Diatom-Inferred TP in MCWD Lakes
(Work Order #116-04)

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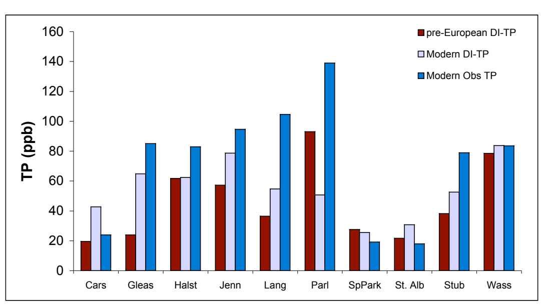
SUPPLEMENT CONTENTS

PROJECT SUMMARY

Contemporary water quality data, surface sediment samples, and long sediment cores were collected from ten lakes and bays of the Lake Minnetonka watershed (Minnesota, U.S.A.) between April and September 2005 to compare background (pre-European settlement) or natural nutrient levels to modern nutrient conditions in these water bodies. Water quality data were collected from each site on five sampling dates between May and September 2005 and included Secchi depth, temperature, dissolved oxygen (DO), conductivity, pH, total phosphorus (TP), soluble reactive phophorus (SRP), total nitrogen (TN), chlorophyll a, dissolved organic carbon (DOC), color, sulfate, chloride, alkalinity, and silicate concentration. Monitoring indicated that the lakes and bays within the Lake Minnetonka watershed have modern water quality conditions ranging from mesotrophic bays on the main body of Lake Minnetonka to hypertrophic lakes and bays along the south, west, and northern reaches of the watershed

Long sediment cores (~1.9 m) were provisionally dated using digital imaging, magnetic susceptibility logging, and gamma analysis of 210-Pb and 137-Cs to determine levels of downcore sediments that corresponded to pre-European settlement (pre-1850 A.D.) sediments. A diatom calibration dataset based on diatom assemblages and modern water quality data from 89 Minnesota lakes, including the ten sites within the Lake Minnetonka watershed, was constructed to facilitate estimation of historical and modern total phosphorus levels from subfossil diatom assemblages. Two downcore samples, representing lake conditions before European settlement, and one upcore sample, representing modern lake conditons, were analyzed from each coring site for diatom microfossils. A transfer function generated from the calibraton dataset and based on each diatom species total phosphorus optimum was applied to all core diatom assemblages to reconstruct diatom-inferred total phosphorus (DI-TP) for pre-European and modern times.

Lakes and bays in the Minnetonka watershed generally showed three patterns of change between pre-European and modern nutrient conditon (Table 1 and Fig. 1). Carsons, St. Albans, and Spring Park Bays have modern mesotrophic nutrient conditions (10-50 ppb TP) and showed little change between pre-European and modern conditions. Gleason Lake, Stubbs Bay and Langdon Lake were all mesotrophic in pre-European times and are currently eutrophic (50-100 ppb TP) to hypertrophic (>100 ppb TP) water bodies with modern TP levels above 60 ppb. Wasserman Lake, Halsteds Bay, and Jennings Bay were eutrophic systems in pre-European times and are currently eutrophic to hypertrophic. One lake, Parley, gave problematic reconstructions of DI-TP. Recommendation is to analyze the Parley Lake core in greater temporal detail, perhaps decadal resolution between 1800-2000 A.D. using a full 210-Pb dated core.



SUPPLEMENT SUMMARY

During Phase I of MCWD sediment coring it was determined that the core collected from Wasserman Lake in 2005 was not of sufficient length to recover pre-European settlement. In August of 2006, we relocated our coring position and collected an additional 2 m of sediment from below the 1.8 m of sediment that was collected. Using gamma Pb-210 analysis we determined that the sample from 332 cm core depth did not have any unsupported Pb-210 and thus represented pre-European sedimentation. Samples from 332 and 337 cm were analyzed for diatom remains and a transfer function based on diatom species-environment relationships was applied to estimate pre-European total phosphorus (TP) levels in Wasserman Lake of approximately 78 ppb TP. Compared to modern diatom-inferred and directly measured TP levels of ca. 84 ppb TP, we conclude that Wasserman Lake has long been a eutrophic system. Included in this Supplement report are updated results, figures, tables and project summary that expand or replace similar sections in the June 2006 Final Report "Diatom-inferred TP in MCWD Lakes (Work Order #116-04)" by Edlund and Ramstack (2006).

RESULTS & DISCUSSION-SEDIMENT CORE RECONSTRUCTIONS

The logTP transfer function was applied to downcore diatom assemblages in nine sediment cores recovered in 2005 from sites in the Minnetonka watershed to calculate diatom-inferred total phosphorus (DI-TP). From each core, two samples representing sediments deposited before regional European settlement provide a measure of baseline or natural nutrient conditions in these lakes. Presettlement conditions can be compared to a DI-TP estimated from a third core sample (0-2 cm) representing modern conditions, the DI-TP based on training set development, and to monitoring records collected by MCWD in 2005 (Table 5). There is an overall trend in the lakes of increased DI-TP in modern vs pre-European conditions (Fig. 3). Several of the lakes/bays with good modern water quality show little change between pre-European and modern DI-TP.

Carsons Bay is currently mesotrophic with observed annual TP of approximately 24 ppb TP. A mean pre-European DI-TP of 19.5 ppb TP suggests that modern Carsons Bay nutrient dyamics are similar to historical conditions. Modern DI-TP reconstructed slightly higher than observed values.

Gleason Lake experiences wide variation in modern TP levels of 25-120 ppb with a annual mean of 85 ppb TP. Modern DI-TP of 65 ppb TP was similar to observed values. Based on pre-European DI-TP values of 24 ppb TP, we can conclude that Gleason Lake has been heavily impacted since European settlement and seen a shift from mesotrophic to very eutrophic conditions.

Halsteds Bay, on Minnetonka's western side, is currently a very productive portion of Lake Minnetonka with a mean observed TP of 83 ppb. Modern DI-TP was estimated at 62.5 ppb, well within the range of observed values. Historical DI-TP estimates of 62 ppb TP suggest that Halsteds Bay has long been a very productive water body with similar nutrient dynamics between historical and modern times.

Jennings Bay is located in the northwest portion of the Minnetonka watershed and is currently a eutrophic to hypertrophic bay with observed TP values of 48-137 ppb (annual mean 95 ppb TP). Modern DI-TP reconstruction was 79 ppb TP whereas pre-European DI-TP values were estimated at 57 ppb TP suggesting that although Jennings Bay has long been a productive system, modern conditions are more eutrophic.

Langdon Lake is located on the western side of the Minnetonka watershed and shows a similar trend to Jennings Lake. Modern observed TP ranges from eutrophic to hypertrophic (76-127 ppb TP) with an annual observed mean of 95 ppb TP. Modern DI-TP estimates were slightly lower than observed values with a mean modern DI-TP of 55 ppb. Pre-European DI-TP was estimated at 36 ppb TP which indicates that modern Langdon Lake is rather impacted by excess nutrients.

Parley Lake is the most problematic lake in this analysis. Modern Parley Lake is hypertrophic with an observed annual mean TP of 139 ppb (range 72-196 ppb). Modern DI-TP reconstructed much too low at 51 ppb TP and pre-European DI-TP was estimated very high at 93 ppb. Surprisingly, all core samples had good analogues in the modern training set of 89 Minnesota lakes. As expected Parley2 had its best analogue in the modern Parley Lake sample. Parley142 and Parley147 were most similar to lakes in the highly agriculturally impacted Western Corn Belt Plains Goose Lake (Lyon Co., 42-0093) and Cottonwood Lake (Cottonwood Co., 17-0022), respectively. I would not be comfortable suggesting that Parley Lake was hypertrophic in pre-European times and would recommend that a more detailed analysis of the Parley Lake core be completed.

Spring Park is a bay along the north shore of the upper portion of Lake Minnetonka. It currently has very good mesotrophic water quality (mean observed 19 ppb TP) with little annual variation in total phosphorus (range 16-22 ppb). Modern DI-TP provided an estimate similar to observed values with 25.6 ppb TP. Pre-European DI-TP suggests that nutrient dynamics in Spring Park Bay are little changed in modern times. Reconstruction of pre-European DI-TP of 27.5 ppb TP was just slightly higher than modern observed or modern DI-TP.

St. Albans Bay is along Minnetonka's southeast shore and enjoys the best modern water quality of the ten sites sampled in 2005. Mean annual observed TP was a respectable 18 ppb TP (range 13-22 ppb). The modern DI-TP estimate was slightly higher at approximately 31 ppb. Historical estimates of pre-European DI-TP were similar to modern observed and inferred values at 21.7 ppb TP and suggest that modern conditions in St. Albans Bay are similar to historical nutrient conditions present before European settlement.

Stubbs Bay is well-separated from the main body of Lake Minnetonka and is currently eutrophic. Modern water quality observations recorded 2005 TP values of 58-101 ppb (mean 79 ppb TP). A modern mean DI-TP value of 52.6 ppb reconstructed a similar story of modern condition in Stubbs Bay. Pre-European estimates of TP suggest that Stubbs Bay was historically a mesotrophic system (pre-European DI-TP 38 ppb), which has in modern times become eutrophic to periodically hypertrophic.

Wasserman Lake is located in the agricultural belt on the very southern reaches of the Lake Minnetonka watershed. Modern Wasserman Lake is eutrophic with observed and DI-TP values of 84 ppb. Wasserman Lake was recored on 11 August 2006 using a Livingston corer to recover an additional 2 m of sediment. Samples from 332 and 337 cm depth were analyzed for diatom microfossils and produced estimates of pre-European DI-TP of 78.5. Wasserman Lake was historically a eutrophic system and is currently in a eutrophic state.

Lakes and bays in the Minnetonka watershed generally showed three patterns of change between pre-European and modern nutrient conditon. Carsons, St. Albans, and Spring Park Bays have modern mesotrophic nutrient conditions and showed little change between pre-European and modern conditions. Gleason Lake, Stubbs Bay and Langdon Lake were all mesotrophic in pre-European times and are currently eutrophic to hypertrophic water bodies with modern TP levels above 60 ppb. Wasserman Lake, Halsteds Bay and Jennings Bay were eutrophic systems in pre-European times and are currently eutrophic to hypertrophic (Figs 3-4).

REFERENCES

Edlund, M.B. and Ramstack, J. 2006. Diatom-inferred TP in MCWD Lakes. Final project report submitted to Minnehaha Creek Watershed District, July 2006. Work Order 116-04, 33 pp.

FIGURES

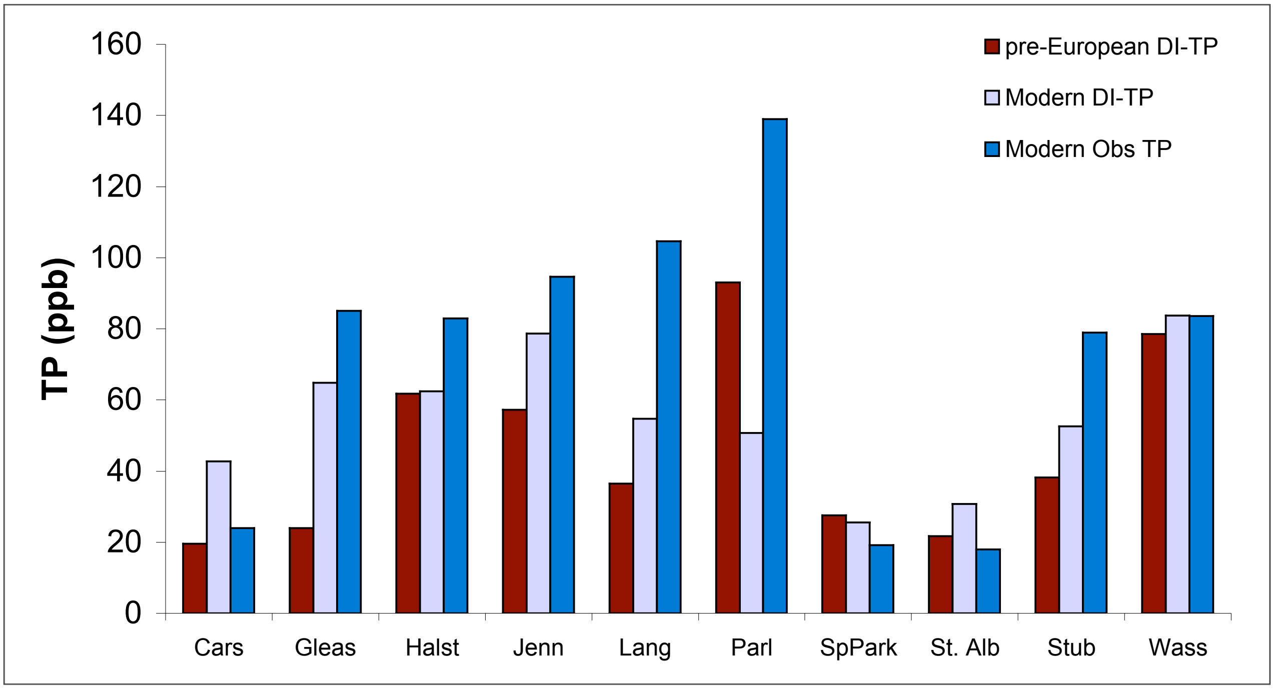


Figure 3. Histogram comparing pre-European diatom-inferred TP (DI-TP) with modern DI-TP and observed annual mean TP for ten lakes and bays in the Lake Minnetonka watershed.

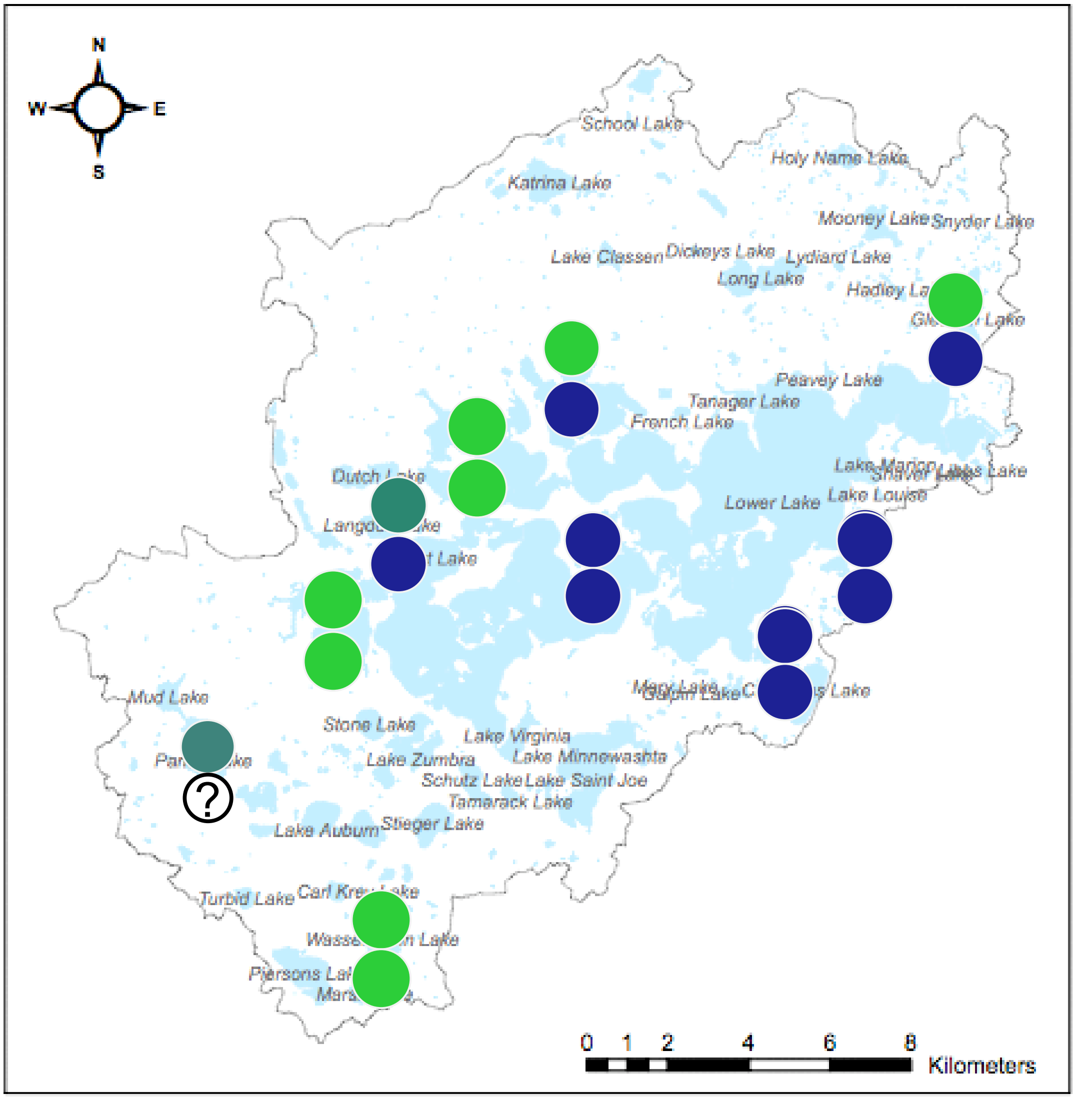


Fig. 4. Comparison of pre-European diatom-inferred total phosphorus levels (bottom filled circles) and modern total phosphorus levels (top filled circles) in ten lakes and bays in the Lake Minnetonka watershed. Blue circles represent better mesotrophic lake conditions with good water quality (total phosphorus of 10-50 ppb), green circles represent eutrophic lake conditions (total phosphorus of 50-100 ppb), and dark green circle represent hypertrophic lake conditions or poor water quality (total phosphorus values >100 ppb).

TABLES

Table 5a. Diatom-inferred total phosphorus (DI-TP) reconstructions from training set surface sediment samples (surf) and sediment core samples (number following lake name is core depth in cm). The uppermost core samples represent modern lake conditions (ca. 2002-2005 AD); the two deepest samples from each core represent sediments deposited before regional European settlement. The 2005 mean epilimnetic TP and range of observed TP values are listed for all ten sites. The dissimilarity coefficient (DC) is calculated as the squared chi-squared distance between a fossil sample and its nearest modern analog among the 76 lakes in the logTP transfer function. A minimum dissimilarity coefficient (DC) score of less than 0.4067 (the first percentile of distance distributions among the modern samples), 0.6699 (the fifth percentile), and 0.8598 (the tenth percentile) identified a fossil sample with a very good, good, or poor modern analogue, respectively. ND = not determined.

Site	Site/core depth	2005 observed mean TP	2005 observed TP range	DI-TP	DC	Modern analogue
	cm	ppb	ppb	ppb	-	-
Carson Bay	Carson (surf)	24	19.5-27.5	44.5	-	-
	Carson2	-	19.5-27.5	40.9	0.4717	VG
	Carson55	-	-	20.0	0.6283	G
	Carson60	-	-	19.0	0.6482	G
Gleason	Gleason (surf)	85	25-120	69.7	-	-
	Gleaso2	-	25-120	59.8	0.3537	VG
	Gleaso75	-	-	26.2	0.8142	P
	Gleaso80	-	-	21.6	0.6356	G
Halsted	Halsted (surf)	83	59.8-104	66.7	-	-
	Halste2	-	59.8-104	58.2	0.5428	G
	Halst125	-	-	80.6	0.6881	P
	Halst130	-	-	43.0	0.8523	P
Jennings	Jennings (surf)	95	48-137	85.8	-	-
	Jennin2	-	48-137	71.5	0.4796	G
	Jenni120	-	-	65.6	0.9832	P
	Jenni125	-	-	48.9	0.8793	P
Langdon	Langdon (surf)	105	76-124	49.4	-	-
	Langdo2	-	76-124	60.0	0.5411	G
	Langd115	-	-	30.2	0.5595	G
	Langd120	-	-	42.8	0.7075	P
Parley	Parley (surf)	139	72-196	54.0	-	-
	Parley2	-	72-196	47.5	0.4641	G
	Parle142	-	-	85.4	0.4698	G
	Parle147	-	-	100.6	0.4891	G

Table 5b. Diatom-inferred total phosphorus (DI-TP) reconstructions from training set surface sediment samples (surf) and sediment core samples (number following lake name is core depth in cm). The uppermost core samples represent modern lake conditions (ca. 2002-2005 AD); the two deepest samples from each core represent sediments deposited before regional European settlement. The 2005 mean epilimnetic TP and range of observed TP values are listed for all ten sites. The dissimilarity coefficient (DC) is calculated as the squared chi-squared distance between a fossil sample and its nearest modern analog among the 76 lakes in the logTP transfer function. A minimum dissimilarity coefficient (DC) score of less than 0.4067 (the first percentile of distance distributions among the modern samples), 0.6699 (the fifth percentile), and 0.8598 (the tenth percentile) identified a fossil sample with a very good, good, or poor modern analogue, respectively.

Site	Site/core depth	2005 observed mean TP	2005 observed TP range	DI-TP	DC	Modern analogue
	cm	ppb	ppb	ppb	-	-
Spring Park	Spring Pk (surf)	19	16-22	26.9	-	-
	Spring2	-	16-22	24.2	0.6896	G
	Sprin147	-	-	31.0	0.7994	P
	Sprin152	-	-	24.1	0.8623	P
St. Albans	St. Albans (surf)	18	13-22	31.1	-	-
	StAlb2	-	13-22	30.6	0.5185	G
	StAlb50	-	-	21.7	0.615	G
	StAlb55	-	-	21.7	0.6027	G
Stubbs Bay	Stubbs (surf)	79	58-101	53.5	-	-
	Stubbs2	-	58-101	51.6	0.5202	G
	Stubb145	-	-	38.7	0.7549	P
	Stubb150	-	-	37.7	0.6869	P
Wasserman	Wasserman (surf)	84	64-107	80.8	-	-
	Wasser2	-	64-107	86.8	0.302	VG
	Wasser332			78.0	ND	ND
	Wasser337			78.9	ND	ND