Restoring Rice Lake at Milltown, Wisconsin. No. 186 1994

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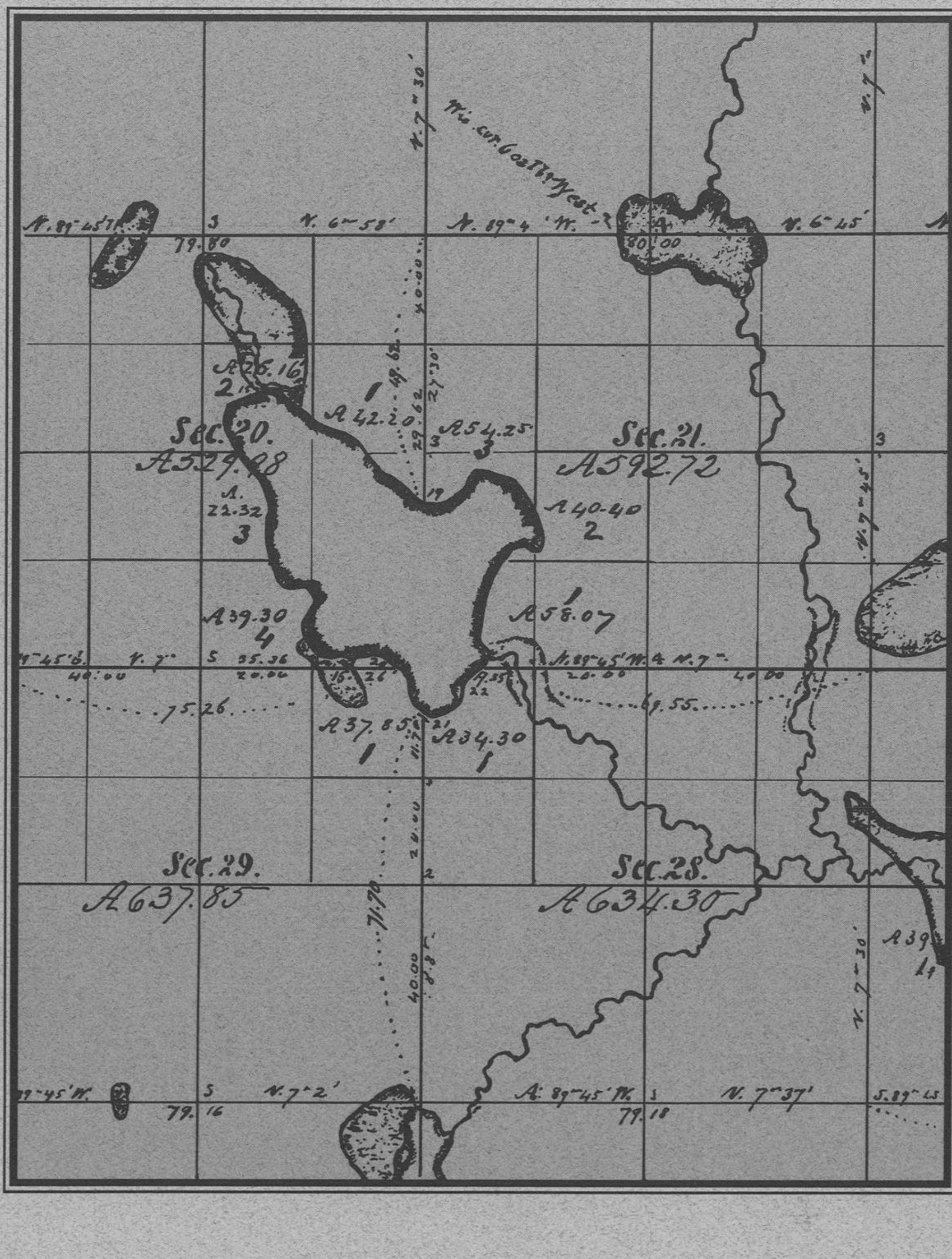
RESTORING RICE LAKE AT MILLTOWN, WISCONSIN



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Cover: An 1853 plat of the Milltown area around Rice Lake.

ABSTRACT

Wind and high water, after decades of erosion and runoff from farms and a municipal wastewater treatment plant, converted a clear lake bordered by wild rice into a turbid one dominated by phytoplankton. Rice Lake at Milltown, a 52-ha (128-acre) kettle in northwestern Wisconsin, had northern wild rice (*Zizania palustris* var. *palustris*), waterfowl, and panfish until the mid-1970s. Then the rice almost disappeared and people gave up fishing and swimming. Now wind, bullheads (*Ameiurus* spp.), and green algae (Chlorophyceae) keep the water turbid. How these changes occurred in Rice Lake was studied from August 1987 through October 1991.

Water turbidity created a depauperate macrophyte flora offshore, dominated by water lilies (*Nuphar variegatum* and *Nymphaea tuberosa*), sago pondweed (*Potamogeton pectinatus*), and floating-leaf pondweed (*P. natans*). Because Secchi disk transparency decreased each June to about 32 cm (13 inches), macrophytes had barely 4-6 weeks to sprout and float leaves before being shaded. Under such poor conditions, dry weight standing crop of all submersed macrophyte clumps averaged just 6-12 g/m^2.

Wild rice planted each fall from seed (0.5 acres in 1988; 2.0 acres in 1989) sprouted well and formed emergent shoots by July. But muskrats (*Ondatra z. zibethicus*) nipped most shoots and must be controlled for wild rice to set seed and return. Then wild rice can blunt wind that creates turbidity and can store nutrients that would otherwise wash into downstream Balsam Lake.

Sediments must also be stabilized and the lake's bullhead population must be controlled before water clarity can improve enough for wild rice to grow. This study shows how difficult habitat reconstruction can become. Only through an integrated, ecosystem approach—with water resources, fisheries, and wildlife managers working together—can such a wild rice community be restored.

Key Words: Bullheads, chlorophyll, ground water, macrophytes, Milltown, paleolimnology, phytoplankton, *Potamogeton*, Rice Lake, sago pondweed, Shallow Lakes Initiative, wastewater treatment, yellow perch, wild rice, *Zizania*.

Restoring Rice Lake at Milltown, Wisconsin

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INTRODUCTION

Wetlands across Wisconsin once covered more than 5 million acres; now more than half the wetlands are gone (Kabat 1972). Many wetland areas that have disappeared were shallow lakes that were either permanently flooded emergent wetlands (Cowardin et al. 1979) or inland deep fresh-water marshes (Type 4 of Shaw and Fredine 1956). They stored runoff water and nutrients, protected shorelines, and gave habitat to fish and wildlife (Sather and Smith 1984).

Wild rice (*Zizania*) once dominated many deep-water marshes. Nineteenth century settlers found it widespread along Wisconsin rivers, streams, and lake shores (Fannucchi et al. 1986). They learned from Chippewa (Vennum 1988) and Menominee (Jenks 1901) how to pick and store the grain. But wild rice has disappeared from many sites, especially in southern Wisconsin. Today it survives in northern Wisconsin (Niemann n.d., Andryk 1986) mainly as the slender or northern variety (*Z. palustris* var. *palustris* L.) having long edible grain.

An annual grass, wild rice grows only from seed and develops shallow roots. Rapid water-level changes from spring runoff and storms uproot the seedlings, water made turbid by erosion prevents early growth, and sustained high water from beaver dams produces spindly plants (Dore 1969, Aiken et al. 1988). Once the foliage is gone, rice seeds can fail to sprout even when sown.

Windswept lakes emerge upon loss of marsh cover such as wild rice. Without this cover, winds sweep across the lake surface with enough force to drive water against the bottom. Sediment becomes scoured, whipping organic matter and inorganic nutrients into suspension. The suspended material can lower water clarity and fuel algal blooms. Toxic materials, if present, can circulate more freely.

Such lakes support a depauperate flora. Bottom scouring destroys seeds, tubers, and root stocks banked in sediment (Foote and Kadlec 1988). Rooting becomes difficult, forcing annual plants to give way to perennial ones with deeper roots. Poor sunlight penetration favors rooted plants able to grow in weak light or spurt rapidly to the water surface. Phytoplankton ultimately dominate over rooted plants. Lake faunas also change as invertebrates in larval and resting stages die, fish eggs fail to hatch, and waterfowl food plants become scarce. These windswept lakes have low habitat diversity and poor nutrient retention.

Restoring windswept lakes to deepwater marshes requires a planned attack. The Wisconsin Department of Natural Resources (DNR) thus formed the Shallow Lakes Initiative in 1986 to:

- integrate management efforts on shallow lakes,
- increase awareness of shallow lakes as habitat,
- promote new approaches to habitat restoration,
- help form a lake classification system.

The initiative emphasizes water quality and habitat improvement (Engel 1988*b*, Engel and Nichols 1992). It encourages aquascaping—growing beds of native aquatic plants—to improve not only habitat but also nutrient retention and thus downstream water quality.

Centerpiece of the initiative is restoring Milltown's Rice Lake, a shallow lake that became windswept after losing wild rice. Another Rice Lake, in the Township of Horse Creek, with extensive wild rice was studied for comparison. The Rice Lake project combined a research and management effort to learn (1) how wind affects plant growth and water quality, (2) how the lake's water quality has changed, and (3) how such lakes can be restored. This project, lasting from 1987 through 1991, involved parallel research and management objectives:

Research objectives	**Management objectives**
• Detail summer plant growth	• Evaluate species for planting
• Evaluate limits to plant growth	• Test planting methods
• Assess past growing conditions	• Re-establish wild rice

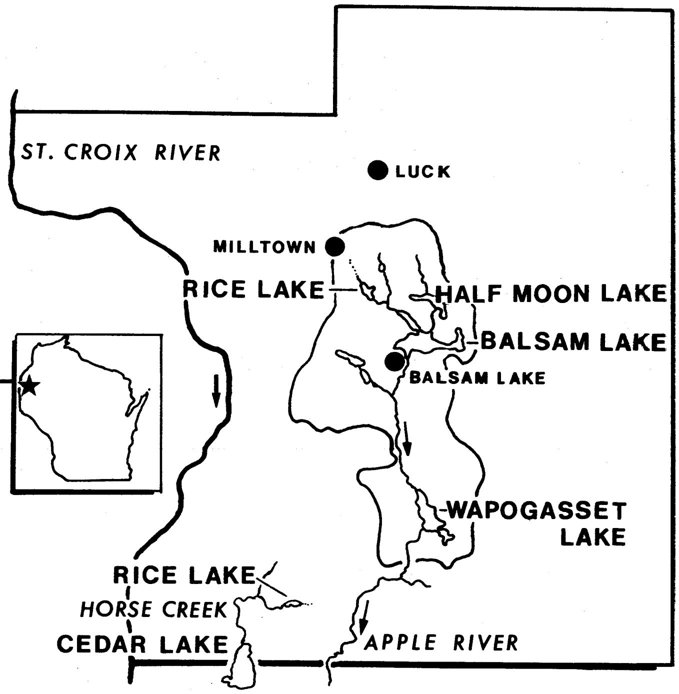


Figure 1. *The Apple River watershed in Polk County, showing each Rice Lake in relation to larger lakes and the villages of Luck, Milltown, and Balsam Lake.*

STUDY AREAS

Both Rice lakes are located in northwestern Wisconsin's Polk County, 18 km apart and less than 100 km northeast of St. Paul and Minneapolis, Minnesota (Fig. 1).[1] Each lake connects to a larger one that in turn drains south to the Apple River, a tributary of the St. Croix River that flows into the Mississippi River.

Sampling and management efforts focused on Rice Lake-Milltown. Rice production and sediment composition were also studied at Rice Lake-Horse Creek for comparison.

Both lakes are glacial, saucer-shaped depressions (Table 1). Each formed either as a simple hollow or by melting of an ice block (Types 1 and 5 of Zumberge 1952, Types 37a and 38 of Hutchinson 1957). They lie in pitted outwash or "ground moraine," formed about 11,000 years ago when the Superior Lobe of the Laurentide Ice Sheet retreated northwest (Sather and Threinen 1961). The St. Croix moraine lies about 0.6 km northwest of each lake.

The watershed of each lake consists of farms and fields, dissected by hardwoods, marshes, and a flowing creek (Table 2). Well drained soils of the Rosholt-Cromwell-Menahga series surround each lake (Kissinger 1979). Fields are steeper, woodier, and more fallow around Rice Lake-Horse Creek. Farming predominates around Rice Lake-Milltown, where the gentle slope allows for more marsh and a 16% larger watershed.

A previous study showed that water in Rice Lake-Milltown had nearly twice the total alkalinity (202 mg $CaCO_3$/L) and conductivity (373 µS/cm at 25° C or 77° F) as that in Rice Lake-Horse Creek (Sather and Threinen 1961). Rice Lake-Milltown was also more eutrophic: Total phosphorus in summer averaged about 150 µg/L in Rice Lake-Milltown, 3-5 times that of most northwestern Wisconsin lakes (Omernik et al. 1988). An ice cover develops on the lakes from about late November until mid-April and the lakes continually overturn during ice-free times.

Both lakes are surrounded by ground-water depression wetlands (Novitzki 1979), fed by ground water as well as direct precipitation and surface water. In northwestern Wisconsin such marshes are more alkaline and fertile than those receiving just precipitation and surface water (Evrard and Lillie 1987).

Table 1. *Morphometry of each Rice Lake in Polk County.**

	Rice Lake at	
Lake Measure	**Milltown**	**Horse Creek**
Area of surface (ha)	52	40
Area shallower than 1.5 m (%)	87	59
Maximum depth (m)	1.8	1.8
Mean depth (m)	0.8	0.9
Length of shore (km)	4.1	3.0
Shoreline development	1.6	1.3
Volume of water (km^3)	0.4	0.4
Volume development	1.4	1.5

* Depth soundings were made during 1989; other data came from DNR lake survey maps for November 1969 (Horse Creek) and July 1970 (Milltown).

Table 2. *Rice Lake watersheds.**

	Rice Lake at	
Land Pattern (percent of total area)	**Milltown**	**Horse Creek**
Farms and fields (%)	73	80
Lake (%)	16	13
Marshes (%)	10	2
Woods (%)	1	5
Inlet creek (%)	<0.1	<0.1
Total area (ha)	**353**	**298**

* Data were based on Sather and Threinen (1961).

[1] Measurements are given only in metric units, except for the following: temperature (reported in °C and °F), large areas (ha and acres), and weights for seeds (kg and lb.) See the metric/English conversion chart at the end of this report.

PHOTOS: SANDY ENGEL

Rice Lake-Milltown in June 1989, windswept and rice-free.

Rice Lake-Horse Creek in May 1989, placid with wild rice still dormant.

Rice Lake at Milltown

Milltown's Rice Lake (sec. 20-21 and 28-29, T. 35 N., R. 17 W.) lies at an altitude of 362 m in the civil town of Milltown, 1 km southeast of the village of Milltown. Once named Glenton Lake, it covers 52 ha (128 acres)—23% larger than Horse Creek's Rice Lake (Table 1). Nearly 75% of the lake is shallower than 0.9 m (3 ft), a depth range suitable for wild rice. Shoreline development factor (Hutchinson 1957) was greater at Rice Lake-Milltown than at Rice Lake-Horse Creek, suggesting more irregular shape and thus greater access to land runoff. A July 1970 DNR lake survey map shows a maximum depth of 3.0 m for Rice Lake-Milltown; a maximum depth of only 1.8 m was found by Sather and Threinen (1961) and by us.

Rice (Glenton) Creek arises from springs 0.9 km north of the lake, meanders 1.4 km through a marsh and tamarack grove, and enters Rice Lake-Milltown. Because of drought in 1987-89 (Reich 1989, Ross 1989), only the downstream 0.2 km of the inlet portion of Rice Creek was deep enough to be canoed. Rice Creek (upper Balsam Branch) leaves the lake larger than it entered and meanders 2.0 km southeast to Little Balsam Bay (35 ha or 86 acres), a northwest basin of Balsam Lake (769 ha or 1,900 acres). The outlet creek crosses a tamarack grove, flows by a dairy barn, joins smaller Otter Creek, and passes over a raised culvert on state highway 46.

The lake is surrounded by 26 ha (64 acres) of wetlands, including a marsh (with tamarack grove) bordering Rice Creek and much of the lake shore. Three farmers raise corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) along the east bay, where cows or horses were formerly watered. Although surrounded by private land, the lake has a public landing and a single lakeside dwelling that burned in summer 1990.

Rice Lake at Horse Creek

Horse Creek's Rice Lake (sec. 11 and 12, T. 32 N., R. 18 W.) lies at an altitude of 285 m in the civil town of Alden, where it covers 40 ha (98 acres). The banana-shaped basin is narrower and a bit more convex than Milltown's Rice Lake (Table 1). Precisely 37% of the lake water is less than 0.9 m (3 ft) deep. Sather and Threinen (1961) reported a maximum depth of 4.3 m though we found 1.8 m (6 ft), the same as shown on a November 1969 DNR lake survey map.

The lake is surrounded by 21 ha (52 acres) of marsh and tamarack grove, drained by a short inlet. The outlet creek, known as Rice Creek, flows about 1.3 km through marsh to join Horse Creek, which enters Cedar Lake (448 ha or 1,107 acres). No active farms bordered the lake during our study, but 2 homes were present on the south shore, and a site was being cleared on the north shore.

METHODS

Macrophyte Sampling

Submersed and floating-leaf plants were surveyed in Rice Lake-Milltown. Plant biomass was estimated from 156 plots on 28 August 1987 and 150 plots on 8 August 1989. Plots were randomly selected along 8 transects (Fig. 2). Plants were sampled with a steel thatching rake, 35 cm wide with 20 tines each 6 cm long. Sweeping the rake for 57 cm alongside a stationary boat removed plants from 0.2-m^2 plots. When tested on plants with long flexuous stems above soft bottoms, the rake collected biomass samples similar to diver-collected samples (S. A. Nichols, unpubl. data). Plants were bagged and iced for transport to the laboratory. They were then sorted by species, cleaned under running water, oven dried at 105° C (221° F) for 48-72 hours, and weighed (±0.01 g). Weighing roots separately gave standing crop (shoot dry weight) and biomass (shoot plus root dry weight). Standing crop was averaged for each submersed macrophyte species to give lakewide standing crop (weight for all plots) and clump standing crop (weight only for plots with that particular species). Percent standing crop expresses the percentage that each species made to the combined standing crop of all submersed macrophytes in all plots.

Plant cover was mapped using line intercepts and aerial photographs. Photographs were taken from a boat and an airplane in August of 1987 and 1989, using normal color and false-color infrared films. A hand-held camera took oblique photographs within 1.5 m of the water surface and from heights of 152 m and 305 m.

Wild rice density was estimated on 7-8 August 1989 by counting stems at the water level from 9 (Rice Lake-Milltown) or 16 (Rice Lake-Horse Creek) plots selected at random. Water depth and distance from shore were noted on a lake map as a measure of total area of rice on each lake. A mature rice plant was also collected from each of 5 sown plots on Rice Lake-Milltown. Stems, leaves, and total seeds (full, preshattered heads) were counted for each plant; roots, stems, leaves, and seeds were weighed separately after drying them at 60° C (140° F) for 6 days.

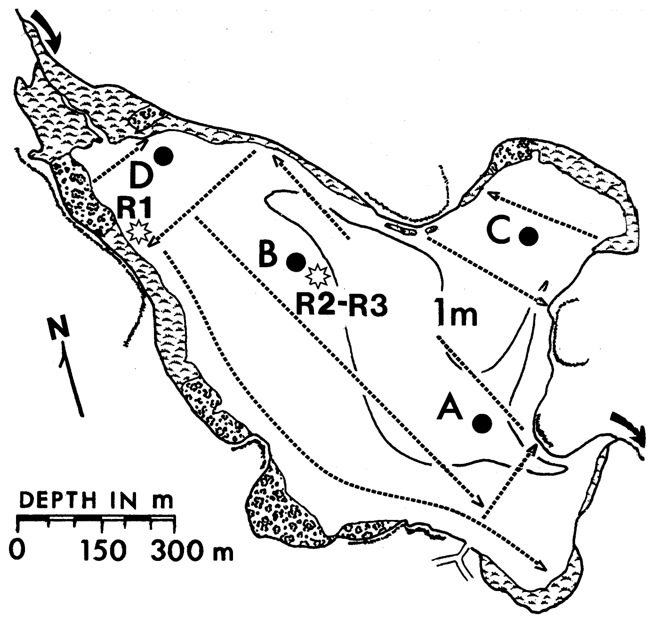


Figure 2. *Macrophyte transects (dashed lines), water and sediment chemistry stations (A-D bullets), and sediment coring sites (R1-R3 stars) in Rice Lake-Milltown.*

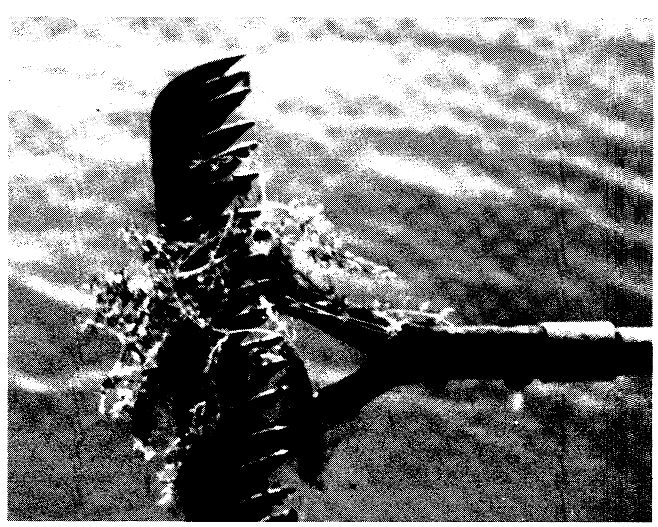


PHOTO: SANDY ENGEL

The steel thatching rake with a clump of coontail planted 2 months earlier in Rice Lake-Milltown.

Each part was analyzed for nutrients and metal content by the University of Wisconsin-Extension Soil and Plant Analysis Laboratory, Madison. Yield and nutrient content of whole plants, shoots, and seeds could then be calculated.

Air and Water Measurements

Wind, cloud cover, and the temperature, clarity, chemistry, and phytoplankton of water were measured at Rice Lake-Horse Creek on 9 May 1989 and at Rice Lake-Milltown every 2-8 weeks from August 1987 through October 1989. The measurements (Tables 3, 4) were repeated at 3 stations on each lake, and at inlet and outlet culverts for Rice Lake-Milltown. The culverts are about 0.9 km northwest (210th Street) and southeast (155th Street) of Rice Lake-Milltown.

Wind speed and direction were measured with a Dwyer anemometer and compass. Temperature was measured with a glass-bulb thermometer at a water depth of 0.2 m. pH was measured at lakeside with a battery-operated meter ($\pm$0.1 units) and at the laboratory with an electric meter ($\pm$0.02 units). Water transparency was observed with a Secchi disk from the shaded side of a boat. Cloud cover, dissolved (true) color of centrifuged samples, total and suspended solids, and water turbidity of suspended samples (American Public Health Association et al. 1985) also provided information on water clarity.

Water chemistry samples were taken with an opaque Kemmerer sampler at middepth (0.4-0.6 m) from each station. Samples were chilled to about 4° C (40° F) with ice upon collection. Total phosphorus and nitrogen samples were fixed with sulfuric acid; those for metals were fixed with nitric acid. Unpreserved samples were analyzed within 24 hours of collection.

Dissolved oxygen concentrations were measured beneath lake ice at Milltown on 21 February 1989. At 13 sites across the lake, ice holes were bored with an electric drill to a diameter of 22 mm. Each hole was opened carefully to avoid mixing the underlying water column. A peristaltic pump drew water from middepth through a hose with a *T*-shaped intake. Water was collected in glass-stoppered bottles (200-ml capacity) allowed to overflow 2-3 times. Each water sample was fixed immediately with chemical reagents and kept chilled until analyzed within 24 hours by the azide-modified Winkler method (American Public Health Association et al. 1985). Water temperature was also measured at each station to calculate solubility of dissolved oxygen, expressed as a percentage of that found in saturated water at 4° C (40° F) and 760 mm Hg pressure (Hutchinson 1957).

Phytoplankton Analyses

Phytoplankton were analyzed from Rice Lake-Milltown to assess changes in water turbidity. Two phytoplankton samples were collected with an opaque Kemmerer sampler from middepth at Stations A, B, and C. One sample was field preserved with 2-3% *v/v* acid Lugol's solution to estimate cell counts and volumes; the other sample was kept on ice in a dark cooler for 1-3 hours until chlorophyll concentrations were measured.

Chlorophyll *a* was measured with a spectrophotometer (8-nm slit width, 10-mm path length), after filtering each sample through a Gelman GA-6 membrane (0.45-µm mesh), pulverizing the cells with an electric tissue grinder, and extracting the pigments in 90% *v/v* acetone. Pigment absorption was measured at 630 nm, 645 nm, and 663 nm before acidification (trichromatic chlorophyll *a*) and at 665 nm after acidification with 0.1N HCl (monochromatic chlorophyll *a*). Chlorophyll was calculated with the SCOR/UNESCO equations (Sournia 1978), after subtracting absorption at 750 nm to correct for turbidity.

Phytoplankton were identified (Smith 1950) and counted by the Utermöhl method (Sournia 1978) from samples settled for 24 hours onto combined plate chambers and examined with a phase-contrast inverted microscope at total magnifications of 140x, 560x, and 1400x. Colonies were counted by cell number; cell volumes were estimated by fitting mean cell size to volume formulas (Rott 1981).

Sediment Texture and Chemical Analyses

Sediment in each Rice Lake was collected with an Ekman grab (15 cm by 15 cm by 15 cm) and analyzed for texture and chemical composition, mostly following methods in Black et al. (1965). Samples were collected from 3 offshore stations on each lake, plus 8 stations upstream and 6 stations downstream from Rice Lake-Milltown. At each station 2-3 nearby grabs were combined. Samples for nutrient and metal concentrations (Table 4) were collected along Rice Creek and Rice Lake-Milltown on 28-29 June 1989. Those for sediment moisture, solids, organic matter, and texture (Table 5) were collected from Rice Lake-Milltown on 15 June 1989 and from Rice Lake-Horse Creek on 12 September 1989.

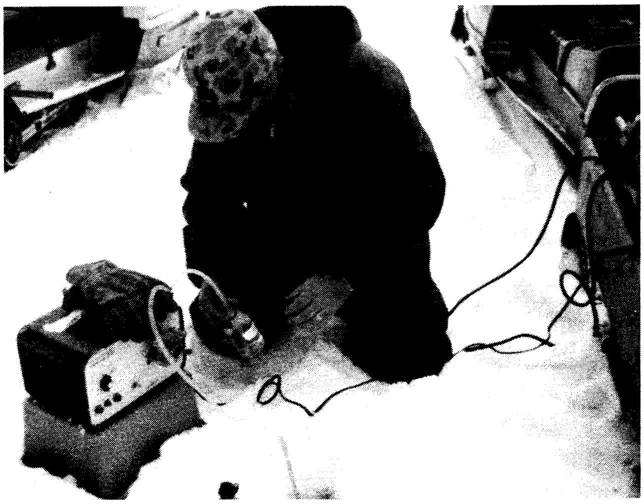


PHOTO: SANDY ENGEL

Gerald D. Wegner pumping water through a hole drilled in Rice Lake-Milltown ice to measure dissolved oxygen.

Table 3. *Physical methods used to analyze lake water and measure wind.**

Physical Measure	Method**
At lake	
Air and water temperature	Glass-bulb thermometer
pH (Oct 1987-May 1989)	Beckman model Phi-21 pH meter (±0.1 units)
Water transparency	Secchi disk: black-white, 20-cm diameter
Wind speed and direction	Dwyer anemometer (±2 miles/hour) & compass
At laboratory	
pH (Oct 1987-Oct 1989)	Orion model SA520 meter with Ross electrode
Dissolved (true) color	Color comparator, after centrifugation
Specific conductance	Wheatstone bridge, corrected to 25 C (77° F)
Suspended and total solids	Residue weight after evaporation at 103-105° C (217-221° F)
Water turbidity	Nephelometric analysis of sample suspension

* Definition of terms and methods follow Welch (1948).
** Reference to products or company names does not constitute an endorsement by the authors or their employers.

Table 4. *Chemical methods used to analyze lake water and sediment.**

Chemical measure	Method**
Alkalinity, total	Titration to pH 4.5 with 0.02 N sulfuric acid
Chloride	Automatic ferric cyanide
Hardness, total	Total hardness = 2.497 (mg Ca/L) + 4.118 (mg Mg/L)
Metals:	
As Hg Se	Atomic absorption: hydride generation (As), cold vapor (Hg), or graphite furnace (Se)
B Ba Cd Cr Cu Ph Ni Zn	Atomic absorption after acid digestion
Ca Fe K Mg Na	ICP emission spectroscopy
Nitrogen:	
Dissolved NH_4	Automated colorimetric phenate
Dissolved $NO_2 + NO_3$	Automated colorimetric cadmium reduction
Total Kjeldahl N	Semi-automated block digestion
Oxygen, dissolved	Azide-modified Winkler titration
Phosphorus:	
Dissolved reactive	Automated ascorbic acid molybdate
Total (<200 μg P/L)	Persulfate-digestion automated ascorbate
Total (>200 μg P/L)	Semi-automated block digestion
Polychlorinated biphenyl	Gas chromatography after Soxhlet extraction and magnesium silicate (Florisil) adsorption
Silica, dissolved	Automated colorimetric molybdate
Sulfate	Automated methyl thymol blue

* Most analyses were completed at the State Laboratory of Hygiene, Madison, Wisconsin, and described in U. S. Environmental Protection Agency (1983).
** Automated methods refer to the Technicon Autoanalyzer II system.

Table 5. *Methods used to analyze sediment collected with an Ekman grab from each Rice Lake in 1989.**

Soil Measure	Method
Moisture	Wet weight minus oven dry weight
Solids	Oven drying for 9 days at 55° C (131° F)
Organic matter	Walkley-Black method (Jackson 1958): dichromate digestion; titration with 0.5 N ferrous solution
Ash	Oven dry weight minus loss-on-ignition, after driving off volatile solids for 4 hours at 550° C (1,022° F)
Sand, silt, clay**	ASTM hydrometer of 50-g ashed sample

* Samples were analyzed at the University of Wisconsin-Extension, Department of Soil Science, Soil and Plant Analysis Laboratory, Madison.
** Samples were ashed before measuring sand, silt, and clay.

Metal and polychlorinated biphenyl (PCB) concentrations in Rice Lake-Milltown were analyzed from sediment cored with a Jenkin surface mud sampler (Macan 1970). Three stations (A, C, and D) (Fig. 2) were cored on 20 September 1988 to a depth of 15 cm; a fourth station (B) was cored to 45 cm and cut into top (0-15 cm), middle (15-30 cm), and bottom (30-45 cm) sections. Heavy metals were analyzed by atomic absorption; other metals, by inductively coupled plasma (ICP) emission spectroscopy; and PCB, by gas chromatography after Soxhlet extraction (American Public Health Association et al. 1985) followed by magnesium silicate (Florisil) adsorption (Table 4).

Fish and Bottom Fauna Surveys

Fish were caught in Rice Lake-Milltown by electrofishing and fyke netting. Electrofishing was conducted from a 4.7-m boat motored along shore between 5:15 and 7:55 p.m. (central daylight time) on 23 May 1988. A field of alternating current (ac) was produced ahead of the boat by a generator with a variable transformer adjustable to 210-230 V and 6-9 a; stunned fish were caught with dip nets of 6.4-mm bar mesh. Fyke netting was conducted with 8 nets set perpendicular to shore on 21-23 May 1990. Each net was lifted on the second and third days, for a total of 16 net sets. The one-tunnel nets measured 1.2 m by 1.6 m, had 23-m leads to shore, and were made of nylon with 12.7-mm bar mesh.

Water temperature inshore was 24° C (75° F) during electrofishing and 14-24° C (57-75° F) during fyke netting. Secchi disk transparency at Station B reached 33 cm during electrofishing and 58 cm during fyke netting. Specific conductance offshore stayed 180-200 µS/cm at 25° C (77° F) during electrofishing and fyke netting.

Body weight (±1 g) and scale samples were taken from most fish with scales. All fish were released after measuring total length (±1 mm) and clipping their upper caudal fin to keep from recounting them in the next day's catch. Condition factor (K_{TL}) was calculated from total length and weight, assuming a regression coefficient of 3.0 (Lagler 1956). Scales of electrofished pumpkinseed and yellow perch were impressed onto cellulose acetate slides and magnified on a microprojector to determine age (Ambrose 1983). Age at capture was defined as the number of summers' growth completed.

Macroscopic invertebrates living on the bottom of Rice Lake-Milltown were sampled on 8 March 1988, when lake ice (51-53 cm thick) was free of snow. Four Ekman grabs (15 cm by 15 cm by 15 cm) were taken each at Stations A and B (67 cm below ice cover) and 4 inshore sites (14-29 cm below ice cover). Sampled invertebrates were washed over a no. 60 (250-µm) mesh soil sieve and preserved in 70% *v/v* ethanol. A dissecting microscope was used to identify and count the invertebrates to family or genus, based on keys in Merritt and Cummins (1984).

Tracing Milltown's Past

Previous writings, sediment cores (Winkler 1989), aerial photographs, and especially interviews helped trace the history of land clearing, farming, and village growth around Rice Lake-Milltown.

Written evidence of Milltown's past came from a June 1853 plat of Milltown by the U. S. General Land Office (filed at the State Commission of Public Lands, Madison) and surveys on wetlands (Bordner et al. 1939), water resources (Sather and Threinen 1961), soils (Kissinger 1979), and Milltown's secondary wastewater treatment plant (Prusak and Franson 1987). Village of Milltown's plans to build wastewater treatment plants and extend water and sewer mains were examined; this information was taken from 26 DNR microfilm files kept at the Bureau of Wastewater Management in Madison, Wisconsin (original paper files remain at the DNR office in Cumberland, Wisconsin). Village and town growth was traced from published accounts (Inter-County Star-Leader 1954, Ericson 1980, Anonymous 1985), unpublished files in the Milltown Public Library, and 10-year census records (U. S. Bur. Census 1870-1990). A 4-page letter from a Balsam Lake resident outlined water quality changes since about 1966 in Rice Lake-Milltown, Rice Creek, and Little Balsam Bay (Harvey H. Ebert, letter to DNR, 10 June 1987, on file at DNR Bureau of Water Resources Lake Management Section, "Balsam Lake" file).

Pollen and algal stratigraphy were analyzed by Winkler (1989); phaeo-pigments were analyzed by Garrison (unpubl. data). Sediment cores near Station B (Fig. 2) were taken with a Peterson corer (Wentz 1967) to a depth of 66 cm (R2 core) and a Jenkin surface mud sampler

PHOTO: SANDY ENGEL

Steven M. Ward (left) and Patrick (Jerry) J. Perkins electrofishing in Rice Lake-Milltown.

(Macan 1970) to a depth of 20 cm (R3 core). The Peterson corer consisted of a Plexiglass tube (inside diameter 88 mm) and a hand-driven piston made from twin stoppers; the Jenkin sampler, designed to reduce sediment mixing during sampling, consisted of a 4-legged stand holding a plexiglass tube (inside diameter 66 mm) that was capped at each end by a messenger-triggered closing mechanism. Both cores were sectioned every 2 cm—the Peterson core to a depth of 56 cm, plus a final section at 62-66 cm—and the sections were refrigerated until analyzed. Samples from 6 sections of the Peterson core and 5 sections of the Jenkin sampler were analyzed for phaeophytins and phaeophorbides (phaeo-pigments of Strickland and Parsons 1972), by extracting them in 90% *v/v* acetone and measuring absorption with a spectrophotometer at 665 nm, 750 nm, and 850 nm (Vallentyne 1955).

Samples from all 18 sections of the Peterson core were analyzed for moisture, organic matter, and pollen grains from upland and wetland plants, algal cells, dinoflagellate cysts, *Pediastrum* coenobia (cell walls fused into colonies), pyrite framboids (opaque ferrous disulfide spheres), and charcoal (Winkler 1989). Organic matter was determined from loss-on-ignition by drying 5-ml samples overnight at 63° C (145° F), ashing them for 3 hours at 450-500° C (842-932° F), and ashing them again for 3 hours at 925° C (1,697° F) to expose siliceous sedge fibers.

Pollen grains were counted in sediment core samples treated chemically to concentrate the grains, mostly following procedures in Faegri and Iversen (1975). The grains were extracted by successive treatment with hot hydrochloric acid (removed sand and quartz), potassium hydroxide (removed humic acids), acetolysis with sulfuric acid and acetic anhydride (etched pollen grains to reveal surface sculpturing), and dehydration in tertiary butyl alcohol (dehydrated the acidified grains). Samples were stored in vials of silicone oil, until spread evenly on microscope slides for counting under a total magnification of 450x. Three *Eucalyptus* tablets, rated at 16,180 grains/tablet (90,080 grains/cm^3), were added to each sample as marker grains to assess pollen concentration.

Aerial photographs of Alden and Milltown townships were examined for aquatic macrophyte growth and land use changes since 1938. Black-and-white photographs of both townships were examined for August 1938, July 1951, May 1958, September 1965, October 1973, and October 1975 and of just Milltown for May 1947, October 1948, October 1952, May 1974, August 1978, October 1980, and May 1988. The photographs, scaled from 1:15,820 to 60,000 inches, were from U. S. Departments of Agriculture or Interior surveys (most on file at Univ. Wis. Madison Arthur H. Robinson Map Library, Science Hall).

Farmers around Rice Lake-Milltown (Gale G. Glenna, Arnold J. Herwick, Clifford L. Ince, Franklin [Red] G. McCurdy, Lloyd Reed, Duane S. Roufs, and La Verne H. Van Gundy) and Milltown's former (Ronald H. Weichelt) and present (Richard C. Fisher) wastewater treatment plant operators were interviewed about past water-quality conditions in Rice Lake and local land use.

Ground-water, Streamflow, and Precipitation Records

Ground-water levels at a well in Milltown Village, 1.5 km from Rice Lake-Milltown (SW 1/4 SW 1/4 sec. 8, T. 35 N., R. 17 W.) were measured by the U. S. Geological Survey (Rose 1993). Sunk 15.8 m deep, the well penetrates a sand and gravel aquifer in unconsolidated glacial drift. Water levels, measured 3-13 times yearly in 1958-90, were corrected to height above mean sea level.

Stream flows at the inlet and outlet culverts of Rice Lake-Milltown (at 210th and 155th streets) were measured after November 1987 by the U. S. Geological Survey to compute water and phosphorus budgets for Balsam Lake (Rose 1993). A staff gage was installed at the outlet culvert and referenced to a continuous-flow gaging station, 1.6 km downstream at state highway 46.

Annual total precipitation was recorded by the U. S. Department of Commerce at Amery and St. Croix Falls, where the closest weather stations to Rice Lake-Milltown were found with records dating at least to 1958. The stations were located within 16 km of the Milltown well and 14 km of Rice Lake-Milltown. Measurements from the 2 stations were averaged to reduce station variability.

Macrophyte Planting

Eight species were planted in Rice Lake-Milltown (Table 6, Fig. 3). Northern wild rice was sown on 9 September 1988 with 12.5 kg (27.5 lb) of seeds picked the day before from Rice Lake-Horse Creek and

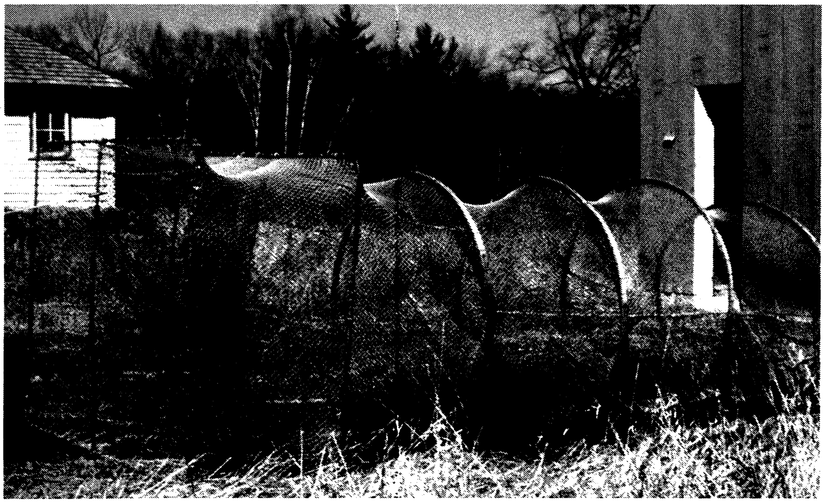


PHOTO: PATRICK J. PERKINS

A one-tunnel fyke net like the 8 used to catch fish in Rice Lake-Milltown.

again on 18 September 1989 with 45.4 kg (100 lb) of seeds purchased from Kester's Wild Game Food Nurseries, Omro, Wisconsin. The seeds, averaging 15,012 seeds/kg in 1988 and 16,348 seeds/kg in 1989, were sown by hand from a boat. In 1988 5 plots (19 m by 22 m) received 2.3 kg (5 lb) of seeds apiece; a sixth plot beside the boat landing (3 m by 5 m) was sown with a few handfuls of seeds (Fig. 3). In 1989 a new plot by the inlet (150 m by 54 m) and one by the outlet (180 m by 45 m) each got 27.7 kg (50 lb) of seeds. On each date sown, the percentage of seeds failing to sink was estimated by floating 1,000 seeds in a beaker of water.

Root stocks or tubers of giant bur-reed, marsh smartweed, Richardson pondweed, sago pondweed, and wild celery were purchased from Lemberger's Wildlife Nurseries, Oshkosh, Wisconsin, and planted in Rice Lake-Milltown on 24 May 1989. Shoots of coontail from Beckman Lake, Green County, and elodea from Halverson Lake, Iowa County, were planted on 14 June 1989. A nail held by rubber band helped sink each plant part. The weighted plants were distributed equally among 2-4 plots, each 50 m by 20 m (1,000 m^2); several adjacent control plots remained unplanted. Emersed species were planted along shore in knee-deep water; submersed ones were planted offshore in water 0.5-1.0 m deep (Fig. 3).

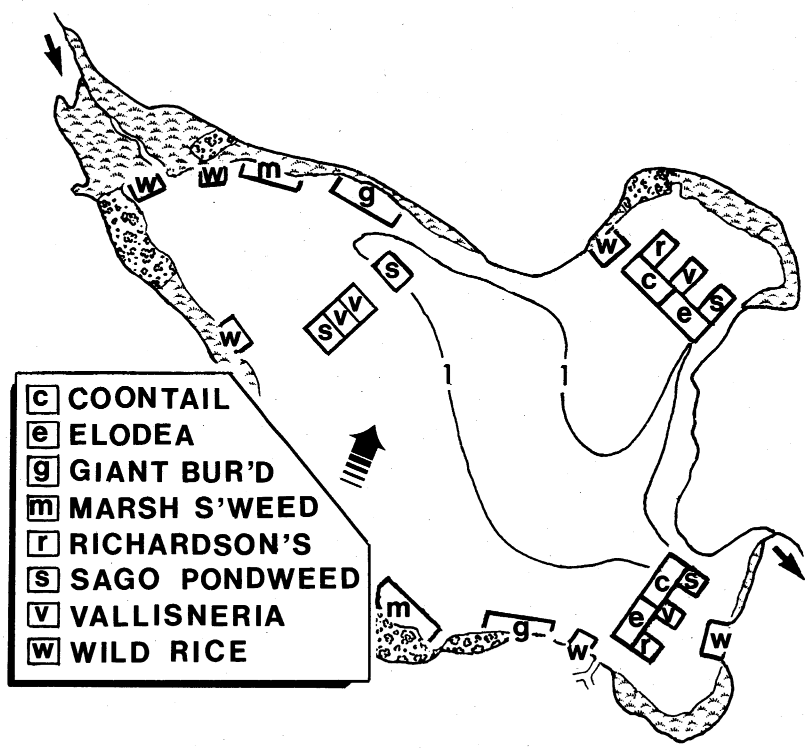


Figure 3. *Plots (drawn enlarged) in Rice Lake-Milltown planted with wild rice in September 1988 or with other macrophytes in May and June 1989. The large arrow shows prevailing summer winds from the southwest.*

Several root stocks, tubers, or shoot bundles of each species were planted in aquaria to test if the plants were viable and could sprout on sediment from Rice Lake-Milltown. Two aquaria contained sediment from Rice Lake-Horse Creek, gathered beneath macrophyte beds and thus able to support macrophyte growth; 2 others contained sediment from Rice Lake-Milltown, gathered from sites we planted. Each all-glass aquarium held about 7 cm of sediment, covered with 70 L (18 gal) of aerated distilled water to a depth of 30 cm (12 inches). The water was kept at 20C (68F) and illuminated daily for 14 hours to simulate June growing conditions in clear lakes. Growth was observed weekly for 3 months, starting a few days after buying or collecting the plants.

Table 6. *Macrophytes planted or sown in Rice Lake-Milltown during 1988-89.*

Text Name	Scientific Name*	Propagules Planted
Emersed plants		
Giant bur-reed	*Sparganium eurycarpum* Engelmann	500 root stocks
Marsh smartweed	*Polygonum amphibium* var. *emersum* Michaux**	500 root stocks
Northern wild rice	*Zizania p.* var. *palustris* L.	12 kg seed (1988)
		45 kg seed (1989)
Submersed plants		
Coontail	*Ceratophyllum demersum* L.	300 shoot bundles
Elodea	*Elodea canadensis* Michaux	500 shoot bundles
Richardson pondweed	*Potamogeton richardsonii* (Benn.) Ryb d.	500 root stocks
Sago pondweed	*Potamogeton pectinatus* L.	1,000 tubers
Wild celery	*Vallisneria americana* Michaux	1,000 tubers

* Spellings of scientific names followed Aiken et al. (1988) for wild rice and Voss (1972, 1985) for the other species.
** Marsh smartweed was bought from nursery stock labeled *"Polygonum muhlenbergii."*

Stanley A. Nichols gathering wild rice seed from Rice Lake-Horse Creek on 5 September 1988.

Stanley A. Nichols sowing wild rice by the inlet on Rice Lake-Milltown.

PHOTOS: SANDY ENGEL

Results and Discussion

Our path to re-establishing wild rice begins with each Rice Lake today: how unplanted macrophytes grow and how wind and turbidity limit this growth. Next, land use changes and how Rice Lake-Milltown lost its wild rice bed are discussed. Finally, the results of planting wild rice and other macrophyte species are discussed.

Recent Macrophyte Growth

Both lakes contained a community of 3 overlapping macrophyte zones: emersed, floating-leaf, and submersed species (Fig. 4). Emersed plants formed a marsh that bordered much of the creek banks and lake shores. At Rice Lake-Milltown the marsh grew onto the water surface and broke loose in spring as floating islands. At Rice Lake-Horse Creek the marsh extended offshore as wild rice, broadly overlapping with water lilies (Nymphaeaceae) to a water depth of about 0.9 m. Submersed plants in both lakes grew beneath water lilies and extended in patches across open water.

Twenty-five macrophyte species were found in Rice Lake-Milltown; 21 species, in Rice Lake-Horse Creek (Table 7). The marsh border held twice as many species at Milltown (14 species) as at Horse Creek (7 species). Cattails dominated the marsh border at Milltown; wild rice, at Horse Creek. Sedges, marsh fern, arrowheads, and swamp dock were among common species forming a floating mat by Milltown's lake shore. The floating-leaf zone (4-5 species) was similar in both lakes and dominated by water lilies. The submersed zone, however, was less diverse at Milltown (6 species) than at Horse Creek (10 species). Sago pondweed dominated the zone at Milltown; chara, at Horse Creek. Flatter topography and greater collecting effort account for more emersed species found in Milltown's broader marsh border; shelter from wind and greater water clarity produced Horse Creek's richer submersed flora.

Although many of the lake's plant species varied in abundance between summers, only floating-leaf pondweed and water crowfoot in Rice Lake-Milltown were not found in 1987. Floating-leaf pondweed grew between transects and thus was missed by sampling; water crowfoot was not found at all until 1989.

Total macrophyte cover remained unchanged between summers but differed between lakes (Table 8). Open water offshore from water lily or wild rice beds constituted

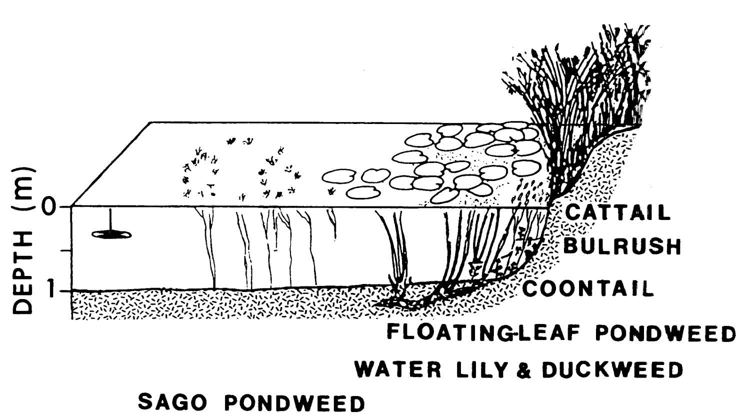


Figure 4. *Plant zonation in Rice Lake-Milltown for 28 August 1987, picturing sago pondweed rings and a Secchi disk disappearing at 30 cm or 12 inches (Engel 1988b).*

Table 7. *Macrophyte species found in 1987-91 and judged abundant (A), common (C), or scarce (S); those not seen (-) could still have been present.**

Text Name	Scientific Name**	Abundance in Rice Lake: Milltown	Abundance in Rice Lake: Horse Creek
Emersed macrophytes		**14**	**7**
Arrowhead, common	*Sagittaria latifolia* Willd.	C	S
Arrowhead, rigid	*Sagittaria rigida* Michaux	S	S
Bulrush, softstem	*Scirpus validus* Vahl	C	C
Bur-reed, giant	*Sparganium eurycarpum* Engelm.	C	–
Cattail, common	*Typha latifolia* L.	A	C
Cattail, narrow-leaf	*Typha angustifolia* L.	C	S
Dock, swamp	*Rumex verticillatus* L.	C	–
Fern, marsh	*Thelypteris palustris* Schott	C	–
Horsetail	*Equisetum fluviatile* L.	C	–
Marigold, marsh	*Caltha palustris* L.	C	–
Sedge, carex	*Carex* sp.	C	–
Sedge, cyperus	*Cyperus strigosus* L.	–	S
Spikerush, tall	*Eleocharis* sp.	C	–
Water arum	*Calla palustris* L.	C	–
Wild rice, northern	*Zizania p.* var. *palustris* L.	S	A
Floating and floating-leaf macrophytes		**5**	**4**
American lotus	*Nelumbo lutea* (Willd.) Pers.	–	S
Duckweed, lesser	*Lemna minor* L.	C	S
Watermeal	*Wolffia columbiana* Karsten	S	–
Water lily, yellow	*Nuphar variegatum* Durand	A	C
Water lily, white	*Nymphaea tuberosa* Paine	A	C
Water shield	*Brasenia schreberi* J. F. Gmelin	S	–
Submersed macrophytes		**6**	**10**
Chara	*Chara* sp.	–	A
Coontail	*Ceratophyllum demersum* L.	C	C
Elodea	*Elodea canadensis* Michaux	S	C
Pondweed, floating-leaf	*Potamogeton natans* L.	C	C
Naiad, slender	*Najas flexilis* (Willd.) Rostk. & Schmidt	R	C
Nitella	*Nitella* sp.	–	S
Pondweed, large-leaf	*Potamogeton amplifolius* Tuckerm.	–	S
Pondweed, flatstem	*Potamogeton zosteriformis* Fern.	–	C
Pondweed, sago	*Potamogeton pectinatus* L.	C	–
Pondweed, whitestem	*Potamogeton praelongus* Wulf.	–	C
Water crowfoot	*Ranunculus longirostris* Godron	C	–
Wild celery	*Vallisneria americana* Michaux	–	S

* **Boldface** numbers are species counts by plant zone.
** Species were identified from Fassett (1966) or Voss (1972, 1985), who list northern wild rice as *Z. aquatica* var. *angustifolia* Hitchc.

Cattails dominated the marsh bordering Rice Lake-Milltown and its navigable inlet (background) in May 1988.

Wild rice covered 47% of combined lake and marsh border on Rice Lake-Horse Creek in September 1988.

PHOTOS: SANDY ENGEL

61% of combined lake and marsh border in Rice Lake-Milltown, 32% in Rice Lake-Horse Creek. Despite being one-fourth smaller in area, Rice Lake-Horse Creek had a larger macrophyte cover (33 ha or 81 acres) than did Rice Lake-Milltown (26 ha or 64 acres). The lake and marsh border at Horse Creek were nearly half covered with wild rice, which had been scarce at Milltown since at least 1985 (Andryk 1986).

Macrophytes in Rice Lake-Milltown formed clumps or discrete stands that varied across the lake (Fig. 5). Speckled alder (*Alnus rugosa* [Du Roi] Sprengel) and cattails nearly encircled the lake; bulrushes formed a few stands along the sandy east shore in water too deep for cattails; water lilies formed larger beds along the west shore and by the inlet and outlet. Beneath the water surface, coontail and some elodea congregated by the inlet; sago pondweed dotted the bottom offshore to a depth of 1.1 m.

Standing crop of submersed macrophytes in Rice Lake-Milltown stayed low even during peak biomass in August (Table 9). Sago pondweed constituted 84% (1987) and 92% (1989) of total standing crop among submersed species. Standing crop of all species combined or sago pondweed alone differed little ($P > 0.05$) between years, whether all plots (lakewide) or just those with plants (clump) were compared. Only coontail and floating-leaf pondweed seemed to change abundance between years, but they were not adequately sampled because of limited distribution.

Frequency of occurrence however increased from 1987 to 1989 for every submersed species except coontail (Table 10). The number of sampling plots with any species rose by 13%; those with sago pondweed rose by 14%.

Patchy growth produced areas of high and low standing crop and thus differences between transects (Fig. 6). In both summers few sago pondweeds grew by the inlet (transect 1) or east bay (transect 5) because of shading by water lilies. From 1987 to 1989 pondweed growth increased along west and south shores (transects 3 and 4) but decreased offshore (transects 7 and 8). Floating-leaf pondweed also grew in widely scattered clumps and increased along the west shore in 1989.

Table 8. *Area covered by macrophyte beds in each Rice Lake during summer 1987, expressed as percent of combined lake and marsh border area.*

	Area on Rice Lake at	
Habitat	**Milltown**	**Horse Creek**
Marsh border (%)	21	20
Water lilies (%)	18	—*
Wild rice (%)	tr	47
Open water (%)	61	32
Combined area of lake and marsh border (ha)**	**66**	**50**

* Not measured.

** This combined area was calculated by planimetry from DNR lake survey maps for November 1969 (Horse Creek) and July 1970 (Milltown).

Present Limits to Growth

Wind and Turbidity

Shall I compare thee to a summer's day?
Thou art more lovely and more temperate:
Rough winds do shake the darling buds of May,
And summer's lease hath all too short a date.

- William Shakespeare, Sonnet 18

Wind fetch—the maximum distance wind could sweep in any direction across open water unhindered by shoreline or macrophyte cover—varied seasonally on each Rice Lake (Table 11). Wind fetch was longest after ice-out in April, when macrophytes were just sprouting. By August, wind fetch had diminished by 52% on Rice Lake-Horse Creek but only by 17% on Rice Lake-Milltown. The marsh border blunted wind on both lakes, but summer emergence of wild rice made Rice Lake-Horse Creek much calmer. Rice Lake-Milltown thus remained more exposed to wind than Rice Lake-Horse Creek because of larger area and greater fetch.

Southwest winds prevailed in summer over Rice Lake-Milltown (Fig. 3), but northwest breezes were almost as common and swept a longer path over the lake. The lake's northwest-southeast long axis and flat watershed thus enhanced lake exposure, increasing wind-generated turbidity and bottom scouring. Such exposure can reduce sago pondweed standing crop by depressing photosynthesis (Kantrud 1990) and shifting growth from shoots to roots, rhizomes, and tubers (Kautsky 1987).

Water clarity decreased after ice-out as dissolved color and suspended particles increased (Table 12). From winter to summer, mean Secchi disk transparency decreased 5 fold, while turbidity increased 23 fold. Dissolved color increased 3 fold, probably from plant leachates entering the water from Rice Creek, the marsh border, and suspended sediment. Mean suspended solids increased 30 fold, mainly because of suspended sediment and phytoplankton. These values usually differed little between Stations A, B, and C.

These changes reduced overall water quality at Rice Lake-Milltown. Carlson's (1977) trophic state index increased about 1.5 fold after winter, reaching means of 75-81 whether based on Secchi disk transparency, chlorophyll *a*, or total phosphorus concentration.

Decrease in water clarity owed more to buildup of phytoplankton than of dissolved color (Table 12). Chlorophyll *a* increased about 14 fold after ice-out. Trichromatic chlorophyll *a* in Rice Lake-Horse Creek, measured only in May and August 1989, stayed 60-90% lower (3-20 μg/L) than in Rice Lake-Milltown.

Water clarity at Station B changed less during summer than between summer and winter. During summer, Secchi disk transparency ranged from 20-30 cm, water turbidity from 20-40 NTU, dissolved color from 30-70 Co-Pt units, and suspended solids from 36-88 mg/L.

Table 9. *Standing crop (mean ± 1 SE) of submersed macrophytes sampled in Rice Lake-Milltown.*

Plant Species	Standing Crop	
	28 August 1987	8 August 1989
Lakewide standing crop (all plots)		
All submersed species (g/m²)	6 ± 1.5	11 ± 7
Sago pondweed (g/m²)	5 ± 1.4	10 ± 7
Coontail (g/m²)	1 ± 0.7	tr
Floating-leaf pondweed (g/m²)	0	1 ± 1.1
Clump standing crop (plots with plants only)		
All submersed species (g/m²)	28 ± 6	31 ± 13
Sago pondweed (g/m²)	37 ± 8	35 ± 15
Coontail (g/m²)	13 ± 4	1 ± tr
Floating-leaf pondweed (g/m²)	0	31 ± 16
Number of plots		
Without submersed macrophytes	125	99
With submersed macrophytes	31	51

Table 10. *Number and percentage of plots with submersed macrophytes sampled in Rice Lake-Milltown.**

Plant Species	Number (%) of Sample Plots	
	28 August 1987	8 August 1989
Lakeside frequency (all plots)		
Plots sampled	156 (100)	150 (100)
Any submersed macrophyte	31 (20)	51 (33)
Sago pondweed	20 (13)	42 (27)
Coontail	11 (7)	11 (7)
Floating-leaf pondweed	0	4 (3)
Water crowfoot	0	1 (<1)
Clump frequency (plots with plants only)		
Plots sampled	31 (100)	51 (100)
Sago pondweed	(65)	(82)
Coontail	(35)	(22)
Floating-leaf pondweed	(0)	(8)
Water crowfoot	(0)	(2)

* Frequency of occurrence is the number (or percentage) of sampling plots with submersed macrophytes, considering all plots or just those with submersed macrophytes. Because of species overlap, frequency of occurrence for plots with plants need not add to 100%.

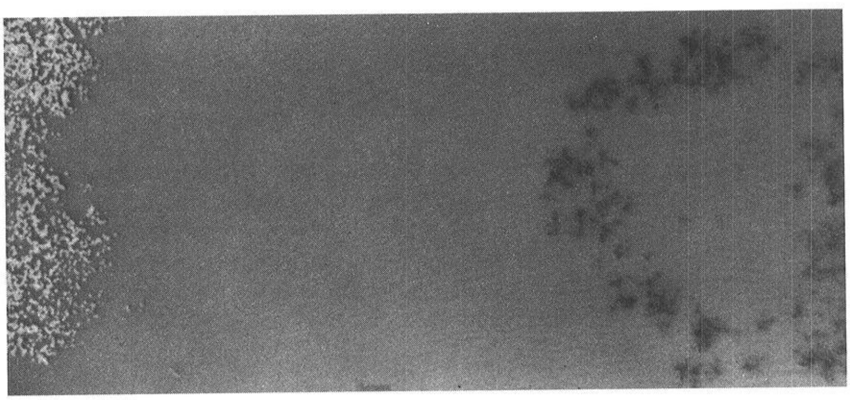


PHOTO: FRED E. KRUGER, JR.

A sago pondweed ring, 3 m across, by water lilies (left) on Rice Lake-Milltown.

Sediment in each Rice Lake stayed loose and flocculent, differing little in moisture and organic matter (Table 13). A steel pipe shoved into Rice Lake-Milltown sediment, near coring site R1 (Fig. 2), hit firm bottom after penetrating 6.0 m of soft sediment. Moisture made up 95-96% of sediment weight. Organic matter and ash made up nearly equal weights of the remaining 4-5% solids. Less ash seemed present in sediment from Rice Lake-Horse Creek because of carbonate loss during ignition.

But the 2 sediments differed in texture: Rice Lake-Milltown had less sand and thus finer sediment than did Rice Lake-Horse Creek. Clay and silt erode easier than sand and stay longer in suspension. Aerial photographs even show Rice Creek building a sediment delta at Rice Lake-Milltown in the 1950s. Snowmelt and heavy rains could have eroded clay and silt from upland soils, transporting the fine sediment that now becomes suspended in ice-free Rice Lake-Milltown. The finer sediments in Rice Lake-Milltown are more easily resuspended by wind.

Suspended clay and silt could lower the standing crop of wild rice (Day and Lee 1989) and sago pondweed (Kantrud 1990), keep other macrophytes from colonizing the lake, hinder feeding by certain fish, and increase recycling of nutrients to fuel denser algal blooms.

Pondweed Rings. Pondweed clumps grow in peculiar ring or loop formations on Rice Lake-Milltown (Figs. 4, 5). Seen first on aerial photographs, rings of 1-3 m diameter were present from late June through August. They formed from floating leaves of rooted plants. Sago pondweed constituted 95% of the formations; floating-leaf pondweed, just 5%. Open or closed rings, double and triple loops, and half-moon or S-shaped loops were found. Open rings had plant-free centers; closed rings had solid growth. Loops were broken rings.

Schiemer (1979) described similar but much larger growth rings for Neusiedlersee (Lake Fertö), a windswept lake on the Austria-Hungary border. He attributed those rings to turbidity caused by algal blooms, wind-stirred sediment, and introduced grass carp (*Ctenopharyngodon idella* [Valenciennes]).

Varga (Schiemer 1979) believed that wind-directed turbulence washed silt from the periphery of sago pondweed rings, but could not so easily wash silt from the center. He thought silt shaded and bent the central plants below the water surface until they died, forming open rings from closed ones. But central plants could lose vigor or become stunted by water turbidity forming open rings independently of closed ones. Peripheral plants, washed free of sediment and putting more biomass into tubers (Van Wijk 1988), could outgrow central plants. A similar mechanism can explain the unique sago pondweed growth pattern in Rice Lake as it is also shallow, windswept, and turbid.

A Window for Growth. Water turbidity can limit submersed macrophyte growth in deep water (Spence 1962). Macrophytes in Rice Lake-Milltown grew only to a depth of 1.1 m, although in clearer water they could reach the lake's maximum depth of 1.8 m. Maximum depth of submersed macrophytes in 68 Wisconsin lakes (Fig. 7) (Nichols 1991) and 90 lakes outside Wisconsin (Chambers and Kalff 1985) correlated significantly ($P < 0.05$) with Secchi disk transparency. These plants grew deeper in less turbid lakes. Maximum depth of submersed macrophytes thus can be estimated from mean summer water clarity (Dunst 1982).

Cold water and turbidity in spring delimited a growth window for submersed macrophytes in Rice Lake-Milltown. Cold water in April delayed tuber development and allowed time for diatoms (Bacillariophyceae) to bloom. Submersed macrophytes in Rice Lake-Milltown must grow rapidly in spring to avoid shading by algae, dissolved color, and wind-stirred sediment. Sago pondweed dominated in Rice Lake-Milltown because food rich tubers allowed growth even in turbid water. Sago pondweed tubers begin to develop at 10-15° C or 50-59° F (Madsen and Adams 1988)—temperatures reached in Rice Lake-Milltown by early May. After May, water turbidity from green algae (Chlorophyceae) shaded developing shoots not yet at the water surface. The sago pondweed thus had 4-6 weeks in spring, when water was clear and warm enough for tubers to sprout and shoots to surface. By June shoots of sago pondweed

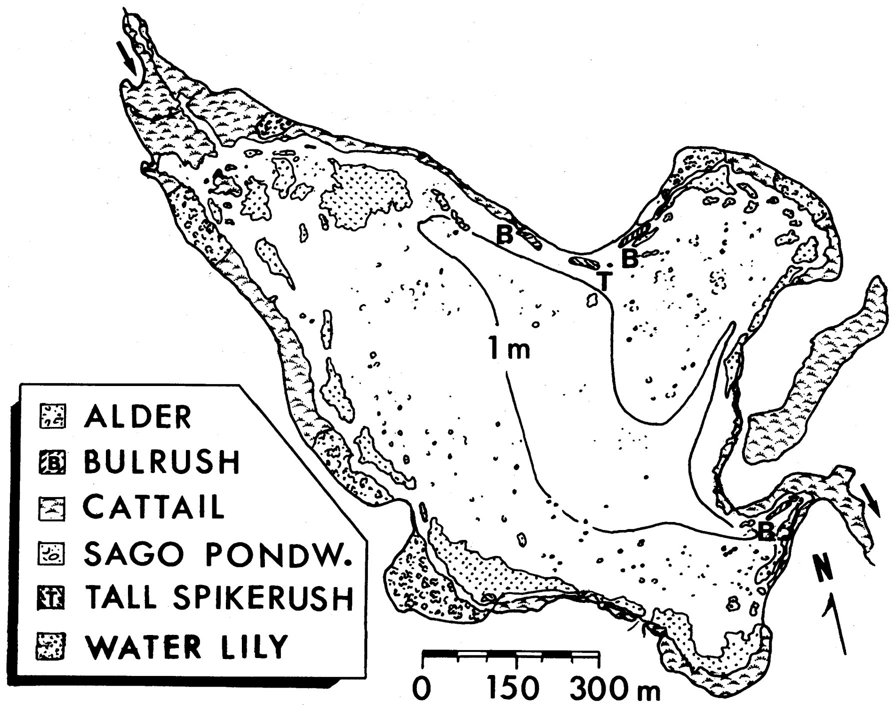


Figure 5. *Plant cover in Rice Lake-Milltown for 28 August 1987, depicting alder and cattail (marsh border), bulrush and tall spikerush (offshore beds), water lily (offshore beds of Nuphar-Nymphaea), and sago pondweed (tiny rings and loops).*

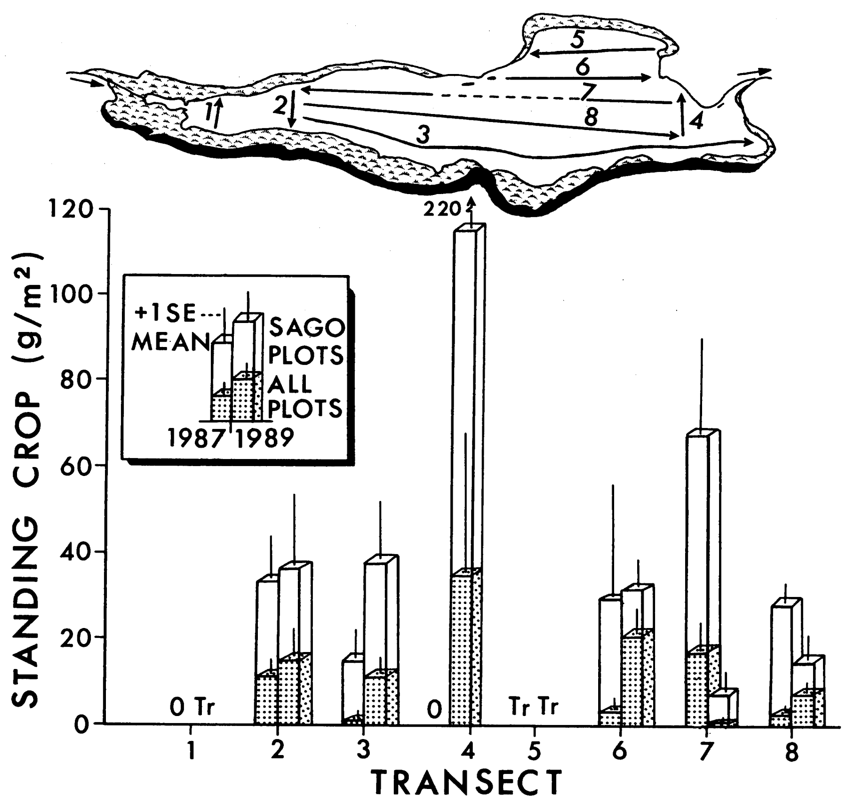


Figure 6. *Mean standing crop of sago pondweed by year and transect (lake map at top), calculated for plots with and without plants (shaded bars) and those only with sago pondweed (shaded plus clear bars).*

Table 11. *Maximum distance wind could sweep in any direction across each Rice Lake in April and August 1989.*

	Distance (m) across Rice Lake at	
Wind Measure	**Milltown**	**Horse Creek**
Greatest length across lake	1,338	2,977
Maximum wind fetch in April	1,227	1,283
Maximum wind fetch in August	1,018	612

Table 12. *Water quality at Station B in Rice Lake-Milltown, when ice covered (8 March 1988 and 20-21 February 1989) and ice-free (mid-May to mid-September of 1988 and 1989).*

	Mean ± 1 SE (number of dates)	
Water Quality Measure	**Ice covered**	**Ice free**
Water clarity		
Secchi disk (SD) transparency (cm)	149 ± 34 (2)	32 ± 2 (14)
Dissolved color (Co-Pt units)	13 ± 2 (2)	43 ± 5 (8)
Suspended solids (mg/L)	<2 (1)	59 ± 8 (6)
Turbidity (NTU)	1 (1)	23 ± 2 (8)
Nutrients		
Total phosphorus (µg/L)	48 ± 20 (2)	147 ± 14 (14)
Dissolved reactive phosphorus (µg/L)	10 ± 0.5 (2)	9 ± 1 (13)
Total nitrogen (mg/L)	4 ± 1.0 (2)	3 ± 0.3 (13)
Total inorganic nitrogen (mg/L)	4 ± 0.3 (2)	0.1 ± 0.04 (13)
Chlorophyll		
Trichromatic chlorophyll *a* (TChl, µg/L)	6 ± 0 (2)	78 ± 9 (13)
Monochromatic chlorophyll *a* (MChl, µg/L)	3 ± 0.4 (2)	41 ± 16 (8)
Trophic state index (TSI)*		
TSI (SD)	55 ± 3 (2)	77 ± 1 (15)
TSI (TChl)	57 ± 0 (2)	81 ± 1 (14)
TSI (MChl)	50 ± 1 (2)	77 ± 2 (8)
TSI (TP)	59 ± 6 (2)	75 ± 5 (14)

* Calculated from equations in Carlson (1977).

Table 13. *Composition of sediment collected with an Ekman grab at 3 stations each in Rice Lake-Milltown (15 June 1989) and Rice Lake-Horse Creek (12 September 1989).*

	Rice Lake-Milltown			Rice Lake-Horse Creek		
Soil Measure	A	B	C	X	Y	Z
Moisture (% wet weight)	96	95	96	95	96	96
Solids (% wet weight)	4	5	4	5	4	4
Organic matter (% dry weight)*	44	41	45	41	47	49
Ash (% dry weight)	53	54	51	42	42	43
Sand (% ash weight)	34	34	34	69	57	49
Silt (% ash weight)	37	41	41	15	23	27
Clay (% ash weight)	29	25	25	16	20	24

* Organic matter was determined by titration (Jackson 1958); other methods followed Black (1965).

reached the water surface and formed a canopy; then it could photosynthesize and develop new tubers despite turbid water below.

Ice-out on April 19 and dense algal blooms by June 7, for instance, would leave 50 days of growth. Sago pondweed can sprout from tubers and grow at the rate of 1.2 cm/day in clear water (Kantrud 1990). Growing at this rate from an average water depth (77 cm), shoots in Rice Lake-Milltown could reach within 17 cm of the water surface—about half the limit of Secchi disk transparency and close enough for branching and net photosynthesis.

Water clarity in Rice Lake-Milltown fell after mid-May, when water temperature offshore reached 15° C or 59° F (Fig. 8). Secchi disk transparency stayed high for about 4 weeks after ice-out. In 1989 it peaked in early May and then fell as trichromatic chlorophyll increased (Table 14). It stayed at this level from June through August. Transparency rose by mid-October. Maximum water clarity occurred in winter, when a Secchi disk could be seen on the bottom.

Water turbidity was related to phytoplankton abundance (Table 14). Water samples from Station B in 1989 were dominated by diatoms in April, green algae from May through August, blue-green algae (Cyanophyceae or Myxobacteria) in September, and both green and blue-green algae in October. Chrysomonads (Chrysophyceae), cryptomonads (Cryptophyceae), and dinoflagellates (Pyrrophyta) formed smaller blooms mainly in May, August, and September; some euglenoids (Euglenophyta) appeared in July, when phytoplankton density peaked at 283,000 cells/ml (22 mm^3/L).

Transparency stayed high during the spring diatom bloom, dominated by *Cyclotella*, *Fragilaria*, and *Synedra*. These large cells perhaps scattered, rather than absorbed, sunlight. The blue-green alga *Aphanothece* appeared in early May, but its small cells added little to total cell volume and failed to lower water clarity. But transparency stayed low from June through August when 9-13 genera of green algae, dominated by *Oocystis*, *Scenedesmus*, and *Sphaerocystis*, made up 60-90% of total cell count and cell volume. Transparency improved again during the September blue-green algal bloom, dominated by *Aphanizomenon* and *Lyngbya*, with some *Anabaena* and *Microcystis*. The fall diatom bloom, dominated by *Synedra*, had little affect on water clarity.

All macrophyte species in Rice Lake-Milltown faced the same growth window. Water lilies, sprouting from root stocks, grew better than wild rice, sprouting from seeds. Sago pondweed, concentrating foliage at the water surface in response to high water turbidity (Van Wijk 1988), could grow farther offshore than coontail or elodea with only underwater foliage. Floating-leaf pondweed and water crowfoot likewise surfaced by June and thus avoided summer shade by phytoplankton.

Macrophytes that spurt to the water surface in spring and produce a canopy of leaves, such as sago pondweed, can thrive offshore in Rice Lake's turbid waters. They take advantage of the few weeks in spring when the lake water is clear. A few plants without leaf canopies, such as coontail and elodea, can still grow in Rice Lake because they tolerate dim light.

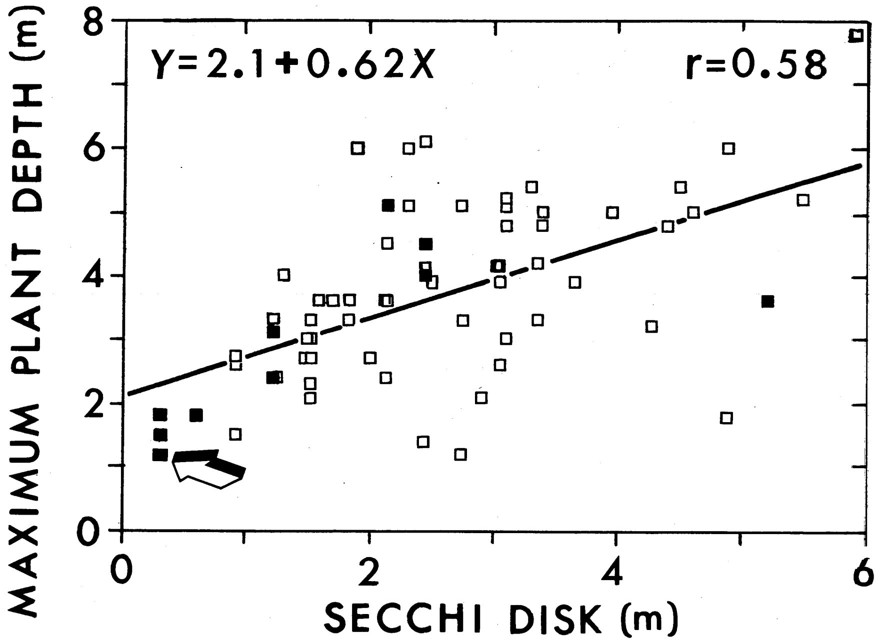


Figure 7. *Maximum depth of submersed macrophytes vs. Secchi disk transparency for 68 Wisconsin lakes sampled in 1975-83 (Nichols 1992). Ten lakes (dark squares) had problems with algae, common carp (*Cyprinus carpio *L.), or both. An arrow points to Honey Lake, Walworth County, having similar maximum plant depth (1.2 m) and Secchi disk transparency (0.3 m) as Rice Lake-Milltown during 1987 and 1989.*

This Secchi disk disappeared in 20 cm when lowered into Rice Lake-Milltown water on 17 September 1990.

PHOTOS: SANDY ENGEL

Green algae (Chlorophyceae) on Rice Lake-Milltown in mid-June 1989, a day after washing ashore by a northeast wind.

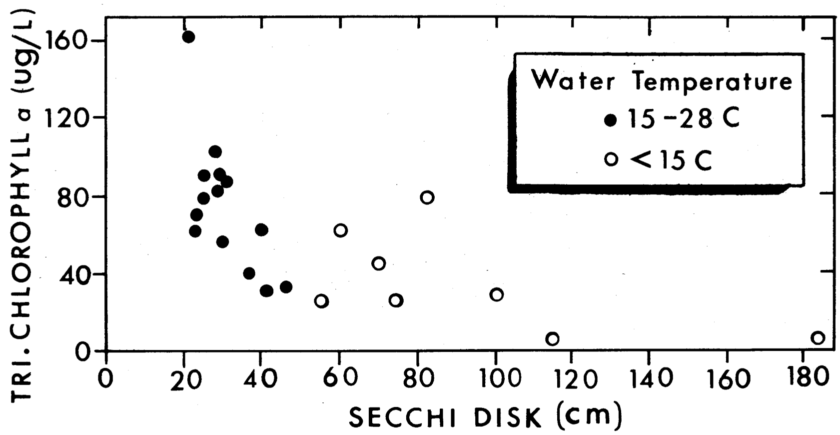


Figure 8. *Trichromatic chlorophyll a vs. Secchi disk transparency at Station B in Rice Lake-Milltown during 1987-89. Open circles show cool water (below 15° C or 59° F) with few algae; closed circles, sampled from mid-May to mid-September, show warm water (above 14° C or 57° F) with many phytoplankton.*

Table 14. *Secchi disk, chlorophyll, and phytoplankton at Station B in Rice Lake-Milltown during 1989.*

Measure	Apr 27	May 9	May 25	Jun 15	Jul 18	Aug 8	Sep 11	Oct 17
Secchi disk (cm)	82	100	46	28	25	23	37	73
Mon. chl. *a* (µg/L)	52	19	18	50	48	42	33	13
Tri. chl. *a* (µg/L)	80	28	34	102	79	64	41	25
Total cell count (10^3/ml)	**73**	**46**	**86**	**176**	**283**	**117**	**124**	**79**
Diatoms (%)	63	26	13	3	1	0	3	13
Green algae (%)	31	22	70	82	88	78	31	39
Blue-green algae (%)	0	22	7	15	11	17	62	38
Chrysomonads (%)	4	27	9	0.2	0	3	1	9
Cryptomonads (%)	1	2	1	0	0	2	3	1
Dinoflagellates (%)	0.4	0.2	0	tr	tr	0.3	0.4	0
Euglenoids (%)	0	0	0	0	tr	0	0	0
Total cell volume (mm^3/L)	**30**	**9**	**10**	**18**	**22**	**11**	**11**	**7**
Diatoms (%)	75	28	47	18	3	0	20	59
Green algae (%)	21	62	46	62	86	76	39	29
Blue-green algae (%)	0	0.1	4	19	8	7	22	6
Chrysomonads (%)	tr	5	2	tr	0	0.3	7	3
Cryptomonads (%)	2	3	1	0	0	12	7	3
Dinoflagellates (%)	1	2	0	2	0.4	5	5	0
Euglenoids (%)	0	0	0	0	2	0	0	0

A growth window of just 4-6 weeks helps explain why some widespread species grew poorly or not at all in Rice Lake-Milltown. Slender naiad (*Najas flexilis* [Willd.] Rostk. & Schmidt), for example, sprouts in mid-May (Engel 1990), leaving little time to reach the water surface ahead of phytoplankton. Plants such as Berchtold's pondweed (*Potamogeton pusillus* L.) and northern watermilfoil (*Myriophyllum Sibiricum* Komarov) fail to produce a canopy of leaves like that of sago pondweed, yet cannot tolerate dim light for long periods, so they fail to grow in highly turbid conditions such as Rice Lake. Rice Lake's growth window thus selects for some plant species and selects against others.

Nutrients and Metals

Nutrients and some metals had much higher mean concentrations in Milltown's marsh than in Rice Creek or Rice Lake downstream from the marsh (Table 15). Water standing in the marsh was more alkaline, mineral rich, stained, and fertile than water in the navigable inlet and lake. It averaged 8-11 times more sodium and chloride than found in Rice Lake-Milltown—amounts higher than expected in uncontaminated ground water (Hem 1985). Such high concentrations suggest contamination of Milltown's marsh.

Sediment also averaged 2-3 times more barium, boron, and sodium in the marsh than in the lake, but lake sediment held about 1.5 times more chromium and lead. Concentrations of other metals differed little between marsh, inlet, and lake sediment.

Severe drought could have concentrated nutrients in stagnant marsh water, while iron or clay particles bound metal ions released from decomposing marsh plants. With much of the marsh surface dry during our study, samples had to be collected from pools less than 12 cm deep.

Outflow was so reduced, the spring-fed inlet could be canoed only 238 m upstream from the lake.

Many parameters decreased in mean concentration between marsh and lake. They include conductivity, total hardness, total alkalinity, and concentrations of chloride, sodium, and sulfate. Mean chloride, for example, decreased 80% from marsh to navigable inlet, 43% from inlet to lake. Mean sodium decreased 87% from marsh to inlet, 29% from inlet to lake. Mean total phosphorus decreased in water from marsh to inlet, then rose in lake water.

But concentrations of nutrients and metals in sediment varied so much along the inlet that no pattern of decrease from inlet to lake was evident. Marsh rather than inlet sediment seemed to trap nutrients and metals from upstream sources.

Rice Lake-Milltown could also behave as a trap when particles settle and rooted plants store nutrients and metals in their foliage. Perhaps dense beds of wild rice, growing in Rice Lake-Milltown until about 1972-76, improved nutrient detention by stabilizing sediment and storing nutrients taken up by roots. Decline of these rice beds has meant greater potential for nutrient transport downstream.

Without wild rice, winds could circulate contaminants in loose sediment. But mean concentrations of heavy metals and polychlorinated biphenyl (PCB) in lake sediment were not unusually high (Hem 1985), despite possible runoff from a public dump, a municipal wastewater treatment plant, and past crop dusting with lead arsenate. PCB concentrations were also low (<0.2 µg/g) in 3 northern pike (546-792 mm) electrofished in May 1988. Metal and PCB concentrations differed little between stations cored to 15 cm or between top, middle, and bottom sections of a 45-cm core at Station B (Table 16).

Table 15. *Water and sediment chemistry (mean ± 1 SE) on 28-29 June 1989 along Milltown's marsh, navigable inlet, lake, and outlet.*

Chemical Measure	Marsh	Inlet	Rice Lake	Outlet
Water chemistry (hand-dipped samples)				
Conductivity (µS/cm)	694 ± 151	268 ± 12	180 ± 0	201 ± 5
Total hardness (mg/L)	295 ± 59	117 ± 7	93 ± 0	89 ± 1
Total alkalinity (mg/L)	164 ± 33	96 ± 1	88 ± 1	89 ± 1
Dissolved color (Co-Pt units)	130 ± 7	27 ± 6	37 ± 3	56 ± 4
Chloride (mg/L)	103 ± 40	21 ± 1	12 ± 0	10 ± 2
Iron (mg/L)	77 ± 22	0.6 ± 0.1	1 ± 0	1 ± 0.4
Sulfate (mg/L)	58 ± 34	10 ± 1	5 ± 0	5 ± 0.2
Sodium (mg/L)	56 ± 22	7 ± 1	5 ± 0	5 ± 0.2
Total Kjeldahl N (mg/L)	42 ± 13	1 ± 0.1	4 ± 0.2	3 ± 0.2
Total phosphorus (mg/L)	13 ± 4	0.1 ± 0	0.2 ± 0	0.2 ± 0.1
Sediment chemistry (Ekman grabs)*				
Total Kjeldahl N (mg/g)	160 ± 57	89 ± 42	250 ± 12	83 ± 35
Solids (% wet weight)	14 ± 6	27 ± 19	4 ± 1	40 ± 15
Iron (mg/g)	104 ± 19	75 ± 95	104 ± 6	97 ± 33
Calcium (mg/g)	91 ± 21	53 ± 23	83 ± 7	52 ± 18
Magnesium (mg/g)	23 ± 3	16 ± 5	28 ± 4	21 ± 3
Sodium (mg/g)	6 ± 2	0.8 ± 0.2	2 ± 0.1	1 ± 0.3
Manganese (mg/g)	2 ± 0.5	6 ± 3	2 ± 0.7	2 ± 0.3
Barium (µg/g)	89 ± 10	116 ± 65	43 ± 1	32 ± 6
Zinc (µg/g)	74 ± 26	58 ± 29	63 ± 3	32 ± 6
Lead (µg/g)	27 ± 4	11 ± 7	41 ± 0.5	16 ± 6
Boron (µg/g)	16 ± 10	2 ± 2	8 ± 2	6 ± 0.7
Chromium (µg/g)	16 ± 5	34 ± 13	27 ± 3	14 ± 3
Copper (µg/g)	23 ± 7	11 ± 4	13 ± 1	8 ± 1
Nickel (µg/g)	13 ± 3	9 ± 5	11 ± 0	9 ± 1
Arsenic (µg/g)	4 ± 0.8	3 ± 0.7	4 ± 1	3 ± 0.8
Selenium (µg/g)	<2 ± 0	<2 ± 0	<2 ± 0	<1 ± 0
Cadmium (µg/g)	0.3 ± 0.3	0.7 ± 0.7	3 ± 2	<1 ±<0.1
Number of stations	**4**	**3**	**2**	**6**

* Metal concentrations are based on sediment dry weight.

PHOTO: SANDY ENGEL

Water pooled in April 1988 by the inlet culvert draining Milltown's marsh.

Table 16. *Sediment chemistry (mean ± 1 SE) on 20 September 1988 across Rice Lake-Milltown, using a core to depths of 15 cm, 30 cm, and 45 cm.*

	Sediment Core Depths (cm)		
Sediment Measure*	**0-15**	**15-30**	**30-45**
Iron (mg/g)	118 ± 3	120	120
Calcium (mg/g)	90 ± 7	82	72
Magnesium (mg/g)	26 ± 1	28	25
Sodium (mg/g)	2 ± 0.1	2	2
Zinc (µg/g)	60 ± 5	66	65
Chromium (µg/g)	28 ± 1	36	28
Copper (µg/g)	12 ± 1	13	11
Nickel (µg/g)	11 ± 1	12	11
Selenium (µg/g)	<5 ± 0	<5	<5
Arsenic (µg/g)	4 ± 0.4	3	3
Cadmium (µg/g)	2 ± 0.7	1	1
Mercury (µg/g)	0.1 ± tr	0.1	0.1
PCB (µg/g)	<0.1 ± tr	<0.1	<0.1
Stations cored	**A, B, C, D**	**B**	**B**

* Metal concentrations are based on sediment dry weight.

The lake and outlet creek had similar water quality but differed in sediment chemistry. Levels of total Kjeldahl nitrogen in sediment averaged 67% lower in the outlet; metals averaged 18-50% lower (Table 15). Strong outlet flow could reduce concentrations in sediment by keeping particles in suspension and allowing less time for nutrients and metals to settle.

Comparing just marsh and outlet, mean concentrations in sediment decreased 30-65% for metals and 48% for total Kjeldahl nitrogen, suggesting that both the marsh and lake acted as chemical traps. During the 1987-89 drought the marsh behaved as a sink, releasing little sediment or water. It received less water from precipitation and groundwater discharge while losing water by evapotranspiration.

But in wet years the marsh could behave as a source, flushing nutrients and metals downstream particularly during snowmelt and heavy rainfall.

Islands from Ice and Wind

Ice and wind have damaged the marsh border of Rice Lake-Milltown by dislodging sediment and uprooting emersed macrophytes. As a result, sediment and debris have clouded the water for days after ice-out. Water lily rhizomes, black and swollen, have blown across the lake often hanging from the water surface as they become waterlogged. Chunks of cattail (*Typha*) with alder (*Alnus*) have torn loose to become drifting islands.

Most islands formed during high water in early spring. Aerial photographs show few islands on Rice Lake-Milltown until 1973. Dozens of islands dotted the lake on 6 May 1974, when rains and high ground water flooded the marsh. Most islands were chunks of marsh that disintegrated within a few weeks; some large islands became grounded for more than a year, acquiring a muskrat house or a hunter's blind.

Islands can be liabilities. They shelter muskrats that damage wild rice emerging in July, spew debris across the lake as they disintegrate, and destroy seeds and tubers of plants buried beneath them in sediment. For example, an island breaking away from the marsh border in April 1989 scraped across a wild rice bed seeded the previous fall. Island debris could have silted over a channel visible on the lake bottom until the 1970s (Arnold J. Herwick, pers. comm. 1990 and 1991).

But islands can be assets. Anchored against wind, marsh islands offer water birds nesting and brooding habitat safe from land predators. Islands can keep wind from uprooting plants or creating turbidity. Roots dangling beneath floating islands add substrate for macroscopic invertebrates and hiding places for young fish.

Fish and Bottom Fauna

Ten fish species were captured in Rice Lake-Milltown (Table 17). Black bullhead, pumpkinseed, yellow perch, white sucker, and fathead minnow together made up at least 95% of electrofishing (23 May 1988) and fyke netting (21-23 May 1990) catches. Yellow perch made up half of the electrofishing catch; black bullhead, three-fourths of the total fyke netting catch. One bluegill and no largemouth bass (*Micropterus salmoides* [Lacepède]) were caught by fyke netting and electroshocking, though anglers hooked them in the early 1970s. No common carp were caught in Rice Lake-Milltown or in Balsam Branch and Balsam Lake during 1976-78 electrofishing surveys (Fago 1986), though they have been widespread in Polk County (Sather and Threinen 1960). Black bullhead constituted 99.8%, yellow bullhead 0.15%, and brown bullhead 0.02% of the 4,051 bullheads fyke netted.

Species abundances may have changed, but gear used, time of day fished, and fishing effort differed between years. Alternating-current electrofishing, with its dispersed electrical field and inability to attract stunned fish (Gordon R. Priegel, pers. comm. 1991), captured just 251 fish. Eight fyke nets, each worked day and night for 45 hours, caught 5,319 fish. Greater effort explains why fyke netting took 29 northern pike (350-991 mm) and electrofishing caught just 3 northern pike (495-805 mm).

Fyke netting took larger and heavier fish than did electrofishing (Table 18). Bullheads and large fish of other species move inshore at night (Becker 1983), making them more vulnerable to overnight fyke netting than to afternoon electrofishing. Fyke nets caught no fathead minnow, which accounted for 9% of the electrofishing catch, because the 25-mm stretched mesh was too coarse.

These warm-water fish spent more than 150 days, from November to April 1988-89, under lake ice. Ice formed on 6 November 1988, melted and reformed a few weeks later, and finally melted on 19 April 1989. Wind exposure, shallow depth, and stream inflow usually cause Rice Lake-Milltown to open 3-4 days earlier than neighboring lakes (Richard C. Fisher, village of Milltown, pers. comm. 1990).

Lake ice became 50-56 cm thick in February 1989, froze into sediment, and formed a wall of solid ice in shallow water (Fig. 9). This ice wall reduced the area of circulating (liquid) water by 36% and thus reduced the living area for fish.

Table 17. *Fish species caught by electrofishing (23 May 1988) and fyke netting (21-23 May 1990) in Rice Lake-Milltown.*

Text Name	Scientific Name*	Catch (%) 1988	Catch (%) 1990
Black bullhead	*Ameiurus melas* (Rafinesque)	11	76
Pumpkinseed	*Lepomis gibbosus* (Linnaeus)	8	13
Yellow perch	*Perca flavescens* (Mitchill)	53	10
Golden shiner	*Notemigonus crysoleucas* (Mitchill)	2	0.6
Northern pike	*Esox lucius* Linnaeus	2	0.5
White sucker	*Catostomus commersoni* (Lacepède)	14	0.3
Yellow bullhead	*Ameiurus natalis* (Lesueur)	0	0.1
Brown bullhead**	*Ameiurus nebulosus* (Lesueur)	0	<0.1
Fathead minnow	*Pimephales promelas* Rafinesque	9	0
Bluegill**	*Lepomis macrochirus* Rafinesque	0.4	0
Total fish catch		**251**	**5,319**

* Spelling of scientific names followed Robins et al. (1991).
** Only a single fish was captured.

Table 18. *Total length and weight (mean ± 1 SE) of fish caught by electrofishing (23 May 1988) and fyke netting (21-23 May 1990) in Rice Lake-Milltown.*

Fish Species	Length (mm) 1988	Length (mm) 1990	Weight (g) 1988	Weight (g) 1990
Northern pike	661 ± 59	725 ± 2	$2{,}474 \pm 490$	$2{,}717 \pm 7$
White sucker	317 ± 9	348 ± 13	35 ± 27	385 ± 2
Bullhead species	157 ± 9	152 ± 0.2	73 ± 13	65 ± 1
Golden shiner	112 ± 4	120 ± 0.7	–	21 ± 0.8
Yellow perch	106 ± 5	183 ± 0.4	122 ± 13	141 ± 0.8
Pumpkinseed	86 ± 3	114 ± 0.1	–	41 ± 0.8
Fathead minnow	81 ± 2	–	–	–

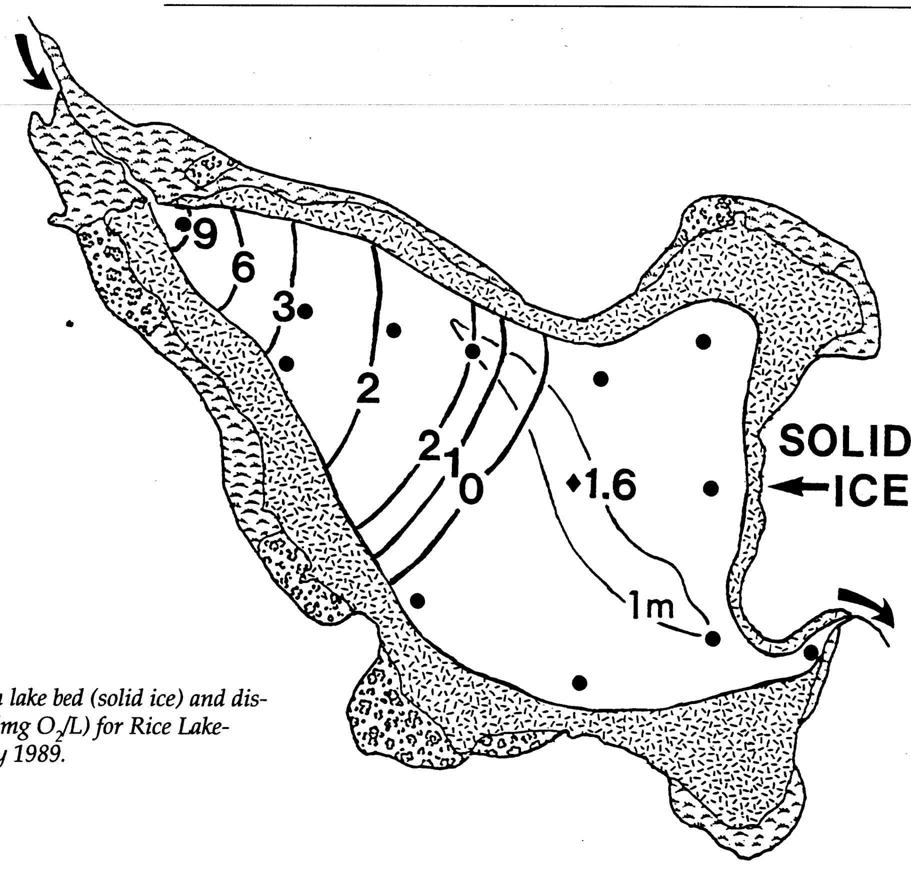


Figure 9. *Area of frozen lake bed (solid ice) and dissolved oxygen isopleths (mg O_2/L) for Rice Lake-Milltown on 21 February 1989.*

Drought reduced water depth in Rice Creek, but springs kept the navigable inlet flowing and ice-free. That allowed surface agitation to aerate the water upstream and provide Rice Lake-Milltown with a steady trickle of dissolved oxygen. The flow was enough to melt lake ice from below, reducing its thickness at the inlet from 19 cm to 10 cm and leaving barely enough water depth for small fish to move upstream.

Gradual loss of dissolved oxygen in the lake further restricted fish movement. Lake ice, covered with 17-26 cm of snow (20.5 cm at Station B), transmitted little sunlight on 21 February 1989. Dissolved oxygen decreased from 9 mg/L (63% saturation) at the inlet to 2 mg/L (14%) at Station B and less than 0.2 mg/L (<2%) at Stations A, C, and the outlet. Just 40-45% of the area of circulating water remained with any dissolved oxygen; 15-20%, with more than 2 mg/L. Thus, ice and anoxic water held lake fish to less than 15% of the living area present during ice-free times.

Lack of snow on 8 March 1988 meant greater light penetration of lake ice and higher dissolved oxygen levels: 6 mg/L (46%) at Station A and 16 mg/L (117%) at Station B. Dissolved oxygen was not measured at other stations, yet lake fish probably found a larger area of oxygenated water than they did the next winter.

Lake water stayed clear in both winters: Stations A, B, and C differed by 0.95-1.8 m for Secchi disk transparency, 5-15 Co-Pt units for dissolved color, and 1.1.-1.3 NTU for turbidity. Lower water temperature and nutrient levels in winter, particularly in February 1989 (total nitrogen 2.6-2.9 mg/L, total phosphorus 17-30 µg/L), meant less chlorophyll *a* (monochromatic 3-5 µg/L, trichromatic 6-12 µg/L) than in summer.

Nitrification at Station B increased soon after ice-up. Total inorganic nitrogen (ammonium, nitrite, and nitrate nitrogen) rose from less than 0.06 mg/L in July-August to more than 3.3 mg/L in February-March. In both winters ammonium nitrogen reached 0.7 mg/L; nitrite and nitrate nitrogen together reached 2.6 mg/L (1989) and 3.5 mg/L (1988). Nitrification can be intense under ice cover (Knowles and Lean 1987): Nitrite and nitrate nitrogen together reached 0.5 mg/L on 7 November 1988, just a day after ice 0.6-cm thick covered the lake. Such conditions suggest nitrifying bacteria in Rice Lake-Milltown water can speed dissolved oxygen loss in winter.

Severe winterkill after about 1972 (when farmers believe angling declined) could explain a shift from bass and bluegill to bullhead dominance at Rice Lake-Milltown. Conditions seemed ripe for a major winterkill in January-March 1989: The worst drought since 1934 (Ross 1989) reduced lake level and inlet flow; snow cover blocked most sunlight for photosynthesis. But we found no fish floating dead in spring, nor do 3 farmers living near the lake (Clifford L. Ince, Franklin [Red] G. McCurdy and Lloyd Reed, pers. comm. 1989-90) recall finding dead fish after the ice-outs of previous years.

Rice Lake-Milltown fish—attracted to aerated currents when winter oxygen levels get low (Johnson and Moyle 1969)—could have escaped winterkill by moving to the flowing inlet or even into Milltown's Rice Creek. These winter refuges would have prevented fish winterkill in past decades too. Aerial photographs of Rice Creek during ice-free months, for instance, show that flow was reduced to a trickle only in August 1938.

Water turbidity rather than winterkill could have shifted the fish community composition in Rice Lake-Milltown. Turbidity caused by wind and algae during ice-free times could favor bullheads, which hunt bottom prey by smell (Becker 1983). It could have also reduced macrophytes harboring invertebrate prey and made food search difficult for bass and bluegill, which hunt prey by sight (Savino and Stein 1982).

Growth of pumpkinseed seemed average and that of yellow perch below average, in Rice Lake-Milltown compared with populations statewide and in northwestern Wisconsin (Table 19). (Growth between ice-out in mid-April and capture on 23 May 1988 was ignored.) Condition factor (K_{TL}), as an index of plumpness, was likewise average for pumpkinseed (2.0 ± 0.1) and below average for yellow perch (1.1 ± 0.04) compared with populations in neighboring states (Carlander 1953, 1977). Below-average growth and condition can result from many factors: water turbidity that hinders feeding, low dissolved oxygen that kills bottom-dwelling prey, and spawning that reduces body weight before capture.

Macroscopic, bottom-dwelling invertebrates in Rice Lake-Milltown were scarce in winter and consisted entirely of late-instar midge larvae (Diptera). Ekman grabs took 130-595 larvae/m^2 from 6 stations (Table 20). In contrast, Ekman grabs in winter took 50-300 times as many invertebrates ($38{,}150 \pm 5{,}080$ organisms/m^2) from 4 inshore stations in Halverson Lake, a 4.2-ha (10.3-acre) impoundment in southern Wisconsin (Engel 1988*a*). Other insects, snails (Gastropoda), and clams (Bivalvia) were surprisingly absent from Rice Lake-Milltown sediment. Larval cases of caddisflies (Trichoptera) were found empty and thus not counted.

Sediment at all stations smelled of hydrogen sulfide gas, suggesting prolonged oxygen depletion that could have reduced invertebrate diversity and abundance (Danell 1981). For instance, Ekman grabs from Halverson Lake in winter took 36% fewer organisms at an anoxic station offshore than at 4 oxygenated ones inshore (Engel 1988*a*).

Midge larvae avoid suffocation by storing oxygen in hemoglobin (Jonasson 1972) or moving away from the bottom when dissolved oxygen or pH declined (Rahel and Kolar 1990). Decline in pH could occur from buildup of carbon dioxide and acids. But avoiding sites low in dissolved oxygen or pH can increase risk of fish predation (Rahel and Kolar 1990). Even bottom scouring by wind and ice heave in spring can kill larvae.

Other taxa cannot withstand sediment freezing into lake ice (Danell 1981). A depauperate bottom fauna in Rice Lake-Milltown therefore could have resulted from winter oxygen loss, fish predation, bottom scouring by wind, ice heave, sediment freezing, or these factors combined.

Table 19. *Age-specific lengths (mean ± 1 SD) of 19 pumpkinseed and 129 yellow perch electrofished in Rice Lake-Milltown on 23 May 1988, compared with populations statewide and in northwestern Wisconsin.*

	Fish Total Length in mm (number of lakes)			
Summers Completed	**Rice Lake**	**NW Wisconsin***	**NW Wisconsin****	**Statewide****
Pumpkinseed				
2	86 ± 6	83 ± 11(26)	74 ± 12(16)	89 ± 19 (72)
Yellow perch				
1	71 ± 5	93 ± 26 (4)	79 ± 23(36)	74 ± 21 (72)
2	94 ± 10	122 ± 15(28)	117 ± 23(82)	119 ± 23(195)
3	131 ± 1	152 ± 24(34)	147 ± 25(89)	152 ± 24(228)
4	169 ± 15	183 ± 28(30)	178 ± 33(82)	180 ± 28(227)
5	200 ± 28	205 ± 34(27)	201 ± 32(71)	206 ± 30(193)
6	205 ± 30	232 ± 34(21)	224 ± 33(52)	226 ± 29(149)

* Snow, H. E. and C. J. Sand (1992).
** DNR Fish Management Reference Book (data compiled 3 May 1990); NW Wisconsin populations came from Ashland, Barron, Bayfield, Burnett, Douglas, Iron, Polk, Price, Rusk, Sawyer, Taylor, and Washburn counties.

Table 20. *Midge larvae (Diptera) found in 6 bottom stations of Rice Lake-Milltown, sampled 8 March 1988 with an Ekman grab.*

Measure	All Taxa	Nonbiting Midges (Chironomidae)	Phantom Midges (Chaoboridae)	Biting Midges (Ceratopogonidae)
Total count (%)	99	53	33	13
Density (no./m^2)	287 ± 68	151 ± 68	96 ± 37	36 ± 12

Looking Back at Milltown: Land and Lake Changes

How Rice Lake-Milltown changed from deepwater marsh to windswept lake owes much to how Milltown developed.

Changes in Land Cover

Northwestern Wisconsin belonged to the Chippewa (Ojibwa) or Sioux until the Treaty of 1837 (Lurie 1987). This treaty opened the Chippewa and St. Croix river valleys to logging, leading to extensive land clearing in the 1850s (Kissinger 1979).

Railroads built after the Civil War made logging sites more accessible, promoted wheat farming (Grimm 1983), and encouraged town growth. The civil town of Milltown grew from 66 to 282 people in the 1870s (U. S. Bur. Census 1860, 1870), when a railroad line was built 12 km southeast of Rice Lake-Milltown. By 1880 Polk County had stagecoach and rail services as well as a network of dirt, gravel, and corduroy roads to link its 1,414 farms (Kissinger 1979).

The U. S. General Land Office began surveying Polk County in 1845 and Rice Lake-Milltown on 27-29 June 1853. Surveyors mapped the land into ranges and townships, subdivided into sections and quarter sections (Martin 1965). The civil town of Milltown (T. 35 N.; Rs. 15, 16, and 17 W.) covered Georgetown, Johnstown, and Milltown townships. Rice Lake in Milltown Township overlapped 4 sections meeting near the south shore and intersected 12 quarter sections (Fig. 10).

Surveyors in 1853 described a rolling country, dotted with ponds amid lightly wooded uplands and marshy lowlands (files of the State Commission of Public Lands, Madison). The nearest house stood unoccupied by Boston Bay on Balsam Lake (sec. 35). Sluggish streams, "unfit for cultivation," arose from springs and meandered through "marsh" or "swamp."

Uplands grew mostly hardwoods with "considerable pine" (Table 21). The surveyors took bearings from 4 elms, 3 white birch, 2 bur oak, 2 tamarack, and 1 each of alder, black ash, ironwood, maple, and white oak. Other ash,

Table 21. *Trees and shrubs surveyed around Rice Lake-Milltown on 27-29 June 1853.*

Text Name	Scientific Name*
Alder	*Alnus rugosa* (DuRoi) Spreng
Ash	*Fraxinus americana* L. and *F. pennsylvanica* Marshall
Basswood	*Tilia americana* L.
Black ash	*Fraxinus nigra* Marshall
Bur oak	*Quercus macrocarpa* Michaux
Elm	*Ulmus americana* L. and some *U. rubra* Muhlenberg
Hawthorn	*Crataegus* spp.
Hazelnut	*Corylus americana* Walter and *C. cornuta* Marshall
Hornbeam	*Carpinus caroliniana* Walter
Ironwood	*Ostrya virginiana* (Miller) K. Koch
Maple	*Acer saccharum* Marshall, *A. saccharinum* L., and some *A. rubrum* L.
Prickly ash	*Zanthoxylum americanum* Miller
Tamarack	*Larix laricina* (DuRoi) K. Koch
White birch	*Betula papyrifera* Marshall
White oak	*Quercus alba* L.

* Scientific names are those suggested for survey plants by Grimm (1984), based on nomenclature in Gleason and Cronquist (1963).

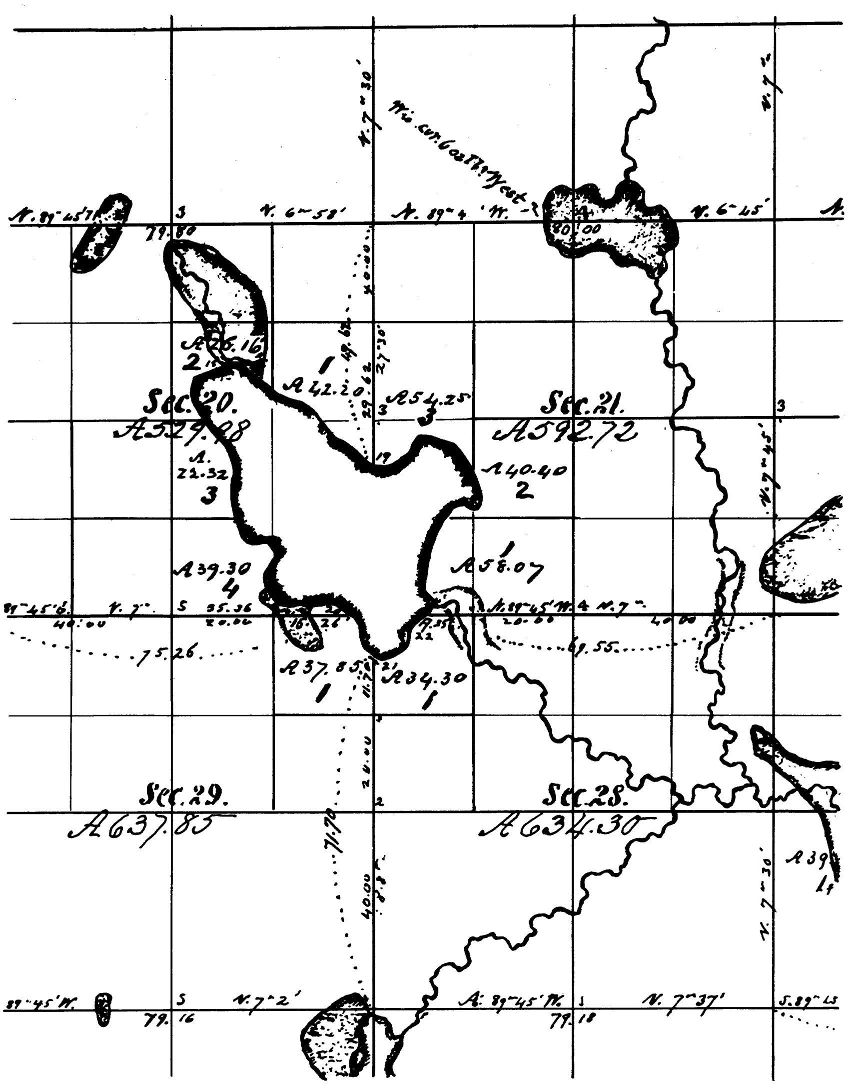


Figure 10. *U. S. General Land Office plat of the Milltown area, traced from a June 1853 sketch showing Rice Lake (center), Otter Creek pond (upper right), marshes (dark borders), streams (wavy lines), and distances along surveyor paths (dotted lines) measured in chains (1 chain = 20 m). The stream south of section 28 would have crossed a rise of 3-6 m to flow as the single channel shown.*

basswood ("limn"), hawthorn, hazelnut, and hornbeam ("blue beech") also grew on dry ground but were not blazed. An undergrowth of hawthorn, hazelnut, ironwood, and especially prickly ash made walking difficult. Tamarack, the one conifer named, grew in wetlands. The uplands were cleared for farming, but the wetlands look much as they did then.

Pollen grains in Rice Lake-Milltown sediment revealed a wooded countryside poised for change after the 1853 survey. Above a sediment depth of 50 cm pollen dominance shifted from trees to herbs (Fig. 11), with spread of ragweed (*Ambrosia*) and grass (Gramineae). Tree pollen decreased from 82% to 50%, while herb pollen increased from 11% to 45% (Winkler 1989).

The herb pollen between core depths of 50 cm and 20 cm included ragweed that increased from 2% to 14% and grass that increased from 3% to 21%. Ragweed produces small airborne pollen (<20 μm), suggesting land clearing from afar (Grimm 1983). But the grass pollen included corn, with large non-arboreal pollen (>40 μm), suggesting land clearing nearby.

The pollen record above 20 cm split between tree and herb pollen, but the herb pollen shifted from ragweed to grass. Ragweed decreased to 11%; grass with much cultivated grain increased above 25%. Farming on already cleared land explains this later shift.

Land clearing in the last century reduced total concentration of upland pollen and changed its composition in Rice Lake-Milltown sediment (Fig. 12). Below a core depth of 50 cm (Zone 1) upland pollen averaged 81,800 grains/cm^3; oak and birch composed 43% of all pollen and 37% of 16 pollen-bearing trees blazed. Above

50 cm (Zone 2), upland pollen averaged 35,000 grains/cm^3, with significant ($P < 0.05$) decrease in oak and birch (43% to 25%), white pine (14% to 3%), ironwood and elm (10% to 7%), and shrubs (7% to 5%). Such changes reduced the ratio of woody:herb pollen from 8 to 1.

Yet some kinds of pollen significantly increased: herbs (11% to 45%), red and jack pine (4% to 6%), willow (*Salix*, 0.4% to 0.9%), basswood (0% to 0.3%), and hemlock (*Tsuga*, 0% to 0.2%). Herb pollen rose when native grass, ragweed, and cultivated grain spread into forest openings and wheat fields. Willow thickets and some basswood also spread into well drained lowlands. Red pine rather than jack pine spread because land clearing was unaccompanied by fire: Charcoal particles in lake sediment decreased between 50 cm and 20 cm.

Other pollen, making up less than 1% of pollen sum, changed little: ash, aspen (*Populus*), cedar (*Juniperus*), hazel, hickory (*Carya*), maple, spruce (*Picea*), and walnut (*Juglans*).

This transition from woodland to farmland produced a pollen shift in Rice Lake-Milltown similar to that found in varved (banded) sediment from 2 Minnesota (Swain 1973, 1980) and 3 Wisconsin lakes (Gajewski et al. 1985). The shift from hardwood to herb pollen in these lakes reflects logging that began in the 1840s and peaked in the 1890s. The pollen record at 50 cm in unvarved Rice Lake sediment similarly shows an increase in airborne pollen from plants invading land cleared within and outside the watershed. A second shift at 39 cm, where pollen from cultivated grain rose with ragweed pollen, reflects farming that spread within the Rice Lake-Milltown watershed.

Milltown Industry and Growth

First settled in 1854, the Milltown area became a civil town in 1869 (population 66). Sawmills and creameries dotted the area after the Civil War and

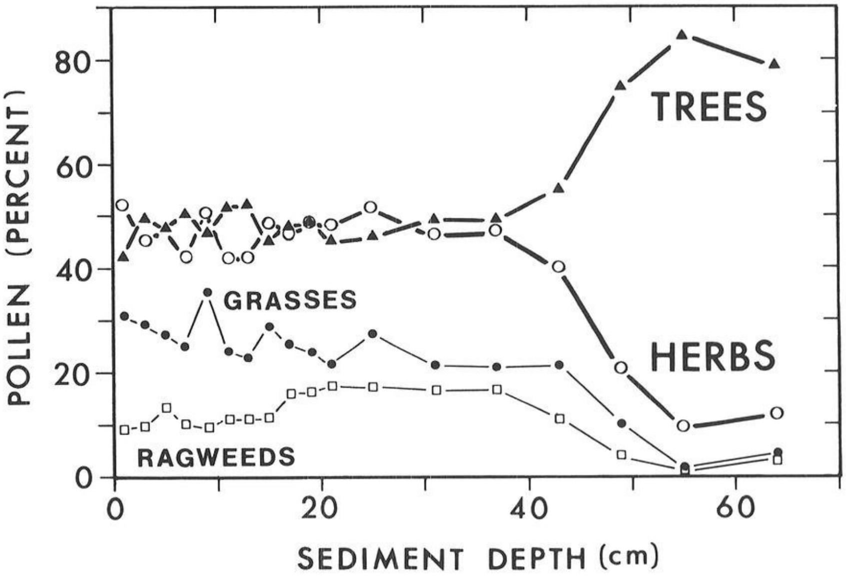


Figure 11. *Pollen profiles showing a shift from trees to upland herbs (comprising mainly grasses and ragweeds) in the R2 sediment core taken 20 September 1988 from Rice Lake-Milltown. (Redrawn from Winkler 1989.)*

PHOTO: SANDY ENGEL

A 1990 view east along Main Street in Milltown Village, once bustling with activity from a creamery, a cannery, and a feed mill.

PHOTO: RICHARD E. WEDEPOHL

Milltown's secondary wastewater treatment plant, built in 1978, consists of 2 aeration ponds and a smaller seepage pond.

became sites for villages. By 1900, when a railroad linked Milltown with Dresser, the best timber had been replaced by hay and corn (Fleming 1975). A decade later Milltown Village became incorporated (population 250) a site boasting a lumber yard, flour mill, and creamery since 1899 (Inter-County Star-Leader 1954). By then, 920 people lived in the town or village.

Milltown industry after 1900 centered around a new creamery and a cannery. The creamery became the Milltown Creamery Company in 1905, then the Milltown Creamery Cooperative Association, and finally part of Minneapolis-based Land O' Lakes, Inc. (Jennie Carlson, "Milltown history," unpubl. and undated memoir, Milltown Public Library). The creamery bought milk from local farmers, separated cream from whole milk, and churned the cream into butter; both products were trucked to St. Croix Falls, to be sold retail or shipped to other markets. A new feed mill was built about 1917; the flour mill burned a year later. A cannery built in 1926 by the Fame Soup Company was later owned by Stokely Brothers and then Stokely-Van Camp Company. The cannery paid area farmers to grow peas, sweet corn, and some beans (Richard C. Fisher, pers. comm. 1990). Private wells supplied water to these factories until 1927, when the village built a public well, a water tower, water mains, and fire hydrants (DNR microfilm file, 4 November 1927). Populations by 1930 reached 853 people in the town, plus 450 people in the village.

Population growth then shifted from town to village (Fig. 13), as drought and recession led banks to foreclose mortgaged farmland. Dry, hot weather caused outbreaks of spur-throated grasshoppers (*Melanoplus*), fought by dusting crops with lead arsenate (Messenger and Popham 1952, Borror et al. 1989). Farm numbers in the county peaked in 1935 (Kissinger 1979). The town population peaked at 927 in 1940 and declined to 691 in 1970, while the village population climbed from 469 to 634 people, owing to migration from town farms and post-war births.

But village prosperity failed to last. The creamery closed about 1954, the cannery in 1962 after a labor dispute, and the feed mill in 1982. People still moved from town to village in the 1980s, for the town grew by just 6 people and the village by 54 people (U. S. Bur. Census 1980, 1990). A village population of 1,215—forecast for the year 2000 (Wis. Dep. Nat. Resour. 1980)—seems unlikely.

Town and village growth led to solid waste and wastewater. Farm implements and household trash were dumped in the marsh, fields, or gravel pits around Milltown's Rice Creek or Rice Lake; other refuse went to a public dump north of Rice Creek. Wastewater from the cannery went to a septic tank; whey and milk waste from the creamery went to a gravel filter bed and septic tank on ground behind the creamery (DNR microfilm file, 9 July 1930)—until the village built a wastewater treatment plant.

A primary wastewater treatment plant and a lift station were completed by December 1939 on a glacial mound 1.7 km northwest of Rice Lake-Milltown (SW 1/4 sec. 17, T. 35 N., R. 17 W.). Designed to treat a mean sewage flow of 197 m^3/day, the plant consisted of a 15-m^3 sedimentation tank, a 69-m^3 sludge digester, a 5.5-m^3 chlorination tank, and two 47-m^2 sludge beds (DNR microfilm file, 17 July 1939). Raw sewage was pumped uphill and fed through a bar screen to the sedimentation (primary clarifier) tank, where liquids were separated from solids. Liquid waste was chlorinated and discharged to the marsh south of the plant; solids were concentrated in a heated digester and spread onto sludge beds to drain and dry. Liquid from the digester returned to the sedimentation tank.

But primary treatment alone proved unacceptable (DNR microfilm file, 27 June 1977). In the 1940s, the plant had to treat raw sewage containing about 77% domestic waste and 23% creamery waste, yet was designed to remove mainly solids rather than dissolved nutrients. Organic matter decomposing in the digester even added dissolved inorganic nutrients to the liquid waste destined for the marsh. Rain, snowmelt, and even ground water entered leaky sewer mains, overloading the sedimentation tank, and sending raw sewage into the marsh untreated. These events occurred repeatedly in the 1970s, including one summer when repairs closed the plant for several weeks (Ronald H. Weichelt, pers. comm. 1991). Rice Creek, usually flowing less than 0.03 m^3/sec (<1 cfs) in ice-free times (Holmstrom 1979), swelled and ran foul (La Verne H. Van Gundy pers. comm. 1989). Rice Lake-Milltown (also called "Dump Lake"—Richard C. Fisher, pers. comm. 1989) was considered one of the most fertile lakes in northwestern Wisconsin based on spring total phosphorus levels in lake water (D. Ryan, to B. J. Baker, in memo., 8 January 1990).

A secondary wastewater treatment plant and a new lift station were built beside the old plant, replacing it in December 1978. Designed to treat a mean sewage flow of 341 m^3/day (90,000 gal/day), today's plant consists of two 30,080-m^3 aeration ponds and a 10,183-m^3 seepage pond (DNR microfilm file 77-651, 27 June 1977). Raw sewage is pumped uphill and feeds through a bar screen to a fully aerated pond with 16 aerators, drains to a pond with 4 aerators at one end so that solids can settle at the opposite end, and finally enters a seepage pond where dissolved wastes percolate into the ground. Because topsoil was removed in building this plant, dissolved wastes seep through just 4.6 m of glacial sand and gravel to reach ground water flowing south or southeast toward Rice Lake-Milltown.

Treated discharge from this plant meets state standards, but improving the discharge could help water quality downstream. The discharge, for example, had suspended solids and 5-day biochemical oxygen demands that exceeded 20 mg/L in 5 of 36 months during 1984-89 (DNR Bur. Solid Waste Manage. microfilm files 85-349, 86-821, and 89-971). Water in no. 2 monitoring well, 7.5 m deep and 41 m downgradient from the plant's seepage area, had high chloride (271-380 mg/L) and total dissolved solids (612-914 mg/L) in 1981-87 as well as high ammonium-nitrogen (3.0 mg/L) and dissolved reactive phosphorus (0.168 mg/L) in September 1987 (Prusak and Franson 1987). Seepage has declined, indicating the seepage pond needs to be restored.

The village of Milltown and the DNR developed a compliance schedule to add tertiary (advanced) treatment. Under the Wisconsin Pollution Discharge Elimination System (WPDES), the village permit (WI-0024741-5) to operate the treatment plant specifies wastewater discharge to ground water, allowing emergency discharge to the marsh should the seepage pond overflow. With advanced treatment, wastewater would be sprayed onto forage crops or shunted into ponds containing aquatic macrophytes, so plants can remove dissolved nutrients left after secondary treatment (Peter J. Prusak, pers. comm. 1991). The compliance schedule calls for a facilities plan by 30 June 1991, an operation plan with construction details by 30 June 1992, construction to begin by 30 March 1993, and work to be completed by 30 September 1994. A larger plant will be needed, however, to protect the marsh if the village grows.

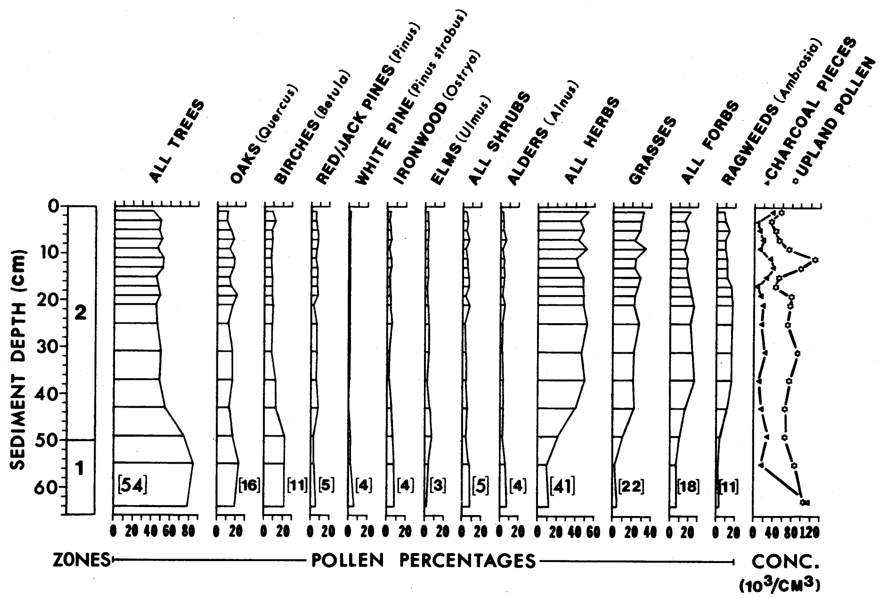


Figure 12. *Pollen profiles of upland plants that contribute at least 5% of all upland pollen in any depth sample, as well as concentrations of charcoal and all upland pollen, in the R2 sediment core from Rice Lake-Milltown. [Brackets show percentage of each pollen type as a mean of all 18 depth samples.] (Redrawn from Winkler 1989.)*

Changes at Rice Lake-Milltown

Wild rice once grew in Rice Lake-Milltown. A survey 50 years ago listed Rice Lake-Milltown as supporting "abundant aquatic vegetation" (Bordner et al. 1939). Farmers recall dense beds of wild rice in the 1950s and 1960s along the inlet creek and northwest lakeshore, plus some rice along the west and southwest shores. Aerial photographs since August 1938 show unidentified macrophyte beds in these locations during summer and fall but not in spring.

Waterfowl flocked to the marsh border with its wild rice. A survey of Polk County lakes in 1960 mentioned mallard (*Anas platyrhynchos* L.) and blue-winged teal (*Anas discors* L.) nesting along the marsh border, with American coot (*Fulica americana* Gmelin) and diving ducks stopping during migration (Sather and Threinen 1961).[2] Until a dozen years ago sora (*Porzana carolina* [L.]) flocked to wild rice crowding the north and west shores (Harvey H. Ebert, letter to DNR, 10 June 1987). The water then was so clear that boaters could watch fish cruising over

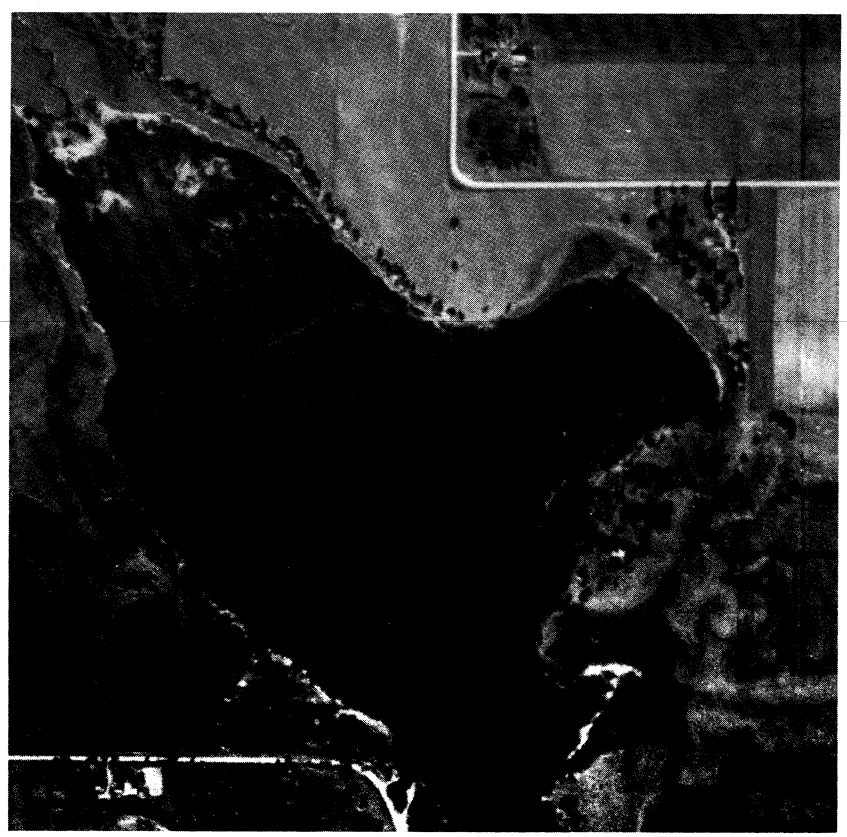


PHOTO: U. S. DEPARTMENT OF AGRICULTURE (1:20,000-inch scale)

Dense plant beds, believed to be wild rice, bordered Rice Lake-Milltown in this September 1965 aerial photograph.

[2]The American Ornithologists' Union (1983) was followed for common and scientific names of birds.

deepwater foliage (Clifford L. Ince, pers. comm. 1990) and follow a channel scoured by water flowing from inlet to outlet (Arnold J. Herwick, pers. comm. 1990).

People once fished bass and bluegill, shot waterfowl, and trapped beaver (*Castor canadensis* Kuhl) and muskrat (*Ondatra* z. *zibethicus* [L.]) on Rice Lake-Milltown. They kept as many as 10 rowboats by the east shore in the late 1950s (Arnold J. Herwick, pers. comm. 1990). Some people picked berries in summer or gathered wild rice grain in autumn. Children crossed Lloyd Reed's farm to swim by the sandy southeast shore, although the town's main public beach has been on Half Moon Lake since 1953 (Inter-County Star-Leader 1954).

Then conditions changed. Wild rice declined, ducks became scarce, anglers gave up fishing, and algae clouded the water. People no longer swam or fished the lake after about 1972 (Lloyd Reed, pers. comm. 1990). Wild rice nearly disappeared between 1972 and 1976 (Franklin [Red] G. McCurdy, pers. comm. 1990) or perhaps a few years later when water clarity deteriorated (Harvey H. Ebert, letter to DNR, 10 June 1987; Frederick J. Christopherson, pers. comm. 1990). Beavers then built dams, and the rice never recovered.

Beavers—increasing statewide for decades (Kunelius 1990) and damaging wild rice beds (Niemann n.d., Andryk 1986)—built dams across the outlet creek in the late 1970s, flooding the marsh downstream from Rice Lake-Milltown (Harvey H. Ebert, letter to DNR, 10 June 1987; Kenneth W. Kellogg, Milltown road crew, pers. comm. 1990). They also flooded the boat landing (Richard C. Fisher, pers. comm. 1990) by raising the lake level perhaps 25-40 cm (Gale G. Glenna and Arnold J. Herwick, pers. comm. 1990). Aerial photographs since 1938 show beaver dams across the outlet creek after 1977. Although the town removed all beaver dams on Rice Creek by 1984 (Kenneth W. Kellogg, pers. comm. 1990), wild rice covered just 0.04 ha (0.10 acres) on Rice Lake-Milltown the next year (Andryk 1986). A few rice plants grew by the boat landing in August 1987 but not the next summer.

Aerial photographs show also the inlet and outlet creeks nearly dry in August 1938, with modest flow from 1947 to 1965, and with high flow in the 1970s. Islands studded the lake in May 1974, when the marsh appeared flooded. Flooding continued in August 1978, when side channels crossed the marsh and the outlet creek formed 2 channels. Flooding subsided after 1980, but wild rice never recovered.

And yet beavers can sometimes benefit wild rice beds by flooding out perennial macrophytes that compete with the rice (James E. Meeker, pers. comm. May 1991). Arrowhead, bur-reed, bulrush, and water lilies, for example, begin spring growth earlier than wild rice and can crowd or shade it (Aiken et al. 1988). Flooding out these species in Rice Lake-Milltown could permit wild rice to spread by seed.

But some changes began a few decades earlier. Farming to support the village feed mill, cannery, and creamery contributed nutrients that now grow phytoplankton. The creek and even the lake stunk (LaVerne H. Van Gundy and Arnold J. Herwick, pers. comm. 1989-90), perhaps from sewage, decomposing algae, or sediment gases. Debris from bank erosion, rotting foliage, and floating islands mucked the lake bed, obliterating the channel (Arnold J. Herwick, pers. comm. 1990). A high abundance of bullheads in 1960 suggested the lake was "subject to partial winter freeze-outs" (Threinen and Sather 1961).

Loss of wild rice from the lake and creek, after decades of water quality change, proved crucial: cover for waterfowl was destroyed, invertebrate prey for panfish declined, and summer winds (aided by bullheads) scoured the lake bottom. With the rice gone and the water turbid, Rice Lake-Milltown lost its value for recreation.

Sediment remains of wetland plants, producing pollen and spores that travel short distances, showed even earlier changes to Rice Lake-Milltown. Sedges, cattails, and macrophytes with floating or submersed leaves dominated all pollen zones (Winkler 1989) but fluctuated in relative abundance (Fig. 14). Surrounding wetlands grew mosses (*Hypnum* and *Sphagnum*), true ferns (Polypodiaceae), horsetail (*Equisetum*), buckbean (*Menyanthes*), reed grass (*Phragmites*), orchids (Orchidaceae), and sedges (Cyperaceae)—plants widespread during early (19th century) land clearing (Burt 1849-50). Water lilies, wild rice, floating-leaf pondweed, watermilfoil, and bladderwort (*Utricularia*) grew offshore.

Below a sediment depth of 50 cm (wetland Zone A = upland Zone 1) wetland pollen comprised 20-25% each of sedges, cattails, and macrophytes with floating or submersed leaves (Figs. 12, 14). Pickerelweed (*Pontederia*) and quillwort (*Isoetes*) grew in shallows, suggesting Rice Lake-Milltown had clearer water and a firmer bottom than at present.

Above 50 cm (Zones B, C, and D) wetland pollen comprised about 30-32% each of sedges, cattails, and macrophytes with floating or submersed leaves. Other wetland pollen decreased from 32% to 8%, suggesting loss of wetland diversity with a shift to a more cultivated and weedy landscape (Winkler 1989). Nettle (*Urtica*), bedstraw (*Galium*), and mint (Labiatae) pollen at Zone B (20-50 cm) indicated wetland disturbance during early land clearing. Mean concentration of all wetland pollen fell by 50% between Zones A and B (Fig. 14), suggesting that early land clearing reduced overall wetland area, plant density, or both.

Sedges (including bulrushes) and cattails fluctuated in relative abundance: Sedge pollen dominated in 11 samples; cattail pollen, in 5 samples. Pollen counts for sedges and cattails differed by at least 2 fold in 13 of 18 samples. Falling water levels could have favored cattails by exposing mudflats for seeding (Curtis 1959); expanding muskrat populations could have favored bulrushes by "eating out" cattail beds (Jackson 1961). Nutrient enrichment in recent decades could maintain the present cattail dominance on Rice Lake (Univ. Wis.-Madison Water Resour. Manage. Workshop 1990).

Waterborne pollen (32-36 μm) from wild rice increased above 50 cm as well, a sign that rice beds had spread after early land clearing. Loss of wetland cover or competing species perhaps opened more shallows in the lake or inlet creek to wild rice.

Remains of algae in Rice Lake-Milltown sediment—cells, cysts, coenobia, and chlorophyll breakdown products—suggest water fertility first rose and then fell during recent decades (Fig. 15). Below 20 cm (Zones A and B) algae remained scarce and included green algae (*Botryococcus*, *Coelastrum*, *Pediastrum*, *Scenedesmus*, and *Tetraedron*), chrysomonads (*Synura*), and other cells (Winkler 1989). From 20 cm to 8 cm (Zone C) algal diversity stayed low; dinoflagellate cysts and *Pediastrum* coenobia increased more than 10 fold. Phaeo-pigments, mainly phaeophytins and phaeophorbides (Strickland and Parsons 1972), increased nearly 4 fold above 35 cm. Correlated significantly ($P < 0.05$) with counts of *Pediastrum* coenobia, the pigments peaked at 8 cm (127 µg/g) and declined by nearly 50%.

Phaeo-pigments can increase, however, when sediment becomes anaerobic rather than when algae proliferate. Anaerobic conditions can develop when microorganisms decompose organic matter that formed outside the lake and thus have no relation to algal production. Yet pyrite framboids, formed when iron and sulfur precipitate under anaerobic conditions, were not significantly correlated ($P > 0.20$) with phaeo-pigments or *Pediastrum* coenobia in Rice Lake-Milltown sediment. Flocculent sediment in the upper core could even have been aerated by wind scouring. The phaeo-pigment rise from 20 cm to 8 cm thus seemed unrelated to anaerobic conditions in the sediment.

The paleolimnology record, together with survey reports and oral testimony, shows that Rice Lake-Milltown remained clear despite a century of nutrient loading from logging, farming, milling, and housing. Wastes were spread on ground or sent to septic tanks about Milltown, until the primary wastewater treatment plant centralized waste disposal and funneled nutrients to the marsh. Soon the creek and lake water ran foul. But Rice Lake-Milltown still remained clear, bass and bluegill still spawned, and wild rice still matured.

Change became evident in the 1970s, when farmers watched the lake flood, wild rice decline, water clarity deteriorate, and bass and bluegill fishing end.

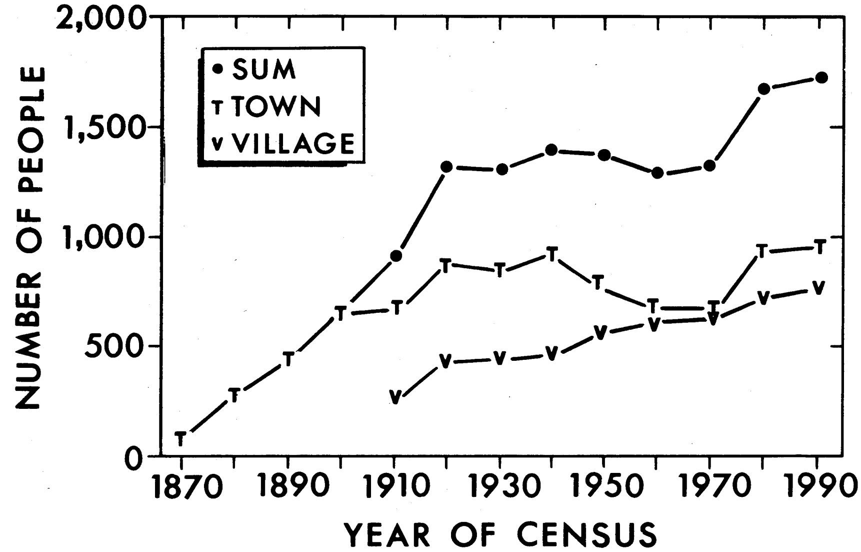


Figure 13. *Population growth of Milltown's village and town as well as the sum of both populations. Data are from U. S. Bur. Census (1870-1990).*

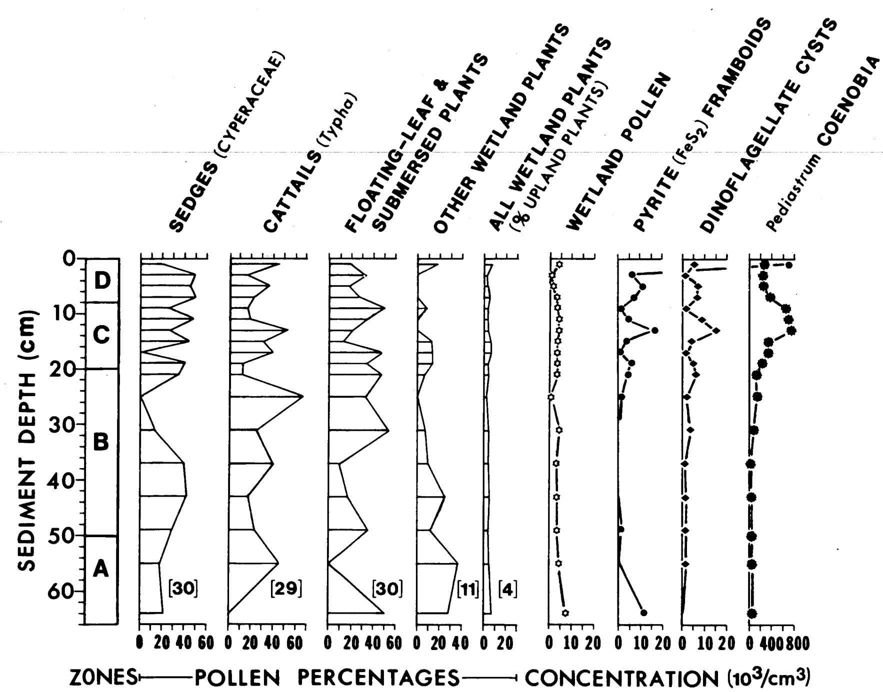


Figure 14. *Pollen profiles of wetland plants, as well as concentrations of algae and all wetland pollen, in the R2 sediment core from Rice Lake-Milltown. [Brackets show percentage of each pollen type as a mean of all 18 depth samples.] (Redrawn from Winkler 1989.)*

The phytoplankton and phaeo-pigment rise in lake sediment from 20 cm to 8 cm attest to the change in lake fertility.

Decline in algal remains above 8 cm suggests recent improvement in water quality but could be due to disturbance or less compaction of top sediment. Perhaps secondary wastewater treatment and drought in the 1980s reduced nutrient loading and thus phytoplankton growth. Perhaps wind scouring disturbed the top sediment and kept it from compacting. Even with reduced nutrient loading, water clarity will remain low until bottom scouring from wind and bullheads can be curtailed.

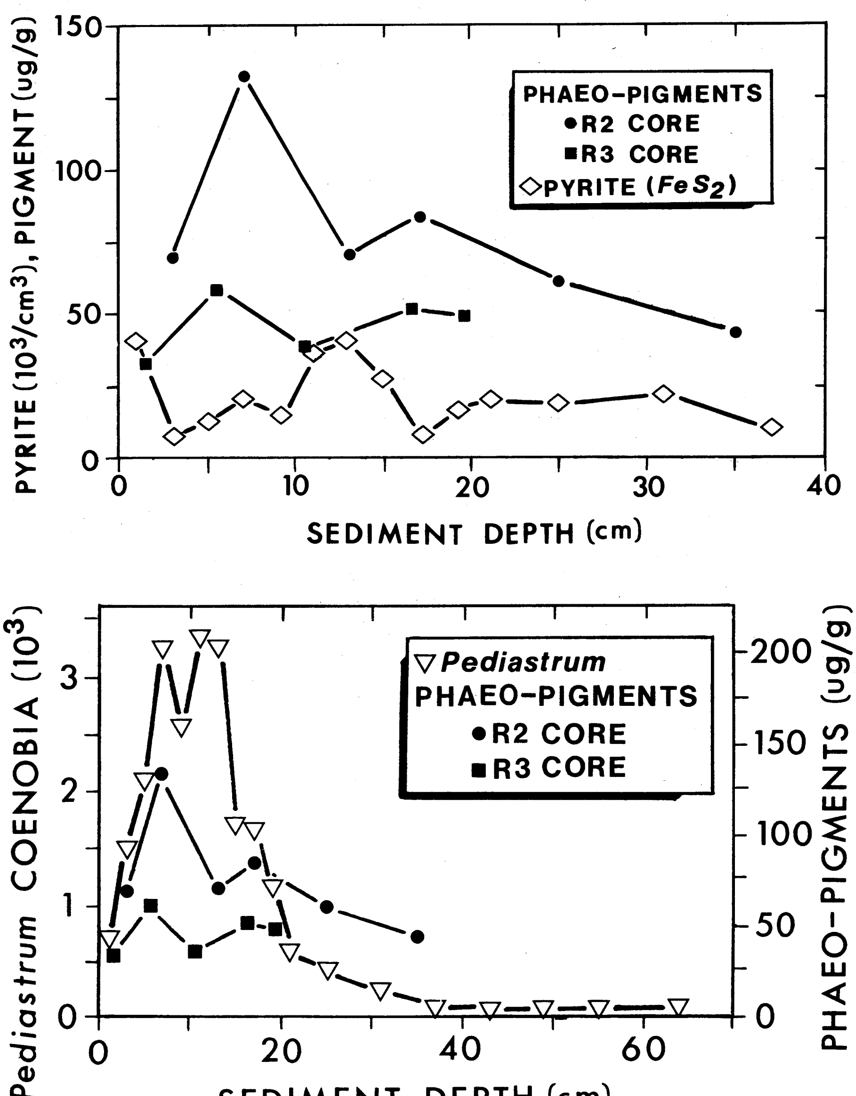


Figure 15. *Plant phaeo-pigments from the R2 and R3 cores compared with pyrite framboids (top) and* Pediastrum *coenobia (bottom) from the R2 core, collected 20 September 1988 at Rice Lake-Milltown. (Redrawn from Winkler 1989.)*

Ground Water and Surface Flow

Because Rice Lake-Milltown is both spring and surface fed, lake levels can fluctuate with ground water and precipitation.

The water table at Milltown Village rose and fell as much as 2.9 m, from a minimum on 13 September 1960 to a maximum on 23 July 1986 (Fig. 16). Differences between highest and lowest levels within years averaged 0.6 m. Nearly one-third of annual lows were recorded in March, just before spring thaw; one-quarter of annual highs occurred in December, after fall rains recharged the ground water.

Despite these annual and seasonal fluctuations, the water table stayed low in 1958-65 and 1988-90 (mean 369.6 m) and stayed high in 1972-73, 1975-76, and 1984-86 (mean 371.3 m).

Stream flow from the marsh 0.9 km northwest of Rice Lake-Milltown also rose and fell with ground-water levels. During base flow, when little rain fell, discharge from the inlet culvert draining the marsh was 7 times greater on 6 dates in 1972-76 (0.014 m^3/sec) than on 27 dates in 1988-89 (0.002 m^3/sec) (Holmstrom 1979; U. S. Geol. Surv., Madison, Wisconsin, unpubl. data). Aerial photographs since 1938 also show greater stream flow in the 1970s than in earlier or later decades. High ground water, plus discharge from Milltown's wastewater treatment plant, account for this greater flow.

Ample snowmelt and rainfall after 1964 recharged the water table and kept it mostly above average in the 1970s. But drought in 1987-89 depressed the water table by 2.7 m after a lag of about 5 months (Fig. 16).

The water level of Rice Lake-Milltown probably rose in the late 1960s and stayed high until a few years ago. Precipitation, ground water, and marsh runoff kept the lake level high until the late 1970s, when beaver dams across the outlet creek continued the flooding despite lower ground water. Although the dams were removed by 1984, high ground-water levels returned and kept the lake level above normal until drought struck in 1987.

Such lake-level changes could have affected water quality and macrophyte growth in Rice Lake-Milltown. High lake levels meant greater nutrient loading; low lake levels meant greater dissolved oxygen loss in winter. High water during the 1970s coincided with decline in swimming, wild rice, and bass and bluegill fishing; low water during the early 1960s would have favored cattails over bulrushes and submersed macrophytes over phytoplankton. Flooding thins wild rice beds, which results in spindly plants (Thomas and Stewart 1969; Stevenson and Lee 1987) that fail to set seed (Pip and Stepaniuk 1988). Flooding also reduces sago pondweed growth (Kantrud 1990).

During the 33 years of groundwater monitoring, the greatest winter stress on fish probably came during low water about 1960. The greatest nutrient loading to Rice and Balsam lakes probably came during high water in the 1970s, when primary wastewater treatment sent nutrient-rich effluent down Rice Creek.

Rice Creek (leaving Rice Lake as upper Balsam Branch) has been a major water and nutrient source to Balsam Lake (Rose 1993). During the 1987-89 drought, it carried 90% of phosphorus received by Little Balsam Bay and 60% of that received by entire Balsam Lake (Table 22). Most nutrients came from Rice Lake and its marsh, enriched by Milltown industry and sewage treatment. Some nutrients came from a dairy farm along the outlet creek and from a pond and marsh drained by Otter Creek. Wet years could drain even more nutrients into Rice Creek, because of greater nutrient release from marsh and farms.

But some nutrients could be held back by planting wild rice in Rice Lake-Milltown. The rice foliage can store nutrients and keep sediment from washing downstream. If enough rice grew, the lake could improve as a nutrient trap or settling basin for Balsam Lake.

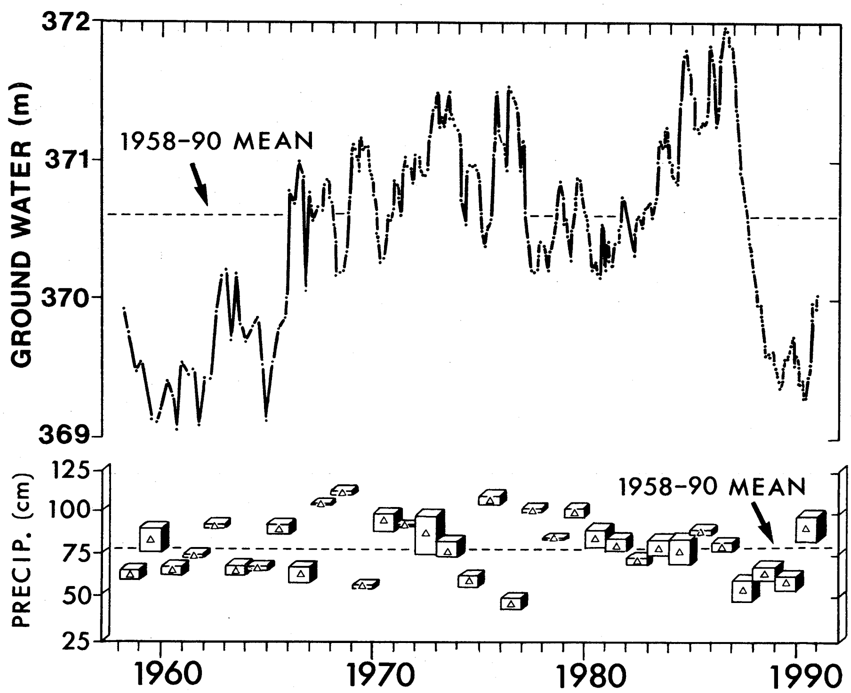


Figure 16. *Groundwater levels (height above mean sea level) at Milltown Village (top) and precipitation totals at Amery and St. Croix Falls (bottom). Vertical bars show mean (triangle) and range (height) of annual total precipitation between sites.*

Table 22. *Sources of total phosphorus and water received by Little Balsam Bay and entire Balsam Lake from December 1987 through November 1989.**

	Little Balsam Bay		Entire Balsam Lake	
Source	Phosphorus	Water	Phosphorus	Water
Rice Creek (%)	90	72	60	26
Ground water (%)	3	21	5	20
Nearshore drainage (%)	6	2	20	4
Harder Creek (%)	–	–	6	12
Precipitation (%)	<1	5	9	38
P (kg); water (acre-ft)**	**277**	**4,132**	**416**	**11,336**

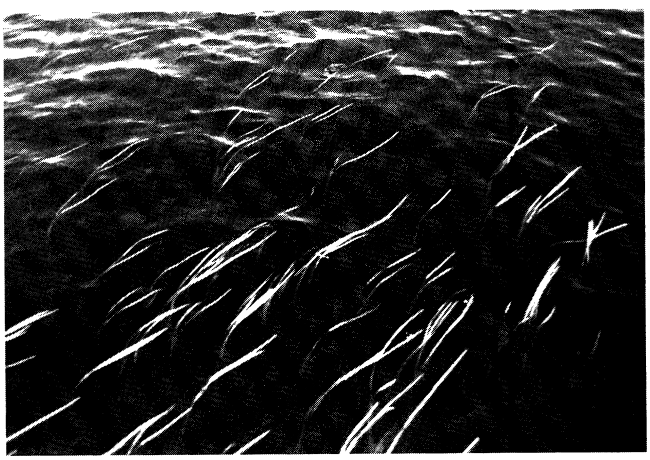
* Data were compiled by William J. Rose, U. S. Geological Survey, Madison, Wisconsin (Rose 1993).

** Total phosphorus (P) and water were total amounts received from 1 December through 30 November, averaged for 1987-88 and 1988-89.

PHOTO: SANDY ENGEL

Rice Creek, draining Rice Lake-Milltown, meanders beside a dairy farm before reaching Balsam Lake.

Two buckets of wild rice seeds, totaling 12.5 kg (27.5 lb), were picked from Rice Lake-Horse Creek and sowed in Rice Lake-Milltown in September 1988.



PHOTOS: SANDY ENGEL

Wild rice, sown in Rice Lake-Milltown, with floating leaves on 25 May 1989.

Re-establishing Wild Rice

None of the macrophytes planted from tubers, root stocks, or shoot bundles (Table 6) in May or June 1989 grew well in Rice Lake-Milltown. Giant bur-reed, marsh smartweed, and Richardson pondweed failed to sprout even in aquaria, indicating poor nursery stock. The other plants grew well in aquaria but not in the lake: Elodea and coontail shoots disappeared, unable to reach the water surface before water clarity deteriorated. Sago pondweed tubers also disappeared or the sprouted shoots became indistinguishable from wild plants invading the plots. Only wild celery tubers showed promise, sending leaves to the water surface by late summer. But they failed to grow the next summer.

Wild rice sown in September of 1988 and 1989 (see Fig. 3 for locations) sprouted in all lake plots by June, formed emergent leaves by July, and set seed by September of the following years. Mature plants developed an average of 19 emergent shoots (culms and tillers) and 825 seeds, of which 92% were able to sink when seed heads were shattered by wind.

Wild rice covered 0.2 ha (0.5 acres) of Rice Lake-Milltown in August 1989, averaging 47 stems/m^2 or about 60% of their mean density in Rice Lake-Horse Creek (Table 23). About 6,000 plants, comprising 112,800 emergent stems, matured from 3% of seeds sown in 1988. They produced nearly 5 million seeds—26 times the number sown (Table 24).

Rice beds covered 0.8 ha (2.0 acres) in August 1990, but averaged only 30 stems/m^2. Yet over 3 times as many plants were produced as in 1989.

Winds, waves, and ice affected rice production in both years. Plots by the inlet more than doubled in area, because of seed drift from winds and waves. An island torn loose during ice-out in 1989 scraped across a plot, carrying away seeds in the sediment. A storm in August 1990 uprooted plants and thinned a rice bed by the inlet, reducing its mean density to less than half of that at the outlet.

Table 23. *Wild rice density and cover in each Rice Lake on 7-8 August 1989.*

Plant Measure	Rice Lake at Milltown	Rice Lake at Horse Creek
Stand density (mean ± 1 SE)		
Stems (number/m^2)	47 ± 8	78 ± 10
Whole plants (number/m^2)	2.5 ± 0.4	4.2 ± 0.5
Total cover (area ± 10%)		
Lake surface covered (%)	0.6 ± <0.1	74 ± 7
Area of rice bed (ha)	0.2 ± <0.1	29 ± 3

But muskrats caused the most damage. Swimming through rice beds, they bend and nip rice shoots (Ronald G. Eckstein, DNR, pers. comm. 1990). More than 90% of shoots emerging from Rice Lake-Milltown in July 1990 were bitten off; damage was much less in 1989. Nipped rice growing in 0.5-1.0 m of water on 24 July 1990 stood 17 ± 0.9 cm (mean ± 1 SE) above the water level—26 cm shorter than unnipped rice. Such damage can destroy small stands, though larger established ones are less vulnerable (Dore 1969, Aiken et al. 1988).

A small muskrat population occupied the marsh bordering Rice Lake-Milltown during the study. Leg traps set from 5 May to 7 June 1991, under a DNR animal damage control permit (Wisconsin statute 29.596), caught 21 adult muskrats, mostly in marsh by the inlet and the outlet (Eugene H. Hallberg, trapper, pers. comm.). Almost as many were trapped in fall 1989, though many more occupied the marsh in the 1960s when wild rice was abundant (Eugene H. Hallberg, pers. comm.).

Rice beds intercept and store nutrients that could otherwise wash downstream and fuel algal blooms. Averaging 1.73% nitrogen and 0.29% phosphorus by dry weight, the entire rice bed in Rice Lake-Milltown stored just 11 kg (25 lb) of nitrogen and 2 kg (4.4 lb) of phosphorus in September 1989 (Table 25). But the rice bed in Rice Lake-

Horse Creek, nearly twice as dense and covering 74% of the lake surface (excluding marsh border), stored about 2,300 kg (5,066 lb) of nitrogen and 400 kg (889 lb) of phosphorus in September.

Harvesting 6,000 wild rice shoots after seeds shatter in September would eliminate about 7.8 kg (17.2 lb) of nitrogen and 1.3 kg (2.8 lb) of phosphorus—nutrients destined to be released into the water column when the shoots decay.

About 75% of Rice Lake-Milltown is shallow enough to grow wild rice. If wild rice covered 20% of the lake, at the same density found on Rice Lake-Horse Creek, 837 kg (1,845 lb) of nitrogen and 140 kg (309 lb) of phosphorus could be stored in summer foliage (Table 26). This much wild rice could hold back one-third of phosphorus that entered Balsam Lake, half of what entered Little Balsam Bay, during the 1987-89 drought (Table 22). But will that be enough to improve water clarity in Rice Lake-Milltown and reduce nutrient loading to Balsam Lake in summer?

Wild rice shoots on 24 July 1970, nipped by muskrats. The shoots stand in water 43 cm deep. Only 12 of 39 shoots in this stand remained unnipped, averaging 44 cm taller than nipped ones.

PHOTOS: SANDY ENGEL

A mature wild rice bed covering about 0.1 ha (0.25 acres) on 11 September 1989, sown a year earlier by the inlet to Rice Lake-Milltown.

Table 24. *Yield from 12.5 kg (27.5 lb) of wild rice seeds sown on 9 September 1988 in Rice Lake-Milltown.*

Plant Measure	Yield (mean ± 1 SE)
Yield for average plant in 1989	
Seeds (number)*	825 ± 119
Stems (number)	19 ± 3
Total biomass (g)	111 ± 18
Yield for all plants in 1989	
Seeds (number)	4,950,000 ± 851,400
Stems (number)	112,800 ± 18,600
Whole plants (number)	6,000 ± 1,032
Total biomass (kg)	665 ± 109
Seeds sown in 1988	**187,000 ± 2,000**

* Seeds were counted from unshattered seed heads of 5 mature plants, chosen randomly from a total of 2 lake plots.

Table 25. *Nutrient content of all wild rice growing in each Rice Lake during September 1989.**

Nutrient	Nutrient Content (kg) for Rice Lake	
(mean percent dry weight)	Milltown	Horse Creek
Nitrogen (1.73%)	11	2,298
Potassium (1.39%)	9	1,882
Calcium (0.47%)	3	640
Phosphorus (0.29%)	2	403
Sulfur (0.25%)	2	394
Magnesium (0.18%)	1	247

* Nutrient content was calculated for each lake by multiplying the mean nutrient weight of 5 whole plants times the mean rice density of 10 random plots and the area covered by all rice plants.

Table 26. *Nitrogen and phosphorus expected in wild rice beds covering 10-40% of Rice Lake-Milltown, grown at 50% or 100% of the wild rice density found in Rice Lake-Horse Creek.*

Rice Density on	Nutrient Content (kg) by Area (%)			
Rice Lake-Horse Creek	10	20	30	40
Nitrogen				
50% (40.3 kg/ha)	209	419	628	837
100% (80.5 kg/ha)*	419	837	1,256	1,675
Phosphorus				
50% (6.7 kg/ha)	35	70	105	140
100% (13.5 kg/ha)*	70	140	210	280
Area of rice bed (ha)	**5.2**	**10.4**	**15.6**	**20.8**

* A 100% density equals the wild rice density (4.2 plants/m^2) found in Rice Lake-Horse Creek on 7 August 1989.

Summary

Shallow lakes can become windswept with loss of emergent plant cover. The DNR's Shallow Lakes Initiative combined a research and management effort to learn how wind affects plant growth and water quality, how water quality has changed, and how wild rice can be reestablished. From August 1987 through October 1991 two Rice lakes in Polk County were compared: one at Milltown that lost wild rice and the other at Horse Creek that still grows wild rice.

Recent Macrophyte Growth

Three macrophytes zones formed in each Rice Lake: an emersed zone of marsh border dominated by cattails (Milltown) or wild rice (Horse Creek), a floating-leaf zone mainly of water lilies, and a submersed zone dominated by sago pondweed (Milltown) or chara (Horse Creek).

Summer macrophyte cover differed between lakes: Emersed and floating-leaf plants covered 39% of lake and marsh border at Milltown but 67% at Horse Creek. The submersed flora comprised 5 species at Milltown but 10 species at Horse Creek. Averaging just 6-11 g/m^2, Milltown's submersed flora consisted of 84-92% sago pondweed and the rest coontail, elodea, floating-leaf pondweed, and water crowfoot. The sago pondweed formed peculiar ring or loop formations related to water turbidity.

Present Limits to Growth

Wind, bullheads, and green algae (Chlorophyceae) muddied lake water in Rice Lake-Milltown. From winter to summer, Secchi disk transparency decreased 5 fold while chlorophyll *a* increased 14 fold. Rice Lake-Milltown's flatter topography, 23% larger lake surface, dearth of wild rice, and finer sediment gave wind greater impact than at Horse Creek.

Milltown's marsh and lake behaved as nutrient sinks during the 1987-89 drought. Marsh water was more fertile and 8-11 times richer in sodium and chloride than lake water. Metal concentrations decreased 30-65%, total Kjeldahl nitrogen decreased 48%, from the marsh to the outlet creek.

Water turbidity limited macrophyte growth to 1.1 m in Rice Lake-Milltown, leaving the lower 0.7 m without attached plants. Cold water in April and rising turbidity after May gave seeds and tubers only 4 weeks to sprout and surface. Those growing later, such as coontail and elodea planted in June 1989, became shaded by green algae (chiefly *Oocystis*, *Scenedesmus*, and *Sphaerocystis*). Water turbidity therefore created a depauperate flora, dominated by macrophytes growing early from tubers or root stocks.

Black bullhead, pumpkinseed, yellow perch, white sucker, and fathead minnow together made up 95% of 10 fish species electrofished or fyke netted in Rice Lake-Milltown. Largemouth bass and common carp were not found. Northern pike, ranging from 350-991 mm long, were top carnivores.

Winter lake ice reduced water volume by one-third; dissolved oxygen depletion further restricted fish to less than 15% of lake water in summer. Yet ample dissolved oxygen by the inlet, and a flowing ice-free creek, permitted winter survival. Water turbidity from wind and algae during ice-free times could explain why sight-feeding bass and bluegill became scarce, while smell-feeding bullheads became dominant.

Midge larvae (Diptera), averaging 827 organisms/m^2 at 6 bottom stations, were the only winter invertebrates collected with an Ekman grab from Rice Lake-Milltown. The sediment smelled of hydrogen sulfide. Sediment freezing, prolonged oxygen depletion, spring ice heave, bottom scouring by wind, and fish predation could explain this depauperate bottom fauna.

Ice and wind dislodged sediment, uprooted emersed macrophytes, and created floating islands in Rice Lake-Milltown. Ice, wind, and islands damaged wild rice sown by the inlet.

Looking Back at Milltown

The lightly wooded uplands and marshy lowlands surveyed in June 1853 gave way to farmland, reducing total upland pollen by 43% in Rice Lake-Milltown sediment. Pollen grains first shifted from trees to herbs, with spread of ragweed and grass, and then from ragweed to cultivated grain. Farming reduced overall wetland area, plant density, or both.

Village growth created solid waste and wastewater. Raw and treated sewage—from mills, farms, and households—went into Milltown's marsh and washed downstream to Rice Lake.

During the 1970s, when precipitation and beavers kept water levels high, wild rice almost disappeared from Rice Lake-Milltown. That exposed the lake bottom to wind scouring and reduced habitat for waterfowl, bass, and bluegill. Water turbidity created by algae and suspended particles limited submersed macrophyte growth as well. No longer used for fishing and swimming, Rice Lake-Milltown went unmentioned in the Village of Milltown's 1981-86 outdoor recreation plan (Polk Co. Plann. Off. 1981).

Re-establishing Wild Rice

Northern wild rice grown from seed covered as much as 0.8 ha (2.0 acres) of Rice Lake-Milltown. Seeded plots averaged 47 stems/m^2, about 60% of the mean density growing wild in Rice Lake-Horse Creek. But wind and muskrat damage kept many stems from maturing and setting seed.

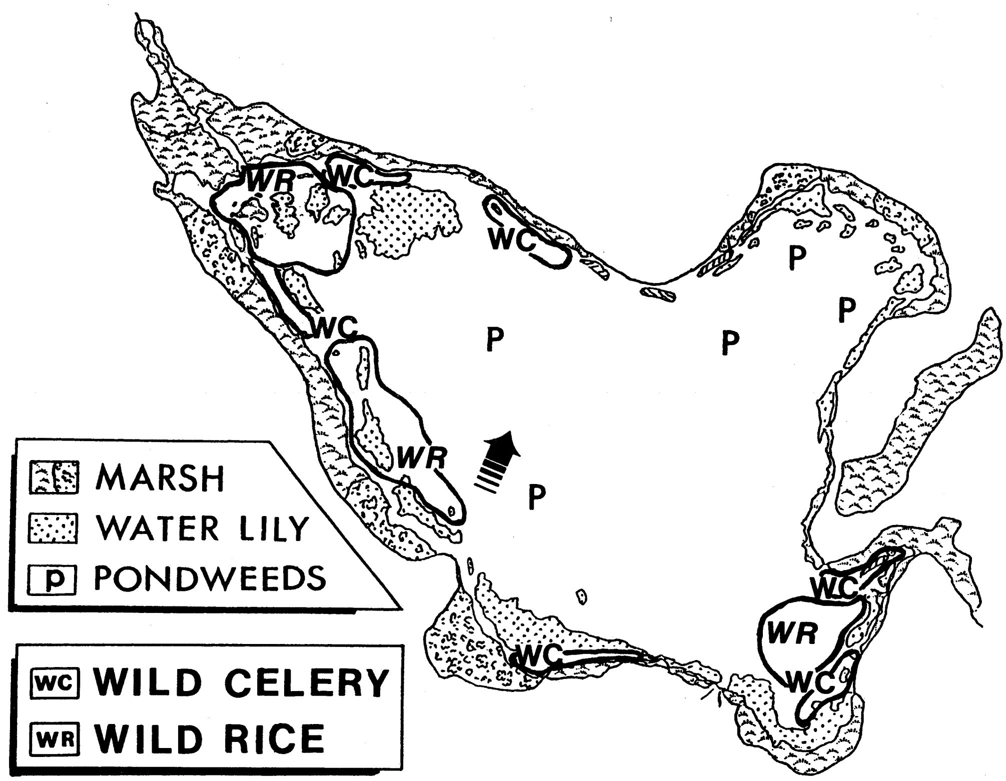


Figure 17. *Aquascaping plan for Rice Lake-Milltown, showing 1991-92 plantings of wild celery tubers (May) and wild rice seeds (September). The large arrow shows prevailing summer winds from the southwest.*

LESSONS FROM RICE LAKE: MANAGEMENT CONSIDERATIONS

Water quality in Rice Lake-Milltown fell from decades of change: nutrient loading from Milltown's village and farms, high water from wet years and beaver dams, bottom scouring from wind and waves, and bullhead dominance from winterkill and especially water turbidity. The fall was a community loss—the reward of community neglect.

Milltown lost more than wild rice. With the lake water turbid, few people visited Rice Lake-Milltown to boat, fish, or swim. Some trashed the boat landing, leaving it in disrepair. A generation of children grew up without knowing the wild rice marsh their parents knew, or the soras and ducks the rice once attracted. The lake lost much of its value—to people and marsh life.

Rice Lake-Milltown can be improved by continuing to plant wild celery tubers in May and wild rice seeds in September along the inlet, west shore, and outlet (Fig. 17). This 20% cover could stabilize sediment and store nutrients during summer. The reward could be improved water clarity, fish and waterfowl habitat, and lake use.

Despite such damage, some seeds sprouted from sediment frozen in winter and scoured in spring. Nipped shoots grew but set few seeds. Yet if 1% of the seeds produced in 1989 sprouted, and 13% of the sprouts matured, 6,000 plants would be replaced. Wild rice therefore can still grow in Rice Lake-Milltown. But annual sowing and muskrat control will be needed to allow wild rice to mature, spread, and build a seed bank.

But restoring Rice Lake-Milltown will take more than just wild celery and wild rice: A community effort is needed. Farmers along the lake and creek must curb cows and conserve fertilizers to reduce nutrient runoff. Trappers must work with DNR wildlife managers and conservation wardens to control muskrats that nip wild rice and beavers that raise water levels. The town must repair and maintain the boat landing to improve lake access. The village must improve wastewater treatment to keep nutrients from reaching the marsh and creek. DNR fish managers must control bullheads to reduce sediment suspension. Everyone must ultimately work together—farmers, trappers, town road crew, village workers, and DNR managers—to restore Rice Lake.

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Laboratory work took expert hands: Robert E. Last counted phytoplankton and sieved bottom fauna; Olaf G. Olson counted bottom fauna; John D. Parsen analyzed sediment texture and wild rice nutrient content at the University of Wisconsin-Extension Soil and Plant Analysis Laboratory; George T. Bowman, Thomas A. Gibson, and Bob A. Schuknecht coordinated chemical analyses of water or sediment at the State Laboratory of Hygiene; James F. Amrhein analyzed contaminants in 3 electrofished northern pike; Patrick J. Perkins and Howard E. Snow examined fish scales to check our age estimates; Paul J. Garrison analyzed phaeo-pigments in the R2 and R3 sediment cores; and Marjorie G. Winkler of the University of Wisconsin-Madison Center for Climatic Research completed algal and pollen analyses of the R2 sediment core.

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Changes to Milltown or Rice Lake became less of a puzzle when we interviewed Wayne D. Lindberg of Amery; Harvey H. Ebert of Balsam Lake; Clifford L. Ince and Franklin (Red) G. McCurdy of Centuria; DNR conservation warden Brian S. Fellrath of Luck; and Frederick J. Christopherson, Richard C. Fisher, Gale G. Glenna, La Verne H. Van Gundy, Eugene H. Hallberg, Arnold J. Herwick, Kenneth W. Kellogg, John (Jack) O. Overby, Lloyd Reed, Duane S. Roufs, and Ronald H. Weichelt of Milltown.

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Approximate Metric-English Equivalents

1 ha = 2.47 acres	1 L = 1.06 qt
1 m = 3.28 ft	1 g = 0.035 oz
1 cm = 0.39 inches	1 kg = 2.21 lb
1 km = 0.62 miles	1 metric ton = 1.10 tons
1 m^2 = 1.20 yd^2	

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