witness the progressive engineering "firsts" that have occurred in water supply watersheds: storage reservoirs, filtration, disinfection, wastewater treatment, watershed planning, land regulation, spill contingency plans, stormwater treatment practices and buffers, to name but a few. Indeed, arguably the earliest known watershed ordinance was enacted in Chicago in 1833, when authorities declared it to be unlawful to throw or put into the Chicago River... "any carcass of any dead animal or animals, under a penalty of three dollars per offense" (CBH, 1871).

The progressive adoption of these sanitary engineering strategies certainly ranks among the greatest public health achievements of our era; outbreaks of waterborne infectious diseases such as typhoid fever, cholera, shigellosis and salmonellosis have virtually been eliminated as a result. Still, the quest to provide a pure supply of drinking water never ceases, as science continuously reveals new risks to public health, such as *giardia*, *cryptosporidium*, disinfection by-products, and a wide spectrum of pollutants and potential carcinogens.

In recent years, water supplies have gradually recognized that improved water treatment, while necessary, is not sufficient by itself to protect public water supplies. Watershed management is also needed to protect source waters, particularly so for communities growing outward into previously undeveloped water supply watersheds.

> Improved water treatment, while necessary, is not sufficient by itself to protect public water supplies.

This article reviews the current state of watershed practice in reservoirs used for water supply. It begins by reviewing some of the unique concerns facing reservoir managers in these watersheds, and then reports on a detailed survey of trends in watershed treatment practices used to protect more than 20 large water supply reservoirs in the U.S. Finally, the article recommends ways in which watershed practices could be improved to meet ever-tighter drinking water standards, and how recently required source water assessment plans could be better integrated into local watershed planning.

**Impact of Watershed Development on Surface Water Supplies**

For much of this century, water supply reservoirs were intentionally located in areas of little or no watershed development. In the last three decades, however, many communities have begun experiencing considerable growth pressures within the watersheds of their water supply reservoirs. Managers are quickly realizing that they must clearly understand the impact land development can have on the quality of their source waters. This realization has been prompted by increasingly tight drinking water standards under the Safe Drinking Water Act (see Table 1 for a summary of these new requirements), as well as by new research on the impact of stormwater runoff on reservoir water quality. The following section reviews recent research on key contaminants in reservoir watersheds.

***Disinfection By-Products***

Nearly all water supplies inject chlorine or bromine to treated waters as an effective last line of defense against pathogens. However, if the source water has high concentrations of organic matter, the disinfection process can create a series of disinfection by-products (or DBPs) under the right conditions. These DBPs include up to 30 different compounds such as trihalomethanes (THMs), haloacetic acids (HAAs) and chloroform, many of which are suspected to adversely affect human health.

DBPs present a severe challenge for reservoir managers, since they are formed at the end of the treatment process.

Recent research has shown a strong association between the consumption of treated water containing DBPs and the occurrence of bladder cancer, and possibly rectal cancer. By some estimates, as many as two to 17% of bladder cancer cases in the U.S. and up to 14 to 16% of bladder cancer cases in Canada could be attributed to the presence of DBPs in drinking water (King and Marret, 1996 and Wigle, 1998). While epidemiologists caution that the research does not prove a causal relationship, the strength of the relationship has prompted the EPA to issue tougher rules on DBPs (US EPA, 1998).

DBPs present a severe challenge for reservoir managers, since they are formed at the end of the treatment process, and few practical alternatives to disinfection currently exist. The primary strategy for reducing DBPs is precursor control, which in simple terms seeks to reduce the amount of organic carbon in source waters prior to treatment (particularly humic and fulvic acids, NRC, 2000). In a practical sense, precursor control is simply another name for watershed treatment to reduce organic carbon and phosphorus loads to a reservoir.

Watershed development makes precursor control very difficult for two reasons. First, stormwater runoff from urban areas often dramatically increase phosphorus loads delivered to a lake, and in turn, increase algal levels (see Caraco and Brown, this issue). Decomposition of algae in the reservoir can help drive up organic carbon concentrations. Thus, the increased eutrophication that often occurs in urban lakes creates an internal source of organic carbon that make it difficult to control DBP levels at the treatment plant. As a consequence, many regulators are setting more stringent limits on the maximum amount of in-lake phosphorus or chlorophyll *a* concentrations allowed with a water supply reservoir, which often translates into limits on watershed phosphorus loadings. For example, some communities have established in-lake chlorophyll limits ranging from five to 15 ug/l and in-lake phosphorus concentrations ranging from 0.01 to 0.05 mg/l. As Caraco (this issue) observes, few urbanizing watersheds can meet such limits given current watershed treatment technology.

The second reason why precursor control is difficult in urban watersheds is that stormwater runoff can deliver significantly higher loads of both total and soluble organic carbon, in comparison to other watershed land uses. Although not much data has been historically collected on total organic carbon (TOC) concentrations in urban stormwater runoff, the Center recently derived a mean TOC concentration of 17 mg/l (median 15.2, range: 5.3 to 41.3 mg/l) based on 19 urban catchments contained in a national STP monitoring database (Winer, 2000).

The primary source of TOC appears to be the decomposition of leaf and other organic matter in curbs, storm drains and streets, along with some combustion by products. Data on dissolved organic carbon (DOC), which is thought to be the main precursor for DBPs, are even more sparse in the stormwater literature. A handful of studies suggest that DOC concentrations in the three to 7 mg/l range for untreated stormwater runoff. Only three studies have monitored DOC removal in stormwater ponds or wetlands, and these suggest that they have little or no DOC removal capability, and may actually increase DOC levels (SWAMP, 2000). Meyer and Couch (2000) report that annual DOC loads were higher in urban streams than in forested or agricultural streams in the southeastern Piedmont.

**Turbidity**

> *"It is believed that an excessive turbidity, caused by sand or clay, is productive of intestinal difficulties, indigestion, dyspepsia and diarrhea."*
>
> Davis, 1889

Turbidity has been used for more than a century as a measure of water clarity and a standard for both the purity of drinking water and the efficient operation of filtration systems in drinking water treatment plants. In addition, turbidity is also used as a surrogate measure to predict pathogen removal. The EPA has recently issued tighter standards on the permissible amount of turbidity in drinking water, shifting from 1.0 to 0.3 NTUs (nephelometric turbidity units, see Table 1).

Watershed development greatly increases the turbidity to reservoirs in three distinct ways. First, turbidity increases as fine particles are washed off impervious surfaces during storm events. The average turbidity of

| Table 1. Condensed Summary of Recent Federal Drinking Water Regulations (NRC, 2000; US EPA, 2001a) | | |
|---|---|---|
| **Year** | **Regulations** | **Key Components** |
| **1974** | Safe Drinking Water Act (SDWA) | • Contains provisions for assessing and preventing biological and chemical contamination of drinking water supplies<br>• Targets specific contaminants in water supplies |
| **1986** | SDWA Amendments | • Regulates 83 specified contaminants<br>• Sets goal of adding 25 new contaminants every three years |
| **1989** | Surface Water Treatment Rule (SWTR) | • Requires filtration for all surface water systems unless it can be proven unnecessary<br>• Outlines conditions for filtration avoidance based on source water quality, disinfection criteria and site-specific criteria<br>• Improved treatment criteria for *Giardia* and viruses<br>• Introduces metrics of log removal of microbes and CT (product of disinfectant concentration and contact time) as control parameter for disinfection |
| | Total Coliform Rule (TCR) | • Criteria to prevent waterborne microbial diseases<br>• Requires suppliers to test drinking water for harmful microorganisms<br>• Set stringent limits on total coliform |
| **1991** | Lead and Copper Rule (LCR) | Requires increased evaluation of treatment processes used to control corrosion |
| **1996** | Information Collection Rule (ICR) | Mandates that suppliers collect water quality data to form a national database, particularly pathogens and DBPs |
| | SDWA Amendments | Establishes Source Water Assessment Program (SWAP) to develop and implement a watershed approach to source water improvement/protection by delineating watersheds that supply drinking water and assessing their susceptibility to known contaminants |
| **1998** | Drinking Water Contaminant Candidate List (CCL) | • List of 50 chemical and 10 microbiological (non-regulated) contaminants known/or anticipated to occur in drinking water<br>• Prioritizes contaminants for future research, additional data needs, and as regulatory candidates |
| | Stage 1 Disinfectants/Disinfectants By-Products Rule (D/DBP) | • Updates MCLs for Total THMs; new MCLs for 5 HAAs, chlorite, and bromate and sets residual levels for chlorine compounds<br>• Sets levels for TOC as DBP precursor |
| | Interim Enhanced Surface Water Treatment Rule (IESWTR) | • Requires tightening of turbidity requirements for filtered systems from 0.5 NTU to 0.3 NTU<br>• Final rule incorporates microbial benchmarking ; require systems to show that filtration and disinfection are reducing *Cryptosporidium*; requires unfiltered suppliers to amend watershed control programs to control for *Cryptosporidium* |
| **2000** | Public Notification Rule | Sets requirements for how and when public notification required; Notification required when water utility fails to meet drinking water standards, or is facing a public risk situation |
| | Radionucleotides Final Rule | • Sets MCL for uranium at 30ug/l<br>• MGCL of 0 for all radionucleotides |
| **2001** | Filter Backwash and Recycling Rule (FBRR) | • Requires recycled filter backwash, sludge thickener supernatant, and liquids from dewatering process to be returned to $1^{st}$ stage of direct filtration/treatment process<br>• First attempt to govern backwash situation that may compromise microbial control |

urban stormwater runoff typically ranges about 100 to 200 NTUs, according to the NURP study. The second source of turbidity in urban watersheds comes from sediments eroded from active construction sites. The median turbidity in construction site runoff in Maryland was reported to be about 450 NTUs (range: four to 8,200 NTUs). Even after effective erosion and sediment control practices were applied to construction sites, median turbidity still exceeded 200 NTUs (Schueler and Lugbill, 1990). The third source of turbidity in urban watersheds is caused by stream channel erosion during large storm events, with concentrations frequently ranging from 200 to 1,000 NTUs, depending on the intensity of the storm event. While turbidity levels in reservoirs often decline due to dilution and settling, they still represent a chronic problem for drinking water treatment plant operators.

Several recent studies have detected high levels of both *cryptosporidium* or *giardia* in stormwater runoff.

Drinking water treatment plants can usually meet the new turbidity standard even when their source waters become highly turbid using a combination of coagulation, flocculation and filtration, but it is neither easy nor inexpensive to do so. Plant operators must carefully monitor the spikes or plumes of turbidity in the reservoir after storms, and then administer the precise dose of chemicals and filter run times to reduce them. As a result, the cost of drinking water treatment increases, and the reliability of treatment can decline within urban watersheds.

**Loss of Reservoir Capacity**

A more long term concern of watershed managers is the gradual loss of reservoir capacity due to sedimentation. Urban land uses often produce higher sediment loadings than other land uses, with the possible exception of agricultural row crops. How much reservoir capacity will be lost over time is usually a function of a reservoir's depth, and its drainage area to surface area ratio (DA/SA). When a reservoir is relatively shallow, has a DA/SA ratio of 50 or more and is highly urban, it is likely that sedimentation could result in a significant loss of capacity within a matter of several decades.

**Pathogens**

A pathogen is a microbe that is actually known to cause disease under the right conditions. Examples of bacterial pathogens frequently found in stormwater runoff include *Shigella spp*. (dysentery), *Salmonella spp*. (gastrointestinal illness), and *Pseudonomas auerognosa* (swimmer's itch). Other species can cause cholera, typhoid fever and staph infections. The actual risk of contracting a disease from a pathogen depends on a host of factors such as the method of exposure or transmission, pathogen concentration, incubation period and the age and health status of the infected party.

***Cryptosporidium* and *Giardia***

In the last several decades, the two most common waterborne diseases in the U.S. have been *cryptosporidium* and *giardia* (NRC, 2000). *Cryptosporidium* was the protozoan responsible for the largest waterborne disease outbreak in the U.S. (Fox and Lytle, 1996). To infect new hosts, these protozoans create hard casings known as cysts (*giardia*) or oocysts (*cryptosporidium*) that are shed in feces, and travel through surface waters in search of a new host. The cysts or oocysts are very durable, and can remain viable for many months.

Sand filtration at drinking water plants has not been found to be fully effective in removing all cysts and oocysts (LeChevallier *et al.*, 1991, 1995), although it is not clear whether the cysts that pass through sand filters remain viable. A series of studies have found that back flushing of sand filters at drinking water treatment plants resuspend protozoa, and can become a significant source of cysts/oocysts (LeChevallier *et al.*, 1995). Chemical disinfection can inactivate cysts and oocysts, but typically requires chemical pretreatment, higher doses, and longer contact times than when used to inactivate fecal coliforms.

Until recently, the major sources of protozoa in surface waters were generally thought to be human sewage, dairy runoff and wildlife. However, several recent studies have detected high levels of both *cryptosporidium* or *giardia* in stormwater runoff (Stern, 1996; Xiao *et al*., 2000, 2001). David Stern (1996) monitored a series of agricultural and urban watersheds within the New York City water supply reservoir system, and found urban subwatersheds had slightly higher rates of *giardia* and *cryptosporidium* detection than agricultural subwatersheds, and a higher rate of confirmed viability. Graczyk and his colleagues (1998) recently discovered that migratory Canadia geese were a vector for both *giardia* and *cryptosporidium* in the Mid-Atlantic region. It is intriguing to speculate whether the large populations of resident geese found in many urban ponds might be a source of *cryptosporidium* transmission, and more research is warranted.

***Total and Fecal Coliforms***

Public health authorities have traditionally used total coliforms or fecal coliform bacteria as an indicator of potential microbial risk, and have set stringent standards for both drinking water supplies and finished water (see Table 1). Watershed development tends to greatly increase coliform levels in source

| Table 2. National Event Mean and Median Concentrations for Chemical Constituents of Stormwater and Maximum Contaminant Goals and Levels | | | | | |
|---|---|---|---|---|---|
| Constituent | Units | Source of Data | EMCs | | MCL[1] |
| | | | Mean | Median | |
| **Copper** | mg/l | (1) | 0.0133 | 0.0111 | 1.3 (a) |
| **Lead** | mg/l | (1) | 0.0675 | 0.0507 | 0.015 (b) |
| **Cadmium** | mg/l | (2) | 0.0007 | | 0.005 |
| **Chromium** | mg/l | (3) | 0.004 | | 0.1 |
| **Nitrate** | mg/l | (1) | 0.658 | 0.533 | 10 |
| **Turbidity** | ntu | (2) | 50 | | 1.0 |
| **Fecal Coliform** | col/100 ml | (5) | 15,038 | | 5% |
| **Atrazine** | mg/l | (6) | | 0.000023 | 0.003 |
| **Simazine** | mg/l | (6) | | 0.000039 | 0.004 |
| **Cryptosporidium** | cysts | (7) | 37.2 | 3.9 | (c) |
| **Giardia** | cysts | (7) | 41.0 | 6.4 | (c) |

(1) Smullen and Cave, 1998; (2) EPA, 1983; (3) Brush *et al.,* 1995; (4) Barrett and Malina, 1998; (5) Schueler,1999; (6) USGS, 1998 (baseflow); (7) Stern, 1996

Shaded rows indicate contaminants found in significant concentrations in urban stormwater, which could potentially threaten maintenance of water quality standards.

[1] Maximum Contaminant Level (MCL) The highest level of a contaminant allowed in drinking water. MCLs are enforceable and are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration.
(a) Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level (1.3 mg/l for copper, and for 0.015 mg/l for lead), water systems must take additional treatment steps.
EPA s surface water treatment rules require systems to meet the following criteria (as of January 1, 2002):
(b) Turbidity: may never exceed 1 NTU and must not exceed 0.3 NTU in 95% of the daily samples in any month.
*(c) Cryptosporidium*: 99% removal; *Giardia lambia*: 99.9% removal/inactivation

waters. For example, the mean concentration of fecal coliforms in urban stormwater runoff is nearly 15,000 counts per 100 ml (Schueler, 1999). The coliforms are generated from a diverse set of sources in an urbanizing watersheds, and may take many complex pathways to reach a reservoir. For a complete discussion of urban bacteria sources, the reader should consult Schueler (1999).

Once coliforms reach a reservoir, they are subject to die-off, and are further reduced by filtration and disinfection at the drinking water treatment plant. Nevertheless, the coliform loading in urban watersheds can make plant operations more expensive, and can exacerbate the DBP problem if greater levels of disinfection are needed to meet coliform standards.

**Organic and Inorganic Chemicals**

The U.S. EPA has established primary drinking water standards for 69 different organic and inorganic chemicals that are known or suspected to cause health problems (US EPA, 2001a). Each of these chemicals has a maximum contaminant level or MCL that must be achieved in the finished water, and water utilities must frequently monitor these levels.

Many of these organic and inorganic chemicals have been detected in urban stormwater runoff or baseflow, but in most cases, they are present in concentrations well below the MCL. Table 2 compares the median pollutant concentrations in urban stormwater runoff with the established MCL for finished drinking water. With the exceptions of lead, turbidity and coliforms, the median concentration of most pollutants found in urban stormwater are about an order of magnitude lower than the MCL. It is important to note that it is probable that the *maximum* reported concentrations could equal or exceed the MCL during some extreme runoff or snowmelt events.

The EPA has also identified several chemicals of critical concern for which it is considering developing MCLs as well. Several of these chemicals have been detected in urban stormwater or streamflow, most notably MBTE, diazinon, chloropyrifos and several other pesticides (Table 3). The USGS (1999) detected one or more pesticides in 99% of urban stream samples in a recent national water quality assessment. They found that insecticides and herbicides were detected more often and at higher concentrations in urban streams than any other watershed land use (including agriculture).

**Taste and Odor**

Various chemicals, organic carbon and algal growth present in source waters can influence the taste and odor of finished water, and consumers are often quick to notice and complain about them. For this reason, the EPA (2001b) has recently issued voluntary guidelines about the taste, odor and appearance of drinking water. Table 3 compares the typical concentrations for some of these pollutants found in urban stormwater runoff against these recommended limits. With the possible exception of chloride levels in snowmelt runoff, most urban pollutants remain below the established limits. It is important to note that the greater algal growth, turbidity, and organic carbon found in urban source waters can impart disagreeable tastes and odors to finished water, often as a result of the greater treatment required at the plant.

**Spills, Leaks and Accidents**

Urban development can increase the risk of spills, leaks and accidents in a reservoir watershed, whether it be a tanker accident discharging into a highway storm drain, the derailment of a train carrying hazardous wastes, a fire at an industrial site, a shutoff valve breaking on a pipeline or storage tank, a slowly leaking landfill, pesticides dumped in a storm drain or any number of other nightmare scenarios. In a larger urban watershed, it is usually not a matter of whether one of these scenarios will happen, but when, and how quickly the utility can react to it. It is for this reason that nearly every utility has developed contingency plans for spill response, and often seeks to restrict or exclude as many of these risks as possible within a watershed.

**Watershed Management for Water Supply Reservoirs**

Given the potential impact of watershed development on the quality of water supply reservoirs, it is not surprising that most communities have sought to strictly regulate how and where new development occurs in water supply watersheds. Under the Safe Drinking Water Act, communities must perform a Source Water Assessment for surface and subsurface water supplies to identify potential sources of contamination for water supplies. It is interesting to note that of the 33 sources of potential water contamination that the EPA has recommended for investigation as part of this assessment, 55% are directly or indirectly associated with urban development in a watershed (see Box 1). Clearly, communities will need to greatly improve the effectiveness of watershed practices in reservoir watersheds where growth and development are anticipated. The following section analyzes some of the key trends in managing reservoirs watersheds across the country.

**Survey of Watershed Practices in Water Supply Reservoirs**

The Center intensively surveyed 22 surface water supply reservoirs, out of a total of 900 surface water supplies of similar size in the country (van der Leeden *et al*., 1990). The purpose of the survey was to examine

**Table 3. Potential Pollutants of Concern Based on Concentration and Detection in Urban Stormwater**

| Constituent | Units | Source of Data | Median EMCs | Concentrations of Concern |
|---|---|---|---|---|
| **Total Dissolved Solids** | mg/l | various | 150 | 500 [a] |
| **Zinc** | mg/l | (1) | 0.129 | 5 [a] |
| **Chloride (snowmelt)** | mg/l | (2) | 116 | 250[a] |
| **Organic Carbon** | mg/l | (3) | 11.9 | 4 [b] |
| **MTBE** | ug/l | (4) | 1.6 | 20 to 40 [c] |
| **Diazinon** | mg/l | (5)<br>(6) | 0.00025<br>0.0055 | 0.0006 [c] |
| **Prometon** | mg/l | (5) | 0.00031 | 0.001 [c] |

(1) Smullen and Cave, 1998; (2) Oberts, 1994; (3) CWP Database, unpubl.; (4) Delzer, 1996; (5) USGS, 1998 (baseflow); (6) Brush *et al*., 1995

[a] Secondary Maximum Contaminant Level (SMCL) Aesthetic guidelines to assist public water systems in managing their drinking water.
[b] EPA Disinfection By-Products Rule -- <2mg/l TOC for treated water and <4mg/l in source water
[c] Contaminant Candidate List (CCL) EPA list of contaminants known or anticipated to occur in public water systems, and may require future regulations under the Safe Drinking Water Act

trends in watershed management for surface water supplies across the country, and to identify innovative practices to protect drinking water supplies from watershed development. While our survey sample encompassed less than 3% of surface water supplies of similar size nationally, it still represents the most widespread survey of watershed practices for surface water supplies since Robbins *et al.* (1991). We used the following criteria to select our sample of reservoir watersheds:

1. The reservoir must be used primarily as a source of drinking water
2. The reservoir must serve a population greater than 50,000
3. The contributing watershed must currently be experiencing land development
4. Respondents in the watershed must be willing to supply detailed information and review our case studies for accuracy

It should be noted that over 10,000 smaller surface water supplies exist in the U.S., and that these survey results may not be transferable to these smaller reservoirs. The basic profile of our reservoir sample is provided in Table 4, and its geographical representation is provided in Figure 1. More details on the survey results and individual case studies can be found in Table 5 and in Kitchell (2001).

**Box 1. Partial List of Potential Sources of Contamination Found in Wellhead Protection Areas and in Watersheds**

| Related to Watershed Development: | Not Development Related: |
|---|---|
| Atmospheric deposition | Agriculture |
| Collection system failure | Contaminated sediment |
| Combined sewer overflow | Debris and bottom deposits |
| Construction | Domestic water lagoon |
| Erosion from derelict land | Groundwater loadings |
| Habitat modification | Groundwater withdrawal |
| Highway maintenance and runoff | Internal nutrient cycling |
| Industrial point sources | Natural sources |
| Land disposal | Recreation and tourism activities (other than boating) |
| Leaking underground storage tanks | Resource extraction |
| Marinas and recreational boating | Sediment resuspension |
| Municipal point sources | Silviculture |
| Salt storage sites | Sources outside state Jurisdiction or borders |
| Sewer line (leaking) | Unknown source |
| Spills (accidental) | |
| Urban runoff/storm sewers | |
| Waste storage/storage tank leaks (above ground) | |

*Source: US EPA, 1998*

The service population of the reservoir watersheds ranged from 60,000 to seven million (median: 450,000). Most of the reservoir watersheds had experienced relatively modest development, with a mean of 8.5% impervious cover (range two to 21%). The actual amount of watershed development is probably somewhat higher, given that only half of the reservoirs surveyed had recent land cover data for their contributing watersheds, and very few explicitly tracked impervious cover over time as an index of watershed development.

Less than 20% of the reservoir watersheds were completely contained within a single local political jurisdiction; the mean number of local jurisdictions was 4.8. About a third of the reservoir watersheds had adopted some form of intergovernmental agreement or legislation that formally established how the local jurisdictions would cooperate together to protect the water supply. The majority of reservoirs utilized filtration, although three unfiltered water supplies were also analyzed.

## Watershed Planning and Management

Surprisingly, only 10% of the reservoir watersheds were covered by a comprehensive watershed management plan. Instead, most localities relied on a progressively stringent series of ordinances, regulations and zoning actions adopted over several decades. A major reason for the lack of comprehensive watershed planning was the need to coordinate among a large number of political jurisdictions and the traditional disconnect between the water utilities who are responsible for meeting drinking water standards and local government(s) who are responsible for regulating land use change in the watershed. On the positive side, water utilities exercised some form of local development review authority in about a third of the surveyed watersheds.

## Watershed Zoning

Zoning was the primary planning tool to protect the water supply, and this tool was utilized in more than 90% of the reservoir watersheds surveyed. Large lot residential zoning was the primary planning tool relied on to reduce the overall density in the watershed. For example, 68% of the reservoir watersheds restricted development to lots of one acre or more in size. In addition, 48% of reservoir watersheds directly or indirectly excluded commercial or industrial development through their current zoning. Even where these uses were allowed, they were a minor component of the watershed land use distribution.

Overlay districts were the preferred mechanism to guide and regulate land use in the reservoir watersheds (60%), whereas regular zoning was used in the remaining watersheds. Overall, nearly 40% of all reservoir watersheds had downzoned portions of the watershed to reduce the overall intensity of development. No reservoir watershed reported that they had established a watershed-wide impervious cover limit, although about 38% had imposed stringent impervious cover limits for individual lots.

In many cases, continued land acquisition was being used as a defensive strategy to counter rapid watershed development.

A unique element of water supply watersheds is that they often exclude or restrict certain land uses or activities that pose a potential water pollution risk or hazard. Eighty percent of surveyed watersheds excluded one or more land uses or activities, including the following:

*Frequently Excluded*

- New point source discharges
- Commercial or industrial land uses that generate, store or dispose of hazardous wastes
- Any commercial or industrial development
- Above or below ground petroleum storage tanks
- Land application of sewage sludge
- New landfills or solid waste disposal facilities
- Confined animal feeding operations

*Less Frequently Excluded*

- Gas stations, service stations, junkyards
- Dry-cleaning establishments
- Golf courses
- Use of reclaimed waters
- Cemeteries
- Asphalt and concrete plants
- Combined sewers
- Sewer extensions
- Septic systems
- Sale of detergents that contain phosphorus

About a third of the sampled watersheds emphasized stormwater runoff treatment over land use control as the major thrust of their watershed protection strategy. These communities tended to allow more development in the watershed in exchange for more stringent phosphorus limits for runoff from individual sites.

**Land Conservation**

Land conservation was a major watershed protection strategy for all of the reservoir watersheds. This is reflected by the fact that forest cover was the dominant watershed land use in nearly all of the reservoir watersheds (Mean 50%: range five to 95%). In general, a large fraction of forest or open space had been acquired over time by the water utility or municipality, although there was a great deal of variability in how much land was retained in public ownership, as shown here:

- 48% owned less than 10% of watershed land
- 19% owned from 10 to 25% of watershed land
- 33% owned more than 25% of watershed land

Shoreline buffers were the key priority for land acquisition in the reservoir watersheds, as 90% of the reservoir watersheds reported that they owned and managed extensive areas of shoreline buffer. These publicly owned buffers ranged in distance from 150 to 2000 feet from the reservoir shoreline.

It is also interesting to note that 72% of reservoir watersheds were still actively acquiring land or obtaining conservation easements. In many cases, the continued land acquisition was being used as a defensive strategy to counter rapid watershed development.

**Shoreline and Stream Buffers**

Every reservoir in the survey either owned the shoreline buffer or required extensive shoreline buffers for new development. In addition, 90% of the watersheds also required buffers on tributary streams to the reservoirs. The median width of shoreline buffer was 150 feet, but the range was very wide: from 25 to 2,000 feet. In general, the widest shoreline buffers were owned by a municipality or utility. The median buffer for tributary streams was 100 feet (range: 25 to 500 feet). The shoreline buffers often had specific vegetative targets (70%), and a wide range of prohibited or restricted uses within the shoreline buffer (80%). A list of the more common uses excluded from shoreline buffers includes the following:

- Impervious cover
- Septic tanks or drain fields
- Clear cutting
- Structures
- Commercial or industrial parking lots
- Grazing or livestock
- Land disturbance
- Pesticide application
- Generation, storage or disposal of hazardous materials

| Table 4: General Characteristics of Drinking Water Watersheds Surveyed | | | | |
|---|---|---|---|---|
| Reservoir Name | Watershed | | | Drainage/ Reservoir Surface Area Ratio |
| | Area ($mi^2$) | (%) Impervious | Political Entities | |
| **Unfiltered Supply** | | | | |
| Wachusett, MA | 111 | 1.6 [1] | 9 | 17.9 |
| Croton Reservoirs, NY | 374 | -- | 21 | 7.7 |
| Kensico, NY | 13.2 | 19 | 5 | 4.0 |
| **Filtered Supply** | | | | |
| Dog River, GA | 78 | 5.0 | 4 | 221.9 |
| Heads Creek, GA | 27 | 11 | 2 | 38.4 |
| University Lake, NC | 30 | 4.5 | 3 | 90.1 |
| Swift Creek (Lake Benson), NC | 66 | 9 | 5 | 93.9 |
| Lee Hall, VA | 14.2 | 6.5 | 2 | 18.4 |
| Occoquan, VA | 592 | 12.0[1] | 6 | 210.5 |
| South Fork Rivanna , VA | 258 | 5.7 [1] | 1 | 423.4 |
| Swift Creek, VA | 65 | 5-10 | 2 | 24.5 |
| Loch Raven, Pretty Boy, & Liberty, MD | 466 | -- | 6 | 42.6 |
| Patuxent Reservoirs, MD | 132 | 4 [1] | 4 | 52.8 |
| Hoopes, DE | 1.9 | 6.0 [1] | 1 | 6.4 |
| Hemlocks, Easton, &Trap Falls, CT | 91 | -- | 12 | -- |
| Lake Vadnais, MN | 23 | 17.0 | 8 | 9.1 |
| Lake Whatcom, WA | 57 | <5 | 2 | 7.3 |
| Nicasio, CA | 36 | < 5 | 1 | 26.5 |
| Sweetwater, CA | 184 | 21 | 1 | -- |
| Lake Dillon, CO | 329 | << 5 | 4 | 65.6 |
| Lake Austin,TX | 41 | 10 [1] | 4 | 16.4 |
| Town Lake, TX | 158 | 13 [1] | 5 | 224.2 |

***Notes:***
[1] *Actual impervious values; remaining values were estimated by survey respondent or the Center*

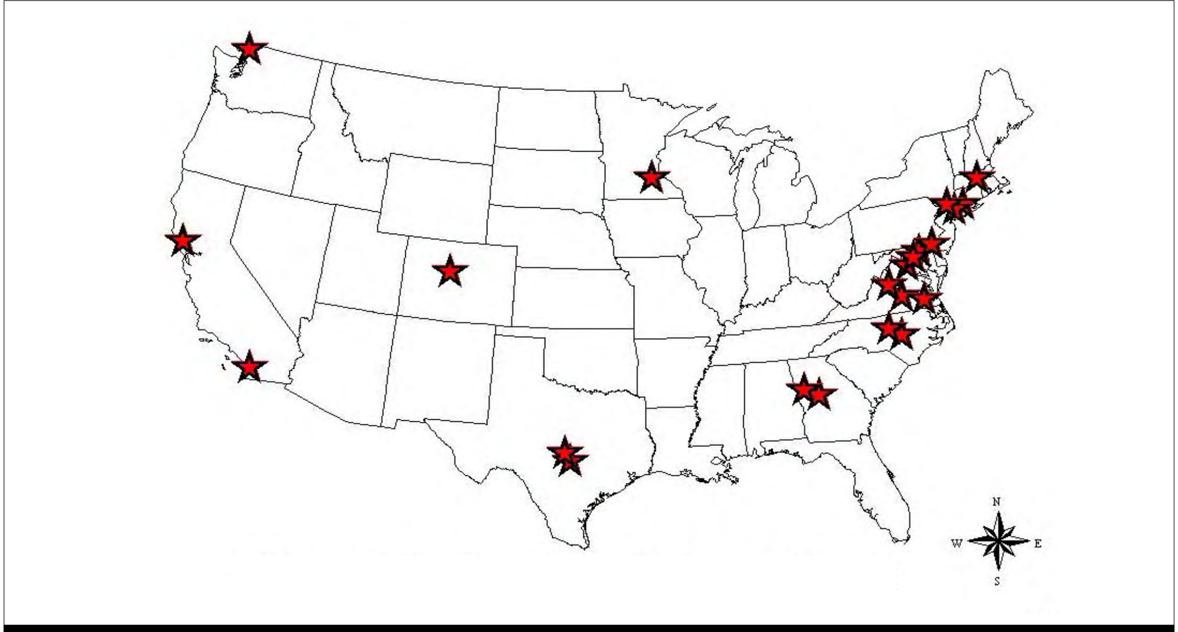



**Figure 1. Reservoir Locations**

It should be noted that septic systems were often required to be located well outside of the designated shoreline buffer zone in many reservoirs. In general, shoreline and stream buffers used to protect water supplies were consistently more stringent than buffer requirements used to protect other water resources, as reported in a national survey of stream buffers (Heraty, 1992).

**Better Site Design**

Better site design refers to a series of design techniques that reduce the impervious cover and increase the natural cover associated with individual development sites. Nearly 70% of the reservoirs surveyed reported that they encouraged better site design in their watersheds, although the same proportion indicated that they could do much more in this respect. The two most common better site design techniques applied in reservoir watersheds were open space or cluster subdivisions (48%) and capping impervious cover for residential lots (38%). Many of the residential impervious cover limits were quite low (median: 12%; range: six to 30%).

Treatment of stormwater runoff quality was required in all but one of the reservoir watersheds surveyed.

It is interesting to note that these two better site design techniques can work against each other. In practice, however, many reservoir watersheds exempted cluster subdivisions from impervious cover limits if it could be demonstrated that the total impervious cover for a subdivision would be lower with clustering than without it. What is more important, many localities were willing to extend sewers or allow shared septic systems in order to make cluster development feasible.

**Erosion and Sediment Control**

Erosion and sediment control (ESC) practices during new construction were required in every reservoir watershed in our survey. However, ESC performance requirements were no more stringent in a reservoir watershed than in the surrounding locality 75% of the time. Slightly more than a third of localities (36%) did report more stringent requirements in regard to ESC plan review or inspections. Many of these localities shared development review and inspection authority with the water utility.

**Stormwater Treatment Practices**

Treatment of stormwater runoff quality was required in all but one of the reservoir watersheds surveyed. It was also noteworthy that 64% had more stringent stormwater requirements within the reservoir watershed than in the surrounding locality. In addition, 71% of the reservoir watersheds indicated that they had started or were planning to start a stormwater retrofit program to treat runoff from existing development.

***Requirements for New Development***

In general, reservoir watersheds require designers to treat a greater volume of stormwater runoff than non-reservoir watersheds. Sizing requirements ranged from one to two watershed inches of treatment, which is about twice the typical treatment volume used elsewhere. Wet ponds were the most frequently used type of stormwater treatment practice in reservoir watersheds. About 25% of the reservoir watersheds required designers to meet a specific phosphorus removal target. Examples of these targets include the following:

- 0.22 lbs/ac/yr
- 50 to 65% phosphorus removal
- Maintenance of predevelopment phosphorus loading

Only a handful of reservoir managers reported that they inspected stormwater treatment practices more frequently within a reservoir watershed.

***Treating Existing Development***

Stormwater retrofitting is becoming an increasingly common practice to treat existing developed areas within reservoir watersheds. For example, 38% of the reservoir watersheds had actually installed stormwater retrofits to improve the quality of runoff from existing development, and another 33% were considering pursuing a stormwater retrofit strategy. However, with the notable exception of the Kensico Reservoir, most watersheds had retrofitted only a small fraction of existing developed areas to date.

**Wastewater Management**

***Surface Wastewater Discharges***

New wastewater discharges were explicitly prohibited in 85% of reservoir watersheds. Three watersheds did have major wastewater discharges to the reservoir, but each relied on advanced tertiary treatment. Nearly all of the reservoirs used sewers to collect wastewater from at least a portion of their watersheds, but 85% pumped the sewage out of the watershed. Further, a third of the reservoir watersheds reported that they had extended sewers to relieve areas prone to failing septic systems.

***Septic Systems***

Septic systems were extensively utilized in about 67% of the surveyed watersheds. They were discouraged or prohibited in 14% of our sample. Many respon-

| Table 5. Survey Results *(n =17-22)* | | | |
|---|---|---|---|
| **Watershed Protection Measure** | **%yes** | **Watershed Protection Measure** | **%yes** |
| ***Watershed Planning*** | | ***Erosion and Sediment Control*** | |
| Have comprehensive watershed plan | 10% | Require ESC during construction | 100% |
| Utilize zoning as primary land use tool | 90% | Have more stringent ESC criteria for reservoir protection | 26% |
| Have protection overlay district | 60% | Report more intensive review or inspection inside watershed | 36% |
| Use large lot zoning (1 acre or more) | 68% | ***Stormwater Treatment*** | |
| Rely primarily on stormwater treatment practices | 32% | | |
| Exclude specific uses/activities from watershed | 80% | Require stormwater treatment | 95% |
| Exclude new commercial or industrial uses (directly or by zoning) | 48% | Have more stringent criteria for water supply watershed | 64% |
| Have down zoned portions of watershed | 37% | Require designer to meet specific phosphorus removal target | 25% |
| Requirements take distance to intake into account | 42% | Require specific practices or larger treatment volumes | 67% |
| Dominant land use is forested/open space | 59% | Have installed retrofits for existing development | 38% |
| Dominant land use is commercial/industrial | 5% | Are considering pursuing a retrofit strategy | 33% |
| Have recent land use data (since 1996) | 55% | ***Non-Stormwater Discharges*** | |
| Track impervious cover | 37% | | |
| ***Land Conservation*** | | Have septics in watershed | 100% |
| | | Have sewers in watershed | 95% |
| > 10% of watershed owned by utility/public | 48% | Have reservoir specific criteria for septics | 76% |
| 10-25% of watershed owned by utility/public | 18% | Require minimum septic setbacks at least 100ft | 89% |
| >25% of watershed owned by utility/public | 33% | Mandate inspections/cleanout | 46% |
| Have a land acquisition/conservation easement program | 72% | Exclude wastewater discharges from watershed | 86% |
| ***Shoreline and Tributary Buffers*** | | Regulate hazardous material storage/disposal/generation in watershed | 73% |
| | | Report having a spill contingency plan | 95% |
| Require or own shoreline buffer | 100% | ***Stewardship*** | |
| Require tributary buffers | 90% | | |
| Minimum shoreline buffer is greater than 100ft | 80% | Monitor tributary and watershed lands | 90% |
| Minimum tributary buffer is greater than 100ft | 50% | Some form of education and outreach for watershed stewardship | 86% |
| Specify vegetative targets for buffer area | 70% | Prohibit swimming in reservoir | 90% |
| Specify allowable or prohibited uses | 85% | Prohibit gasoline engines in reservoir | 90% |
| ***Better Site Design*** | | Restrict public access to reservoir | 27% |
| Mandate impervious cover at the site | 38% | | |
| Mandate BSD in watershed | 4% | | |
| Have active clustering/open space development | 48% | | |
| Encourage BSD | 68% | | |
| Admit that they could do more | 65% | | |

dents indicated concerns about septic systems as a possible pollutant source, and nearly all had developed reservoir-specific regulations for them. The most frequent regulations included larger setbacks, that ranged from 50 to 600 feet in distance. Just less than half of the reservoir watersheds required mandatory inspection and pumpouts. In addition, many of the reservoirs recently adopted innovative programs to improve the performance of septic systems in their watersheds, including the following:

- Free inspections
- Requirements for non-discharge units
- Reservoir setbacks of up to 600 feet
- Requirements that innovative septic systems be used with higher nitrogen removal capability
- Proof of pumpout required to maintain public water service
- Utility monitoring to detect failing systems
- Sewering of failed septic systems
- Drain field rotation

**Watershed Stewardship**

***Watershed Education***

While 86% of the surveyed reservoirs reported that they had some kind of watershed education program, most were relatively modest in scope. For example, less than half of the outreach programs devoted full-time staff to watershed education. Even fewer had developed an overall strategy to guide their watershed outreach efforts (e.g., targeting specific watershed behaviors or conducting pollution prevention training).

We recommend that every source water assessment measure the amount of current watershed impervious cover.

***Spill Response***

The potential risk of spills or leaks of hazardous material in the watershed has always been a concern for reservoir managers. More than 90% of the surveyed watersheds reported that they had developed and tested a spill contingency plan. In most cases, these plans focused on potential spills from transportation corridors, such as highways or railroads. Most reservoir watersheds (76%) regulated the generation, storage and disposal of hazardous wastes within their watershed, usually by excluding these types of industrial uses, or requiring setbacks from the shoreline. However, few reservoirs had any kind of reporting program to track existing sources of hazardous materials in the watershed.

***Monitoring***

Robbins *et al*. (1991) noted that few reservoir watersheds were monitoring their watersheds and tributary streams, but this has changed greatly in the last decade. According to our survey, 90% of the reservoir watersheds indicated that they were monitoring within their watersheds and tributary streams. Only a handful, however, reported that they were monitoring the effectiveness of treatment practices, such as stormwater ponds.

***Reservoir Restrictions***

Reservoir managers often restrict public access to the reservoir itself. While only 27% of survey respondents indicated that they completely prohibited public access to the reservoir, nearly all of the reservoirs restricted access or use in some manner. The most common restrictions were to prohibit swimming (90%) and the use of gasoline engines within the reservoir (90%).

**Overall Findings**

Based on our survey, it is evident that nearly all reservoirs apply the eight watershed protection tools described above, at least in some form (Figure 2). Water supplies have traditionally been heavily regulated, given the paramount public health concern and increasingly stringent drinking water standards. It is fair to say that no other kind of watershed has regulated development to the extent seen in water supply watersheds.

Given this, it is surprising that only 10% of the reservoir watersheds had developed a comprehensive watershed plan. And despite the fact that development was expected to continue in nearly all of the watersheds, none had established a maximum upper limit on the total amount of watershed development that could occur in the future. This shortcoming reflects the disparity between water utilities who want clean source water and local government(s) who want growth, and are responsible for regulating land use in the watershed. Still, the lack of watershed land use planning is disturbing, given that watershed development is at the root of most potential sources of drinking water contamination.

And indeed, many reservoir managers acknowledged shortcomings in their watershed management programs. Most notable were consistent concerns about the long term maintenance of stormwater practices, septic systems, and buffers. Others reported chronic problems with the actual implementation of watershed practices in the field. The cumulative impact of inadequate staffing, waivers, infrequent inspections, poor

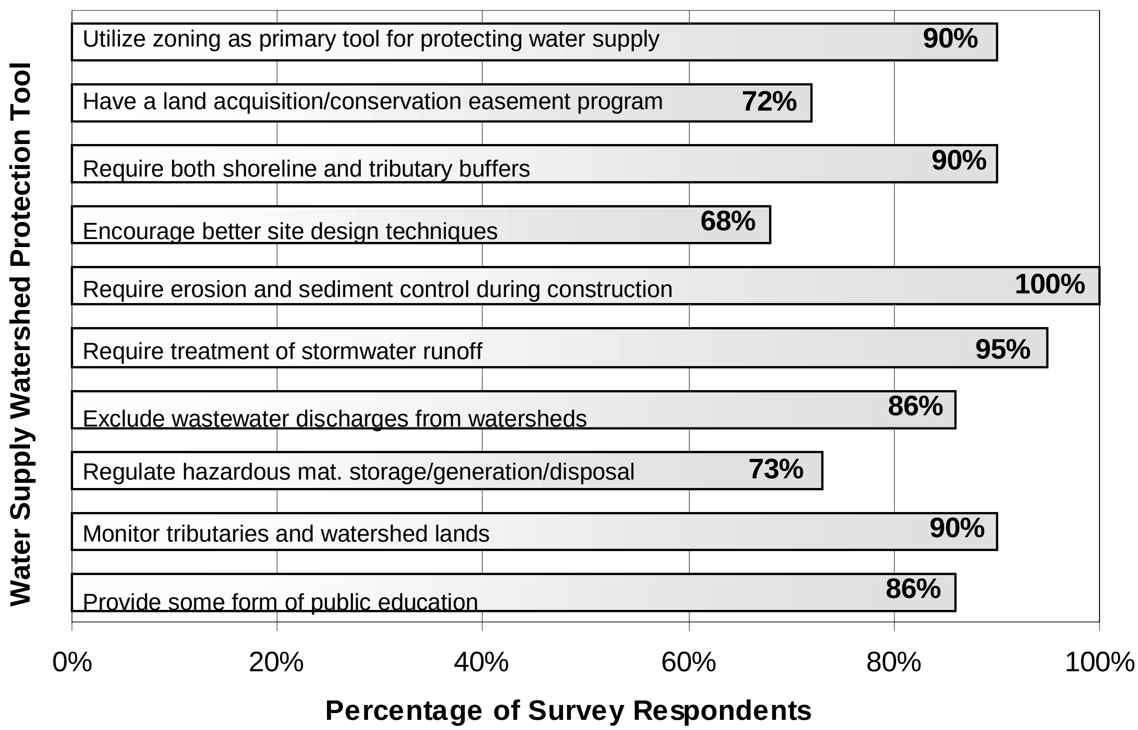



**Figure 2. Percentage of Survey Respondents Utilizing Watershed Protection Tools**

design standards and limited enforcement was believed by many to compromise the overall effectiveness of watershed protection programs. Some managers also lamented the lack of actual performance data for watershed treatment practices, at both the site and watershed level.

**Integrating Watershed Planning Into Source Water Protection**

One of the key requirements of the 1996 Safe Drinking Water Act Amendments is for water providers to conduct a *source water assessment plan* (SWAP) to identify potential contaminants, and then develop a *source water protection plan* (SWPP) to minimize these risks. Most states have just developed guidance on the minimum elements that water providers need to incorporate into these plans (see also a national manual developed by NEIWPPC, 2000). The major components of a SWPP are public involvement, use of regulatory and non-regulatory practices to manage drinking water contaminants and adoption of spill response contingency plans.

While state and federal water regulators clearly endorse a watershed approach for developing SWPPs, and, in particular, promote stakeholder involvement and intergovernmental partnerships (US EPA, 1999), they do not mandate that the cumulative impact of current or future watershed development be explicitly considered in the planning process. As a consequence, it is not likely that many water providers will be able to develop effective watershed land use plans. To some extent, this reflects the fact that not all reservoir watersheds are experiencing development, and both water regulators and water providers are reluctant to interfere with the land use prerogatives of local governments.

We recommend that every source water assessment measure the amount of current watershed impervious cover, and forecast the amount of new impervious cover to be created over the next 20 or 30 years. If current or future impervious cover is expected to exceed 10% in the watershed, we strongly recommend that communities adopt more stringent treatment practices for new development. Table 6 summarizes the critical elements of a source water protection plan we recommend for water supply watersheds expected to exceed 10% impervious cover. These recommendations are based on results from the watershed population we surveyed; smaller systems may want to take a simpler approach. These recommendations are a general framework to integrate watershed management into source water protection plans, and should be modified for unique watershed conditions such as unfiltered supplies, lake geometry, and amount of impervious cover.

| Table 6. Elements of a Source Water Protection Plan for Urban Surface Water Supplies | |
|---|---|
| **Watershed Protection Tool** | **More Than 10% Watershed Imperviousness** |
| Watershed Planning, Management and Zoning | Adopt a comprehensive watershed plan that can provide consistent implementation across all jurisdictions<br>Establish an ongoing watershed management structure<br>Update land use and development trend analysis  track land use and impervious cover every four years.<br>Designate a watershed manager for the reservoir<br>Create a reservoir protection overlay district and/or ordinance (see Cappiella and Schueler, this issue)<br>Exclude or restrict pollutant hotspots (i.e industry, WWTP, and land fills)<br>Establish maximum level of watershed development/impervious cover |
| Land Conservation | Prioritize land acquisition to critical water supply protection areas (i.e. corridors, streams, and intakes)<br>Maintain rural land through conservation easements |
| Shoreline and Tributary Buffers | Require, or acquire, wide shoreline (minimum 300 ft) and tributary (minimum 125 ft.) buffers<br>Maintain natural shoreline vegetation and establish allowable uses |
| Better Site Design | Set impervious cover caps for individual zoning categories<br>Allow cluster design for residential subdivisions to conserve open space |
| Erosion and Sediment Control | Make inspection and enforcement efforts more stringent for construction sites |
| Stormwater Treatment Practices | Size and design stormwater treatment practices for maximum phosphorous removal<br>Use environmentally-sensitive design on lake-front properties to minimize creation and concentration of stormwater runoff (see Cappiella and Schueler, this issue)<br>Consider retrofitting existing development where necessary |
| Wastewater Management | Prohibit new WWTP discharges in watershed; require advanced tertiary treatment  of existing discharges or pump out of watershed<br>Enforce tighter regulations for septic system design, siting, and maintenance if non-sewered development allowed<br>Perform regular surveys to identify failing septic systems<br>Establish minimum 150 ft setbacks from tributaries<br>Mandate regular clean out and inspection of septic systems |
| Watershed Stewardship | Expand monitoring efforts to include tributary monitoring and watershed land assessments<br>Target education efforts towards relevant pollution prevention activities such as lawn care and contractor education for proper fertilizer and pesticide usage<br>Establish a spill response contingency plan and tracking system for existing sources<br>Restrict recreational activities and gas motorboats |

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# In-Lake Treatment to Restore Urban Lakes


by Tom Davenport and Susan Kaynor

**Introduction**

Restoring the quality of highly urban lakes is very challenging given our limited ability to reduce existing phosphorous loads from their watersheds. In many cases, the only feasible option for the lake manager is to employ in-lake restoration techniques to improve water quality and aesthetics. These techniques treat the symptoms of eutrophication, and require continuous effort and resources to maintain the desired level of lake quality. However, when the proper restoration and treatment techniques are combined with local support, the quality of urban lakes can be at least maintained and in some cases significantly improved. Given that most urban lakes are highly visible and receive intense recreational use, employing the proper combination of treatment and restoration techniques to maintain the water quality, improve the aesthetic appeal and support the desired uses of the lake can not only improve the quality of life for the community, but reap economic benefits as well.

When managers consider lake restoration, they must first diagnose whether their lake is dominated by algae or aquatic weeds. As Jon Simpson notes in the perspective that accompanies this article, effective lake restoration strategies must directly address the dominant plant community in the lake (see Box 1). When a shallow urban lake is dominated by aquatic weeds, it may be more resistant to traditional phosphorus therapies, since it derives nutrients from bottom sediments and not the water column. In these lakes, managers need to understand and manage the ecological factors that sustain and reinforce dense populations of aquatic weeds. To succeed in this endeavor, lake managers must often combine "biomanipulation" practices within the lake with watershed treatment practices that reduce phosphorus inputs to the lake.

Communities that have a large number of urban lakes often expend considerable effort in lake management. For example, Baird *et al.* (1997) surveyed over 60 local governments in Florida and found that lake management was an increasing local concern. Many urban lakes are constructed to provide multiple benefits and have to be managed accordingly. Baird and his colleagues reported that the top three urban lake management concerns were excessive aquatic plant growth (20%), water quality (18%), and water quantity (15%), in terms of staff time and effort. The water quantity category included both flooding and drought. These rankings changed somewhat when actual local government expenditures were considered: aquatic plants (20%), water quality (18%) and water quantity (12%).

The remainder of this article reviews nine in-lake restoration techniques available to the lake manager. In general, the most commonly used restoration techniques include alum treatment, dredging, and the mechanical harvesting of aquatic plants. Less frequently employed techniques include hypolimnetic withdrawals, artificial circulation, lake draw down, sediment covers, biological controls and biomanipulation techniques. The use of herbicides to control nuisance aquatic plant growth is generally discouraged because of potential deleterious side effects and public concerns over this technique.

**Alum Treatment**

Many urban lakes experience significant release of internal phosphorus loads from sediment which can spur nuisance algal growth, particularly if extensive littoral areas are present. To reduce this internal source, phosphorus in the water column or sediments must be precipitated and inactivated. This is done by adding alum, or aluminum sulfate, to the water column, which forms a precipitate of aluminum phosphate that effectively binds up the available phosphorus.

> The impact of watershed development on lake quality is so pervasive that it is worth treating urban lakes as a distinct group.

This technique is most effective in lakes where the external phosphorus loads have been controlled and sediment phosphorus release has been documented as a major internal source. In rare cases, alum is directly injected into stormwater before it enters the lake to help reduce watershed phosphorus loads. More commonly, phosphorus is precipitated from the lake with relatively low dosages of alum, although several treatments may be needed per year. In some instances, larger dosages are needed to inactivate phosphorus in sediments and thereby provide long-term control. Payne (1992), in a review of nearly 20 lake restoration studies using alum treatment, concluded that phosphorus inactivation produced statistically significant reductions in water column phosphorus concentrations of treated lakes.

Careful application of alum can provide a nontoxic control of algae, but if watershed sources of phosphorus are not controlled, the phosphorus-alum bound layer will eventually be covered by a new layer of phosphorus-rich sediments. Lake managers should also be aware that improvements in lake water clarity as a result of alum treatment may make conditions more favorable for the growth of aquatic weeds in shallow areas.

**Dredging**

Perhaps the most common restoration technique involves physically removing enriched bottom sediment from the lake by dredging. Other objectives for sediment dredging include removing heavy metals and other potentially toxic chemicals, or deepening the lake for recreation, navigation or other purposes.

There are two basic methods for removing sediment from lakes. The first method involves draining the lake and then scraping or excavating the "dry" sediments. This technique works best in small lakes that can be easily drawn down and dewatered. The second method involves the use of dredges. There are a wide range of dredging techniques, the most common being hydraulic dredges with cutterheads. The cutter loosens bottoms sediments and then transports them as a slurry to a holding or disposal area. Bucket dredges can also be used, but these have several disadvantages. For example, disposal sites for the dredged sediments are confined to locations near shore areas, unless one can afford the cost of hauling sediments by truck or barge to a more distant area. In addition, bucket dredging tends to be a relatively slow procedure, and creates high turbidity and uneven bottom contours in the lake.

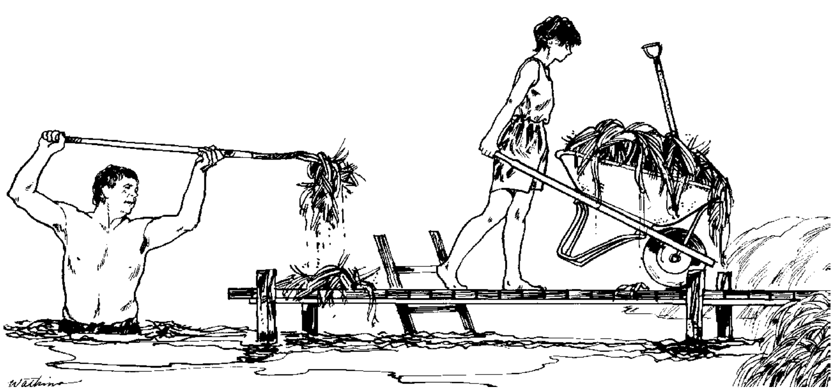
And certainly, a key problem associated with urban lake dredging is the disposal of dredged sediments. To realistically calculate the costs of dredging, managers should project the cost of monitoring, dredging equipment, labor, and transportation and disposal of dredged material. Depending upon the nature of the dredged material, finding a disposal site may be a problem, because disposal of contaminated sediments must meet requirements governing toxic and hazardous material. In general, lake sediments should be tested for toxic substances prior to dredging, and certainly before disposal. Downstream discharge of slurry water should also be avoided, since the nutrient-rich slurry could cause turbidity, algal blooms and dissolved oxygen problems in downstream receiving waters.

The volume of sediment removed by dredging is determined by the objectives of the restoration project. If the objective is to reduce algal growth, dredging must extend to remove all nutrient-enriched sediment layers. Often, even greater sediment volumes must be removed to meet recreation or navigation purposes. Lake managers should carefully choose the most appropriate dredging and sediment disposal methods that can both satisfy project objectives and minimize local and downstream impacts.

**Weed Harvesting**

Mechanical harvesting has proved to be an effective technique for temporarily removing nuisance growths of aquatic weeds that interfere with swimming, boating and other lake uses. Harvesting has few of the environmental drawbacks associated with herbicides, and can be integrated with other restoration techniques such as biological controls and water level manipulations. The advantages of mechanical harvesting include an ability to control the size of the treatment area, as well as the removal of nutrients incorporated in the harvested plants. Harvesting disturbs lake users for a relatively short period of time, poses little threat to non-target organisms, and the harvested plant matter can be a beneficial by-products for gardens and farms.

However, mechanical harvesting does have some disadvantages. For example, there is a risk that plant fragments may stimulate rapid re-growth of vegetation of the target or other non-target species. In addition, harvesting is confined to a peak growing season during favorable weather conditions. The initial outlay for harvesting equipment can be high, and mowing may be needed every year. Other factors to consider with regard to harvesting include finding good access to harvesting sites, the possible habitat disturbance for fish and other aquatic life, and the costs to dispose of harvested vegetation. Lake managers should thoroughly evaluate lake conditions before starting a harvesting program (i.e., the species, density, and distribution of aquatic weeds). Excellent guidance on devel-



oping a weed harvesting program for urban lakes is available from WLP (1998) and McComas (1993).

**Hypolimnetic Withdrawal**

Nutrient-rich waters can be removed from the bottom of a lake by manipulating the depth at which water is released from the lake. Frequently, a pipe is used as a siphon for the hypolimnetic waters located near the deepest point to the lake's outlet. One objective of hypolimnetic withdrawal is to eliminate the mixing of the nutrient-rich bottom layers with the epilimnion. Another objective is to reduce the residence time of water in the hypolimnion, which can reduce the opportunity for anaerobic conditions to develop.

This technique only works in lakes that are thermally stratified, and one consequence is that nutrient-laden waters will be discharged to downstream waters, unless it discharge is directed into a constructed wetland for proper treatment. In addition, the removal of hypolimnetic waters may cause thermal instability that results in destratification of the lake. If this occurs, nutrient-rich waters in the hypolimnion will mix with the epilimnion, and possibly trigger an algal bloom.

**Circulation/Aeration**

In this technique, compressed air is pumped into the lake by a pipe or ceramic diffuser in order to better circulate lake water. By thoroughly mixing the water column from top to bottom, algal biomass can be reduced by limiting the light penetration needed for plankton cells to flourish. In lakes where iron complexes bind phosphorus at the sediment-water interface under aerobic conditions, the increased dissolved oxygen levels in bottom waters caused by aeration can decrease internal phosphorus loads generated by sediment release during anoxia.

However, in lakes where calcium, rather than iron, controls phosphorus dynamics at the sediment-water interface, the internal loading may actually increase as a result of improved circulation. Also, artificial circulation is often of limited value in shallow, unstratified lakes with significant internal phosphorus loading. Indeed, Pastorak *et al.* (1982) found that while these techniques usually did increase hypolimnetic dissolved oxygen levels, they usually did not improve overall in-lake phosphorus concentrations or water clarity. Consequently, lake managers need to acquire a thorough understanding of the chemical, biological and physical processes of each lake in order to predict the success of recirculation/aeration.

**Drawdown**

Manipulation of lake water levels has long been used as a lake restoration practice, and can accomplish several lake management objectives. If aquatic weeds are a problem, a drawdown that exposes some plant roots to drying/and or freezing conditions can permanently damage seeds and roots. The effectiveness of a drawdown is very species-dependent; some species will be unaffected or even thrive with this treatment. Nuisance growths of milfoil, coontail and water lilies have been successfully controlled with drawdown in northern climates, whereas alligator weed and hydrilla are reported to increase under this treatment. Lake drawdowns also make it much easier to remove lake sediments, install sediment covers and repair docks, dams and other shoreline structures. In addition, lake drawdowns are often used to install fish habitat structures in the littoral zone, and to manage fish populations.

Lake managers need to acquire a thorough understanding of the processes of each lake in order to predict the success of any restoration technique.

**Sediment Covers**

Sediment covers are plastic, fiberglass or nylon sheets that are installed flush on the lake bottom and securely anchored. They prevent aquatic weed growth since the covers block sunlight and prevent plants from growing through the cover. As might be expected, sediment covers are a costly restoration technique, and are usually reserved for small areas around docks and swimming areas. Sediment covers need to be periodically maintained to remove accumulated sediments where plants could eventually take root. Urban watersheds that generate sediment-laden runoff and cause extensive deposition may not be good candidates for this technique.

**Biological Controls**

Another option for controlling nuisance aquatic vegetation is to introduce aquatic organisms that consume aquatic weeds, or plant pathogens. Grass carp (*Ctenopharyngodon idella Val*.), an exotic fish originally imported from Malaysia to the U.S. in the early 1960s, can consume aquatic weeds at high rates. Like any other biological control, grass carp need to be carefully applied. In particular, stocking densities need to be set to ensure that the target weeds are consumed and not overlooked in favor of more desirable plants. Overstocking of grass carp can dramatically change the structure of fish communities and totally eradicate the aquatic plant community in lakes (which, in turn, can lead to increases in-lake nutrient concentrations, algal blooms, and turbidity). A number of insect species have been introduced to lakes as a biological control for aquatic weeds, and some success in controlling alligator weed and water hyacinth has been reported in southern regions. Integrating biological controls with mechanical harvesting can also enhance the chance for successful control of aquatic weeds.

### Biomanipulation

Biomanipulation seeks to sharply reduce fish species in a lake that consume zooplankton, and thereby enhance algal grazing by zooplankton, such as *Daphnia* (see Box 1). When zooplankton populations are high in a lake, they can be efficient algal consumers and sharply improve water clarity. Biomanipulation is often used in shallow lakes, and typically involves eliminating the existing fish community with rotenone, followed by restocking the lake with largemouth bass or walleye that consume planktivore species. While some success with biomanipulation has been reported for an urban lake (Noonan, 1998), the overall experience with biomanipulation has been decidedly mixed (Demelo *et al.*, 1992). Noonan (1998) noted that fish stocking is a useful complement to a comprehensive lake management strategy that features control of phosphorus loads at the watershed level.

### Summary

Phillips and her colleagues (2000) in *The Lake Pocket Book* state it best: “Don’t expect the moon.” Some urban lakes can never be restored or economically managed to support desired uses. While this article has focused on treating the immediate symptoms of algal blooms, aquatic weeds and sediment deposition, all efforts should be guided by a long-term watershed management plan. The plan should identify opportunities for pollutant reduction in the watershed, consider practical in-lake treatment techniques, and strike a balance between what lake users want with what can actually be achieved. Watershed managers should also work closely with the appropriate state resource agencies before commencing with in-lake restoration.

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**Box 1. Managing Algae Blooms or Aquatic Weeds? A Perspective on Biomanipulation**

***—by Jon Simpson***

Given that shallow urban lakes receive a continuous supply of phosphorus from external loading and internal recycling, it is almost inevitable that lake managers will have to deal with nuisance levels of plant growth. The key question is which type of plants will end up dominating the lake? Will it become an open water system dominated by algal blooms or a more closed system dominated by aquatic weeds? Both types of plants can become established over a wide range of phosphorus loads and lake conditions, so it is difficult to predict which type will be favored.

Once macrophytes become dominant in a lake, they tend to maintain their dominance for some time, barring extreme events or stressors. The same generally holds true for algal dominated lakes. This stability in the plant community is due in part to ecological factors that tend to favor the incumbent plant species, and/or discourage its competitors. A knowledge of these ecosystem factors helps lake managers understand the long-term consequences of their management actions, whether it be to control aquatic weeds or manage algae blooms. The key idea is to avoid unintended shifts in plant dominance that may create a whole new set of lake management problems.

While most lake managers firmly grasp the concept of eutrophication and its impact on algal biomass, they may be less familiar with aquatic weeds. The precise term for aquatic weeds is *macrophytes*, which are aquatic plants with true roots, stems, and leaves. Macrophytes can be grouped into four categories:

- *Emergent* plants are rooted and have stems or leaves that rise well above the water surface. They grow in very shallow water, often close to the shoreline.

- *Rooted floating-leaved* plants have leaves that rest on, or slightly above, the lake surface. Long stalks connect them to the lake bottom, which allows them to inhabit moderately deep water.

- *Submergent* plants grow with all or most of their leaves and stems below the water surface. Their roots and tubers are anchored in the lake sediments.

- *Free-floating* plants are found on the lake surface. Their root systems hang freely from the plant.

***Factors That Cause or Reinforce Dominance by Aquatic Macrophytes***

The existence of macrophytes in a shallow urban lake can inhibit the growth and dominance of algae populations in several different ways. First and foremost, macrophytes provide a refuge for zooplankton from fish, which are their main predators. Zooplankton are microscopic organisms that consume algae and come in many sizes and shapes. The three most common groups are *rotifers*, *cladocerans*, and *copepods.* Rotifers are very small and posses a “wheel” of fine hairs that beat the water to create micro currents that direct food to their mouths. Cladocerans are larger and move through the water through a jumping and drifting motion, hence their common nickname, "water fleas." Cladocerans filter water and collect algae cells and other organic particles with fine hairs on their front limbs. The third group, the copepods, have a 12-stage life cycle. The animal is very small in the first six stages of life, and moves slowly, filtering the water for food. In the next six stages of their life cycle, copepods grow much larger and move more quickly through the water collecting food, some by filtering water, others by grasping food particles.

Zooplankton serve as the primary food source for many species of young fish and for some adult fish. These “zooplanktivorous” fish tend to select the largest, slowest zooplankton available, by sight. In the zooplankton community, this usually means that larger cladocerans are detected first, since they have a predictable “jump/rest” motion. Rotifers and the young copepods, on the other hand, are much harder to see because of their small size. Older and larger copepods are also hard to catch, since they can move quickly to evade predators.

The submersed matrix of macrophyte leaves and stems creates a good refuge for cladocerans and other zooplankton. The tight spaces and reduced light conditions make hunting conditions more difficult for zooplanktivorous fish than in open water. As a result, the zooplankton community and the cladocerans, in particular, tend to thrive in macrophyte beds because of reduced predation pressures. Given how effective zooplankton are in filtering algae from the water column, they can make a real difference in algal biomass levels.

***Asplanchna* (rotifer)**

Macrophytes can also suppress algal growth in other subtle ways. For example, macrophyte beds tend to suppress water turbulence. This is important, since most algal species are not buoyant and tend to gradually sink to the lake bottom. The life span and reproduction potential of algal cells can be greatly extended, however, if they can stay near the lake surface. Wind action on the lake surfaces can help by causing turbulence and upwelling, which counteracts the sinking process and transports algal cells back toward the surface. Macrophyte populations, especially emergent species, block the transfer of wind energy to the water. This suppresses water turbulence and causes algal cells to sink.

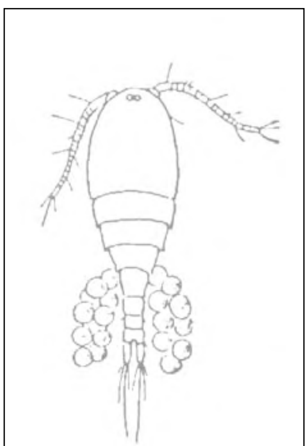
Macrophytes and algae compete for light in the lakes water column. Once a macrophyte bed becomes established in a shallow lake (especially species with floating leaves), it tends to block sunlight from penetrating down into the water column. Algae, like other plants, must photosynthesize to survive. Consequently, macrophyte beds will generally reduce the amount of available light and naturally inhibit algae growth.

Macrophyte beds often replace themselves two or more times per summer (Cooke *et al.*, 1993). The dead plant matter is deposited on the lake bottom where it decomposes, using oxygen in the process. Lowered and sometimes depleted oxygen levels in macrophyte beds discourage zooplankton-eating fish from cruising the macrophyte beds in search of prey. Once again, this phenomenon tends to reinforce macrophyte dominance.

Many species of macrophytes can take up more nutrients from bottom sediments than necessary for their immediate growth. This "luxury uptake" can reduce the availability of phosphorus in the sediments that could be released for algae growth. Finally, there is circumstantial evidence that some species of macrophytes excrete organic compounds that inhibit algae growth. The exact substances and process have yet to be identified by lake researchers. However, it is widely known that growing macrophyte beds can increase the pH of lake waters, which could potentially inhibit algae reproduction. Fish are also sensitive to elevated and/or fluctuating pH levels and could potentially be discouraged from cruising the water in search of zooplankton prey.

### *Factors That Cause or Reinforce Algal Dominance*

Algae maintain their dominance in shallow lakes by growing rapidly in the spring and filling the water with algal cells, before macrophyte beds become established. Algal blooms reduce sunlight levels reaching the lake bottom, thereby inhibiting the growth of young and dormant macrophytes rooted in the sediments. By getting an early start, algae can maintain the open water conditions that favor their growth, and, at the same time, shade out their macrophyte competitors.



***Clyclops* (copepod)**

The ability to start up early in the spring is due to the fact that a variety of algae species take turns dominating the water column during the growing season. Some species are better adapted for cold water/low light conditions, while others thrive in warm water/high light conditions. For example, algae-dominated lakes experience blooms of diatoms in the spring when water temperatures are still low but sunlight intensity is increasing. As water temperature rises, the baton is passed to other algal species that take over and dominate the community. This ability to quickly shift to a new community structure helps algae maintain their dominance, even in the face of rapidly changing physical and chemical conditions.

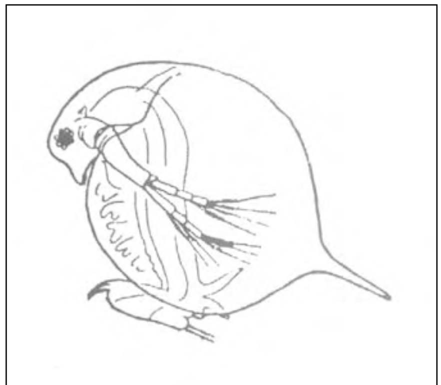
Zooplankton graphics from NY DEC, 1990

Another factor that gives algae a competitive advantage in shallow urban lakes is the historical absence of macrophyte beds. As noted earlier, open water conditions make it easier for wind energy to be transferred to the water which, in turn, creates currents and upwelling that counteracts algal sinking. As a result, the turbulence associated with open water keeps algae cells near the lake's surface where they can continue to photosynthesize and reproduce. In addition, without the sheltering cover of macrophytes, zooplankton (especially cladocera) are easier prey for fish. Consequently, zooplanktivorous fish often shift the structure of the zooplankton community towards domination by rotifers and copepods. Such a change tends to favor algae growth because it reduces grazing pressure by eliminating of the most efficient algae-grazers in the lake.

The rapid life cycle of algae results in a "rain" of organic material floating down to the lake bottom. Consequently, bottom sediments in algal-dominated lakes tend to have the consistency of mayonnaise, and will easily move when disturbed by currents. As a result, these bottom sediments may not be suitable for the setting of young macrophyte roots.

***Implications for Lake Managers***

Lake managers should carefully diagnose the ecological condition of an urban lake to determine if it is primarily dominated by algae or aquatic weeds. Historical data on the nature of the lake's plant community can often be very helpful, although in some cases invasive species of aquatic weeds may have recently colonized the lake. If this diagnosis indicates that the lake is dominated by algal biomass, lake managers should follow the normal prescription for lake eutrophication, namely the reduction of phosphorus inputs.



***Daphnia* (cladocera)**

If, on the other hand, a lake is found to be dominated by aquatic weeds, lake managers may need to be more careful. If aquatic weeds dominate an urban lake, it is doubtful whether a phosphorus "diet" alone will achieve lake management goals.  Aquatic weeds are often quite resistant to traditional eutrophication management techniques, since they obtain their nutrients from the sediment. In these settings, lake managers may want to acquire more ecology data about the lake before deciding on the next course of treatment.

Successful management of shallow urban lakes that are dominated by aquatic weeds should focus on the specific lake uses that are being impaired. In many cases, aquatic weeds impair the use of a lake for boating and swimming, primarily as a result of physical entanglement. In a few cases, aquatic weeds spread so much that the lake has little or no open water, and loses it aesthetic value to adjacent residents. Based on the seasonal severity of aquatic weeds, lake managers may choose to control aquatic weeds in selective locations or across the whole lake.

Lake managers can pursue a two-stage strategy to move a lake from macrophyte dominance to algal dominance. In the first stage, macrophytes are directly removed or destroyed through physical or chemical means. The second stage involves manipulation of the ecological factors that reinforce algal growth and inhibit additional macrophyte growth. This combined strategy should usually increase the chance for long-term success in a given lake.

First-stage control techniques for eliminating  macrophytes vary according to the target plant (e.g., whether it is submergent, emergent or floating), but typically involve dredging, water level manipulation, harvesting and the use of environmentally safe herbicides. Second-stage techniques are designed to manipulate ecological factors that lead to macrophyte dominance. These include initial destruction of the zooplankton population by pesticides or other toxins, and/or increasing the zooplanktivorus fish population (to increased grazing pressure on the zooplankton population). It should be noted that most state natural resource agencies require permits before biomanipulation techniques are applied to any lake.

Of course, lake managers may want to shift from algal to macrophyte dominance in their lake. This kind of change is more complex and difficult to undertake. A more permanent approach to algae suppression employs biomanipulation techniques to increase the zooplankton population so it can efficiently graze on the algae population. This is generally accomplished by increasing the ratio of piscivorous fish to zooplanktivorous fish, thereby relaxing grazing pressure on the zooplankton population. When the fish community is altered so that large zooplankton, especially cladocera, can thrive, there will be a natural check on algae.

At the same time, lake managers will need to develop an effective plan to establish a healthy macrophyte community. This often entails coordinated planting of desirable species at the same time that exotic or invasive species are suppressed. In some cases, substrate amendments may need to be added to the lake bottom to make it more stable for macrophyte root systems.

Phosphorus reduction has been the mantra of lake management for the last three decades. While this has been an effective and appropriate strategy for open water lakes, it is probably not transferable to shallow lakes dominated by aquatic weeds. These lakes often require direct intervention in the form of biomanipulation. While our understanding of urban lake ecology is quite limited, more research and experimentation should soon provide lake managers with more practical guidance.

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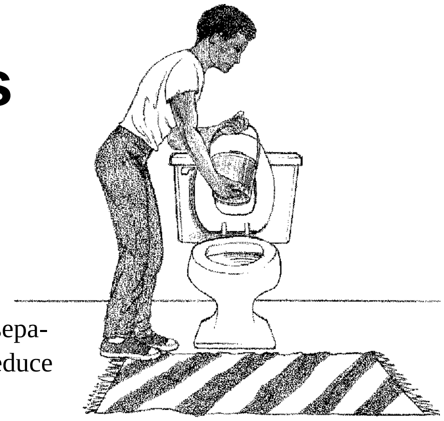
# The Influence of Septic Systems at the Watershed Level

*by Chris Swann*



### Introduction

Septic systems remain an enigmatic but potentially significant pollutant source in small watersheds. An estimated 23% of all households in the United States rely on septic systems to meet their wastewater disposal needs (US Census, 1999), and watershed managers routinely express concern about their potential impact on the quality of lakes, coastal waters and drinking water supplies. However, while we know a great deal about the performance of individual septic systems at the site level, we know very little about their aggregate impacts at the watershed level, and what influence they may collectively have on water quality.

A quick perusal of the literature will reveal hundred of citations on the performance of different septic system technologies under a variety of soil conditions. But at almost any level, we lack the hard data on the collective influence of septic systems on the watershed. We are often in the dark about questions like the following:

- How many septic systems are actually located in any given watershed?
- How many of these systems are failing, and what exactly constitutes failure?
- What nutrient loads are generated from a functioning septic system?
- What happens to nutrients after they leave the drainfield?
- How much does septic system performance decline with age?
- How much vertical and lateral separation distance is needed to reduce loadings?
- Is there a threshold value for septic loadings to the soil on a watershed basis?

This article summarizes current research on the potential risk of surface and subsurface pollution from septic systems. First, we provide a quick overview of basic septic system concepts and define some of the terminology every watershed manager should know when examining septic systems as a pollutant source. Next, we review research on nutrient loading from septic systems and estimate their potential nitrogen and phosphorus loads. From there, we examine the causes of septic system failure and explore recent changes in technology that could address possible failures. Next, we look at the pros and cons of using septic system regulation as a growth management technique for sensitive watersheds. Finally, we suggest some priorities for future watershed research.

### Basic Concepts for Septic Systems

The diverse terminology used to describe septic system technologies can often be quite confusing. For example, septic systems are sometimes referred to as onsite wastewater treatment systems (OWTS), onsite sewage disposal systems (OSDS), or wastewater infiltration systems. To facilitate understanding, we have simplified the terminology and placed septic systems into three basic categories: conventional, alternative, and innovative (Table 1).

**Table 1. Summary of Septic System Types**

| System Type | Construction Cost | Maintenance Needs | Nitrogen Removal Capability | Acceptance by Public Health Officials |
|---|---|---|---|---|
| Conventional | ° | ° | ° | — |
| Alternative | ™ | ™ | ° | ™ |
| Innovative | — | — | — | ° |

° - Low ™ - Moderate — - High

The *conventional septic system* is composed of two main parts: a septic tank, designed to collect and hold wastewater, and a septic absorption system, which disperses wastewater into the soil (Figure 1). The principal purpose of the septic tank is to act as a settling chamber and an anaerobic digester to break down and retain solid matter while passing the partially treated liquid phase of the wastewater on for disposal through a soil absorption system. The soil absorption system (also known as a drainfield) is designed to dispose of and treat the liquid portion of wastewater by filtering it through a layer of material (often sand or gravel) placed around distribution pipes and then through the soil below the drainfield. Conventional systems constitute the vast majority of septic systems approved for use, as long as soil conditions permit. A 1993 survey conducted by the National Small Flows Clearinghouse found that 97% of the health departments in the U.S. permitted the conventional septic tank-soil absorption system (NSFC, 1996). A conventional system usually costs less than $5,000 to install, and has a relatively low maintenance burden. However, the conventional system has very low nitrogen removal capabilities, since it is primarily designed to remove solids from wastewater and protect human health by disposing of wastewater below the soil surface.

Conventional septic systems constitute the vast majority of septic systems, but have very low nitrogen removal capability.

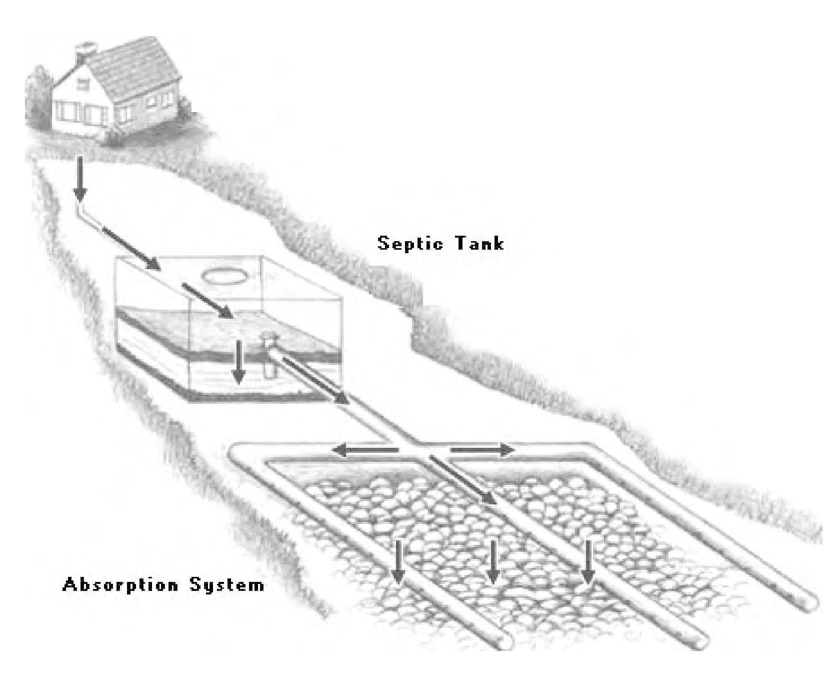



**Figure 1. Conventional Septic System Design (Soap and Detergent Association, 2001)**

*Alternative septic systems* refer to a group of septic system technologies primarily intended to relieve site constraints, such as unsuitable soils or water tables, that would otherwise prevent the use of conventional systems. Alternative septic systems use the same basic design as conventional systems, but make alterations to achieve separation distance (mound systems) or disperse wastewater (low pressure dosing) in order to comply with septic regulations. Alternative systems often provide no material gain in nitrogen removal, and are only installed when conventional systems are not feasible at the site. Alternative systems typically cost $5,000 to $10,000 to install, and require more annual maintenance effort.

The last category contains the *innovative septic systems*. These systems utilize new technologies that are primarily intended to increase the removal of nutrients or other pollutants, especially compared to conventional septic systems. Innovative systems are primarily installed when local water quality concerns require greater nitrogen removal. And indeed, several innovative septic system designs have been demonstrated to achieve nitrogen removal on the order of 40-60% (Table 2). Aerobic treatment units, sand filters, and constructed wetlands have all been designed to improve the removal of nitrogen from septic tank effluent before its discharge to the drainfield. The drawback to innovative septic systems is that the installation cost and annual maintenance effort are high, primarily because of pumps and mechanical equipment that require more routine care. In addition, some innovative systems are still considered experimental, and may not be permitted in some jurisdictions. Furthermore, some researchers are dubious about the long-term performance of these systems, given that regular maintenance is critical to their performance.

**Septic System Regulation and Cleanout**

Currently, most septic systems are regulated by local public health authorities. Typically, the authorities review permits and siting for systems prior to installation, with a possible inspection after construction to assure that the system complies with permit conditions. After construction, long-term maintenance of the septic system is typically the responsibility of the individual homeowner. This is less than ideal, since studies have suggested that only about half of all septic owners maintain their systems according to recommended guidelines (*i.e.*, annual inspection and pumpout of the septic tank every three to five years (Swann, 1999; Gomez *et al*., 1992).

| Table 2: Nitrogen Removal for Innovative Septic Systems | | | | | |
|---|---|---|---|---|---|
| System Type | Nitrogen Removal Range (mg/L) | Average Nitrogen Removal (%) | Estimated Lbs. of N Removed * | Capital Cost ($ Per System) | Annual Maintenance Cost ($/yr) |
| Conventional Septic System | 10-40 | 20 | 5.5 | 2,700-6,700 | 95 |
| Intermittent Sand Filter System | 10-65 | 45 | 12.5 | 5,360-10,720 | 140 |
| Recirculating Sand Filter System | 40-85 | 60 | 16.75 | 6,000-10,700 | 195 |
| Aerobic Treatment Units | 25-65 | 55 | 15 | 3,000-6,300 | 225 |
| Constructed Wetland | 25-90 | 55 | 15 | 4,000-10,000 | 55 |
| *Sources: U.S. EPA, 1993; Reed et al., 1995; Tetra Tech, Inc., 1999; Mooers and Waller, 1997; MSSAC, 2000. *assumed 2.5 persons per system* | | | | | |

Inspection and maintenance can have a direct impact on the life span of septic systems. The design life of a septic system is estimated to be 12 to 20 years (MOSDTF, 1999). However, many existing septic systems are much older, having been installed several decades ago. For example, one national survey (US EPA, 2000) indicated that more than half of existing systems are more than 30 years old. The same survey found that at least 10% of all systems are not working at any given time. Another survey discovered that about one fourth of all septic systems in the Chesapeake Bay watershed are more than 30 years old (Swann, 1999). Nationally, more than 80 million homes were built before 1979, and many of these are served by septic systems that are presumably well beyond their design life.

**Septic System Failure From a Watershed Perspective**

For the watershed manager, it could be argued that every septic system experiences failure to some degree, since they can never produce zero wastewater discharge. Nationwide, failure rates for septic systems vary, but the regional rate of septic failure is reported to range between five and 40%, with an average of about 10%. Maryland and Virginia have reported failure rates of 5% for their septic systems (Fehr and Pae, 1997).

To further complicate the picture, septic system authorities often give conflicting definitions of failure. At the watershed level, a failing system may be considered one that discharges effluent with pollutant concentrations that can impair downstream water quality. An understanding of septic system failure is important, since it has implications for watershed-appropriate management.

Failures can usually be placed into one of three categories: hydraulic failures, subsurface failures, and treatment failures. *Hydraulic failure* is the type that people traditionally think of when talking about failing systems: the drainfield or distribution system has become completely clogged, and sewage backs up in the house or breaks out on the surface of the field. With hydraulic failure, the septic system discharges partially treated wastewater that can have nitrogen, phosphorus, bacteria, and BOD levels similar to untreated wastewa-

**Figure 2. An Example of Hydraulic Failure (Houston/Galveston Area Council, 2000)**

ter. This type of failure is often short-term in nature, since it is readily noticeable to the homeowner (see Figure 2). Because of the risks for public health, hydraulic failures are usually quickly corrected by local agencies once they are identified.

Hydraulic failures obviously deliver a significant amount of pollutants to local water bodies, especially in coastal and lake shoreline areas. For example, a study of phosphorus contribution from older septic systems to a lake in Washington state found a failing system that daily contributed 3.5 mg/L total phosphorus directly to the lake through surface flow (Gilliom and Patmont, 1983). The author suggested that poor siting in a wet area may have contributed to the problem.

Hydraulic failures obviously deliver a significant amount of pollutants to local water bodies.

With hydraulic failure, the threat of bacterial contamination becomes very important. Many reports of disease outbreaks are linked to ground water contamination by septic system effluent. In fact, effluent from septic systems is the most frequently cited source of ground water contamination leading to diseases such as acute gastrointestinal illness, hepatitis A, and typhoid (US EPA, 1986). Surface and groundwater impacts from hydraulic failures have been documented in a number of studies. For example, Cogger (1988) reported incomplete microbe removal when groundwater is near or at the same depth as the absorption trench. Another study of seasonally used septic systems in coastal Rhode Island found that fecal coliform concentrations at two sites were often in excess of marine recreational standards, even at 20 meters away from the soil absorption system. This was attributed to the absence of a biological clogging mat and poor distribution of effluent throughout the drainfield (Postma *et al.*, 1992).

The second category of septic system failure involves *subsurface plumes*. In this case sewage is distributed into the drainfield, but a plume of partially treated sewage moves through soil macropores, cracks or ditches. The extent of subsurface failure depends on site conditions and system age, but plume formation appears to be a fairly common occurrence in sandy soils. The main water quality problems associated with subsurface plumes are high nitrogen and phosphorus loads to downstream receiving waters.

Many studies have shown that subsurface nitrogen plumes have a major impact on local water quality. Several studies have reported nitrate ($NO_3$) concentrations varying from 10 mg/l to 70 mg/l within 10 to 100 feet from the drainfield (Caradona, 1998). For phosphorus, subsurface movement depends on soil texture and structure, pH, mineral content, and depth to the water table or confining soil layer. Most research has shown that phosphorus plumes are unusual in unsaturated soils with finer textures because most phosphorus is absorbed by the soil (Stolt and Reneau, 1991), and numerous studies have documented a high degree of phosphorus removal within the first few meters downgradient from the drainfield (Weiskel and Howes, 1992; Robertson *et al.*, 1991; Wilhelm *et al.*, 1994). It appears that for a properly functioning system not

**Table 3. Subsurface Plumes and Septic Systems**

| Study | Location | Results |
|---|---|---|
| Grant, 1998 | Indiana | A study of near-shore development on 18 lakes found septic plumes entering the lakes even though all failing septic systems had been replaced. Orthophosphate concentrations were found to be 2-10 times higher near-shore than for mid lake samples. |
| Harman *et al.*, 1996 | Ontario | Found nitrate plumes in the groundwater beneath a 44-year-old septic system with nitrate concentrations above drinking water limits as far as 100 meters from the drainfield. |
| Robertson *et al.*, 1991 | Ontario | A study documented rapid nitrification in a septic plume, with. nitrate concentrations in the plume core varying within a range from 21 to 48 mg/l. Nitrate concentrations did not change as the septic plume moved downgradient through a distance of 330 feet. |
| Robertson and Harman, 1999 | Ontario | A study of two decommissioned septic systems found that if a phosphate plume is present before decommissioning, downgradient P loading is not likely to diminish for several years and may constitute a threat to downgradient surface waters. |

| Table 4. Treatment Failure and Nitrate Contamination | | |
|---|---|---|
| Study | Location | Results |
| Arnade, 1999 | Florida | A study of 60 residential wells found a correlation between increasing nitrate and phosphate concentrations and decreasing well and septic tank distance during the wet season from July to September. |
| Horsley and Witten, 1994 | Massachusetts | Found that 74% of nitrogen entering the Buttermilk Bay estuary was due to septic system effluent. |
| MPCA, 1999 | Minnesota | A study in the town of Baxter found higher concentrations of nitrate in unsewered areas compared to sewered areas. These concentrations decreased with increasing well depth. |
| Pinnette *et al.*,1999 | Maine | Analysis of 18 subdivisions found that wells paired with septic systems older than 15 years had higher nitrate levels. |
| Tinker, 1991 | Wisconsin | Samples from five unsewered subdivisions found a correlation between decreasing lot size and increasing nitrate values in groundwater. |
| Tuthill *et al.*, 1998 | Maryland | Study found negative correlation between lot size and well contamination. The study also found that increasing well casing length was correlated with lower nitrate levels. |

located in soils conducive to plume formation, as much as 95% of the phosphorus may be retained in the soil (Mandel and Haith, 1992). The exception appears to be sandy soils and/or saturated soils, where movement of phosphorus into surface waters due to lower phosphorus adsorption capacity has been cited as a source of phosphorus to lakes (Sagona, 1988; Grant, 1998). Table 3 examines the results of number of studies of plume formation and nitrate and phosphate movement.

The final septic system failure category, *treatment failure*, may be the most ominous for the watershed manager trying to protect water quality, particularly in coastal waters that are nitrogen sensitive. Treatment failure means that sewage is adequately treated within the soils of the drainfield, but nitrogen is not reduced before it reaches groundwater. Nitrogen is delivered to groundwater in the form of nitrate, which can contribute to eutrophication in nitrogen-sensitive waters such as estuaries, coastlines and some springs. (It should be noted that nitrogen loads are also produced by the discharge of wastewater treatment plants, given how difficult it is to reduce nitrate from wastewater).

Research has shown that conventional septic systems can only remove about 10 to 20% of the nitrogen that enter them. As a result, an average of about 23 pounds of nitrogen (primarily nitrate) each year can move from the drainfield and into groundwater, if no treatment in the soil occurs. The ultimate fate of this nitrogen load is not known, although several research studies indicate that as much as 75% can be delivered to surface waters, depending on the terrain, soils and the physiographic region. Horsley and Witten (1994) reported that nitrogen concentrations attributable to septic effluent accounted for more than 74% of the anthropogenic nitrogen entering Buttermilk Bay, MA. Table 4 summarizes six studies that have examined well contamination and nitrate movement from septic systems.

**Causes of Failure**

Failure has many different causes, most commonly poor installation/location, hydraulic overloading and lack of maintenance (Table 5). Reported failure rates are quite variable, but even the most conservative estimates suggest that at least 5% of all septic systems are failing in any given year. Many failures are associated with inappropriate location of systems in areas with inadequate separation distances to ground water, insufficient absorption area, fractured bedrock, sandy soils (especially in coastal areas), or inadequate soil permeability. Improper design or installation, including smearing of trench bottoms during construction, compaction of the soil bed by heavy equipment, or improperly performed percolation tests can also contribute to system problems (US EPA, 1993).

| Table 5. Watershed Factors That Suggest Potential Subsurface Plume or Nitrogen Failure |
|---|
| Density |
| Lot Size |
| Well Casing Length |
| Proximity to Lakefront |
| Gradient |
| Soil Type |
| Water Table |

**Watershed Tank Density**

What indicators can be used to determine the potential impact of septic systems in a watershed? One useful indicator of potential impact is septic tank density (tanks per square mile). For example, based on our best estimates, about two million septic systems are currently in the ground in the Chesapeake Bay watershed, with another 15,000 to 20,000 new systems installed each year. The majority of the septic systems utilize the conventional septic tank and drainfield design. This equates to one tank per 20 acres. However, in a small watershed tank density can become significant: Figure 3 illustrates the relationship between septic density, watershed development and residential zoning for a 10 square mile watershed.

And certainly, an understanding of density is critical to the watershed manager concerned with collective septic system impacts. A number of studies have indicated that septic density is correlated to nitrogen loading to groundwater. Cogger (1988) reported on a study of nitrate levels in a shallow aquifer beneath a densely populated, 30 square mile unsewered area east of Portland, Oregon. Nitrate averaged nearly 8 mg/L, with some wells exceeding the 10 mg/L EPA standard. Population density was about five people/acre. Gold *et al.* (1990) also found that unsewered residential development using half-acre zoning could produce nitrogen loadings comparable to production agriculture. He recommended that denitrification systems be required on small lot zoning to ensure potable groundwater in coastal areas.

A knowledge of watershed tank density helps managers calculate potential subsurface waste flows from existing systems, identify areas of concern and plan for more intensive monitoring. In addition, septic density can be combined with information on system age to locate areas with high potential failure rates. Finally, septic density permits the watershed manager to estimate the sum of the potential pollutant load from both existing and future systems and determine the best way to control septic system discharges to meet water quality standards. Suggestions for changes in land use planning to limit new development in areas with high septic densities can be made to avoid additional nutrient loading to local waters.

**Potential Pollutant Loadings From Septic Systems**

Conventional septic tank effluent can contribute nitrogen, phosphorus, and bacteria to the drainfield, a fraction of which will eventually enter ground or surface waters. Of paramount concern to the watershed manager is the amount of these pollutants that will enter local lakes, streams, or estuaries. The many studies on septic system performance are often conflicting or confusing in this regard. However, a review of some basic numbers can help watershed managers understand the potential pollutant loads from septic systems.

The first numbers needed to make an estimate of potential septic system loads are per-capita or per household sewage flows. The average person generates about 40 - 80 gallons per day of wastewater, with households on septic systems tending to fall on the lower end of the range. The household sewage flow is easily estimated by multiplying the per capita flow rate by the average number of people per household (nationally, about 2.7 people per household). Under these calculations, approximately 108 - 218 gallons of waste-

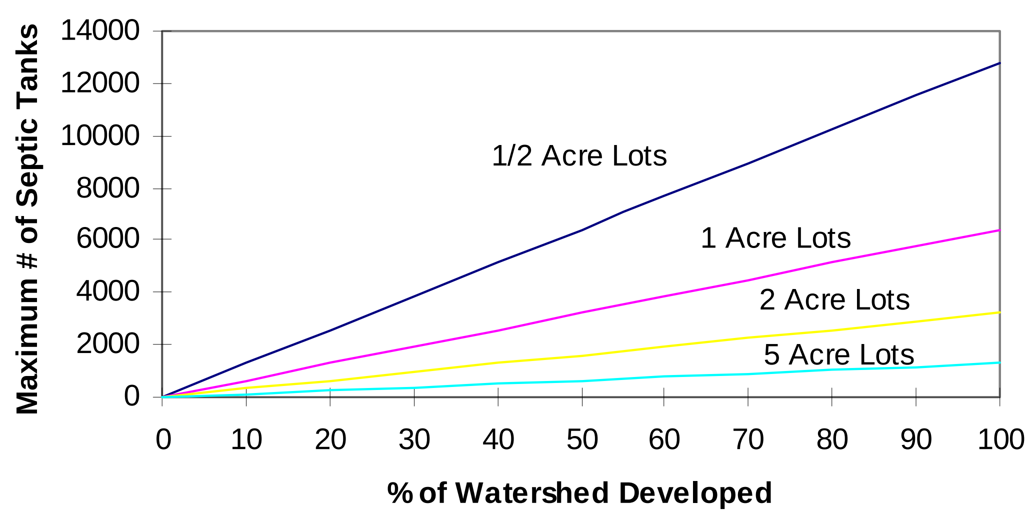



**Figure 3. The Relationship Between Septic Density and Watershed Development**

| Table 6: Characteristics of Untreated Residential Wastewater | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Source | | | | | |
| Constituent | Unit | Canter and Knox, 1985 | | Tchobanoglous and Burton, 1991 | | Burks and Minnis,1994 | |
| | | Range | Typical | Range | Typical | Range | Typical |
| TSS | mg/L | 221-300 | **250** | 240-600 | **436** | 100-400 | **220** |
| $BOD_5$ | mg/L | 217-310 | **300** | 216-540 | **392** | 100-400 | **250** |
| Total N | mg/L | 37-76 | **38** | 31-80 | **57** | 15-90 | **40** |
| Total P | mg/L | 24-25 | **25** | 10-27 | **19** | 5-20 | **12** |
| Total Coliform | # /100 ml | ND | **ND** | $10^7$-$10^{10}$ | **$10^8$** | $10^6$-$10^8$ | **$10^8$** |

*ND = no data*
*Numbers have been rounded*

water flows are produced daily by each household. To put these statistics into perspective, a one million gallon per day sewer system that collects and treats wastewater typically serves from two to 10 thousand households (with a mean of 7,500).

The next key number to calculate is the basic "strength" of untreated residential wastewater. Table 6 compares the relative concentrations of several pollutants frequently considered when determining septic system impacts.

Next, it is useful to calculate the potential household nutrient loading rate for septic tank effluent that could move into groundwater or surface waters. Table 7 provides typical concentrations of nitrogen, phosphorus, and fecal coliform bacteria found in septic tank effluent.

The actual nutrient load that ultimately reaches receiving waters is the most difficult number to calculate. The final delivery of pollutants to receiving waters is determined by both site conditions and the type of failure that a system might be experiencing. Some estimates of "edge of drainfield" concentrations have been reported (see Table 8), but final estimates for discharge of nitrogen to ground and surface waters are usually reported with the assumption that no attenuation in the soil occurs since the anaerobic conditions required for denitrification are usually absent.

**Septic Systems: An Agent of Sprawl or a Tool of Watershed Protection?**

One of the most difficult decisions facing a watershed manager involves deciding how to treat and dispose of wastewater in lightly developed watersheds (i.e., less than 15% impervious cover). Should a sewer be extended to collect wastewater, or should individual septic systems be relied upon to serve new development instead? The choice of how wastewater will be handled in a small watershed often has an enormous influence on its ultimate development density and percent impervious cover.

One of the most difficult decisions involves deciding how to treat and dispose of wastewater in lightly developed watersheds.

We recently engaged in an intensive search of the planning literature to find quantitative data on this topic. While there was no shortage of opinions on it, we could find little or no hard data to guide watershed planning. This gap is surprising, given the hundreds of local battles over sewer extensions or septic system regulations that have occurred in recent decades. This section seeks to outline the complex choices that accompany handling wastewater dischargers in a small watershed. On one hand, choosing to sewer a watershed can induce growth, since most communities cannot easily restrict which future developments will tap into the sewer. In addition, since extending sewers is costly, planners often concentrate development in fairly dense zoning categories that often collectively exceed 10% impervious cover in a small watershed. While the cumulative amount of potential development in a watershed can be controlled to some extent by the diameter or capacity of the sewer line, it is important to keep in mind

| Table 7: Characteristics of Septic Tank Effluent | | | | | |
|---|---|---|---|---|---|
| | | Source | | | |
| Constituent | Unit | Tchobanoglous and Burton, 1991 | SSWMP, 1978 | U.S. EPA, 1980 | Canter and Knox, 1985 |
| | | Range | Typical | Typical | Typical |
| TSS | mg/L | 50-90 | 49 | 77 | 75 |
| $BOD_5$ | mg/L | 140-200 | 138 | 142 | 140 |
| Total N | mg/L | 25-60 | 45 | 42 | 40 |
| Total P | mg/L | 10-30 | 13 | NR | 15 |
| Fecal Coliform | # /100 ml | $10^3$-$10^6$ | 5 x $10^6$ | NR | NR |

*NR = not reported*
*All numbers have been rounded*

that sewer capacity often increases over time. Sewer lines are much like roads, in that they can be easily expanded once capacity is exceeded. Consequently, a decision to sewer a watershed can often make it very difficult to meet a low watershed impervious cover limit over the long run. Other watershed implications associated with choosing to extend sewers are summarized in Table 9.

On the other hand, septic systems are often argued to be an agent of sprawl. Residential development that relies on septic systems for wastewater disposal is inherently of a low density nature, as most public health authorities require minimum lot sizes, reserve fields and soil suitability that effectively make it impossible to use individual septic systems on lots smaller than a half acre in area (and often one to two acres in size). Choosing to rely on septic systems typically means that large-lot zoning will become the primary watershed planning tool to stay below a watershed impervious cover threshold or limit.

| Table 8: Nitrogen Loading Rates From the Edge of the Drainfield (lbs N/yr) | |
|---|---|
| **Source** | **Pounds of Nitrogen** |
| Bauman and Schafer, 1985 | 20.98 ± 7.3 |
| EPA, 1980 | 22.8 |
| Mandel and Haith, 1992 | 25.6 |
| EPA, 1993 | 21.0 |
| Urish and Gomez, 1998 | 23.7 |

*Table adapted from Maizel et.al., 1997, and assumed 2.5 persons per system.*

In addition, planners should realistically assess how conventional septic systems make land development in a watershed easier and cheaper. For example, Swann (2000) recently compared the actual costs of constructing and maintaining septic systems on a typical residential lot in the Chesapeake Bay watershed, as compared with serving it with a public sewer. The cost analysis utilized recent survey data on septic and public sewer costs as reported by more than 20 localities in the Chesapeake Bay area. Swann found that the cost for a conventional septic system at a residential lot was about $3,400 less than the cost of providing public sewer, over a 20-year span.

This difference, termed a "septic subsidy," suggests that the life cycle costs for a conventional septic system are about 25% lower than for public sewer, assuming that they are regularly maintained. If a homeowner fails to regularly perform cleanouts, the cost differential grows to nearly 40%. This large septic subsidy makes land development with septic systems extremely attractive, particularly if rural land prices are low. Consequently, planners should be careful when using septic systems, given their potentially powerful influence on the conversion of open space in the watershed.

**Table 9. Key Watershed Issues to Consider When Choosing Wastewater Options**

| EXTEND SEWERS | | EMPLOY SEPTIC SYSTEMS | |
|---|---|---|---|
| **PRO** | **CON** | **PRO** | **CON** |
| Single NPDES permit | possible infiltration/inflow | potential growth control in watershed | harder to treat multiple units or dense development |
| greater probability of regular maintenance | probability of sanitary sewer overflows | lower life cycle cost per dwelling unit | subsurface nitrogen loads |
| potentially higher nitrogen removal, if BNR used | risk of induced growth | potentially higher nitrogen removal, if innovative systems | high potential for future failure, in some areas |
| immediate repair for failing septic systems | higher life cycle cost per dwelling unit | | hundreds of owners to monitor |
| utility structure exists for wastewater mgmt | physical alteration of stream corridor by sewer line construction | | no enforcement mechanism to maintain, upgrade or rehab older units |
| | | | potential well contamination |

It should be noted that the septic subsidy completely disappears when innovative septic systems are installed to reduce nitrogen loads. Over a 20-year period, the cost to construct and maintain innovative septic systems was roughly equivalent to the average cost for public sewer.

Still, septic systems can be a useful tool for achieving watershed impervious cover limits of 10 or 15%, if their aggregate impact on pollutant loading and land conversion are considered in a watershed plan. For example, watershed managers might want to consider setting a minimum residential lot size greater than one acre. As noted by Cappiella and Brown (this issue), even one-acre lot zoning produces more than 10% impervious cover across a small watershed, unless a considerable fraction of watershed area cannot be developed because of the presence of parks, farms, steep slopes, flood plains, wetlands, buffers, conservation areas or unsuitable soils.

Watershed managers should also carefully evaluate the available range of alternative septic systems that can be installed in the watershed. Often, these alternative systems enable septic treatment on sites where conventional septic systems are unsuitable, and consequently, increase the inventory of buildable residential lots in a watershed. In some cases, this may exceed maximum impervious cover thresholds or targets for a small watershed. In addition, while alternative septic systems alleviate many site constraints, most provide no material improvement in pollutant reduction, particularly for nutrients. Lastly, alternative systems usually have higher maintenance needs, and thus may present a higher risk of one of the three kinds of potential failure.

**Septic System Criteria for Sensitive Watersheds**

If septic systems are chosen to treat wastewater in a sensitive watershed, managers should carefully regulate where and how they are installed, and whether or not they should use innovative technologies to reduce nitrogen. With this in mind, 10 criteria should be considered when regulating septic systems to protect a sensitive watershed:

> Planners should realistically assess how conventional septic systems make land development in a watershed easier and cheaper.

*1. Designate Areas of Concern in the Watershed.* More stringent septic system setbacks and/or innovative technologies should be required for new systems located within areas of concern (MOSDTF, 1999). Examples of potential areas of concern that might be delineated within a watershed include areas with the following characteristics:

- Have experienced prior widespread failures
- Drain to water supply reservoirs
- Are within a wellhead protection area

- Currently experience high nitrate concentration in wells
- Are in close proximity to tidal waters
- Are in close proximity to lake shorelines
- Have karst terrain
- Drain to shellfish beds or swimming beaches

*2. Setbacks*: Communities should examine their mandatory distances from streams, ditches, tidal water waters, lake shorelines, and down gradient wells to ensure adequate water quality protection.

*3. Separation Distances*: The vertical separation from bedrock, confining soil layers, or seasonally high water table should be based on soils and terrain, but should be a minimum of two to four feet.

4. *Reserve Fields*: For communities that have a reserve field requirement, the reserve area should also be afforded protection. This might include marking the location on septic systems plans, placing restrictions on how the land is used, and avoiding activities that could compact the soil. In addition, communities might examine the concept of alternating drainfields on a regular basis to extend the life of the system.

*5. Alternative Technology*: Communities should establish a certification/verification process for alternative technologies (MOSDTF, 1999).

*6. Innovative Technology*: When an onsite wastewater treatment system is to be located in an area of concern, regulations should require either mandatory or preferred use of recirculating sand filters, aerobic treatment units or constructed wetlands.

*7. Creation of septic management districts or enforceable maintenance agreements*. Lack of maintenance is a leading cause of septic failure, and communities should create a mechanism to guarantee continued maintenance (see Table 10).

*8. Minimum Lot Size*: Given the minimum lot sizes established by zoning, watershed managers should calculate what the impervious cover will be to ensure that impervious cover limits or targets are not exceeded.

9. *Inspections and certification*: Many communities have made inspections of existing systems mandatory at time of real estate transfer, expansion or change in use (*e.g*., Massachusetts, Wayne County, MI, Cuyahoga County, OH, Thurston County, WA, Stinson Beach, CA). An example of a septic inspection ordinance is available at the Center for Watershed Protection website at www.cwp.org.

10. *Allow shared systems*: Shared wastewater systems should be permitted for appropriate open space or cluster subdivisions that promote greater watershed protection.

EPA plans to publish a new *Onsite Wastewater Treatment Systems Manual* in 2001 that will encourage the use of performance-based systems and will contain current information on the performance and design of alternative systems, especially those installed in areas with sensitive or threatened water resources. Check the EPA Office of Wastewater Management website at http://www.epa.gov/owm/decent for more information.

**Septic System Maintenance Programs**

Proper maintenance of existing and new septic systems should be an integral part of local watershed plans. A recent survey found that 46% of septic system owners in the Chesapeake Bay had not performed a pumpout in the recommended timeframe (Swann, 1999). An extrapolation of this number across the Chesapeake Bay suggests that almost a million septic systems are not properly inspected or maintained.

A number of variables should affect how the management of septic systems occurs. These include protection of public health, the sensitivity of the receiving environment, the cost of the treatment processes and/or equipment employed, and the resources and administrative authority of the local government. A comprehensive septic system management program should ultimately contain the following elements:

1. System performance requirements to protect human health and the environment
2. System management agreements or guidelines to maintain performance
3. Compliance inspection and enforcement to ensure system performance is maintained
4. Technical guidelines for site evaluation, design, construction, operation and acceptable designs for specific site conditions and use
5. Training and certification/licensing for system installers and septage haulers

6. Program audits to maintain the foundation of the management program on sound practices and procedures

A number of program options exist to improve the maintenance of septic systems. These programs may use a variety of tools to keep existing septic systems properly maintained, such as regular inspection programs, discharge permits, certification at time of sale and resale, operational permits, and mandatory inspection contract requirements. Several innovative septic system management programs are profiled in Table 10. Communities should consider adopting these innovative programs, especially for sensitive watersheds such as drinking water reservoirs, natural lakes, and coastal shellfish areas. In addition, the responsibilities of septic system ownership should be a stronger and more consistent theme of watershed education programs.

The US EPA recognized the importance of improved management with its recently issued draft guidelines for management of septic systems. The guidelines include a description of five model management programs designed to improve the level of septic system performance. The goal of these model programs is to manage septic systems on a watershed basis through performance standards and progressively more rigorous management requirements. The draft guidelines and outline of the guidance manual are available at http://www.epa.gov/owm/decent.

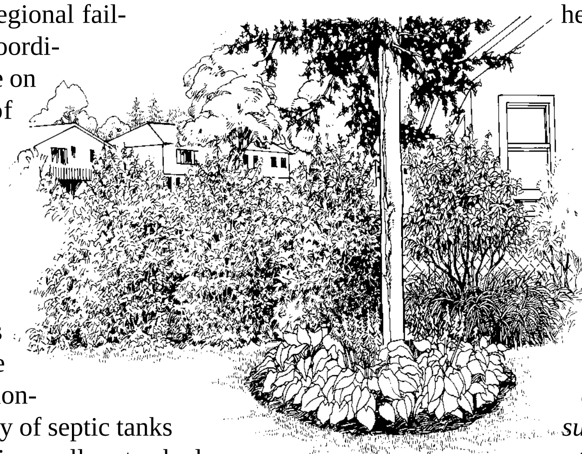
**Watershed Research Needs**

A recurring theme of this article is our uncertain understanding of real world performance of septic systems. Consequently, there are four critical research priorities that would be of great value to watershed managers.

**Table 10. Existing Septic System Management Programs**

| Entity | Management Activity |
|---|---|
| Catskill Watershed Corporation, New York | Not-for-profit corporation that provides subsidies for septic system upgrades or replacements. The CWC reimburses 60-100% of the eligible costs for residents in areas designated as highly sensitive to water quality for repair of failing systems. |
| Cuyahoga County Board of Health, Ohio | Annual operational permits required. Operation and Maintenance Program provides for countywide stream monitoring and sampling. Point-of-sale inspections and nuisance complaint investigations, operational maintenance inspections of household sewage systems. Offers low interest loans to homeowners to repair or replace failing systems. Registers septic system installers. |
| Hamilton County, Ohio Health Department | Inspect mechanical septic system on a yearly basis. Non-mechanical systems inspected at least once every 5 years. Final inspection performed after system installation. Department reviews plans for all new subdivisions less than five acres and individual plots for soil suitability for system use. |
| Kitsap County-Bremerton Health Department, Washington | Certifies maintenance specialists. Keeps records of as-built drawings of most installed drainfield after 1970. Provides inspections and places notices on titles for properties with alternative systems. |
| Stinson Beach County Water District, California | Operational permits issued for 1-2 years following inspection by staff. Every system inspected at least once every three years and at change of ownership. District approval of system design required before issuing of a building permit for new construction. Monitoring of surface and groundwater to detect possible occurences of failure. |
| Thurston County Department of Environmental Health, Washington | Professional training and certification of designers, installers, pumpers, and monitoring specialists. Review of permit applications for new systems, repaired systems, or expanded systems. Issuance and renewal of Operational Certificates for 1-4 years. Evaluation of systems when property is sold and initial inspection when a permit is issued. Administration of a low-interest loan program to help those who need financial assistance to repair failing systems. |

First, most watershed managers lack basic research and tracking of the performance of septic systems in their watershed. More systematic reporting of working and failing septic systems is recommended in order to accurately assess the potential impacts of system discharges on water quality. Better coordination among local public health authorities is also needed to get better estimates of regional failure rates. In addition, coordination is needed to agree on common definitions of failure, standard inspection protocols, and isolate critical site factors that lead to higher nitrogen loading.



Second, research is required to determine whether consistent relationships between the density of septic tanks and water quality exist in small watersheds, especially with regards to bacteria, nitrogen and phosphorus. Research is also needed to determine whether these relationships can be detected during storm events or dry weather flow.

Third, we need to improve our ability to predict the delivery of nutrients from the edge of the drainfield to surface waters, and in particular, isolate the critical factors at a site that influence this subsurface delivery. Further research is needed to identify whether denitrification can be promoted or enhanced within stream or shoreline buffers.

Lastly, more data is needed on the performance of aging septic systems in order to determine whether these older systems contribute higher nitrogen and phosphorus loads. This research effort could involve systematic groundwater sampling around both older and younger drain fields under controlled soil, terrain and geologic conditions. This monitoring would help watershed managers determine whether the estimated 12 million septic systems nationwide that are more than 30 years old should be targeted as a controllable source of nutrients.

**Conclusion**

Septic systems are a frequently cited but poorly understood water quality problem. In 1996, septic systems were identified as a leading source of pollution for ocean shorelines, and were reported to be the third most common source of groundwater contamination (US EPA, 1996). Unfortunately, septic systems have seldom been managed or regulated from a watershed perspective. The need to revamp siting and maintenance requirements for septic systems has recently received much-needed attention by government agencies and wastewater professionals. The push for new performance standards as part of a comprehensive watershed approach is welcomed, but many questions still remain about the true role of septic systems in watershed management. More watershed research is needed to get a clearer picture of the impact of these enigmatic pollutant sources on the health of out nation's watersheds.

***Editors Note:*** *The Center recently completed a review of septic system related literature, and has made the bibliography available at our Stormwater Manager's Resource Center (SMRC) website at www.stormwatercenter.net. The bibliography contains short synopses of more than 80 references dealing with numerous issues regarding septic system impacts, costs, performance and design, and policy and management. The bibliography provides an excellent starting point for watershed managers interested in learning more about the role of septic systems in watershed management.*

**Septic System Websites**

National On-Site Wastewater Recycling Association (NOWRA): **www.nowra.org**

National Small Flows Clearinghouse (NSFC) **www.estd.wvu.edu/nsfc**

Septic System Owner's Guide and Other Sewage Treatment Pubs **www.extension.umn.edu**

U.S. EPA Office of Wastewater Management **www.epa.gov/owm/decent**

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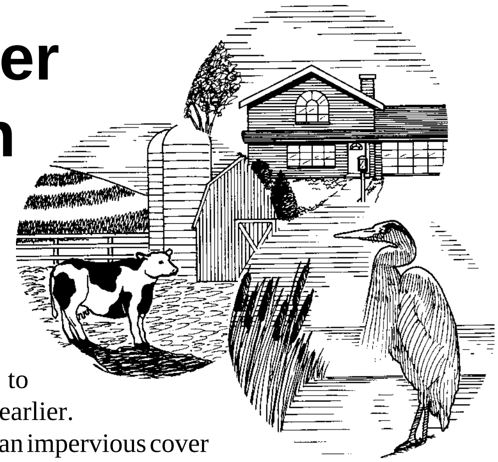
# Land Use and Impervious Cover in the Chesapeake Bay Region



*by Karen Cappiella and Ken Brown*

**Introduction**

Recent research has revealed a strong relationship between impervious cover and various indicators of stream quality. But while more than 40 scientific studies have confirmed this general relationship in different regions of the country (Sturm, in press), only a handful have directly examined how much impervious cover is produced by different urban land uses or zoning categories.

And certainly, accurate estimates of current and future impervious cover are critical to rapid urban watershed planning (CWP, 1998a). Impervious cover is an excellent index of watershed development, and can be used to predict potential stream quality within subwatersheds, identify which are most vulnerable to future development, and guide watershed zoning and protection efforts. Impervious cover is also a fundamental input to most models that predict runoff or pollutant loadings in watersheds, regardless of whether they are simple or complex.

While existing impervious cover can be directly measured using aerial photographs or satellite imagery, it is often much easier to estimate it based on the current land use distribution in a watershed. In addition, land use/impervious cover relationships are indispensable for forecasting future levels of impervious cover in a watershed, based on the gradual buildout of zoned land. In either case, the total area in each land use category is multiplied by its mean percent impervious cover to obtain the impervious cover for the watershed as a whole. Clearly, the accuracy of this approach depends on a strong and consistent relationship between each land use and the corresponding percentage of impervious cover. A series of regional land use/impervious cover relationships have been published over the last two decades (Beyerlin and Brascher, 1994; COPWD, 1995; Kluitenberg, 1994; NRCS, 1986; NVPDC, 1980; Prisloe *et al*., 2000, and Roberts, 1999).

Typically, these studies present an average percent impervious cover associated with common zoning categories (one-acre residential lots, commercial, townhouses, etc). However, when these land use/impervious cover relationships are compared, it is evident that they are not very consistent. For example, the mean percent impervious cover for one-acre lot residential zoning ranged from seven to 20% in the seven studies cited earlier. For commercial zoning, the mean impervious cover ranged from 45 to 95%. Similar variability was found for industrial zoning (53 to 90%), quarter-acre residential lots (14 to 38%) and townhouses (39 to 65%).

The extreme variability among regional land use/impervious cover relationships could have several causes. For example, the variability could reflect real differences in regional development patterns, which implies that specific and unique relationships must be derived for each region of the country. The most probable explanation for the variability, however, is that it simply reflects a lack of standardization in how impervious cover is actually measured by individual researchers.

Indeed, a lack of standardization in study methodology becomes evident upon close inspection of the individual studies. In some cases, the relationships were derived based on best professional judgement, while others reflect actual measurement. Even when impervious cover was actually measured, the researchers did not use a consistent definition of impervious cover. For example, roads and highways were excluded from some estimates, while driveways and sidewalks were omitted from others. In addition, total impervious cover was measured in some studies, while others measured "effective" impervious cover (i.e., hard surfaces directly connected to the storm drain system). Finally, the studies had no uniform standards to account for urban open space in each land use category, such as stream buffers, parks, wetlands, forest conservation areas and other "unbuildable" land.

> Accurate estimates of current and future impervious cover are critical to rapid urban watershed planning.

Given the fundamental role of impervious cover in watershed planning, it is important to establish standard techniques for identifying consistent relationships between urban land uses and impervious cover. To fill this gap, the Center recently completed a major study exploring these relationships in four suburban communities in the Chesapeake Bay Region.

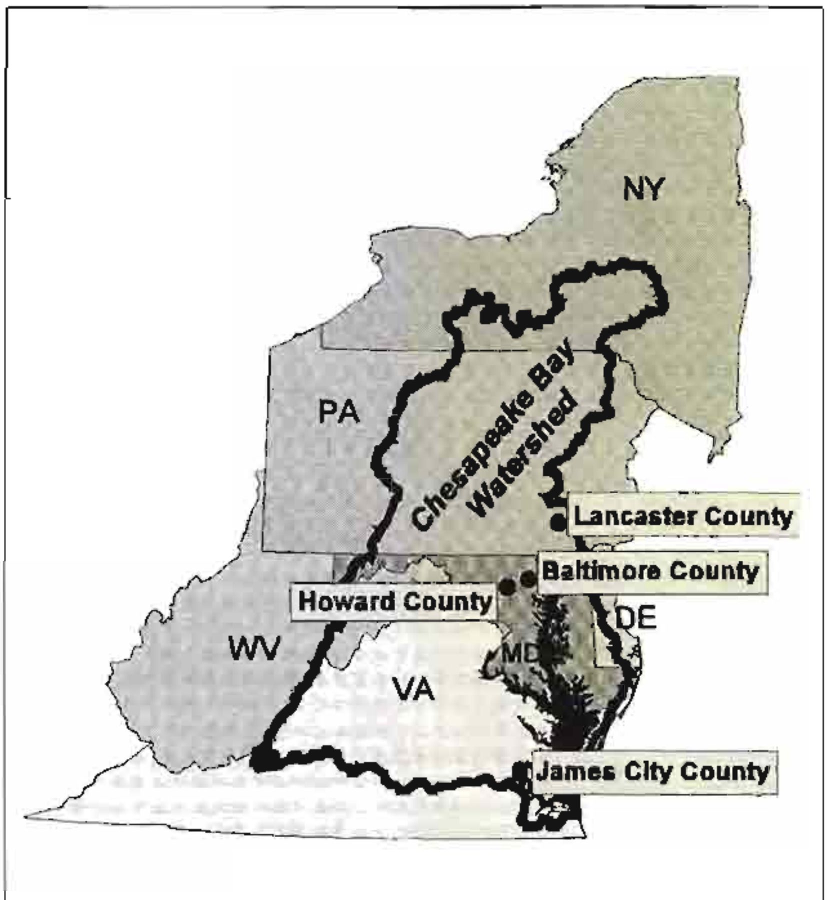


Figure 1. Suburban Counties Analyzed in the Study

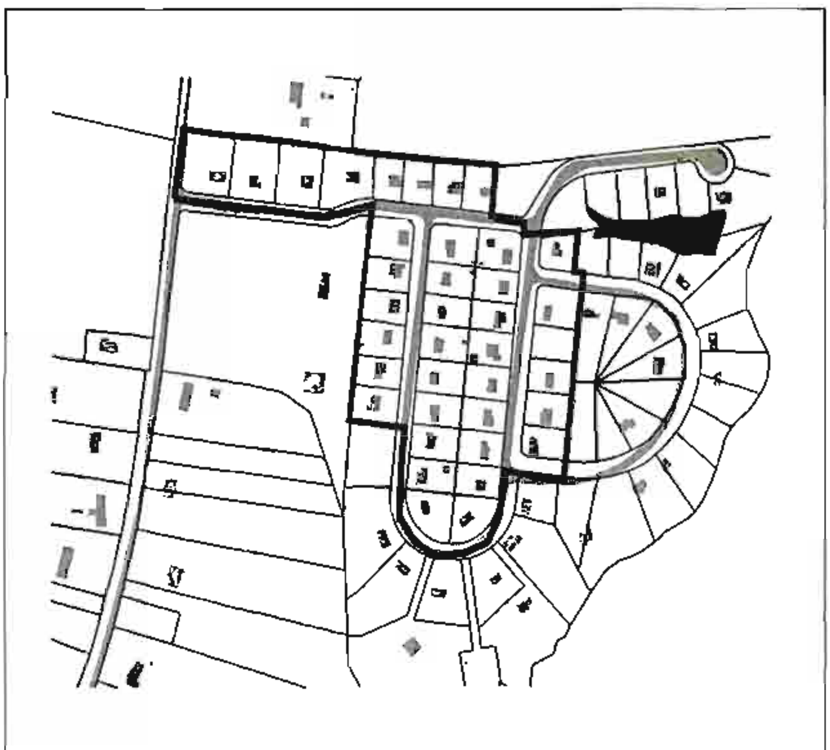


Figure 2. Example of a Typical Land Use Polygon Analyzed in the Study

The Center analyzed 210 polygons of homogeneous land use from the Geographic Information Systems (GIS) of four Chesapeake Bay communities. The study was designed to obtain more precise estimates of the mean impervious cover associated with 12 common land use categories. The four communities sampled were Baltimore County, MD; Howard County, MD; James City County, VA; and Lancaster County, PA; their locations are shown in Figure 1.

Development patterns in each county were suburban in nature, and most of the polygons sampled included developments that were constructed in the last three decades. Consequently, the impervious cover estimates reported here primarily apply to recent suburban development, and may not be transferable to either ultra-urban areas or older developments. Lastly, large freeways and limited access arterials were excluded from the sample polygons; therefore, their contribution to impervious cover must be calculated separately. A typical example of the land use polygons produced by the GIS and evaluated in the impervious cover study is shown in Figure 2.

The standard protocol for deriving a total impervious cover estimate for each polygon is provided in Cappiella and Brown (2001). It is important to note that each county GIS was slightly different, and several adjustments were performed. A common example is that many GIS do not include sidewalks or driveways, as shown in Figure 3. We developed simple algorithms to estimate their contribution to impervious cover.

Our impervious cover estimates for individual suburban land use categories are presented in Table 1. Surprisingly, impervious cover estimates within each land use category exhibited little variation, as indicated by the small standard error associated with the group means.

Statistical analysis demonstrated that the mean impervious cover estimates for the same land use category were consistent across the four counties sampled. A statistically significant difference between mean impervious cover for an individual county and its peers was detected in only five out of 48 comparisons. The differences that occurred were typically found for low-density residential development categories. Overall, it appears that the impervious cover/land use relationships were robust, and can be generalized beyond the individual counties in which they were derived. We expect that they are broadly transferable to other Chesapeake Bay communities with similar development patterns.

The institutional and open urban land categories exhibited greater variability in impervious cover than any other land use category. The primary reason for this is the diversity of development types that occurs within these loosely defined categories. Institutional land uses included schools, churches, and other municipal operations, while the open urban land category included golf courses, urban parks, and cemeteries. More specific estimates of impervious cover were derived for these subcategories, and these are presented in Table 2.

Because the individual components of impervious cover were directly measured in this study, it was possible to determine what percentage of the urban landscape was devoted to building footprints (i.e., people habitat), as compared to streets, driveways and parking lots (i.e., car habitat). Car habitat exceeded the building footprint in every land use category, ranging from 55 to 75% of the total impervious surface area, as shown in Table 3.

In addition, the vast majority of land use polygons analyzed in this study used traditional subdivision geometry, as opposed to more innovative development that incorporates better site design techniques (CWP, 1998b). This finding suggests that better site design techniques that reduce the amount of car habitat have the most potential to reduce the mean impervious cover associated with that land use category. Consequently, if widespread implementation of better site design is anticipated within a locale, it may be necessary to adjust the numbers downward (Caraco, this issue).

### An Improved Method to Estimate Impervious Cover at the Watershed Level

A simple four-step procedure was developed to use these new impervious cover relationships to produce reliable estimates of current or future impervious cover at the watershed level. First, the area of each land use and major roads such as freeways and limited access arterial roads is calculated. Current land maps are used to estimate current impervious cover use, and zoning maps of future watershed buildout are used to calculate future impervious cover. Second, areas of known "unbuildable" land are subtracted from each land use area. These may include large tracts of lands in floodplains, wetlands, stream valleys and major conservation areas, and these areas may be calculated from sources such as flood maps, contour maps and national wetland inventory maps. Next, the built and buildable area of each land use is multiplied by our land use/impervious cover coefficients to yield a provisional estimate of impervious cover for each land use. This step is also done for the area of major roads, assuming 75% imperviousness (based on Roberts, 1999). Finally, the impervious area for each land use and major roads are added and divided by the watershed area to determine the imperviousness of the entire watershed. This standard method for estimating existing and future impervious cover should be useful for both watershed planners and researchers. The four-step method to estimate watershed impervious cover is illustrated in Table 4 using the hypothetical example of Sadie Run.

**Figure 3. GIS Data Does Not Always Reveal All Impervious Cover (note missing sidewalks and driveways)**

**Table 1. Impervious Cover Estimates for the Chesapeake Bay Region**

| Land Use Category | Sample Number (N) | Mean Impervious Cover (SE) |
|---|---|---|
| Agriculture | 8 | 1.9 ± 0.3 |
| Open Urban Land | 11 | 8.6 ± 1.64 |
| 2 Acre Lot Residential | 12 | 10.6 ± 0.65 |
| 1 Acre Lot Residential | 23 | 14.3 ± 0.53 |
| ½ Acre Lot Residential | 20 | 21.2 ± 0.78 |
| 1/4 Acre Lot Residential | 23 | 27.8 ± 0.60 |
| 1/8 Acre Lot Residential | 10 | 32.6 ± 1.6 |
| Townhome Residential | 20 | 40.9 ± 1.39 |
| Multifamily Residential | 18 | 44.4 ± 2.0 |
| Institutional | 30 | 34.4 ± 3.45 |
| Light Industrial | 20 | 53.4 ± 2.8 |
| Commercial | 23 | 72.2 ± 2.0 |

**Table 2. Impervious Cover Results for Institutional and Open Urban Land Uses**

| Land Use Category | Sample Number (N) | Mean Impervious Cover (SE) |
|---|---|---|
| Churches | 8 | **39.9** – 7.8 |
| Schools | 13 | **30.3** – 4.8 |
| Municipal | 9 | **35.4** – 6.3 |
| Golf Courses | 4 | **5.0** – 1.7 |
| Cemeteries | 3 | **8.3** – 3.5 |
| Parks | 4 | **12.5** – 0.7 |

**Applicability and Future Research Needs**

Are these numbers transferable outside of the Chesapeake Bay Watershed? As stated earlier, the counties used in this study were suburban in nature, and most developments were constructed after 1970. Therefore, the resulting numbers may not be transferable to either highly urban areas or developments that predate World War II. However, the numbers do provide a better estimate than most existing coefficients because of the standardized methods used.

Table 5 compares our impervious cover coefficients with those derived from 360 test sites in Milwaukee, Wisconsin (Bannerman, 2001). These numbers were derived using direct measurement; however, only the connected impervious cover was measured (i.e., Effective Impervious Area). Bannerman's numbers are consistently higher than our impervious cover estimates, which suggests that there is less green or open space available in highly urban areas such as Milwaukee as compared with suburban developments. Bannerman's numbers provide reasonable estimates of impervious cover for ultra-urban areas until new numbers are derived using the standard methods developed here. Currently, the Center is partnering with Nonpoint Education for Municipal Officials (NEMO) to obtain regional estimates around the country (Prisloe, 2000 provides a description of NEMO's impervious cover research).

While this project was successful in both estimating impervious cover for common land uses and establishing a standard method for doing so, further impervious cover research would be helpful for both planners and engineers. Specifically, four key issues merit further investigation. First, the age of development may influence the basic land use/impervious cover relationship. Second, the amount of impervious cover on a lot may actually increase with property value; an example is shown in Figure 4. Third, a growing number of communities are employing better site design techniques that minimize impervious cover, such as open space or cluster residential subdivisions. This needs to be taken into account when computing overall impervious cover estimates. Lastly, some pervious areas such as lawns and athletic fields may essentially act as impervious surfaces due to years of compaction (CWP, 2000). Further research could focus on accounting for urban soil compaction in estimating impervious cover at the watershed level.

**Table 3. Car Habitat % for Suburban Land Uses**

| Land Use Category | Car Habitat* (%) |
|---|---|
| Agriculture | 56 |
| Open Urban Land | 65 |
| 2 Acre Lot Residential | 75 |
| 1 Acre Lot Residential | 65 |
| ‰ Acre Lot Residential | 60 |
| 1/4 Acre Lot Residential | 56 |
| 1/8 Acre Lot Residential | 56 |
| Townhome Residential | 55 |
| Multifamily Residential | 61 |
| Institutional | 67 |
| Light Industrial | 67 |
| Commercial | 72 |

** percent of total impervious surface allocated to streets, driveways and parking lots*

**Figure 4. The Affluence Effect on Imperviousness**

## Table 4. The Four Steps to Estimating Impervious Cover

**Step 1.** Calculate area of current or future land use and major roads in the watershed

**Step 2.** Calculate area of unbuildable land within each land use and subtract from each land use area

$$\mathbf{A_{LU} - A_{UL} = A_{BL}}$$

where $A_{LU}$ = area of land use

$A_{UL}$ = area of unbuildable land

$A_{BL}$ = area of built and buildable land

**Step 3.** Multiply the built and buildable area for each land use and major roads by the corresponding impervious cover coefficient (derived from Cappiella and Brown, 2001)

$$A_{BL} * IC = A_{IC}$$

where $A_{BL}$ = area of buildable land

IC = impervious cover coefficient

$A_{IC}$ = impervious area

**Step 4.** Add the impervious area for each land use and major roads, divide by the watershed area and multiply by 100 to get an impervious percent for the watershed

$$\mathbf{SUM(A_{IC}) = TA_{IC}}$$

$$\mathbf{(TA_{IC} / TA) * 100 = IC\%}$$

where $TA_{IC}$ = total area of impervious cover

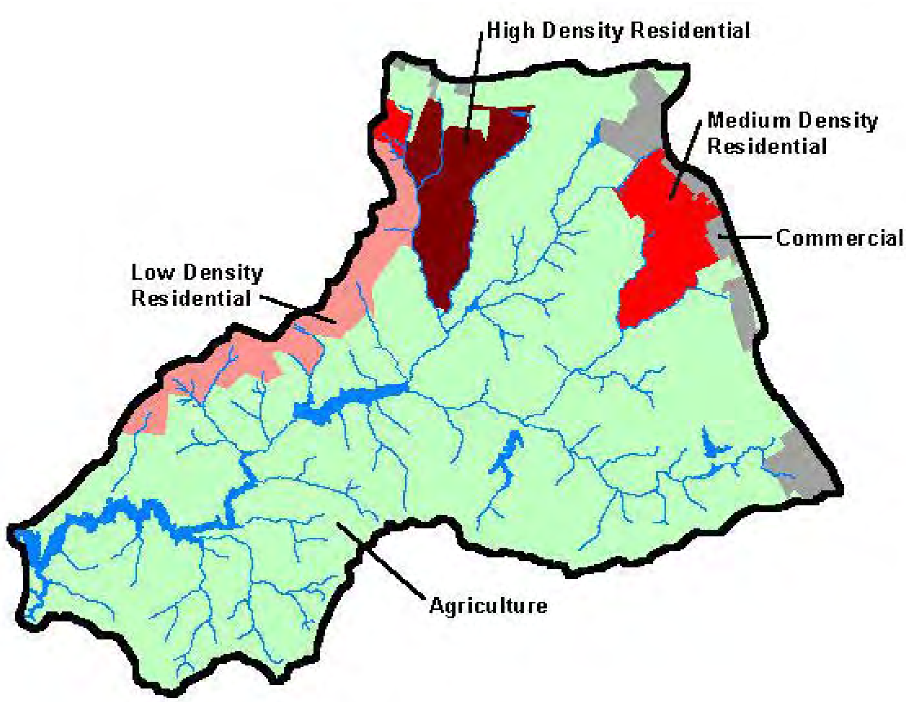
TA = total area of watershed

IC% = impervious cover percent for the watershed

**Example Calculation For Sadie Run Watershed**

| Land Use | Total Acres | Acres Unbuildable Land | Acres Buildable Land | Impervious Cover Coefficient | Acres Impervious Area |
|---|---|---|---|---|---|
| Agriculture | 408 | 32 | 376 | .02 | 8 |
| Low Density Residential | 42 | 3 | 39 | .13 | 5 |
| Medium Density Residential | 48 | 5 | 43 | .25 | 11 |
| High Density Residential | 54 | 8 | 46 | .33 | 15 |
| Commercial | 36 | 4 | 32 | .72 | 23 |
| Major Roads | 12 | 0 | 12 | .75 | 9 |
| Total | 600 | 52 | 548 | | 71 |

**Watershed Imperviousness = 12%**



| Table 5. Comparison of Impervious Cover for Suburban and Ultra-Urban Areas | | |
|---|---|---|
| **Landuse** | **Chesapeake Bay Impervious Cover %** | **Ultra-Urban Connected Impervious Cover % (Bannerman, 2001)** |
| High Density Residential* | 33% | 41% |
| Multifamily | 43% | 49% |
| High-Rise Residential | - | 64% |
| Schools | 30% | 39% |
| Industrial | 53% | 69% |
| Commercial* | 72% | 83% |
| Shopping Center | - | 92% |
| Downtown Commercial | - | 96% |

**high density residential is defined as lot size < 1/5 acre, commercial includes strip malls and office parks*

**Implications for Watershed Managers**

As impervious cover is an excellent indicator of watershed development and potential stream quality, accurate impervious cover estimates are essential for watershed planning. However, many watershed organizations and local communities have not measured impervious cover in their watersheds, and may not have the GIS capability to do so. Our study provides these groups with two important tools: impervious cover estimates for a dozen common land use categories, and a simple, standard method for estimating current and future impervious cover at the watershed level.

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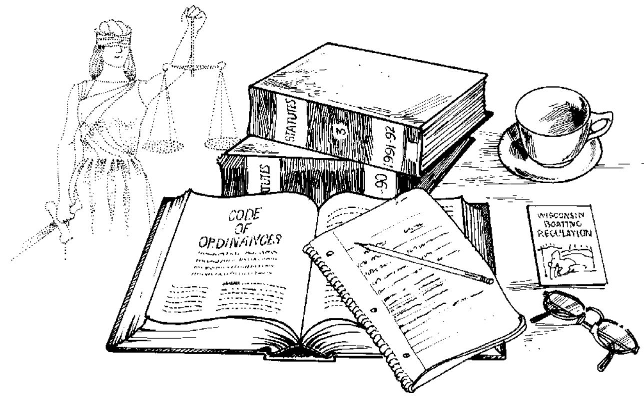
# New Resources from the Center for Watershed Protection




The past year has seen the Center busily working to continue our tradition of developing current, comprehensive and practical technical guidance. Some of our most notable accomplishments are designed to help smaller communities comply with the NPDES Phase 11 stormwater regulations soon to take effect, while other initiatives focused on quantifying the relationships between different land uses and impervious cover, analyzing the effectiveness of current stream restoration techniques, and tracking the effectiveness of various water quality treatment techniques.

All of the publications and products discussed here are available right online from the Center's website at http://www.cwp.org.

**The Stormwater Manager's Resource Center**

Located at http://www.stormwatercenter.net, the Stormwater Manager's Resource Center was created to provide a free technical resource for communities trying to protect, restore or enhance their local water resources. The website features more than 2,000 pages of technical content designed to give stormwater managers and watershed planners the practical, technical know-how they need to restore and protect aquatic resources, including a manual builder section that planners can use to create their own stormwater management manual, a dozen graphic-intensive slideshows, samples of model ordinances from around the country, comprehensive pollution prevention fact sheets, easy-to-use tools for monitoring and assessment, and a searchable 600-reference library.

***The Practice of Watershed Protection: Techniques for Protecting and Restoring Urban Watersheds***

Some 10 years in the making, this comprehensive handbook assembles 150 articles on all aspects of watershed protection in one magnificent reference. Drawn from past issues of *Watershed Protection Techniques* as well as a wealth of other Center publications and reports, *The Practice of Watershed Protection* represent a broad interdisciplinary approach to restoring and maintaining watershed health. Indexed for easy reference and with new thought-provoking introductory material by the Center's Tom Schueler, this massive volume is an invaluable reference for watershed planners, engineers, local government officials, citizen groups and anyone interested in the whys and hows of watershed protection practices. Approximately 800 pages hardback; also available on CD-ROM.

***Watershed Treatment Model***

This publication documents the Watershed Treatment Model (WTM), a simple spreadsheet that tracks pollutant sources and the effectiveness of various watershed treatment options in urban and urbanizing watersheds. The WTM tracks a full range of treatment options, and allows engineers and watershed planners to adjust practice performance based on the level of implementation in the watershed. Watershed managers can use the WTM for several purposes, including developing TMDLs for nutrients or sediment; directing bacteria detective work in urbanized watersheds; determining the effectiveness of watershed education programs; and targeting the future program in a Phase II community. The WTM spreadsheet is included with the publication on CD-ROM. Approximately 115 pages plus appendices.

***National Pollutant Removal Performance Database* - 2nd Edition**

The second edition modifies, clarifies, and expands upon the original *National Database of BMP Pollutant Removal Performance*. This comprehensive report contains summaries of more than 135 urban pollutant removal monitoring studies. Includes a statistical and graphical comparison of removal rates for six groups of stormwater management practices: ponds, wetlands, open channels, filters, infiltration and onsite devices. In addition, key research gaps in terms of parameters and practices are identified. For ease of use, the report contains a full bibliography. Approximately 29 pages, plus a 139-record database and appendices.

***Impervious Cover and Land Use in the Chesapeake Bay Watershed***

This report summarizes a Center study that analyzed 12 suburban land uses in four Chesapeake Bay watershed communities. The study derived impervious cover-land use coefficients that can be used along with land use data to estimate current and future impervious cover in your own watershed. Also included in the report is a method of using these numbers to estimate impervious cover, a detailed study methodology, a review of other methods of estimating impervious cover, and an analysis of research documenting the relationship between impervious cover and stream quality. Approximately 51 pages.

### *Urban Stream Restoration Practices: An Initial Assessment*

This photo-rich publication assesses the performance of 24 different urban stream restoration practices from sites around the Mid-Atlantic and Mid-west and provides recommendations for improving their application in a variety of urban stream environments. Approximately 232 pages plus appendices.

### *The Do-It-Yourself Local Better Site Planning Roundtable Kit*

Designed for watershed planners, government officials, and citizen activists alike, this innovative Do-It-Yourself kit contains all the information and materials you need to get a local better site planning roundtable started in your community. Based on the Center's award-winning local roundtable in Frederick County, MD, the kit contains two ready-to-show slideshow presentations on CD-ROM, materials and instructions to guide workshop participants through a site planning exercise, documentation of the benefits of better site design, and electronic copies of all of the agendas, invitation letters, and other correspondence you'll need to get the roundtable process started. Even those who aren't planning to start a local roundtable will find this kit to be a great resource for teaching others about the benefits of more environmentally-friendly site design.

### *The Do-It-Yourself Watershed Planning Kit*

This second kit in our new Do-It-Yourself series focuses on watershed planning, pulling together everything you need to begin crafting your own local watershed protection plan. Included are two ready-to-show slideshow presentations on CD-ROM, a watershed mapping exercise, resource protection templates, case studies, guidance on what local resources to use for information about your watershed, and a wealth of research on the detrimental effects of impervious cover on watershed health and strategies for mitigating these impacts.

### *Approaches to Stormwater Treatment* Slideshows on CD-ROM

When you can't have Tom Schueler give the presentation himself, purchasing our slideshows on CD-ROM is the next best thing. "Approaches to Stormwater Treatment" is the latest addition to our family of graphics- and photo-intensive animated training presentations and contains three presentations designed to teach you everything you need to know about the design and implementation of stormwater treatment practices: *A Review of Stormwater Treatment Practices*, the *Sizing of Stormwater Treatment Practices*, and *Choosing the Right Stormwater Treatment Practice*. Running in PowerPoint, the presentations come complete with extensive speaker's notes and can be run as-is, or you can cut-and-paste slides to tailor the information to individual needs. The CDs are compatible with both Windows and Mac operating systems, although Mac users must have PowerPoint installed to use this software.

Other presentations currently available on CD-ROM include the Impacts of Urbanization, Eight Tools of Watershed Protection, and Better Site Design.

*To order any of the publications and products discussed here, visit the Center's website at http://www.cwp.org.*