Draft Report Following April 2008 Aquatic Herbicide Treatments of Three Bays on Lake Minnetonka

John G. Skogerboe and Michael D. Netherland
US Army Engineer Research and Development Center

BACKGROUND

In Minnesota generally and on Lake Minnetonka in particular, there is interest in the potential for active aquatic plant management techniques to provide selective control of Eurasian watermilfoil (*Myriophyllum spicatum*, dicot) and curly-leaf pondweed (*Potamogeton crispus,* monocot). Selective control of dicotyledonous plants, which include Eurasian watermilfoil, may be achieved with 2,4-D (Green and Westerdahl 1990) and triclopyr (Netherland and Getsinger 1992), which are commonly used systemic herbicides (Getsinger et al. 1997, Poovey et al. 2004). Endothall is a broad-spectrum herbicide (Netherland et al. 1991), which can be used to control a wide range of aquatic plants. Research has shown that endothall can be used to selectively control curly-leaf pondweed with careful selection of application rates (Skogerboe and Getsinger 2002) and seasonal timing (Poovey et al. 2002). Additional research has shown that low rates of endothall combined with 2,4-D or triclopyr can provide selective control of two invasive exotic species, Eurasian watermilfoil and curly-leaf pondweed, if applied in early spring when most native species are dormant (Skogerboe and Getsinger 2006).

In 2007 a project was initiated on Lake Minnetonka to demonstrate the potential of aquatic plant management strategies to provide selective control of Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*). Three basins were selected for pre treatment aquatic plant surveys: Carmen’s, Grays, and Phelps bays. Potential aquatic plant management strategies have not been selected to date. Eurasian watermilfoil and curlyleaf pondweed were present in all basins, and native plants were abundant in depths $\leq$ 15 ft.

In April 2008, large areas of Carmen’s Bay, Phelps Bay, and Grays Bay on Lake Minnetonka were treated with a combination of the registered aquatic herbicides endothall and triclopyr. Treatment plans called for endothall and triclopyr to be applied at target concentrations of 1 mg a.i./L and 0.25 mg a.e./L respectively. For perspective, the maximum label rate of endothall is 5.0 mg a.i./L and triclopyr is 2.5 mg a.e./acre. In conjunction with these treatments, US Army ERDC personnel collected water samples and conducted analyses to determine residuals for the two active ingredients. Sampling protocols were designed to determine initial dilution and dispersion patterns in order to link efficacy to herbicide residues.

METHODS

Treatments:
Three basins were selected in cooperation with the Minnesota Department of Natural Resources (MN DNR), and the Lake Minnetonka Conservation District (LMCD) including Carmen’s Bay, Grays Bay, and Phelps Bay.

Carmen's Bay – Approximately 95 acres (avg. 6.4 feet deep) were treated on April 13, 2008. Herbicides were applied by boat with subsurface injection via trailing hoses. The shorelines closer to the main body of the lake (shaded in yellow) were treated with endothall at 1 mg/L and triclopyr at 0.5 mg/L (Fig 1). The entire treatment represented 48% of the littoral area or 23% of the 403-acre bay. Notes from the treatment date indicated that prevailing winds averaged between 10 and 15 mph on the day of treatment. Water temperatures were between 12 and 12.5 C.

Phelps Bay - Approximately 150 acres (average 5.9 feet deep) were treated on April 14, 2008. Herbicides were applied by boat with subsurface injection via trailing hoses. This treatment represented 55% of the littoral area or 40% of the 373-acre bay. Notes from the treatment date indicated that winds were < 6 mph and remained light and variable for several days post-treatment. Water temperatures were between 12 and 12.5 C.

Grays Bay - Approximately 160 acres (average 5.7 feet) were treated on April 14, 2008. Herbicides were applied by boat with subsurface injection via trailing hoses. This treatment represented 91% of the 175-acre bay. Notes from the treatment date indicated that winds were between 4 to 6 mph and remained light and variable for several days following the application. Water temperatures were between 12 and 12.5 C. Grays Bay is located near the outlet of Lake Minnetonka, and water flow rates were measured at approximately 150 CFS (or 300 acre feet per day). This issue was discussed in a pretreatment conference call and it was decided that while the rate of outflow was not optimal from a treatment efficacy standpoint, the closed nature of the bay would insure that exposures would be dictated by outflow versus dispersion from the treatment zone.

Aquatic Plant Evaluations:

At the request of the Minnesota Department of Natural Resources, the US Army Engineer Research and Development Center (ERDC), Vicksburg, MS initiated plant surveys on all three basins to evaluate the plant communities and establish background data for potential future aquatic plant management demonstrations. The survey was conducted by John Skogerboe, ERDC Eau Galle Aquatic Ecology Laboratory, Spring Valley, WI. Surveys were conducted in late June, 2007 and early September 2007. Additional surveys will be collected following the initiation of plant management demonstrations in order to evaluate their effectiveness.

Prior to conducting the first surveys, 50x50 m grids were established for each basin using computer mapping software. The grids were downloaded unto GPS (Global Positioning System) equipment accurate to 10 to 20 ft. Samples were collected using a 36-cm wide rake attached to a rope. At each sample point, the rake was thrown from the boat approximately 10 to 20 ft and then raised up to the water surface. Each species was then recorded for each sample point. Percent occurrence of plant species was calculated by dividing the number of points where a particular species was present by the total number of sample points in the littoral zone. The average number of species per sample point, and the total the number of native plant species in each basin were calculated.

Water Sampling:
Water samples were collected by US Army ERDC personnel prior to the treatment and at 1 (15-18 hour), 2, 3, and 4 days post-treatment on all three bays. Carmen's was further sampled at 5, 8, and 15 days, and Phelps and Grays were sampled at 7 and 14 days post-treatment. Sample sites for each bay were selected both within and outside of the application zones. This allowed for determination of herbicide residence within the plots as well as dispersion of residues from the treated areas. Maps showing the treated areas and water sample sites are included in Figures 1, 2, and 3.

Based on prior experience with liquid herbicide applications, the majority of water samples were collected at mid-depth. Within each bay sites were also designated for vertical sampling at 3 depths (25, 50, and 75% of the average depth). Vertical water column sampling is conducted to insure that herbicides spread from top to bottom in the water column.

Following collection, water samples were acidified and shipped to the University of Florida Center for Aquatic and Invasive Plants. Endothall analyses were conducted via immunoassay. For triclopyr analyses, water samples were shipped to the SePRO Corporation for analysis via immunoassay and HPLC. Results are analyzed and reported as the endothall acid and triclopyr acid. This is an important distinction, as the recommended treatment rates of 1.0 mg/L endothall represent the active ingredient concentrations of the endothall salt. The maximum recoverable endothall acid would be 0.71 mg/L (710 ppb) based on the 1.0 mg/L treatment. The maximum recoverable residue of the triclopyr would be 0.25 mg/L. The y-axis of the residue graphs in Figures 4, 5, and 6 reflect the maximum detectable residues for both endothall and triclopyr based on the target application rates to the treatment plots.

Results

Water Sampling:
Pretreatment sampling indicated residues of both endothall and triclopyr were not detectable. Following herbicide application, data indicate there was a rapid dilution within and dispersion of residues from Carmen's Bay (Figure 4). While the target endothall concentration was 710 ppb in the treatment plots following application, residues collected at ~15 hr post-treatment were typically reduced by 80 to 90%. Moreover, residues were essentially equivalent both within and outside the treated areas, suggesting rapid dispersion from the treated area. A similar pattern of dilution and dispersion was also noticed for triclopyr residues (Figure 4). Based on the cold water temperatures (12 C) at the time of application, it is highly unlikely that microbial degradation played a role in the loss of endothall from any of the treatment sites during the initial 15-hour period.

The residues detected in Phelps Bay showed better retention through ~15 hr post-treatment when compared to Carmen's Bay; however these initial concentrations were still less than 50% of the target rate (Figure 5). The pattern of residue dissipation from the individual sites was not consistent.

Despite the above-mentioned concerns with outflow from Grays Bay, this treatment provided the most consistent pattern of initial residue detection and degradation over time (Figure 6). Treatment of a large fraction of this Bay still only resulted in detection of initial residues less than half of the predicted concentration. Nonetheless, in contrast to Carmen's and Phelps, residue dissipation was much slower resulting in several days of exposure to herbicide concentrations that could provide herbicidal impacts.

Vertical water column sampling in all three bays (Carmen's sites 2 and 4, Phelps sites 1 and 2, and Grays site 3) indicated that herbicides were distributed evenly through the water column. This is indicative of isothermal conditions at the time of treatment and it may explain the rapid mixing of residues from the treatment sites to the deeper water areas within the bays.

Aquatic Plant Evaluations:

<u>Carmen's Bay</u>
Pre-treatment: The littoral zone (depth $\leq$ 15) contained 181 sample points which was 59% of all sample points (Figure 8). The distribution of Eurasian watermilfoil, curly-leaf pondweed, and native aquatic plants in Carmen's Bay are shown in Figure 9. Eurasian watermilfoil was found at 58% (Jun 07) and 60% (Sep 07) of littoral zone sample points, and curly-leaf pondweed was found at 28% (Jun 07) and 4% (Sep 07) of the littoral zone sample points (Table 1). The decline in percent occurrence of curly-leaf pondweed was due to normal senescence in late spring and early summer. The native plant community was dominated by coontail (*Ceratophyllum demersum*, dicot), clasping-leaf pondweed (*Potamogeton richardsonii*, monocot), flat-stem pondweed (*Potamogeton zosteriformis*, monocot), and sago pondweed (*Stukenia pectinata*, monocot). Plant species were distinguished as monocots or dicots because some aquatic herbicides are selective for dicots while others are broad spectrum herbicides which can affect both monocots and dicots. The native plant community was composed of 18 different species including 6 dicots, 11 monocots, and 1 macro-alga.

Post treatment: Post treatment plant data showed no decline in the percent occurrence of Eurasian watermilfoil (Table 1). The data did indicate a decline in curly-leaf pondweed in Jun 08 (28%) compared to Jun 07 (4%). Two native species (wild celery and water star-grass) significantly increased in occurrence in Sep 08 compared to Sep 07, and one species (flat-stem pondweed) significantly declined. Overall the number of native species per sample point increased in Sep 08 compared to Sep 07 and the percentage of sample points with native species increased.

<u>Grays Bay</u>
Pre-treatment: The littoral zone (depth $\leq$ 15) contained 216 sample points which was 84% of all sample points (Figure 10). The distribution Eurasian watermilfoil, curly-leaf pondweed, and native aquatic plants in Grays Bay are shown in Figure 11. Eurasian

watermilfoil was found at 86% (Jun 07) and 86% (Sep 07) of littoral zone sample points, and curly-leaf pondweed was found at 20% (Jun 07) and 3% (Sep 07) of the littoral zone sample points (Table 2). The decline in percent occurrence of curly-leaf pondweed was due to normal senescence in late spring and early summer. The native plant community was dominated by coontail (*Ceratophyllum demersum*, dicot), big-leaf pondweed (*Potamogeton amplifolius,* monocot), clasping-leaf pondweed (*Potamogeton richardsonii,* monocot), flat-stem pondweed (*Potamogeton zosteriformis,* monocot), and sago pondweed (*Stukenia pectinata*, monocot). Plant species were distinguished as monocots or dicots because some aquatic herbicides are selective for dicots while others are broad spectrum herbicides which can affect both monocots and dicots. The native plant community was composed of 18 different species including 6 dicots, 11 monocots, and 1 macro-alga.

Post treatment: Post treatment plant data showed a decline in the percent occurrence of Eurasian watermilfoil (Table 2) from 54 % in Sep 08 compared to 86 % in Sep 07. The data also indicated a decline in curly-leaf pondweed in Jun 08 (5%) compared to Jun 07 (20%). Four native species (coontail, slender naiad, wild celery and water star-grass) significantly increased in occurrence in Sep 08 compared to Sep 07, and one species (flat-stem pondweed) showed a significant decline. Overall the number of native species per sample point decreased in Sep 08 compared to Sep 07 and the percentage of sample points with native species remained about the same.

<u>Phelps Bay</u>

Pre-treatment: The littoral zone (depth ≤ 15) contained 257 sample points which was 703% of all sample points (Figure 12). The distribution Eurasian watermilfoil, curly-leaf pondweed, and native aquatic plants in Phelps Bay are shown in Figure 13. Eurasian watermilfoil was found at 65% (Jun 07) and 67% (Sep 07) of littoral zone sample points, and curly-leaf pondweed was found at 36% (Jun 07) and 5% (Sep 07) of the littoral zone sample points (Table 3). The decline in percent occurrence of curly-leaf pondweed was due to normal senescence in late spring and early summer. The native plant community was dominated by coontail (*Ceratophyllum demersum*, dicot), big-leaf pondweed (*Potamogeton amplifolius*, monocot), clasping-leaf pondweed (*Potamogeton richardsonii,* monocot), flat-stem pondweed (*Potamogeton zosteriformis,* monocot), and sago pondweed (*Stukenia pectinata*, monocot). Plant species are distinguished between monocots and dicots because some aquatic herbicides are selective for dicots such as Eurasian watermilfoil while others are broad spectrum herbicides which can affect both dicots and monocots. The native plant community was composed of 23 different species including 8 dicots, 14 monocots, and 1 macro-alga

Post treatment: Post treatment plant data showed no decline in the percent occurrence of Eurasian watermilfoil (Table 3). The data did indicate a decline in curly-leaf pondweed in Jun 08 (36%) compared to Jun 07 (1%). Two native species (wild celery and water star-grass) significantly increased in occurrence in Sep 08 compared to Sep 07, and one species (flat-stem pondweed) significantly declined. Overall the number of native species per sample point increased in Sep 08 compared to Sep 07 and the percentage of sample points with native species increased.

Discussion:

The detection of much lower than expected residues at 15 hr post application in the treatment plots of all 3 bays indicates an initial rapid dilution of herbicides within the bays. It is very likely the water from the treated areas rapidly mixed with untreated water in the deeper zones resulting in much lower than predicted initial concentrations. The detection of relatively high residues in plots established outside of the treatment zones is evidence of rapid dilution within the bays. Furthermore, within both Carman and Phelps bay, the inability to maintain these initial, albeit lower residues over time, suggests rapid dispersion of the treated water into the main lake.

Our research group has focused numerous trials on the relationship between herbicide concentration and exposure time (CET) and target plant control. Higher concentrations of herbicide can provide control given shorter exposure periods, while lower concentrations can often provide excellent control under longer-term exposure scenarios. While there is ample evidence that combinations of endothall and triclopyr can provide control of Eurasian watermilfoil, the effectiveness of this combination (or any treatment combination) is dictated by the actual concentrations and exposures that result following application to the treatment site. As noted above, the treatment concentrations used for the applications to the bays in Lake Minnetonka were on the lower end of the maximum label use rates.

To provide some perspective on the residue profiles achieved in the three bays, a theoretical 24-hour half life decay curve was plotted and compared to the average endothall residue values obtained within the treated sites of the bays (Figure 7).

The reports of less than desired Eurasian watermilfoil control on Carmen's Bay are not totally unexpected given the residue profiles. The loss of more than 80 to 90% of the herbicide from the treated plots within 15 hr indicates a very short initial exposure to the targeted residues. Moreover, the inability to maintain a prolonged exposure period to these lower residuals was not conducive to achieving target plant control.

While the residue profile on Phelps bay presents a more complicated profile than that observed on Carmen's bay, the same factors likely impacted plant control. The initial treatment did not provide for maintenance of the higher residues within the treated plots and the resultant lower rate residuals that spread throughout the bay were rapidly dispersed into the main body of the lake. In contrast to Carmen's, the residue data from Phelps suggest it is likely that some areas received an initial adequate exposure to cause some level of herbicide injury, while other areas within the bay did not. This type of residue patchiness would make efficacy evaluations difficult to evaluate on a bay wide scale.

Grays bay showed a much different long-term residue pattern than either Carmen's or Phelps bay. While the initial residues were much lower than predicted, these concentrations did persist for several days. It is likely that exposure to extended low concentrations in Grays Bay resulted in the level of Eurasian watermilfoil control that was initially achieved. Despite the ability to maintain longer-term residues in Grays bay, there are reports of some Eurasian watermilfoil recovery in this plot. It is likely that outflow did have an impact on the results achieved in this bay.

Eurasian water milfoil control was significantly less than anticipated in all three bays based on previous, growth chamber mesocosm, and field data. Herbicide residue data indicate that the exposure times of the herbicides in all three bays were insufficient for good control, even though the large size of the treatment areas should have allowed for longer exposure times. The cause of the short exposure times is still being investigated. Residue data for Grays bay showed that exposure times were longer due to the enclosed setup of the bay. Grays bay did show a decline in Eurasian watermilfoil, while the other bays did not. Curly-leaf pondweed was significantly reduced in occurrence. The native plant community was not adversely affected, even though some species (wild celery and water star-grass) showed consistent increases in all three bays and once species (flat-stem pondweed declined in all three bays. Water-lilies did not appear to be adversely affected.

References

Crowell, W.J., N. Troelstrup, L. Queen, and J. Perry. 1994. Effects of harvesting on plant communities dominated by Eurasian watermilfoil Lake Minnetonka, MN. Journal of Aquatic Plant Management 32:56-60.

Getsinger, K.D., J.D. Madsen, E.G. Turner, and M.D. Netherland. 1997. Restoring native vegetation in a Eurasian watermilfoil-dominated plant community using the herbicide triclopyr. Regul. Rivers Res. And Manage. 13: 357-375.

Green, W.R. and H.E. Westerdahl. 1990. Response of Eurasian watermilfoil to 2,4-D concentrations and exposure times. J. Aquat. Plant Manage. 28: 27-32.

Madsen, J.D. and K.D. Getsinger. 1995. Assessment of aquatic plants before and after a triclopyr treatment in Lake Minnetonka, Minnesota. pp. 90-95 in Proceedings, 29th Annual Meeting, Aquatic Plant Control Research Program. Miscellaneous Paper A-95-3. US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi 39180.

Netherland, M.D., W.R. Green, and K.D. Getsinger. 1991. Endothall concentration and exposure time relationships for the control of Eurasian watermilfoil and hydrilla. J. Aquat. Plant Manage. 29: 61-67.

Netherland, M.D. and K.D. Getsinger. 1992. Efficacy of triclopyr on Eurasian watermilfoil-concentration and exposure time effects. J. Aquat. Plant

Manage. 30:1-5.

Parsons, J.K., K.S. Hamel, J.D. Madsen, and K.D. Getsinger. 2001. The use of 2,4-D for selective control of an early infestation of Eurasian watermilfoil in Loon Lake, Washington. J. Aquat. Plant Manage. 39:117-125.

Poovey, A.G. J.G. Skogerboe, and C.S. Owens. 2002. Spring treatments of diquat and endothall for curly-leaf pondweed control. J. Aquat. Plant Manage. 40:63-67

Poovey, A.G., K.D. Getsinger, J.G. Skogerboe. T.J. Koschnick, J.D. Madsen, and R.M. Stewart. 2004. Small-Plot, Low-Dose Treatments of triclopyr for Selective Control of Eurasian Watermilfoil. Lake and Reserv. Manage. 20(4): 322-332.

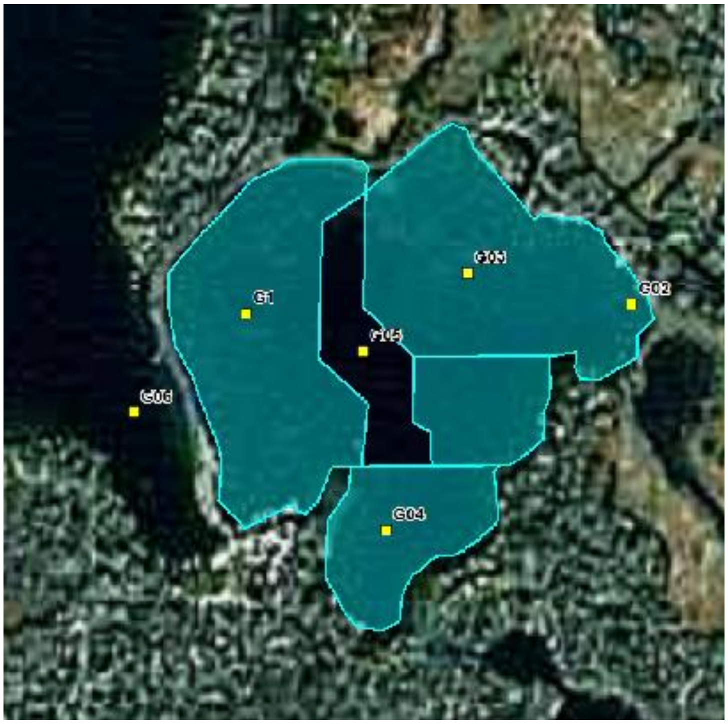
Skogerboe, J.G., and K.D. Getsinger. 2002. Endothall species selectivity evaluation: Northern latitude aquatic plant community. J. Aquat. Plant Manage. 40: 1-5.

Skogerboe, J.G., and K.D. Getsinger. 2006. Selective control of Eurasian watermilfoil and curly-leaf pondweed using low doses of endothall combined with 2,4-D. APCRP Technical Notes Collection (ERDC/TN APCRP-CC-05). Vicksburg, MS: U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Figure 1. Carmen's Bay treatment area (shaded sites) and locations of 6 water sampling sites.

Figure 2. Phelps Bay treatment area (shaded sites) and locations of 6 water sampling sites.

Figure 3. Grays Bay treatment area (shaded sites) and locations of 6 water sampling sites.



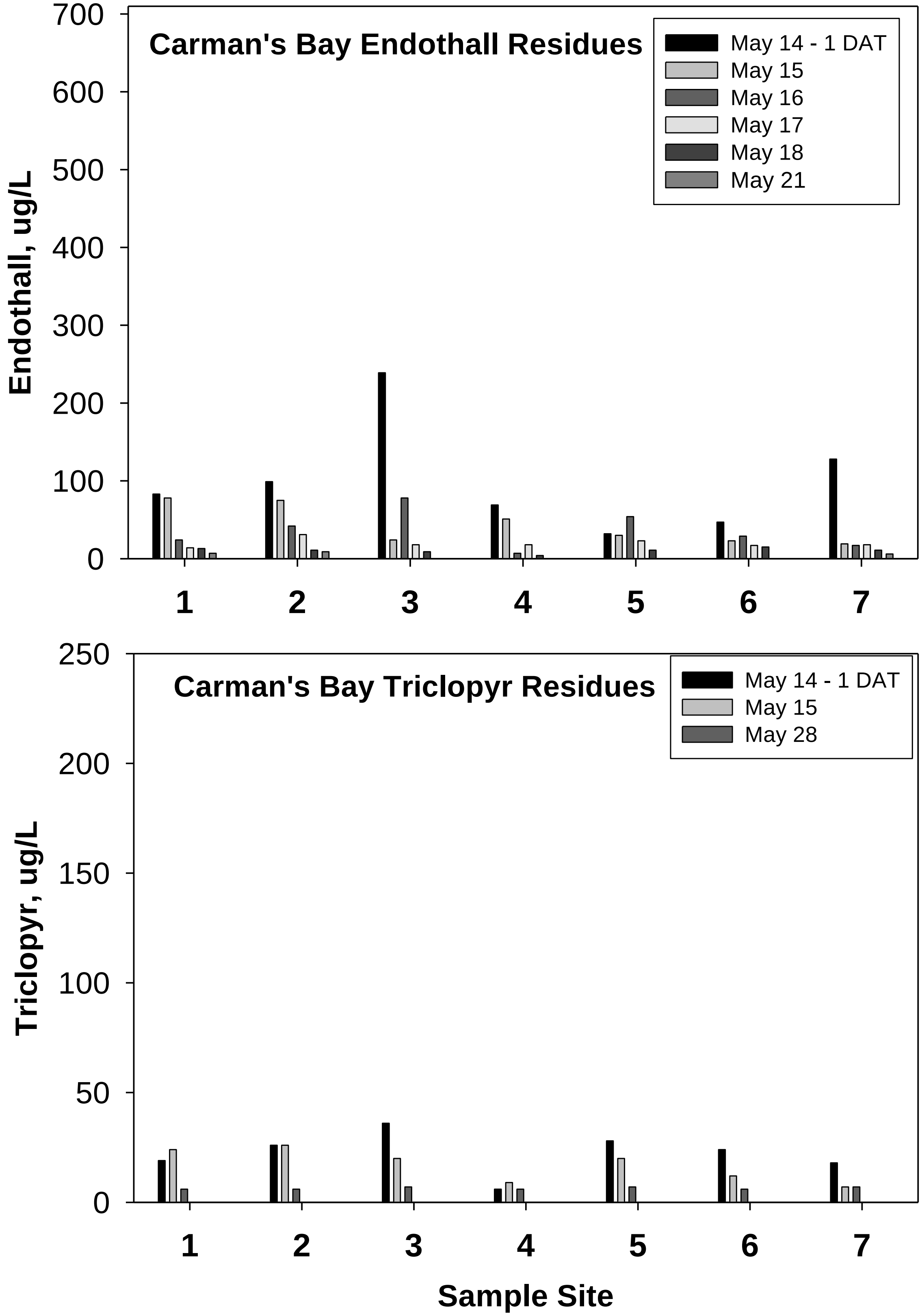


Figure 4. Endothall and triclopyr residues collected from seven sites in Carmen's Bay, Lake Minnetonka.

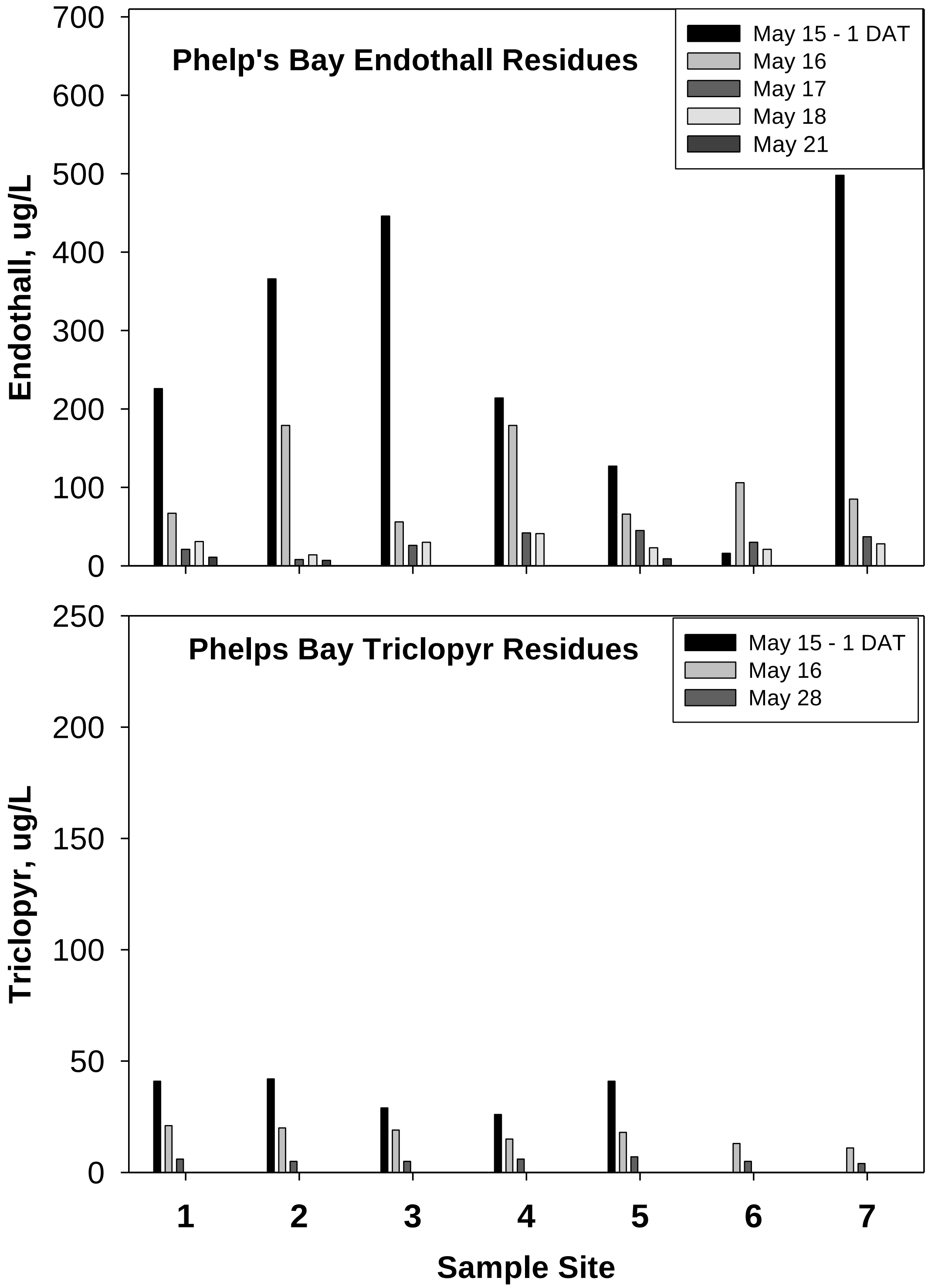
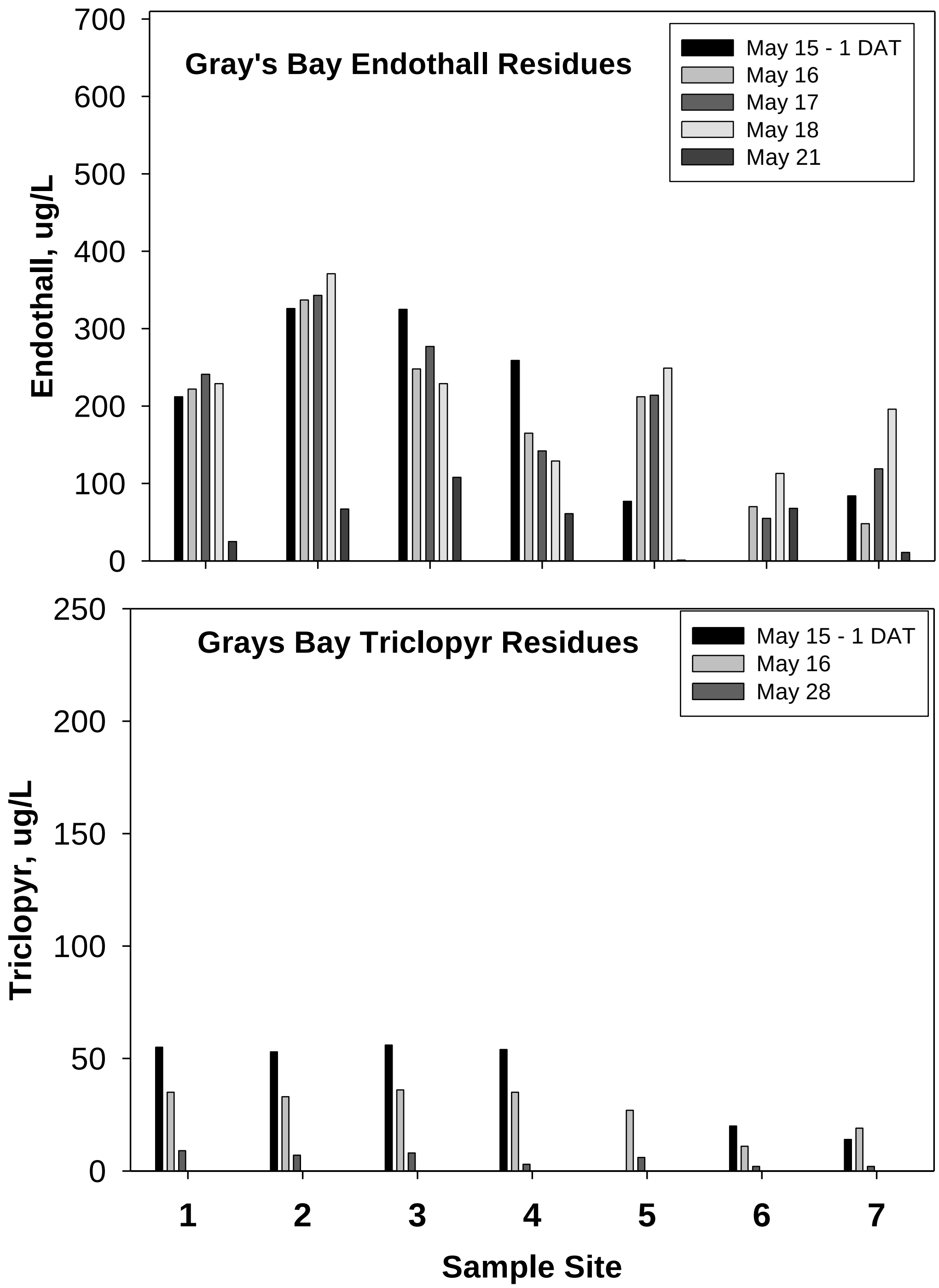


Figure 5. Endothall and triclopyr residues collected from seven sites in Phelps Bay, Lake Minnetonka.



Gray's Bay Endothall Residues
May 15 - 1 DAT
May 16
May 17
May 18
May 21
Endothall, ug/L
0
100
200
300
400
500
600
700
Grays Bay Triclopyr Residues
May 15 - 1 DAT
May 16
May 28
Triclopyr, ug/L
0
50
100
150
200
250
1
2
3
4
5
6
7
Sample Site

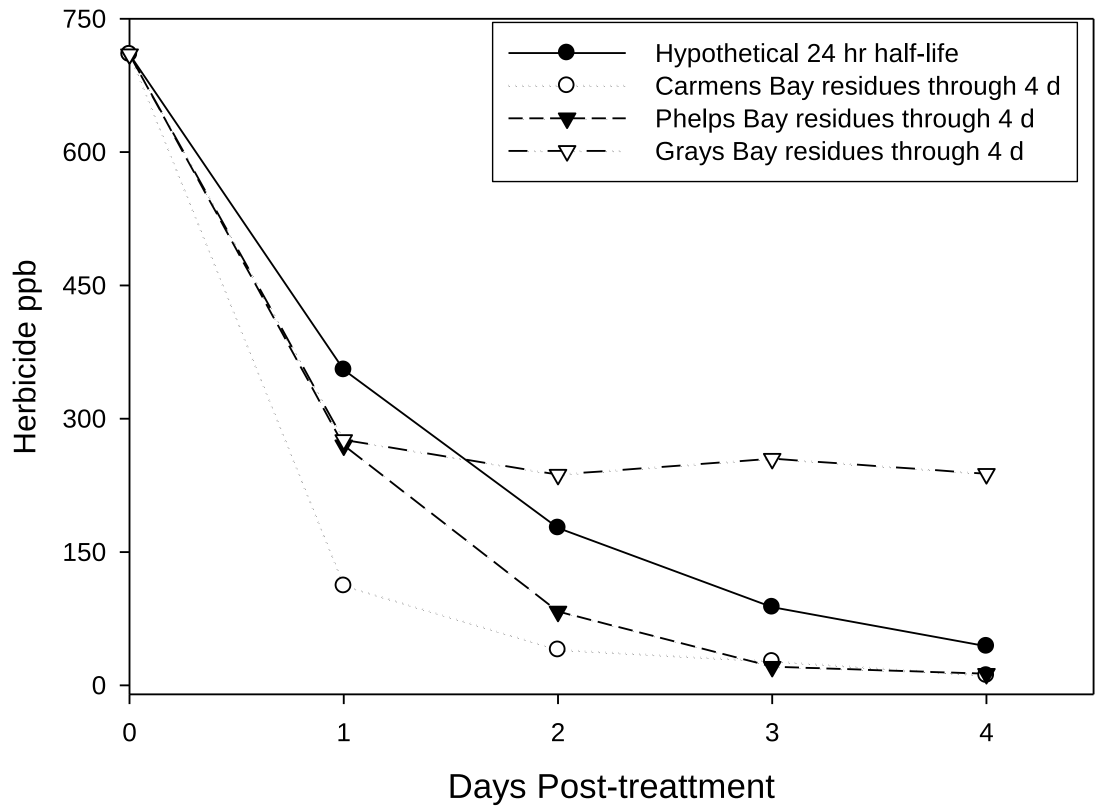


Figure 7. A hypothetical residue profile comparing a 24-hour half-life versus the actual average values obtained following sampling of treatment sites on 3 bays of Lake Minnetonka.

Figure 8. Carmen's Bay 2007 point intercept sample grid (50x50 m)

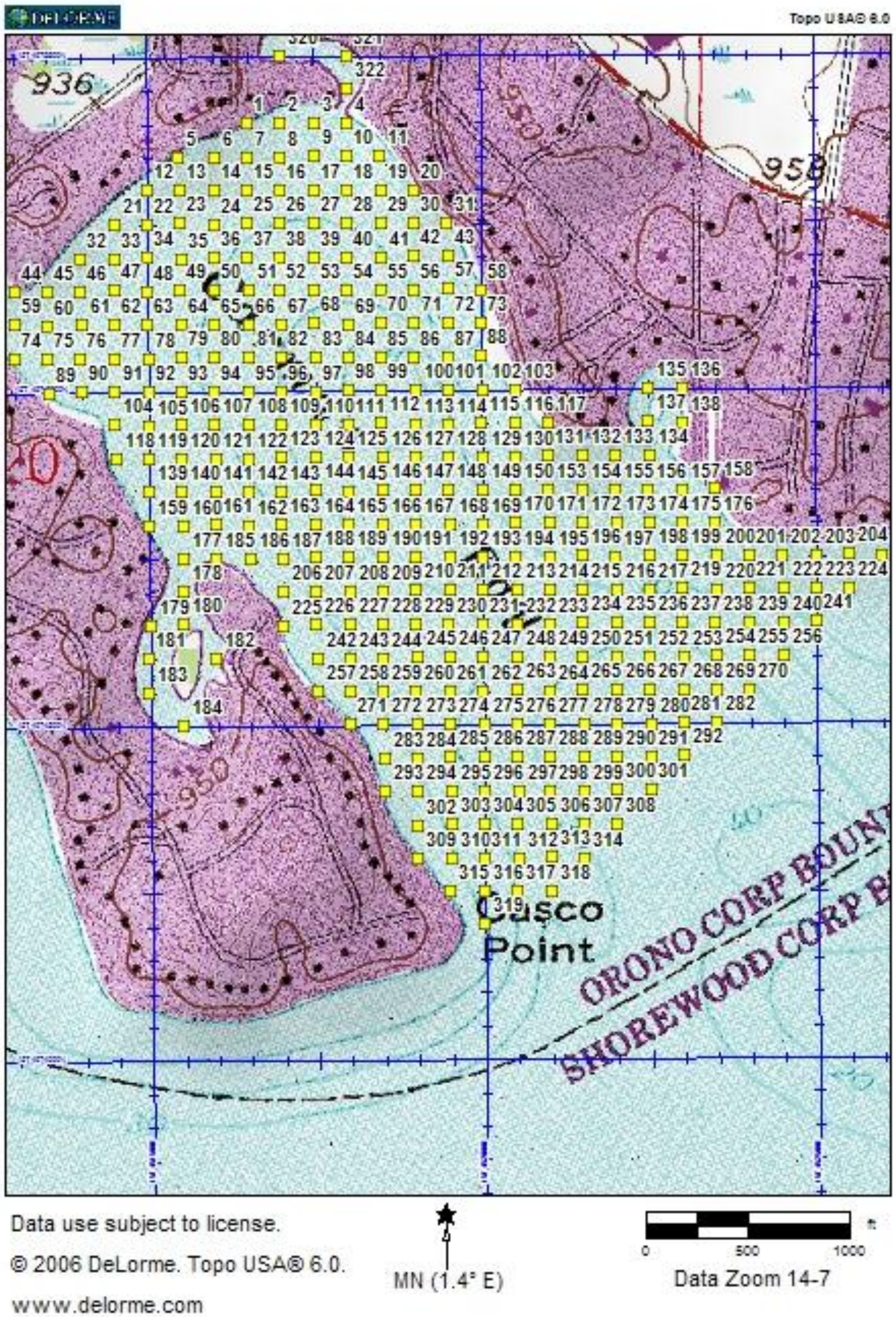
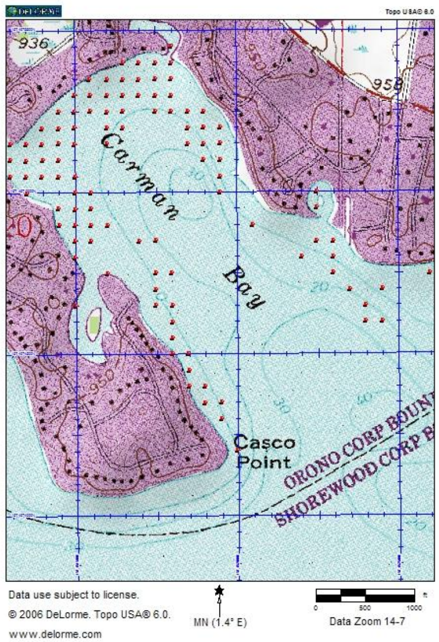
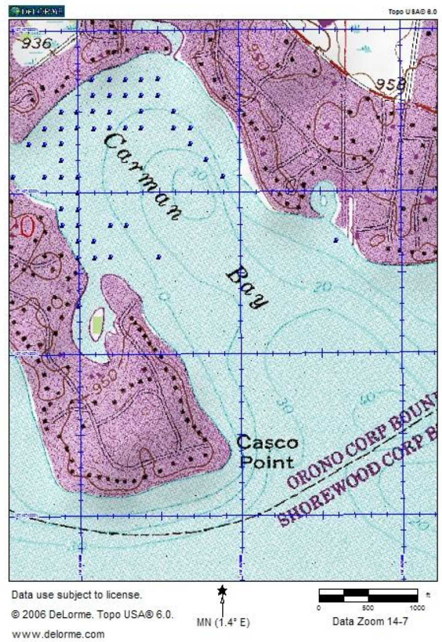


Figure 9. Carmen's Bay aquatic plant distribution, 2007

Eurasian watermilfoil (red dot)



Curly-leaf pondweed (blue dot)



Native plants (green dot)

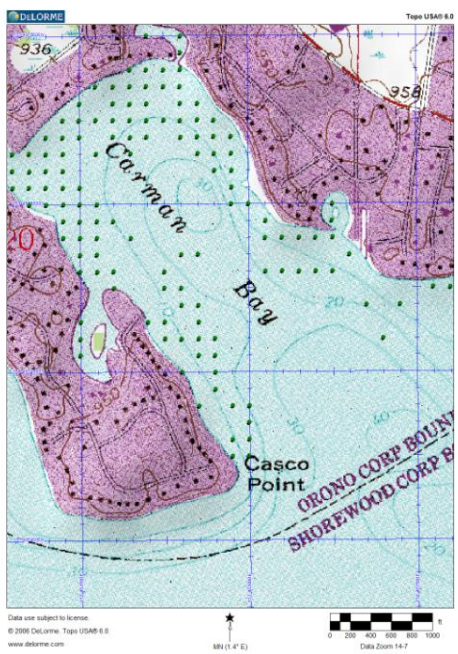


Figure 10. Gray's Bay 2007 point intercept sample grid (50x50 m)

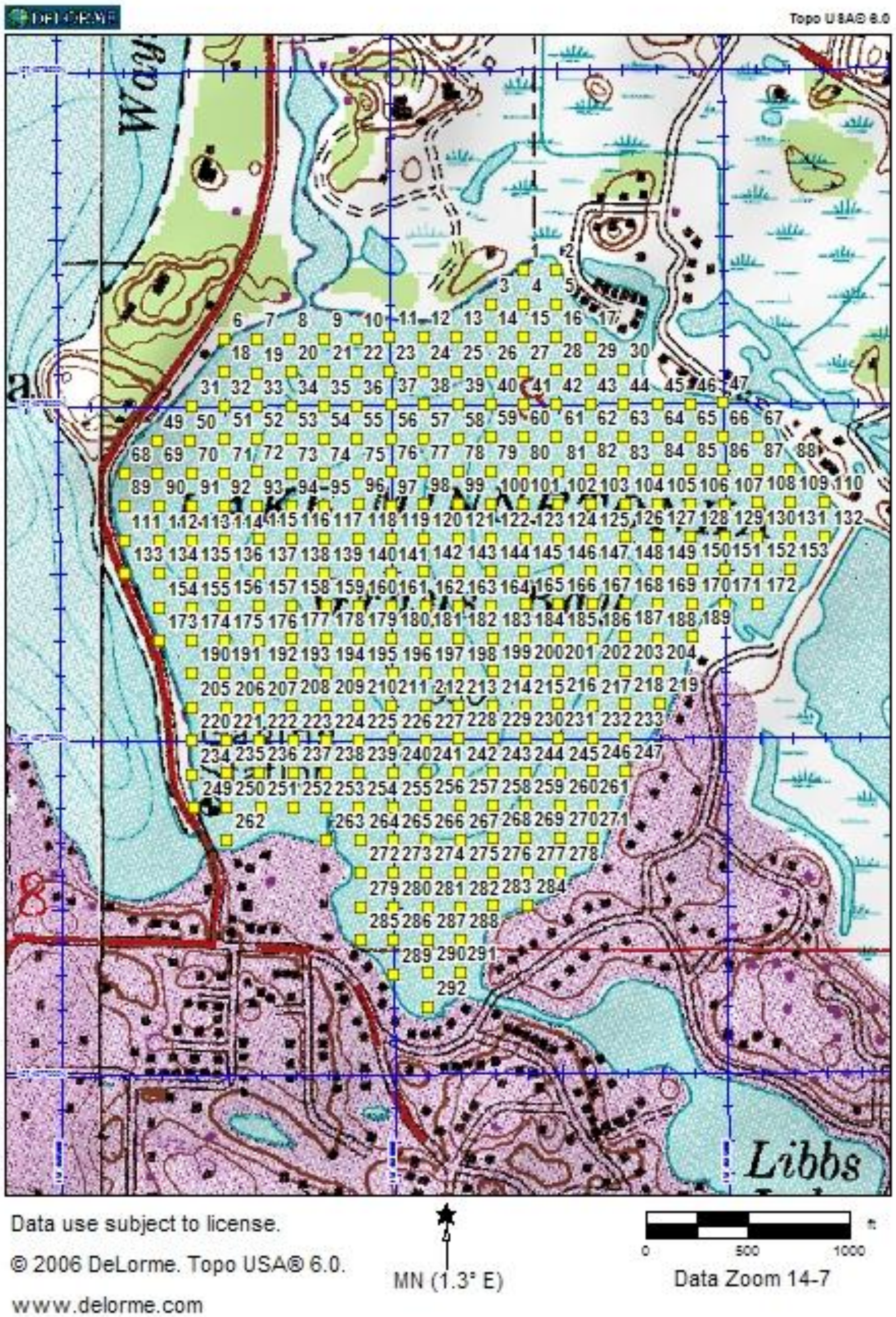
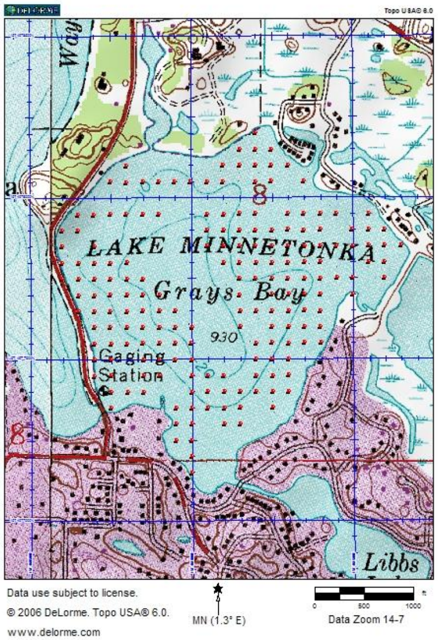
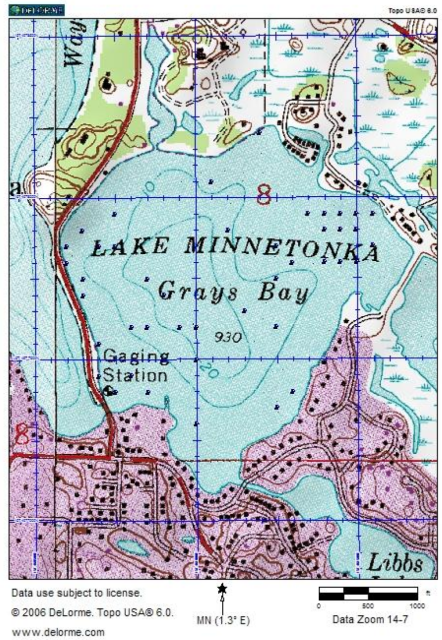


Figure 11. Grays Bay aquatic plant distribution, 2007

Eurasian watermilfoil (red dot)



Curly-leaf pondweed (blue dot)



Native plants (green dot)

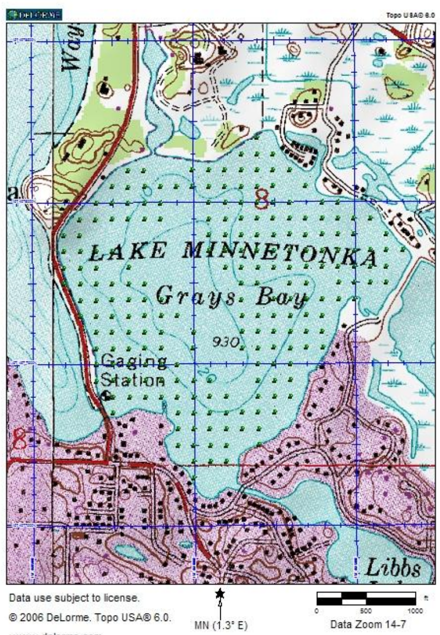


Figure 12. Phelp's Bay 2007 point intercept sample grid (50x50 m)

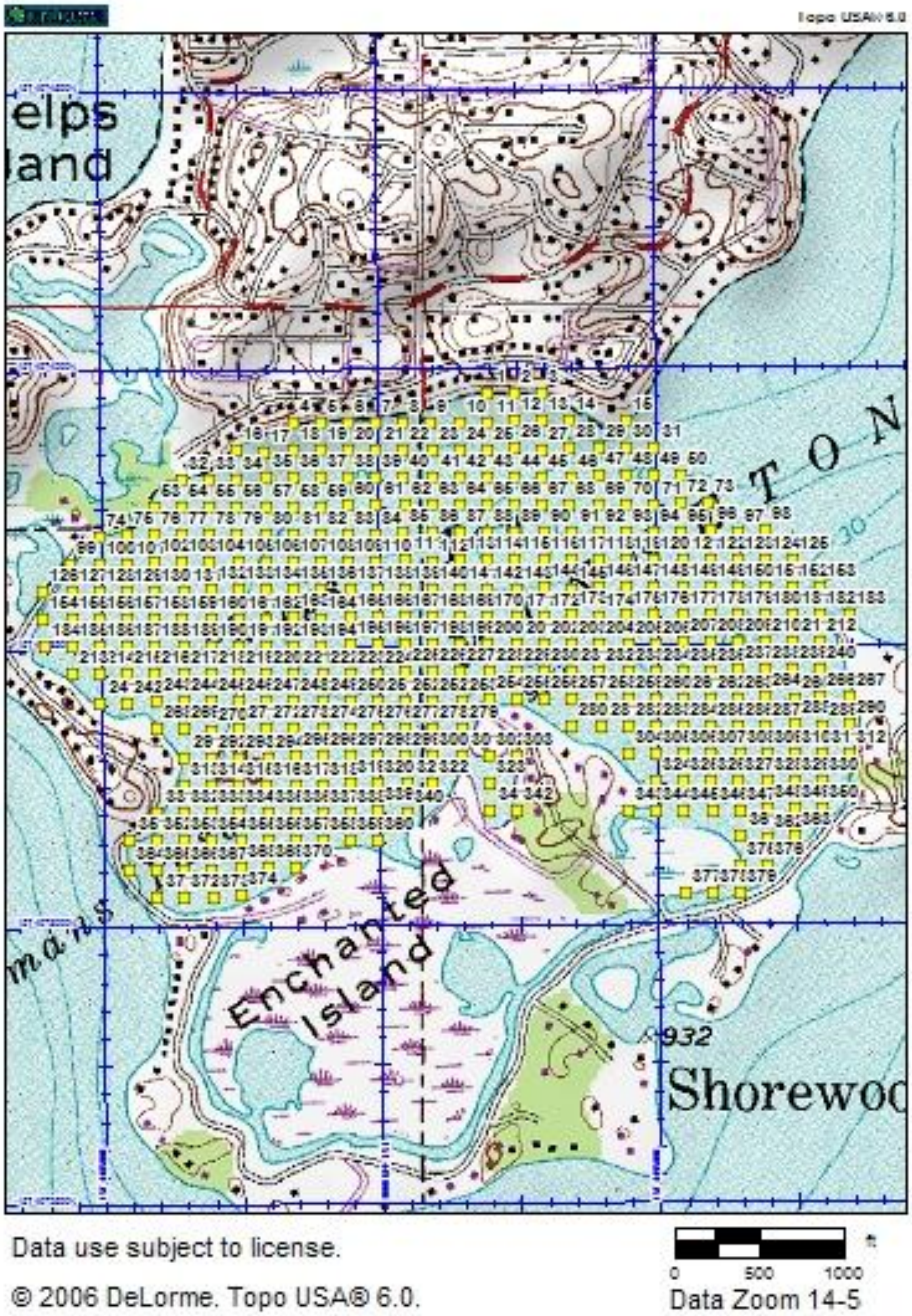
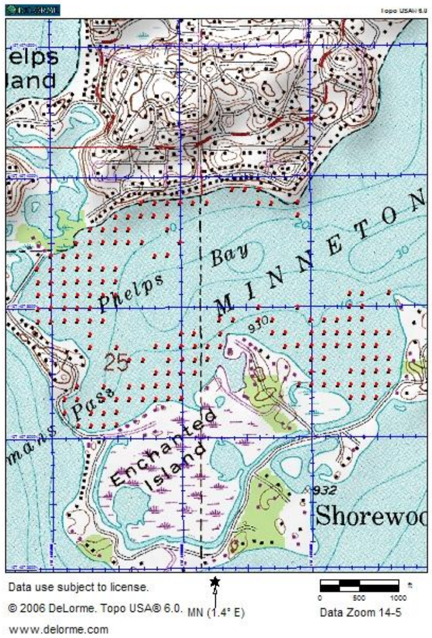
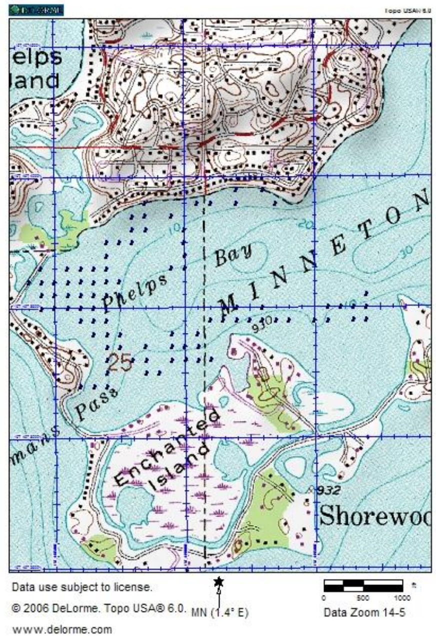


Figure 13. Grays Bay aquatic plant distribution, 2007

Eurasian watermilfoil (red dot)



Curly-leaf pondweed (blue dot)



Native plants (green dot)

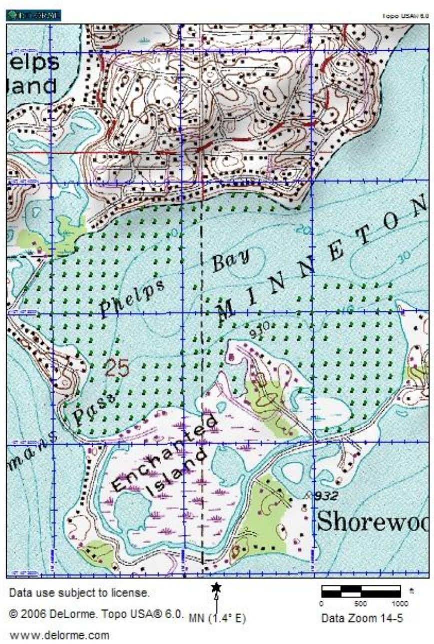


Table 1. Plant diversity data for Carmen's Bay

Percent occurrence results: Carmen's Bay

	Jun 07	Sep 07	Jun 08	Sep 08
Exotic submersed macrophytes (%)				
Eurasian watermilfoil (*Myriophyllum spicatum*)	58	60	62	72
Curly-leaf pondweed (*Potamogeton crispus*)	28	4	4	0
Native submersed macrophytes (%)				
water marigold (*Bidens beckii*)	4	4	1	10
coontail (*Ceratophyllum demersum*)	42	40	39	35
elodea (*Elodea canadensis*)	3	5	3	6
Northern milfoil (*Myriophyllum sibiricum*)	7	8	2	7
slender naiad (*Najas flexilis*)	12	10	3	24
big-leaf pondweed (*Potamogeton amplifolius*)	9	9	3	1
Illinois pondweed (*Potamogeton illinoensis*)	3	4	3	15
white-stem pondweed (*Potamogeton praelongus*)	2	2	1	4
small pondweed (*Potamogeton pusillus*)	2	1	1	1
clasping-leaf pondweed (*Potamogeton richardsonii*)	24	25	15	28
flat-stem pondweed (*Potamogeton zosteriformis*)	24	21	5	4
white water crowfoot (*Ranunculus longirostris*)	2	0	2	0
sago pondweed (*Stukenia pectinata*)	17	20	10	16
great bladderwort (*Utricularia vulgaris*)	2	2	1	1
wild celery (*Vallisneria americana*)	4	6	5	23
water star-grass (*Zosterella dubia*)	7	7	5	26
Native floating-leaf macrophytes (%)				
fragrant water-lily (*Nymphaea odorata*)	10	10	13	14
Submersed macro-algae (%)				
chara	7	6	6	14
Number of sample sites	305	305	304	301
Number of sample sites in littoral zone (depth $\leq$ 15 ft)	181	181	175	170
Percent points in littoral zone	59%	59%	58%	56%
Mean number of species per point (littoral zone)	2.64	2.30	2.10	3.05
Mean number of native species per point (littoral zone)	1.78	1.68	1.25	2.32
Percentage of points with plants	85	83	85	95
Percentage of points with native plants	72	73	69	85
Number of plant species	20	19	21	20
Number of native plant species	18	17	19	19

*All percent occurrence data is based on percentage of littoral zone

Table 2. Plant diversity data for Gray's Bay

Percent occurrence results: Gray's Bay

	Jun 07	Sep 07	Jun 08	Sep 08
Exotic submersed macrophytes (%)*				
Eurasian watermilfoil (*Myriophyllum spicatum*)	86	86	50	54
Curly-leaf pondweed (*Potamogeton crispus*)	20	3	5	0
Native submersed macrophytes (%)*				
water marigold (*Bidens beckii*)	1	1	1	2
coontail (*Ceratophyllum demersum*)	38	40	45	56
elodea (*Elodea canadensis*)	8	9	15	19
slender naiad (*Najas flexilis*)	5	2	21	35
big-leaf pondweed (*Potamogeton amplifolius*)	27	28	18	16
Illinois pondweed (*Potamogeton illinoensis*)	3	3	1	4
white-stem pondweed (*Potamogeton praelongus*)	7	8	1	0
small pondweed (*Potamogeton pusillus*)	10	5	2	2
clasping-leaf pondweed (*Potamogeton richardsonii*)	62	60	51	45
fern pondweed (*Potamogeton robbinsii*)	24	23	16	17
flat-stem pondweed (*Potamogeton zosteriformis*)	54	51	12	6
white water crowfoot (*Ranunculus longirostris*)	3	1	2	0
sago pondweed (*Stukenia pectinata*)	19	21	13	16
wild celery (*Vallisneria americana*)	5	5	6	17
water star-grass (*Zosterella dubia*)	1	1	2	13
Native floating-leaf macrophytes (%)*				
spatterdock (*Nuphar advena*)	4	5	4	4
fragrant water-lily (*Nymphaea odorata*)	7	7	6	7
Submersed macro-algae (%)*				
chara	13	8	3	11
Number of sample sites	258	258	262	264
Number of sample sites in littoral zone (depth $\leq$ 15 ft)	216	216	218	238
Percent points in littoral zone	84%	84%	83%	90%
Mean number of species per point (littoral zone)	3.95	3.75	3.22	3.24
Mean number of native species per point (littoral zone)	2.89	2.91	2.4	2.7
Percentage of points with plants (littoral zone)	99	98	94	98
Percentage of points with native plants (littoral zone)	94	94	91	97
Number of plant species	20	20	20	18
Number of native plant species	18	18	18	17

*All percent occurrence data is based on percentage of littoral zone

Table 3. Plant diversity data for Phelp'sBay

Percent occurrence results: Phelps Bay

	Jun 07	Sep 07	Jun 08	Sep 08
Exotic submersed macrophytes (%)				
Eurasian watermilfoil (*Myriophyllum spicatum*)	65	67	60	69
Curly-leaf pondweed (*Potamogeton crispus*)	36	5	1	7
Native submersed macrophytes (%)				
water marigold (*Bidens beckii*)	7	8	2	4
coontail (*Ceratophyllum demersum*)	52	55	56	69
elodea (*Elodea canadensis*)	1	2	3	5
northern milfoil (*Myriophyllum sibiricum*)	5	8	5	11
slender naiad (*Najas flexilis*)	13	10	8	21
big-leaf pondweed (*Potamogeton amplifolius*)	18	23	15	6
Illinois pondweed (*Potamogeton illinoensis*)	16	17	8	11
floating-leaf pondweed (*Potamogeton natans*)	1	1	1	1
white-stem pondweed (*Potamogeton praelongus*)	2	3	3	7
small pondweed (*Potamogeton pusillus*)	4	0	2	7
clasping-leaf pondweed (*Potamogeton richardsonii*)	27	29	23	24
fern pondweed (*Potamogeton robbinsii*)	3	3	3	1
flat-stem pondweed (*Potamogeton zosteriformis*)	37	40	10	17
white water crowfoot (*Ranunculus longirostris*)	5	1	5	0
grassy arrowhead (*Sagittaria graminea*)	<1	1	0	1
softstem bulrush (*Scirpus validus*)	1	1	1	1
sago pondweed (*Stukenia pectinata*)	15	17	5	10
great bladderwort (*Utricularia vulgaris*)	2	2	2	2
wild celery (*Vallisneria americana*)	8	9	12	25
water star-grass (*Zosterella dubia*)	5	7	5	27
Native floating-leaf macrophytes (%)				
spatterdock (*Nuphar advena*)	7	7	5	5
fragrant water-lily (*Nymphaea odorata*)	19	21	18	22
Submersed macro-algae (%)				
chara	3	2	1	2
Number of sample sites	365	365	363	360
Number of sample sites in littoral zone (depth ≤ 15 ft)	257	257	255	255
Percent points in littoral zone	70%	70%	70%	71%
Mean number of species per point (littoral zone)	3.53	3.12	3.2	3.44
Mean number of native species per point (littoral zone)	2.51	2.7	2.2	2.66
Percentage of points with plants	97	96	91	92
Percentage of points with native plants	89	91	85	90
Number of plant species	25	24	24	24
Number of native plant species	23	22	22	22

*All percent occurrence data is based on per