DEPARTMENT OF AGRICULTURE

Pesticides in Minnesota Lakes

A Review of Pesticide Lake Water Quality Data Collected with the United States Environmental Protection Agency's National Lake Assessment in 2007, 2012 and 2017.

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Abbreviations

AMPA	aminomethylphosphonic acid (breakdown product of glyphosate)
BMP	best management practice
ELISA	Enzyme-Linked Immunosorbent Assay
ETF	East Temperate Forests ecoregion
GC-MS	Gas chromatography-mass spectrometry
GC-MS/MS	Gas chromatography-tandem mass spectrometry
GP	Great Plains ecoregion
LC-MS	Liquid chromatography-mass spectrometry
LC-MS/MS	Liquid chromatography- tandem mass spectrometry
MPCA	Minnesota Pollution Control Agency
MDA	Minnesota Department of Agriculture
MRL	method reporting limit
mL	milliliter
NF	Northern Forest ecoregion
ng/L	nanogram per liter (equivalent to one part per trillion)
NLA	National Lakes Assessment
OPP	Office of Pesticide Programs
SOP	Standard Operating Procedures
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture

Executive Summary

Pesticide water quality samples were collected from randomly selected lakes in Minnesota in 2007, 2012 and 2017 in conjunction with the United States Environmental Agency's (USEPA) National Lake Assessment (NLA). With the exception of two detections of the insecticide chlorpyrifos in 2017, all other pesticide detections were very low compared to the applicable water quality reference values. In each of the NLA years, the majority of detections were herbicide degradates and herbicides. The number of pesticide compounds detected and associated concentration of those compounds tended to increase with an increasing amount of row crop production in a lakeshed. In contrast, increasing amounts of forest in a lakeshed lead to fewer pesticide detections and lower pesticide concentrations.

There was little variability in the pesticides that were detected, and the concentration of detected pesticides, between the 2007, 2012 and 2017 NLA. This is a key finding given the changes since 2007 in agricultural pesticide use in Minnesota. The changes include the increase of corn and soybean acres, increased pesticide resistance of insects and weeds, and the increasing presence of soybean aphid's since the start of the millennium.

1.0 Introduction

1.1 Agriculture and Minnesota Water Resources

Minnesota, known as "The Land of 10,000 Lakes", has a history and heritage linked to its abundant water resources. Minnesota is also a major agricultural state and is ranked fourth nationally in corn for grain production and third nationally in soybeans for bean production (USDA, 2017). Minnesota's economy is dependent on agriculture and a tourism industry that relies on high-quality water resources.

In the last decade, agricultural pesticides usage in Minnesota has changed due to several factors. Factors include economics, improved plant genetics and longer growing seasons that have expanded the corn and soybean-growing region further into western and northern Minnesota. Minnesota had 16.2 million acres planted to corn and soybeans in 2017, a net increase of 1.45 million acres of these crops compared to 2007 (USDA, 2018). The presence of weeds resistant to herbicides (*e.g.,* glyphosate) has expanded greatly in Minnesota since 2007 (Gunsolus, 2018). The University of Minnesota Extension Service now recommends full label rate application for herbicides, the use of pre-emergent herbicides (particularly in farming operations utilizing glyphosate), diversification of herbicide mode of actions and using multiple active ingredients (Gunsolus et al., 2017).

Just as the footprint of Minnesota's dominant row crops, corn and soybeans, has expanded over the past decade, so has the ways that pesticides are used to control weeds and insect populations. Insect populations, primarily soybean aphids, have increased greatly since the early 2000's (Ragsdale et al., 2011) and insecticide resistance in soybean aphids have been reported in recent years (Koch et al., 2018). The continually changing resistance to pesticides has resulted in a number of changes in pesticide management to reduce crop losses due to unwanted weeds and insects.

1.2 Pesticides Water Quality Monitoring in Minnesota

The Minnesota Department of Agriculture (MDA) has been conducting pesticide monitoring in surface waters since 1991. Annually, the MDA completes approximately 800 samples from surface waters across the state. In general, the MDA collects water samples from agriculture and urban areas of Minnesota and analyzes water for up to approximately 150 different pesticide compounds that are widely used and/or pose the greatest risk to water resources. The purpose of the MDA's pesticide monitoring program is to "determine the impact of pesticides on the environment, including impacts on surface water and groundwater in this state" (MN Statute 18B.04). The MDA completes this by analyzing the presence and concentration of pesticides in Minnesota waters, and present long-term trend analysis. All monitoring is conducted following annual work plans and standard operating procedures (SOPs) developed by the MDA available on the MDA Monitoring and Assessment Unit webpage.

The MDA uses a network of river and stream locations to conduct annual pesticide water quality monitoring. In addition to performing the analysis of the annual river and stream monitoring pesticide water samples, the MDA Laboratory provides capacity to analyze pesticide water samples collected in Minnesota with national monitoring projects such as the National Wetlands Condition Assessment, Environmental Monitoring and Assessment Program and the National Lake Assessment (NLA) on a five-year rotating schedule. In general, the MDA detects a larger number of pesticides, and at higher concentrations, in rivers and streams compared to lakes and wetlands (MDA, 2016; MDA, 2017).

There are 14 waterbodies in Minnesota that are either designated, or proposed to be designated, by the Minnesota Pollution Control Agency (MPCA) on the United States Environmental Protection Agency (USEPA) 303(d) Impaired Waters List for currently registered pesticides. One impairment is for acetochlor (herbicide) and 13 impairments are for chlorpyrifos (insecticide). Excluding one lake chlorpyrifos impairment, all other pesticide impairments are located on rivers or streams.

Acetochlor, atrazine and chlorpyrifos are identified as "surface water pesticides of concern" by the Minnesota Commissioner of Agriculture. This designation prompts development of specific best management practices (BMPs) and education and outreach to reduce the impacts of these pesticides to water resources.

1.3 National Lakes Assessment

"The National Lakes Assessment is designed to provide statistically valid national and regional estimates of the condition of lakes. It uses a probability-based sampling design to represent the condition of all lakes across the coterminous United States. The survey is a collaborative effort between EPA, states, tribes, federal agencies, and other organizations.

Lakes are selected randomly using a statistical survey design to represent the population of lakes in their ecological region – the geographic area in which climate, ecological features, and plant and animal communities are similar.

Lake ecosystems are dynamic and indicators selected to characterize them should represent their varied aspects. For the NLA 2012, a suite of chemical, physical and biological indicators were chosen to assess biological integrity, trophic state, recreational suitability, and key stressors affecting the biological quality of lakes.

Although there are many more indicators and/or stressors that affect lakes, NLA analysts believe these to be among the most representative at a national scale" (USEPA 2018a).

2.0 Methods

2.1 Lake Selection

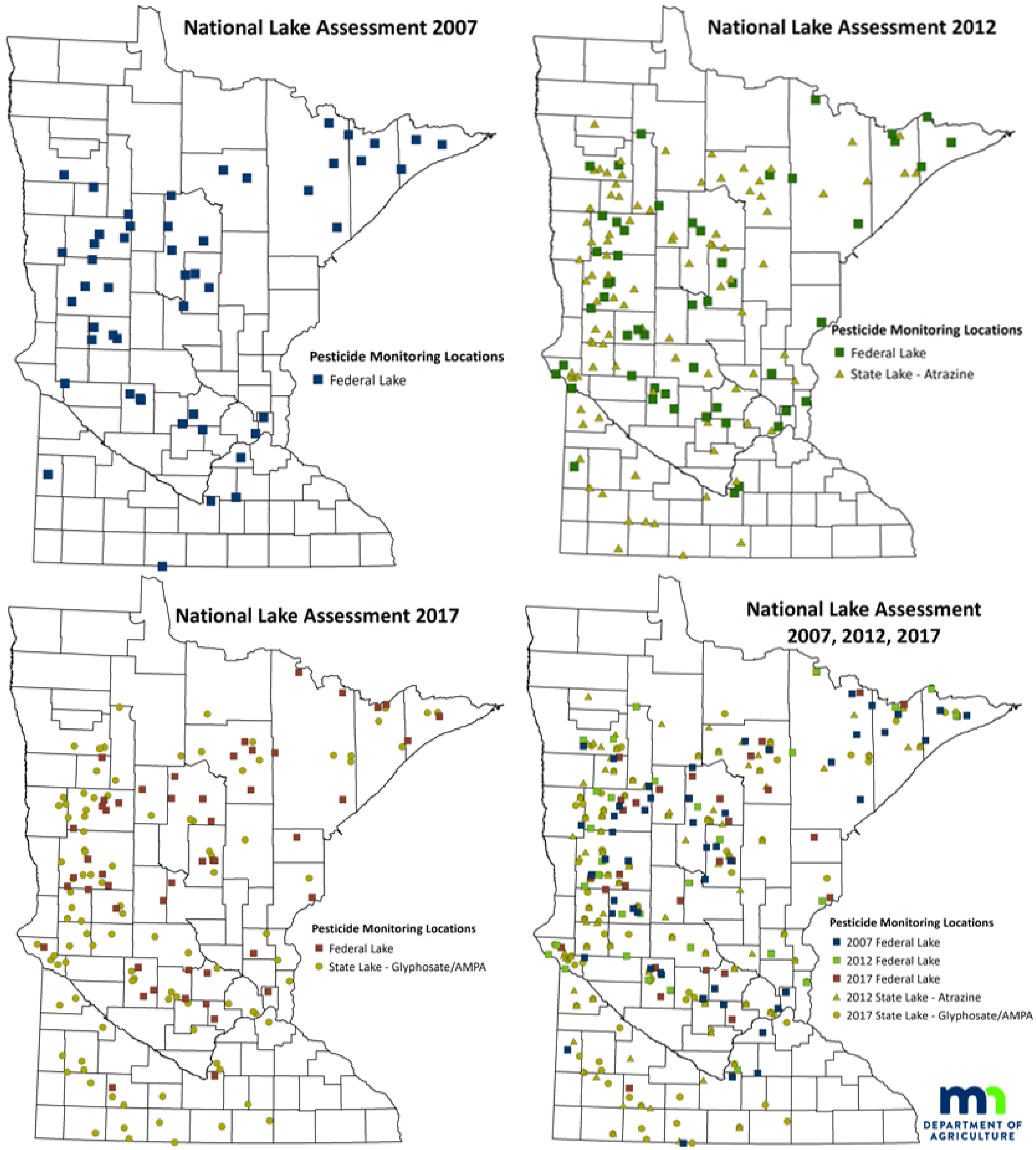
For the NLA, lakes were randomly selected from natural lakes, ponds and reservoirs across the lower 48 states by the USEPA. "The NLA 2007 assessed only those lakes greater than 10 acres (4 hectares) in size. Starting with the NLA in 2012, to be included in the survey, a water body had to be a natural or man-made freshwater lake, pond or reservoir, greater than 2.47 acres (1 hectare), at least 3.3 feet (1 meter) deep, a minimum quarter acre (0.1 hectare) of open water and a minimum retention time of 1 week. The Great Lakes and the Great Salt Lake were not included in the survey, nor were commercial treatment and/or disposal ponds, brackish lakes, or ephemeral lakes" (USEPA, 2018a). The lakes selected by the USEPA are referred to as "Federal Lakes" throughout this report. The NLA occurred on a five-year rotating schedule (2007, 2012 and 2017) and provided an opportunity for review changes in pesticide water quality over-time.

In addition to the lakes randomly selected by the USEPA, the MPCA randomly selected additional lakes in 2012 and 2017 to be sampled in order to complete an ecoregion-based assessment within Minnesota. These lakes are referred to as "State Lakes" throughout this report.

The Federal Lakes included 53 lakes in 2007, 51 lakes in 2012 and 50 lakes in 2017. The samples from the Federal Lakes were analyzed with advanced pesticide methods for a wide variety of pesticides including herbicides, fungicides, insecticides and breakdown products of these pesticide types. During the 2012 NLA, all 51 Federal Lakes and 72 State Lakes received a thiazine Enzyme-Linked Immunosorbent Assay (ELISA) screen for atrazine (herbicide). During the 2017 NLA, all 50 Federal Lakes and an additional 101 State Lakes were analyzed for glyphosate and aminomethylphosphonic acid (AMPA; glyphosate breakdown product). Lake information for the NLA 2007, 2012 and 2017 are presented in Appendix 1.

In each NLA (2007, 2012 and 2017), the majority of sampled Federal Lakes were located in central and northeast Minnesota with fewer lakes being sampled in western, southwestern and southcentral Minnesota (Figure 1). Since lakes were randomly selected for sampling, this pattern follows the relative number of lakes throughout Minnesota. As such, no lakes were sampled in southeast Minnesota in any of the three monitoring years due to the proportional lack of lakes. In addition, due to random lake selection, urban lake monitoring was limited; therefore, urban pesticide use over time was not examined.

Figure 1. Lakes sampled for pesticides as a part of the National Lakes Assessment in 2007, 2012 and 2017.



2.2 Sample Collection

Minnesota Pollution Control Agency staff collected pesticide water quality samples following the MPCA lake monitoring SOP for collecting a surface sample by hand. The pesticide sample bottles were submerged and filled directly as surface grab samples over the deepest area of the lake. Nitrile gloves were worn during all pesticide sample collections. Water quality samples were chilled on ice following collection, and transported on wet ice. Samples were either frozen or refrigerated prior to delivery to the MDA Laboratory following the MDA Laboratory receiving protocols.

Pesticide samples were analyzed using gas chromatography with mass spectrometry (GC-MS), gas chromatography with tandem mass spectrometry (GC-MS/MS) or liquid chromatography with tandem mass spectrometry (LC-MS/MS). Samples were collected into certified clean, 950 mL amber glass bottles. Samples that were analyzed using thiazine ELISA and glyphosate LC-MS/MS methods were collected into 50 mL centrifuge bottles. Lakes were sampled from June through September, with most samples collected in August of each NLA year (Table 1).

Table 1. Lake sample collection events by month in NLA 2007, 2012, and 2017.

NLA Year	June	July	August	September	Total*
2007	4	24	27	0	55
2012	17	12	19	4	52
2017	0	16	24	10	50
Total	21	52	70	14	157

* In 2007, two lakes were sampled twice; in 2012 one lake was sampled twice.

2.3 Laboratory Analytical Methods

The MDA Laboratory made several analytical method advancements from 2007 through 2017 that expanded the number of pesticide compounds included, and lowered Method Reporting Limits (MRL) for most compounds. In 2007, 37 pesticide compounds were analyzed with a GC-MS and a chloroacetamide degradate method. In 2012, 126 pesticide compounds were analyzed with a GC-MS and a LC-MS/MS method. In 2017, 148 pesticide compounds were analyzed with a GC-MS/MS and a LC-MS/MS method (Table 2), and glyphosate and AMPA were analyzed with a separate LC-MS method. Finally, the University of Wisconsin- Stevens Point analyzed samples with a triazine (atrazine) ELISA screen during the 2012 NLA. The triazine (atrazine) ELISA screen had a MRL of 100 ng/L, and is not included in Table 2.

Table 2. MDA Laboratory pesticide analytes for NLA 2007, 2012 and 2017.

Note: a dash (-) indicates the analyte was not analyzed within that NLA year.

Pesticide Analyte	Pesticide Type	2007 MRL (ng/L)	2012 MRL (ng/L)	2017 MRL (ng/L)
2,4,5-T	Herbicide	-	50	50
2,4,5-TP	Herbicide	-	50	50
2,4-D	Herbicide	-	8.3	8.3
2,4-DB	Herbicide	-	20	20
Acetamiprid	Insecticide	-	25	25
Acetochlor	Herbicide	50	50	30
Acetochlor ESA	Herbicide Degradate	70	30	30
Acetochlor OXA	Herbicide Degradate	70	33.3	33.3
Alachlor	Herbicide	50	50	30
Alachlor ESA	Herbicide Degradate	70	41.6	41.6
Alachlor OXA	Herbicide Degradate	70	33.3	33.3
Aldicarb Sulfone	Insecticide Degradate	-	15	15
Aldicarb Sulfoxide	Insecticide Degradate	-	50	50
Aminopyralid	Herbicide	-	-	25
Atrazine	Herbicide	50	50	30
DEDI Atrazine	Herbicide Degradate	-	50	50
Deisopropylatrazine	Herbicide Degradate	200	200	25
Desethylatrazine	Herbicide Degradate	50	50	50
Hydroxyatrazine	Herbicide Degradate	-	6.7	6.7
Azoxystrobin	Fungicide	-	10	10
Benfluralin	Herbicide	-	150	25
Bensulfuron-methyl	Herbicide	-	16.7	16.7
Bensulide	Herbicide	-	-	250
Bentazon	Herbicide	-	5	5
Benzovindiflupyr	Fungicide	-	-	50
Bicyclopyrone	Herbicide	-	-	10
Bicyclopyrone SYN503780	Herbicide Degradate	-	-	100
Bifenthrin	Insecticide	-	100	20
Boscalid	Fungicide	300	300	50
Bromacil	Herbicide	-	30	30
Bromoxynil	Herbicide	-	-	25
Carbaryl	Insecticide	-	25	25
Carbendazim	Fungicide	-	10	10
Carbofuran	Insecticide	-	13.3	13.3
Chlorantraniliprole	Insecticide	-	50	50
Chlorimuron-ethyl	Herbicide	-	20	20
Chlorothalonil	Fungicide	-	120	50
Chlorpyrifos	Insecticide	100	40	40
Chlorpyrifos Oxon	Insecticide Degradate	-	40	40
Clomazone	Herbicide	-	100	15
Clopyralid	Herbicide	-	41.6	41.6
Clothianidin	Insecticide	-	25	25
Cyanazine	Herbicide	200	200	25

Pesticide Analyte	Pesticide Type	2007 MRL (ng/L)	2012 MRL (ng/L)	2017 MRL (ng/L)
Cyantraniliprole	Insecticide	-	-	100
Cyfluthrin	Insecticide	-	500	100
Diazinon	Insecticide	120	100	30
Diazinon Oxon	Insecticide Degradate	-	150	75
Dicamba	Herbicide	-	50	50
Dichlobenil	Herbicide	-	50	5
Dichlorprop	Herbicide	-	50	50
Dichlorvos	Insecticide	-	90	15
Dicrotophos	Insecticide	-	25	25
Difenoconazole	Fungicide	-	25	25
Dimethenamid	Herbicide	50	50	15
Dimethenamid ESA	Herbicide Degradate	70	6.7	6.7
Dimethenamid OXA	Herbicide Degradate	70	10	10
Dimethoate	Insecticide	220	220	50
Dinotefuran	Insecticide	-	25	25
Disulfoton	Insecticide	-	150	60
Disulfoton Sulfone	Insecticide Degradate	-	20	20
Diuron	Herbicide	-	13.3	13.3
EPTC	Herbicide	230	230	10
Esfenvalerate	Insecticide	-	200	150
Ethalfluralin	Herbicide	-	150	50
Ethofumesate	Herbicide	-	100	50
Flufenacet OXA	Herbicide Degradate	-	8.3	8.3
Flumetsulam	Herbicide	-	50	50
Flupyradifurone	Insecticide	-	-	10
Flutriafol	Fungicide	-	-	10
Fluxapyroxad	Fungicide	-	-	10
Fonofos	Insecticide	100	100	15
Glyphosate	Herbicide	-	-	1,020
Aminomethylphosphornic acid (AMPA)	Herbicide Degradate	-	-	5,090
Halauxifen-methyl	Herbicide	-	-	10
Halauxifen Acid	Herbicide Degradate	-	-	25
Halosulfuron-methyl	Herbicide	-	30	30
Hexazinone	Herbicide	-	10	10
Imazamethabenz-methyl	Herbicide	-	5	5
Imazamethabenz Acid	Herbicide Degradate	-	10	10
Imazamox	Herbicide	-	13.3	13.3
Imazapic	Herbicide	-	10	10
Imazapyr	Herbicide	-	8.3	8.3
Imazaquin	Herbicide	-	16.7	16.7
Imazethapyr	Herbicide	-	6.7	6.7
Imidacloprid	Insecticide	-	20	20
Imidacloprid Olefin	Insecticide Degradate	-	-	50
Imidacloprid Urea	Insecticide Degradate	-	-	50

Pesticide Analyte	Pesticide Type	2007 MRL (ng/L)	2012 MRL (ng/L)	2017 MRL (ng/L)
Isoxaflutole	Herbicide	-	40	40
Isoxaflutole DKN	Herbicide Degradate	-	50	50
lambda-Cyhalothrin	Insecticide	-	200	75
Linuron	Herbicide	-	20	20
Malathion	Insecticide	90	90	50
Mandestrobin	Fungicide	-	-	25
MCPA	Herbicide	-	5	5
MCPB	Herbicide	-	20	20
MCPP	Herbicide	-	50	50
Mesotrione	Herbicide	-	50	50
Metalaxyl	Fungicide	-	8.3	8.3
Methoxychlor	Insecticide	-	150	50
Metolachlor	Herbicide	70	70	25
Metolachlor ESA	Herbicide Degradate	70	10	10
Metolachlor OXA	Herbicide Degradate	70	10	10
Metribuzin	Herbicide	100	100	75
Metribuzin DA	Herbicide Degradate	1,000	1,000	25
Metribuzin DADK	Herbicide Degradate	1,000	1,000	500
Metribuzin DK	Herbicide Degradate	1,000	1,000	500
Metsulfuron-methyl	Herbicide	-	23.3	23.3
Momfluorothrin	Insecticide	-	-	50
Myclobutanil	Fungicide	200	200	10
Neburon	Herbicide	-	10	
Nicosulfuron	Herbicide	-	26.6	26.6
Norflurazon	Herbicide	-	20	20
Norflurazon-desmethyl	Herbicide Degradate	-	50	50
Oxadiazon	Herbicide	-	50	75
Oxathiapiprolin	Fungicide	-	-	100
Oxydemeton-methyl	Insecticide	-	20	20
Parathion-methyl	Insecticide	120	120	100
Parathion-methyl Oxon	Insecticide Degradate		25	25
Pendimethalin	Herbicide	80	80	75
Phorate	Insecticide	120	120	25
Picloram	Herbicide	-	41.6	41.6
Picoxystrobin	Fungicide	-	-	50
Prometon	Herbicide	-	100	100
Prometryn	Herbicide	-	3.3	3.3
Propachlor	Herbicide	-	100	30
Propachlor ESA	Herbicide Degradate	-	30	30
Propachlor OXA	Herbicide Degradate	-	10	10
Propazine	Herbicide	-	100	25
Propiconazole	Fungicide	200	200	10
Pyraclostrobin	Fungicide	-	-	25
Pyroxasulfone	Herbicide	-	-	50
Saflufenacil	Herbicide	-	15	15

Pesticide Analyte	Pesticide Type	2007 MRL (ng/L)	2012 MRL (ng/L)	2017 MRL (ng/L)
Sedaxane	Fungicide	-	-	75
Siduron	Herbicide	-	6.7	6.7
Simazine	Herbicide	-	100	75
Sulfometuron-methyl	Herbicide	-	8.3	8.3
Tebuconazole	Fungicide	200	200	10
Tebupirimfos	Insecticide	100	100	30
Tembotrione	Herbicide		50	50
Terbufos	Insecticide	190	190	30
Tetraconazole	Fungicide	150	150	10
Thiacloprid	Insecticide	-	-	50
Thiamethoxam	Insecticide	-	25	25
Thifensulfuron-methyl	Herbicide	-	16.7	16.7
Thiobencarb	Herbicide	-	8.3	8.3
Tolfenpyrad	Insecticide	-	-	100
Triallate	Herbicide	170	100	50
Triasulfuron	Herbicide	-	23.3	23.3
Triclopyr	Herbicide	-	50	50
Trifluralin	Herbicide	-	170	50
zeta-Cypermethrin	Insecticide	-	500	500

2.4 Data Analysis

The advancement of analytical methods at the MDA Laboratory since 2007 allowed for more pesticides to be analyzed, and at lower MRLs over time. These advancements improved the quality of data collected; however, it complicates long-term data analysis because of the ability to report detections that were below the MRLs used in previous NLAs. Only pesticide analytes detected above their respective MRL (*i.e.,* pesticide detection) are presented in the Results and Discussion section (Section 3.0).

To provide the most recent and comprehensive dataset with the most pesticide analytes and lowest MRLs, the 2017 NLA results are presented independently. The long-term water quality results were censored to the highest MRL from the 2007, 2012 or 2017 NLA. Censoring was required to remove bias that may have occurred as a result of the advancements in analytical methodologies used in the 2012 or 2017 NLA that allowed for reporting of detections below a higher, historical MRL. The data collected in 2007, 2012, and 2017 NLA are not robust enough to statistically compare the three years of data and compute trends. The statewide results, regional results, and data collected from the 12 lakes that were sampled in each of the 2007, 2012 and 2017 NLA are presented to show pesticide occurrence and concentration over-time.

The MPCA provided the landuse data for each Federal Lake lakeshed. Each lakeshed was delineated in Arc GIS using the Arc Hydro tool and the 2017 National Land Cover Dataset was used for landuse. For the purposes of this analysis, several similar landuse categories were combined. For example, the “forest” category included forest, barren and rangeland landuses and the “water” category included landuses classified as water and wetland. Statistical analysis was completed for each landuse category versus the average number of pesticide detections and average total pesticide concentration. A linear regression was calculated using PRISM statistical software and was used to determine significance at the 95th percent confidence level (α =0.05) and relationship strength.

Spatial correlation analysis was completed using the Global Morans-I autocorrelation tool in ArcGIS. This correlation assessed if similar results were clustered spatially. The 2017 water quality results were spatially analyzed for the number of pesticides detected per lake and the total pesticide concentration per lake.

Results were also analyzed regionally, by the North American Level I ecoregions. Ecoregions are regions of similar ecosystems where the type quality and quantity of environmental resources are generally similar (USEPA, 2018b). In Minnesota, there are three Level I ecoregions: Northern Forests (NF), East Temperate Forests (ETF) and Great Plains (GP). Additional data parameters collected during the NLA were grouped, and presented using the North American ecoregions.

3.0 Results and Discussion

3.1 2017 National Lake Assessment Pesticide Results

All pesticide surface water quality data collected by the MDA is available for download from the National Water Quality Monitoring Council's Water Quality Portal. The following summarized results only include detected analytes (*i.e.,* an analyte with a concentration above its respective MRL).

3.1.1 Statewide Results – Individual Analyte Analysis

To provide the most relevant information on the current extent of pesticides in Minnesota lakes, the 2017 NLA results are presented with each pesticide analyte's MRL. The results, primarily detection frequency, of each individual pesticide analyte in this section should not be directly compared to other pesticide analytes that have a different MRL. Directly comparing the results from one analyte to another does not remove the potential bias of a higher detection frequency for a pesticide analyte with a lower MRL.

Seventeen of the 150 pesticide analytes were detected at least once during the 2017 NLA (Table 3). Of the 17 detected pesticide analytes, 9 analytes were detected in less than 8% of samples and 8 analytes were detected in more than 16% of samples. The three most frequently detected analytes included 2,4-D (46%), hydroxyatrazine (46%) and atrazine (38%). A total of 147 pesticide detections were reported including 97 herbicide degradate detections (9 different analytes), 47 herbicide detections (6 different analytes), 2 insecticide detections (1 analyte), and 1 fungicide detection. Maps displaying the concentration for all detected pesticide analytes are presented in Appendix 2.

All pesticide detections were below the lowest applicable water quality reference values, with the exception of two chlorpyrifos detections. Both chlorpyrifos detections were above the Minnesota chronic standard (41 ng/L) and below the Minnesota maximum standard (83 ng/L). No neonicotinoid insecticides were detected in the 2017 NLA.

Glyphosate and AMPA were not detected in 152 samples collected from 151 lakes with the 2017 NLA.

Table 3. Pesticide analytes detected in the 2017 NLA.

Pesticide Analyte	Detections	Detection Frequency (%)[1]	90th Percentile (ng/L)	Maximum (ng/L)	Water Quality Reference Value (ng/L)
Fungicide					
Carbendazim	1	2	<10.0	12.3	990[2]
Herbicide					
2,4-D	23	46	183	1,380	79,200[2]
Acetochlor	1	2	<30.0	89.1	3,600[3]
Atrazine	19	38	50.9	97.3	10,000[3]
Diuron	1	2	<13.3	1,120	2,400[2]
Imazethapyr	1	2	<6.70	11.6	59,200,000[2]
Metolachlor	2	4	<25.0	56.6	23,000[3]
Herbicide Degradate					
Acetochlor ESA	14	28	201	445	9,900,000[2]
Acetochlor OXA	14	28	219	486	unavailable
Alachlor ESA	2	4	<41.6	60.4	3,600,000[2]
DEDI Atrazine	1	2	<50.0	52.8	>50,000,000[2]
Dimethenamid ESA	8	16	11.0	25.8	unavailable
Dimethenamid OXA	4	8	<10.0	17.8	unavailable
Hydroxyatrazine	23	46	62.3	223	>1,500,000[2]
Metolachlor ESA	18	36	188	370	24,000,000[2]
Metolachlor OXA	13	26	79.5	259	7,700,000[2]
Insecticide					
Chlorpyrifos	2	4	<40.0	68.8	41[3] / 83[4]

[1]50 samples were analyzed for all detected pesticide analytes

[2]USEPA Office of Pesticide Program (OPP) aquatic life benchmark

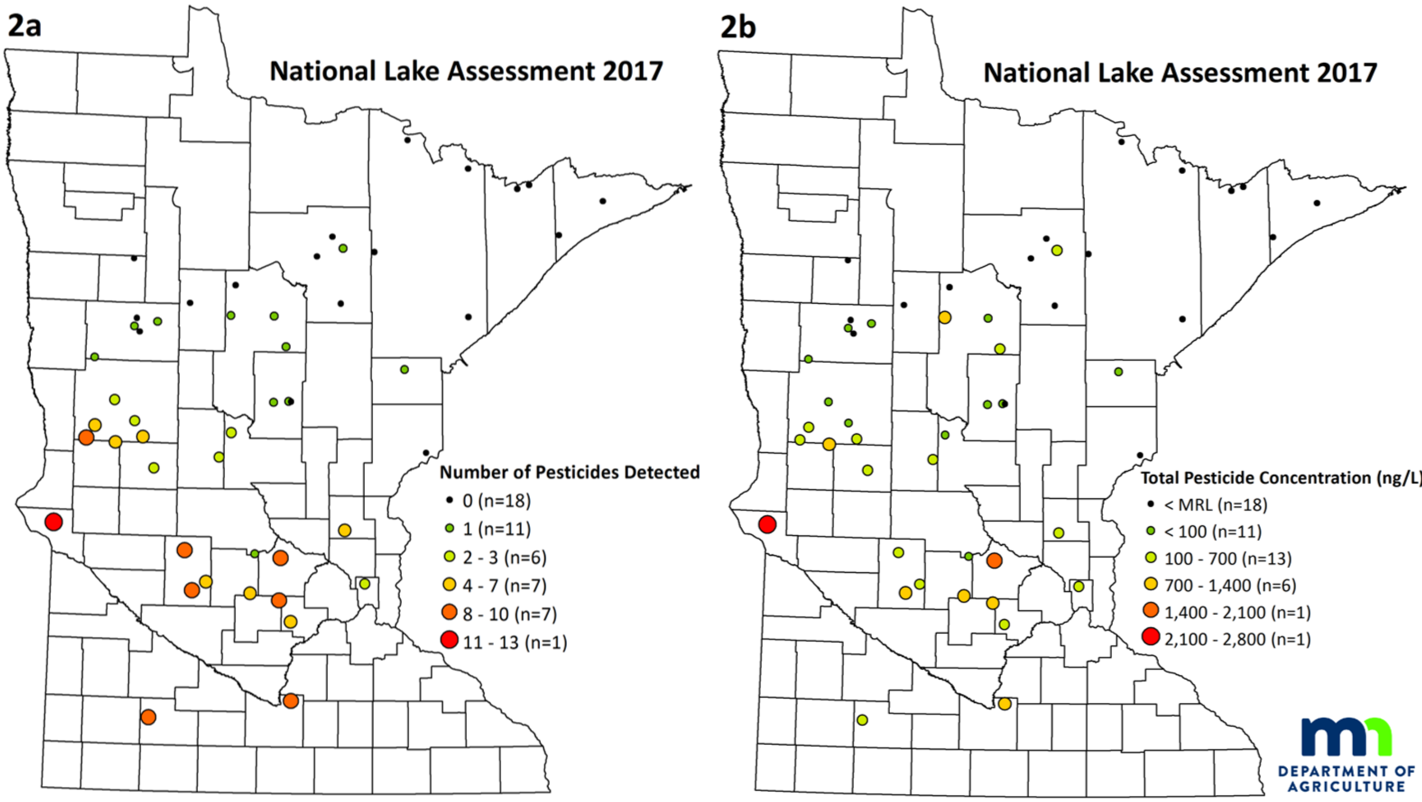
[3]Minnesota chronic water quality standard

[4]Minnesota maximum water quality standard

The total number of pesticide detections, and total pesticide concentration within each Federal lake in the 2017 NLA is presented in Figures 2a and 2b. There are no water quality reference values to assess these pesticide matrixes; however, it does provide an indicator to compare the concurrence and concentration magnitude of pesticides in lakes across Minnesota and to develop regional assumptions.

The total number of pesticide detections in a lake increased moving southwest across Minnesota (statistically significant ($p<0.01$)). No pesticides were detected in eight lakes located in far northeast Minnesota (Cook, Lake and St. Louis Counties). No more than one pesticide was detected in lakes in northcentral Minnesota (Becker, Cass, Crow Wing, Hubbard, Itasca and Mahnomen Counties). Lakes south of the aforementioned counties generally had at least two, with up to 13 different pesticide compounds detected (The 13 detections were found in one lake in Big Stone County).

Figure 2a) Total number of pesticide compounds detected and 2b) total pesticide concentration from Federal Lakes in NLA 2017.



The total (cumulative) pesticide concentration in lakes across Minnesota ranged from <MRL to 2,628 ng/L, and spatial analysis did not show a statically significant (p=0.056) correlation. Eighteen lakes, primarily across northern Minnesota, did not have a pesticide detection. The maximum total pesticide concentration (2,628 ng/L) occurred in a lake in Big Stone County. For most lakes with a pesticide detection, total pesticide concentrations did not vary greatly across Minnesota. There are no water quality reference values available for the index of total (cumulative) pesticide concentration. Pesticide toxicity varies greatly among the detected analytes (Table 3), and total pesticide concentration is not directly reflective of risk to aquatic life.

3.1.2 Lakeshed Landuse Analysis

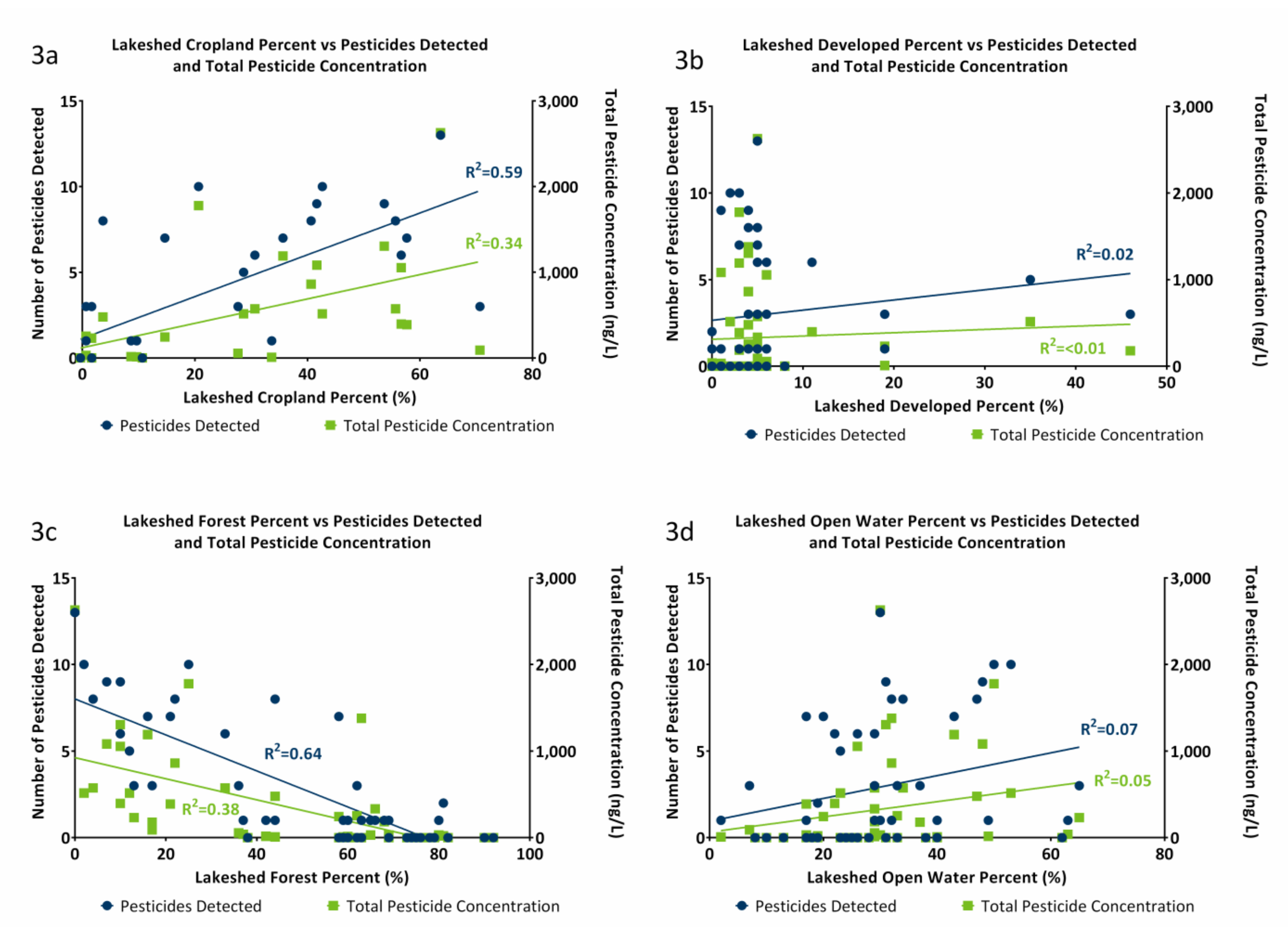
The relationship between landuse within each lakeshed versus the number of pesticide detections and total pesticide concentration in the 2017 NLA was analyzed to observe if landuse had a relationship with these variables (Table 4, Figure 3).

Table 4. Statistical results of landuse within individual lakesheds and pesticides.

Landuse	Landuse within individual lakeshed (%)	Number of Pesticides Detected				Total Pesticide Concentration			
		Significant	Relationship Direction	P-Value	R^2	Significant	Relationship Direction	P-Value	R^2
Cropland	0 - 72	Yes	+	<0.01	0.59	Yes	+	<0.01	0.34
Developed	0 - 46	No	+	0.69	0.02	No	+	0.34	<0.01
Forested	0 - 92	Yes	-	<0.01	0.64	Yes	-	<0.01	0.38
Water	2 - 65	No	+	0.07	0.07	No	+	0.12	0.05

The significant positive relationship with the percent of the lakeshed in cropland and the number of detected pesticides and the total pesticide concentration indicated that more pesticides were likely to be detected, and at higher concentrations as the percentage of cropland in a lakeshed increased. Inversely, the significant negative relationship with the percent of the lakeshed in forest and the number of detected pesticides and the total pesticide concentration indicated that fewer pesticides were likely to be detected, and at lower concentrations as the percentage of forest in a lakeshed increased. The percent of a lakeshed that was developed, or open water were not reliable indicators of the presence, or concentration, of pesticides in lakes.

Figure 3. Relationships between the lakeshed landuse and the number of pesticides detected and total pesticide concentration in a lake (2017 NLA)



3.2 Long-term National Lake Assessment Pesticide Results

3.2.1 Long-term Statewide Results (Censored to Highest Individual MRL)

Statewide water quality results from the 2007, 2012 and 2017 NLA were analyzed to observe pesticide occurrence, and concentrations over-time. All pesticide analytes that were detected in the NLAs were included, and data were censored to the highest individual MRL (Table 2) to remove potential bias from lowered MRLs that were available during the 2012 and 2017 NLA. After censoring the data, some previously reported low-level detections below the highest individual MRL were considered non-detections in this analysis.

Only one detection of a fungicide, carbendazim, occurred in the 2017 NLA. No other fungicides were detected in either the 2007 or 2012 NLA (Table 5). No insecticides were detected above the highest individual MRL in any NLA year.

On a statewide level, only two herbicides, 2,4-D and atrazine, were detected in more than 4% of samples during any NLA year (Table 4). The 2,4-D detection frequency was 55% in 2012 and was 46% in 2017. 2,4-D was not analyzed during the 2007 NLA. The 2,4-D 90th percentile concentration increased from 73.7 ng/L in 2012 to 183 ng/L in 2017. The atrazine detection frequency was 42% in 2007, 33% in 2012 and 10% in 2017. The atrazine 90th percentile concentration was 60 ng/L in 2007, 80 ng/L in 2012 and <50 ng/L in 2017.

Herbicide degradates were the most often detected pesticide type in each NLA year (Table 5). Acetochlor ESA, acetochlor OXA, DEDI atrazine and metolachlor OXA had increasing detection frequencies over each successive year of monitoring. Alachlor ESA, desethylatrazine, and hydroxyatrazine had decreasing detection frequencies over each successive year of monitoring. The other detected herbicide degradates had variable detection frequencies in the three monitoring years. The 90th percentile concentrations were variable for acetochlor ESA and acetochlor OXA, decreasing for alachlor ESA, desethylatrazine, and hydroxyatrazine, and stable for the other detected herbicide degradates.

The majority of the detections in each NLA year were herbicide degradates, primarily degradates (ESA and OXA forms) of chloroacetamide pesticides including acetochlor, dimethenamid and metolachlor. Overall, the detection frequency and 90th percentiles were generally consistent from 2007 to 2017. Atrazine, alachlor ESA, and degradates of atrazine generally showed a decrease in detection frequency and 90th percentile from 2007 to 2017.

Table 5. Pesticide analytes detected in the 2017 NLA with data censored to the highest historical MRL value for each detected analyte.

Pesticide Analyte	Censored MRL (ng/L)	2007 Detection Frequency (%)	2012 Detection Frequency (%)	2017 Detection Frequency (%)	2007 90th Percentile (ng/L)	2012 90th Percentile (ng/L)	2017 90th Percentile (ng/L)
Fungicide							
Carbendazim	10	na	0	2	na	<10	<10
Herbicide							
2,4-D	8.3	na	55	46	na	73.7	183
Acetochlor	50	0	2	2	<50	<50	<50
Atrazine	50	42	33	10	60	80	<50
Bentazon	5	na	2	0	na	<5	<5
Dimethenamid	50	0	2	0	<50	<50	<50
Diuron	13.3	na	0	2	na	<13.3	<13.3
Flumetsulam	50	na	2	0	na	<50	<50
Imazethapyr	6.7	na	0	2	na	<6.7	<6.7
MCPA	5	na	4	0	na	<5	<5
MCPP	50	na	2	0	na	<50	<50
Metolachlor	70	0	4	0	<70	<70	<70
Saflufenacil	15	na	2	0	na	<15	<15
Herbicide Degradate							
Acetochlor ESA	70	16	20	26	146	129	201
Acetochlor OXA	70	18	18	26	140	115	219
Alachlor ESA	70	16	2	0	106	<70	<70
DEDI Atrazine	50	na	0	2	na	<50	<50
Desethylatrazine	50	16	10	0	50	<50	<50
Dimethenamid ESA	70	0	2	0	<70	<70	<70
Dimethenamid OXA	70	0	2	0	<70	<70	<70
Hydroxyatrazine	6.7	na	69	46	na	120	62.3
Metolachlor ESA	70	27	18	20	196	132	188
Metolachlor OXA	70	7	8	10	<70	<70	<70
na= not applicable							

3.2.2 Long-term Regional Results (Censored to Highest Individual MRL)

Regional results were analyzed to observe changes over time to the average number of pesticides detected per lake and the average total pesticide concentration per lake in the three North American Level I ecoregions in Minnesota. Figure 4 displays the lakes monitored in the 2007, 2012 and 2017 NLA in each of the three ecoregions. All results were censored to the highest MRL. In addition, averages of the number of pesticides detected per lake and the total pesticide concentration per lake were calculated to normalize the results due to the differences in the number of lakes monitored in each ecoregion (Figure 5). Statistics were not calculated due to a small sample size.

There were more lakes monitored in the Northern Forests (NF) and East Temperate Forests (ETF) ecoregions, compared to the Great Plains (GP) ecoregion in each NLA (Figure 4). The GP ecoregion generally had the greatest number of pesticides detected per lake and highest average total pesticide concentration per lake while the NF had the lowest number of detections per lake and the lowest average total pesticide concentration per lake. The NF and ETF ecoregions had consistent results for the number of pesticides detected and the average total pesticide concentration over the 2007, 2012 and 2017 NLA. The GP ecoregion showed the most variability in the number of pesticides detected and the total pesticide concentration in each of the NLA years, likely a function of fewer lakes monitored and higher percentages of cropland landuse in the lakesheds.

The long-term regional results are consistent with the 2017 NLA lakeshed landuse analysis. Lakesheds with higher percentages of cropland tended to have more pesticides detected and at higher concentrations. Lakesheds with higher percentages of forest tended to have fewer pesticides detected and at lower concentrations. The NF ecoregion had the most forest landuse and the GP ecoregion had the most cropland when comparing the three ecoregions in Minnesota (Figure 6).

Figure 4. Pesticide sampling in lakes during the 2007, 2012, and 2017 National Lakes Assessment in Minnesota ecoregions.

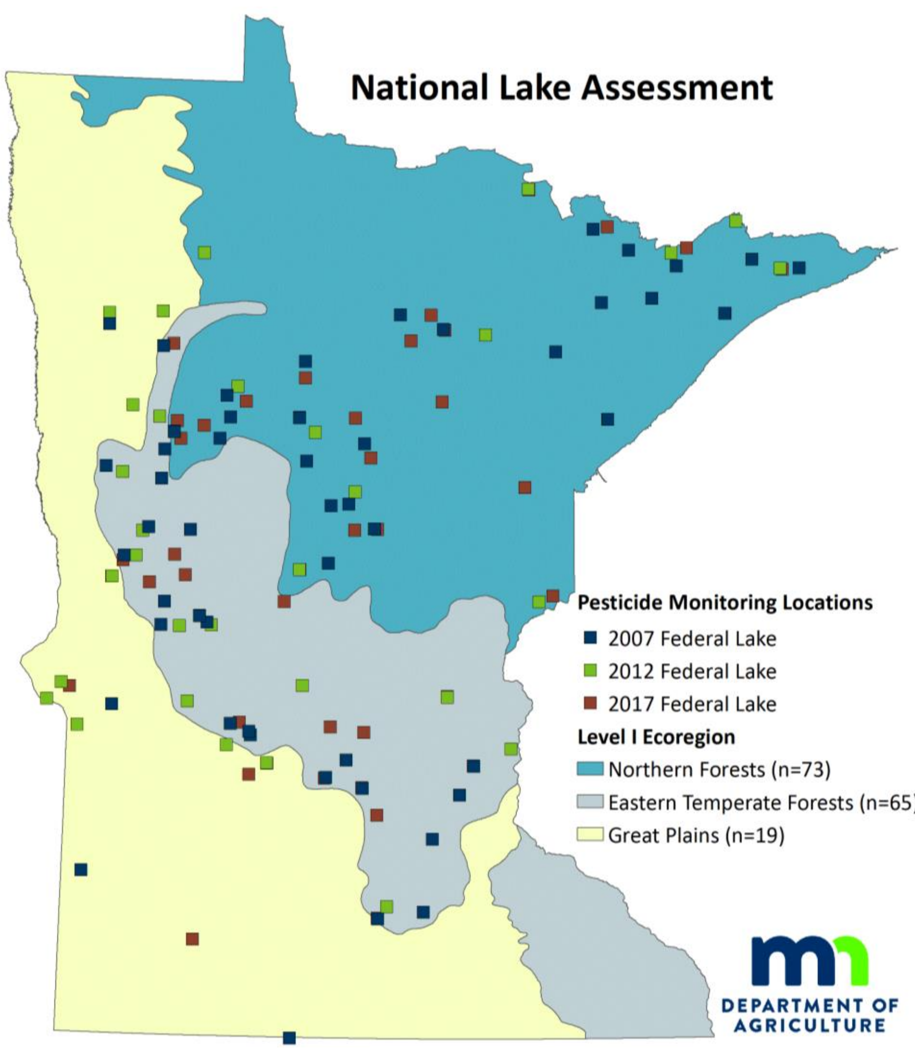


Figure 5. Analysis of lakes sampled by Minnesota ecoregion during the 2007, 2012 and 2017 National Lakes Assessment.

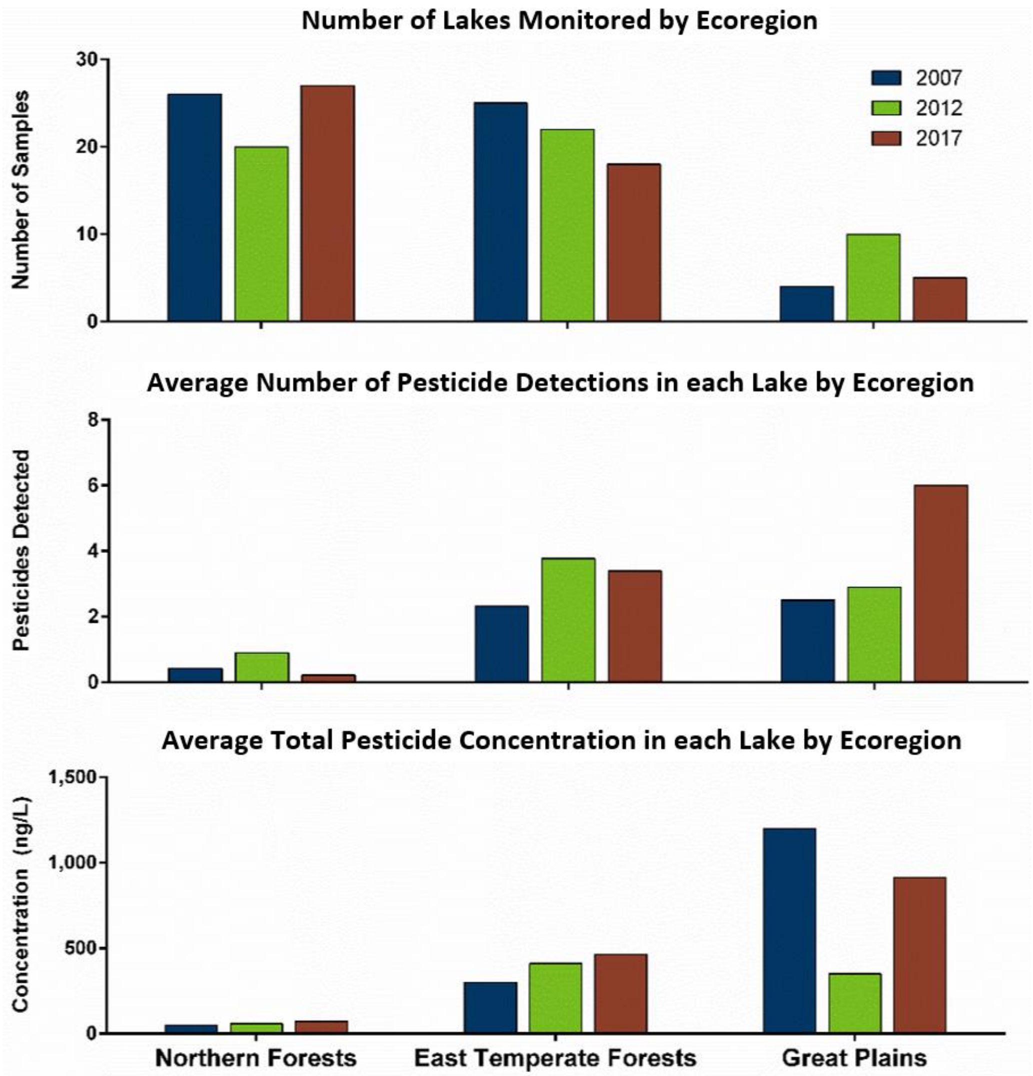
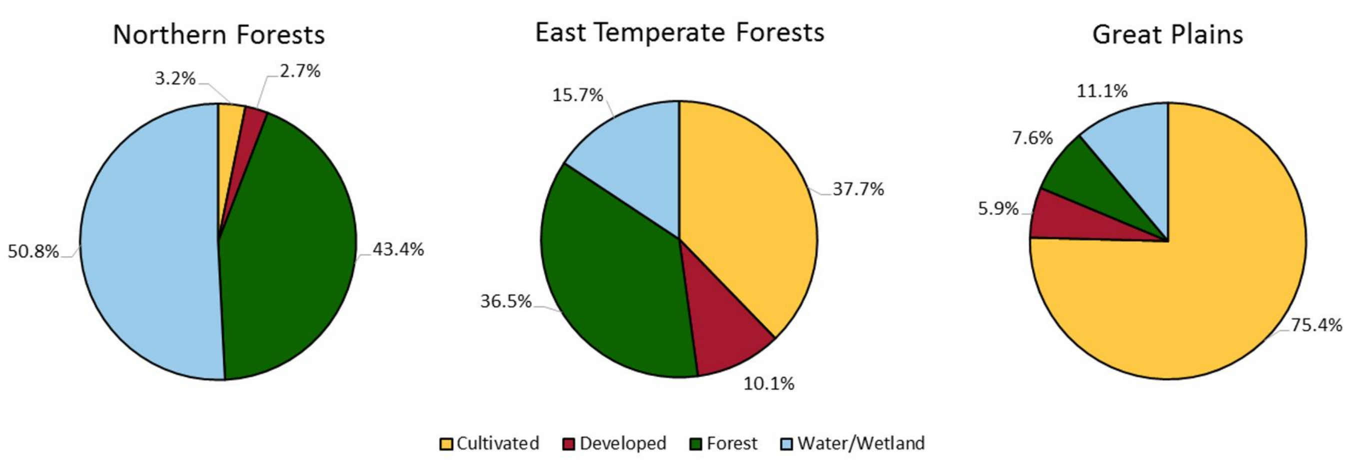


Figure 6. Landuse within the three Level I USEPA Ecoregions in Minnesota.



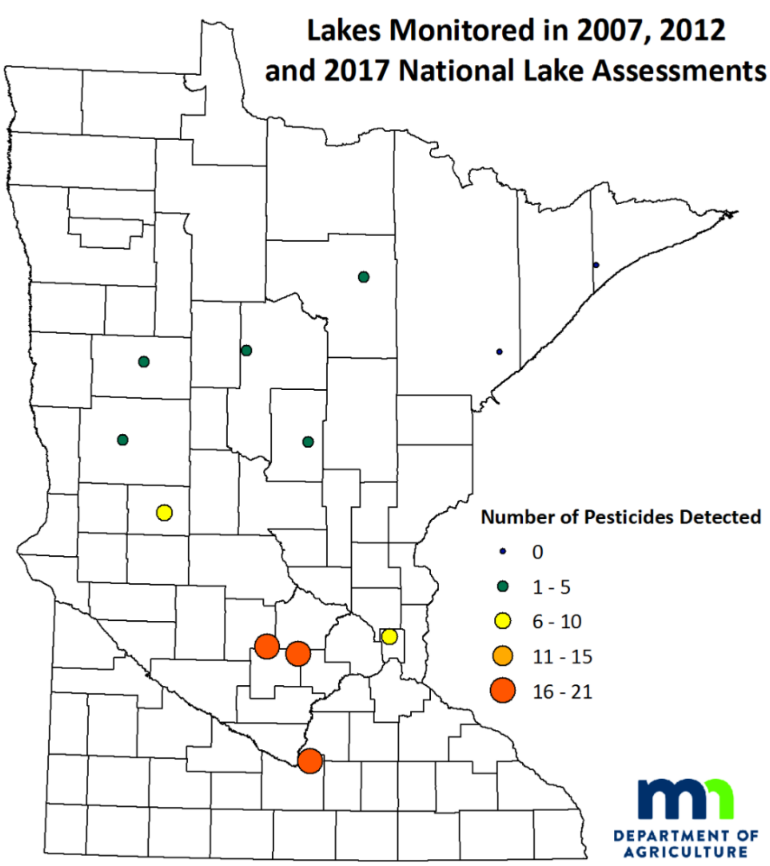
3.2.3 Long-term Individual Lake Results (Censored to Highest Individual MRL)

This analysis presents pesticide occurrence and concentration, within a single lake in three sample collection events over a 10-year period. These results were reflective only of these specific lakes, and general information for lakes across Minnesota should be obtained from the statewide and regional summaries above.

In Minnesota, 12 lakes were sampled during each of the 2007, 2012 and 2017 NLA (Appendix 1). All detected pesticide analytes in the 2007, 2012 and 2017 NLA were included, and data were censored to the highest individual MRL to remove potential bias from lowered MRLs in the 2012 and 2017 NLA. After censoring the data, previously reported low-concentration detections below the highest individual MRL were considered non-detections in his analysis. When two sample events occurred at a single lake within a specific NLA year (2 lakes), only the first sample collected in that year was included in the analysis.

The 12 lakes included in this analysis were geographically distributed across central, southcentral and northern Minnesota (Figure 7). A total 82 pesticide detections were reported (12 different pesticide analytes) including 29 detections of herbicides and 53 detections of herbicide degradates. This analysis will exclude the following pesticide analytes due to limited detections: alachlor ESA (2 detections), MCPA (1 detection), MCPP (1 detection) and metolachlor (1 detection).

Figure 7. Total number of pesticides detected in lakes monitored in the 2007, 2012 and 2017 National Lakes Assessment.

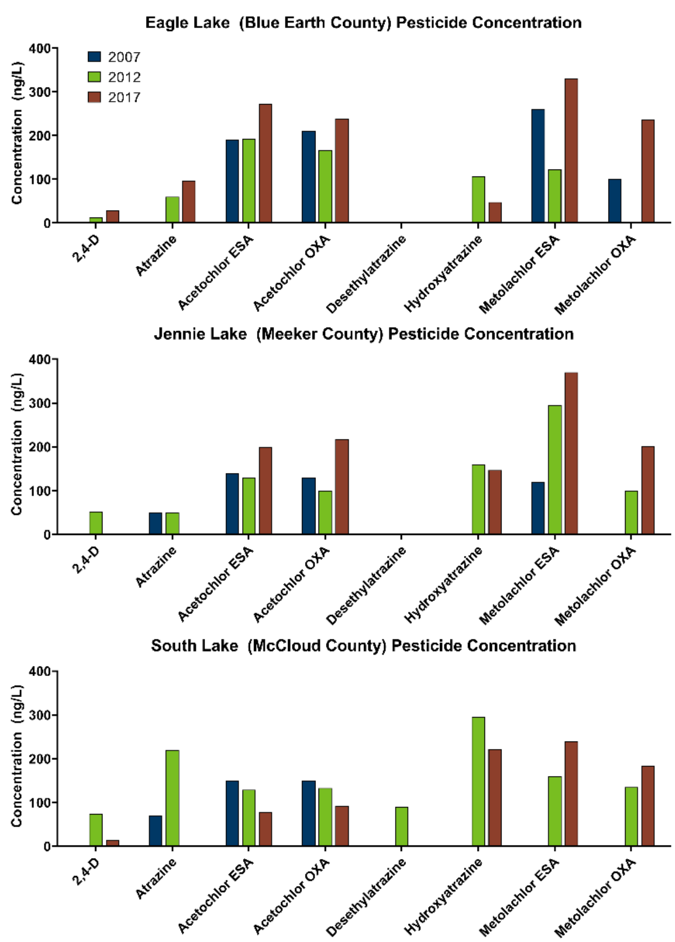


Nine of the 12 lakes had between zero and eight total pesticide detections. For these nine lakes, the overall lack, or low detection frequency of any pesticide analyte, is indicative of stable pesticide occurrence and concentrations over-time. Fifty-five of the 82 pesticide detections (68%) were reported from three lakes (Figure 7) in southcentral Minnesota: Eagle Lake (Blue Earth County), Jennie Lake (Meeker County) and South Lake (McCloud County).

This analysis will focus on the concentration of two herbicides (2,4-D and atrazine) and six herbicide degradates (two degradates each of acetochlor, atrazine and metolachlor) within these three lakes. 2,4-D and hydroxyatrazine were not analyzed with the 2007 NLA.

Pesticide occurrence and concentration were generally stable for the eight pesticide analytes in Eagle, Jennie and South Lakes in the 2007, 2012 and 2017 NLA (Figure 8). Acetochlor ESA and acetochlor OXA were detected in every sample from these three lakes and concentrations ranged from 47.8 ng/L to 295 ng/L. In general, concentrations of herbicide degradates were higher compared to herbicide (parent) concentrations. The detection of herbicide degradates in lakes without the presence of the parent compound is consistent in each NLA year. The results from these three lakes indicate consistency in the pesticide compounds that were detected, and measured concentrations over-time.

Figure 8. Concentration of eight selected pesticides from Eagle, Jennie and South Lake in the 2007, 2012 and 2017 National Lakes Assessment.



4.0 Conclusions

Pesticide water quality samples were collected from randomly selected lakes in Minnesota in 2007, 2012 and 2017. Except for two detections of the insecticide chlorpyrifos in 2017, all other pesticide concentrations were very low compared to the applicable water quality reference values. In each of the NLA years, the majority of detections were herbicide degradates followed by the parent herbicides. The number of pesticide analytes detected and total pesticide concentrations increased when there was an increasing amount of row crop production in a lakeshed and also moving southwest across Minnesota. Increasing amounts of forest in a lakeshed lead to fewer pesticide detections and lower total pesticide concentrations.

There was little variability in the pesticides that were detected, and the concentration of detected pesticides in these three years.

This is a key finding given the changes since 2007 in agricultural pesticide use in Minnesota. The changes include the increase of corn and soybean acres, increased pesticide resistance of insects and weeds, and the increasing presence of soybean aphid’s since 2007.

5.0 References

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Appendix 1. Lake Information

County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
Aitkin	Jenkins	01-0100	46.6512	-93.4855				1	1
Becker	Straight	03-0010	46.9548	-95.2803	1				
Becker	Hungary Man	03-0029	47.0636	-95.1817	1				
Becker	Unnamed	03-0077	47.0129	-95.4041			1		1
Becker	Johnson	03-0199	46.9345	-95.5982			1		1
Becker	Carman	03-0209	47.0361	-95.6304			1		1
Becker	Unnamed	03-0236	47.0850	-95.5783				1	1
Becker	Flat	03-0242	46.9747	-95.6549	1	1	1	1	1
Becker	Pickerel	03-0287	46.8706	-95.7290	1				
Becker	Bear	03-0303	47.0575	-95.7826		1		2	1
Becker	Unnamed	03-0393	46.8620	-95.9138				2	1
Becker	Gandrud	03-0414	46.9294	-95.8934				1	1
Becker	Baker	03-0478	47.1005	-95.9360					1
Becker	Cucumber	03-0571	47.1176	-96.0113		1		1	
Becker	Unnamed	03-0627	46.8435	-96.1617				1	1
Becker	Unnamed	03-0751	46.7324	-96.0760		1	1		1
Beltrami	Popple	04-0014	47.5182	-94.4710				1	1
Beltrami	Cass	04-0030	47.4246	-94.6288	1				
Beltrami	Fox	04-0251	47.8427	-95.0446				1	
Big Stone	Unnamed	06-0005	45.3107	-96.2310					1
Big Stone	Otrey	06-0050	45.3572	-96.3356					1
Big Stone	Bentsen	06-0090	45.3876	-96.3634				1	
Big Stone	Thielke	06-0102	45.3978	-96.4016				1	
Big Stone	Cup	06-0120	45.4880	-96.4426			1		1
Big Stone	Big Stone	06-0152	45.3608	-96.4899		1		1	
Big Stone	Unnamed	06-0188	45.5128	-96.5414					1
Big Stone	Unnamed	06-0206	45.4422	-96.3856				1	
Big Stone	Unnamed	06-0266	45.4028	-96.2911				1	1
Big Stone	Unnamed	06-0349	45.5080	-96.5131		1		1	
Big Stone	Unnamed Pool	06-0460	45.2657	-96.3693		1			
Blue Earth	Eagle (North)	07-0060	44.1952	-93.9005	1	1	1	1	1
Blue Earth	Lieberg	07-0124	44.1533	-94.3127				1	
Carlton	Jaskari	09-0050	46.6787	-92.7005			1		1
Carver	Braunworth	10-0107	44.7881	-93.9128			1		1
Cass	Spring	11-0022	47.1227	-93.8806	1				
Cass	Mule	11-0047	46.8456	-93.9955			1		1
Cass	Island	11-0102	46.9279	-94.0385	1				
Cass	Pistol	11-0110	46.8142	-94.0857				1	
Cass	Lomish	11-0136	47.0755	-94.1310			1		1
Cass	Tamarack	11-0150	46.8461	-94.2706				1	1
Cass	Tamarack	11-0241	46.8614	-94.3148				1	1
Cass	Pine Mountain	11-0411	46.8199	-94.5329	1				
Cass	Unnamed	11-0440	46.6420	-94.6382				1	
Cass	Long	11-0480	47.0737	-94.6020	1	2	1		1
Cass	Little Twin	11-0487	47.3002	-94.5600			1		1

County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
Cass	Diamond Pond	11-1013	46.9877	-94.4677		1		1	
Chisago	Unnamed	13-0061	45.4039	-92.9906				1	1
Clay	Unnamed	14-0029	46.7634	-96.2152	1				
Clay	Unnamed	14-0081	47.0496	-96.2502				1	1
Clay	Unnamed	14-0088	46.9818	-96.2085					1
Clay	Cromwell	14-0103	46.9644	-96.3156					1
Clay	Unnamed	14-0389	46.6464	-96.3394				1	
Clearwater	Elk	15-0010	47.1877	-95.2147	1				
Clearwater	Miskogineu	15-0107	48.0074	-95.4395		1		1	1
Clearwater	Unnamed	15-0279	47.2474	-95.4662				1	1
Clearwater	Unnamed	15-0491	47.2039	-95.2641				1	
Cook	Musquash	16-0104	47.9137	-90.3414	1				
Cook	Ball Club	16-0182	47.9112	-90.4866		1	1	1	1
Cook	Lac	16-0236	47.9531	-90.5089					1
Cook	Unnamed	16-0399	47.9533	-90.6723					1
Cook	Vesper	16-0414	47.9745	-90.7463	1				
Cook	Tenor	16-0613	48.1964	-90.8758		1			
Cook	Richey	16-0643	47.6678	-90.9889	1	1	1	1	1
Cottonwood	String	17-0024	43.8756	-95.2022				1	1
Cottonwood	Long	17-0048	43.9584	-95.3731					1
Cottonwood	Double	17-0056	44.0536	-95.3760			1		1
Cottonwood	Talcot	17-0060	43.8787	-95.4491				1	
Cottonwood	Summit	17-0073	43.8565	-95.0691				1	
Crow Wing	Chrysler	18-0095	46.3130	-93.9448					1
Crow Wing	Lookout	18-0123	46.4368	-93.9578	1	1	1	1	1
Crow Wing	Cole	18-0127	46.5317	-94.0183					1
Crow Wing	Unnamed	18-0146	46.4289	-94.1235			1		1
Crow Wing	Crow Wing	18-0155	46.2363	-94.3394	1	1			
Crow Wing	Pelican	18-0308	46.5498	-94.1833	1				
Crow Wing	Cross Lake Reservoir	18-0312	46.6500	-94.1258		1		1	
Crow Wing	Mayo	18-0408	46.5673	-94.3251	1				
Crow Wing	Unnamed	18-0430	46.4353	-93.9334			1		1
Crow Wing	Pennington Mine	18-0439	46.4845	-93.9800				1	1
Crow Wing	Unnamed	18-0527	46.4060	-94.1377				1	
Dakota	Kegan	19-0011	44.7578	-93.1167					1
Douglas	Victoria	21-0054	45.8695	-95.3457	1				
Douglas	Kruegers Slough	21-0060	45.9460	-95.3322				1	1
Douglas	Darling	21-0080	45.9194	-95.3968	1	1	1		1
Douglas	Crooked	21-0199	45.8600	-95.5534		1		1	
Douglas	Red Rock	21-0291	45.8606	-95.7181	1				
Douglas	Fanny	21-0336	45.9930	-95.6877	1				
Douglas	Unnamed	21-0729	45.8664	-95.2956		1			1
Faribault	South Walnut	22-0022	43.6669	-93.7890				1	1
Freeborn	Unnamed	24-0067	43.7316	-93.1052					1
Grant	Unnamed	26-0043	45.8616	-95.8431				1	
Grant	Unnamed	26-0071	46.1015	-95.8197			1		1

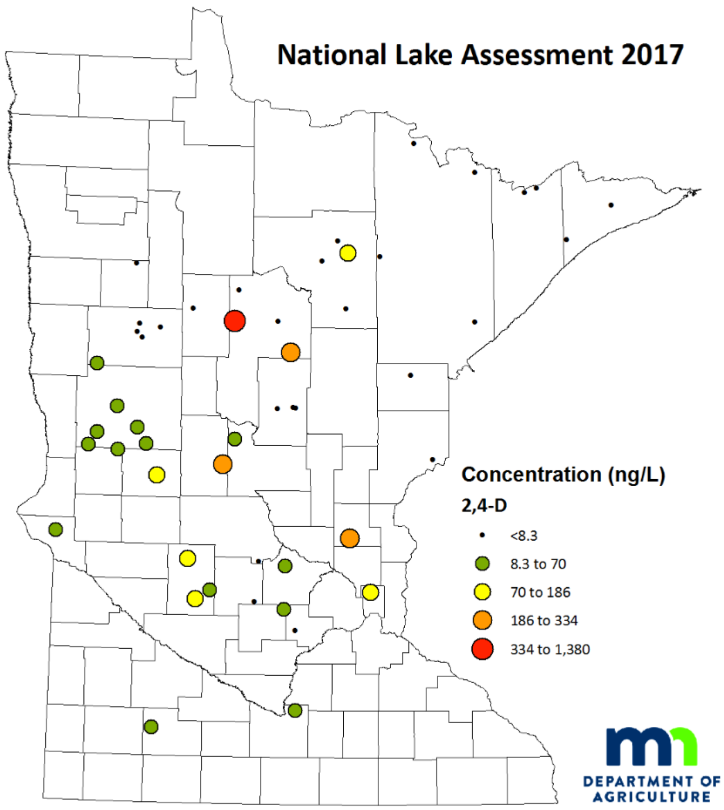
County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
Grant	Patchen	26-0111	45.7732	-95.9055					1
Grant	Graham	26-0204	45.7942	-96.1138					1
Grant	Unnamed	26-0205	45.7868	-96.1147				1	1
Grant	Unnamed	26-0217	45.7647	-96.0802				1	
Grant	Hodgson	26-0228	45.9130	-96.0554				1	1
Grant	Lightning	26-0282	46.0693	-96.0848					1
Hennepin	Penn	27-0004	44.8454	-93.3057					1
Hennepin	Nokomis	27-0019	44.9094	-93.2411	1	1		1	
Hennepin	Edina	27-0029	44.8683	-93.3475				1	1
Hennepin	North Little Long	27-0179	44.9502	-93.7090				1	1
Hubbard	Sunday	29-0144	46.8943	-94.9085				1	1
Hubbard	Belle Taine	29-0146	46.9353	-94.9040				1	
Hubbard	Unnamed	29-0296	47.1600	-95.0545			1		1
Hubbard	Lost	29-0303	47.2436	-95.1291		1		1	
Isanti	Section	30-0060	45.6806	-93.1533				1	1
Isanti	Long	30-0072	45.4743	-93.3452		1	1		1
Itasca	Unnamed	31-0142	47.4838	-93.2664					1
Itasca	Mississippi	31-0200	47.1721	-93.4003			1		1
Itasca	Unnamed	31-0211	47.2112	-93.4255				1	
Itasca	Long	31-0266	47.5971	-93.4017	1	1	1	1	1
Itasca	Walters	31-0298	47.6700	-93.3732				1	1
Itasca	Hay	31-0407	47.3736	-93.5288				1	1
Itasca	Charlie	31-0419	47.5374	-93.5504				1	
Itasca	Gale	31-0513	47.6727	-93.4959			1		1
Itasca	Cottonwood	31-0594	47.4285	-93.6935				1	
Itasca	Boy	31-0623	47.5226	-93.6656			1		1
Itasca	Upper Hatch	31-0770	47.6729	-93.7596	1				
Itasca	Lower Pigeon	31-0893	47.5644	-94.1615				1	1
Itasca	Unnamed	31-1366	47.6711	-93.8066				1	
Itasca	Unnamed	31-1367	47.8192	-94.3130				1	
Jackson	Pearl	32-0033	43.5273	-95.1157					1
Jackson	Summer Marsh	32-0040	43.6354	-95.1885					1
Kanabec	Spring	33-0027	45.8883	-93.2756	1				
Kandiyohi	Ella	34-0033	45.0777	-94.8104		1	1	1	2
Kandiyohi	Woodcock	34-0141	45.2424	-94.9488	1	1		1	
Kandiyohi	Nest	34-0154	45.2593	-94.9619	1				
Kandiyohi	Unnamed	34-0194	45.1904	-95.0987					1
Kandiyohi	Andrew	34-0206	45.3100	-95.0438			1		1
Kandiyohi	Unnamed	34-0247	45.1680	-95.1234					1
Kandiyohi	Norway	34-0251	45.3066	-95.0979	1	1			
Kandiyohi	Lindgren	34-0294	45.1779	-95.1454		1		1	
Kandiyohi	Swenson	34-0321	45.2670	-95.1387				1	1
Kandiyohi	Johnson	34-0440	45.0108	-94.9573			1		1
Koochiching	Miller	36-0012	47.9590	-94.0773					1
Lac Qui Parle	Andrew	37-0026	44.9692	-95.9490				1	1
Lac Qui Parle	Unnamed	37-0100	44.8932	-96.1808				1	1
Lac Qui Parle	Unnamed	37-0134	45.0495	-96.2253				1	

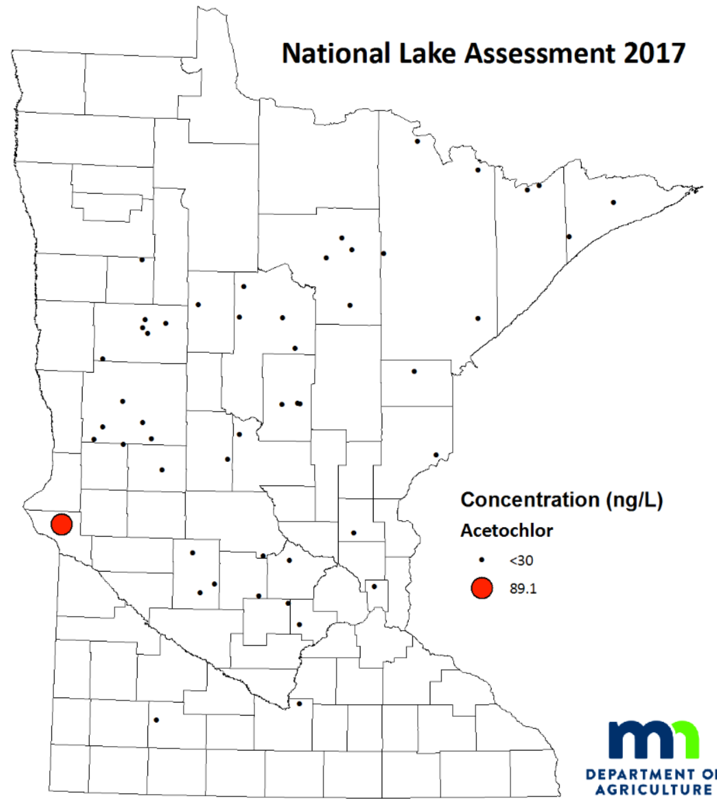
County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
Lake	Crooked	38-0024	47.6049	-91.0750				1	1
Lake	Divide	38-0256	47.6088	-91.2540				1	
Lake	Becoosin	38-0472	47.9478	-91.3926	1	1		1	
Lake	Neglige	38-0492	48.0497	-91.3030			1		1
Lake	Cattyman	38-0510	48.0131	-91.3203				1	1
Lake	Horseshoe	38-0580	47.8786	-91.4314					1
Lake	Spree	38-0623	48.0222	-91.4390		1	1		1
Lake	Two Deer	38-0671	47.6870	-91.5736				1	
Lake	August	38-0691	47.7630	-91.6090	1				
Le Sueur	Upper Sakatah	40-0002	44.2236	-93.5488	1				
Le Sueur	Unnamed	40-0098	44.2658	-93.8299		1		2	1
Le Sueur	Savidge	40-0107	44.3260	-93.8697				1	1
Lincoln	Slough	41-0022	44.3686	-96.1100					1
Lincoln	Popowski	41-0044	44.5214	-96.2041				1	
Lincoln	North Ash	41-0055	44.4308	-96.2903	1	1		1	
Lyon	Lake Of The Hill	42-0032	44.2277	-95.7925					1
Lyon	Jacobsons Marsh	42-0036	44.3199	-95.8277					1
Lyon	Section Thirty-Three	42-0066	44.1988	-96.0331					1
Lyon	East Twin	42-0070	44.2137	-96.0456				1	
Mcleod	South	43-0014	44.9472	-94.0349	2	1	1	1	1
Mcleod	Bear	43-0076	44.9518	-94.3058				1	1
Mahnomen	Circle	44-0140	47.3387	-95.7602				1	1
Mahnomen	Unnamed	44-0155	47.4808	-95.6850			1		1
Mahnomen	Allen	44-0157	47.4653	-95.7702	1				
Mahnomen	Unnamed	44-0228	47.3535	-95.8896				1	
Mahnomen	Unnamed	44-0244	47.4740	-95.8140				1	
Martin	Iowa	46-0049	43.4992	-94.4595					1
Martin	Okamanpeedan	46-0051	43.5213	-94.5681	1				
Martin	Dutton Slough	46-0098	43.5218	-94.6380				1	
Martin	Round	46-0116	43.7019	-94.6850					1
Meeker	Jennie	47-0015	44.9967	-94.3410	1	1	1	1	1
Meeker	Greenleaf	47-0062	45.0112	-94.4709					1
Meeker	Hoosier	47-0116	45.0596	-94.5467					1
Meeker	Goose	47-0127	44.9879	-94.5866					1
Mille Lacs	Unnamed	48-0019	46.1351	-93.8102				1	
Morrison	Unnamed	49-0139	46.1967	-94.5742		1	1		1
Murray	Smith	51-0027	44.0944	-95.6871					1
Murray	Summit	51-0068	43.9971	-95.8583				1	
Murray	Iron	51-0079	44.1610	-95.8643				2	
Nobles	Ocheda	53-0024	43.5745	-95.5966				1	1
Norman	Home	54-0013	47.2036	-96.2158				1	
Otter Tail	Unnamed	56-0113	46.3577	-95.4750				1	1
Otter Tail	West Leaf	56-0114	46.4102	-95.4827	1				
Otter Tail	Unnamed	56-0134	46.1490	-95.5220			1		1
Otter Tail	Unnamed	56-0147	46.1798	-95.6210				1	1
Otter Tail	Peterson	56-0171	46.2664	-95.6186			1		1

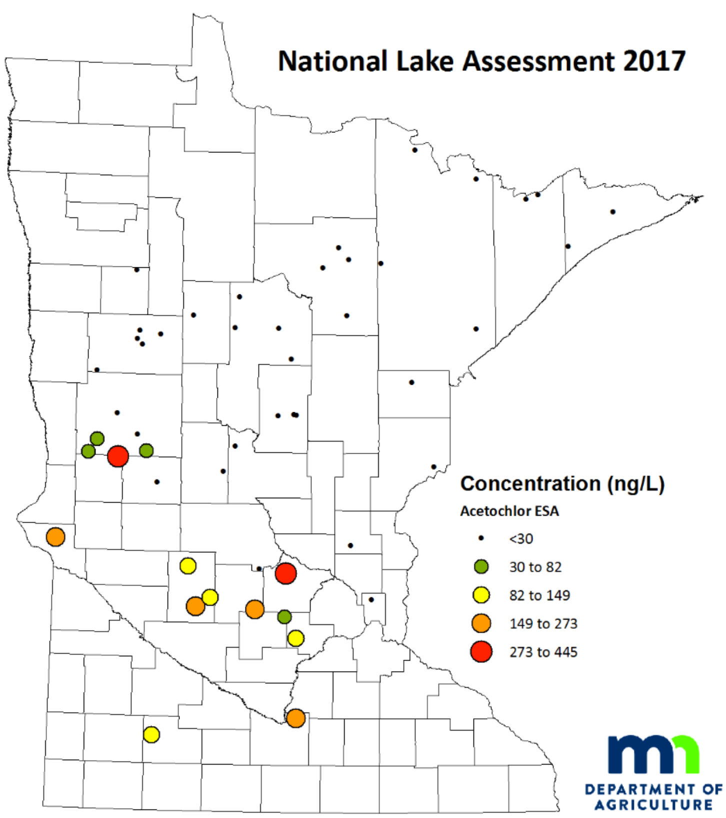
County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
Otter Tail	Fairy	56-0356	46.7015	-95.7477	1	1			
Otter Tail	Fiske	56-0430	46.2570	-95.7911				1	1
Otter Tail	Maine (Round)	56-0476	46.4194	-95.8400	1	1	1		1
Otter Tail	Round	56-0490	46.5110	-95.8951					1
Otter Tail	Horseshoe	56-0492	46.4932	-95.8864				1	1
Otter Tail	East Red River	56-0573	46.3994	-95.8901		1			
Otter Tail	Holbrook	56-0578	46.7049	-95.9207				1	1
Otter Tail	South Stang	56-0629	46.2521	-95.9376		1			
Otter Tail	Unnamed	56-0630	46.2522	-95.9053					1
Otter Tail	Unnamed	56-0810	46.1274	-96.1332		1	1	1	1
Otter Tail	Pebble	56-0829	46.2522	-96.0363	2				
Otter Tail	Iverson	56-0846	46.2232	-96.0438			1		1
Otter Tail	Unnamed	56-0853	46.2085	-96.0519				1	1
Otter Tail	Unnamed	56-0985	46.4279	-96.2253				1	
Otter Tail	Unnamed	56-1002	46.3821	-96.2388					1
Otter Tail	Unnamed	56-1582	46.4872	-96.1381				1	
Clay	Unnamed	57-0027	48.0989	-96.1921				1	
Pine	Greigs	58-0013	46.0528	-92.4722			1		1
Pine	Wilbur	58-0045	46.0202	-92.5887		1		1	
Pine	Unnamed	58-0205	46.2547	-92.5168					1
Polk	Whitefish	60-0015	47.5859	-95.6527					1
Polk	Unnamed	60-0078	47.5707	-95.7248				1	1
Polk	Unnamed	60-0099	47.6649	-95.7811		1		1	
Polk	Unnamed	60-0129	47.7184	-95.7507				1	
Polk	Unnamed	60-0211	47.5875	-95.9665				1	
Polk	Unnamed	60-0244	47.5849	-96.1125					1
Polk	Unnamed	60-0275	47.6222	-96.0832				1	
Polk	Unnamed	60-0281	47.6102	-96.1700				1	
Polk	Unnamed	60-0307	47.5790	-96.2353	1				
Polk	Unnamed	60-0319	47.6434	-96.2423		1		1	
Pope	Unnamed	61-0091	45.4235	-95.4747		1			
Pope	Pelican	61-0111	45.6480	-95.4510					1
Pope	Unnamed	61-0189	45.5261	-95.7205				1	1
Ramsey	Snail	62-0073	45.0757	-93.1297	1	1	1	1	1
Redwood	Unnamed	64-0096	44.3684	-95.3717				1	
St Louis	Alruss	69-0005	48.0435	-91.8033	1				
St Louis	Butterball	69-0044	47.4635	-91.8662					1
St Louis	Big	69-0050	47.5252	-91.8600				1	1
St Louis	Spring	69-0129	47.0693	-92.0010	1	1	1		1
St Louis	Arthur	69-0154	47.7425	-92.0407	1				
St Louis	Nibin	69-0208	48.1783	-91.9847			1		1
St Louis	Colby	69-0249	47.5314	-92.1339					1
St Louis	Little Crab	69-0296	47.9547	-92.0758				1	
St Louis	Lamb	69-0341	48.1638	-92.1055	1				
St Louis	Lost (Horseshoe)	69-0611	47.4644	-92.4401	1				
St Louis	Long	69-0653	47.4033	-92.5430				1	
St Louis	Net	69-0757	48.3955	-92.6581		1	1		1

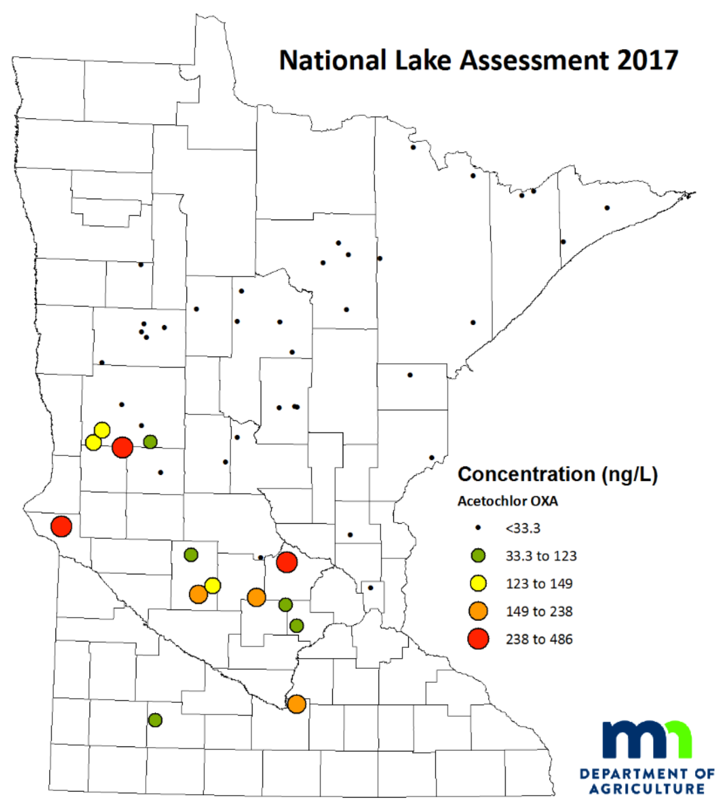
County	Lake Name	Location ID	Latitude	Longitude	2007 Federal Lake	2012 Federal Lake	2017 Federal Lake	2012 Atrazine Screen	2017 Glyphosate/ AMPA
St Louis	Stuart	69-0920	47.5597	-93.0326		1	1	1	1
Scott	Fish	70-0069	44.6499	-93.4588	1				
Sherburne	Little Diamond	71-0044	45.4781	-93.6213				1	
Sibley	High Island	72-0050	44.6623	-94.2097				1	1
Stearns	Clear	73-0172	45.5299	-94.5329		1			
Stearns	Black Oak	73-0241	45.6318	-94.8104				1	1
Stearns	Unnamed	73-0317	45.4743	-94.3114				1	1
Stearns	Unnamed	73-0425	45.2935	-94.3013			1		1
Stevens	Bjork	75-0034	45.6426	-95.8141					1
Stevens	Silver	75-0164	45.7599	-95.9292				1	
Stevens	Unnamed	75-0205	45.5091	-96.0666				1	1
Swift	South Drywood	76-0149	45.3920	-96.0937	1				
Swift	Unnamed	76-0166	45.3400	-96.1156					1
Todd	Beauty	77-0035	46.0096	-94.6982			1		1
Todd	Unnamed	77-0258	45.8419	-94.9134				1	
Waseca	St. Olaf	81-0003	43.9031	-93.4168					1
Washington	Terrapin	82-0031	45.1821	-92.8178		1			1
Watonwan	St. James	83-0043	43.9762	-94.6477					1
Wright	Unnamed	86-0065	45.3182	-93.8822				1	1
Wright	Long	86-0069	45.2934	-93.8459	1				
Wright	Somers	86-0230	45.2638	-94.0267			1		1
Wright	Cokato	86-0263	45.1160	-94.1694	1	1		1	
Yellow Medicine	Mud	87-0032	44.6739	-95.5421					1

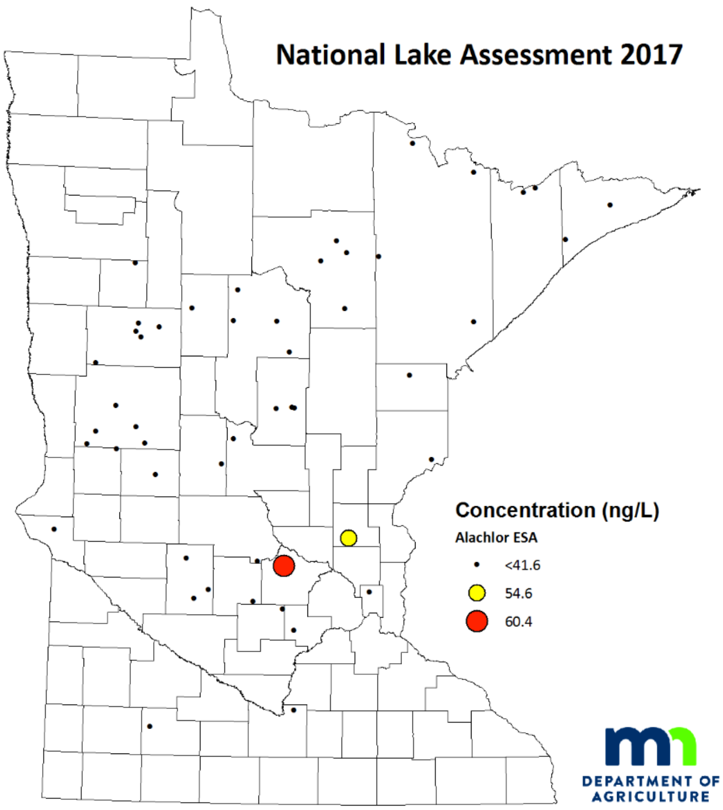
Appendix 2. 2017 NLA Pesticide Concentration Maps



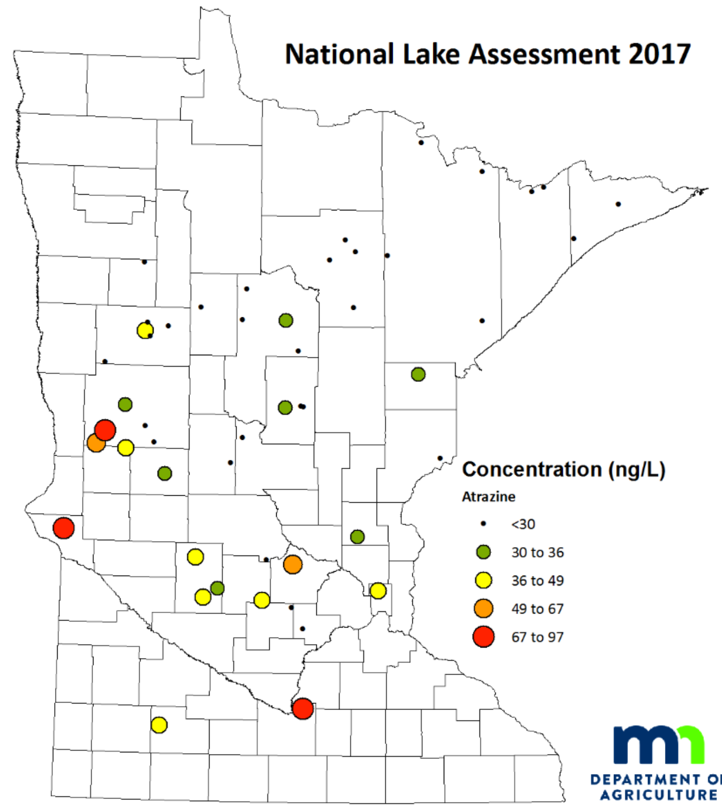




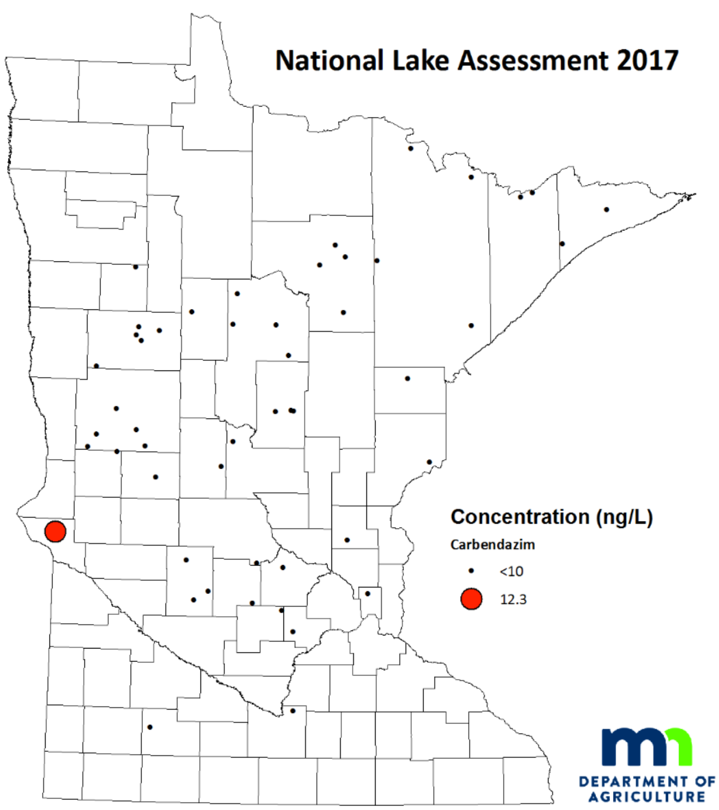




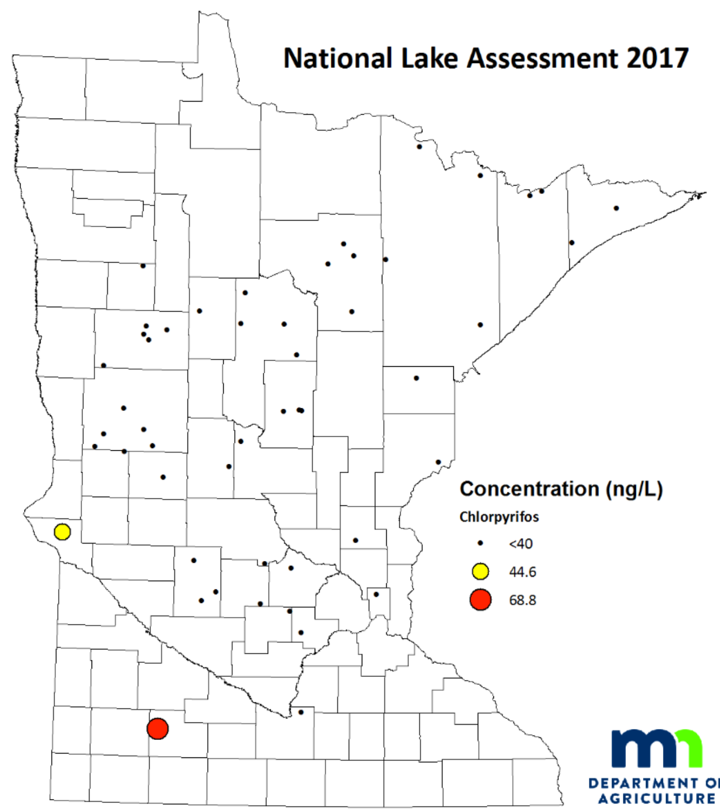
National Lake Assessment 2017
Concentration (ng/L)
Alachlor ESA
<41.6
54.6
60.4
DEPARTMENT OF AGRICULTURE



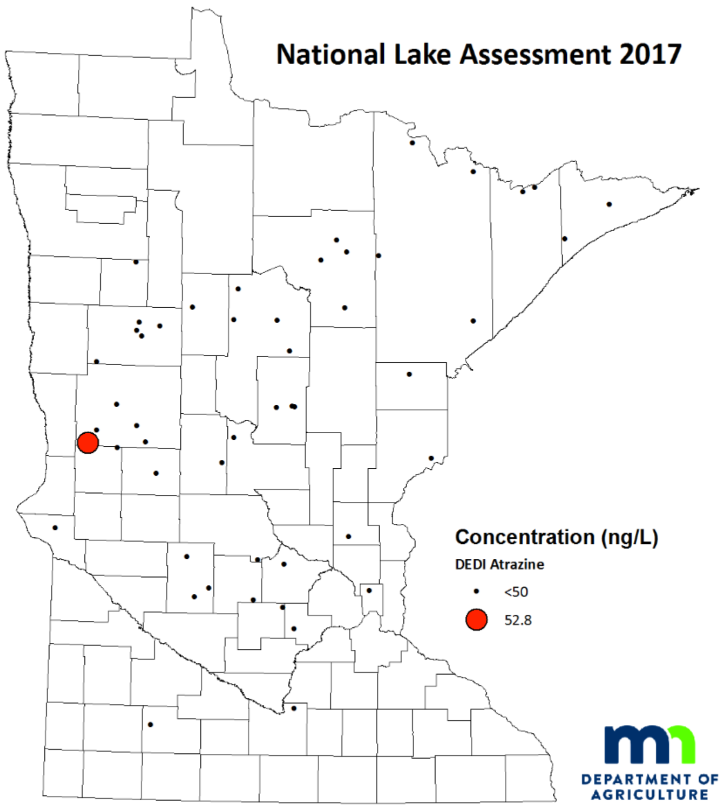
National Lake Assessment 2017
Concentration (ng/L)
Atrazine
<30
30 to 36
36 to 49
49 to 67
67 to 97
DEPARTMENT OF AGRICULTURE

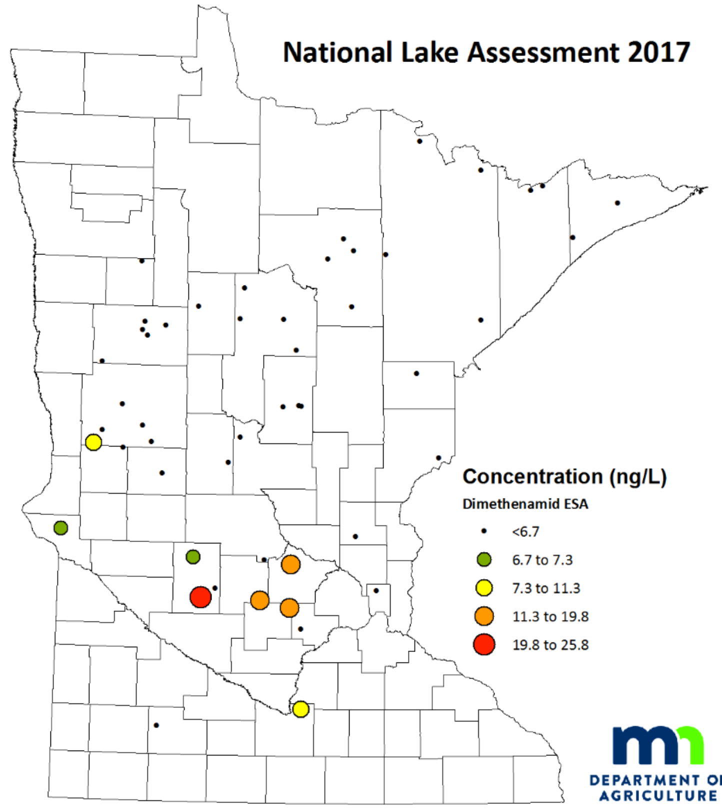


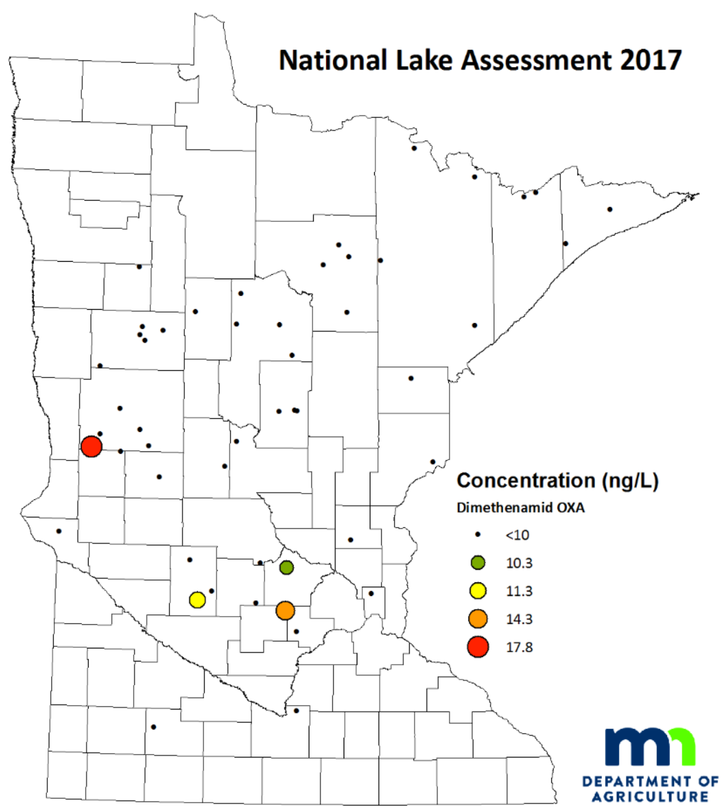
National Lake Assessment 2017
Concentration (ng/L)
Carbendazim
<10
12.3
DEPARTMENT OF AGRICULTURE

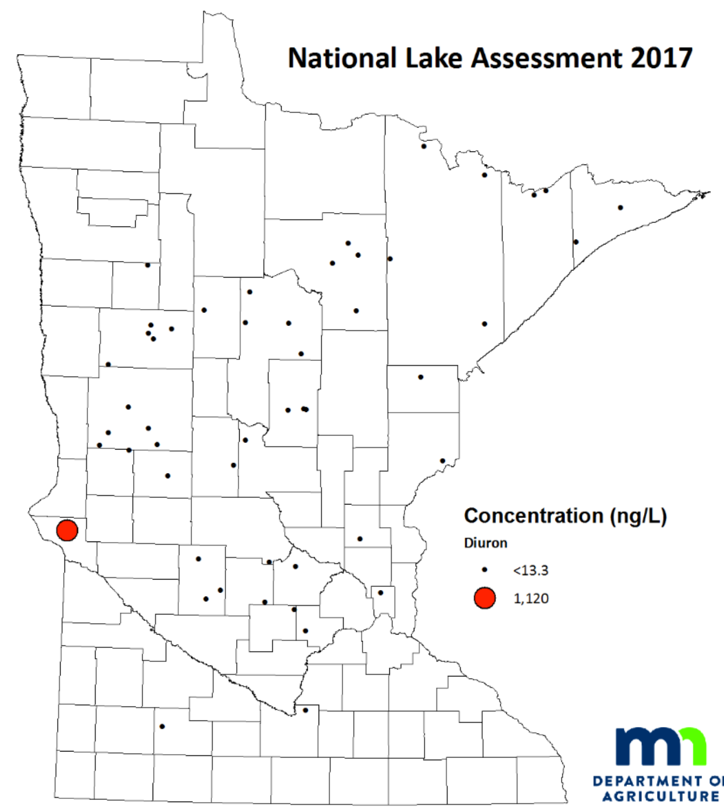


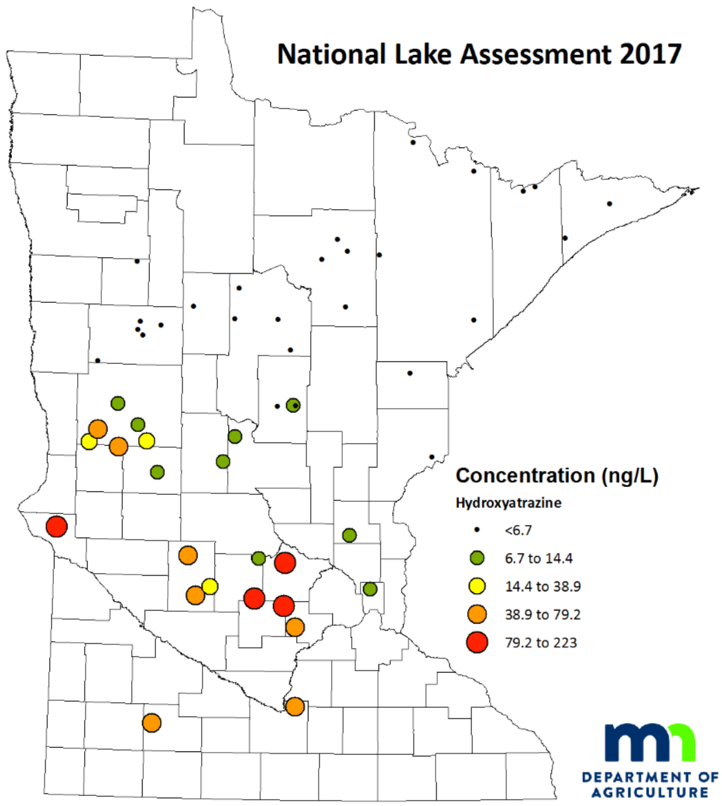
National Lake Assessment 2017
Concentration (ng/L)
Chlorpyrifos
<40
44.6
68.8
DEPARTMENT OF AGRICULTURE

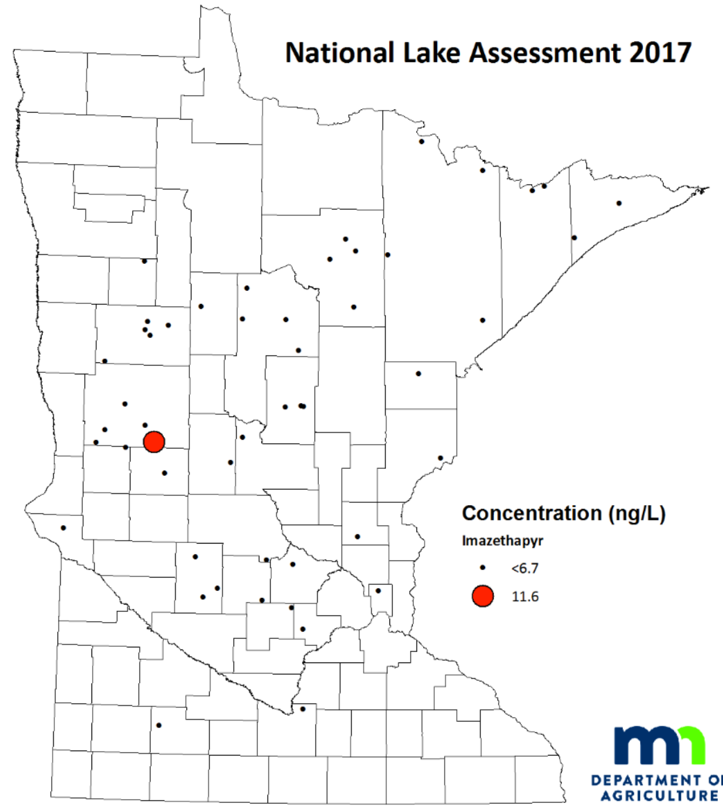

National Lake Assessment 2017
Concentration (ng/L)
DEDI Atrazine
<50
52.8
DEPARTMENT OF AGRICULTURE

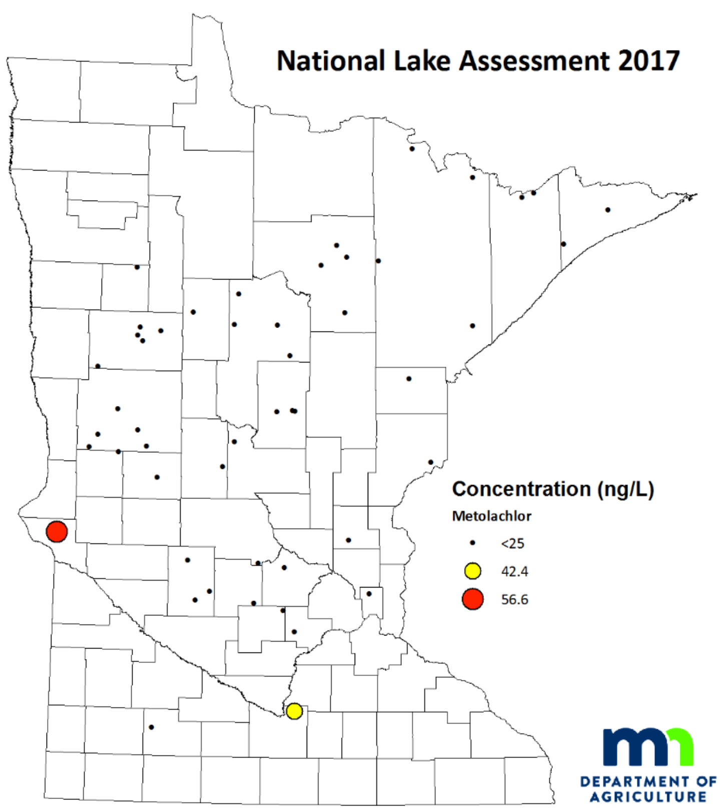

National Lake Assessment 2017
Concentration (ng/L)
Dimethenamid ESA
<6.7
6.7 to 7.3
7.3 to 11.3
11.3 to 19.8
19.8 to 25.8
DEPARTMENT OF AGRICULTURE

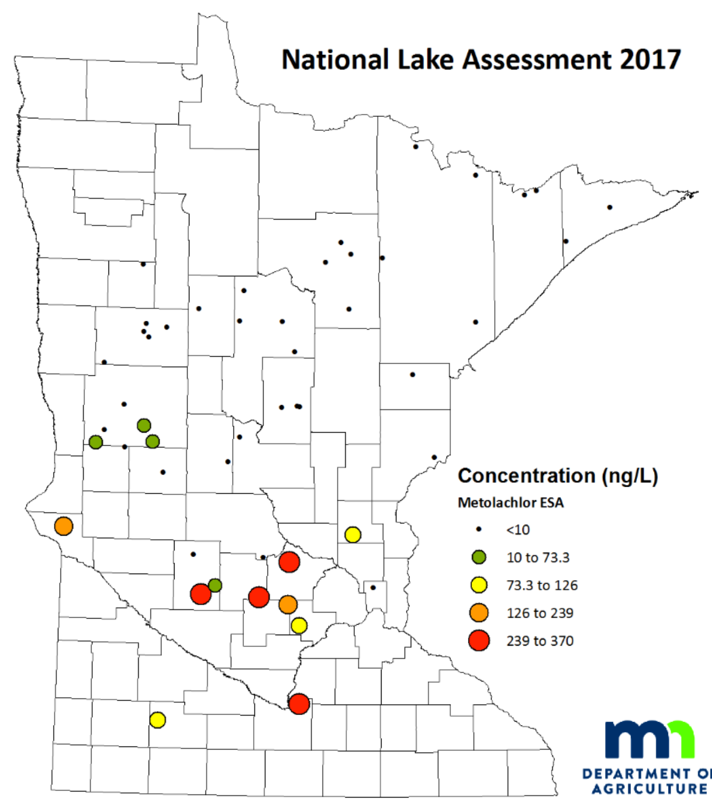

National Lake Assessment 2017
Concentration (ng/L)
Dimethenamid OXA
<10
10.3
11.3
14.3
17.8
DEPARTMENT OF AGRICULTURE

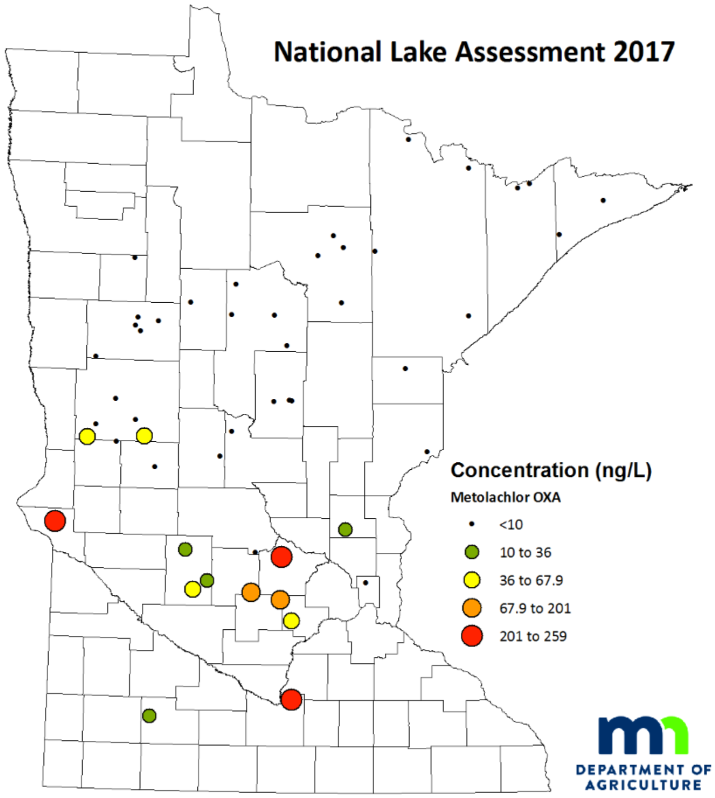

National Lake Assessment 2017
Concentration (ng/L)
Diuron
<13.3
1,120
DEPARTMENT OF AGRICULTURE


National Lake Assessment 2017
Concentration (ng/L)
Hydroxyatrazine
<6.7
6.7 to 14.4
14.4 to 38.9
38.9 to 79.2
79.2 to 223
DEPARTMENT OF AGRICULTURE


National Lake Assessment 2017
Concentration (ng/L)
Imazethapyr
<6.7
11.6
DEPARTMENT OF AGRICULTURE


National Lake Assessment 2017
Concentration (ng/L)
Metolachlor
<25
42.4
56.6
DEPARTMENT OF AGRICULTURE


National Lake Assessment 2017
Concentration (ng/L)
Metolachlor ESA
<10
10 to 73.3
73.3 to 126
126 to 239
239 to 370
DEPARTMENT OF AGRICULTURE


National Lake Assessment 2017
Concentration (ng/L)
Metolachlor OXA
<10
10 to 36
36 to 67.9
67.9 to 201
201 to 259
DEPARTMENT OF AGRICULTURE