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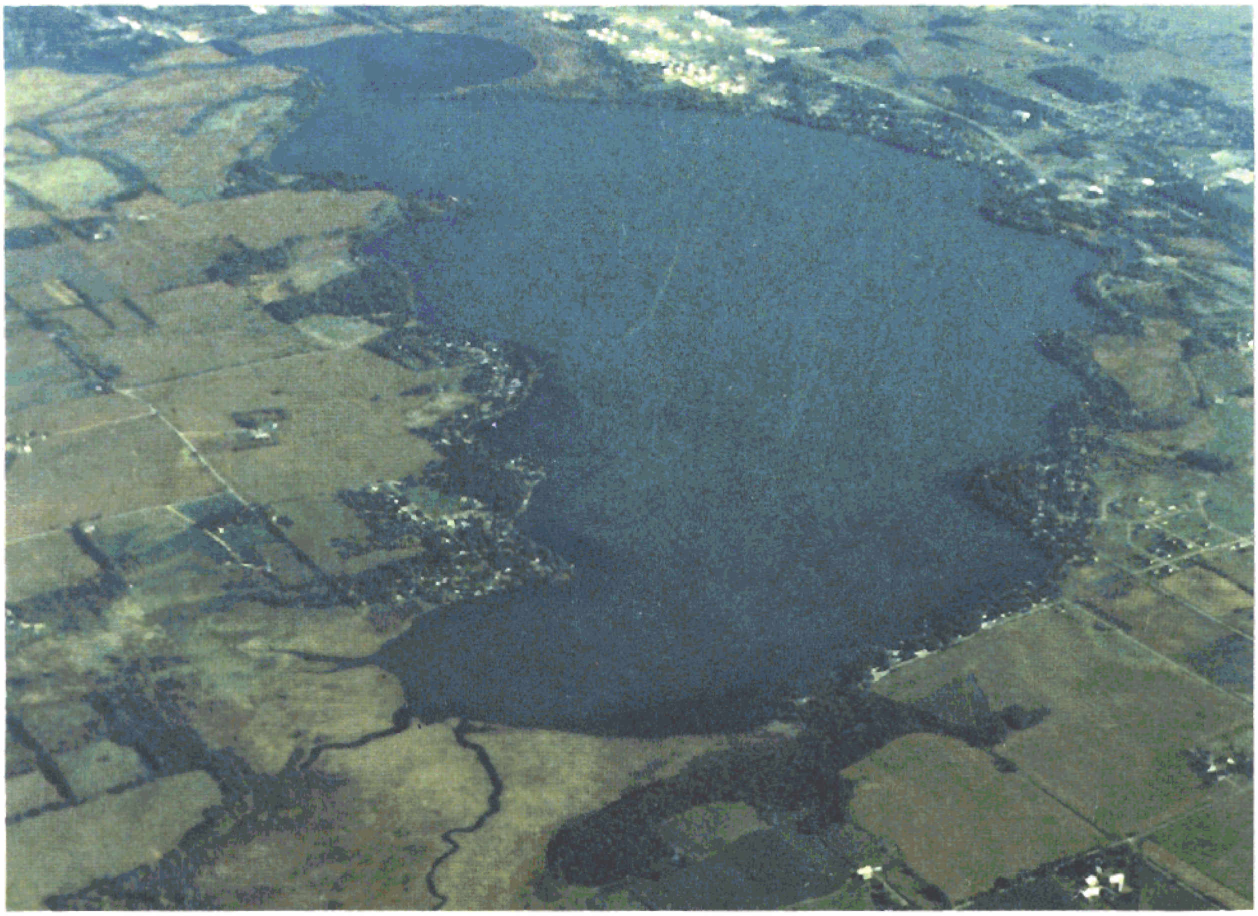
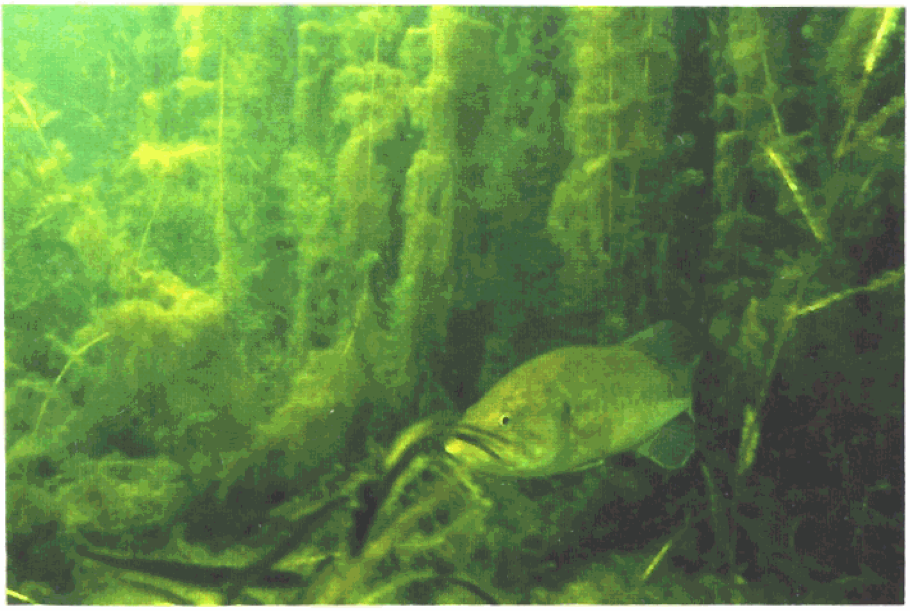


AQUATIC PLANTS IN LAKE WAUBESA: THEIR STATUS AND IMPLICATIONS FOR MANAGEMENT



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**AQUATIC PLANTS IN LAKE WAUBESA
THEIR STATUS AND IMPLICATIONS FOR MANAGEMENT**

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ABSTRACT

In 1992, the Dane County Lakes and Watershed Commission (DCLWC) contracted with the Wisconsin Department of Natural Resources Bureau of Research to evaluate the submersed aquatic plant communities in Lakes Monona and Waubesa and to develop 2 reports that propose aquatic plant management to enhance both water-based recreation and aesthetics as well as the quality of the lake resources. The following report on Lake Waubesa has been technically reviewed by scientists and individuals involved in different aspects of lake management in Wisconsin. The DCLWC will hold public meetings and conduct a review process to evaluate the management proposals presented in this report. Following the review process, the final APM plan for Lake Waubesa, which will be prepared by the DCLWC staff, will be presented to the County Board for adoption as policy.

Using a rake survey method, aquatic plants in Lake Waubesa were identified and their densities assessed. In the context of surveys from previous years, major changes in plant densities and community composition have occurred between 1990 and 1992. Overall, plant densities have declined dramatically. In particular, the densities of Eurasian water milfoil, curly leaf pondweed, and coontail have decreased. These are the "weedy" aquatic plants that cause nuisance conditions and interfere with recreation on the lake. In addition, more native species are being found in the lake, resulting in a more diverse aquatic plant community. In the Yahara lakes, native species such as pondweeds, wild celery, and water stargrass are not associated with nuisance conditions. Their presence in the lake is desirable because they improve habitat quality for fish, wildlife, and wildfowl.

Implementing a focused integrated management plan improves the chance of sustaining these positive changes in the plant community and maintaining reduced biomass of Eurasian water milfoil. It should be emphasized that because aquatic plants are a significant part of a lake's ecology, control of excessive nuisance plant growth and not total eradication of all aquatic plants is the goal. In addition, the Yahara lakes are eutrophic (nutrient rich), and realistic management goals that include the presence of aquatic plants should be set. An aquatic plant community of native, as opposed to weedy species, can be promoted by flexible management practices and restoration efforts.

Based on the survey findings coupled with a review of available plant control practices, APM that integrates harvesting, chemical control, shoreline cleanup, nutrient reduction, and education is proposed. Harvesting should remain the backbone of APM because it efficiently manages plants in large areas, removes nutrients from the lake, and does not affect areas beyond those harvested. In addition, this report includes suggestions for expanding the kinds of harvesting techniques used to include options such as surface cutting, which removes plant biomass at the water surface. As opposed to cutting plants near the lake bottom, surface cutting enables immediate relief from nuisance conditions while improving conditions for native plants to compete with the weedy ones. The weedy species tend to form surface canopies, thus shading native species. Consequently, harvesting can be used to control the negative impacts of excessive weed growth, and at the same time, enhance the establishment of the native plant community. In the long term, the prevalence of native plants in the lake should reduce the amount of nuisance conditions occurring.

Furthermore, the proposed APM identifies controversial aspects of chemical control and makes suggestions for improving the application of herbicides. Such suggestions are intended to minimize the effects of herbicides on valued native plant species and on adjacent shoreline properties where herbicides are not permitted.

In the past, clearly defined management criteria for harvesting were not used. A cornerstone of the proposed APM is a framework that defines harvesting criteria based on shoreline ownership, distance from shore, area designation, and ecological importance (i.e., the presence and density of plant species). While area designations are permanent; management within these years is dynamic, reflecting changing aquatic plant growth in a given year.

INTRODUCTION

PURPOSE OF REPORT

It is the goal of this report to (1) create a realistic set of long-term objectives for managing aquatic plants in Lake Waubesa based on public use of the lake and results of a scientific survey of the aquatic plant community; and (2) recommend aquatic plant management practices that will enhance the recreational value of Lake Waubesa while minimizing negative impacts to the lake's natural features, including the structure and function of its littoral zone (the lake shallows where aquatic plants grow). The report focuses on management activities carried out principally by the Dane County Department of Public Works. The recommendations presented in this report will hopefully lead to a coordinated program of integrated aquatic plant management that improves the efficiency of existing aquatic plant control programs by increasing their overall effectiveness and duration of control, and by reducing costs. Finally, the development of an approved aquatic plant management plan fulfills the funding eligibility requirements established by the State Waterways Commission and U.S. Army Corps of Engineers for Dane County to purchase new harvesting equipment.

LINK TO WHOLE LAKE USE PLAN

The recommendations generated by this report will strive to take into consideration the multiple uses of the lake; however, the development of an APM program does not preempt the need for a whole lake use plan. Because certain lake uses are not compatible with others, lake zoning and goal-oriented management based on patterns of use should be considered in a comprehensive lake use plan (Engel 1987, Nichols et al. 1988, Engel 1990a). Currently, the safety of lake users is threatened by having multiple kinds of water-based recreation occurring in the same area of the lake, for example wind surfing and motorboating. Also, with increasingly powerful motor boat engines, some "no wake zones" need to be more than 100 ft from shore. A whole lake use a plan would likely reduce user conflicts, optimize the recreational potential of the lake resource, and support its natural areas. In Wisconsin, a number of communities have worked with lake managers to generate this type of program (e.g., Lake Pewaukee Sanitary District).

GENERAL DESCRIPTION OF THE YAHARA LAKES SYSTEM

The Yahara lakes (Mendota, Monona, Waubesa and Kegonsa), also called the Madison lakes, are located in central Dane County. The city of Madison is centered on a narrow isthmus located between the two larger lakes (Mendota and Monona). Because Madison is the site of the state capital and home of the University of Wisconsin-Madison, the lakes are on display to residents of the entire state as well as national and international visitors. The Yahara lakes are among the most heavily recreated lakes in Wisconsin, attracting boaters and anglers from throughout the state as well as from out of state (Wis. Dep. Nat. Resour. 1991). For local residents, the proximity of the lakes lends them to intense use throughout the year. Boating, fishing, and sailboarding occur while the lake is free of ice; swimming is limited to the summer months. In addition, winter lake sports include ice fishing, ice skating, ice boating, cross country skiing, and snow mobiling. Consequently, expectations of a large number of people regarding the aesthetics and recreational use of the lakes must be addressed.

Recent surveys indicate that the public perceives that the lakes contain undesirable levels of algae and other aquatic vegetation (Dane Co. Reg. Plan. Comm. 1987, Saley 1987). These undesirable conditions have resulted from deteriorating water quality, caused by urban development and agricultural practices in the watersheds. Over the years, intensive over-fertilization of the lakes, known as eutrophication, has been spurred by urban and rural nutrient runoff and particularly sewage effluent discharge (Lathrop et al 1992). Although sewage effluent is no longer discharged into the lakes, runoff continues to enrich the lakes with nutrients. Dredging, water level control, and shoreline development has disturbed the natural shoreline vegetation. The introduction of European common carp to Dane County lakes in the late 1800s and its subsequent population explosion contributed to the demise of native aquatic plant species (Frey 1940, Lathrop et al. 1992).

Aquatic Plants

Aquatic plants, also called macrophytes or weeds, are a natural component of virtually all lake ecosystems and are associated with many benefits. They provide habitat (i.e., cover, food, and substrate) for different life stages of aquatic and semiaquatic organisms such as fish, insects, wildlife, and waterfowl. They function in the internal cycling of nutrients, oxygenate the surrounding waters, reduce the effects of wind and wave action, and overall, play an important role in littoral zone processes (Engel 1985, Andrews 1986, Carpenter and Lodge 1986, Engel 1990a, Lillie and Budd 1992).

Because they are fertile, the Madison lakes exhibit the typical conditions of eutrophication: excessive aquatic plant and algae growth. Negative impacts can result from excessive growth of macrophytes. Such impacts include decreasing diversity of plant species, impeding fish movement, stunting panfish growth, and depleting oxygen through plant respiratory processes during darkness or through natural die-off of large quantities of plants (Dionne and Folt 1991, Nichols 1991, J. Leverance, WDNR Southern District, pers. comm.).

Inevitably, major disturbances to the lakes have affected aquatic plant communities. The variety of different species decreased and were replaced by species more tolerant of disturbed conditions. Records from Lake Mendota, the most studied of the Yahara lakes and the best source of baseline information about their natural plant communities, indicate that the plant communities began changing in the 1940's with the invasion of the exotic curly leaf pondweed (*Potamogeton crispus*; Nichols et al. 1992). By the early 1960s broad-leaved pondweeds disappeared, which include highly desirable native plants (e.g., large-leaved pondweed, *Potamogeton amplifolius*). The macrophytes grew at increasingly shallower depths coincident with the invasion and subsequent success of the exotic Eurasian water milfoil (*Myriophyllum spicatum*). In the past, programs that cut aquatic plants prior to the use of harvesters may have facilitated the spread of Eurasian water milfoil (Lathrop et al. 1992). Cut plants were allowed to drift to shore where they were collected on barges. Because Eurasian water milfoil can root and grow from small pieces, it undoubtedly spread rapidly throughout the lake where cutting was occurring.

In all of the Yahara lakes including Lake Wingra, a shallow lake that drains to Lake Monona, the ensuing years of Eurasian water milfoil dominance were followed by its relative decline in the late 1970s and early 1980s (Carpenter 1980, Lathrop 1989). In Lake Wingra, native macrophyte species, including northern water milfoil (*Myriophyllum sibiricum*, formerly *exalbescens*) have subsequently reappeared (Nichols and Lathrop [manuscr. in prep.]). Lake Wingra has been an important resource for understanding macrophyte dynamics. It has the most diverse aquatic plant community in the Yahara chain of lakes and may be a source of native species recolonizing these lakes. Recent studies detail earlier aquatic plant communities in the Yahara lakes (Lathrop 1989, Lathrop et al. 1992, Nichols et al. 1992, and Nichols and Lathrop [manuscr. in prep.]).

In the Yahara lakes, the aquatic plants that interfere most with recreation and impair aesthetic enjoyment of the lakes are Eurasian water milfoil, coontail, and curly leaf pondweed. These submersed aquatic plants create nuisance conditions that interfere with water-based recreation by dominating deeper areas of the littoral zone (4–12 ft deep), growing prolifically, filling the water column, and forming canopies on the water surface. The depth at which plants grow is in part a function of water clarity (Canfield et al. 1985).

The most troublesome of the three species, Eurasian water milfoil, grows throughout the littoral zone from spring until late fall and even winters as green shoots. Its early start in spring permits rapid dispersal and colonization by plant fragments. Major growth in shallow waters occurs in both spring and late summer (Kimbel and Carpenter 1979), when its canopy of leaves shades and possibly eliminates other species. Such bushy growth since invading the Yahara lakes in the 1960s nearly doubled plant biomass cut and removed from these lakes (Lathrop 1989).

The other two species that can cause nuisance conditions generally have not been as persistent as Eurasian water milfoil. Coontail, the only species growing at nuisance levels that is native to the Yahara lakes, has increased in dominance in recent years and in some years exceeded the densities of Eurasian water milfoil (Deppe and Lathrop 1993, Nichols and Lathrop [manuscr. in prep.]). Coontail is rootless and is one of the few submersed species that obtains most of its nutrients from the water column instead of the sediments. Curly leaf pondweed usually reaches its greatest biomass in early summer (Sculthorpe 1967, Nichols and Shaw 1986). Its relatively early growth and dieoff is associated with its preference for cooler water temperatures.

Most of the other submersed species in the lakes are narrow-leaved, native species, such as water celery (*Vallisneria americana*) and sago pondweed (*Potamogeton pectinatus*). Native species usually grow in shallow regions of the littoral zone (≤ 1.5 m). Most native species do not form surface canopies or reach high densities. As a result, they do not hamper swimmers or foul boat propellers to the extent that weedy species do. In addition, many of the native species provide desirable waterfowl and fish habitat thus providing a more diverse recreational opportunity for lake users (Engel 1990a). Floating-leaved plants also occur in the Madison lakes, but they are limited to certain shoreline areas in Lake Mendota, Lake Wingra, and isolated patches in Lakes Monona and Waubesa.

Aquatic plants have been a source of conflict and a target for various management practices since the 1900s. . The specific problems, namely different amounts of algal and macrophyte growth, and modes of management have changed with time. Over the years, city and county lake managers have applied arsenic and copper compounds and other herbicides and conducted harvesting and shoreline cleanup programs (Domogalla 1926, 1935; Andrews 1986, Saley 1987, Nichols and Lathrop [manuscr. in prep.]). Currently, only Diquat and copper sulfate are used in herbicide treatments which are applied for solely by private property owners.

LAKE WAUBESA AND ITS USES

Site Description

Lake Waubesa, lies downstream from Lake Monona and upstream from Lake Kegonsa. Other tributaries that drain into Lake Waubesa are Swan Creek, Murphy Creek and Nine Springs Creek. Swan Creek and Murphy Creek enter Lake Waubesa through a large wetland on the southern lake end, while Nine Springs Creek flows into Upper Mud Lake, a widespread of the Yahara River upstream of Lake Waubesa.

Lake Waubesa thermally stratifies only briefly in the summer because it is relatively shallower than Lake Mendota and Monona (Table 1). It is eutrophic and alkaline (Table 2), a characteristic of many lakes in southern Wisconsin. Water level is controlled by locks at the Yahara River outlet of Lake Waubesa, near the city of McFarland. Winter drawdown (about 1.5 ft) prevents shoreline damage by heaving ice and prevents flooding when spring runoff is excessive (K. Koscik, Dane County Department of Public Works, pers. comm.).

The Waubesa watershed is mostly agricultural. As part of the Wisconsin Nonpoint Source Pollution Abatement Program, the watersheds of Lake Waubesa and Lake Monona together comprise the Yahara-Monona Priority Watershed Project that began in 1988. More than 150,000 people live in the Yahara-Monona Watershed.

The Village of McFarland is located on the northeast shore of Lake Waubesa. About half of the lakes overall shoreline is urbanized or privately owned. The Nature Conservancy, WDNR, and Dane Co. (parkland) bear title to the rest of the shoreline, most of which is relatively undisturbed.

Table 1. Morphometric characteristics of Lakes Monona and Waubesa.[*]

Characteristic	Monona	Waubesa
Area (acres)	3,270	2,080
0–10 ft	840 (26%)	890 (43%)
10–30 ft	810 (25%)	860 (41%)
>30 ft	1,620 (50%)	330 (16%)
Volume (acre-ft)	89,700	33,000
0–30 ft	68,600 (76%)	32,100 (97%)
>30 ft	21,100 (24%)	900 (3%)
Maximum depth (ft)	74	38
Water residence time (years)	1.1	0.31
Shoreline length (miles)	13.2	9.4
Total watershed area (sq. miles)	45.7	47.1
Direct drainage	40.6	43.8
Lake	5.1	3.3

[*] Adapted from Lathrop et al. (1992).

Table 2. Water chemistry characteristics of Lakes Monona and Waubesa, 1980–88.[*]

	Mean Concentration	
Characteristic	Monona	Waubesa
pH	8.5	8.6
Alkalinity (mg/L as $CaCO_3$)	170	176
Calcium (mg/L)	31	32
Magnesium (mg/L)	32	33
Total nitrogen (mg/L)	0.31	0.41
Total phosphorus (mg/L)	0.04	0.07
Potassium (mg/L)	3	3
Sodium (mg/L)	15	15
Chloride (mg/L)	28	28
Sulfate (mg SO_4/L)	24	24
Specific conductance (μmhos/cm)	434	439

[*] Data sources: adapted from Lathrop et al. (1992); WDNR, Bur. Res. (unpubl. data). All measurements, except specific conductance, were determined from samples of the surface water at the deep-hole location. Specific conductance was measured at the lake outlet.

Recreational Use

Summer recreation on the lake includes swimming, boating, fishing, canoeing, sailing, water skiing and sailboarding. There are 11 public access points; of which 2 are swimming areas and 3 are boat ramps with parking facilities (Fig. 1). Fishing is popular for panfish (including bluegills, yellow perch, and crappies), walleye, northern pike and largemouth and smallmouth bass. Park users, riparian residents and residents of McFarland enjoy the Lake Waubesa visually from shore.

Natural Features

Today, only the north and south parts of Lake Waubesa are natural shorelines. In particular, stands of emergent, riparian vegetation border the lake in the south. Wetlands in the drainage basin constitute less than 27% of predevelopment conditions (Lathrop 1992). While

Wis. Admin. Code NR 107 defines aquatic plant management in the state, under Wis. Admin. Code NR 103 (Water Quality Standards for Wetlands) all of the littoral zone is included in the definition of "wetlands".

Migratory waterfowl, especially ducks, geese and herons, visit the lake in the spring and fall. Courting Sandhill cranes have been observed at Lake Farm County Park. Thirty-four species of fish are known in Lake Waubesa.

Historical Aquatic Plant Communities and Their Management

Historical accounts of aquatic plants are limited (Table 3). Early accounts describe the effort of rowing through dense beds of macrophytes (Lathrop et al. 1992). Water celery is known to have been plentiful until its sudden demise in the mid-1930's. Table 4 identifies the outer limit of plant growth for 1920–92. In the 1930s–40s, the City of Madison conducted extensive herbicide treatments in Lake Waubesa, using copper sulfate to control algal blooms (Lathrop and Johnson 1979).

In 1936, an expanded water treatment facility, operating since 1928, began discharging increased amounts of sewage effluent into Nine Springs Creek. The subsequently reduced water clarity in Lake Waubesa and a corresponding explosion in the population of introduced carp are ascribed with the ensuing changes in the aquatic plant community. For years, little more than sago pondweed was observed in the lake.

Although effluent discharge into the lake ceased after 1958, eutrophic conditions have impacted the natural distribution and diversity of aquatic vegetation along Lake Waubesa's shoreline. In the last few decades, macrophytes have been growing in nuisance proportions. Nuisance conditions correspond with the 1960s when Eurasian water milfoil successfully invaded the Madison lakes and rapidly became pervasive. The current status of macrophytes in Lake Waubesa is detailed in the Technical Information Section of this report.

During this century, plant management activities on Lake Waubesa have included chemical applications of copper compounds, Endothall, and Diquat; cutting and later harvesting; and shoreline cleanup (Andrews 1986, Saley 1987, Nichols and Lathrop [manuscr. in prep.]).

PROBLEM IDENTIFICATION

Aquatic plant management (APM) issues are controversial because a wide range of human interests need to be addressed, as well as the ecology of the resource. What one group of people perceives as a problem may be considered desirable by others. As a result, a clear definition of the problem is elusive. A tradition of conflict surrounds the issue of APM, and there is a lack of consensus about how to approach it. The following section will focus on three APM issues: aquatic plant growth, public opinion, and management.

Aquatic Plant Growth and Eutrophic Conditions

The heart of the APM issue is excessive weed growth, the key words being "excessive" and "weed." Aquatic plants are not inherently bad. However, overabundant plants can impair human use, safety, and enjoyment of the lake. Excessive plant growth, particularly dominance by one or two plant species, also has negative effects on the natural system. Aquatic plant species that reach nuisance levels are typically the species most likely to be associated with the term "weed", i.e., they grow prolifically where humans do not want them. These species are prone to dominate throughout the littoral zone, reproduce vegetatively, fill the water column, and form canopies on the water surface in shallow waters.

Throughout the following report, the three macrophytes responsible for creating nuisance conditions, Eurasian water milfoil, coontail, and curly leaf pondweed, will be termed "weedy" species, as opposed to native species. Coontail is a native species but shares characteristics of the other two "weedy" species, which are exotics. Filamentous algae can also be a problem in certain years and is often misidentified by the general public as a "weed".

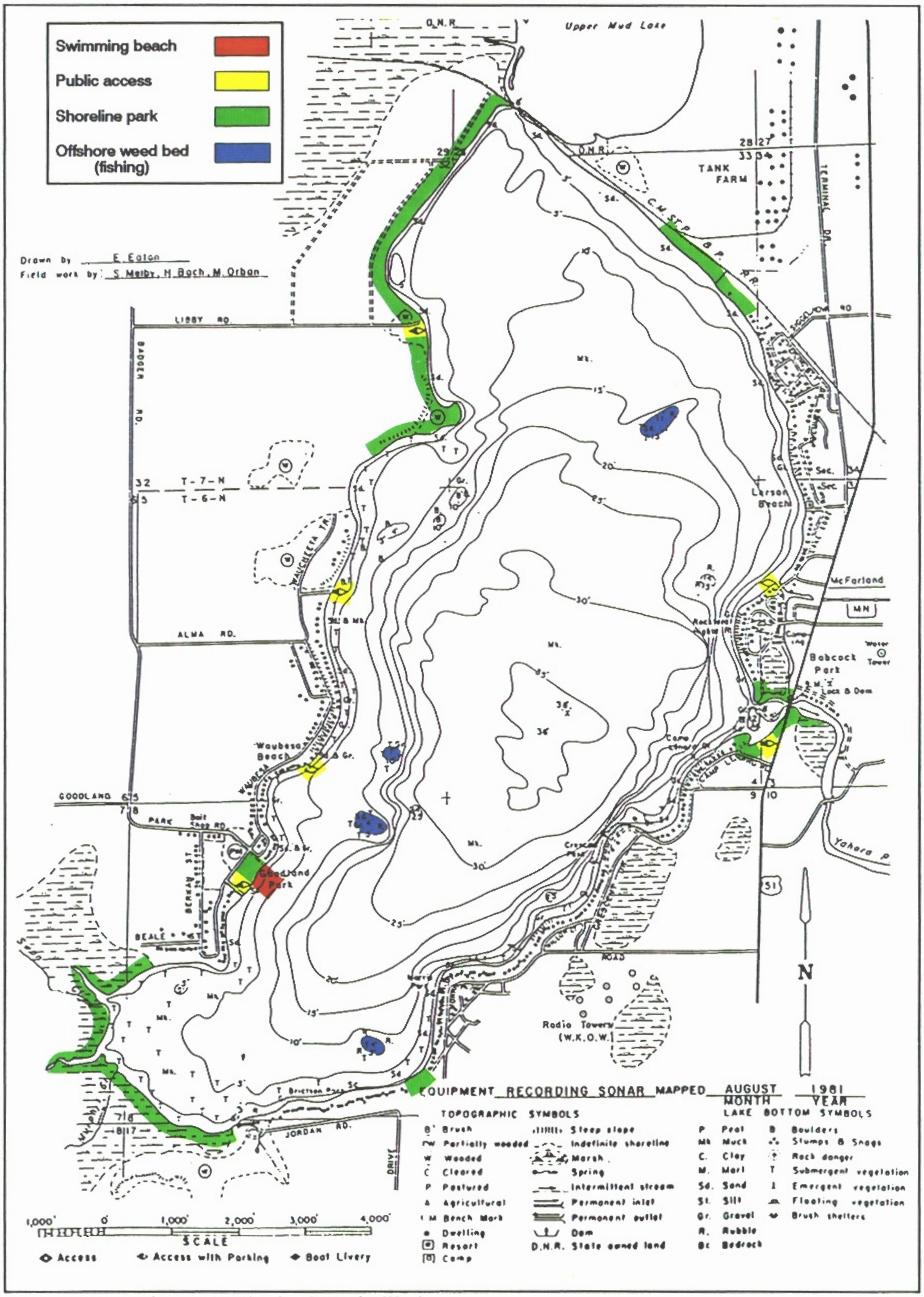

Figure 1. Areas of recreational value for Lake Waubesa.

Table 3. Historical records of aquatic plants in Lake Waubesa, 1877–92.

Plant species	1893–95	1929	1938–39	1948	1951	1955	1961	1972–74	1979–80	1990–92
Ceratophyllum demersum (coontail)						h		j	k	l,m,n
Chara sp. (muskgrass)										n
Elodea canadensis (elodea)	a									n
Heteranthera dubia (water stargrass)	a,b									l,m,n
Myriophyllum sibiricum (= *M. exalbescens*; northern water milfoil)	a,b									
M. spicatum (Eurasian water milfoil)								j	k	l,m,n
Nuphar variegetum (yellow pond lily)	a		e						k	m,n
Nymphaea tuberosa (white water lily)	a									
Potamogeton amplifolius (large-leaved pondweed)	a									
P. crispus (curly leaf pondweed)						h				l,m,n
P. foliosis (leafy pondweed)				f						l,m,n
P. frieseii (Fries's pondweed)		d								
P. gramineus (grass-leaved pondweed)							i			
P. illinoensis (Illinois pondweed)	c									
P. natans (floating pondweed)	a									
P. nodusus (= *P. americanus*; long-leaved pondweed)			e							
P. pectinatus (sago pondweed)		d	e	f	g	h	i	j		l,m,n
P. richardsonii (= *P. perfoliatus*; Richardson's pondweed)	a									n
P. vaginatus (swift-water pondweed)										
P. zosteriformis (flat-stemmed pondweed)							i			n
Ranunculus trichophyllus (white water crowfoot)	a									
Utricularia vulgaris (great bladderwort)	a									
Vallisneria americana (water celery)	a		e							n
Zannichellia palustris (horned pondweed)										n

a=1893, Cheney and True (1893; "common in all Dane Co. lakes"); b=1893, Cheney, UW herbarium; c=1895, Cheney, UW herbarium; d=1929, Mahoney, UW herbarium; e=1938–39, Frey (1940) and Frey and Vike (1941); f=1948, Threinen (1949); g=1951, Threinen and Helm (1952); h=1955, B. Jacob Wis. Conserv. Dep., Madison Area (pers. comm.); i=1961, C. Brynildson, Wis. Conserv. Dep., Madison Area files, memo; j=1972–74, C. Brynildson, WDNR, Madison Area files, memo; k=1979–80, J. Warren, WDNR, Madison Area Files, memo; l=1990–91, Deppe and Lathrop (1993); m=1991, S.A. Nichols, UW Extension (pers. comm. and unpubl. data); n=1992, WDNR Bur. Res. (unpubl. data).

Table 4. Deepest limits of macrophyte growth in Lakes Monona and Waubesa, 1920–1992 (m).[*]

Year	Monona	Waubesa
1920	3.0	–
1935	5.5	–
1939	–	1.5
1948	2	1.3
1951	1.7	<1.0
1961	1.8	–
1990	3.6 ±0.6[**]	3.4 ±0.2
1991	2.6 ±0.6	2.0 ±0.6
1992	3.9 ±0.7	2.6 ±0.6

[*] Data sources: 1920–61, adapted from Nichols and Lathrop (ms. in prep.); 1990–92 WDNR, Bur. Res. (unpubl. data).
[**] Mean ±std where statistics were available.

The eutrophic, or nutrient-rich, conditions of the lake create an environment characterized by high productivity. Phosphorus and nitrogen levels, from both internal and external sources, are generally available in excess concentrations in the lake sediment. These high concentrations of nutrients provide the "fuel" for plant growth.

Public Perception

Public expectations of APM can change with the way that the lake is utilized. Vegetation that provides fish habitat may also foul motor boat propellers and impair swimming, water skiing, and sailboarding. Dense plants can also create a safety concern for swimmers by entangling their legs. Most people enjoy the lake from onshore. Those recreating on the lake and viewing it from its shore enjoy the beauty of certain plants (e.g., water lilies), and waterfowl attracted by aquatic plants. However, there are problems associated with vegetation that accumulates on the shoreline. Such vegetation may have detached naturally from the rest of plant, been cut by motor boat propellers, or not removed during harvesting. It is unclear whether strong winds and waves can cause chemically treated plants to accumulate on the shoreline or whether such plants remain on the bottom and die as observed by divers (D. Marshall, WDNR Madison Area, pers. comm.). Other debris, including filamentous algae, branches, and litter, also collect in shoreline areas and contribute to unsightly conditions as well as offensive odors. Lakefront residents seek unimpaired swimming, boating, and/or viewing from their shoreline property. Among others, resource managers recognize the role of plants in the ecology of the lake. In a city of lakes, such as Madison, many people enjoy the lakes in multiple ways and therefore fall into several categories of lake users.

When a "problem" is perceived, solutions are demanded by individuals negatively affected by macrophyte growth. Often solutions are expected to provide total elimination of plants from the area in question. However, depending on the type and degree of nuisance, removal of aquatic plants may not be satisfactory, economically feasible, or environmentally sound; may conflict with other user groups' wants; and/or may be detrimental to other functions of the lake. Certain issues concerning APM and public perception highlight the need to involve the lake user community in developing lake use plans and to deepen their understanding of lake management. These issues include:

(1) Allowable levels of management need to be clarified to reduce friction among user groups and between user groups and management agencies.
(2) The desirability of a diverse community of native species needs to be promoted. The positive benefits of aquatic plants are not understood by most people. Control of aquatic vegetation should not imply total eradication.

(3) Ecologically realistic goals need to be set. The Madison lakes are eutrophic. Programs implemented to reduce the nutrient load may result in improved water clarity that may also cause increased plant growth. Compared to a lake dominated by heavy growths of planktonic blue-green algae, which tends to float and accumulate along downwind shores, a lake with clear water and a diverse population of native plants can be highly desirable. Because the Yahara lakes will never become oligotrophic (nutrient-poor, the opposite of eutrophic), standards or expectations for oligotrophic lakes should not be set.

(4) A clear distinction between management of filamentous algae and management of macrophytes needs to be made. Filamentous algae, often mistaken for macrophytes, presents a different set of problems for control. If not attached to densely growing plants, it is not effectively controlled by conventional harvesting. New harvesting techniques and adaptations to the harvesting machines that improve their ability to collect filamentous algae are being explored. Through properly identifying filamentous algae and recognizing the limitations on its control, public tolerance level may be heightened in cases where macrophyte growth is sparse, but filamentous algae is dense.

Management

The final aspect of the problem of macrophytes focuses on their management. Available means of control include a successful, established harvesting program. However, the full potential of control programs is not realized because:

(1) Dane County harvesting policy mostly describes the program operation (Append. A). Goals are not clearly outlined. The"understood" goal is to harvest the most weeds possible (K. Koscik, Dane County Department of Public Works, pers. comm.).

(2) Mechanical and chemical means of control are not coordinated due in part to being operated by different organizations.

(3) Public pressure often influences where harvesting occurs. Objective criteria for making management decisions are lacking.

(4) Enhancing and protecting natural features of the resource are not emphasized because specific resource objectives have not been defined.

(5) Available methods of control need to be expanded to deal effectively with different types of problems (such as filamentous algae vs. rooted plant growth, and alternatives to chemical control for lakefront residents).

TECHNICAL INFORMATION—RESULTS OF THE 1992 AQUATIC PLANT SURVEY

In 1992, the Dane County Lakes and Watershed Commission (DCLWC) contracted the Wisconsin Department of Natural Resources (WDNR) Bureau of Research to 1) conduct a detailed scientific survey of the aquatic plant communities in Lakes Monona and Waubesa, and 2) to compile an herbarium of the locally common aquatic plants. A full copy of the final report "Results of the 1992 Aquatic Plant Surveys of Lakes Monona and Waubesa" is available from the DCLWC. Three complete sets of aquatic plant species recorded in the Yahara lakes, including Lake Wingra, in 1992 (Table 5) were preserved as laminated, dried specimens. They reside in the herbarium collections of the DCLWC, Dane County Department of Public Works, and the WDNR Bureau of Research.

The results of the macrophyte survey are discussed below. The 1992 data is interpreted in the context of similar research conducted by the Bureau of Research on Lakes Monona, Waubesa and Kegonsa since 1990 and on Lake Mendota since 1989. Methodology, site information, and an explanation of statistical analysis and terminology appears in Appendix B.

SPECIES FOUND

In Lake Waubesa, the number of submersed macrophyte species increased from 6, recorded in 1990 and 1991, to 7 found during the 1992 transect survey (Table 6). The new species, horned pondweed (*Zannichellia palustris*), was commonly found along the west and north side of the lake. No previous record of this species exists for the lower Yahara lakes, although it has been found in Lakes Mendota and Wingra. Under similar survey conditions, relatively few species were found in Lake Kegonsa, while Lake Mendota had the highest number of species in the four Yahara lakes (Table 7).

*Table 5. Aquatic plants found in the Yahara lakes and Lake Wingra, 1989–92.**

Scientific name	Common name
Ceratophyllum demersum	coontail
Chara sp.	muskgrass, chara
Elodea canadensis Michx.	elodea
Heteranthera dubia (Jacq.) MacM.	water stargrass
Myriophyllum sibiricum Komarov (formerly, *M. exalbescens*)	northern water milfoil
M. spicatum L.	Eurasian water milfoil
Najas flexilis (Willd.) Rostk. & Schmidt	slender naiad
Nelumbo lutea (Willd.) Pers.	American lotus
Nuphar variegatum Engelm.	yellow pond lily
Nymphaea tuberosa Paine	white water lily
Potamogeton crispus L.	curly leaf pondweed
P. foliosis Raf.	leafy pondweed
P. illinoensis Morong.	Illinois pondweed
P. natans L.	floating pondweed
P. pectinatus L.	sago pondweed
P. richardsonii (Benn.) Rydb.	Richardson's pondweed
P. zosteriformis Fern.	flat-stemmed pondweed
Utricularia vulgaris L.	great bladderwort
Vallisneria americana Michx.	water celery
Zannichellia palustris L.	horned pondweed

* Common names used in this report. Taxonomy sources: Wisconsin vascular plants and DNR codes compiled by R.H. Read, WDNR (unpubl. data); S. Engel, WDNR, Northern District (pers. comm.); Engel (1990).

*Table 6. Aquatic plants recorded in Lakes Monona and Waubesa, 1990–92.**

Plant species	Monona				Waubesa			
	1990	1991	1992	1992**	1990	1991	1992	1992**
Submersed species								
Coontail	+	+	+	+	+	+	+	+
Elodea	–	+	+	+	–	–	–	+
Muskgrass	–	–	–	–	–	–	–	+
Pondweed, curly leaf	–	+	+	+	+	+	+	+
Pondweed, flat-stemmed	–	–	–	+	–	–	–	+
Pondweed, horned	–	–	–	–	–	–	+	+
Pondweed, leafy	–	+	+	+	+	+	+	+
Pondweed, Richardson's	+	+	+	+	–	–	–	+
Pondweed, sago	+	+	+	+	+	+	+	+
Water celery	+	+	+	+	–	–	–	+
Water milfoil, Eurasian	+	+	+	+	+	+	+	+
Water milfoil, northern	–	–	+	+	–	–	–	–
Water stargrass	+	+	+	+	+	+	+	+
Floating-leaved species								
Pond lily, yellow	–	–	–	–	–	–	–	+
Water lily, white	–	–	–	+	–	–	–	–
Number of species:	6	9	10	12	6	6	7	13

* Data sources: 1990–91 data from Deppe and Lathrop (1993); 1992 data from this survey.
** Intertransect sampling.

During the 1992 intertransect survey, an additional 6 species were recorded (Table 6). Of these species, neither muskgrass (*Chara* sp.) nor Richardson's pondweed (*Potamogeton richardsonii*) had been observed in the past in Lake Waubesa, although a lack of detailed earlier surveys may account for this. Flat-stemmed pondweed and Richardson's pondweed were found beneath the floating leaves of yellow pond lily (*Nuphar variegetum*). Water celery and elodea (*Elodea canadensis*) may have been found only during the intertransect sampling because they grow later in the season; however, since both species were recorded only once in August, they were probably rare in the lake. The greatest diversity of species was concentrated in the northern part of the lake, in the vicinity of the Lake Farm Park and the inflow from Upper Mud Lake (Fig. 2). Including results from the intertransect survey, 12 submersed species and 1 floating-leaved species were present in Lake Waubesa.

PLANT COVER AND RELATIVE FREQUENCY

Eurasian water milfoil was the most pervasive species in Lake Waubesa, growing in 80–93% of the littoral zone during 1990–92 (Table 8). In 1990, coontail was also "abundant" (see Appendix B for quantification of this measure of abundance), occurring in 77% of the littoral zone. However, in subsequent years, the distribution of coontail plummeted by more than 85%; it grew in only 11% of the littoral zone in 1991 and 1992. In recent years, dramatic declines in the population of coontail have occurred in the other Yahara lakes (Deppe and Lathrop 1993) and other Wisconsin lakes (e.g., Clark Lake, Door County; T. Rasman, WDNR Lake Michigan District).

At the same time that coontail declined, native species such as sago pondweed and leafy pondweed (*Potamogeton foliosis*) became "abundant". In particular, by 1992 sago pondweed's distribution increased from 10 to 50%, and leafy pondweed was found in 40% of the littoral zone. Horned pondweed, which colonized the lake as a "common" species in 1992, occurred in 18% of the littoral zone.

Table 7. Aquatic plants recorded in Lakes Mendota, Kegonsa and Wingra, 1989–92.[*]

Plant species	Mendota 1989–92	Kegonsa 1990–92	Wingra 1991–92
Submersed species			
Bladderwort, great	–	–	+
Coontail	+	+	+
Elodea	+	+	+
Muskgrass	–	–	+
Naiad, slender	–	–	+
Pondweed, curly leaf	+	+	+
Pondweed, flat-stemmed	+	–	+
Pondweed, horned	+	–	+
Pondweed, Illinois	–	–	+
Pondweed, leafy	+	–	+
Pondweed, Richardson's	+	–	+
Pondweed, sago	+	+	+
Water celery	+	–	+
Water milfoil, Eurasian	+	+	+
Water milfoil, northern	+	–	+
Water stargrass	+	+	+
Floating-leaved species			
Lotus, American	+	–	–
Pond lily, yellow	–	–	+
Water lily, white	+	–	+
Number of species:	14	6	18

[*] Data sources: For Lakes Mendota and Kegonsa, 1989–91 data from Deppe and Lathrop (1993); 1992 data from this study. For Lake Wingra, from S.A. Nichols, UW-Extension and WDNR (unpubl. data).

Following a decline in coontail after 1990, the change in Lake Waubesa's community composition was pronounced (Fig. 3). The macrophyte community continued to be dominated by Eurasian water milfoil, but as a group, native species became more prevalent in the plant community, increasing from a relative frequency of <5% in 1990 to about 40% in 1992 (Fig. 3). Initially, both Eurasian water milfoil and curly leaf increased. However, in 1992 sago pondweed became the second most dominant species increasing in relative frequency from <5% to 21%. Additional species also appeared.

PLANT DENSITIES

Density information reflects how the water column is occupied and the degree to which aquatic plants are likely to affect water-based recreation. Due to overall low plant densities, the following discussion focuses on the densities of the more dominant species: Eurasian water milfoil, coontail, and sago pondweed. Transect locations and rake densities are described in Appendix B.

Transect Densities

In general, transect densities of Eurasian water milfoil, coontail and sago pondweed were very sparse in 1991–92 (Figs. 4–6; note that the scale for milfoil is different). The greatest density in any transect did not exceed 6, compared to a possible value of 30, given that all depth stations between 0.5 and 3.0 m could have density ratings of 5. While overall plant densities were low, densities varied between species. Total rake densities (i.e., for all species) closely resembled that of Eurasian water milfoil, indicating that Eurasian water milfoil occurred in the greatest

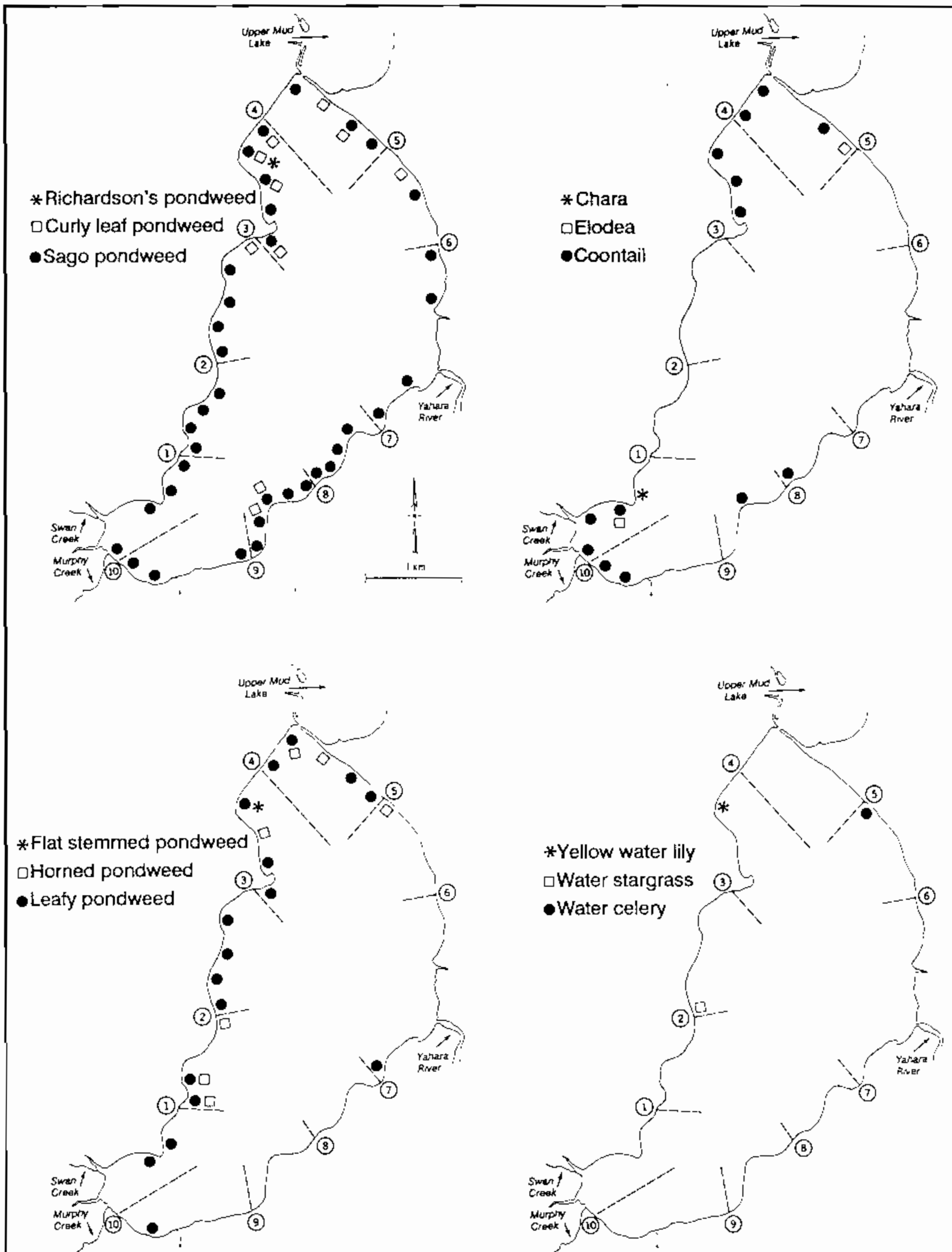

Figure 2. Macrophyte species found in Lake Waubesa during the intertransect survey, 1992. Eurasion water milfoil was found at all sites.

Table 8. Percent plant cover in the littoral zones of the 4 Yahara lakes, 1989–92.***

	Mendota				Monona			Waubesa			Kegonsa		
Plant species	1989	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992
Submersed species													
Coontail	75	62	53	54	87	25	39	77	11	11	10	19	19
Elodea	13	9	21	29	9	6	17	–	–	–	–	–	1
Pondweed, curly leaf	4	2	3	3	41	9	24	23	9	38	3	6	14
Pondweed, flat-stemmed	<1	–	–	–	–	–	–	–	–	–	–	–	–
Pondweed, horned	–	–	–	2	–	–	–	–	–	18	–	–	–
Pondweed, leafy	–	<1	6	15	–	2	8	–	14	38	–	–	–
Pondweed, Richardson's	1	2	2	3	1	6	3	–	–	–	–	–	–
Pondweed, sago	17	18	25	35	10	28	25	10	46	49	13	6	21
Water celery	16	12	15	21	1	6	11	–	–	–	–	–	–
Water milfoil, Eurasian	61	55	67	72	89	80	97	90	80	93	67	85	95
Water milfoil, northern	–	–	–	7	–	–	4	–	–	–	–	–	–
Water stargrass	15	15	21	33	6	9	8	12	3	11	–	2	7
Floating species													
Lotus, American	<1	<1	<1	<1	–	–	–	–	–	–	–	–	–
Water lily, white	<1	<1	<1	<1	–	–	–	–	–	–	–	–	–

* Calculated as the no. of depths in which the species occurred, divided by the total no. of depths sampled.
** Data sources: 1989–92 data from Deppe and Lathrop (1993); 1992 data from this survey, excluding plants found during intertransect sampling.

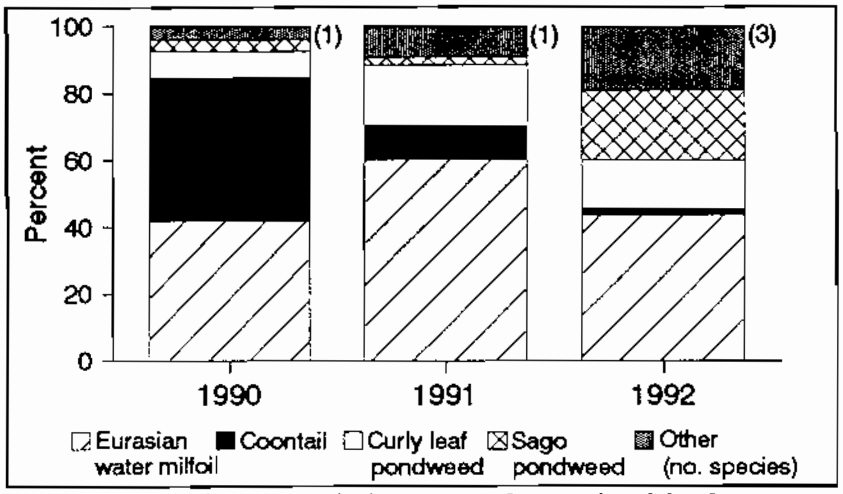

Figure 3. Relative frequencies of primary macrophyte species of the plant communities in Lake Waubesa, 1990–92.

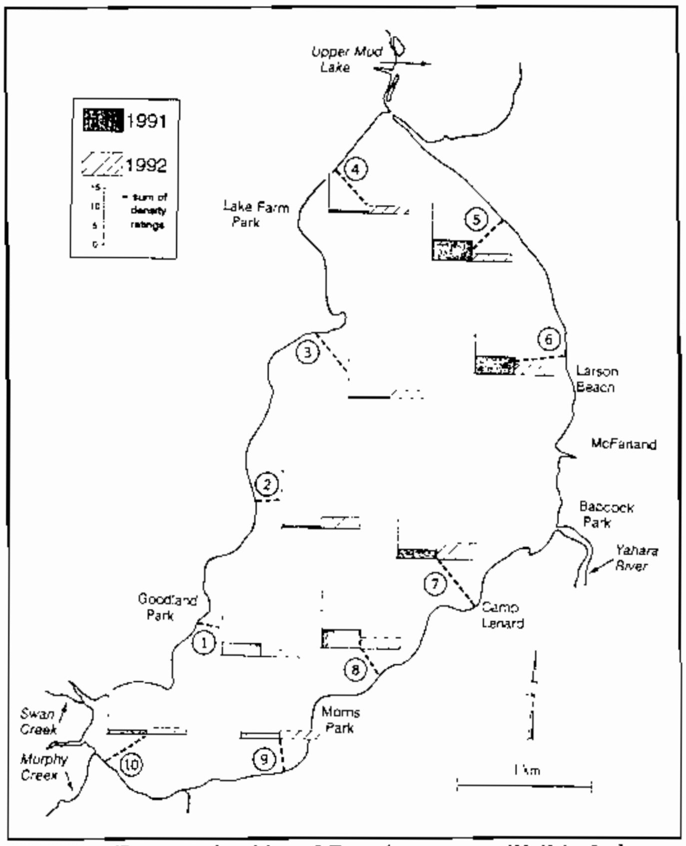

Figure 4. Transect densities of Eurasian water milfoil in Lake Waubesa during 1991 and 1992. (Scale range 0–15; maximum possible value of 30.)

amounts (Figs. 4 and 7). Eurasian water milfoil grew slightly denser on the eastern side of the lake in 1991 (transects 5–8); in 1992 densities were similar among transects. Coontail was observed, in small amounts, in only three out of ten transects in 1991 and in four transects in 1992. Although low densities were recorded for sago pondweed, it was widespread.

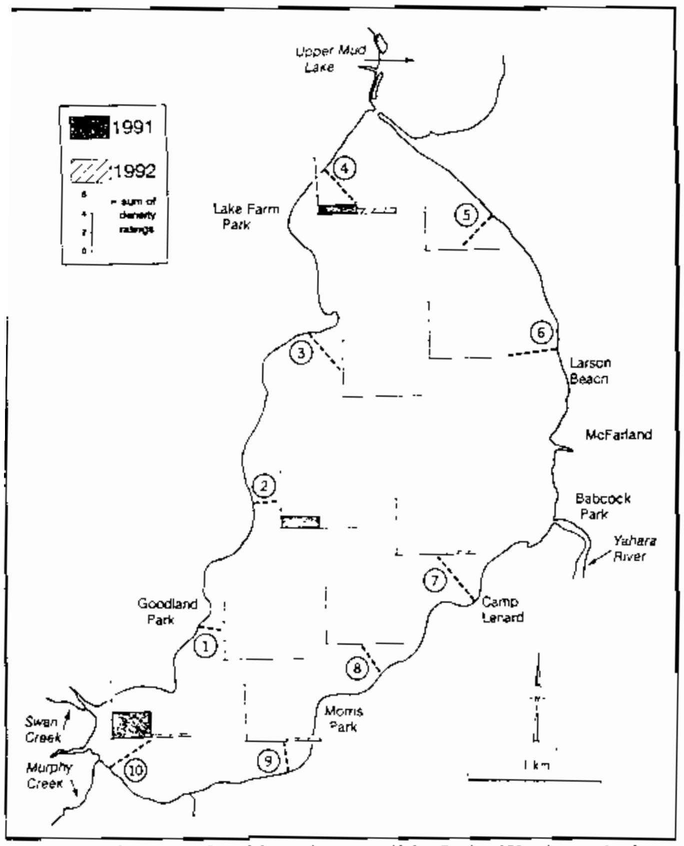

Figure 5. Transect densities of coontail in Lake Waubesa during 1991 and 1992. (Scale range 0–6; maximum possible value of 30.)

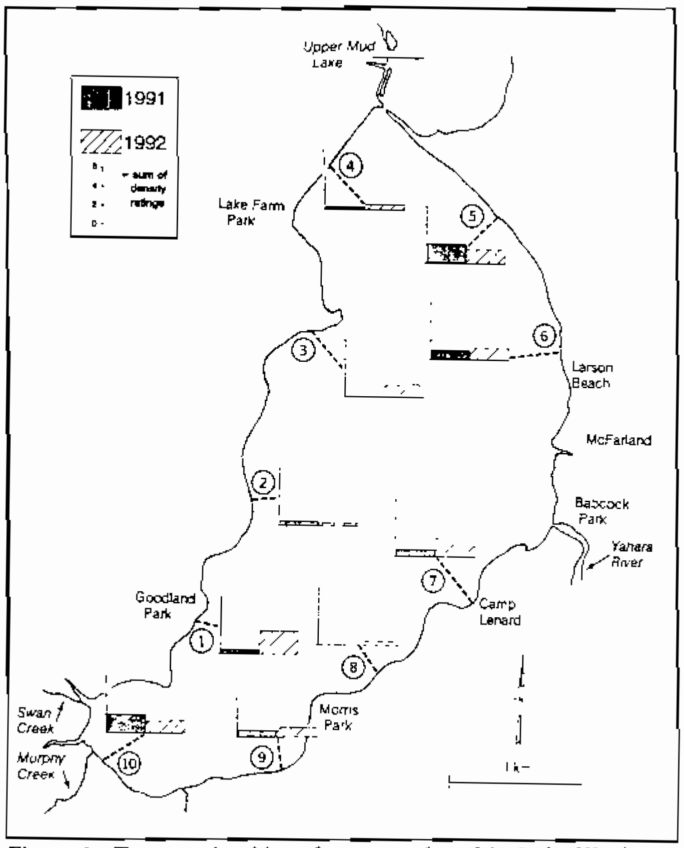

Figure 6. Transect densities of sago pondweed in Lake Waubesa during 1991 and 1992. (Scale range 0–6; maximum possible value of 30.)

Depth Densities

Clearer water in 1992 was paralleled by Eurasian water milfoil growing 0.5 m deeper than in 1991 (Fig. 8). However, Eurasian water milfoil as well as coontail grew at lower densities in 1992 than in 1991 (Fig. 9). Sago pondweed's nearshore densities rose, but declined beyond 0.5 m deep, which may be associated with the appearance of additional species colonizing the shallow littoral zone (Fig. 10).

Extrapolating from the four-year growth pattern in Lake Mendota, plant density was probably greater in the lower lakes in previous years. Greater tonnage of aquatic plants harvested from Lake Waubesa prior to 1991 supports this conclusion (see Aquatic Plant Management, Fig. 11). Overall, Dane County harvesting data supports the results of this survey, indicating that macrophyte biomass in Lake Waubesa was dramatically lower in 1991 and 1992 compared to previous years.

Filamentous Algae

Filamentous algae grew primarily in the shallows (<1 m) of Lake Waubesa in 1992. In particular, filamentous algae was characterized as excessive along the west (transect 2) and southwest shorelines (transects 8 and 9).

RELATIONSHIP TO WATER CLARITY

The changes in macrophyte community composition in Lake Waubesa may be due to low water clarity in the spring of 1990 (Table 9) combined with a slow recovery of dominant species. In the following year, rooting depths were 0.5 m shallower and submersed plants grew in less of

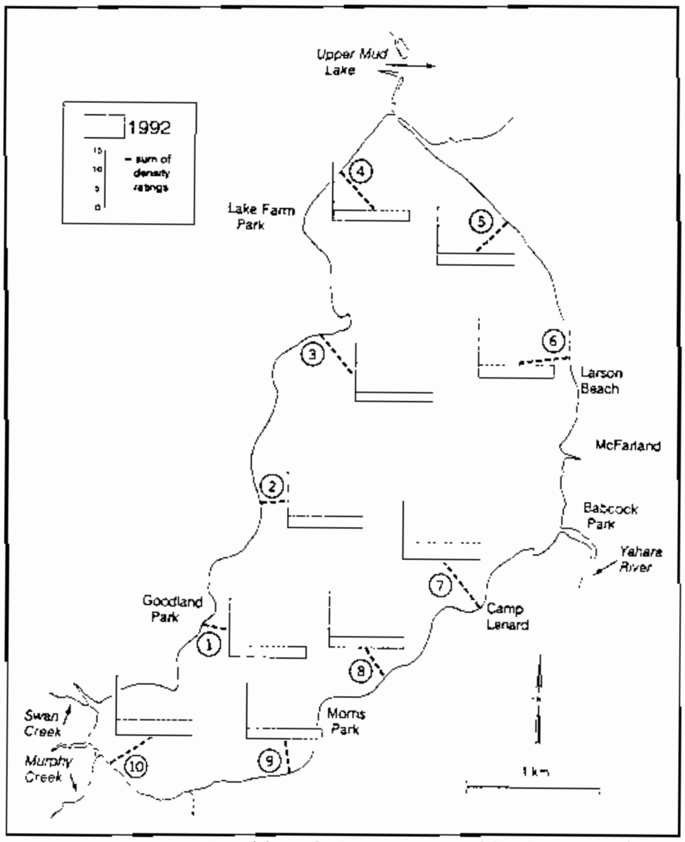

Figure 7. Transect densities of all species combined (total rake density) in Lake Waubesa during 1992. (Scale range 0–15; maximum possible value of 30.)

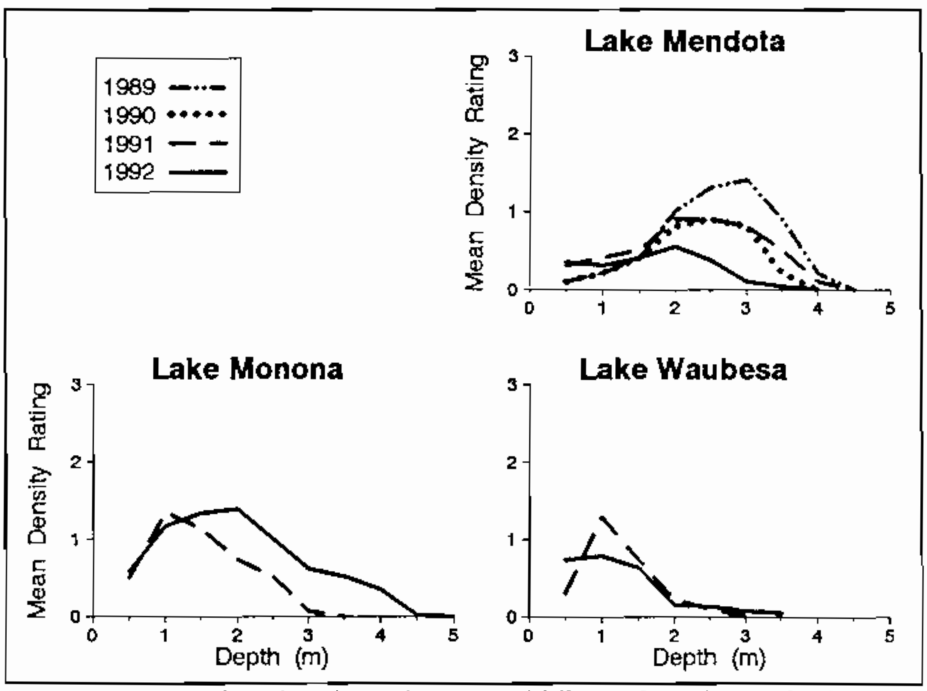

Figure 8. Mean density rating of Eurasian water milfoil at each depth on Lakes Monona, Waubesa, and Mendota, 1989–92. (Scale range 0–3.)

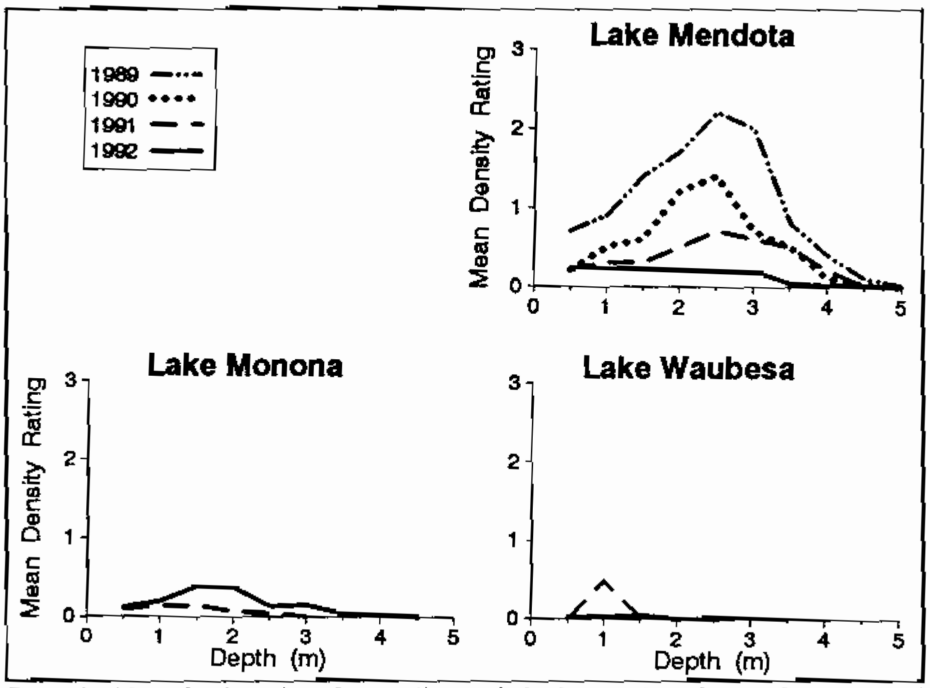

Figure 9. Mean density rating of coontail at each depth on Lakes Monona, Waubesa, and Mendota, 1989–92. (Scale range 0–3.)

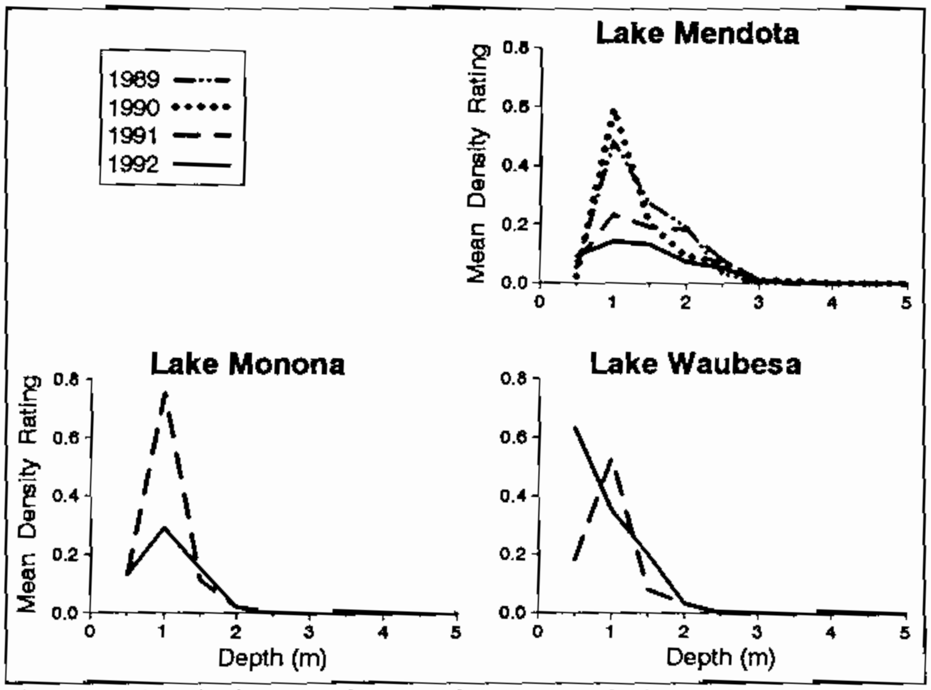

Figure 10. Mean density rating of sago pondweed at each depth on Lakes Monona, Waubesa, and Mendota, 1989–92. (Scale range 0–0.8.)

the littoral zone (Table 10). The apparent success of shallow growing species in 1992 may reflect less competition from coontail and Eurasian water milfoil, as well as clear water in the spring. Because water temperatures were unusually cold in 1992 (WDNR Bur. Res. unpubl. data), the

Table 9. Spring and summer water clarity as measured by a secchi disk (m) in Lakes Monona and Waubesa, 1989–92.[*]

	Monona		Waubesa	
	Median	Range	Median	Range
1989				
May/June	5.5	4.0–10.3	1.8	1.5–3.7
July/August	2.5	2.4–4.3	1.5	1.4–1.8
1990				
May/June	2.5	2.0–4.4	2.2	1.0–3.0
July/August	1.4	1.3–2.0	1.0	0.8–1.2
1991				
May/June	4.7	2.2–7.1	1.5	1.4–4.6
July/August	1.6	1.3–1.9	1.1	0.8–1.1
1992				
May/June	3.7	2.6–6.3	3.0	1.6–4.7
July/August	2.2	1.8–2.3	1.0	0.8–1.3

[*] WDNR, Bur. Res. (unpubl. data).

Table 10. Percentage of sites in the littoral zone where macrophytes were found, 1989–92.[*]

	Mendota	Monona	Waubesa	Kegonsa
1989	90	-	-	-
1990	80	93	99	42
1991	80	70	52	79
1992	72	95	75	78

[*] WDNR, Bur. Res. (unpubl. data).

growth of weedy species may have been prevented from reaching high densities. The lake appears to be in a state of transition following a severe decline in the biomass of competitive macrophytes. It will be interesting to see how the macrophyte community develops in the near future.

SUMMARY

(1) Low plant densities of all species were encountered in Lake Waubesa.

(2) Eurasian water milfoil was the most widespread. While it grew more densely than other plants, overall densities were low.

(3) Native species became more important components of the macrophyte community, while the relative dominance of coontail declined in recent years.

(4) More species were found in 1992 than in previous years. Rarer species found included new species (e.g., horned pondweed, Richardson's pondweed and flat-stemmed pondweed). In general, a trend towards greater diversity of native species seems to be occurring as the presence of nuisance species declines.

(5) Plant cover in the littoral zone increased from 1991 to 1992. Probably due to improved water clarity in the spring months of 1992, plants were observed in a higher proportion of the stations sampled and in deeper zones (0.5 m deeper) than in 1991.

AQUATIC PLANT MANAGEMENT

CURRENT AQUATIC PLANT CONTROL ACTIVITIES

Most publicly funded plant control activities on the Madison lakes are administered by Dane County. These activities include mechanical harvesting, limited shoreline cleanup, and coordination of the annual, volunteer spring lake cleanup event called "Take a Stake in the Lakes". To a small extent a Youth Conservation Crew Program, which is sponsored jointly by Dane County and the City of Madison, contributes to lake maintenance in the Madison area.

Aquatic herbicides are an alternative for aquatic plant control. All chemical treatments must be conducted in compliance with WDNR Regulations (Wis. Admin. Code NR 107, Aquatic Plant Management) and commercial applicators are required to be registered and licensed in the state by the Department of Agriculture, Trade, and Consumer Protection (DATCP).

Below is an overview of aquatic plant control activities conducted in the Yahara lakes in recent years. Where possible, information specific to the management of Lake Waubesa is included.

Harvesting Operation

Areas and Amounts Harvested. Since 1971, harvesting operations have been handled by the Dane County Department of Public Works. Aquatic plant harvesting follows the program described in Appendix A. Macrophytes are harvested from Lakes Mendota, Monona, Waubesa, Kegonsa, the Yahara River and its widespreads, Vilas and Tenney lagoons, and other smaller lakes throughout Dane County. Lake Wingra is not affected by routine harvesting. However, plants are harvested in localized areas prior to special events, such as the Badger State Games and regattas. In past years, except 1992, Dane County has provided the use of a cutter to a small boat livery on the west end of Lake Wingra, but no provision was made for removing cut plants.

The most intensive period of aquatic plant removal occurs from prior to Memorial Day weekend through the Fourth of July, lasting roughly 6 weeks. Harvesting usually occurs out to 150 ft from shore, where maximum plant growth is found. Beyond 150 ft, the lake usually deepens and aquatic plants cease to grow. However, in areas where the lake remains shallow offshore beyond 150 ft, plants are also harvested. Channels, approximately 50 ft wide, are sometimes cut to access deep, open water. Plants are harvested at public beaches at the beginning of the swimming season and afterwards as requested by lifeguards. Some lifeguards maintain their beaches without assistance from harvesters.

Certain public shorelines considered "natural" are not harvested. The north and south ends of Lake Waubesa and the Olin-Turville shoreline in Lake Monona and are among public shorelines that are not supposed to be harvested (Append. A).

An estimate of the quantity of aquatic plants removed from the Yahara lakes is depicted in Fig. 11. Each load removed from the lakes roughly equals one U.S. ton of harvested material. However, the estimate of plant biomass removed is influenced by the amount of time spent on a lake. When plant densities are low, only a partial load (counted as a full load) may be removed at the end of a day. The small amount of weeds harvested from Lake Waubesa in 1992 reflects the effort spent in assessing densities more than the quantity removed from the lake.

Harvested material is made available to farmers and area gardeners. Because lake vegetation has a high water content and their foliage is contains nutrients, they are considered excellent mulch and fertilizer. Plants thought to have been exposed to direct chemical treatment in the lakes are kept separate, even though the manufacturer of Diquat does not the chemical detrimental to gardens or animals (Mike O'Connor, Valent, pers. comm.). These plants are disposed of only at the county compost site where they are mixed with other organic materials (e.g., leaves) and composted at high temperatures (about 160 F) for about a year (K. Koscik, Dane County Department of Public Works, pers. comm.).

Prior to harvesting, the operations manager visually inspects an area by boat and decides whether or not to harvest. Areas where complaints are filed are also investigated. However,

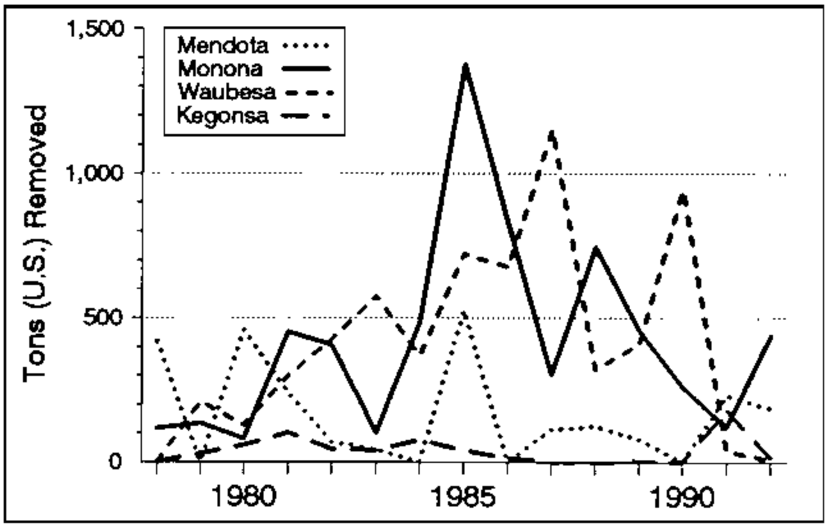

Figure 11. Tons of weeds harvested from the Yahara lakes, 1978–92.

measurable criteria for determining whether or not aquatic plants pose a nuisance and require harvesting are lacking. The discretion of the operations manager influences the kind of decisions that are made.

Public complaints can have a strong influence on the decision of where to harvest. The public may call the "lake weed hotline" to request pickup of vegetation that they have collected and placed on their piers and/or to file complaints about aquatic plant growth in their area. Unfortunately, in some instances the public has locally organized around the idea that maximum pressure (complaints) produces a response. Ultimately the County decides whether or not to harvest. Nonetheless, because harvesting decisions are not based on objective measures, the basis for rejecting requests to harvest certain areas is ambiguous.

Equipment and Staff. Currently, the Dane County harvesting fleet consists of 6 harvesters, 5 barges, and 2 cutters. Harvesters can cut to a depth of 5–8 ft and in water as shallow as 18 inches, depending on the capabilities of each harvester. Cutters are smaller than harvesters and do not collect cut plants. When cutters are used in park lagoons, an onshore crew removes cut material. Due to their maneuverability, cutters are used to maintain channels in the Yahara River.

All of the equipment maintenance, and some construction of new harvesters, is done by the Dane County Department of Public Works. In recent years, a new harvester was purchased. However, when construction of units is done inhouse, harvester designs are improved on, sturdier machines are built, and costs are cut approximately in half.

In 1992, harvesting began on May 12 and ended on August 8. Twenty-eight seasonal or limited term employees (LTEs) and 3 salaried county workers comprised the lake management staff. Beginning in 1989, after years of excessive macrophyte biomass, harvesting operations were budgeted for a double shift. In 1992 a double shift was run from June 1 until July 24. When macrophytes were not abundant, employees were occupied with other Department of Public Works' projects not related to lake management. Costs of the 1992 harvesting program appear in Table 11.

<u>**Shoreline Cleanup**</u>

In the past, shoreline maintenance was included in regular lake management services, but was reduced by a policy that supported the participation of lakefront residents in maintaining their shorelines. From the period prior to 1947 until 1971, shoreline cleanup and weed cutting

*Table 11. Dane County weed harvesting expenditures in 1992 (dollars).**

Budget Item	Cost
Personnel**	
Permanent staff (3)[a]	
Salary	$ 89,376
Benefits	36,584
Temporary staff (28)	80,000
Other	
Social security	13,897
Unemployment compensation	2,814
Overtime	1,500
Reimbursement from other public works activities[b]	(–) 25,000
Work done at no charge to other departments[c]	(-) 45,000
Operation of Tenney locks	(-) 20,000
Operating capital[d]	20,000
Operating expenses[e]	55,000
TOTAL:	209,171

* Data sources: K. Van Vlack, Lakes and Watershed Coordinator (pers. comm.).
** Includes activities other than aquatic plant management, such as locks operation, landfill operations, and assistance to other county departments with tasks such as moving.
a Is based on the entire year.
b Represents contribution from Solid Waste Division, to offset personnel costs.
c Includes services to Parks Division, Dane County Regional Airport, Dane County Coliseum, Badger Prairie Health Center, and City County Building throughout the year.
d Is based on annual average.
e Includes costs for weed harvesting program only.

programs were conducted by different departments of the City of Madison. After 1971, when the operation of the harvesting program was transferred to Dane County Department of Public Works, the City Parks Division continued to conduct the shoreline cleanup program until 1983 (Saley 1987). In 1986, the Madison Dept. of Public Health sponsored a pilot project cleaning a limited area of Lake Monona's shoreline; thereafter, it was not included in budgets. Since that time, no regular program for shoreline cleanup has been conducted by any government body.

Dane County Lake Management Division. The Dane County Department of Public Works operates barges to remove vegetation and shoreline debris that riparian owners collect and place on their piers. Collections are made on a per call basis and is a service available to all residents. During years when aquatic plants are sparse, harvester personnel may be diverted to clear accumulated plants from nearshore areas. No other public program of plant removal from nearshore areas is routinely managed.

Youth Conservation Crews. Since 1989, Dane County Lakes and Watershed Commission has coordinated the activities of a Youth Conservation Crew (YCC). The objectives of the program are threefold: (1) complete projects that improve the overall quality of water and land resources in the county, (2) provide meaningful work for youth aged 14-17, and (3) increase their understanding and appreciation for the beauty and value of natural areas in the county.

Program funding in 1992 was $25,000 of which $10,000 was allocated by the City of Madison. Since 1991, Operation Fresh Start, a nonprofit youth services organization targeting at-risk youth, has managed the crews. Overall, 92 teenagers (6 crews) worked 6,442 hours in 1992. Project applications for the 1993 YCC were accepted through January 1993.

"Take a Stake in the Lakes." Since 1989, the Dane County Lakes and Watershed Commission has sponsored "Take a Stake in the Lakes" effort each June. This volunteer

shoreline cleanup event takes place on three consecutive Saturdays on Lakes Mendota, Monona, Waubesa, and Kegonsa. Volunteers rake macrophytes, algae, and litter from the lake and load this debris on barges and harvesters operated by the Dane County Department of Public Works. In 1992, over 200 tons of lake debris were removed from the lakes: 128 tons from Lake Monona, 35 tons from Lake Waubesa, 30 tons from Lake Kegonsa, and 10 tons from Lake Mendota.

A part-time employee coordinates the program. This involves rallying citizen participation by talking to different neighborhood associations and local groups, advertising the event, arranging media coverage, preparing maps, organizing shoreline area captains, finding sponsors for equipment (e.g., cellular phones), etc.. The number of participants varies from year to year depending on the weather conditions and the amount of promotion.

Chemical Treatment

Regulations. All aquatic herbicide use must comply with state and federal regulations. The U.S. Environmental Protection Agency (EPA) regulates the production, sale, distribution, and registration of all pesticides. The Department of Agriculture, Trade, and Consumer Protection registers pesticides for use in Wisconsin. The WDNR regulates the use of aquatic herbicides according to Wis. Admin. Code NR 107 (Aquatic Plant Management). This includes a permit process and compliance with standards of application detailed in Wis. Admin. Code NR 107 as well as an approved product labels. All herbicide application in the Yahara lakes is done by a commercial applicator in the presence of WDNR on-site supervisor.

In 1990, the WDNR identified critical spawning habitats for bass and bluegills under the "sensitive areas" provision of Wis. Admin. Code NR 107. In these areas, herbicide treatments were prohibited from mid-May until mid-June (so-called "early treatments"). At the same time, the WDNR sponsored a University of Wisconsin (UW) research study evaluating the effects of the aquatic herbicide Diquat on spawning fish.

The UW study was recently concluded. It found that spawning adults or fry, showed no direct adverse effects when exposed to Diquat concentrations approved for vegetation control in the laboratory and in the field (N. Raffetto, UW-Madison, pers. comm.). As a result, the moratorium on early spraying will be lifted in 1993 (J. Huntoon, WDNR Southern District, pers. comm.). It should be noted that the "sensitive areas" provision of Wis. Admin. Code NR 107 encompasses criteria beyond spawning habitat. The establishment of the 1990 sensitive areas designation was specifically designed to protect spawning bass and bluegills. A future, more comprehensive sensitive areas designation, which protects native vegetation, may restrict herbicide use, harvesting or certain kinds of other activities (e.g., riprap).

It should also be noted that the UW Diquat study did not evaluate potential indirect impacts. Indirect impacts, such as removal of critical nursery habitat, mortality of invertebrate food sources, localized dissolved oxygen depletion, etc., may exert other types of localized stress. These indirect impacts are difficult to quantify and assess in lakes as large as the Madison lakes. Most likely there is some impact, but what that impact is given the relatively small areas that are treated, is not known.

Types, Costs, Quantities, and Location of Herbicide Control. Two chemicals were applied to the Yahara lakes in 1992: Diquat was used on Eurasian water milfoil and copper sulfate was applied to filamentous algae. Although chemical treatment targeted Eurasian water milfoil and filamentous algae, other macrophytes in the treatment area would have been affected. Diquat is a non-selective contact herbicide that kills desirable native species (such as pondweeds) as well as weedy ones. Also, although immediate weather conditions are taken into account during herbicide application, drift of the herbicide impacts areas beyond those permitted.

The herbicide 2,4-D is highly selective for controlling only species that are dicotyledonous, such as Eurasian water milfoil, as opposed to monocotyledonous species such as pondweeds, naiads and wild celeries. In some lakes in Wisconsin, only 2,4-D is allowed to be used for herbicide treatment (e.g., Lake Wisconsin in Sauk and Columbia counties, and Rock and Ripley lakes in Jefferson County). Because of public controversy mistaking 2,4-D for Agent Orange, it is not used in the Madison lakes, even though it is a common ingredient of herbicides used in lawn treatments. A comparison of some chemical control options appears in Appendix C.

In 1992, all permits for herbicide application in Lake Waubesa were coordinated through a private company called Clean Lakes Association. Herbicide spraying in 1992 cost each purchaser $0.69 per frontage foot + $6.00 DNR permit fee + $18.00 administrative fee. Clean Lakes Association subcontracted Scientific Weed Control, Gurnee, IL., a state certified applicator, to apply the herbicides.

All applications for herbicide treatment in Lake Waubesa are made by private property owners. Such applicants bear all costs involved, whether they apply herbicides independently or through a private contractor.

Herbicides were applied only once in Lake Waubesa, on June 24, 1992. No early treatment was allowed on Lake Waubesa. At this time all private shorelines were considered non-critical. The shoreline areas where treatment out to 100 ft was permitted by WDNR are illustrated in Fig. 12 (C. Molter, WDNR on-site supervisor, pers. comm.). Only the areas whose vegetation conditions complied with Wis. Admin. Code NR 107 were sprayed; therefore, not all of the permitted shoreline may have been treated with herbicides. Table 12 summarizes the amounts and types of herbicides applied during each treatment.

Interaction Between Harvesting and Chemical Control Operations. Harvesting and chemical treatment are administered completely independently. As a result, a lack of coordination between these two practices has led to instances of reduced efficiency and of friction. Four examples from 1992 illustrate these problems:

(1) Harvested plants are distributed to local residents for their gardens. To the best of the harvester operator's knowledge, vegetation affected by chemical spraying are separated. Only those plants not contaminated with herbicides are distributed directly to gardeners and farmers. Preferring to err on the conservative side, harvester operators take many uncontaminated macrophytes (possibly tons), to a county compost site.

2) Public complaint has accused harvester operators of not collecting vegetation that later accumulates on the shoreline. Most plants cut by harvesters are collected via conveyors located on the head of the machine. Plants cut by motor boat propellers or broken off as a part of their lifecycle are blown ashore by prevailing winds and contribute to shoreline accumulations.

(3) Some harvester operators working in the vicinity of spraying operations felt that their safety from exposure to these chemicals was not considered by the applicator.

(4) Concern that harvesting in an area where herbicides are being applied may increase the turbidity of the water, which can decrease herbicide effectiveness, has provoked complaints by both the herbicide applicator and those paying for chemical treatment.

LITERATURE REVIEW OF AQUATIC PLANT CONTROL TECHNIQUES

General Considerations

Undesirable ramifications of macrophyte control are associated with every management method. Such ramifications include altering the physical and chemical environment, eliminating habitat (for invertebrates, fish, wildlife, and waterfowl), and enabling the weedy plants to spread in the lake via fragments (Engel 1990a, Nichols 1991). In addition, treating plants with herbicides without removing them can lead to oxygenation depletion and nutrient release due to plant decomposition, as well as subsequent regrowth (Engel 1990b). Treating a large area may increase the negative impact, while treating small areas may not be effective in reducing nuisance conditions.

Negative impacts are associated with no management as well. These include aesthetic and recreational impairment, degraded habitat, health and safety problems, and lowered property

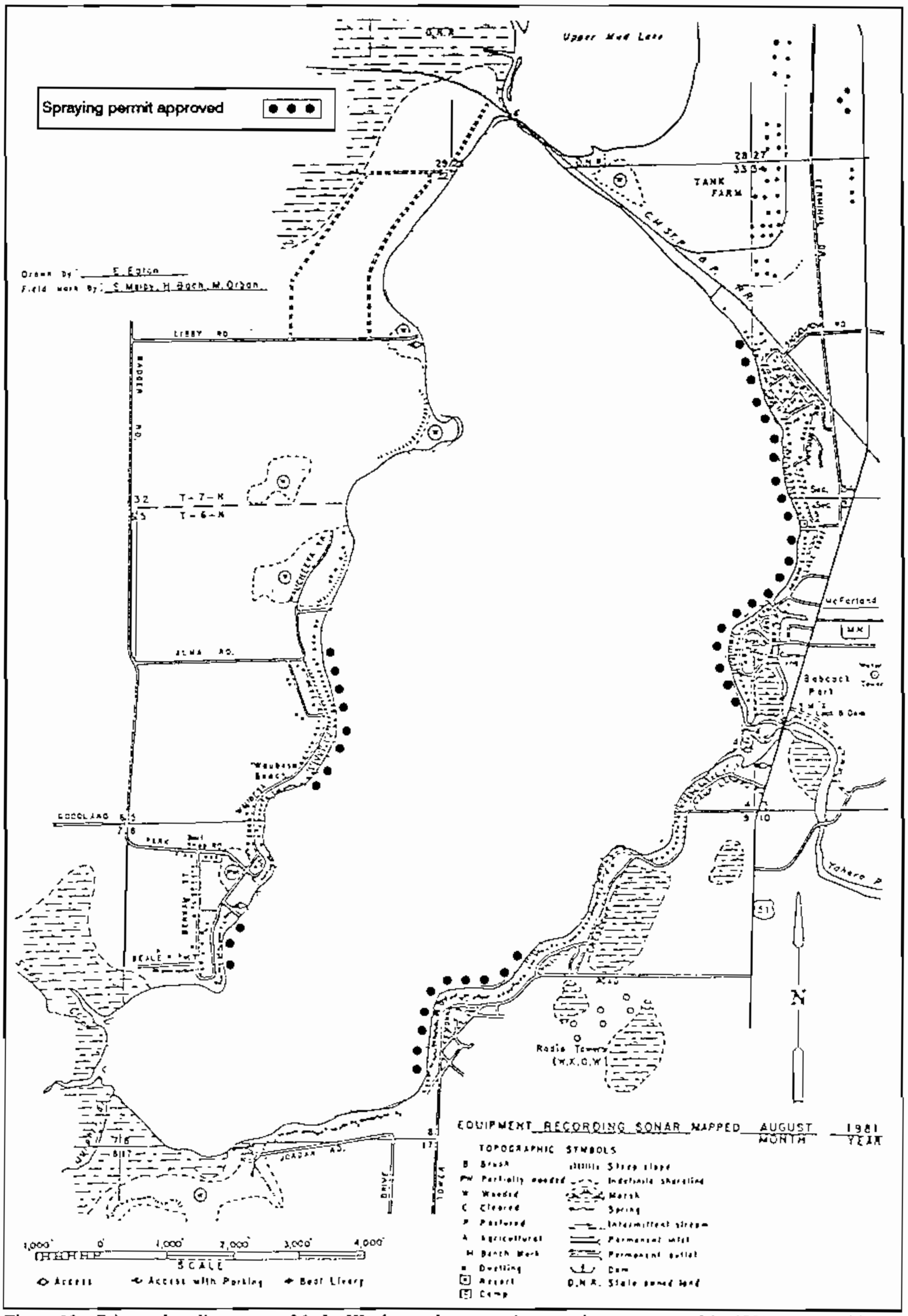

Figure 12. Private shoreline areas of Lake Waubesa where spraying permits were granted in 1992. (Herbicides were applied only when conditions warranted, as determined by WDNR on-site supervisor.)

Table 12. Amounts of herbicides applied to Lake Waubesa in 1992.[*]

Applications	Diquat	Copper Sulfate
First treatment - None		
Second treatment - June 23, 1992		
Area of lake (acres)	4	-
Length of shoreline (ft)		
Ft	1800	-
Percent shoreline treated[**]	3.6	-
Amount of herbicide	8 gal	0

[*] Data source: J. Leverance, Lake Management Planning Analyst, WDNR (pers. comm.).

[**] Percentages do not reflect separate shoreline areas (e.g., Diquat and copper sulfate may have been applied in the same area).

values (Andrews 1986). By weighing the relative advantages and disadvantages of each plant control method, an integrated program, which minimizes negative impacts, can be developed from the best ones.

Methods of Control

Methods for controlling aquatic plants can be divided into physical, mechanical, biological, habitat manipulation, and chemical technologies (Nichols et al. 1988). Integrated plant management identifies the desired level of control based on economic and environmental considerations and combines different plant control methods in a strategic manner (Andrews 1986).

Biological control refers to the use of natural enemies such as predators, parasites, pathogens, or competitors to maintain nuisances at tolerable levels. The ideal biological control agent is host specific, easily dispersed, capable of maintaining a natural population without affecting other species when its own host declines, not dangerous to animals or humans, and able to limit plant populations without destroying them (Nichols 1991).

Wisconsin prohibits the introduction of biological controls (Wis. State Statutes Sec. 29.47(6) and Wis. Admin. Code NR 19.27) due to habitat destruction and alteration of ecosystem communities following the introduction of species that subsequently reproduce (e.g., grass carp and crayfish). Regulation of biological control methods may change as new technologies are tested and as biological engineering enhances their selectivity.

Habitat manipulation refers to a type of control that changes habitat conditions for macrophyte growth. Habitat conditions can be manipulated directly and indirectly. Modifying substrate or light penetration are examples of direct manipulation. Indirect manipulation includes altering chemical and biological processes occurring in the lake, such as nutrient release or predation.

Chemical treatment is easy to use and can produce immediate as well as delayed results (Engel 1990a). Although, herbicides approved for use must be registered with the U.S. Environmental Protection Agency (EPA), this means only that the economic benefits of the herbicide's use have been determined to outweigh the health risks. Because product use is not without ecological risk, the EPA does not define any pesticide as "safe." Recent changes in federal pesticide laws require additional information from product manufacturers. EPA will then reassess the potential hazards arising from herbicide use (WDNR herbicide information sheets, 1990). Diquat and copper sulfate, the herbicides used in the Yahara lakes, are presently being reassessed by the EPA reregistration process.

Concerns about liability connected with herbicide use are emerging. The Lake Minnetonka Conservation District, near Minneapolis, will not apply herbicides due to liability (N. Paurus, Lake Minnetonka Conservation District, pers. comm). Recently, the Pewaukee Lake

Citizens Advisory Committee in southern Wisconsin reached similar conclusions (C. Shong, Pewaukee Sanitary District, pers. comm.).

Various technologies are reviewed and compared in Appendix C. Of the methods discussed, currently harvesting and chemical control are implemented in the Yahara lakes for plant control. Inadvertently, water level drawdown affects plant growth along the lake's edge. Winter drawdown is implemented to protect the shoreline from damaging effects of flooding and ice scour. It is not feasible to further lower the lake level to control macrophyte growth because of conflict with authorized minimum and maximum lake levels which must be maintained. If these levels are exceeded, there are likely impacts on other users/interests and downstream resources including the risk of not being able to refill the lake, or those lakes downstream in the Yahara River chain, in the springtime and reducing northern pike spawning in adjacent wetlands.

FUTURE MANAGEMENT CONCERNS

If recent trends continue, a diverse community of native aquatic plants, as well as the exotic Eurasian water milfoil, may be established. However, lake ecosystems and plant communities are dynamic. Physical and chemical components (e.g., temperature, water clarity, and nutrient concentrations) as well as biological ones (e.g., plants and animals) are interconnected so that variations in one can impact the others. Changes in the Yahara lakes are expected to influence future aquatic plant conditions. These changes may influence how aquatic plants are managed, if and when they occur. To counter those changes that may threaten, lake management should emphasize prevention. In addition, lake managers should anticipate the need to respond early, in order to mitigate the impact of these future concerns.

The arrival of the exotic zebra mussel (*Dreissena polymorpha*) into the Yahara lakes appears inevitable and is of most concern to lake managers. First identified in the Great Lakes in the 1980s, where millions of dollars are spent annually to control damages. Immature mussels are transferred via boat traffic. They settle on any available hard substrate, including intake and discharge pipes, riprap, locks, boats, piers, as well as other zebra mussels. Because of their explosive growth, thick layers of mussels are created that clog pipes, foul propellers, damage boat hulls, etc. Zebra mussels are filter feeders that feed on material suspended in the water column. As mussel densities increase, tremendous volumes of water are filtered through their systemsthus removing free-floating algae (phytoplankton) from the lake. This filtering capacity may improve water clarity, which could significantly increase aquatic plant densities and allow them to grow in deeper water. Other ecological impacts of zebra mussels are of concern, including a reduction in the food base for fish, which could result in a decline in the fish populations and the associated impacts of this on up the food chain.

Changes in the lake system associated with nutrient reduction and the introduction of new exotic plant species should also be considered in the long-term. Management practices proposed in the Yahara-Monona Priority Watershed Project are aimed at decreasing the amount of nutrients entering the lake and as a result, may improve water clarity by reducing algal blooms. A likely result of increased light penetration is deeper, and therefore more extensive, macrophyte growth. Exotic plant species, such as Hydrilla (*Hydrilla* spp.) have the potential to mirror the invasion of Eurasian water milfoil, resulting in massive growth and reduced plant diversity. Currently, Hydrilla is limited to warmer regions, but it may over time, become tolerant of cold conditions and survive Wisconsin's climate.

IMPLICATIONS FOR MANAGEMENT

OVERLYING IDEAS

Local lake managers recognize the need to remove excessive aquatic plant growth from Lake Waubesa. The aquatic plant management (APM) challenge is to define a plan to remove excessive growth in a way that balances sometimes disparate interests. The key is to focus on effective control, but not on the total eradication of all plants. Use by humans as well as by wildlife needs to be considered. Based on the information in this report, this section outlines goals of APM and presents recommendations on how to achieve them.

The recommendations were developed to reflect a set of guiding principles. By designating areas in the lake according to use, shoreline ownership, and ecological importance; setting desirable levels of management, and creating objective means of evaluating aquatic plant conditions, plant control can be focused and individualized. Integrating methods of management acknowledges the rights and responsibilities of different constituencies and encourages cooperation and coordination between the practices. APM should remain flexible and responsive to reevaluation. Alternatives and new developments (e.g., growth regulators) should be explored. Political (e.g., legislative) and environmental (e.g., invasion of new species) changes need to be anticipated, and the response of management should be planned not reactive. The largest constituency of lake users enjoy the lakes from onshore; APM, together with efforts by local municipalities, needs to consider this constituency's perception of nuisance conditions as well as those who recreate on the lake. Finally, to gain the support of the public, an understanding of the benefits of macrophytes coupled with realistic management goals for a eutrophic lake must be reached through creating awareness and through education.

GOALS

* **Manage for long-term ecological integrity of the lake**
    - Establish criteria for APM decision-making.
    - Control exotic and weedy plant species (e.g., Eurasian water milfoil).
    - Preserve stocks of native aquatic plants.
    - Encourage development of a diverse community of native plant species.
    - Identify and protect natural areas in the littoral zone (Wis. Admin. Codes NR 103, NR 107).

* **Enhance lake for recreation**
    - Manage aquatic plants according to recreational use, including aesthetics and fishing.
    - Control filamentous algae.

* **Educate users and lake managers**
    - Inform users about lake functioning and the value of macrophytes, especially native species.
    - Develop a shared community responsibility for stewarding the lakes.
    - Encourage support for plant diversity.

* **Reduce nutrient loading**
    - Remove cut and accumulated plants and filamentous algae.
    - Implement recommendations of the Dane County Lakes and Watershed Commission Water Quality Implementation Plan.
    - Secure designation of Yahara-Mendota as a Priority Lake or Watershed.
    - Pursue public information and education program.

APM TECHNIQUES

A means of measuring the degree of nuisance aquatic plant conditions is proposed. By measuring conditions, appropriate and consistent management can be facilitated, and decisions by lake managers can be supported in the face of sometimes subjective pressures.

Most of the recommendations outlined below focus on implementation of the harvesting program. Harvesting, an effective and efficient means of aquatic plant control for large, multiple use, is less controversial than herbicide treatments, which also affect adjacent areas through drift. In addition, removal of cut plants, which are in demand by gardeners and farmers, reduces nutrients in the lake. By implementing innovative cutting techniques, management levels can be more flexible than in the past. More than any other single method considered (Append. C), harvesting, when coupled with a defined program for evaluating nuisance plant conditions, has the greatest potential to reduce interference of plant growth with recreational use and to enhance the quality of the aquatic plant community.

Chemical control, the chosen plant control method of some lake users, needs to be brought into line with true integrated management goals. Although these chemical treatments are contracted by private parties, they affect success of native plant recovery and restoration in the lake as a whole. Finally, shoreline cleanup, education, and continued efforts to reduce nutrient input are required to round out the picture of integrated APM in Lake Waubesa.

Criteria Development

• **Develop a hierarchy of management decisions.** Different shorelines will require different levels of management. Shoreline ownership, distance from shore, area designation and presence and abundance of macrophyte species need to be taken into consideration when managing aquatic plant growth. The following section proposes a clear plan for making APM decisions based on measurable criteria.

• **Distinguish between public and private shorelines.** There need to be some distinctions between APM on public shorelines compared to that for privately owned shorelines. This distinction is necessary because of certain legal rights (e.g., erection of piers) and the recreational needs of private shoreline owners.

• **Identify distance from shore.** Shoreline areas within 150 ft from shore will receive more intensive plant control, because recreation and aesthetics are most intensive in this region. Beyond 150 ft from shore, APM will emphasize the importance of macrophytes in the lake system, while providing access to the open lake.

The distance of 150 ft was selected to be consistent with the distance from shore where herbicides may be applied under Wis. Admin. Code NR 107. In the event that a whole lake use plan is developed that conflicts with this 150-ft dividing point, aquatic plant management criteria for both harvesting and chemical application should be reevaluated.

• **Designate areas for different management.** Shoreline designations should be based on a consideration of recreational use, shoreline ownership, and ecological importance (e.g., presence of native plant species). A three-tiered system to should be used to divide the littoral zone of the lake into areas classed "no restriction areas", "watch areas", and "natural areas." Any of the three area designations can apply to public shorelines; whereas only "watch areas" and "no restriction areas" pertain to private shorelines. It should be noted that these designations relate specifically to the Yahara lakes. These areas are defined as:

> "NO RESTRICTION AREAS" - *These are shoreline areas identified as heavily recreated and/or providing major public access points to the lake. Plant control is optimized.*

Table 13. Recommendations for aquatic plant control in different parts of the lake.

	NO RESTRICTION AREA	WATCH AREA	NATURAL AREA
Criteria	Ecological Importance: Ownership: Private shorelines (up to 150 ft from shore) extending out from community or commercial piers (e.g., boat liveries, marinas, restaurants). Public shorelines at boat launches, beaches, channels from river mouths and outlets. Use: Intensive recreational demands; major access points to rest of lake; public beaches; public boat landings (launching channels between piers).	Ecological Importance: Includes highly valued species (NR 107)*; native species; declining densities of Eurasian water milfoil, coontail, and curly leaf pondweed; and fish habitat. Ownership: If not "no restriction area" or "natural area", all private and public shorelines within 150 ft from shore. All shorelines beyond 150 ft, except for "natural areas". Use:	Ecological Importance: Relatively undisturbed habitat and wetland. Includes highly valued species (NR 107)* and native species other than coontail. Reflects sensitive areas in NR 107: critical fish habitat (e.g., spawning, nursery, food, and cover); and wildlife habitat (e.g., nesting, food, and migration). Protects water quality; prevents shoreline erosion. Ownership: Public shoreline only. Extends throughout littoral zone wherever aquatic plants grow, including beyond 150 ft from shore (NR 103). Use: Fishing, canoeing, and enjoyment of relatively undisturbed areas of the lake.
Aquatic Plant Management	Is maximized and should be done as follows: - Base decisions on flow chart (Figs. 14 and 15). - Priortize management due to recreational demand and lack of restrictions. - Focus on relief near piers and launches and access to deeper water.	Is RESTRICTED and should be done as follows: - Base decisions on flow chart (Figs. 14 and 15). - Use biology (e.g., knowledge of life cycles, seasonality, interspecific competition) to enhance management. - Control, but at the same time maintain aquatic vegetation (even Eurasian water milfoil may be more desirable than none). - Defer management to "no restriction" zones during peak season, except in certain situations where "weedy" species dominate.	Is RESTRICTED and allowed only in conjunction with approved projects (e.g., restoration projects). Includes shoreline cleanup for removal of lake vegetation, fish, and litter only.
Aquatic Plant Harvesting	Is maximized according to Figs. 14 and 15 and Table 14.	Is LIMITED, and if warranted, then according to Figs. 14 and 15 and Table 14.	Is not allowed, unless directed by an approved restoration project.
Chemical Control	Is limited to private shorelines only and must comply with WDNR regulations.	Is limited to private shorelines only and must comply with WDNR regulations.	Is prohibited.
Activity Restrictions	Are none.	Are none.	Involves limiting motor traffic with "natural area" buoys through such means as no wake zones.**
Aquatic Plant Restoration	Is of low priority.	Is, where feasible, the same as for "natural areas".	Is of high priority. Should focus on restoring floating-leaved plants and broad-leaved pondweeds.

* Species listed in Wis. Admin. Code NR 107 and currently found in Yahara lakes and/or Lake Wingra: *Potamogeton illinoensis* (Illinois pondweed), *P. pectinatus* (sago pondweed), *P. richardsonii* (Richardson's pondweed), *Zannichellia palustris* (horned pondweed), *Vallisneria* spp. (wild celeries), *Eleocharis* spp. (spikerushes). Other species listed in NR 107 but not currently found in Yahara lakes: *Potamogeton amplifolius* (large-leaved pondweed), *P. praelongus* (white-stemmed pondweed), *P. robbinsii* (fern pondweed), *Brasenia schreberi* (water shield), *Scirpus* spp. (bulrushes), and *Zizania aquatica* (wild rice), .

** "No wake zone" minimizes damage to plant from propellers of fast moving motor boats passing through area.

PUBLIC SHORELINE

WITHIN 150 ft from shore

Designation (see Table 13):	NO RESTRICTION AREA			WATCH AREA					NATURAL AREA
Species:	"Weedy" species only	Mixed or native species		"Weedy" species only		Mixed species		Mostly native species	All species
Density:	All densities	Low densities	Medium to high densities	Low to medium densities	High densities	Low to medium densities	High densities	All densities	All densities
Management (see Table 14):	**Bottom cut** "channels" to open lake	**Not cut**	**Surface cut** "channels" to open lake	**Not cut**	**Surface cut,** also **bottom cut** in "lanes"	**Not cut**	**Surface cut**	**Not cut**	**Not cut**

BEYOND 150 ft from shore

Designation (see Table 13):	NO RESTRICTION AREA			WATCH AREA					NATURAL AREA
Species:	"Weedy" species only	Mixed or native species		"Weedy"species only		Mixed species		Mostly native species	All species
Density:	All densities	Low densities	Medium to high densities	Low to medium densities	High densities	Low to medium densities	High densities	All densities	All densities
Management (see Table 14):	**Bottom cut** "channels" to open lake	**Not cut**	**Surface cut** "channels" to open lake	**Not cut**	**Surface cut,** also **bottom cut** in "lanes"	**Not cut**	**Surface cut** "lanes" to open lake	**Not cut**	**Not cut**

Figure 14. Harvesting recommendations for public shorelines. (Definitions of "weedy" species and rake densities appear in text).

PRIVATE SHORELINE

WITHIN 150 ft. from shore

Designation (see Table 13):	NO RESTRICTION AREA			WATCH AREA						
Species:	"Weedy" species only	Mixed or native species		"Weedy" species only		Mixed species		Mostly native species		
Density:	All densities	Low densities	Medium to high densities	Low densities	Medium to high densities	Low densities	Medium to high densities	Low to medium densities	High densities	
Management (see Table 14):	**Bottom cut** "channels" to open lake	**Not cut**	**Surface cut** "channels" to open lake	**Not cut**	**Bottom cut**	**Not cut**	**Surface cut**	**Not cut**	**Surface cut** "lanes" to open lake	

BEYOND 150 ft. from shore

Designation (see Table 13):	NO RESTRICTION AREA			WATCH AREA					
Species:	"Weedy" species only	Mixed or native species		"Weedy" species only		Mixed species		Mostly native species	
Density:	All densities	Low densities	Medium to high densities	Low densities	Medium to high densities	Low densities	Medium to high densities	Low to medium densities	High densities
Management (see Table 14):	**Bottom cut** "channels" to open lake	**Not cut**	**Surface cut** "channels" to open lake	**Not cut**	**Surface cut**, also **bottom cut "lanes"** to open lake	**Not cut**	**Surface cut** "lanes" to open lake	**Not cut**	**Surface cut** "lanes" to open lake

Figure 15. Harvesting recommendations for private shorelines (Definitions of "weedy" species and rake densities appear in text).

Harvesting

• **Implement decision-making criteria.** As described above, these criteria consist of using the rake method to assess plant densities and identify species (Append. B). Nuisance conditions and the level of management appropriate to areas with such conditions should be evaluated using flow charts and area designation map (Table 13 and Figs. 14 and 15). Copies of area designation maps and flow charts (Figs. 13–15) should be laminated and kept onboard each harvester for reference.

• **Employ a harvest "scout".** Such a scout will use the rake method from a boat to gather information about the location and densities of aquatic plants prior to harvesting. On a daily basis, the scout will consult with the operations manager to decide where and how to harvest. Having a mobile scout in the field makes using the flow charts practical and streamlines decision-making. The scout will:

(1) use the rake method to identify aquatic plant species and their densities,
(2) use the flow chart to make management decisions,
(3) mark the locations of beds of native species so that harvesters can avoid them (e.g., with anchored milk jugs),
(4) share information about locations of native species with the WDNR on-site supervisor of chemical treatment,
(5) act as a liaison between the harvesting program and the general public (e.g., answering complaints, explaining APM program, educating, etc.),
(6) act as a liaison between the harvesting program and herbicide applicators (sharing information about location of native plants, scheduling with each other to avoid working near each other, etc.),
(7) train the harvester operators about the goals of APM and how to identify plants,
(8) assist the operations manager in supervising the harvester operators in the field (e.g., monitoring cutting distance from shore, following harvesting protocol, etc.), and
(9) collect year-to-year survey data by mapping vegetation distribution and monitoring plant densities.

The value of the harvesting scout position would increase greatly if the same person could be employed in this seasonal position year after year. The program and employee would benefit from consistent methodology, familiarity with the resource, and a chance to develop working relationships with all interest groups. A science teacher might be wellsuited to this type of summer work.

• **Apply appropriate harvesting techniques.** By expanding the uses of harvesters to do innovative cutting, goal-oriented APM is possible (Figs. 14 and 15 and Table 14). The conventional "bottom cut" should be used to reduce biomass of weedy species only and not to clearcut the lake of aquatic plants. Other cuts actually benefit native species and permit access to different areas in the lake while still removing nuisance conditions. In particular, the "surface cut" removes surface canopies formed by weedy species that shade native plants beneath them. Harvester operators should receive training about the APM program and the different capabilities of the harvesting units.

• **Reduce aquatic plant growth near public and private piers.** Since lake use along both public and private shorelines is focused around piers, harvesting needs to keep these areas open for recreation and access.

• **Harvest boat lanes or channels.** Such passages should be cut to access deeper, vegetation-free water (Table 14); cutting should be done according to the flow charts (Table 14 and Figs. 14 and 15). The area beyond 150 ft from shore should be made navigable, without clearcutting aquatic plants.

Table 14. Harvesting options.

Type of cut	Rationale	Method
Bottom cut	- Remove maximum plant biomass.	- Cut plant stem near sediment surface. - Cut only Eurasian water milfoil, coontail, and curly leaf pondweed in this manner.
Surface cut	- Remove plant biomass at surface. - Remove large amounts of "weedy" species (Eurasian water milfoil, coontail, and curly leaf pondweed). - Minimize impact on native species. - Improve light conditions in understory. - Improve competitive ability of native species.	- In water >4 ft deep, cut only surface canopy. - Cut not more than 2 ft from water surface. - Cut only Eurasian water milfoil, coontail, and curly leaf pondweed. - Do not cut: Floating-leaved plants (e.g., water lilies) Sago pondweed at water surface
Shallow cut	- Encourage plant growth where diversity is greatest and where "weedy" species grow less densely. - Minimize harvesting where recreational use is not hindered and where swimmers are less imperiled by submersed plants.	- In water <4 ft deep, set cutting bar at no more than 2 ft from surface. - Cut only nuisance conditions (rake >50%). - Cut only Eurasian water milfoil, coontail, and curly leaf pondweed.
Lanes	- Beyond 150 ft from shore, create access from riparian zone to open lake. - Open weed beds for fish movement and angler access. - Create edge.	- Depending on species and densities, bottom or surface cut. - Make lane width only as wide as the harvester (i.e, one pass of the harvester). - Beyond 150 ft from shore, cut lanes at regular intervals to access deeper water. - Minimize impact on native species present.
Channels	- Permit unobstructed public access in no restriction zones.	- Bottom cut Eurasian water milfoil, coontail, and curly leaf pondweed. - Surface cut mixed species. - Cut channel 50 ft wide.
Skimming	- Remove filamentous algae that is floating or attached to sparsely growing plants.	- Drive harvester slowly. - Set cutting bar at about 1 ft from surface.

• **Priortize zones by recreational use.** During peak season (prior to Memorial Day until July 4), the harvesting operation should focus on "no restriction" zones. Operating the harvesters on a double shift facilitates handling the onslaught of harvesting demands concentrated into a relatively short time period. By anticipating recreational demands, harvesting should be more productive and effective in heading off public complaints.

• **Lower the priority of areas receiving chemical control.** This will increase the efficiency of harvesting by eliminating the overlap of harvesting areas on which plants have already been controlled by another method. Harvesting can then concentrate on managing areas where no other control has been exercised.

• **Pursue long-term management.** After the Fourth of July weekend, priorities should be expanded to enhance other areas in the lake and to manage for long-term effectiveness. Enlarging harvesting objectives does not preclude continued management of recreational areas.

Harvesting to enhance native plant communities requires time and finely tuned decisions. Native species generally begin to grow later in the season than do the species prone to cause nuisance conditions. Using the flow chart, selective harvesting could improve other areas of the lake by thinning out Eurasian water milfoil and coontail. Curly leaf pondweed, a nuisance early in the growing season, will not need to be targeted since its biomass usually recedes after June.

Alternative harvesting techniques such as early, late, and deep cuts should be tried (Table 15) and pilot studies conducted. A possible site for demonstrating early and late cutting is Monona Bay in Lake Monona, an area typically afflicted with dense aquatic plant growth.

Table 15. Alternative harvesting techniques.

Type of cut	Rationale	Method
Early cut	- Stress plants at a vulnerable time. - Increase effectiveness and duration of harvesting. - Give later-growing native species a competitive edge.	- Bottom cut until surface water temperature reaches 60 F, not later than June 1.
Late cut	- Stress plants at a vulnerable time. - Minimize success of overwintering. - Delay or diminish spring regrowth.	- Harvest when native species complete reproduction and when dormant states won't be affected (Sept-Oct). - Remove maximum biomass of Eurasian water milfoil and coontail which overwinter in a green state.
Deep cut*	- Increase the effect of harvesting to last for more than one growing season.	- Use deep cut harvester to cut plants at the base of the stem in up to 25 ft of water. - Follow with a barge or harvester to collect cut plants for disposal.

* Wis. Dep. Nat. Resour. (1990). For information see Append. C.

• **Do not harvest where shoreline owners are opposed.** Shoreline owners who do not want their shoreline harvested should post a sign on their pier. Harvester operators should lift the cutting head and pass that stretch of shoreline without cutting.

• **Pick up piles of aquatic plants on piers.** The county should continue to remove vegetation collected by shoreline owners cleaning up their own shorelines.

• **Throw back trapped fish and wildlife.** Fish, turtles, and other aquatic organisms collected during harvesting of plants should be returned to the lake whenever possible.

• **Recycle harvested aquatic plants.** Plants removed from the lake should continue to be distributed to people who request them for their gardens or farm fields. Vegetation considered exposed to herbicides should be kept separate and disposed of at the county compost facility.

• **Identify filamentous algae growth and harvest limitations.** If not attached to densely growing plants, filamentous algae eludes the harvesters by getting pushed ahead or to the sides of the cutting bar. If it is brought up on the conveyor, it tends to either slip through the mesh or not fall off of the conveyor into the collection area.

• **Use harvesters adapted to deal with filamentous algae conditions.** Filamentous algae can be collected by harvester adaptations, such as front flares, smaller mesh size, pontoons, and floating booms to contain algae. Other suggestions include using a barge crew to remove filamentous algae directly from the water or using a small boat with a "plow" to push it to shore, for pickup.

• **Skim filamentous algae.** This would be done as described in Table 14. If not removed, filamentous algae will eventually drift to shore. Also, dense growths of filamentous algae are associated with a decline in macrophyte species, which may be detrimental to native species early in the season.

• **Use Lake Management personnel for other lake management projects.** When plants are not being harvested, use available staff to work on other lake related projects, such as shoreline cleaning, and building plant collection structures and settling basins near storm drain outlets.

Chemical Control

• **Acknowledge use by applicants.** Chemical control is recognized as an available option for plant control by applicants, when applied in compliance with product labels, DATCP, and WDNR regulations (Wis. Admin. Code NR 107). As policy, Dane County does not use herbicides to control aquatic plants (Dane Co. Lakes Water. Comm. 1992).

• **Inform the applicators where valued species grow.** The harvesting scout should share information about the location of native macrophytes with the WDNR on-site supervisor in order to reduce or prevent the application of non-selective herbicides in these areas, or to use highly selective herbicides.

• **Request that WDNR inspect lakes prior to chemical treatment.** By inspecting the lakes not more than one week prior to chemical treatment, the WDNR on-site supervisor will be able to identify the location of native species and use this information to make better decisions about where chemicals should be applied.

• **Evaluate ways to reduce amount of herbicides entering lake and minimize effect of herbicide drift.** The effects of early spraying should be studied. Such a study may be able to determine whether early spraying can control plant growth for the rest of the summer, thereby eliminating the need to reapply herbicides.

Herbicide drift can affect macrophyte species not targeted for control as well as areas not permitted for spraying. Ways to keep herbicide application localized should be explored. It may be possible to use a surfactant to bind more of the herbicide on its intended target plant and reduce drift (D. Helsel, WDNR Southeast District and J. Leverance, WDNR Southern District, pers. comm.).

Shoreline Cleanup

• **Implement regular program on public shorelines.** Barge crews should continue to be used to pick up vegetation placed on piers by shoreline residents. In conjunction with local municipalities, crews operating off barges should be used to remove accumulated algae, macrophytes, and other lake debris from public shorelines.

Debris should be placed on onloading and offloading conveyors on the barge to expedite cleanup. On shorelines prone to plant accumulations, collection structures (such as at Olbrich Park) should be built to facilitate clearing and to streamline the operation. If Dane County provides this service, harvester operators should be used for barge crews following the peak harvesting season (after July 4).

• **Initiate late cleanups.** Onshore perception of shoreline accumulations and use of the lakeshore continues well past the peak recreational period. Removing plants reduces the potential of some species, especially Eurasian water milfoil, for colonizing new areas, and takes the nutrients found in the plant foliage out of the lake system.

• **Continue volunteerism.** "Take a Stake in the Lakes" serves the dual function of contributing to lake maintenance and building a sense of community stewardship of the lakes. For reasons above, a second "Take a Stake in the Lakes" should be held in the autumn. Another avenue for community volunteerism is to create an "Adopt A Shoreline" or "Adopt A Launch" program that parallels the "Adopt A Highway" program for local groups, scouting organizations, or neighborhood associations.

• **Continue to sponsor Youth Conservation Crews.**

Integrated Plant Control Activities

• **Coordinate chemical application and harvesting.** Harvesting crews should be safeguarded from inadvertent exposure to herbicides. Also, the chance of harvesters producing turbidity that may compromise a herbicide's effectiveness should be eliminated. Both of these problems can be avoided by not applying chemicals and not harvesting in the same area on the same day.

Quantities of aquatic vegetation exposed to herbicides and not eligible for use in gardens or fields should be minimized by harvesting prior to chemical treatment. This has a second advantage in that plants stressed by harvesting may be more susceptible to herbicides.

• **Strive to balance harvesting and herbicide spraying.** Where chemical treatment is limited because of environmental concerns, harvesting should also be limited. Future "sensitive area" designations under Wis. Admin. Code NR 107 should apply equally to chemical and harvesting treatments. At this time, chemical control is not restricted on any private shorelines.

• **Complement harvesting with routine shoreline cleaning.** Shoreline work may remove filamentous algae better than harvesters. Coordination is particularly important if municipal units other than Dane County are involved in the shoreline cleanup programs.

Alternative Techniques

• **Evaluate APM options for shoreline property owners.** These options include using a fiberglass bottom barrier, called Aquascreen, which has been widely used in Wisconsin (Append. C). Despite perceived setbacks of a 1987 study in Tenney Park, Aquascreens effectively reduced plant biomass (S. Engel, WDNR Bureau of Research, pers. comm.). Aquascreens provide effective, long-lasting non-chemical means for private shoreline residents to control aquatic plants in the vicinity of their piers (Engel 1984). Permits are required from the WDNR for Aquascreen installation in navigable waters. The initial cost of materials is offset by their longevity, about 10–15 years. The fabric should be set in spring and removed in fall for cleaning, but this can be done quickly, particularly on sandy shorelines (S. Borman, WDNR Western District, pers. comm.; Append. C).

• **Organize demonstration projects.** Such projects should be organized with individual lake property owners.

Education

• **Educate managing groups.** Harvesting and shoreline crews should be informed about objectives of APM. Slideshows and the laminated herbarium collection should be used to teach macrophyte identification. Identification of filamentous algae versus macrophytes and recognition of nuisance conditions should be taught. Harvester operators should be trained to accurately assess distances (namely 150 ft) from shore.

• **Educate user groups.** All user groups should be informed about objectives of the APM program, the benefits of macrophytes, and the value of native species; taught to identify filamentous algae from macrophytes and to recognize limitations on its removal; and provided information about ways to prevent the spread of Eurasian water milfoil. One specific group of people—owners of property where rare or native plant species are found—should be targeted with information.

Such information should be distributed at boat landings, beaches, Law Park, UW Memorial Union, county and city parks, sporting goods stores, and public events (e.g., canoeing races, sailing regattas, foot races around the lakes, water ski events, fishing competitions, etc.), and through press releases in the media.

Slideshows and the laminated herbarium collection should be accessible to the public. Schools, scouting organizations, neighborhood associations, and local groups should be able to take them out on loan.

• **Involve citizenry in stewardship.** The opportunity for public involvement in volunteer cleanup events (e.g., "Take a Stake in the Lakes"), Youth Conservation Crews and restoration activities should be expanded. A whole lake use plan should be developed. Where different views of management exist, a work group, comprised of representatives of different user groups, should be created to negotiate a compromise.

Nutrient Reduction

• **Remove accumulated and/or cut vegetation.** Nonpoint sources in the watershed contribute significantly more nutrients to the system than do cut or decomposing vegetation. Notwithstanding, decomposition of lake vegetation perpetuates internal cycling of nutrients and intensifies problems of excessive macrophyte growth in localized areas.

• **Network with existing programs.** The APM considerations recommended in this report are primarily in-lake mechanisms for coping with one symptom of high nutrient input (i.e., excessive macrophyte growth). For the most part, nutrient reduction extends beyond the scope of this report to watershed issues, requiring a multidisciplinary approach. However, the importance of approaching the problem of excessive aquatic plant growth from its origin as well as from a curative standpoint needs to be underscored.

• **Secure designation of Yahara-Mendota as a Priority Watershed.** As part of the Wisconsin Nonpoint Source Pollution Abatement Program, the Yahara-Monona Priority Watershed Project aims at reducing the amounts of nutrients entering Lakes Monona and Waubesa from nonpoint sources. This program should be augmented by improving conditions upstream, namely in the Yahara-Mendota watershed, because Lake Mendota is a major source of nutrients to Lakes Monona and Waubesa.

• **Develop APM plans for all of the Yahara lakes.** Increasing numbers of native species have been observed in all of the Madison lakes and such species should be promoted by selective harvesting, identifying their locations, and coordinating with other plant management efforts.

FUTURE ASSESSMENT

The aquatic plant management program should be reassessed on a regular basis to ascertain (1) whether it is fulfilling its objectives, (2) whether the problems associated with plant growth are being alleviated, and (3) what is its long-term effect on vegetation in the lake. The severity or mildness of aquatic plant growth each season may require different levels of control. Changes in plant community composition and location may also require some fine tuning of the management objectives. In addition, the APM program may need to be adjusted to accommodate development of a whole lake use plan, changing lake conditions, public input, new legislation pertaining to lake habitat, or changing policy regarding plant control. For example, in 1993, the ban on early chemical treatments will be lifted based on research that indicated no direct adverse impacts on spawning bass or bluegills. (Indirect effects have not yet been addressed).

Public Perception

The evaluation process should include surveys of the public to assess the understanding of lake resource issues as well as changing attitudes, needs, and perceptions of the problem.

Aquatic Plant Communities

Biological monitoring provides feedback about the relative success of the control program and identifies the location of native species. The plant community should be evaluated routinely to provide scientific information for management decisions. Biological monitoring should include species' lists and maps depicting the distribution and density of vegetation. In the event that another exotic species invades the lakes, regular assessment will function as an early warning, enabling early action to be taken to mitigate undesirable effects.

Most of the responsibilities of biomonitoring could be undertaken by the "harvesting scout." Records of plant densities, plant species, and their locations should be maintained and translated into vegetation distribution maps characteristic of early and mid summer conditions. In addition, as a liaison between the harvesting program and the public, the harvesting scout would be aware of public perceptions of aquatic plant conditions in the lake.

CONCLUSIONS

In recent years, the native aquatic plant community in Lake Waubesa has diversified, and densities of weedy plants have decreased. APM proposed in this report focuses on sustaining these changes because they benefit both the lake users, by decreasing the degree of nuisance conditions, as well as the lake resource, by improving the quality of habitat. Furthermore, by striving to control nuisance levels of growth and not eliminate all aquatic plants from the lake, APM goals become aligned with the reality of plant growth in an eutrophic lake system.

The proposed APM designates areas and levels of management, yet it remains flexible. It considers the relative value of weedy, mixed, and native species and their densities in certain areas of the lake, and provides a variety of management options to deal with them. This flexibility enables APM to respond appropriately to different conditions of plant growth which may vary from year to year. In the long-term, a prevalence of native species in the lake should reduce the degree of nuisance conditions.

In addition, APM is based on objective harvesting decisions using measurable criteria that can be rationalized to the public. Restoration of native plants, education of managers and users, and attacking nutrients at their source are integrated into this comprehensive look at APM in Lake Waubesa.

With a rising population and subsequent recreational demand, there exists a clear need to develop a lake use plan for the whole lake. Already lake users are endangered by having multiple kinds of water-based recreation occurring in the same area of the lake. One component of such a plan would be aquatic plant management. By designating areas in the lake for different kinds of recreation, plant management could become even more streamlined based on the needs of that sport. Wherever, possible the principles of the proposed APM in this report should be considered, including the inherent value of macrophytes and the dynamics of their growth and distribution.

REFERENCES

Andrews, J.H. (ed.). 1986. Nuisance vegetation in the Madison lakes; current status and options for control. University of Wisconsin-Madison. 196 pp.

Canfield, D.E., K.A. Langeland, S.B. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. *J. Aquat. Plant Manage.* 23:25–28.

Carpenter, S.R. 1980. The decline of *Myriophyllum spicatum* L. in a eutrophic Wisconsin lake. *Can. J. Bot.* 58:527–535.

Carpenter, S.R. and D.M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquat. Bot.* 26:341–370.

Cheney, L.S. and R.H. True. 1893. On the flora of Madison and vicinity, a preliminary paper on the flora of Dane County, Wisconsin. *Trans. Wis. Acad. Sci., Arts and Lett.* 9:46–136.

Cooke, G.D., E.B. Welch, S.A. Peterson, and P.R. Newroth. 1986. Lake and reservoir restoration. Butterworth Publ., Boston, MA. 392 pp.

Dane County Lakes and Watershed Commission. 1992. Water quality implementation plan. Dane Co. Lakes Watershed Comm., Madison, WI. 40 pp.

Dane County Regional Planning Commission. 1987. Yahara River lakes water recreation study. Dane Co. Reg. Plan. Comm., Madison, WI. 54 pp.

Deppe, E. and R.C. Lathrop. 1992. A comparison of two rake sampling techniques for sampling aquatic macrophytes. Wis. Dep. Nat. Resour. *Res. Manage. Find.* No. 32. 4 pp.

Deppe, E. and R.C. Lathrop. 1993. The aquatic macrophyte community of Lake Mendota in 1989–1991. *Trans. Wis. Acad. Sci., Arts and Lett.* (in press).

Dionne, M. and C.L. Folt. 1991. An experimental analysis of macrophyte growth forms as fish foraging habitat. *Can. J. Fish. Aquat. Sci.* 48:123–131.

Domogalla, B.P. 1926. Treatment of algae and weeds in lakes at Madison: obnoxious conditions of lake waters, investigated and remedied—sodium arsenite and sulphate of copper applied by dragging and spraying—weed cutting. *Engineering News-Record.* 97:950–954.

Domogalla, B.P. 1935. Eleven years of chemical treatment of the Madison lakes: its effect on fish and fish foods. *Trans. Amer. Fish. Soc.* 65:115–121.

Engel, S. 1984. Evaluating stationary blankets and removable screens for macrophyte control in lakes. *J. Aquat. Plant Manage.* 22:43–48.

Engel, S. 1985. Aquatic community interactions of submerged macrophytes: phytoplankton, zooplankton, macrophytes, fishes, benthos. Wis. Dep. Nat. Resour. *Tech. Bull.* No. 156. 79 pp.

Engel, S. 1987. The restructuring of littoral zones. Lake Reservoir Manage. 3:235–242. Proc. North Am. Lake Manage. Soc., Washington, DC.

Engel, S. 1989. Lake use planning in local efforts to manage lakes. pp. 101–105. *In* Enhancing states' lake management programs. Proc. Nat. Conf. U.S. Environ. Prot. Agency, 12–13 May 1988, Chicago, Ill. North Am. Lake Manage. Soc. Washington, DC.

Engel, S. 1990a. Ecosystem responses to growth and control of submerged macrophytes. Wis. Dep. Nat. Resour. *Tech. Bull.* No. 170. 20 pp.

Engel, S. 1990b. Ecological impacts of harvesting macrophytes in Halverson Lake. *J. Aquat. Plant Manage.* 28:41–45.

Fassett, N.C. 1957. A manual of aquatic plants. University of Wisconsin Press, Madison, WI. 405 pp.

Fenneman, N.M. 1902. Lakes of southeastern Wisconsin. Geol. Nat. Hist. Surv. Bull. No. 8. Educat. Ser. No. 2. 178 pp. (reprinted in 1910).

Frey, D.G. 1940. Growth and ecology of carp, *Cyprinus carpio* L., for lakes of the Madison region, Wisconsin. Unpubl. Ph.D. thesis. University of Wisconsin, Madison. 248 pp.

Frey, D.G. and L. Vike. 1941. A creel census on Lakes Waubesa and Kegonsa, Wisconsin in 1939. *Trans. Wis. Acad. Sci. Arts and Lett.*

Kimbel, J.C. and S.R. Carpenter. 1979. The dynamics of *Myriophyllum spicatum* in a eutrophic Wisconsin lake. pp. 43–50. *In* J.E. Breck, R.T. Prentki, and O.L. Loucks (eds). Aquatic plants, lake management and ecosystem consequences of lake harvesting, Madison, Wisconsin. Inst. Envir. Stud., Madison, WI. 435 pp.

Koegel, R.G. and D.F. Livermore. 1979. Reducing capital investment in aquatic plant harvesting systems. pp. 329–338. *In* J.E. Breck, R.T. Prentki, and O.L. Loucks (eds). Aquatic plants, lake management and ecosystem consequences of lake harvesting, Madison, Wisconsin. Inst. Envir. Stud., Madison, WI. 435 pp.

Lathrop, R.C. and Johnson. 1979. Dane County water quality plan. Appendix B: Water quality conditions. Dane County Regional Planning Commission. Madison, WI.

Lathrop, R.C. 1989. The abundance of aquatic macrophytes in the Yahara lakes. Wis. Dep. Nat. Resour. *Res. Manage. Find.* No. 22. 4 pp.

Lathrop, R.C. 1992. Lake Mendota and the Yahara River chain. pp. 71–98. *In* J.F. Kitchell (ed). Food web research and its application to lake management: a case study of Lake Mendota, Wisconsin. Springer-Verlag, New York. 553 pp.

Lathrop, R.C., S.B. Nehls, C.F. Brynildson, and K.R. Plass. 1992. The fishery of the Yahara lakes. Wis. Dep. Nat. Resour. *Tech. Bull.* No. 181. 214 pp.

Lillie, R.A. and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. *J. Freshwat. Ecol.* 7(2):113–126.

Nichols, S.A. 1991. The interaction between biology and management of aquatic macrophytes. *Aquat. Bot.* 41:225–252.

Nichols, S.A., S. Engel, and T. McNabb. 1988. Developing a plan to manage lake vegetation. *Aquatics* 10(3):10,14–19.

Nichols, S.A., R.C. Lathrop, and S.R. Carpenter. 1992. Long term vegetation trends: a history. pp. 151–173. *In* J.F. Kitchell (ed). Food web research and its application to lake management: a case study of Lake Mendota, Wisconsin. Springer-Verlag, New York. 553 pp.

Nichols, S.A. and R.C. Lathrop. 1992. Impacts on macrophytes in the Yahara lakes. (manuscr. in prep.).

Nichols, S.A. and B.H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus* and *Elodea canadensis*. Hydrobiologia 131:3–21.

Saley, B. 1987. Report on the Lake Monona shorezone project—1986. City of Madison Dep. Public Health. 67 pp.

Sculthorpe, C.D. 1967. The biology of aquatic vascular plants. Edward Arnold Publ., London. 610 pp. (reprinted in 1985).

Threinen, C.W. 1949. The effect of carp upon the normal aquatic habitat. Wis. Conserv. Dep., Div. Fish Manage. Invest. Rep. No. 709. Madison, WI. 21 pp.

Threinen, C.W. and W.T. Helm. 1952. A comparative summary of the vegetation surveys on important carp waters in southeastern Wisconsin. Wis. Conserv. Dep. Invest. Rep. No. 669. Madison, WI. 15 pp.

Wisconsin Department of Natural Resources. 1990. Managing deep water stands of Eurasian water milfoil to improve habitat and boating access: small-scale aquatic plant harvesting demonstration. Wis. Dep. Nat. Resour. 8 pp.

Wisconsin Department of Natural Resources. 1991. Boating on Lakes Mendota and Monona: results of the 1989–90 Wisconsin recreational boating survey. Wis. Dep. Nat. Resour. 3 pp.

APPENDIXES

APPENDIX A. DANE COUNTY WEED HARVESTING PROGRAM

The following material is excerpted from the Dane County Lakes and Watershed Commission files, written in 1990.

Background

"The Dane County Department of Public Works operates an active lake management program. In the summer of 1988, the Dane County Lakes and Watershed Commission recognized the weed harvesting program was limited by lack of staff and equipment. The Commission recommended a budget increase to hire seasonal (LTE) workers to increase weed cutting shifts in 1989. ... In 1989, the Lakes and Watershed commission endorsed an expanded weed harvesting policy statement. The description below describes the 'where, when, and how' of the 1990 weed harvesting program without getting into the details of specific site selection for weed harvesting. Since weed growth is highly variable from one year to the next, program managers need flexibility to determine appropriate weed harvesting sites each season. However, the rationale for site selection should not change from year to year.

"It is important to take a long term view when it comes to weed control. Weed growth depends to a large extent upon the nutrients that enter our lakes and act as 'weed food'. However, other factors including weather, algae growth, rough fish and drought can all play a significant role in the amount of weeds found in a particular year. Since weed growth is affected by a lot of changeable things, weed growth can vary greatly from year to year or place to place. Over the long term we need to reduce the amount of nutrients entering our lakes. In the short term, we can expect good and bad years of weed growth and we must be prepared to address nuisance problems while we work on the overall long term nutrient reduction program.

Where Dane County Harvests Weeds

"Dane County Lake Management staff harvest weeds on all of the Yahara lakes (Mendota, Monona, Waubesa, Wingra, and Kegonsa), in the four miles of the Yahara River between Lakes Waubesa and Kegonsa and in the Vilas and Tenney Park lagoons. The County will also consider requests to cut weeds in other places around the county subject to the availability of staff and equipment and the severity of the problem. ...

When Aquatic Weed Harvesting Occurs

"The intent of the program is to harvest aquatic weeds to enhance the overall recreational or aesthetic value of Dane County water resources. The weed harvesting program usually begins in the Yahara Chain of Lakes the third or fourth week of May and continues through late August. The greatest pressure to cut is before July 4th. After that time the number of calls, requests and complaints decreases dramatically, The order in which the sites are selected for cutting is based on a number of factors which evaluated together indicate where the cutting will do the most good at a particular point in time. As the Dane County staff and equipment can only cover so much water in a day, setting priorities for the order of harvesting is a necessity.

"Dane County's permanent Lake Management staff install the boating buoys in the spring on the Yahara lakes. This gives them an early opportunity to tell which lakes will have 'harvestable' weed crops first. Usually, Vilas and Tenney Park lagoons are cut first because they are so shallow they heat up quickly and grow the first weeds. Lakes Monona and Waubesa are usually cut next because weeds usually grow on these lakes early due to a variety of physical and environmental characteristics. Mendota and Kegonsa are usually cut last because weed growth comes later or is slower on these lakes. Wingra is usually cut only for special events.

"After choosing which lake to cut first, the staff must decide where on the lake to start harvesting. Several factors are considered. Beaches. boat landings, and public piers receive top priority because of the large amount of daily usage at these facilities. The next priority is public and private shorelines. Once a starting point is selected, the harvesters move in one direction around the lake without interruption. Where the crew stops and starts is affected by the access sites for unloading weeds. Strong winds may also require changes in the harvesting schedule.

"The Lake Management staff try to be responsive to special requests for special events such as the ski show in Monona Bay, the milk carton regatta at Vilas, the triathalon at Warner Bay, the Badger State Games and various rowing events on Wingra and University Bay.

"One weed cutting job takes priority over all weed cutting in the lakes. Weed growth in the Yahara River can limit flow out of the upper lakes. When this happens and lake levels are high, the Department of Public Works Director must pull equipment off the lakes and cut weeds on the Yahara River to try to maintain water levels below legal maximums.

"Large weed beds in certain locations around the Yahara lakes (Turville Bay, University Bay, Warner Bay, etc.) are not cut. These areas provide habitat for fish and aquatic life and are not used by the public for swimming or boating, If time and money allow, limited paths through the weeds may be cut to provide access for anglers.

"Weed harvesting is repeated in the fall in Vilas and Tenney Park lagoons. The purpose of the late harvest is to prevent weeds form freezing in the ice. If weeds are left in the ice, the dark weeds absorb enough solar energy to melt holes in the ice which can be a safety hazard for ice skaters. ...

"Lakes Hotline"

"This year, Dane County has established a Lakes Hotline. If people want to know where weed harvesters are, they may call 267-4510, from 5:30 PM to 7:30 AM (telephone number updated for 1993). The Lakes Hotline message will be changed on a weekly basis. Shoreline property owners are encouraged to place weeds collected from their shoreline on the end of their piers. County weed harvesting crews will pick up the weeds before they leave a cutting area. Only lake weeds will be picked up. The County will not pick up trash left on the piers, since the weeds are taken to compost sites.

Weed Disposal

"Weeds are taken away from the lakes in dump trucks. All of the weeds are either composted or given to farmers. The weeds contain a high moisture content and a large amount of nutrients, so they are very desirable from a gardening standpoint. The crew will take a truck load of weeds to an individual property owner if they live close enough to the areas being harvested and have adequate access for the dump trucks.

Equipment and Staff

"This year Dane County will run two weed harvesting crews. Due to the short working season, college students make up most of the labor force. One crew will start in mid-May. The other crew will probably start the first week in June. This double shift work effort started in 1989 and was very successful. The first crew starts at 5:30 AM and works until 1:30 PM. The second shift starts at 12:30 PM and works until 8:30 PM. The County presently has six weed harvesters and three elevators. The harvesting team consists of a supervisor, five people to operate the harvesters, and four people on shore to load the weed elevators, truck the weeds to disposal, and keep the unloading sites clean. Multiple cutters can use the same unloading team and weed elevator. Special care is taken by the crew to clean the unloading site and a couple of shoreline lots on either side to clean-up any loose weeds that may have escaped from the harvester."

APPENDIX B. SURVEY METHODS, SITE INFORMATION, AND EXPLANATION OF STATISTICAL ANALYSES AND TERMINOLOGY

Regular Survey

Aquatic plants in Lake Waubesa were surveyed during the last two weeks in June 1992; Lake Monona's macrophytes were surveyed during the first two weeks of July 1992. The sites sampled were identical to those surveyed in 1990 and 1991 (Deppe and Lathrop 1993). These sites were selected to characterize the aquatic vegetation occurring in the littoral zone around each lake. In 1990, the survey of both Lake Monona and Lake Waubesa assessed only the presence and absence of macrophytes, using what is known as the rake frequency technique (RF; Deppe and Lathrop 1992); plant density was not evaluated. In 1991 and 1992, both species presence as well as plant density were measured using the rake coverage (RC) method, described below. Consequently, frequency and distribution data can be compared for all 3 years, while density data is limited to 1991 and 1992. Survey results from Lakes Mendota and Kegonsa are included to provide perspective on observed trends. Lake Mendota has been surveyed using the RC method since 1989 (Deppe and Lathrop 1993). Lake Kegonsa was surveyed in the same manner as Lakes Monona and Waubesa.

From sites located on the shoreline, a transect was created by motoring a boat into the lake perpendicular to the shoreline. Along the transect, sampling began at 0.5 m deep and continued at depth intervals of 0.5 m until no aquatic vegetation was detected. The last depth where plants grew is considered the maximum rooting depth. Thirteen transects were sampled in Lake Monona and ten transects were surveyed in Lake Waubesa in 1992 (Fig. B-1).

Depths ≤ 3 m were located using a marked pole; depths >3 m were found using a Lowrance FISH-LO-K-TOR. The boat was centered at the desired depth and anchored at each end. Plants were sampled by throwing a weighted, double-headed rake with a 14-inch wide head

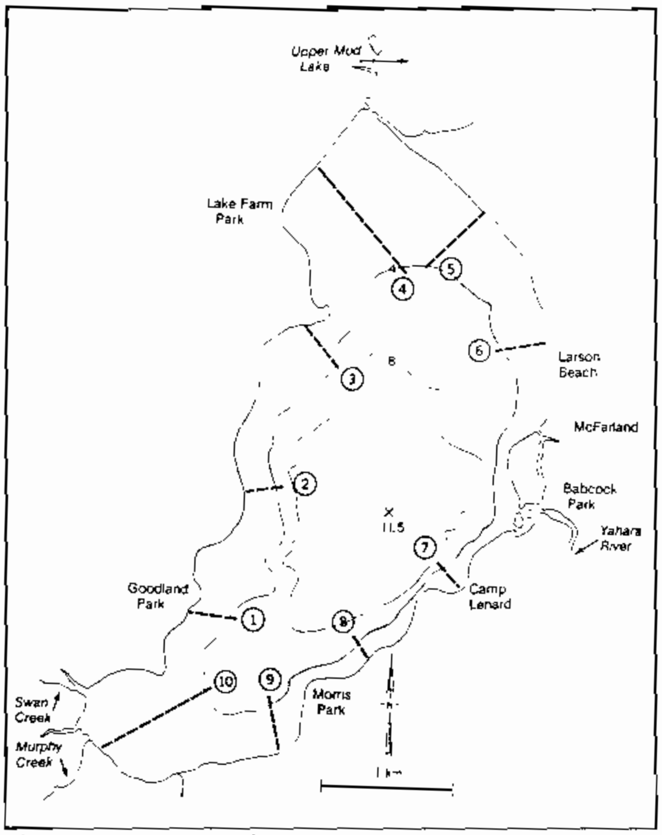

Figure B-1. Location of transects on Lake Waubesa.

and 14 teeth, each two inches long. The rake was dragged approximately seven feet (2 m) along the bottom of the lake by means of an attached line. As the rake was lifted off the bottom of the lake, it was rotated 180 degrees to prevent the ensnared plants from falling off of the rake head. The rake was thrown four times at each depth: from the front right, front left, rear right, and rear left of the boat.

A 0–5 rating was assigned to the density of all plants retrieved on the rake as well as to each species individually (Fig. B-2). Ratings were based on the extent to which the teeth of the

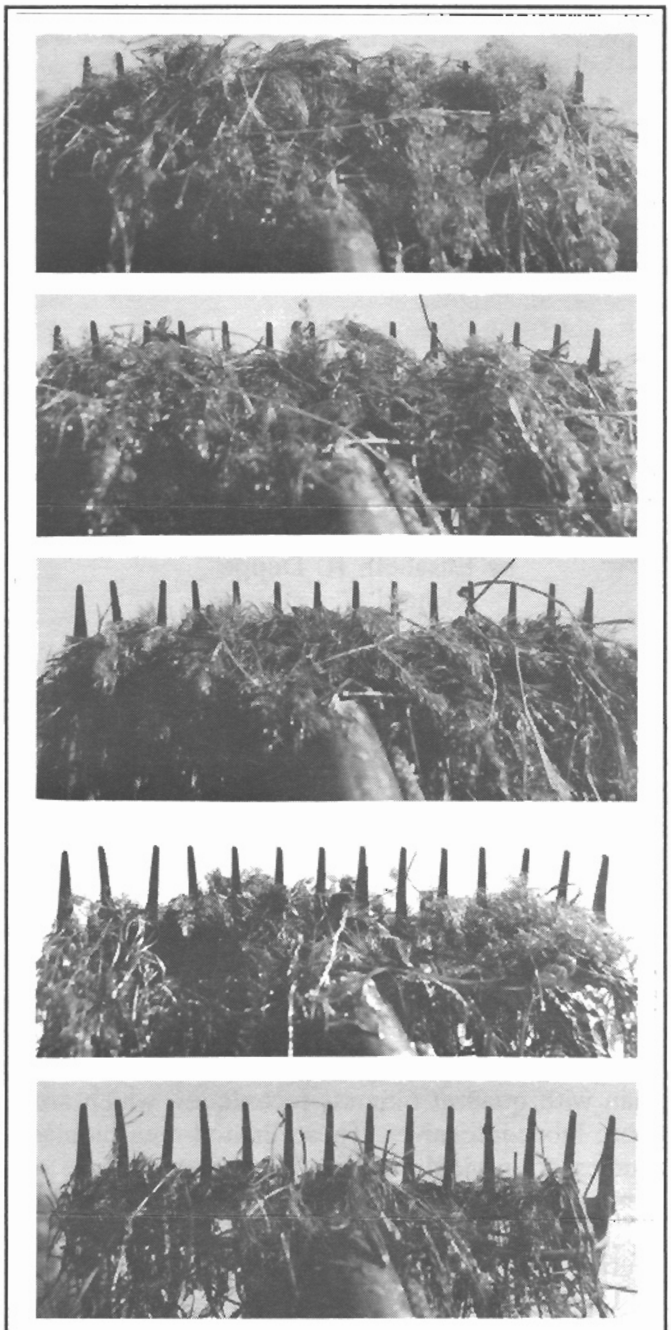

Figure B-2. Examples of rake fullness, illustrating density ratings assigned by the rake coverage technique for an individual species. Ratings, from top to bottom, are 5 to 1.

upper rake head were covered, as follows (Deppe and Lathrop 1992): 0 = no plants were recovered, 1 = 1-20% coverage, 2 = 21–40% coverage, 3 = 41–60% coverage, 4 = 61–80% coverage, and 5 = > 80% coverage.

Filamentous algae were separated from the macrophytes, so that rake coverage reflects densities of plants alone. For the purposes of this report, only vascular aquatic plants and muskgrass (*Chara* sp., a large, benthic alga) were termed macrophytes. Filamentous algae were considered separately. In 1992, filamentous algae was evaluated on the rake on a 0–3 scale, where 0 = absent; 1 = present in moderate amounts; 2 = present in moderate to heavy amounts; and 3 = present in excessive amounts.

Macrophytes were identified using Fassett (1957). Unusual species were verified by Dr. Stanley A. Nichols, a UW Extension botanist.

Intertransect Survey

The 1992 survey also included a survey of plants between the established transects in Lake Monona and Lake Waubesa, which provided additional information about rarer species and the distribution of vegetation in the lake. This intertransect work was conducted during the second and third weeks of August 1992.

Sampling was conducted along the contour where the greatest diversity was observed (0.75 m in Lake Waubesa and between 0.75 m and 1.0 m in Lake Monona). The area between each transect was divided into five shoreline regions. In each region, the boat was positioned at the desired depth and the rake was thrown out behind the boat and dragged 40–45 ft (12–14 m) along the bottom of the lake while rowing. Macrophyte species collected on the rake or sighted with the aid of a viewbox were recorded as present.

Statistical Analyses and Terminology

Several assessments of density were computed: (1) *Average density*. The average density value (n = 4 rake throws) was used to compute the density of vegetation at each depth along each transect. The mean density, like the density of plants retrieved on the rake, have a maximum value of 5. (2) *Transect density*. The total density of aquatic vegetation at each transect was determined by summing the individual depth values along the transect. (3) *Depth density*. The mean density of plants per depth was calculated by adding the density ratings obtained at each depth in all transects and dividing by the number of transects.

In addition to density, other terms were defined or analyses made to quantify the macrophyte data collected: (1) *Littoral zone*. In this report, depths of ≤3 m are considered the littoral zone, even though plants were occasionally found in sparse densities at greater depths. (2) *Plant cover*. Plant cover (frequency of occurrence) indicates the percent of the littoral zone covered by plants in each lake and enables an evaluation of how common a species was in the lake; it is based on the presence and absence of species rather than densities. Plant cover is calculated as the number of depths in which a species occurred at least once, divided by the total number of depths sampled at ≤3 m. (3) *Abundance*. Plant species were considered abundant if they occurred in >30% of the stations, very common if in 11–30% of the stations, common if in 1–10% of the stations, and rare if in <1% of the stations. (4) *Relative frequency*. Relative frequency represents the relative proportion of each species in the macrophyte community; it does not reflect densities. Relative frequency for each species was determined by summing the number of times that each species was found on the rake and dividing by the sum of the total number of encounters for all species.

APPENDIX C. SUMMARY OF MECHANICAL, PHYSICAL, BIOLOGICAL, HABITAT MANIPULATION, AND CHEMICAL MEANS OF CONTROLLING AQUATIC PLANTS

Table C-1. Mechanical and physical control technologies for aquatic plants.[*]

Method	Procedure	Cost	Advantages	Disadvantages
HARVESTING[**]	Plant stems and leaves are cut up to 8 ft below the water surface, collected, and removed from lake. Up to 10-ft-wide swath can be cut at once. Machine can work in shallow water (to 18 inches).	Cost of new machine is $40,000 and up[a]. Cost does not include dump trucks, offloading conveyor, and other equipment for efficiency. 1992 personnel, maintenance and operational costs were $209,171 (see Table 11, section III).	Can be used on a large scale. Immediately creates open water areas. Removes nutrients from the lakes. Permits removal of weedy species (through selective cutting by adjusting cutting depth), minimizes impact to native species, and can leave lower part of plant intact as habitat.	Creates plant fragments, increasing potential for vegetative spread of weedy plants. Requires plant disposal (Sec. 30.125, Wis. Stats.). Requires constant machine maintenance. Involves short-term results. Removes small aquatic organisms (e.g., invertebrates and fish).
DEEP CUTTING	A steel blade attached to a hydraulic arm works like a hedge trimmer to cut aquatic plants in water up to 25 ft deep. A barge or conventional harvester follows behind to collect cut plants.	Cost of a new machine is $75,000.	Immediately creates open water areas. Control is long-term. Can cut up to three times deeper than regular harvesters.	Creates plant fragments. Requires plant collection by either a barge or harvester. Requires plant disposal (Sec. 30.125 Wis. Stats.). Requires maintenance.

Table C-1. Continued.

Method	Procedure	Cost	Advantages	Disadvantages
HYDRO-RAKING	Mechanical rake removes plants (including some roots) and deposits them on shore. Machine can work in up to 14 ft of water.	Operational cost is $1,500–2,000/acre. Raking is done most frequently by hired consultants rather than local groups purchasing a machine.	Immediately creates open water areas. Controls plants long-term. Removes nutrients from the lake.	Creates fragments. Disturbs organisms on the lake bottom and degrades habitat. Creates short-term turbidity. Requires plant disposal (Sec. 30.125, Wis. Stats.). Is followed by rapid regrowth of plants. Involves small-scale use only. Requires a permit (Sec. 30.20, Wis. Stats.).
ROTOTILLING	Sediment is "tilled" to a depth of 4-6 inches to dislodge plant roots and stems. Tiller head is 10 ft wide. Machine can work in depths up to 17 ft. Plants are collected by a harvester; if done in late fall, plants wash ashore and dry out over winter.	Operational cost is $700–$1200/acre. Cost of new machine is $100,000+.	Immediately decreases stem density. Offers large-scale control. Controls plants long-term.	Creates short-term turbidity. Disturbs organisms on the lake bottom and degrades habitat. Requires constant machine maintenance. Requires plant disposal (Sec. 30.125, Wis.Stats.). Requires a permit (Sec. 30.20, Wis. Stats.).
HYDRAULIC DREDGING	Steel cutter blade dislodges sediment and plants which are removed by a suction pump. Spoils are pumped to a barge or directly to land.	Operational costs start at $2,500/acre and more. Cost of new machine is $100,000+. Work usually hired out to a consultant.	Effectively removes roots.	Is expensive. Requires removal of spoils. Creates turbidity. Disturbs organisms on the lake bottom and degrades habitat. Short-term, small-scale results. Requires a permit (Sec. 30.20, Wis. Stats.).

Table C-1. Continued.

Method	Procedure	Cost	Advantages	Disadvantages
DIVER-OPERATED SUCTION HARVESTING	One or two SCUBA divers operate a 4 inch suction hose that selectively remove plants from the lake bottom. Plants are collected in a wire basket which is later unloaded.	Operational cost is from \$800–10,000/acre, depending on divers, type of sediment, travel time to sites within the lake, etc. Cost of new machine starts at \$22,000 and more.	Effectively removes roots. Is not limited by depth as are other mechanical methods. Selectively removes plants. Can work in confined and rocky areas. Controls plant long-term.	Is slow and labor intensive. Is expensive. Involves small-scale use only. Creates short-term turbidity. Involves potential hazards to SCUBA divers. Requires constant machine maintenance. Requires plant disposal (Sec. 30.125, Wis. Stats.). Requires a permit (Sec. 30.20, Wis. Stats.).
HANDPULLING	Plants and roots are removed by hand, using SCUBA diving, snorkeling, or wading. Plants and fragments are collected in mesh bags carried by handpullers and are later disposed of on shore.	Cost is variable, depending on whether or not volunteers are used. Diver costs range from \$25–60/hour.	Can selectively remove weedy plants. Can be done with volunteers to keep costs down. Can be done in hard-to-access areas. Is effective on newly established populations that are scattered in density.	Is too expensive to use on a large-scale. Creates short-term turbidity, which makes it difficult to see remaining plants. Creates fragments. Is slow and labor intensive.
HAND-HELD HARVESTER	Stainless steel blades on a pole work like a hedge trimmer to cut weed stems at their bases. Machine cuts a 4 ft-wide swath, which can be expanded to 12 ft wide. Machine operates off of a boat battery.	Operational cost is negligible. Cost of a hand-held harvester alone is \$350.	Immediately creates open area. Can be done in hard-to-access areas.	Is only a short-term solution. Creates fragments. Requires plant disposal (Sec. 30.125, Wis. Stats.) Involves small-scale use only. Is not selective for weedy species in deep water.

Table C-1. Continued.

Method	Procedure	Cost	Advantages	Disadvantages
MANUAL RAKING	A small rake with long tines and attached rope is used to drag weeds off of lake bottom. Rake can be used from a pier or boat or while wading.	Cost of rake alone is $90.	Immediately creates open water areas. Has no depth limit. Can be done in hard-to-access areas.	Creates fragments. Requires plant disposal (Sec. 30.125, Wis. Stats.). Creates short-term turbidity. Disturbs organisms on the lake bottom. Is not selective for weedy species in deep water. Involves small-scale use only.
WEED ROLLER	Three rollers with fins mount on dock and roll in a broad arc over the lake bed, dislodging weeds and silt. Machine is power operated, and each roller is up to 30 ft long (i.e., the 3 10-ft rollers are linked).	Operational cost depends on how much it is used and electricity costs; it runs on 24 volts DC. Cost of roller alone is $1,800.	Is easy to operate. Removes weeds at their roots. Immediately creates open water areas.	Is a new product and its effectiveness is unknown. Creates plant fragments. Requires plant removal (Sec. 30.125, Wis. Stats.). Involves small-scale use only. Is not selective for weedy species. Disturbs organisms on the lake bottom and degrades habitat. Requires a permit (Sec. 30.12, Wis. Stats.).

* Data sources: Vt. Dep. Environ. Conserv. (1991); Cooke et al. (1986); Andrew (1986); Wis. Dept. Nat. Resour. (1990); Aquarius Systems, D&D Products Inc., North Prairie, WI; Aquatic Biologists, Inc., Fond du Lac, WI; Waterside Products Corp., Lake Carmel, NY; Lake Restoration, Inc., Hamel, MN; and Crary Co., West Fargo, ND.

** Currently used in Yahara lakes.

[a] D & D harvester manufacturer quote; however, Dane County Department of Public Works usually constructs their own machinery, reducing costs by about one half.

*Table C-2. Biological technologies for aquatic plant control.**

Method	Procedure	Cost	Advantages	Disadvantages
GRASS CARP	Plant-eating fish native to the Orient are stocked. Stocking in lakes occurs at varying rates depending on plant species present, water temperature, amount of vegetation present, etc.	Cost is based on number of fish per vegetated area. A 8-to-11 inch fish costs $3.50. Cost does not include transport of fish, stocking, or containment barriers. Cost also excludes indirect impacts to the resource (e.g., habitat destruction, increasing turbidity).	May provide cost-effective, long-term control. Does not interfere with water supplies or water use. Is maintenance free (unless barriers need to be cleaned of plant debris). Does not involve risk of fish population explosion since sterile hybrids (triploid carp) are available.	Is difficult to properly gauge, since accurate stocking rate for large, cold water lakes are hard to determine. Eliminates desirable plant species more palatable than Eurasian water milfoil, the primary weed. Has potential for negative impacts to water quality, native plants and fish and wildlife habitat destruction. May spread to surrounding water bodies. Is prohibited in Wisconsin (Sec. 29.47(6), Wis. Stats.).
CRAYFISH (*Orconectes* spp.)	Plants are eaten by crayfish.	Cost is not available at this time.	Reduce macrophyte biomass. Involves a species that is native to Wisconsin and that already exists in the Madison lakes.	Is not selective for weedy species. Is not successful in productive, soft bottom lakes with many fish predators. Is prohibited in Wisconsin (Wis. Admin. Code NR 19.27).

Table C-2. Continued.

Method	Procedure	Cost	AdvantageS	Disadvantages
PATHOGENS	Plant tissue is intentionally infected with a pathogen, such as bacteria or fungi, to induce plant mortality.	Product is still in experimental stage and costs are not available at this time.	If feasible, may provide more cost-effective, long-term control. Appears to be host specific. Involves a wide variety of organisms. Exerts a limiting effect on plants without eradication. Poses few dangers to humans or animals.	Involves unknowns (e.g., shelf-life and delivery system of fungus not yet determined). Is not commercially available at this time. Involves some organisms that may not be highly pathogenic on their own (e.g., may penetrate plant only through wounds) and thus are potentially more effective in conjunction with harvesting. Encourages development of host resistance. Plant specificity is important. May involve legal issues, but these are unclear at this time.
BIOMANIPULATION	Food web dynamics are modified by manipulating lake biota to effect a change in water quality and improve the fishery. Fish community is restructured to favor fish-eating vs. plankton-eating fish.	Cost is not available at this time. Cost of fish stocking depends on numbers and species stocked.	Improves the quality of the fishery. Increases water clarity and interrupts internal nutrient cycling. Attacks plant control at its source. Has potential for long-term, cost-effective control.	Is experimental and ability to control macrophytes is uncertain. Is not immediately effective. Creates improved water clarity which may improve conditions for macrophyte growth.

Table C-2. Continued.

Method	Procedure	Cost	Advantages	Disadvantages
ALLELOPATHY	Aquatic plants that release chemical compounds into the water or sediment and inhibit other plants from growing are introduced.	Cost is unavailable at this time.	May provide long-term, cost-effective, maintenance-free control. Includes one species (small spikerushes or *Eleocharis* spp.) that appears to inhibit Eurasian water milfoil growth.	For spikerushes, involves initial transplanting that is slow and labor intensive. Spikerushes are native to Wisconsin, and if they could effectively limit growth they would probably already do it. May not work if wave action along shore makes it difficult for plants to establish themselves. Cannot be used in deep water. Involves limited commercial availability of plants. May involve legal implications, but these are unclear at this time.
HERBIVOROUS INSECTS	Native or exotic aquatic insects (moths, weevils, etc.) that feed on plant stems and leaves and cause damage or death when introduced.	Cost is not available at this time.	If feasible, may provide cost-effective, long-term control. Is maintenance-free once insects are introduced. Includes one species (a weevil native to North America) that appears to feed mainly on milfoil.	Involves insects that are not commercially available at this time. Is sometimes slow (i.e., results may not be quickly seen). May involve potential problems associated with introducing new species. May not be host-specific. May involve legal implications, but these are unclear at this time.

* Data sources: Vt. Dep. Environ. Conserv. (1991); Nichols (1991); Cooke et al. (1986); Andrews (1986).

*Table C-3. Habitat manipulation technologies for aquatic plant control.**

Method	Procedure	Cost	Advantages	Disadvantages
SEDIMENT BLANKETS	Bottom sediments are covered with fly ash, sand, gravel, or clay to physically isolate nutrient rich sediments from plant roots.	No cost estimate found.	Inactivates "fertilizer" in sediments.	For fly ash, raises pH, depletes dissolved oxygen, reduces sulfate to sulfide, releases heavy metals and clogs and crushes bottom organisms, bioaccumulates, and poisons fish and macroinvertebrates. May not sufficiently alter sediment. Adds nutrients, thereby offsetting its effectiveness. Is not feasible for large areas. Requires a permit (Sec. 30.12, Wis. Stats.).
BOTTOM BARRIERS	Sheets of material (nylon, silicone, rubber, fiberglass, polypropylene) are anchored to the lake bottom; they kill plants by compression and by blocking out sunlight. One barrier - fiberglass products known as Aquascreens - has been extensively used in Wisconsin.	Cost varies by product but is generally from $0.15–0.35/ft^2$, not including installation (which may be done individually). Aquascreen is sold in 7 by 100-ft rolls for $250/roll.	Does not require weeds to be removed. May provide long-term control if properly installed and maintained. Screens may last 10–15 yrs. if maintained. Provides immediate control throughout the entire water column. May be used in areas not accessible by other methods. Involves uncomplicated installation, either in water or from boat.	Is not feasible on a large scale because of cost and labor intensiveness. Requires seasonal maintenance (installation and removal). If not firmly anchored, may float up allowing plants to grow beneath it. Can be snagged by fish hooks. Requires a permit (Sec. 30.12, Wis. Stats.).

Table C-3. Continued.

Method	Procedure	Cost	Advantages	Disadvantages
DRAWDOWN**	Lake water level is lowered so plants are exposed to drying and freezing temperatures. Current conditions reflect winter drawdown of about 1.5 ft in Lakes Monona and Waubesa.	Operational cost is frequently low or non-existent. If drawdown is increased above the current levels, costs of undesirable impacts (e.g., lowers level of shallow wells, habitat destruction, and poor refill) to resource may need to be considered.	May provide opportunity to work around shoreline while water level is low.	Drawdown over current levels has potential for significant negative impacts to aquatic plants, invertebrates, and fish and wildlife. May affect water intakes and shallow wells. Kills some plants and enhances growth of others. Cannot exceed authorized minimum and maximum levels. Is affected by weather for success of refill. If poor refill occurs, may impact water levels along Yahara chain of lakes.
COLORANTS (DYES)	Blue dye is used to darken water in order to prevent sunlight from reaching plants.	Cost is $62.00/acre for average water depth of 4 ft.	Reduces plant growth.	Can be used only in small, contained, shallow ponds that have little or no outflow and are not used for human consumption. Impairs aesthetics.
NUTRIENT REDUCTION**	Nutrients (phosphorus and nitrogen) which stimulate weed growth, are removed and internal internal nutrient cycling is disrupted by removing weeds and filamentous algae. Chemical treatments (e.g., alum) can make nutrients unavailable to macrophytes (see Table C-4). Eliminate external sources by modifying watershed practices.	Cost is integrated into expense of operating lake management program (e.g., harvesting program, shoreline cleanup) and watershed pollution abatement programs.	Attends to problem at its source. Prevents further deterioration of lake conditions. Involves long-term, large-scale results. Native plants may be able to compete better in low nutrient, clear water conditions.	Is slow (i.e., results may not be quickly seen). Will probably increase water clarity, creating potential for macrophyte growth. Most nutrient reduction/inactivation targets phosphorus, while nitrogen may be more important. Ability to control macrophytes is unknown.
BIOMANIPULATION	See Table C-2.			

* Data sources: Vt. Dep. Environ. Conserv. (1991); Cooke et al. (1986); Engel (1982, 1984); Nichols (1991); S. Borman, WDNR Western District (pers. comm.); and Aquatic Biologists, Inc., Fond du Lac, WI.

** Currently used in the Yahara lakes.

Table C-4. Chemical control technologies for aquatic plant control. All chemical applications require a WDNR permit.[*]

Chemical	Description	Cost	Advantages	Disadvantages
DIQUAT[**]	A non-selective contact herbicide that is absorbed by plant foliage and directly damages cell tissues. May be used only to control Eurasian water milfoil, duckweed (*Lemna* spp.), and elodea.	Cost was $0.69/ft^2 frontage + $18.00 administrative fee + $6.00 WDNR permit fee per property in 1992, as organized through Clean Lakes Association (see section III). Clean Lakes charges one price for all treatments.	Reduces plant growth. Is easy to apply. Has no direct toxic effects on spawning fish.	Involves water use restrictions during and after treatment. Is not selective for "weedy species and kills native species (e.g., pondweeds, water celery, naiads). May affect, through drift, areas that were not treated. May perpetuate monotypic stands of weedy species by slowing recovery of native plants. May be associated with health risk, but testing of health effects is not complete.
2,4-D	A systemic herbicide that moves through the plant and interferes with normal cell growth and division. Is a "selective" herbicide, targeting Eurasian water milfoil and not affecting most submersed native species. Can be applied at surface or subsurface in early spring as soon as plants start to grow, or later in the season.	Cost is not applicable since chemical is not allowed in the Yahara lakes.	Reduces plant growth. Is easy to apply. Targets Eurasian water milfoil, leaving most native submerged species unharmed.	Involves water use restrictions during and after treatment. May be associated with health risk, but testing of health effects is not complete. May affect, through drift, areas not treated.

Table C-4. Continued.

Chemical	Description	Cost	Advantages	Disadvantages
ENDOTHALL	A non-selective contact herbicide that prevents certain plants from making necessary proteins.	Cost is not applicable, since this chemical is not allowed in the Yahara lakes.	Reduces plant growth. Is easy to apply.	Kills native and weedy species alike. Not especially effective on Eurasian water milfoil. Involves water use restrictions during and after treatment. Involves some products that may be toxic to fish. May affect, through drift, areas not treated. May be associated with health risk, but testing of health effects is not complete.
COPPER COMPOUNDS**	A systemic herbicide that prevents photosynthesis. Is used primarily to control planktonic and filamentous algae.	1992 cost was the same as for Diquat because is purchased and applied through Clean Lakes Association (see section III).	Reduces plant growth. Is easy to apply. Involves no water use restrictions.	Accumulates and persists in sediments. Involves short-term results; algae degradation releases nutrients, enabling regrowth. In alkaline waters, precipitates rapidly. May be associated with health risk, but testing of health effects is not complete.
ALUM	A chemical treatment that tightly binds phosphorus to sediments (retarding its release to water column during anoxic conditions) which makes the phosphorus unavailable to rooted plants.	Cost is expensive when chemical, application equipment, and labor considered.	Makes phosphorus in sediments unavailable to macrophytes. Has long-term effects.	Introduces a potentially toxic substance to the lake. Increases water transparency, which may extend the outer limit of macrophyte growth. Ability to control plant growth is questionable.

* Data sources: Andrews (1986); Vt. Dep. Environ. Conserv. (1991); WDNR herbicide information sheets (1990); Cooke et al. (1986); Nichols (1991); S. Borman, WDNR Western District (pers. comm.); S. Nichols, UW-Extension (pers. comm.); Diquat manual - Valent.

** Currently used in the Yahara lakes.

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Cover photo credits: Richard Lathrop (aerial photograph of Lake Waubesa) and Dave Marshall (underwater photograph of macrophytes).