Changes in the Aquatic Plant Community of Lake Hallie, Chippewa County, Wisconsin

1998-2005

Wisconsin Department of Natural Resources
Eau Claire, WI

June 2006

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Submitted by:

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EXECUTIVE SUMMARY

Lake Hallie is a 79-acre, mesotrophic oxbow lake with good water quality and very good water clarity. Filamentous algae is abundant in the lake.

The plant community in Lake Hallie is characterized by low quality, fair diversity, dense growth, a high tolerance to disturbance and high level of disturbance in the community. The plant growth in Lake Hallie in provided 100% cover within the littoral zone. *Wolffia columbiana* was the dominant species in August 2005, especially in the 0-5ft depth zones. *Potamogeton robbinsii* was subdominant, most abundant in the 5-11ft depth zones in 2005. These species exhibited a dense form of growth in Lake Hallie.

The aquatic plant community has changed significantly since 1998.
Some changes have occurred seen since the harvesting program began in 2000. There has been an increase in water clarity, abundance of filamentous algae, cover of free-floating species, species diversity and frequency of *Potamogeton amplifolius* (a valuable habitat species). There has been a decrease in the dominance of *Potamogeton crispus* and cover of submergent species.

Changes that have occurred since hybrid watermilfoil was introduced have been an increase in disturbance in the community and a decrease in quality of the aquatic plant community. Hybrid watermilfoil, which was first recorded in spring 2005. In August 2005, hybrid milfoil occurred throughout most of the Lake, at nearly half of the sample sites, at below average density. It comprised less than on-tenth of the plant community.

A healthy aquatic plant community plays a vital role within the lake community. This is due to the benefits that plants provide in improving water quality, providing valuable resources for fish and wildlife, resisting invasions of non-native species and checking excessive growth of tolerant species that could crowd out the more sensitive species, therefore reducing the diversity.

Management Recommendations

1) Residents and Lake Association preserve and expand the natural buffer zones of native vegetation around the lake.
2) Lake Association to cooperate with programs to manage run-off from the watershed.
3) Lake Association update aquatic plant management plan as scheduled to include modifications as the plant community changes.
4) Lake Association continue the mechanical harvesting program to control curly-leaf pondweed and its impacts, provide navigational access and improve fish habitat and control newly introduced hybrid watermilfoil. Avoid harvesting in areas with valuable habitat plants
    a) Continue early summer curly-leaf pondweed program to remove curly-leaf biomass from Lake Hallie
    b) Continue mid and late summer harvest to improve fish habitat and areas for boating.
    c) Develop a plan for hybrid milfoil harvesting modeled after the early summer and fall target harvest program used for Eurasian milfoil.

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I. INTRODUCTION

Studies of the aquatic macrophytes (plants) in Lake Hallie were conducted in July 1991; June and August of 1998 and 2001; August 2005 by Water Resources staff of the West Central Region - Department of Natural Resources (DNR).

During routine water sampling in spring 2005, a new species, a watermilfoil, was seen in Lake Hallie. DNA analysis confirmed that the watermilfoil was hybrid watermilfoil, *Myriophyllum sibiricum x spicatum.* The 2005 study was conducted to map the colonization of the recently introduced hybrid watermilfoil. This study will also provide information that is important for effective management of *Potamogeton crispus* (curly-leaf pondweed) and hybrid watermilfoil, fish habitat improvement, protection of sensitive wildlife areas and water resource regulations. The added data that it provides will be compared to past and future plant inventories and track changes occurring in the lake.

A study of the diversity, density, and distribution of aquatic plants is an essential component of understanding a lake due to the important ecological role of aquatic vegetation and the ability of the vegetation to characterize the water quality (Dennison et al. 1993).

Ecological Role: All other life in the lake depends on the plant life (including algae) - the beginning of the food chain. Aquatic plants provide food and shelter for fish, wildlife, and the invertebrates that in turn provide food for other organisms. Plants improve water quality, protect shorelines and lake bottoms, add to the aesthetic quality of the lake, impact recreation, and serve as indicators of water quality.

Characterize Water Quality: Aquatic plants serve as indicators of water quality because of their sensitivity to water quality parameters, such as water clarity and nutrient levels (Dennison et. al. 1993).

Background and History: Lake Hallie is a 79-acre oxbow lake near the Chippewa River in Chippewa County, Wisconsin. Lake Hallie was formed when a bend in the Chippewa River was cut off from the main Chippewa River channel. The northeast end of the lake has been completely cut off from the Chippewa River, but the west end of the lake still drains into the Chippewa River. The maximum depth of Lake Hallie is 11 feet. Springs contribute water to the lake and a dam controls and maintains the water level.

The lake was used as a log reservoir for saw mill operations during the mid- to late-1800's. The sawmill closed in 1890 and the lake became a recreational site. By 1990, the dam had deteriorated and needed to be repaired or removed. The dam repair at Lake Hallie was completed October 1997.

There are records of complaints pertaining to disagreeable odors from algae growth, as early as 1952. Swimmer's itch was reported in 1970. Algae and swimmer's itch treatments with copper sulfate were attempted for a few years, but copper compounds have no long-term effectiveness on the algae or swimmer's itch parasites, so the treatments were discontinued.

In April 1998, a lake association was formed to help manage and protect the lake.

In 2000, an 18-acre parcel of land was obtained as a natural area to protect the wetlands and springs at the northeast end of the lake. The land was partially donated by American Materials and partially purchased by the lake association, with grants and moneys from Wisconsin DNR and Chippewa County.

In 2000, the lake association also received a grant from the state to purchase a used aquatic plant harvester and started a harvesting program for curly-leaf pondweed. The main goal was to reduce the coverage and density of *Potamogeton crispus* in Lake Hallie and reduce the severity of the algae blooms that occur as the *P. crispus* decays. After the mechanical harvesting program was begun in 2000, water clarity increased the dominance of *Potamogeton crispus* decreased, disturbance indices decreased and the number of species increased (Konkel 2002).

II.METHODS

Field Methods

The same methods and sampling sites were used for the 1991, 1998, 2001 and 2005 aquatic plant studies, based on the rake-sampling method developed by Jessen and Lound (1962). Transects (16) were place equidistant along the shoreline, perpendicular to the shoreline and mapped for future surveys (Appendix X).

One sampling site was randomly located in each depth zone (0-1.5ft, 1.5-5ft, 5-10ft, and 10-11ft) along each transect. Using a long-handled, steel, thatching rake, four rake samples were taken at each sampling site. The four samples were taken from each quarter of a 6-foot diameter quadrat. The aquatic plant species that were present on each rake sample were recorded and each species was given a density rating (0-5) based on the number of rake samples on which it was present at each sampling site.

A rating of 1 for each species present on one rake sample at a sampling site;
A rating of 2 for each species present on two rake samples at a sampling site;
A rating of 3 for each species present on three rake samples at a sampling site;
A rating of 4 for each species present on four rake samples at a sampling site;
A rating of 5 indicates that a species was abundant on all rake samples at that sampling site.

The sediment type at each sampling site was recorded. The type of shoreline cover was recorded at each transect. A section of shoreline, 50 feet on either side of the transect intercept with the shore and 30 feet back from the shore, was evaluated. The percentage of each cover type within this 100' x 30' rectangle was recorded.

Visual inspection and periodic samples were taken between transect lines in order to record the presence of any species that did not occur at the sampling sites. Specimens of all plant species present were collected and saved in a cooler for later preparation of voucher specimens. Nomenclature was according to Gleason and Cronquist (1991).

Data Analysis

Data from each survey year was analyzed separately and compared. The percent frequency of each species was calculated (number of sampling sites at which it occurred / total number of sampling sites) (Appendices I-III); relative frequency was calculated (the number of occurrences of a species/total occurrence of all species (Appendix I-III). The mean density was calculated for each species (sum of a species' density ratings / number of sampling sites) (Appendices IV-VI); relative density was calculated (a species density / total of all plant densities); "mean density where present" was calculated for each species (sum of a species' density ratings / number of sampling sites at which the species occurred) (Appendix IV-VI). The relative frequency and relative density were summed to obtain a Dominance Value (Appendix VII-IX). Simpson's Diversity Index was calculated $1-(\sum(\text{Relative Frequency}^2))$ (Appendix I-III) to measure species diversity in the plant community. Coefficients of Community Similarity were calculated to compare the sampling years.

The Aquatic Macrophyte Community Index (AMCI) developed by Nichols (2000) was applied to Lake Hallie (Table 7). Values between 0 and 10 are given for each of seven categories that characterize a plant community and summed.

The Average Coefficient of Conservatism and Floristic Quality Index were calculated, as outlined by Nichols (1998), to determine disturbance in the plant community. A coefficient of conservatism is an assigned value, 0-10, the probability that a species will occur in an undisturbed habitat. The Average Coefficient of Conservatism is the mean of the coefficients for all species found in the lake. The FQI is calculated from the Average Coefficient of Conservatism (Nichols 1998) and is a measure of a plant community's closeness to an undisturbed condition.

III. RESULTS

PHYSICAL DATA

Many physical parameters are important determinants of the type of aquatic plant community that will ultimately inhabit a lake. Water quality (nutrient concentrations, algae growth, clarity, water hardness) impact the plant community as the plant community can in turn modify these parameters. Lake morphology, sediment composition and shoreline land use also impact the plant community.

WATER QUALITY - The trophic state of a lake is an indication of its water quality. Phosphorus concentration, chlorophyll concentration, and water clarity data are collected and combined to determine the trophic state.

Eutrophic lakes are high in nutrients and support a large biomass.

Oligotrophic lakes are low in nutrients and support limited plant growth and smaller populations of fish.

Mesotrophic lakes have intermediate levels of nutrients and biomass.

Nutrients

Phosphorus is a limiting nutrient in many Wisconsin lakes. So, increases in phosphorus in a lake can feed algae blooms and excess plant growth.

August 2004 phosphorus in Lake Hallie was 31 ug/l.

This concentration of phosphorus in Lake Hallie was indicative of a eutrophic lake (Table 1).

Table 1. Trophic Status

	Quality Index	Phosphorus ug/l	Chlorophyll ug/l	Secchi Disc ft.
Oligotrophic	Excellent	<1	<1	> 19
	Very Good	1-10	**1-5**	**8-19**
Mesotrophic	Good	10-30	5-10	6-8
Eutrophic	Good	**30-50**	10-15	5-6
	Poor	50-150	15-30	3-4
Hypereutrophic	Very Poor	>150	>30	>3
Lake Hallie 2004	Good	31	2.6	9.95

After Lillie & Mason (1983); Shaw et. al. (1993)

Algae

Measuring the concentration of chlorophyll in the water gives an indication of algae concentrations. Algae is natural and essential in lakes, but high algae levels can increase turbidity and reduce the light available for plant growth.

August 2004 chlorophyll a in Lake Hallie was 2.6 ug/l.

Chlorophyll concentrations indicate that Lake Hallie was an oligotrophic lake (Table 1).

Filamentous algae occurred at:

69% of the sites in August 1998.
96% of the sites August 2001
98% of the sites in August 2005 (Figure 1).

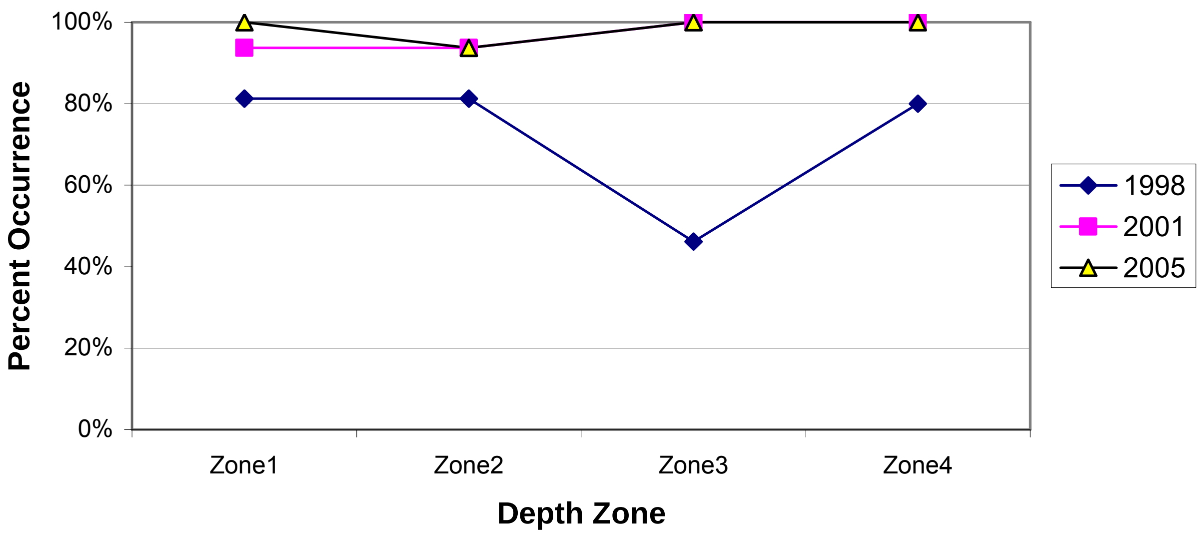

Figure 1. Occurrence of filamentous algae in August surveys, by depth zone, 1998-2005.

Water Clarity

Water clarity is a critical factor for plants. When plants receive less than 1 - 2% of the surface illumination, they can not survive. Water clarity is reduced by turbidity (suspended materials such as algae and silt) and dissolved organic chemicals that color the water. Water clarity can be measured with a Secchi disc that shows the combined impact of turbidity and color.

2005 Mean summer Secchi Disc Clarity was 9.95 ft.

The water clarity indicates that Lake Hallie was an oligotrophic lake that had very good water clarity (Table 1).

The combination of phosphorus concentration, chlorophyll concentration, and water clarity indicates the trophic status of a lake. The nutrient values for Lake Hallie are not in the same trophic state as the data for water clarity and chlorophyll. This is likely due to the high population of filamentous algae that is taking up the nutrients and is not captured in the chlorophyll samples. Lake Hallie is likely a mesotrophic lake with good water quality. This trophic state favors moderate to high levels of plant or algae growth.

George Wanserski has been monitoring the water clarity in Lake Hallie since 1995 as a volunteer lake monitor in the Self-Help Lake Monitoring Program. The Self-Help Volunteer Monitoring data is valuable because volunteer data is collected more frequently throughout the season and for more consecutive years than Department of Natural Resource monitoring.

George Wanserski's data showed that the mean water clarity was lowest in 1995 (5 feet) and greatest in 1996 (10.5 feet). The 1997 mean clarity decreased to 7.3 feet (Figure 2). Water clarity has been increasing since 1997.

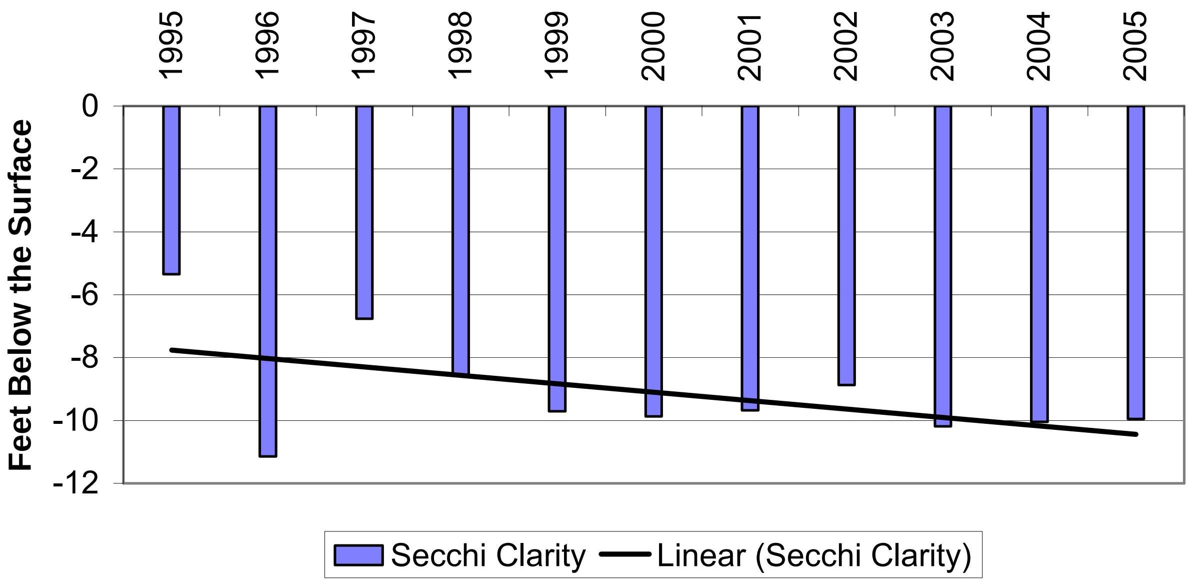

Figure 2. Mean water clarity in Lake Hallie, 1995-2005.

The data collected by George Wanserski also shows that water clarity changes during the season. The 1995-2005 data collected at the same time during the year was averaged. This shows that generally the lowest clarity is in early spring, then increases to the greatest yearly clarity in Late-May. The clarity decreases until Late-July, likely due to the curly-leaf pondweed die-back and decay. The clarity increases again to a second maximum in September (Figure 3).

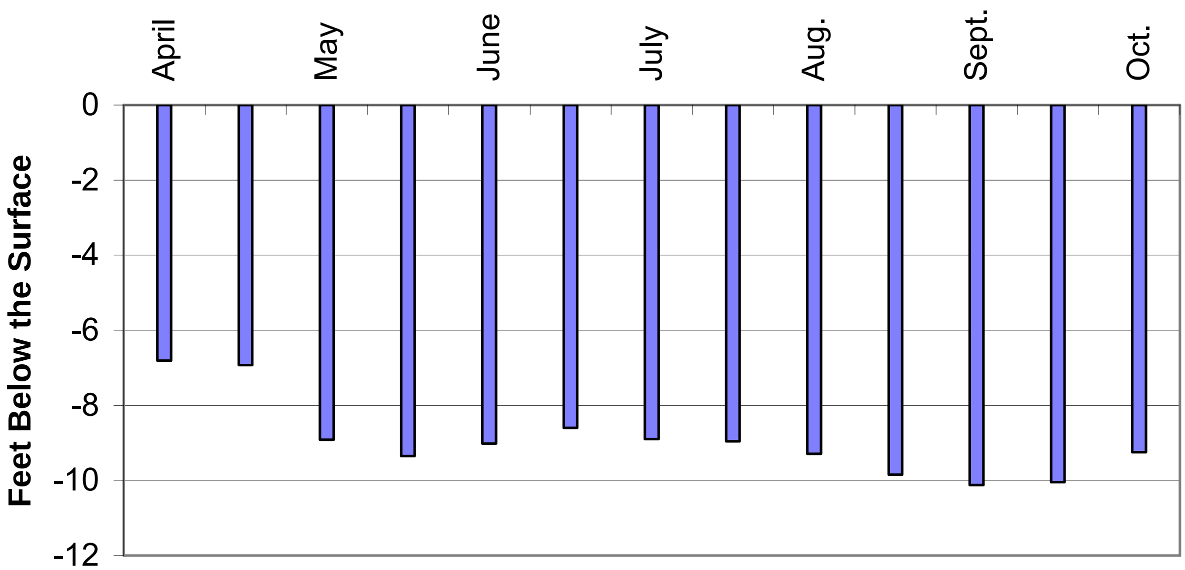

Figure 3. Changes in mean water clarity during the season, 1995-2005.

Hardness

The hardness or mineral content of lake water also influences aquatic plant growth. The 2001 hardness values in Lake Hallie ranged from of 30-60 mg/l CaCO3. Lakes with hardness values less than 60 mg/l CaCO3 are considered soft water lakes. Soft water lakes support less plant growth than hard water lakes.

LAKE MORPHOMETRY - The morphometry of a lake is an important factor in determining the distribution of aquatic plants. Duarte and Kalff (1986) found that the slope of the littoral zone could explain 72% of the observed variability in the growth of submerged plants. Gentle slopes support more plant growth than steep slopes (Engel 1985). Lake Hallie has a narrow, V-shape basin and a mean depth of 6 feet. Most of the basin has a gradually sloped littoral zone. The gradual slope and shallow depths of Lake Hallie favor abundant plant growth.

SEDIMENT COMPOSITION - Many plants depend on the sediment in which they are rooted for their nutrients. The richness or sterility of the sediment will determine the type and abundance of aquatic plant species that can survive in a location.

Silt sediment was the dominant sediment in Lake Hallie, especially at depths greater than 1.5ft (Table 2) (Figure 4). The availability of mineral nutrients for growth is highest in sediments of intermediate density, such as silt (Barko and Smart 1986).

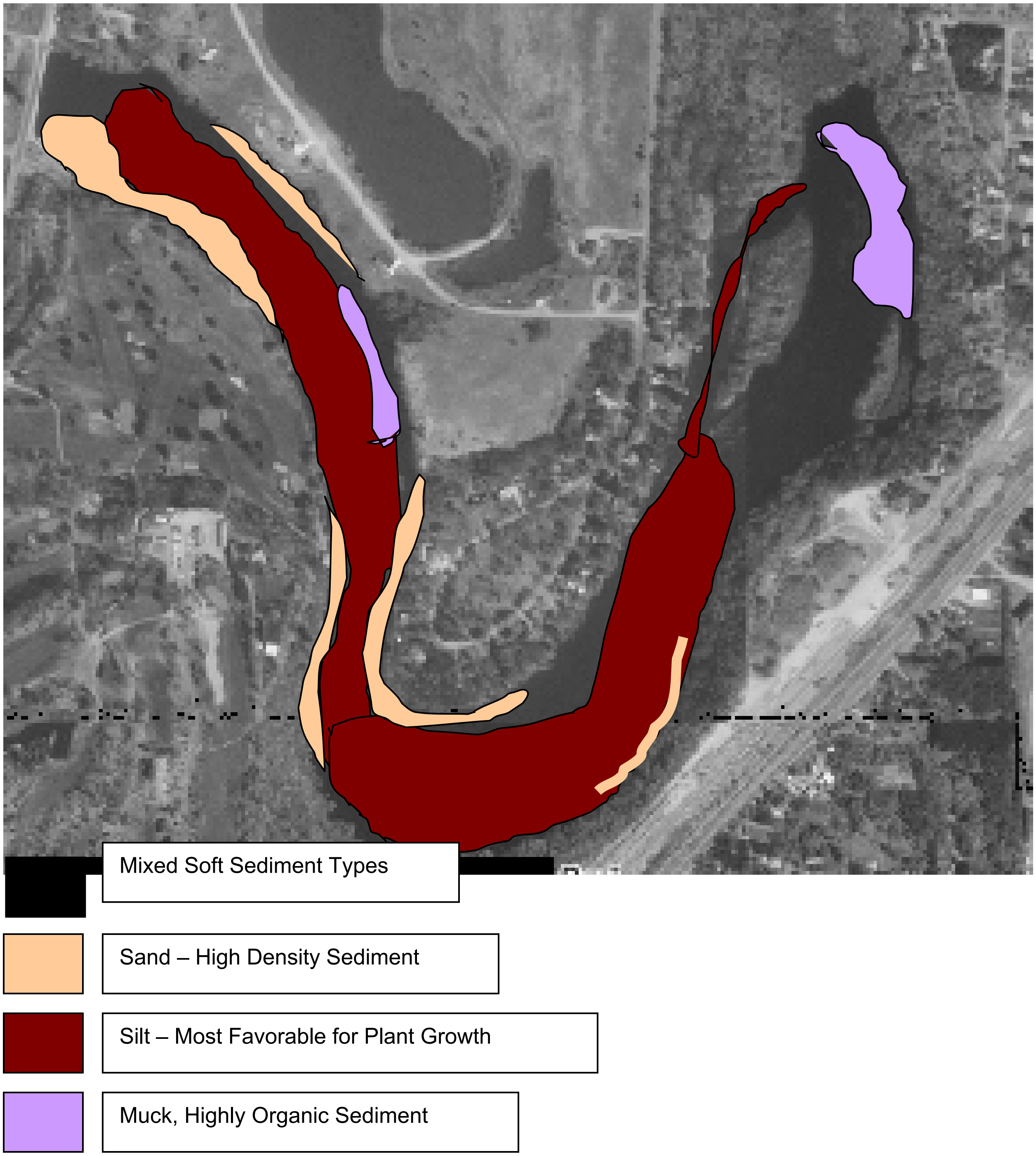

Figure 4. Sediment distribution in Lake Hallie, 2005.

Sand, gravel and rock are high density sediments. High-density sediments could be limiting to plant growth due to lower nutrient availability. Sand was dominant in the shallowest zone and, mixed with muck or peat, was common in the shallow zone.

Table 2. Sediment Composition, Lake Hallie - 2005

		0-1.5 ft	1.5-5 ft	5-9 ft	9-11ft	Overall
Soft Sediments	Silt	13%	38%	75%	75%	42%
	Peat				25%	2%
	Muck	13%	25%			13%
Mixed Sediments	Sand/Silt	13%	25%	17%		13%
	Sand/Muck/Peat	20%	6%	8%		13%
Hard Sediments	Sand	33%	6%			13%
	Sand/Gravel	7%				2%

All sediment types supported vegetation at the sampling sites. Sediment does not appear to be a major factor determining aquatic plant growth in Lake Hallie.

SHORELINE LAND USE - Land use practices strongly impact the aquatic plant community and therefore the entire aquatic community. Practices on shore can directly impact the plant community through increased sedimentation from erosion, increased nutrients from fertilizer run-off and soil erosion and increased toxics from farmland and urban run-off.

Wooded cover and native herbaceous cover were the most frequently encountered shoreline cover at the transects. Shrub and cultivated lawn were also commonly encountered (Table 3). Wooded cover had the highest mean coverage, it covered nearly half of the shoreline (Table 3). However, cultivated lawn occurred at half of the sites and covered one-quarter of the shore. Cultivated lawn is problematic in that run-off from lawns are likely to carry pesticides, fertilizers and pet waste and lawn does not filter the run-off as effectively as natural plant cover.

Table 3. Shoreline Land Use

	Cover Type	Frequency of Occurrences at Transects	Mean % Coverage
Natural Shoreline	Wooded	88%	46%
	Native Herbaceous	88%	18%
	Shrub	44%	8%
Total Natural Cover			72%
Disturbed Shoreline	Cultivated Lawn	50%	26%
	Eroded Soil	6%	1%
	Hard Structures	6%	0.3%
Total Disturbed Cover			27%

Some type of natural shoreline (wooded, shrub, native herbaceous) was found at all of the sites and covered of 72% of the shoreline. Some type of disturbed shoreline (cultivated lawn, eroded and hard structures) was found at 56% of the sites and covered 27% of the shoreline.

MACROPHYTE DATA

SPECIES PRESENT

Over the course of several survey years, 33 species have been found in Lake Hallie. Of the 33 species, 14 were emergent species, 4 were a floating-leaf species, and 15 were submergent species (Table 4).

No endangered or threatened species were found.

One species of special concern was found in 1991 but has not been found since: *Eleocharis robbinsii.*

Two non-native species have been found: *Myriophyllum spicatum* x *sibiricum* and *Potamogeton crispus*

Table 4. Lake Hallie Aquatic Plant Species; 1991-2005

Scientific Name	Common Name	I. D. Code
Emergent Species		
1) *Calla palustris* L.	water arum	calpa
2) *Carex comosa* F. Boot.	bristly sedge	carco
3) *Eleocharis robbinsii* Oakes.	Robbin's spikerush	elero
4) *Impatiens pallida* Nutt.	pale jewelweed	impbi
5) *Iris versicolor* L.	blue flag iris	irive
6) *Juncus effusus* L.	soft rush	junef
7) *Leersia oryzoides* (L.) Swartz.	rice cut-grass	leeor
8) *Myosotis laxa* Lehm.	smaller forget-me-not	myola
9) *Phalaris arundinacea* L.	reed canary grass	phaar
10) *Rorippa nasturtium-aquatica* (L.) Hay.	water-cress	rorna
11) *Sagittaria rigida* Pursh.	stiff arrowhead	sagri
12) *Scirpus validus* Vahl.	softstem bulrush	sciva
13) *Typha angustifolia* L.	narrow-leaf cattail	typan
14) *Typha latifolia* L.	common cattail	typla
Floating Species		
15) *Lemna minor* L.	small duckweed	lemmi
16) *Lemna trisulca* L.	forked duckweed	lemtr
17) *Spirodela polyrhiza* (L.) Schleiden.	greater duckweed	spipo
18) *Wolffia columbiana* Karsten.	common watermeal	wolco
Submergent Species		
19) *Ceratophyllum demersum* L.	coontail	cerde
20) *Chara* sp.	muskgrass	chasp
21) *Elatine minima* (Nutt.) Fisch. & Meyer	waterwort	elami
22) *Eleocharis acicularis* (L.) Roemer & Schultes.	needle spikerush	eleac
23) *Elodea canadensis* Michx.	common water-weed	eloca
24) *Myriophyllum spicatum* x *sibiricum*	hybrid watermilfoil	myrhy
25) *Najas flexilis* (Willd.) R. & S.	northern water-nymph	najfl
26) *Nitella* sp.	nitella	nitsp
27) *Potamogeton amplifolius* Tuckerman.	large-leaf pondweed	potam
28) *Potamogeton crispus* L.	curly-leaf pondweed	potcr
29) *Potamogeton foliosus* Raf.	leafy pondweed	potfo
30) *Potamogeton pusillus* L.	slender pondweed	potpu
31) *Potamogeton robbinsii* Oakes.	fern-leaf pondweed	potro
32) *Potamogeton zosteriformis* Fern.	flatstem pondweed	potzo
33) *Ranunculus longirostris* Godron.	white watercrowfoot	ranlo

FREQUENCY OF OCCURRENCE

The species with the highest frequency of occurrence in the 1991-2001 surveys was *Elodea canadensis* (Table 5). By 2005, *E. canadensis* had decreased and *Wolffia columbiana* increased so that *W. columbiana* became the most frequently occurring species in 2005. *Potamogeton robbinsii* has increased since 1991; *Chara* and *Spriodela polyrhiza* have decreased since 1991.

The frequency of *Potamogeton crispus* has been higher during June surveys (Konkel 2002): *P. crispus* frequency declined substantially between 1998 and 2001, since mechanical harvesting began in 2000 (Table 5).

Table 5. Most frequently occurring species, Lake Hallie, August 1998-2005

	1998	2001	2005
Wolffia columbiana	36%	86%	**89%**
Potamogeton robbinsii	46%	78%	85%
Elodea canadensis	**86%**	**88%**	64%
Ceratophyllum demersum	14%	59%	55%
Lemna minor	26%	49%	53%
Myriophyllum spicatum x sibiricum	-	-	49%
Chara sp.	4%	30%	4%
Potamogeton crispus	24%	4%	4%
Spirodela polyrhiza	6%	4%	0

DENSITY

Elodea canadensis had the highest mean density in Lake Hallie in 1998 (Table 6). The density of *E. canadensis* decreased and the density of *Wolffia columbiana* increased such that *W. columbiana* was the species with the highest mean density in August 2001 and 2005.

The density of *Potamogeton crispus* decreases from June to August (Konkel 2002). *P. crispus* density has also decreased substantially since 1998 (Table 6) and the density of *Potamogeton robbinsii* has increased (Table 6).

Table 6. Species with the highest mean density, Lake Hallie, August 1998-2005.

	1998	2001	2005
Wolffia columbiana	1.08	**2.96**	**3.47**
Potamogeton robbinsii	1.00	2.35	2.87
Elodea canadensis	**3.20**	2.69	1.64
Ceratophyllum demsersum	0.20	1.24	1.21
Lemna minor	0.56	0.86	1.04
Myriophyllum spicatum x sibiricum	-	-	0.89
Chara sp.	0.04	0.56	0.11
Potamogeton crispus	0.40	0.04	0.04

(Density on a scale of 0-4)

The "density where present" of *Wolffia columbiana* was 3.88 (scale of 0-4) indicating that *W. columbiana* exhibited a dense growth form in Lake Hallie. *Elodea canadensis* and *Potamogeton robbinsii* also had "densities where present" greater than 2.5 indicating they also exhibited growth form of above average density in Lake Hallie (Appendices IV-VI).

DOMINANCE

Combining the relative frequency and relative density of a species into a dominance value indicates the dominance of a species within the aquatic plant community (Appendix VII-IX). Based on the dominance value, *Elodea canadensis* was the dominant species within the plant community in 1998 and subdominant in 2001. *Potamogeton robbinsii* was the sub-dominant species in 1998 and again in 2005 (Figure 5). The dominance of *Wolffia columbiana* increased, becoming the dominant species in 2001-2005 (Figure 3).

The dominance of *Potamogeton crispus* has decreased from June to August surveys due to its early season life cycle (Konkel 2002). Its dominance in the August community has decreased since 1998.

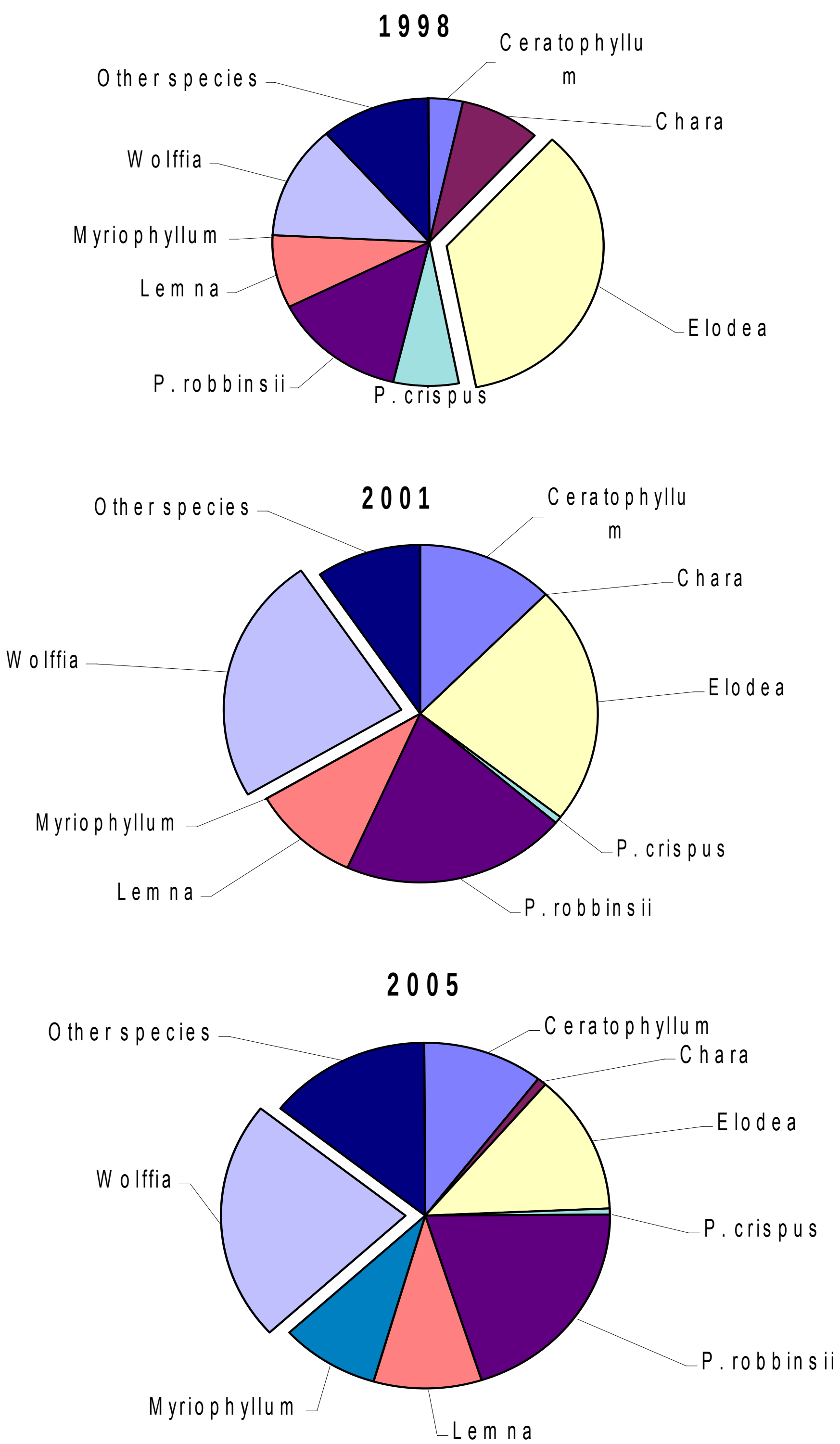

Figure 5. Dominance within the aquatic plant community of the most prevalent plant species, August 1998-2005.

DISTRIBUTION

Aquatic plants were found growing at 100% of the sampling sites in Lake Hallie in 2005 to the maximum depth of the lake. *Ceratophyllum demersum, Chara, Elodea canadensis Potamogeton crispus* and *P. robbinsii* were found at the maximum depth of 11.5 ft.

Water clarity data can be used to calculate a predicted maximum rooting depth for plants in the lake (Dunst 1982).

Predicted Rooting Depth (ft.) = (Secchi Disc (ft.) * 1.22) + 2.73

Based on the 2005 Mean summer water clarity, the predicted maximum rooting depth was 14.9 ft. in the Lake Hallie.

This is greater than the maximum depth of the lake, meaning that aquatic vegetation has the potential to colonize the entire lake bed.

The dominant and common species occurred throughout the lake. The hybrid milfoil is currently distributed throughout the lake except the far northeast corner (Figure 6). The milfoil colonized approximately 33 acres (42% of the lake) in August 2005.

The 0-1.5 ft. depth zone has had the highest total occurrence and total density of plants (Figure 7, 8). The occurrence and density of plant growth decreased with increasing depth. The highest total occurrence and density of plant growth occurred in 2005.

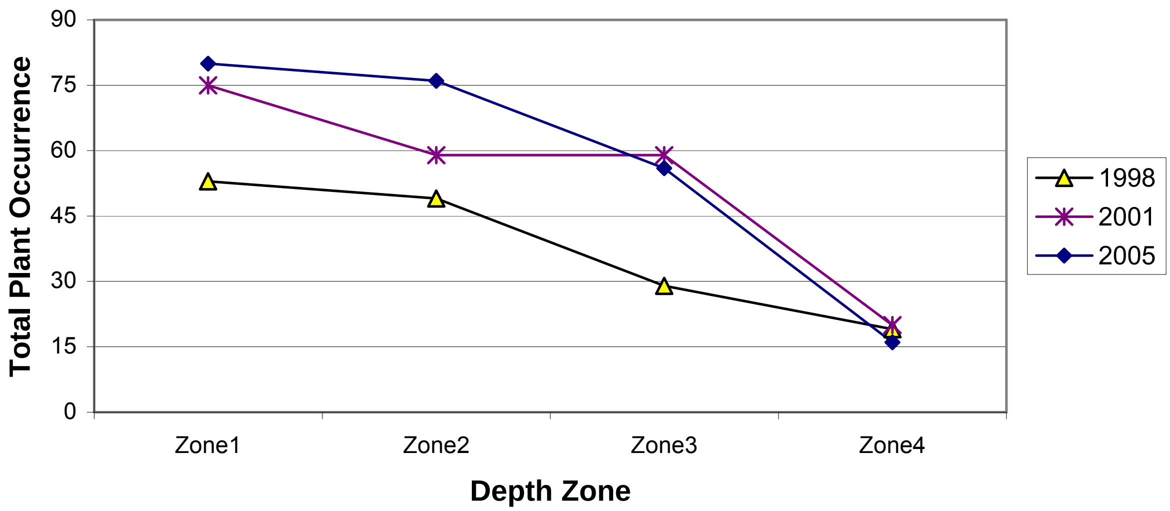

Figure 7. Total occurrence of aquatic plants by depth zone in Lake Hallie, 1998-2005.

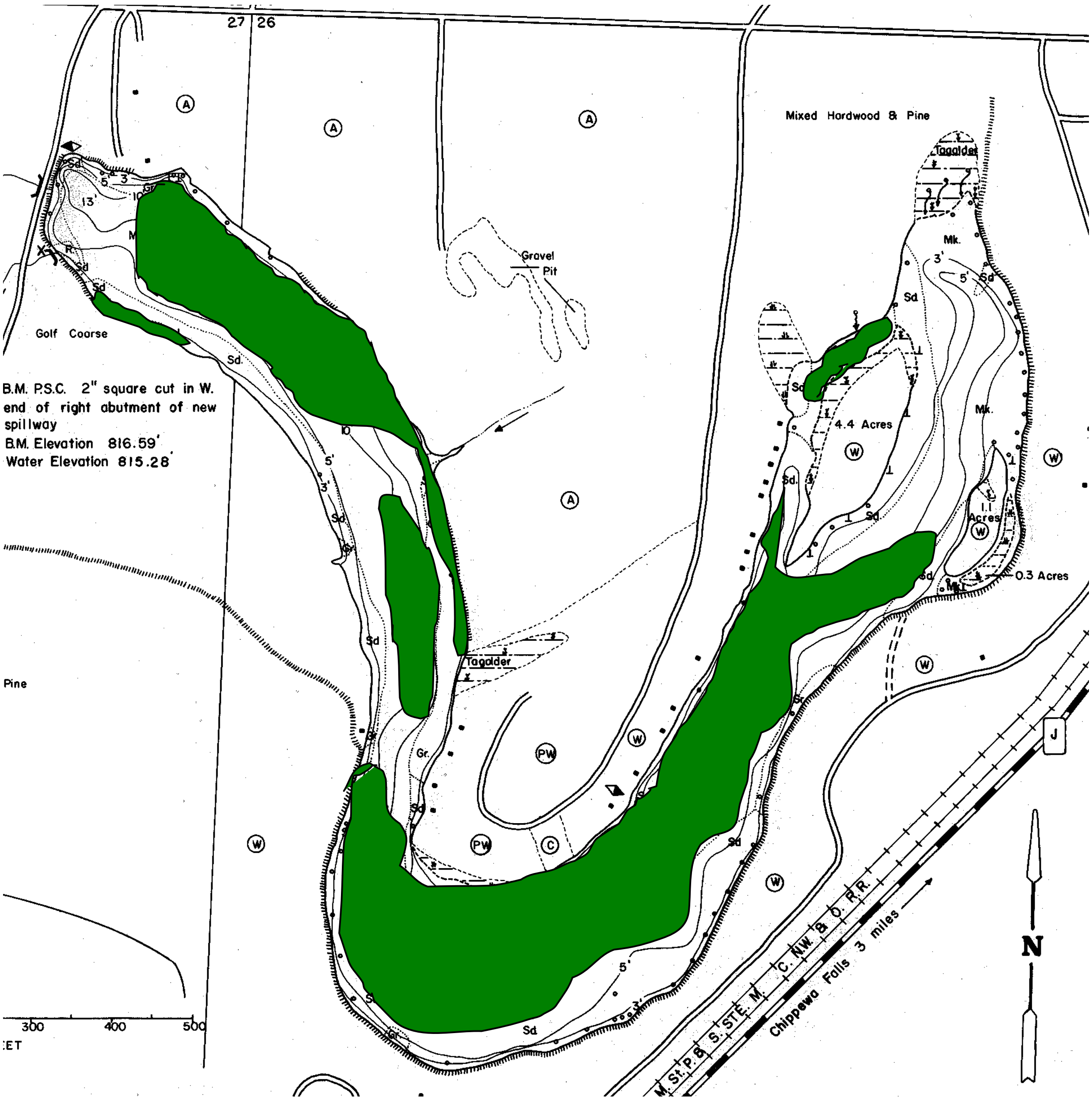

Figure 6. Location of Hybrid milfoil in Lake Hallie, August 2005.

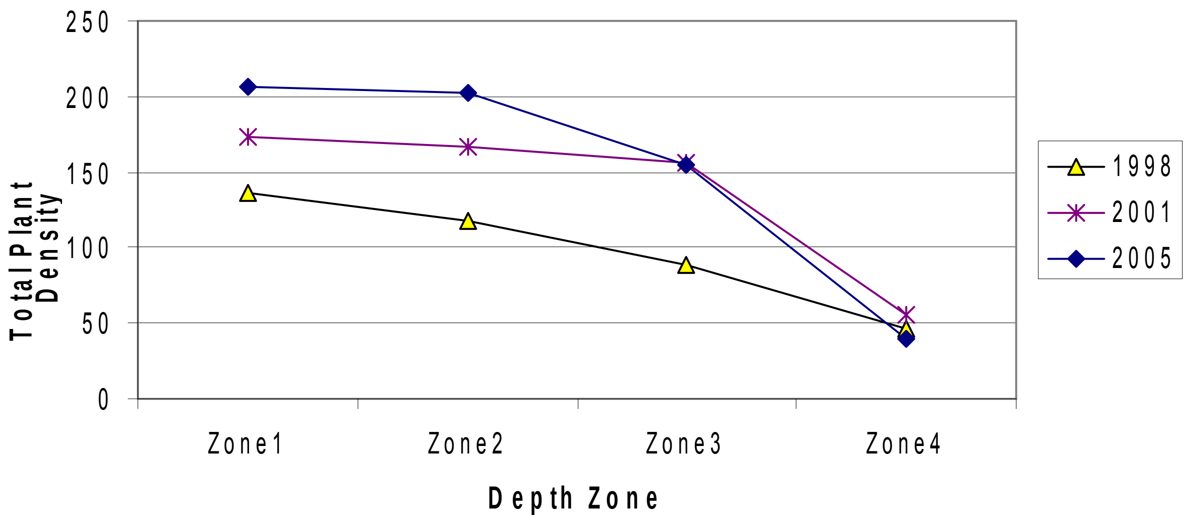

Figure 8. Total density of aquatic plants by depth zone in Lake Hallie, 1998-2005.

The greatest Species Richness has been in the 0-1.5ft depth zone, except in 1998, when the greatest Species Richness was in the deepest zone (Figure 9).

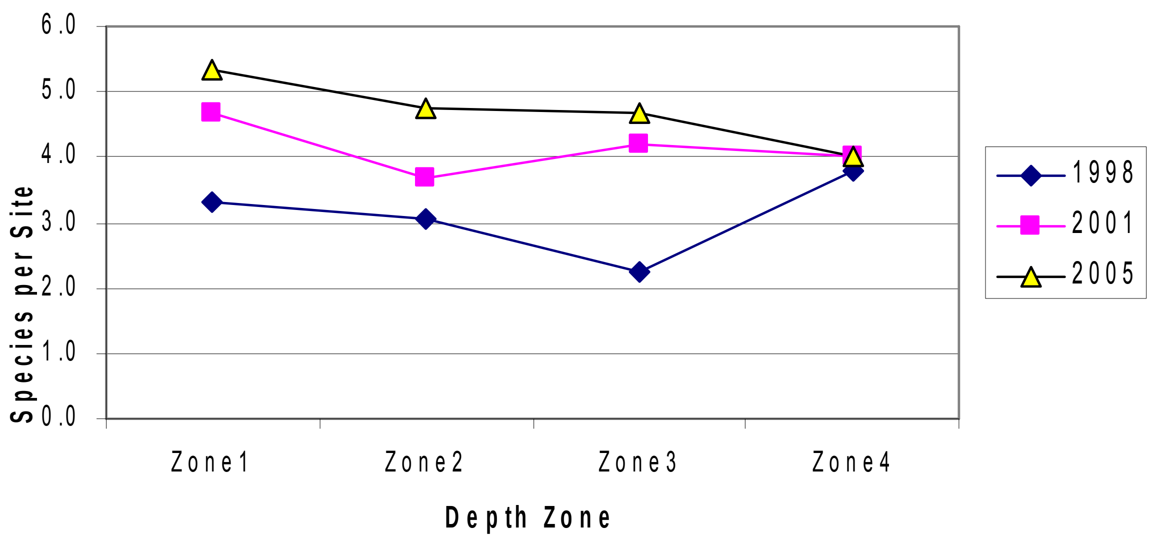

Figure 9. Species Richness, by depth zone, in Lake Hallie, 1998-2005

The frequencies and densities of individual species varied in different years and with depth zone. Late summer frequency and density of *Potamogeton crispus* has declined since the harvesting program began and has remained low (Figure 10, 11).

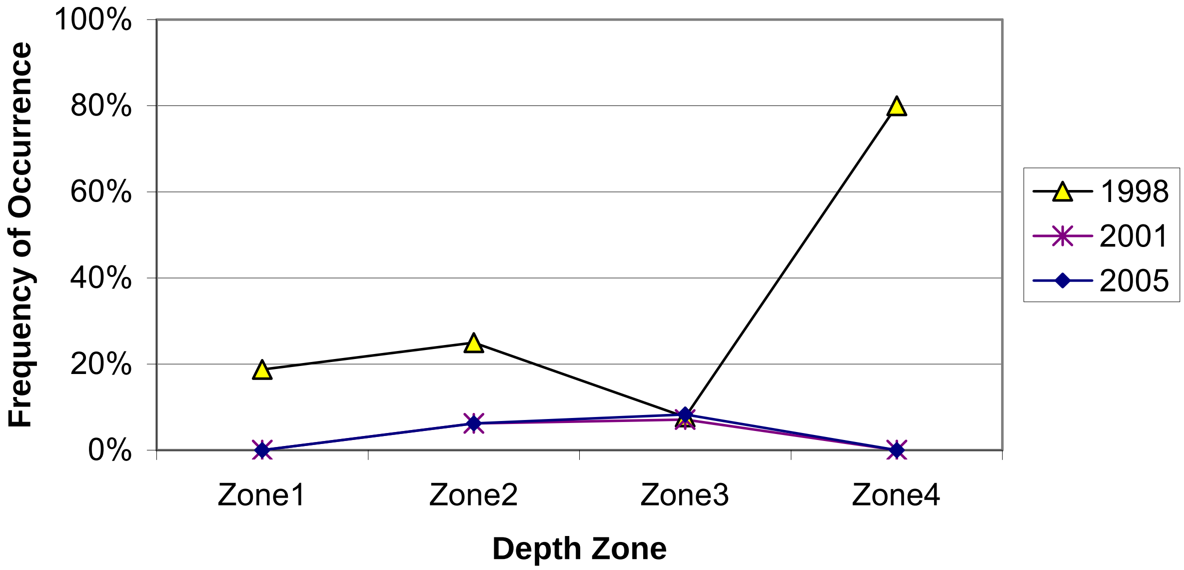

Figure 10. Frequency of *Potamogeton crispus* in late summer by depth zone.

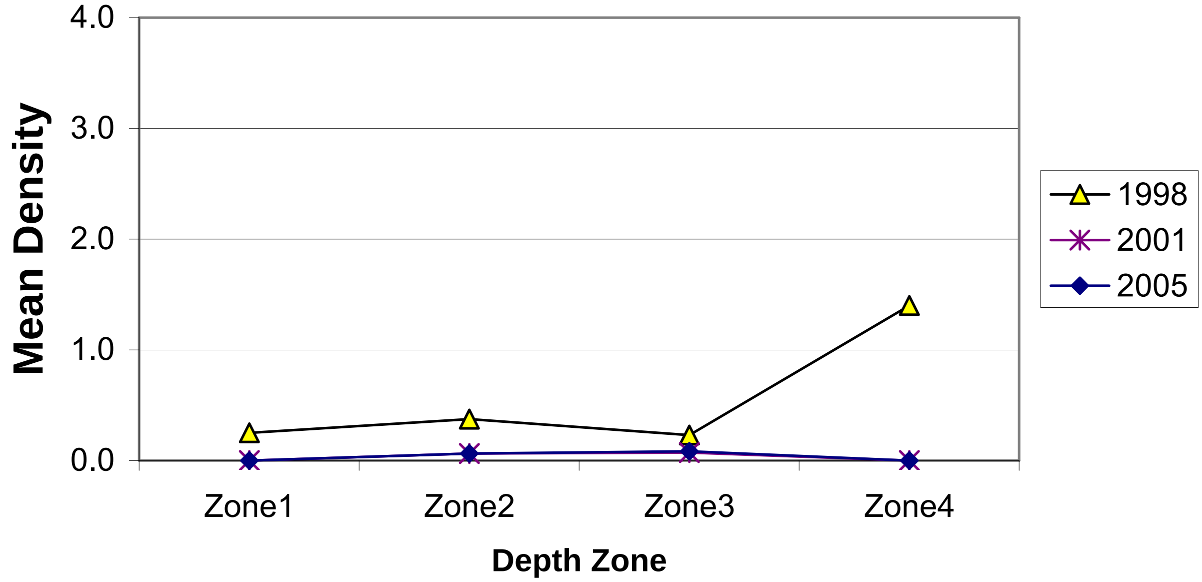

Figure 11. Density of *Potamogeton crispus* in late summer by depth zone.

Elodea canadensis was the dominant species in 1998, declined somewhat in 2001 and declined even more in 2005 (Figure 12, 13).

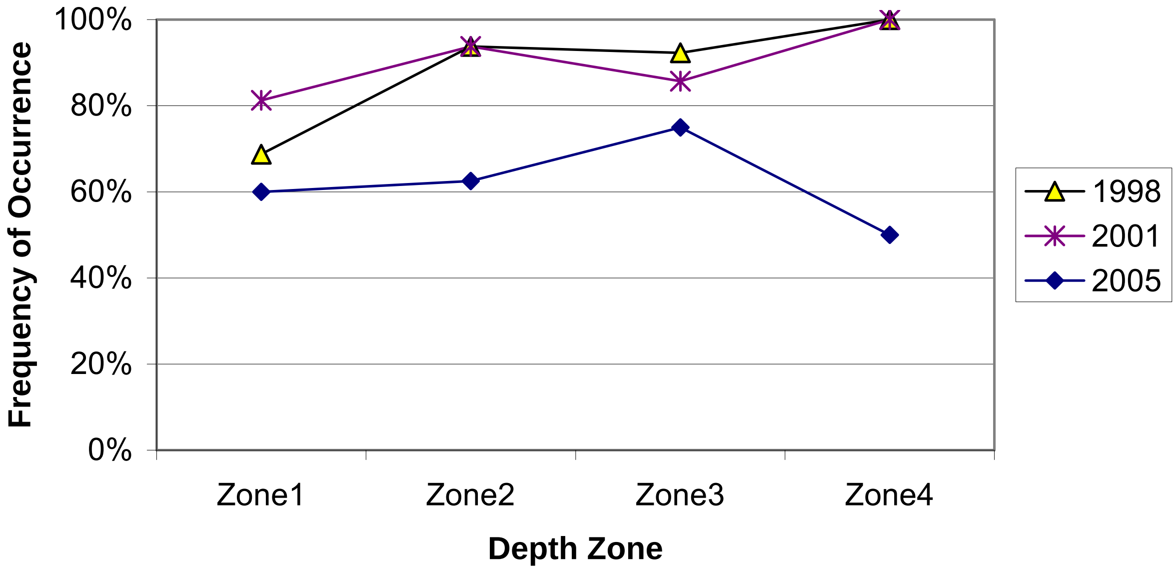

Figure 12. Frequency of *Elodea canadensis* by depth, 1998-2005.

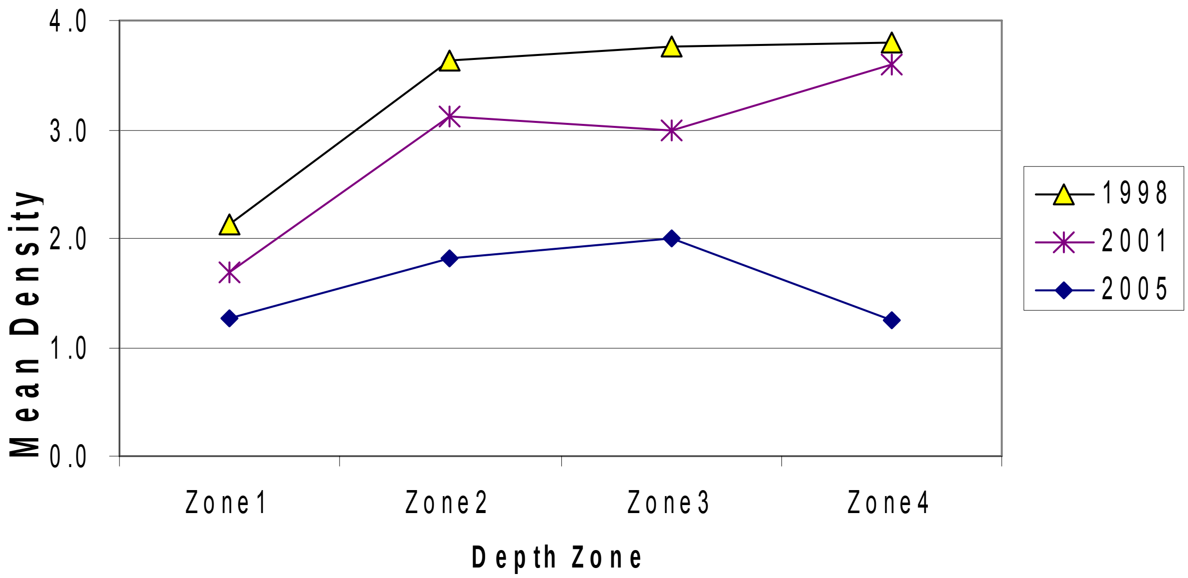

Figure 13. Density of *Elodea canadensis* by depth, 1998-2005.

Wolffia columbiana, a duckweed species, has increased since 1998 and became the dominant species in 2001-2005, dominating the 0-5ft depth zone in 2005 (Figure 14, 15).

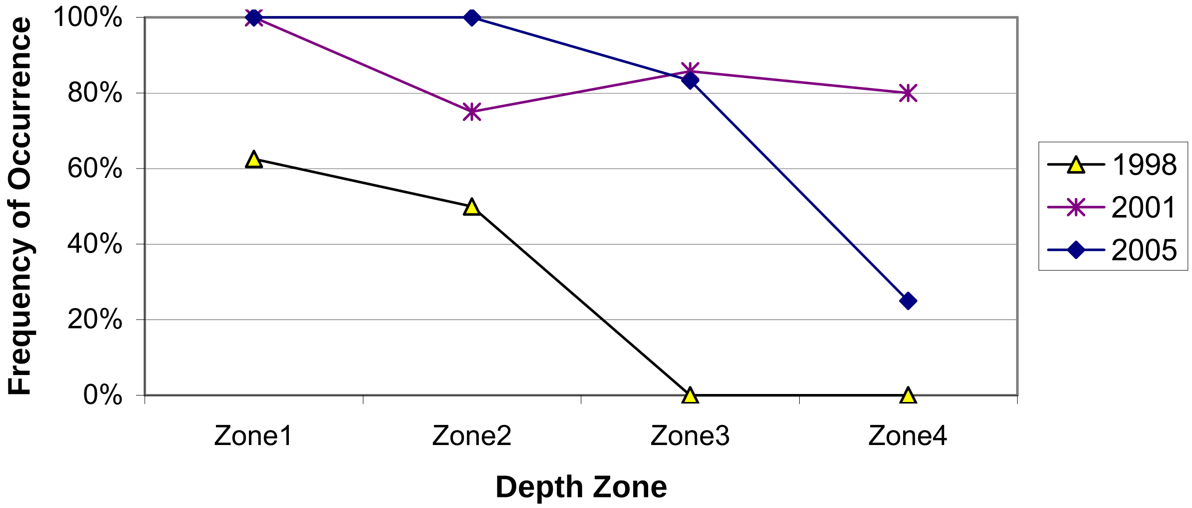

Figure 14. Frequency of occurrence of *Wolffia columbiana,* by depth zone.

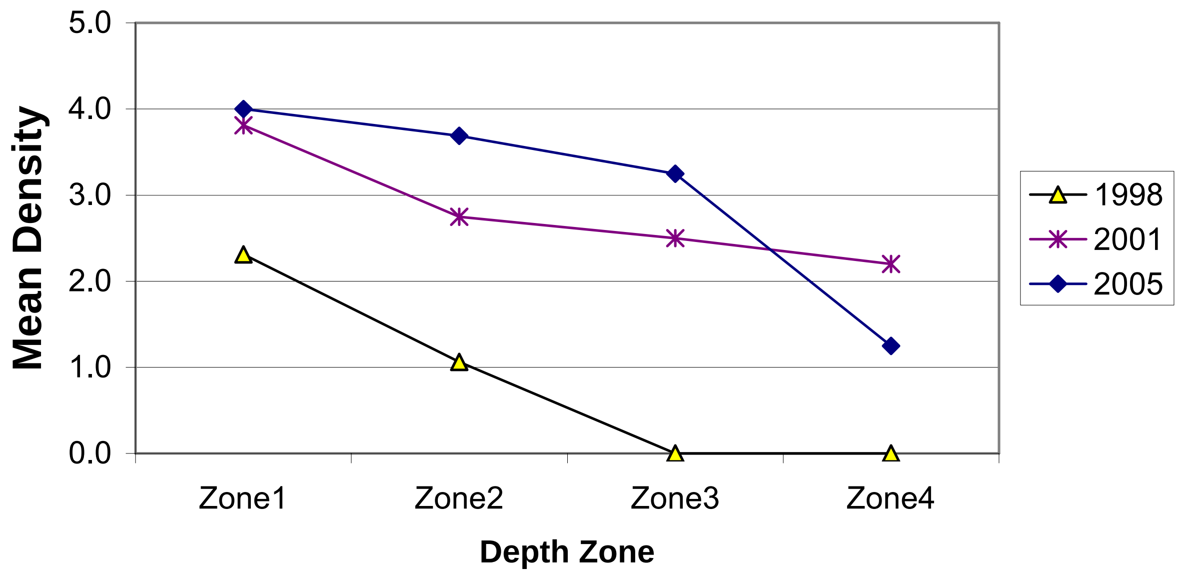

Figure 15. Density of *Wolffia columbiana,* duckweed species by depth zone.

Potamogeton robbinsii did not occur at the sample sites in 1991, but was found in 1998 and its frequency and density has been steadily increasing, especially in the deeper depth zones (Figure 16, 17). In August 2001 and August 2005, it was dominant in the 5-11ft depth zone.

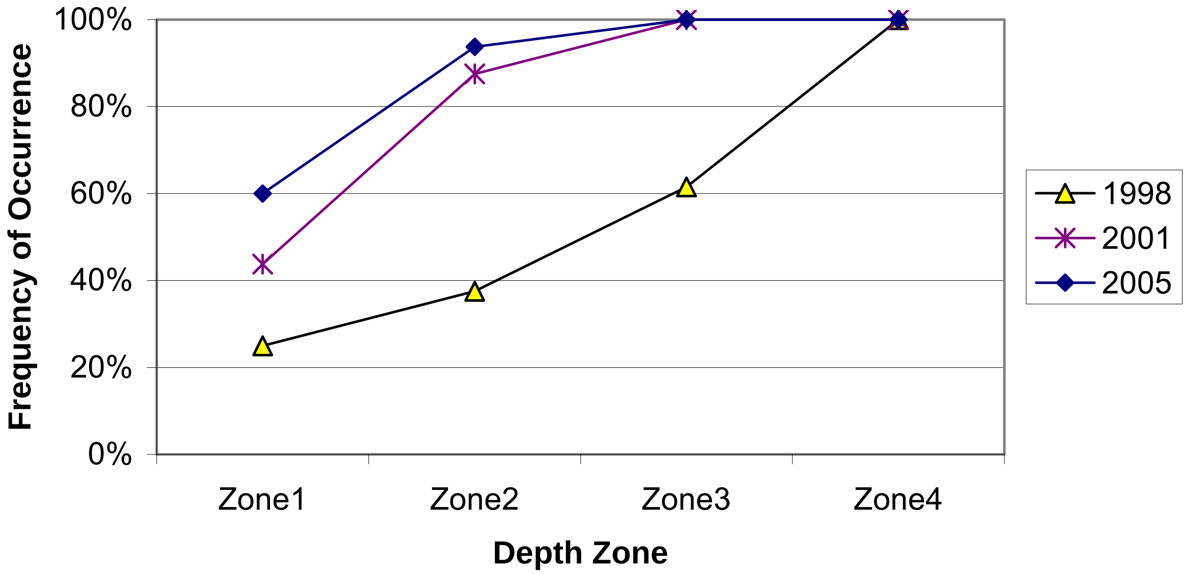

Figure 16. Frequency of *Potamogeton robbinsii* by depth zone, 1998-2005.

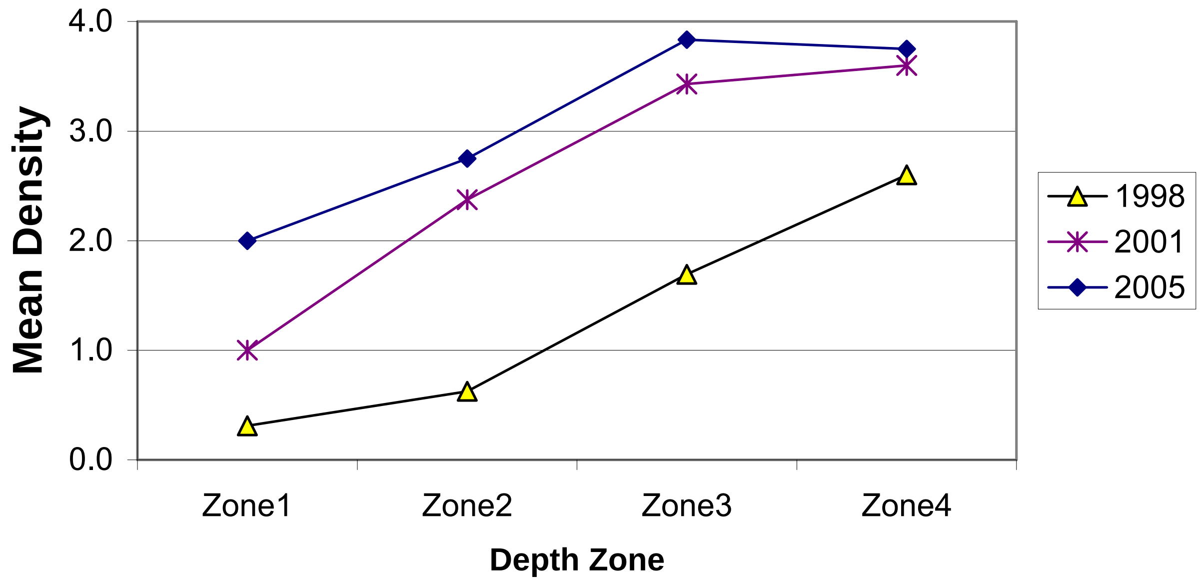

Figure 17. Density of *Potamogeton robbinsii* by depth zone 1998-2005.

In spring 2005, a new plant species was observed in Lake Hallie during water monitoring procedures. DNA analysis confirmed that the species was the hybrid watermilfoil. In August 2005, this species colonized large areas of Lake Hallie, commonly occurring in all depth zones but at low densities (Figure 18). Its frequency and density increased with increasing depth, occurring at its highest frequency and density at depths greater than 10 feet.

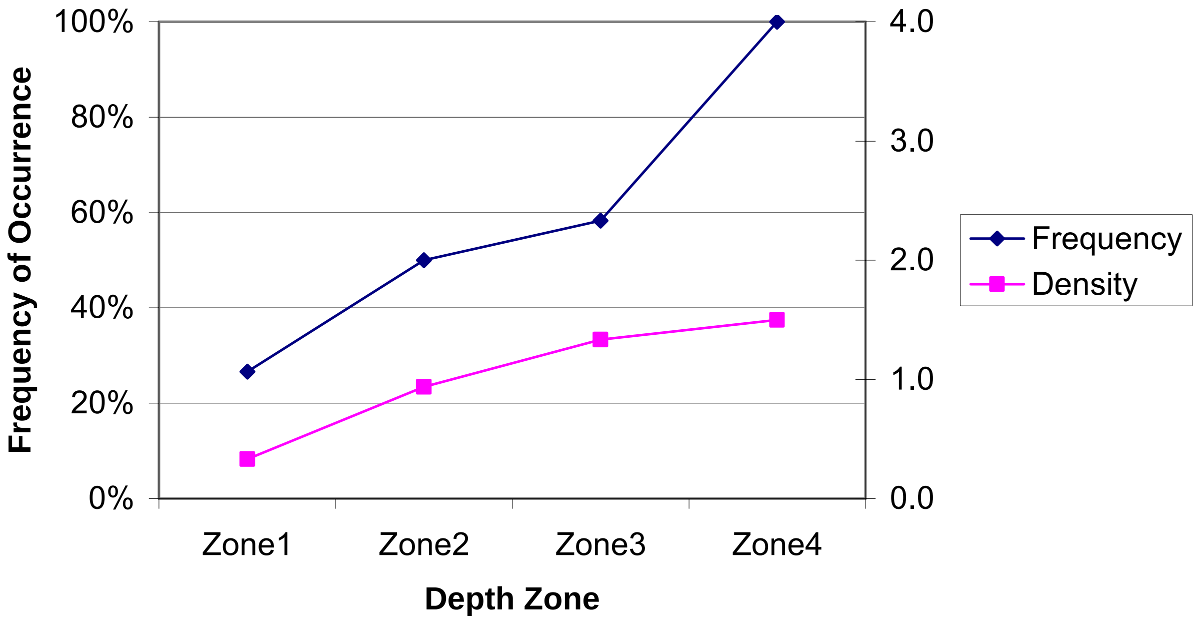

Figure 18. Frequency and density of hybrid watermilfoil in Lake Hallie, by depth zone, 2005.

THE COMMUNITY

The Coefficients of Community Similarity is a measure of the percent similarity between two communities. Coefficients less than 0.75 indicate that the two communities are only 75% similar and are considered significantly different.

The coefficients for Lake Hallie indicate that the late summer aquatic plant communities were significantly different each year (Table 7). The 1998 and 2001 communities were only 70% similar and the 2001 and 2005 plant communities (after the introduction of hybrid milfoil) were only 57% similar. The change in the late summer plant communities accumulated over the seven years so that the 1998 and 2005 communities were only 41% similar (Table 7).

Table 7. Coefficients of Community Similarity, 1998-2005

	Coefficient	% Similarity
August Plant Community		
1998-2001	0.69634	70%
2001-05	0.57123	57%
1998-2005	0.40938	41%

Different parameters and indices can be used to determine what changes have occurred in the plant community. In Lake Hallie, several parameters increased from 1998 to 2005: the number of species at the sampling sites, the percent of the littoral zone that was vegetated, the percent coverage of emergents and free-floating species and the diversity of species (Table 8). Simpson's Diversity Index increased but has maintained fair diversity. An index of 1.0 would mean that each individual plant in the lake was a different species (the most diversity achievable).

Since 1998, there has been a decrease in the coverage of submergent vegetation, the Average Coefficient of Conservatism, the Floristic Quality Index (measuring increased disturbance, discussed later in document) and the AMCI Index (measuring decreased quality of the community, discussed later in document).

The largest percentage increase is in the coverage of emergent vegetation and the largest percentage decrease is in the Average Coefficient of Conservatism (increased tolerance to disturbance) (Table 8).

Table 8. Changes in the Lake Hallie Aquatic Plant Community, 1998-2005

	1998	2001	2005	%Change 1998-2005
Number of Species	14	20	16	14.3%
% of Littoral Zone Vegetated	94.0	100.0	100.0	6.4%
%Sites/Emergents	4.0	20.0	14.9	272.5%
%Sites/Free-floating	42.0	88.0	95.7	127.9%
%Sites/Submergents	94.0	96.0	91.5	-2.7%
%Sites/Floating-leaf				
Simpson's Diversity Index	0.85	0.84	0.87	2.4%
Ave. Coefficient of Conservatism	4.90	4.47	4.18	-14.7%
Floristic Quality	17.75	19.50	16.75	-5.6%
AMCI Index	49	48	46	-6.1%

The Aquatic Macrophyte Community Index (AMCI) for Lake Hallie was below average for lakes in Wisconsin and in the region in 1998. The quality has decreased to the lowest quartile of lakes in the region in 2005 (Table 9). This indicates that the quality of the aquatic plant community in Lake Hallie was below average for lakes in the state and region in 1998 and that the quality decreased until by 2005, Lake Hallie was within the group of lakes in the North Central Hardwood Region with the lowest quality aquatic plant community.

Table 9. Aquatic Macrophyte Community Index, 1998-2005

Category	August 1998	August 2001	August 2005
Maximum Rooting Depth	5	6	6
% Littoral Zone Vegetated	10	10	10
% Submersed Species	8	3	3
# of Species	7	9	8
% Exotic species	6	6	4
Simpson's Diversity	6	6	7
% Sensitive Species	7	8	8
Totals	49	48	46

The highest value for this index is 70.

The Average Coefficients of Conservatism for Lake Hallie during 1998-2005 were in the lowest quartile for all Wisconsin lakes and lakes in the North Central Hardwood Region (Table 10). This indicates that Lake Hallie was in the group of lakes that are most disturbance-tolerant, likely from being subjected to disturbance. During this time period, the Average Coefficient of Conservatism declined, which suggests increasing tolerance to disturbance from increasing disturbance.

Table 10. Mean Coefficient of Conservatism and Floristic Quality of Lake Hallie Compared to Wisconsin Lakes and Region Lakes, 1998 - 2005.

	Average Coefficient of Conservatism †	Floristic Quality‡
Wisconsin Lakes	5.5, 6.0, 6.9*	16.9, 22.2, 27.5*
NCHF	5.2, 5.6, 5.8*	17.0, 20.9, 24.4*
August 1998	4.90	17.75
August 2001	4.47	19.5
August 2005	4.18	16.75

* upper limit of lower quartile, mean, lower limit of upper quartile

†Average Coefficient of Conservatism for all Wisconsin lakes ranged from a low of 2.0 (the most disturbance tolerant) to a high of 9.5 (least disturbance tolerant).

‡The lowest Floristic Quality was 3.0 (farthest from an undisturbed condition) and the high was 44.6 (closest to an undisturbed condition).

(NCHF) The North Central Hardwood Forest Region is the region in which Lake Hallie is located.

The Floristic Quality Index for Lake Hallie (1998-2001) was below the mean for Wisconsin Lakes and for lakes in the North Central Hardwood Region (Table 10) in 1998 and 2005. This indicates that Lake Hallie was farther from an undisturbed condition than the average lake in Wisconsin and the North Central Hardwood Region and increased in 2005. The disturbance appears to have decreased in 2001. In 2005, the Floristic Quality decreased and put Lake Hallie in the lowest quartile, the 25% of lakes in the state and region farthest from an undisturbed condition (Table 10).

Disturbances can be of many types:

1) Direct disturbances to the plant beds result from boat traffic, plant harvesting, chemical treatments, the placement of docks and other structures, etc.
2) Indirect disturbances can be the result of factors that impact water clarity and thus stress species that are more sensitive: resuspension of sediments, sedimentation from erosion, increased algae growth due to nutrient inputs.
3) Biological disturbances include the introduction of a non-native or invasive plant species, grazing from an increased population of aquatic herbivores, destruction of plant beds by the fish population, etc.

Major disturbances in Lake Hallie are likely the introduction of two exotic plant species, shoreline development, mechanical harvesting and past drawdowns for dam repair.

Plant communities change because the occurrence of individual species within the communities change. In Lake Hallie, 5 plant species have disappeared since 1998, but these species were not frequently occurring species and may still be there in scattered locations (Appendix XI). Besides the five that have disappeared, 4 species have decreased. *Chara* spp. and *Potamogeton crispus* have decreased the most, 80-90% decreases.

Ten species have increased (half of these being species newly recorded since 1998). *Ceratophyllum demersum* has increased the most, a 3-fold increase in frequency and 5-fold increase in density (Appendix XI).

IV. DISCUSSION

Based on 2004 water quality data, Lake Hallie is a mesotrophic lake with good water quality and very good water clarity. Water clarity has increased since 1997. However, the dense growth of filamentous algae and aquatic plants indicate a eutrophic lake. Filamentous algae was abundant (98% of the sites) in Lake Hallie and has increased since 1998.

Good water clarity, abundant nutrients, shallow depths, a gradually-sloped littoral zone and the dominance of favorable silt sediments favor aquatic plant growth. The combination of the shallow basin and water clarity result in the ability for aquatic plants to colonize the entire lake bottom. Soft water could limit plant growth.

The Plant Community

Elodea canadensis (common waterweed) had been the dominant plant species in Lake Hallie in 1998, especially in the 1.5-5ft depth zone, but decreased in frequency and density in 2001-05. *Wolffia columbiana* (watermeal) increased in frequency and density and became the dominant species in August of 2001 and 2005, especially in the 0-5ft depth zones, exhibiting a dense form of growth. Common waterweed is adapted to low water clarity due to the placement of its chloroplasts near the leaf surface; watermeal is adapted to low clarity because of its growth on the surface of the water. *Elodea canadensis* and *Potamogeton robbinsii* (sub-dominant in 2005) also exhibit growth forms of above average density. *P. robbinsii* has been increased since 1998 and is especially abundant in the 5-11ft depth zones.

Potamogeton crispus (curly-leaf pondweed) was the sub-dominant plant species in June 1998. The dominance of this non-native species declined between June and August (Konkel 2002). It also declined substantially between 1998 and 2001. The frequency and density of *P. crispus* declined substantially since June 1998 (80-90% decline) after the harvesting program began.

Hybrid watermilfoil, which was first recorded in spring 2005. In August 2005, hybrid milfoil occurred throughout most of the Lake, at nearly half of the sample sites, at below average density. It comprised less than on-tenth of the plant community.

The aquatic plant community in Lake Hallie is characterized by high density of growth, a fair diversity of species, low quality (AMCI Index) and a high tolerance to disturbance. Lake Hallie is in the groups of lakes in the state and region farthest from an undisturbed condition. Dense plant growth is found throughout Lake Hallie to the maximum depth of the lake; aquatic plants were found at 100% of the sites. The greatest species richness, highest occurrence and density of plants were found in the 0-1.5 foot depth zone in all surveys. The dominant and common species were found throughout the lake.

Changes in the Plant Community
The plant community in Lake Hallie has changed significantly. The Lake Hallie plant community in 1998 was only 70% similar to the 2001 community. The 2001 community was 57% similar to the 2005 plant community, based on the Coefficients of Community Similarity. The accumulated change resulted in only a 41% similarity between the 1998 and 2005 communities.

Changes in the plant community in Lake Hallie from 1998 to 2005:

1) A shift in the dominant aquatic plant species from the submerged species, *Elodea canadensis,* to a free-floating duckweed species, *Wolffia columbiata.*
2) The increased abundance of *Potamogeton robbinsii* (fern-leaf pondweed) and *Ceratophyllum demersum* (coontail).
3) An decrease in the quality of the plant community as measured by the AMCIndex.
4) The increase in plant growth (total occurrence and density of aquatic plants and percent of vegetated cover).
5) The decrease in frequency, density and dominance of *Potamogeton crispus*, especially in the deeper depth zones.
6) Increase in species diversity (Simpson's Diveristy Index, number of species occurring at the sample sites and species richness).
7) Decrease in Average Coefficient of Conservatism and Floristic Quality Index (which suggests an increase in disturbance in the community)
8) Decrease in submergent vegetation
9) Increase in emergent vegetation

Eleocharis robbinsii has disappeared from Lake Hallie. It is a species of special concern and may be a sensitive species whose decline may indicate disturbance. Since a drawdown was conducted for the dam was repaired in 1997 and *E. robbinsii* disappeared during this time period, the drawdown may be responsible.

Shoreline Impacts
The occurrence of natural shoreline (wooded, shrub and native herbaceous growth) on Lake Hallie was high. Wooded cover occurred at more than three-quarters of the sites and covered nearly half of the shore. Although natural shoreline was abundant, cultivated lawn occurred at half of the sites and covered more than one-quarter of the shore. Cultivated lawn can result in increased run-off of fertilizers, pet wastes and other nutrients. Mowed lawn speeds the run-off to the lake without filtering these pollutants as natural buffers would. Expanding and preserving the buffer of natural vegetation along the shore will provide habitat and protect the water quality of the lake from toxic run-off, nutrient run-off and erosion.

To measure the impact of shoreline disturbance, the aquatic plant transects at sites with 100% natural shoreline were compared to aquatic plant transect sites at shoreline that contained any amount disturbance (Appendices XII-XV). The comparison of various parameters indicate that disturbance on the shore may have had some impact on the aquatic plant community at those sites.

The natural shoreline communities supported greater Species Richness, which indicates a diverse distribution of plant species (Table 11).

The natural shoreline communities provide slightly more habitat. The percent cover of submergent plant species is higher at natural shoreline sites (Table 11).

Disturbance may be playing a key role in the spread and colonization of exotic plant species. The newly introduced hybrid watermilfoil occurred at a higher frequency and had a higher dominance at sites near disturbed shoreline. The other exotic plant species was found only at disturbed shoreline sites (Table 11).

Table 11. Comparison of the Aquatic Plant Community at Natural Shoreline Sites and Disturbed Shoreline Sites: Lake Hallie 2005.

Parameter		**Natural Shoreline**	**Disturbed Shoreline**
Species Richness (mean number of species per site)		5.15	4.64
Amount of Habitat	% Cover of Submergent Species	95%	89%
Exotic Species: Hybrid Milfoil	Dominance	0.14	0.19
	Frequency	42%	54%
Exotic Species: Curly-leaf pondweed	Frequency	0	7%

V. CONCLUSIONS

Lake Hallie is a 79-acre, mesotrophic oxbow lake with good water quality and very good water clarity. Filamentous algae is abundant in the lake.

The plant community in Lake Hallie is characterized by low quality, fair diversity, dense growth, a high tolerance to disturbance and high level of disturbance in the community.

Elodea canadensis had been the dominant species within the plant community in 1998 and curly-leaf pondweed was sub-dominant during its peak growth in June. *E. canadensis* decreased and *Wolffia columbiana* increased, resulting in *W. columbiana* becoming the dominant species in August 2001 and 2005, especially in the 0-5ft depth zones. *Potamogeton robbinsii* has increased since 1998 and was most abundant in the 5-11ft depth zones in 2005. All three of these species exhibited a dense form of growth in Lake Hallie.

Hybrid watermilfoil, which was first recorded in spring 2005. In August 2005, hybrid milfoil occurred throughout most of the Lake, at nearly half of the sample sites, at below average density. It comprised less than on-tenth of the plant community.

The aquatic plant community has changed significantly since 1998.

Several changes have been seen since the harvesting program began in 2000.

1) Water clarity has increased since 1997.
2) The dominance of *Potamogeton crispus* has decreased 80-90%, especially in the deeper depth zones
3) Species diversity measures have increased
4) The frequency of *Potamogeton amplifolius*, an aquatic plant that is valuable for habitat, has increased.
5) Filamentous algae has increased
6) The coverage of submergent species have declined
7) The coverage of free-floating species has increased

Changes that have occurred since hybrid watermilfoil was introduced:

1) Increase in disturbance in the community
2) Decrease in quality of the aquatic plant community

A healthy aquatic plant community plays a vital role within the lake community. This is due to the benefits that plants provide in

1) improving water quality 2) providing valuable resources for fish and wildlife 3) resisting invasions of non-native species and 4) checking excessive growth of tolerant species that could crowd out the more sensitive species, therefore reducing the diversity.

Plant communities improve water quality in many ways: they trap nutrients, debris, and pollutants entering a water body; they absorb and break down some pollutants; they reduce erosion by damping wave action and stabilizing shorelines and lake bottoms; they remove nutrients that would otherwise be available for algae blooms (Engel 1985).

Aquatic plant communities provide important fishery and wildlife resources (Table 12). Plants (including algae) start the food chain that supports many levels of wildlife, and at the same time produce oxygen needed by animals. Plants are used as food, cover and nesting/spawning sites by a variety of wildlife and fish. Cover within the littoral zone should be about 25-85% to support a healthy fishery.

Table 12. **Wildlife Uses of Aquatic Plants in Lake Hallie**

Aquatic Plants	Fish	WaterFowl	Shore Birds	Upland Birds	Muskrat	Beaver	Deer
Submergent Plants							
Ceratophyllum demersum	F,I, C, S	F, I, C			F		
Chara sp.	F*, S	F*, I*					
Eleocharis acicularis	S	F			F		
Elodea canadensis	C, I	F, I					
Nitella sp.		F, I*					
Potamogeton amplifolius	F, I, C	F*					
Potamogeton foliosus	F, C	F*					
Potamogeton pusillus	F, C	F					
Potamogeton robbinsii	F, C	F					
Potamogeton zosteriformis	F, I, S*,C	F* (Seeds)			F*	F	F
Ranunculus longirostris	F	F		F			
Floating-leaf Plants							
Lemna minor	F	F*, I	F	F	F	F	
Spirodela polyrhiza	F	F		F			
Wolffia columbiana		F			F		

Aquatic Plants	Fish	WaterFowl	Shore Birds	Upland Birds	Muskrat	Beaver	Deer
<u>Emergent Plants</u>							
Carex comosa			F	F	F	F	F
Iris versicolor		F, C	F		F		
Myosotis spp.			F (fruits)	F (fruits)			
Rorippa nasturtium-aquatica	F*, I	F			F		F
Sagittaria sp.		F*, C		F, C	F	F	
Scirpus validus	F, C, I	F*	F	F	F		
Typha angustifolia	S, C					F	

F=Food, I= Shelters Invertebrates, a valuable food source C=Cover, S=Spawning
***=Valuable Resource in this category**

*Current knowledge as to plant use. Other plants may have uses that have not been determined.

After Fassett, N. C. 1957. A Manual of Aquatic Plants. University of Wisconsin Press. Madison, WI

Nichols, S. A. 1991. Attributes of Wisconsin Lake Plants. Wisconsin Geological and Natural History Survey. Info. Circ. #73

The plant growth in Lake Hallie provided 100% cover within the littoral zone for habitat. This amount of plant growth provides over-abundant cover and may limit fish and wildlife use.

Compared to non-vegetated lake bottoms, plant beds support larger, more diverse invertebrate populations that in turn will support larger and more diverse fish and wildlife populations (Engel 1985). Additionally, mixed stands of plants support 3-8 times as many invertebrates and fish as monocultural stands (Engel 1990). Diversity in the plant community creates more microhabitats for the preferences of more species. Plant beds of moderate density support adequate numbers of small fish without restricting the movement of predatory fish (Engel 1990).

Management Recommendations

1) Residents and Lake Association preserve and expand the natural buffer zones of native vegetation around the lake. This will benefit water quality and wildlife habitat. Replace mowed lawn at the shoreline with a buffer of natural vegetation 50 feet deep. Natural shoreline cover was abundant, but cultivated lawn occurred at half of the shoreline sites and covered one-quarter of the shore. Comparison of the littoral zones and natural sites versus developed sites indicate that disturbance at the shore may already be impacting the plant community and habitat

    a) There was greater species richness (number of species per site) at natural shore littoral zone. This would provide better diversity for more diverse fish and wildlife communities.
    b) There was more cover of submergent vegetation at natural shore littoral zone which would provide more habitat
    c) There was a higher frequency and dominance of the hybird watermilfoil at developed shoreline littoral zones and curly-leaf pondweed occurred only at developed shoreline sites. This suggest that disturbed areas provide ideal conditions for the introduction and spread of exotic species.

2) Lake Association cooperates with programs to manage run-off and erosion in the watershed.
3) Lake Association update aquatic plant management plan as scheduled to include modifications as the plant community changes.
4) Lake Association continue the mechanical harvesting program during the early season to control curly-leaf pondweed and its impacts, provide navigational access and improve fish habitat and control newly introduced hybrid watermilfoil.
    a) Early summer. The curly-leaf pondweed program should concentrate on removing curly-leaf biomass from Lake Hallie early in the summer before its die-off to reduce the nutrients that are released during the die-back and reduce the algae blooms that feed on the nutrients. Harvesting early before turion development will also reduce next year's curly-leaf crop. Curly-leaf has already declined substantially since harvesting began and water clarity and species diversity has increased.
    b) Mid and late summer: in Harvest lanes in dense plant beds to improve fish habitat by opening up cruising lanes for predatory fish. These openings improve the hunting success of the predatory fish and promote a better

balanced fishery. Harvest to open areas for boating.

c) Early summer and late summer: Develop a program to control hybrid milfoil. Much of this will be experimental since it is not clearly known if the phenology of hybrid milfoil is the same as Eurasian milfoil.
    1) Early harvesting wherever hybrid milfoil is found to set it back nutritionally. This harvesting should be conducted as soon as the milfoil reaches the surface and should be harvested as deep as possible.
    2) Determine if autofragmentation occurs in hybrid milfoil as it does in Eurasian. If so, harvest milfoil where ever it is feasible in September to remove these stems before fragmentation.
    3) Residents hand pull scattered milfoil plants in shallow water.

d) Avoid harvesting in areas with valuable habitat plants

Lake Hallie's proximity to an urban area makes it an important resource that deserves protection. These practices will protect the water quality and fish and wildlife habitat in the lake.

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Appendix . Chemical Treatments for Algae Control.

	Copper Sulfate
1972	500
1973	250
1974	400
Totals	1150