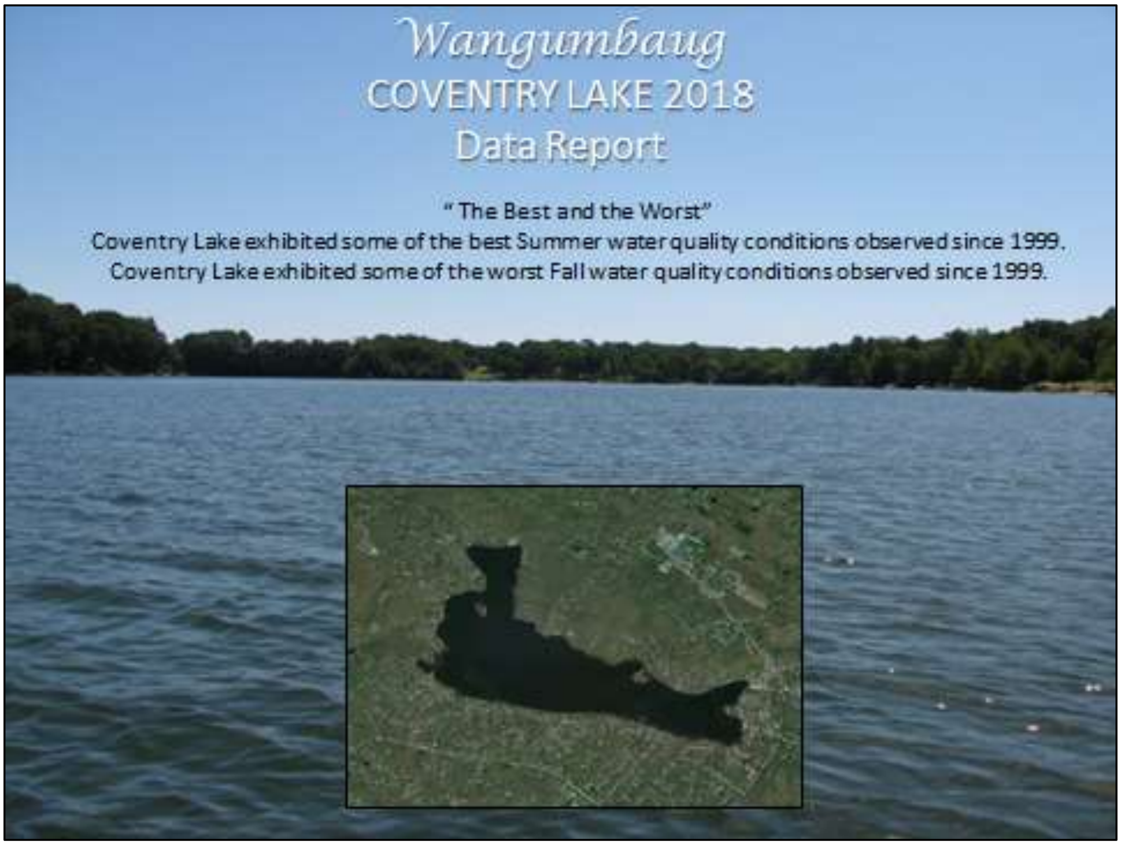


Executive Summary: Coventry Lake Monitoring 2018

Prepared for: Town of Coventry
Prepared by: Ecosystem Consulting Service, Inc.
Robert (Bob) Kortmann, Ph.D.

An annual lake monitoring program has been conducted at Coventry Lake for several decades. Lake water quality conditions were excellent during the Summer of 2018. Summer water clarity (as measured by a standard Secchi disk) was excellent, indicated deep penetration of light. Summer transparency was the best observed since the late 1990s. However, cyanobacteria increased abruptly to high cell densities during Fall, and reduced Secchi transparency to the worst condition recorded since the late 1990s. *Aphanizomenon sp.*was the dominant phytoplankton organism in October. It fixes atmospheric nitrogen, so it doesn't depend on the availability of inorganic nitrogen in the lake water. It produces akinete spores which can tolerate extreme environmental conditions (cold, dessication) and a seedbank of akinetes can initiate an *Aphanizomenon* population during future years. It becomes very buoyant during the latter stage of its growth cycle, which can result in wind-drift accumulation in near-shore locations (coves, beaches). Hence, cell densities can become much higher in those wind-drift accumulation locations than out in the middle of the lake. That can pose a problem because *Aphanizomenon* is a potential toxin producer. Cyanobacteria cell densities during October exceeded the 20K cells/ml threshold that is used to identify a developing, potentially toxic bloom condition (by three fold), although densities did not reach the 100K cells/ml that would trigger posted warnings regarding a potential cyanotoxin threat (at least not at the center of the lake). The “Fall bloom” also occurred after the main contact recreation season.

This needs to be monitored closely in future years. Additional monitoring, specific to potential health risks in areas where wind-drift accumulations develop, may become prudent if cyanobacteria continue to increase; especially earlier in the season.

It should be noted that the lake-wide fluridone treatment program to treat Hydrilla was initiated in July 2018. Based on the review of limnological data, and timing of treatment, I do not believe the fluridone treatment caused the conditions that stimulated the cyanobacteria. Based on the data review, I believe the “Fall bloom” was triggered by a unique set of climatic conditions and lake responses, and that fluridone treatment “coincidentally coincided” with the “Fall bloom”. Again, this needs to be watched closely.

COVENTRY LAKE 2018-SAMPLING DATA

Temperature (°C) — >24°C

Depth (m)	10-Apr	31-May	29-Jun	30-Jul	10-Aug	28-Aug	22-Oct
0.5	6.7	24.0	24.4	25.4	27.9	26.4	12.6
1		23.7	24.1	25.5	28.0	26.3	12.8
2		22.9	23.7	25.8	28.0	26.1	12.9
3		21.9	23.7	25.9	28.0	25.8	13.1
4		20.9	23.5	25.9	28.0	25.6	13.3
5		20.0	23.3	26.0	27.0	25.5	13.4
6		17.9	23.0	25.3	24.3	25.1	13.4
7		15.8	17.5	21.8	18.0	22.6	13.5
8		14.5	14.4	19.1	14.7	18.2	13.5
9		13.7	13.0	16.0	12.0	15.7	13.5
10				14.3	10.5	15.7	13.5

Fluridone treatment was initiated 7/12/18

RTRM — >20 — >50

Depth (m)	31-May	29-Jun	30-Jul	10-Aug	28-Aug	22-Oct
0.5	0	0	0	0	0	0
1	9	12	-3	-3	3	-1
2	24	9	-10	0	7	-3
3	29	3	-3	0	10	-1
4	27	6	-3	0	10	-3
5	26	3	0	35	3	-2
6	50	9	19	87	10	-2
7	**44**	**141**	**107**	**170**	**78**	0
8	22	64	70	67	114	-2
9	15	22	68	44	51	0
10			32	19	2	0
11						
SumRTRM	**247**	**269**	**277**	**419**	**287**	**-14**
MaxRTRM	**50**	**141**	**107**	**170**	**114**	**0**

Surface waters became very warm during 2018, and were mixed deeper than during “typical years”. A very steep thermocline developed at 7m deep (23ft). That typically occurs at approximately 5m (15-16 ft) and gradually deepens through the summer.

COVENTRY LAKE 2018-SAMPLING DATA

Dissolved Oxygen (mg/L) <1.0mg/L <0.5mg/L

Depth (m)	10-Apr	31-May	29-Jun	30-Jul	10-Aug	28-Aug	22-Oct
0.5	12.5	9.1	8.4	8.6	6.7	7.9	8.8
1		9.2	8.4	8.5	6.7	7.9	8.7
2		9.3	8.5	8.3	7.0	7.9	8.6
3		9.8	8.5	8.3	6.8	7.8	8.6
4		9.9	8.5	8.3	6.7	7.7	8.5
5		9.6	8.4	8.0	6.6	7.7	8.5
6		9.4	7.3	7.3	6.7	7.4	8.4
7		8.4	7.9	7.5	5.7	4.7	8.4
8		7.4	2.5	5.9	2.2	1.8	8.4
9		6.5	1.0	1.4	0.7	1.4	8.4
				0.4	0.7	1.3	8.3

DO % Saturation > 100%

Depth (m)	31-May	29-Jun	30-Jul	10-Aug	28-Aug	22-Oct
0.5	109.8	102.4	106.2	87.0	99.5	83.8
1	109.7	102.3	105.0	88.0	99.5	83.4
2	110.1	102.7	103.7	92.0	99.0	82.9
3	113.6	102.5	103.4	90.0	97.7	82.3
4	112.5	102.2	103.0	90.0	96.2	82.0
5	107.1	100.3	100.2	84.0	95.4	81.9
6	100.9	86.4	89.6	82.0	90.5	81.8
7	86.2	84.5	86.1	63.0	54.6	81.8
8	73.5	25.2	64.7	21.0	19.9	81.2
9	63.7	9.7	14.2	6.9	14.2	81.2
10			3.9	6.9	13.6	81.1

Fluridone treatment was initiated 7/12.18

Dissolved oxygen concentrations were higher than typical, deeper in the water column. % dissolved oxygen saturation is useful to identify how intense photosynthetic productivity becomes (as oxygen is produced). During intense surface water "blooms", % saturation can exceed 150% or more. From May through July % DO saturation in surface water slightly exceeded 100%, indicating a healthy level of productivity. During August through October % saturation remained well below 100%, indicating that respiratory consumption of oxygen (and oxygen demand from the bottom) exceeded photosynthetic production. Surface water photosynthesis was not "intense, a bloom condition". Fluridone acts by preventing susceptible plants from producing a substance that protects chlorophyll from being damaged by solar radiation. Hence, the whole lake fluridone treatment may have contributed to a decrease in photosynthetic oxygen production and lower % saturation.

COVENTRY LAKE 2018-SAMPLING DATA

ORP < 0

Depth (m)	31-May	29-Jun	30-Jul	10-Aug	28-Aug	22-Oct
0.5	247	231	230	86	153	100
1	235	214	213	87	141	97
2	221	204	182	87	132	91
3	203	197	173	88	124	78
4	203	189	165	88	117	71
5	205	186	155	90	113	65
6	212	174	149	95	111	57
7	215	170	140	105	112	54
8	213	171	142	114	117	49
9	211	104	104	33	85	46
10			-35	-115	83	44

Iron (mg/L)

Depth (m)	29-Jun	30-Jul	28-Aug
OB	1.306	0.1439	0.2945

Manganese (mg/L)

Depth (m)	29-Jun	30-Jul	28-Aug
OB	1.682	1.618	1.973

Total Phosphorus as P (µg/L)

Depth (m)	4/13/18	5/31/18	6/29/18	7/30/18	28-Aug	22-Oct
1m	13	7	12	10	11	22
Mid		14	11	15		
OB		14	30	45	51	22

Ammonia as N (µg/L)

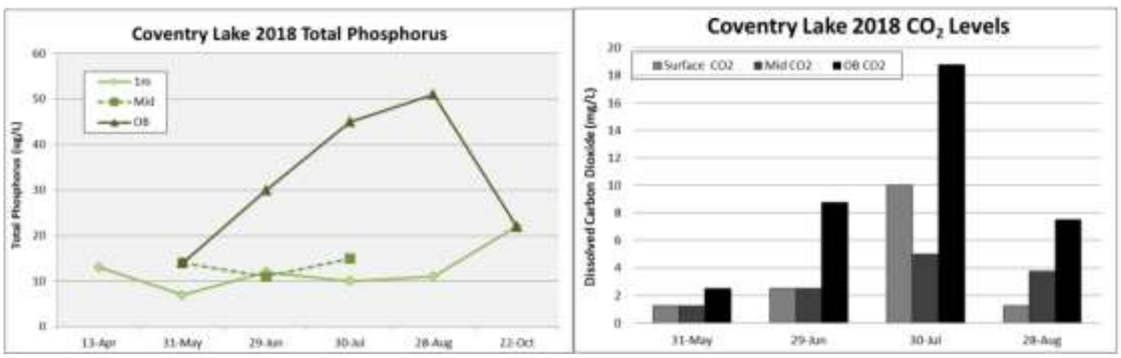
Depth (m)	13-Apr	31-May	29-Jun	30-Jul	28-Aug	13-Oct
1m	18	4	10	ND	3	73
Mid		4	10	ND		
OB		93	366	3	4	70

Nitrite / Nitrate (µg/L)

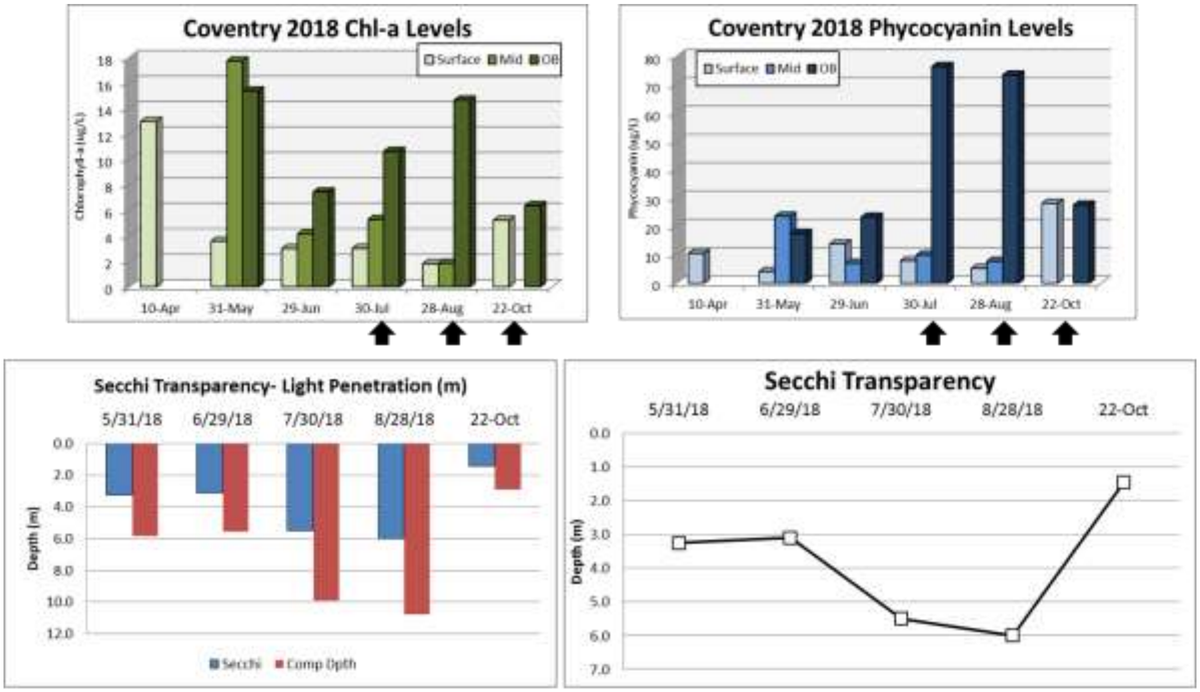
Depth (m)	13-Apr	31-May	29-Jun	30-Jul	28-Aug	13-Oct
1m	128	5	3	ND	ND	11
Mid		ND	6	ND		
OB		64	8	4	4	11

Oxidation-reduction potential (ORP) became highly negative at the bottom (not unusual). Iron and manganese concentrations became elevated over the deepest bottom in June (also, not unusual). In July and August, over-bottom iron concentrations remained relatively low, while manganese concentrations remained very high. Iron is re-oxidized and settles rapidly when it encounters dissolved oxygen, while manganese remains in the water column much longer. Total phosphorus (TP) is especially important because it tends to limit how much total phytoplankton productivity can occur in the water column. TP was very low in surface water throughout the summer. However, TP did increase steadily in the deepest over-bottom water through August, and increased throughout the water column after Fall circulation ("turnover"). Ammonia-N increased in deep over-bottom water in June, but decreased in July through October (likely due to oxygen availability and nitrification). Nitrate became exhausted very early in surface waters. When Nitrate-N decreases below about 30 µg/L the N-fixing cyanobacteria are favored and stimulated (including *Aphanizomenon*).

COVENTRY LAKE 2016-PROFILE DATA

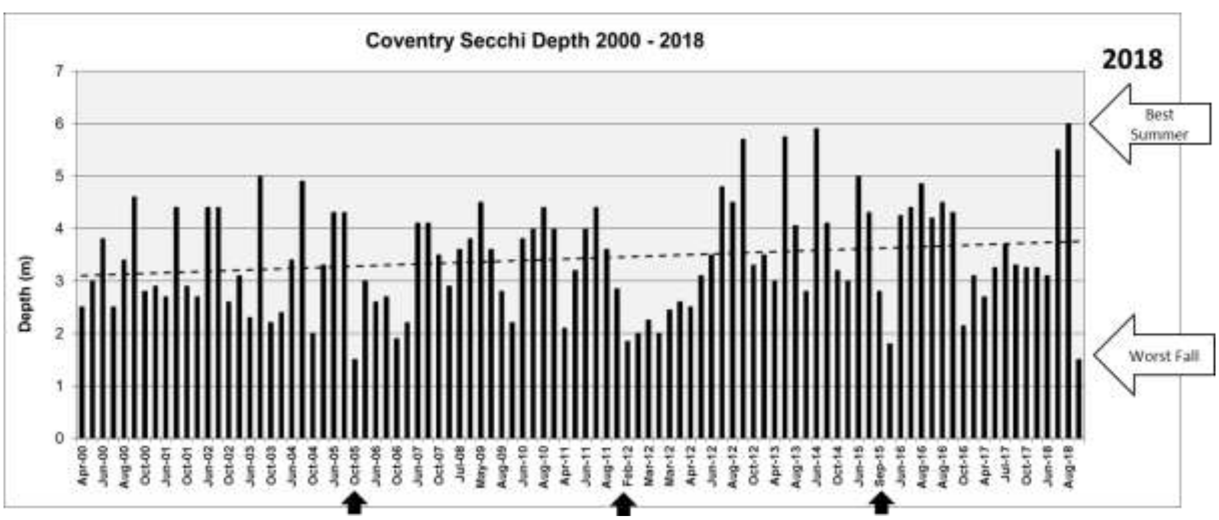


CO_2 is the common product of respiration (aerobic and anaerobic). It accumulated to high over-bottom concentrations, along with the increased TP in deep waters.

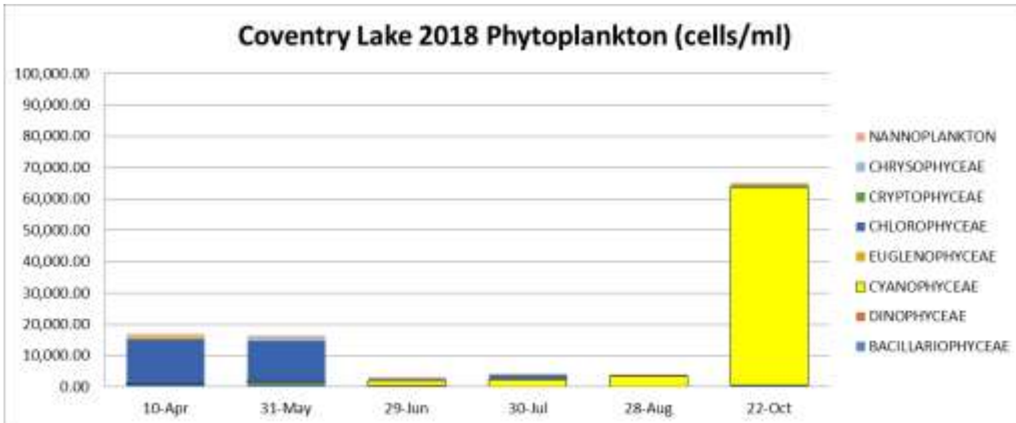


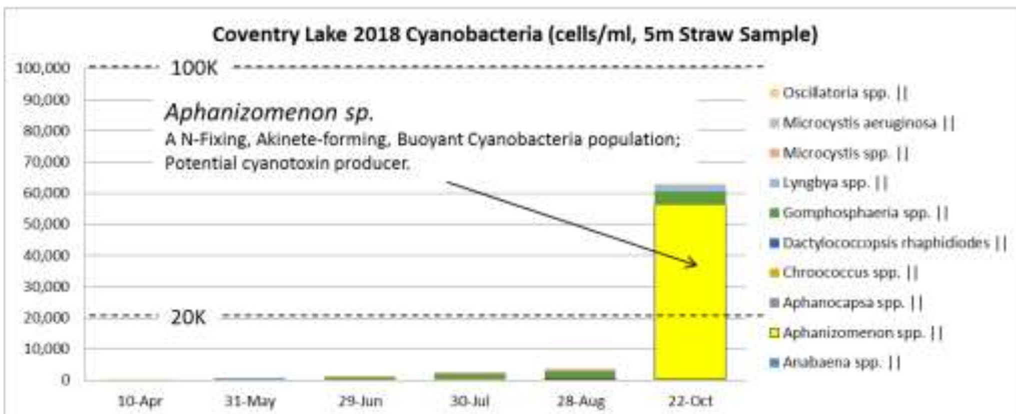
Increasing Chlorophyll-a and Phycocyanin (a Cyanobacteria specific pigment) in deep strata during the Summer, mixed through the water column during Fall. PAR penetrates to 9-10 m).

Chlorophyll-a is an indicator of overall phytoplankton productivity potential. Phycocyanin is a photosynthetic pigment specific to the cyanobacteria. Both increased to very high concentrations in deep over-bottom waters through the Summer, and increased concentrations throughout the water column after the lake mixed during Fall. Adequate light for photosynthesis penetrated to 9-10 m (28-32 ft) during July and August. Transparency increased from 3m (10 ft) in May and June to 6m (20 ft) in July and August. Transparency decreased dramatically during Fall (<2m; 6.5 ft).

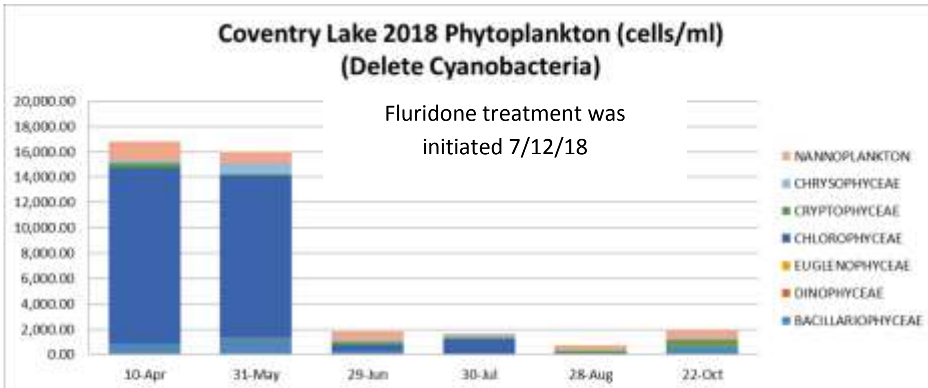


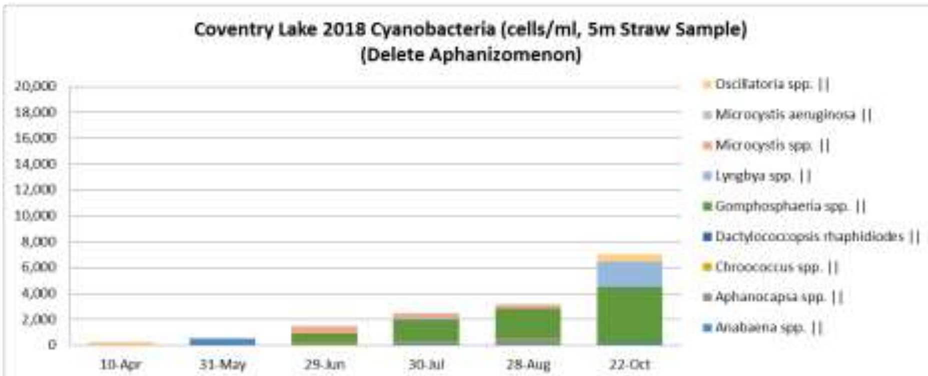
Summer Secchi disk transparency, which indicates the depth of light penetration, was as high as at any time since 1999. However, Secchi transparency during October was poorer than at any time since 1999. Transparency decrease during Fall is "normal-typical". However, the magnitude of changes are of concern.





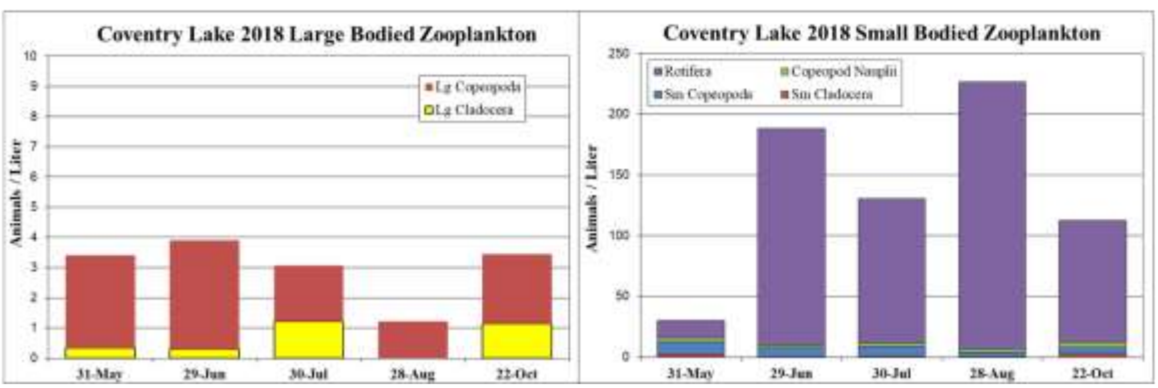
Phytoplankton densities in the top 5m (surface to 16 ft) were very low during the Summer. Then in October a very high cell density of *Aphanizomenon* was observed (and these data are from the lake center, not wind-drift accumulations). The 20K cells/ml density is used as a "threshold" to identify potential development of a cyanotoxin-producing population. The 100K cells/ml is used to identify when a public warning about lake use may be appropriate.



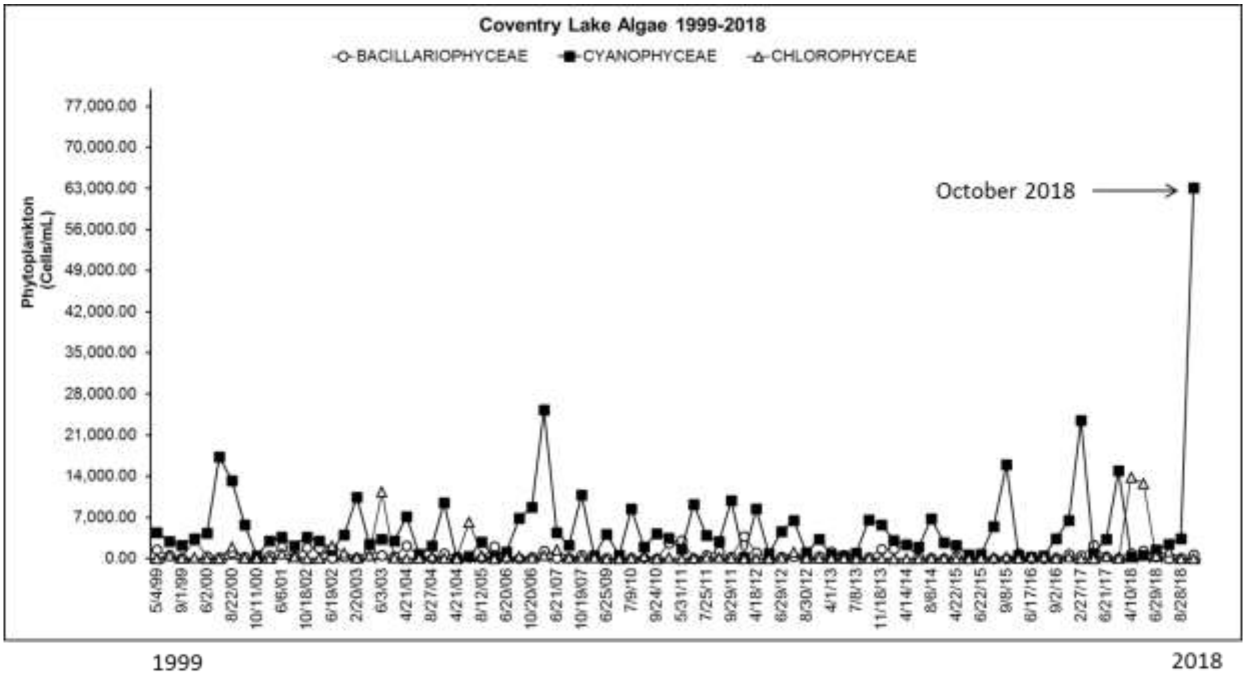


Deleting Aphanizomenon reveals low densities of all other algae and cyanobacteria during 2018. It isn't known whether the whole lake fluridone treatment contributed to sustained very low phytoplankton densities.

COVENTRY LAKE 2018-ZOOPLANKTON RESULTS



Large-bodied cladocera are important grazers on phytoplankton (and also serve as a "canary" for toxicity). Although higher densities are desirable it is encouraging to observe persistence of the populations. Also, numbers may be underestimated because cladocera could have been very deep because of deep oxygen availability and light penetration.

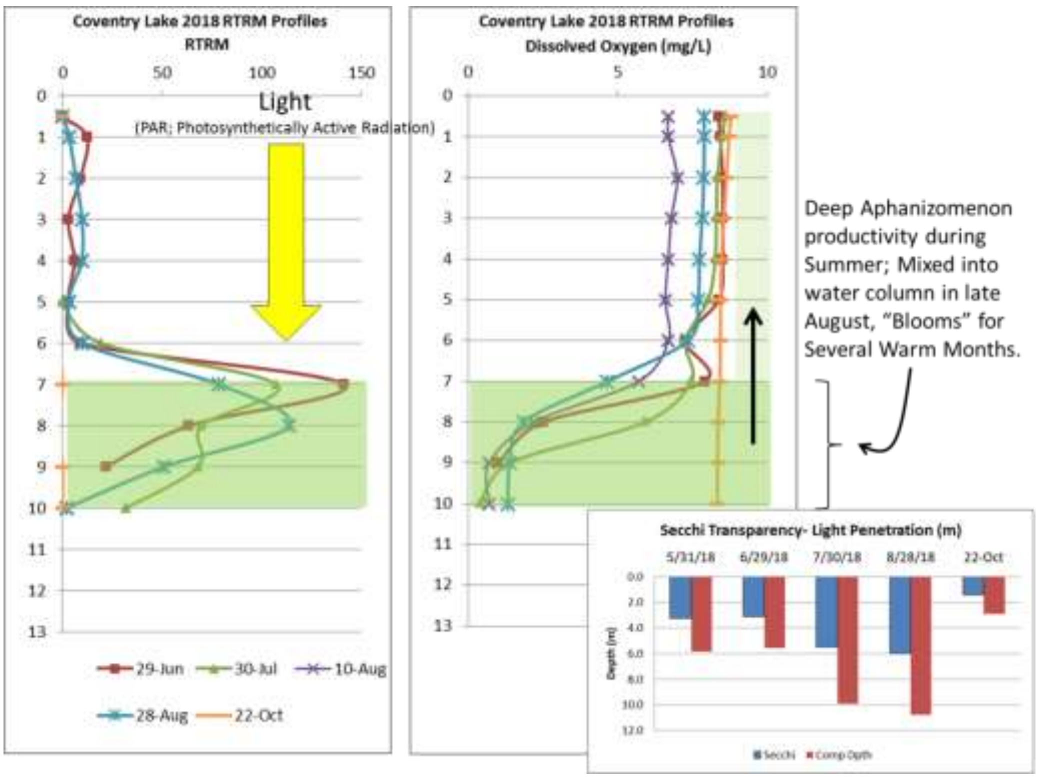


The cyanobacteria cell density in October (mid-lake) was the highest observed since 1999, and was nearly a mono-culture of *Aphanizomenon*, that fixes atmospheric nitrogen, produces akinete spores which can tolerate extreme environmental conditions. An increase in the deposition of akinete spores can increase the seedbank that initiates an *Aphanizomenon* population during future years. Aphanizomenon becomes very buoyant during the latter stage of its growth cycle, which can result in wind-drift accumulation in near-shore locations (coves, beaches). Hence, cell densities can become much higher in those wind-drift accumulation locations than out in the middle of the lake. That can pose a public health risk because *Aphanizomenon* is a potential toxin producer. Cyanobacteria cell densities during October exceeded the 20K cells/ml threshold that is used to identify a developing, potentially toxic bloom condition, but densities did not reach the 100K cells/ml that would trigger posted warnings regarding a potential cyanotoxin threat (at least not at the center of the lake). The "Fall bloom" also occurred after the main contact recreation season.

So why did *Aphanizomenon* reach such high cell densities so abruptly after Fall circulation ("turnover")?

A hypothesis that "fits the data observations":

It is likely that *Aphanizomenon* was growing all Summer in the deep over-bottom waters. Light penetration was very deep, which would support their photosynthetic production. Also, germination of the akinete spores is triggered by light (and to some degree by warm temperatures). Hence, more light reaching more bottom area in 2018 may have resulted in the germination of akinetes deposited over many previous years. Although low in surface water, nutrient availability was relatively high in deep over-bottom water, especially Total Phosphorus (TP). The chlorophyll-a data indicate that most was in the deepest strata. Likewise, phycocyanin (the pigment specific to cyanobacteria) reached very high over-bottom concentrations during Summer. Cyanobacteria in the deep over-bottom water are not detected by the 5m deep integrated phytoplankton sampling approach (depth-specific sampling of phytoplankton should be added in future years). Deep cyanobacteria would not be exposed to the fluridone treatments of the surface water layer.

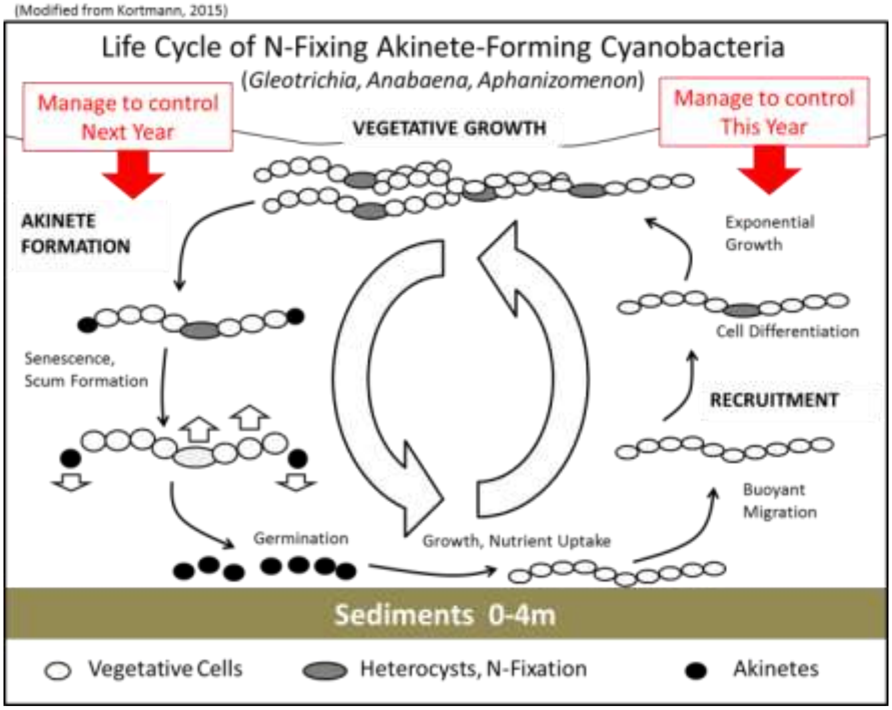


The "working hypothesis", based on all monitoring data, is that *Aphanizomenon* was growing in the deepest water all summer and was mixed up into the surface during Fall Overturn. Recall that we experienced an extended duration of summer-like weather in September and October 2018 (late leaf fall and frost). That provided *Aphanizomenon* additional growth potential. Deposition of akinete spores may have been very high during Fall 2018, which may increase *Aphanizomenon* in future years. Continued monitoring will be very important. Also, if wind-drift accumulations of cyanobacteria occur, it would be prudent to develop a monitoring approach for such locations, and a response plan relative to a potential cyanotoxin risk.

The product label, and most research publications, indicate that phytoplankton (algae and cyanobacteria) are not as susceptible to effects of fluridone as the sensitive aquatic macrophytes. However, some studies have shown that long duration exposure to fluridone can retard both eukaryotic algae and cyanobacteria (although at somewhat higher concentrations than used at Coventry Lake for Hydrilla control). The potential influence of fluridone on phytoplankton abundance and composition should be monitored as the fluridone treatment program continues.

Additional Information

(Modified from Kortmann, 2015)



Cyanotoxins

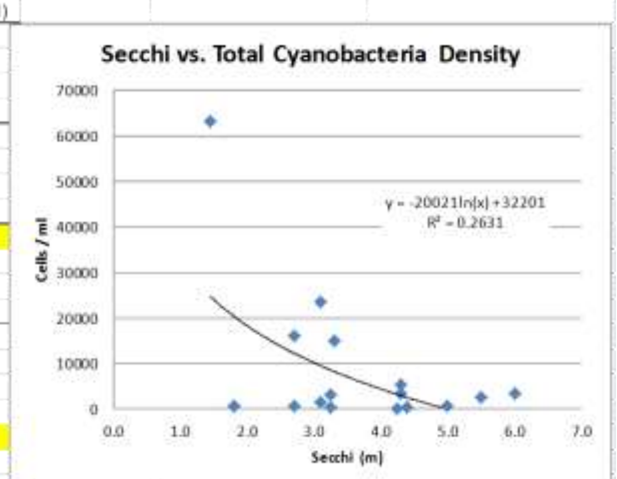
TOXIN GROUP	Cyanobacteria genera	Affects	Ecostrategist Categories	Natural Forcing Factors
Alkaloids				
Anatoxin-a	***Anabaena, Aphanizomenon,*** *Planktothrix (Oscillatoria)*	Nerve Synapse	Buoyant N-Fixers	N:P Ratio, pH, Temp, De, Light Penetration, Grazing Rate
Aplysiatoxins	*Planktothrix (Oscillatoria), Lyngbya, Schizothrix*	Skin Rash	Benthic, Stratifying,	Stratification Boundaries, Light Penetration
Cylindrospermopsins	*Cylindrospermopsis,* ***Aphanizomenon***	Liver Function	Buoyant N-Fixers	N:P Ratio, pH, Temp, De, Light Penetration, Grazing Rate
Lyngbyatoxin	*Lyngbya*	Gastro-Intestinal, Skin	Benthic, Stratifying, Buoyant	Stratification Boundaries, Light Penetration
Saxitoxins	***Aphanizomenon***, *Cylindrospermopsis*	Nerves	Buoyant N-Fixers	N:P Ratio, pH, Temp, De, Light Penetration, Grazing Rate
Cyclic Peptides				
Microcystins	*Microcystis,* ***Anabaena***, *Planktothrix (Oscillatoria), Nostoc*	Liver Function	Buoyant N-Fixers	N:P Ratio, pH, Temp, De, Light Penetration, Grazing Rate
Nodularin	*Nodularia*	Liver Function	Brackish	Nitrogen Availability and Form

Cyanotoxins are not produced by all species of a genera, and a specific population may or may not be producing a toxin.

Modified from Kortmann, 2015

Examples of wind-drift accumulations of the cyanobacteria *Anabaena* and *Aphanizomenon* at several lakes and reservoirs. Wind-drift accumulations that concentrate cyanobacteria in near shore locations likely poses the greatest risk of cyanotoxin exposure.

	Secchi (m)	Total Cyanobacteria (cells/ml)
5/15/2015	1.8	665
6/22/2015	5.0	719
8/12/2015	4.3	5426
9/8/2015	2.7	15980
4/11/2016	1.8	561
6/17/2016	4.3	250
7/18/2016	4.4	426
9/2/2016	4.3	3351
2/27/2017	3.1	23500
4/25/2017	2.7	823
6/21/2017	3.3	3254
8/16/2017	3.3	14990
5/31/2018	3.3	548
6/29/2018	3.1	1464
7/30/2018	5.5	2490
8/28/2018	6.0	3378
10/22/2018	1.5	63177



"Caution Thresholds":
PC > 15 µg/L
Secchi < 3m (10 ft)

"Warning Thresholds":
PC > 25 µg/L
Secchi < 1.5m (5 ft)

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Alternative Alert System for Cyanobacterial Bloom, Using Phycocyanin as a Level Determinant

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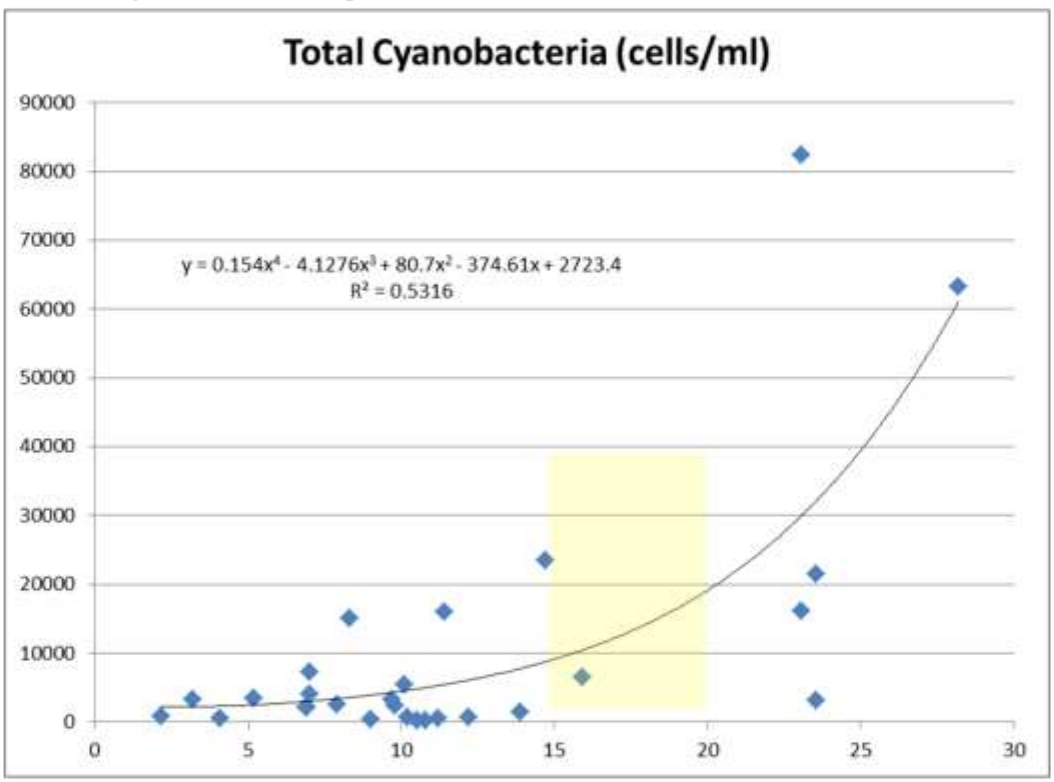
Chlorophyll *a* concentration and cyanobacterial cell density are regularly employed as dual criteria for determinations of the alert level for cyanobacterial bloom. However, chlorophyll *a* is not confined only to the cyanobacteria, but is found universally in eukaryotic algae. Furthermore, the determination of cyanobacterial cell counts is notoriously difficult, and is unduly dependent on individual variation and trained skill. A cyanobacteria-specific parameter other than the cell count or chlorophyll *a* concentration is, accordingly, required in order to improve the present cyanobacterial bloom alert system. Phycocyanin has been shown to exhibit a strong correlation with a variety of bloom-related factors. This may allow for the current alert system criteria to be replaced by a three-stage alert system based on phycocyanin concentrations of 0.1, 30, and 700 μg/L. This would also be advantageous in that it would become far more simple to conduct measurements without the need for expensive equipment, thereby enabling the monitoring of entire lakes more precisely and frequently. Thus, an alert system with superior predictive ability based on high-throughput phycocyanin measurements appears feasible.

Keywords: alert system, bloom, chlorophyll *a*, cyanobacteria, phycocyanin

Coventry and Waramaug Data

Cells/ml



Phycocyanin (in vivo)