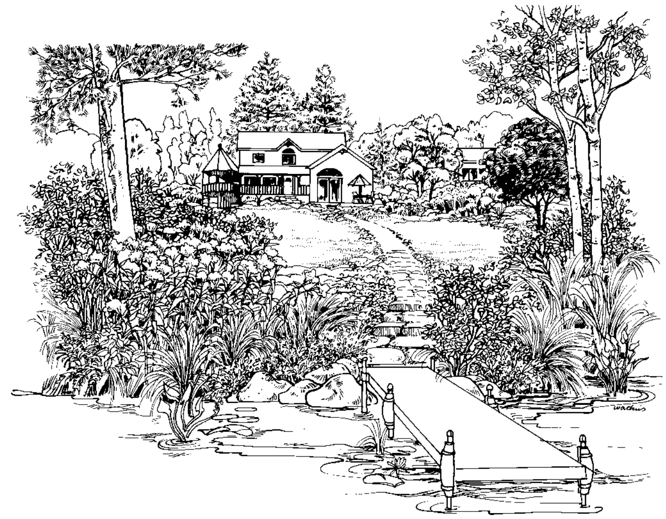
Introduction:
Why Urban Lakes Are Different

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.

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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.

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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

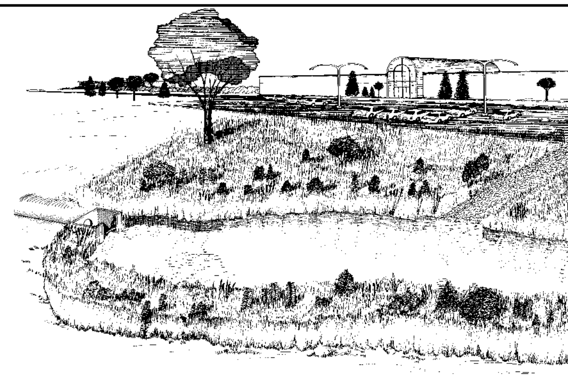
such as the composition and texture of bottom sediments, water depths, lake levels, and most importantly, the availability of light. Once beds of aquatic weeds become established, a series of ecological factors help to sustain and reinforce their presence for many years.

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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