Impacts of Neonics in New York Water

Their Use and Threats to the State's Aquatic Ecosystems

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FOREWORD

This report represents the abbreviated version of a more complete analysis and discussion of neonicotinoid water contamination in New York and across the country. The reader is referred to the complete report for more details.

EXECUTIVE SUMMARY

Neonicotinoid insecticide (neonic) use in New York has increased markedly in the last 15 years, as it has nationwide. Neonics now frequently appear in New York surface waters at levels expected to cause significant harm to the state's aquatic ecosystems. Substantial reductions in outdoor neonic use are recommended to avoid these harms. More intensive monitoring of both surface and groundwater is also needed, especially for those compounds not currently monitored, including acetamiprid, clothianidin, and thiamethoxam.

It is estimated that somewhere between 70 to 76 U.S. tons (141 to 152 thousand pounds) of neonic active ingredients were used in New York in 2014, but this does not account for consumer use products. It is believed that a high proportion of this total (86 to 93 thousand pounds) comes from agricultural uses. While imidacloprid was the most heavily used neonic overall (~76 thousand pounds per year), clothianidin appeared to be the dominant neonic used in agriculture (~38 thousand pounds per year), even though no outdoor use clothianidin products are approved in the state. This anomaly is explained by the fact that many crop seeds are coated with clothianidin before planting, and that New York State's Department of Environmental Conservation does not currently regulate these treated seeds as "pesticides" under state law.

Residues of the neonic imidacloprid have appeared frequently in New York surface water sampling since 2001. The vast majority of detections (from 90% to 100% each year) exceed the U.S. Environmental Protection Agency's (USEPA) and our chosen 0.01 µg/L benchmark for harm to aquatic ecosystems. Many detections exceed that benchmark by a 10-fold margin. The highest water concentrations (typically 6-8 µg/L) tend to be from sampling locations where imidacloprid has been detected over multiple years, suggesting that more frequent monitoring would uncover other significant spikes. Groundwater detections of imidacloprid have been less frequent, but show maximum values in the same range, suggesting that wetlands recharged by ground water will be impacted also. On Long Island, the latest (2016-2017) U.S. Geological Survey groundwater testing reveals detections in ~31% of samples taken—although none above the current USEPA drinking water guideline.

Water sampling for other neonics has been sparse, but given the high runoff potential for clothianidin and thiamethoxam (both greater than imidacloprid), and their significant use in New York, regular monitoring for these chemicals is needed. Research on the use of these compounds elsewhere suggests that they are also present in New York surface waters at biologically damaging levels. More importantly, the aggregate amount of neonics is the relevant concern; research elsewhere has shown that several neonics often contaminate the same water course.

Scientific research has demonstrated that neonic use results in the loss of invertebrate life in both terrestrial and aquatic systems with effects that can lead to ecosystem-wide perturbations, diminishing consumer species such as birds, fish, mammals, and other vertebrates. Detected levels of imidacloprid alone in New York streams exceed levels at which deleterious effects on stream ecology were observed in other research. The probability that imidacloprid and other neonics are causing ecosystem-wide damage in New York is very high. Substantial reductions in outdoor neonic use are needed to mitigate further damage.

USEPA drinking water benchmarks remain high for all neonics except thiacloprid, and were not exceeded by the water testing results reviewed in this report. However, recent research on the toxicity of neonic active ingredients, their breakdown products or degradates, and the chlorinated by-products they form when passing through normal drinking water treatment processes creates cause for concern. As new human health research on neonics emerges—particularly on chronic exposures—New York should monitor water sources for the presence of all neonics (not only imidacloprid) down to detection levels of 0.01 µg/L or lower, especially in areas where surface waters are used for drinking water and on Long Island.

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1. GENERAL INFORMATION

1.1. Introduction

Neonicotinoids or "neonics" are a relatively new, but widely used, class of insecticides, approved extensively for home, garden, and indoor use as well as for agriculture (Jeschke et al. 2010). They are frequently applied as a coating on seeds, meaning that treatment is applied whether or not it is warranted by pest pressure. As "systemic" compounds, neonics have the ability to penetrate plant tissues, making the plant—including its sap, nectar, and pollen—toxic to insects. Neonics are highly soluble in water, which, combined with their persistence in soils, popularity, and prophylactic use, have led to widespread contamination of the environment (Goulson 2013, Morrissey et al. 2015).

While much has been written about the link between neonic use and the collapse of honeybee and other pollinator populations around the world, their extensive presence in and potential impacts on aquatic environments have only recently become better known. This report addresses these issues in the aquatic environment of New York State.

1.2. Growing Evidence of Neonic Surface and Ground Water Contamination in North America

As the ability to detect neonics in water has grown, so has their frequency of detection. At this point in time, imidacloprid, the first registered neonic, is still the only neonic routinely looked for in most water monitoring programs; not surprisingly, it is often found in surface waters. On a national level, the U.S. Environmental Protection Agency (USEPA) recently completed a review of available U.S. Geological Survey (USGS) and California surface water monitoring data (USEPA 2017a). They report both high detection frequencies for imidacloprid as well as exceedances of USEPA benchmark levels for ecological harm (described below) by over a thousand-fold (details in section 2.3.). In New York State, imidacloprid detection in routine surface water monitoring samples has reached as high as 50% of yearly samples (see section 2.2.).

Table 1: Surface Water Mobility Indices (SWMIs) for neonicotinoid insecticides and atrazine

	SWMI Value[a]
Atrazine	0.76
Acetamiprid	0.35
Clothianidin	0.66
Dinotefuran	0.85
Imidacloprid	0.56
Thiacloprid	0.30
Thiamethoxam	0.82

a Physicochemical properties obtained from Pesticide Properties database (PPDB 2018).

Although water testing data for the other four major neonic chemicals are less common, a number of research studies and data reviews have found that clothianidin and thiamethoxam, where used, are found in surface water samples also (Mineau and Palmer 2013; Main et al. 2014; Anderson et al. 2015; Morrissey et al. 2015; Miles et al. 2017, 2018; Struger et al. 2017; Bradford et al. 2018; Hladik et al. 2015, 2018). These results are hardly surprising given that several of the newer neonics have a higher potential to run off to surface waters than imidacloprid—as determined by their water solubility, ability to bind to soil, and persistence in soils. Pesticide industry scientists (Chen et al. 2002) introduced a validated indicator of runoff potential called the 'Surface Water Mobility Index' or SWMI, ranging from 0 (low mobility) to 1 (high mobility). The SWMI values for all the major neonic chemicals are tabulated in Table 1, along with the pesticide atrazine—a ubiquitous contaminant of agricultural watersheds—for comparison.

As can be seen, three neonics (clothianidin, thiamethoxam and dinotefuran) are expected to be more likely to run off to surface water than imidacloprid, an already frequent surface water contaminant. Not surprisingly, neonics have been found to be ubiquitous in tap water drawn from surface waters as well as shallow alluvial wells in areas of heavy neonic use (Klarich et al. 2017; Sultana et al. 2018).

Ground water studies are fewer and smaller in scope, but evidence of contamination is clear (Mineau and Palmer 2013). As reviewed by this author, over a decade ago, USEPA (2008) reported imidacloprid levels in New York groundwater as high as those found in surface streams (7 μg/L; see more complete analysis below). At about the same time, thiamethoxam was also recorded at even higher levels in Wisconsin wells (Huseth and Groves 2013).

Where detected in water, neonics tend to be present for extended periods of time. For example, in a study of California flowing water sources, concentrations of imidacloprid were found to remain steady for periods exceeding three months at all sites monitored throughout the summer (Starner and Goh 2012).

1.3. What is the 'No Harm' Level of Neonics in Water?

1.3.1. Environmental benchmarks: How does USEPA determine these levels and how does their approach compare to other jurisdictions?

To evaluate whether a pesticide may harm aquatic ecosystems, scientists estimate the concentration of that pesticide in water at or above that at which they would expect ecological impacts to occur. These 'benchmark values' try to provide a single concentration that is sufficiently protective of diverse ecosystems. However, different experts and governments disagree on the best way to derive these benchmarks.

USEPA has long favored the 'most sensitive' species method—setting the benchmark at the lowest acute or chronic toxicity value from the available species data. Unfortunately, this method often misleads, because USEPA has data on a handful of species and even closely related species differ greatly in their sensitivity to pesticides. Truly finding the 'most sensitive' species in an ecosystem may require testing hundreds (if not thousands) of different species, which USEPA is never in a position to do. Indeed, data sets typically available to USEPA include testing results for one to three species only.

Reliance on these small data sets causes benchmark values to fluctuate wildly when new species data become available, as the history of USEPA's aquatic benchmark for imidacloprid shows. From 1994 to 2017, USEPA's benchmark for acute harm from imidacloprid became 90-fold more protective and the chronic benchmark 50-fold more protective—taking nearly 25 years to align these values with those produced by other international efforts. This history, detailed in the full report, also demonstrates how the benchmark setting processes for "newer" neonics, such as clothianidin, thiamethoxam, and others remain at a very early stage of development and are likely to follow the same course.

USEPA's benchmark setting process for estuarine and marine waters—dating back to 2004—also is misguided. Even for imidacloprid, the most-researched neonic, USEPA admits to a higher uncertainty for its 16.5 μg/L acute and 0.16 μg/L chronic estuarine/marine benchmarks given the paucity of toxicity data for salt water species (USEPA 2017a). This reliance on a few arbitrarily-chosen brackish or saltwater species to characterize the entire marine environment is scientifically unsound. A more credible scientific position is to combine both freshwater and saltwater species and adopt the same benchmark values for all aquatic environments. This approach has been shown to be scientifically justified (Maltby et al. 2005). Selecting an appropriate estuarine/marine benchmark has particular relevance for New York, which has a marine coastline and valued estuaries such as the Hudson River estuary.

Recognizing the shortcomings of the USEPA method, most other jurisdictions now have adopted alternate strategies—reviewed in detail in the full report. These rely on curve-fitting of toxicity distributions and/or the application of safety factors.

1.3.2. Choosing between acute and chronic benchmarks

Regulatory agencies typically produce two types of benchmarks: acute and chronic. Acute benchmarks attempt to identify pesticide concentrations expected to cause harms from short-term exposure (hours to days). Chronic benchmarks identify levels that may cause harm when organisms are exposed for prolonged periods of time, typically measured in weeks or months and potentially encompassing the full life cycle of exposed species.

For neonics, acute benchmarks do not have much predictive value. Widely reviewed and available research (e.g., Morrissey et al. 2015) suggests that neonic toxicity is essentially cumulative—meaning the length of exposure is directly related to the toxicity (Sanchez-Bayo 2009, Tennekes 2010a). Further, several studies have also shown that neonics' high runoff potential leads to prolonged watershed exposures, ranging from weeks to months to possibly years. For example, Whiting et al. (2014, 2015) studied the consequences of a clothianidin seed treatment in corn at 0.25 mg/kernel, or 1/5 of the federally-allowed amount, and found residues in runoff water right until the end of the sampling period—156 days after planting. Similarly, Schaafsma et al. (2015) found pre-planting levels of both clothianidin and thiamethoxam in ditches and puddles situated in areas outside seeded fields in central Canada, indicating neonic contamination from the previous growing season (max. of 16.2 µg/L for clothianidin; 16.5 µg/L for thiamethoxam). Cumulative impacts and likely long exposure periods led Pisa et al. (2017) to conclude in the second iteration of a worldwide, multi-year assessment of neonics and other systemic insecticides that acute benchmarks are essentially "irrelevant for risk assessments of these chemicals…"

Chronic benchmarks are much more meaningful, although lab testing used by USEPA in benchmark setting may underestimate actual risks in the field. For example, USEPA (2017a) in their benchmark setting for imidacloprid did not track whether degradation of the chemical had occurred during the test, even though imidacloprid breakdown compounds are less toxic to aquatic organisms than the parent molecule (USEPA 2017a). Neonics' primary breakdown happens through photolysis—i.e., exposure to light—which is much more likely to occur in laboratory tests, generally performed in clear water with strong illumination, rather than in a turbid or shaded waterbody more typical in nature. Accordingly, as USEPA identified, its benchmark setting process may underestimate actual risk in the real world.

1.3.3. Choosing an appropriate benchmark for neonics

As mentioned above, and reviewed in detail in the full version of this report, USEPA benchmark values typically underestimate risks due to insufficient data and simplifying assumptions. Benchmarks can and do shift dramatically as new data become available. For example, USEPA's initial acute freshwater benchmark for imidacloprid dropped from 34.5 µg/L in 2007 to 0.385 µg/L in 2017; the chronic benchmark dropped from 0.5 µg/L to 0.01 µg/L over the same period. Recent evaluations by Canada's Pesticide Management Regulatory Agency (PMRA) proposed new benchmarks for three major neonics (Table 2). While there is now some agreement between the two countries' benchmarks for imidacloprid, there is sizeable discrepancy for the newer neonics.

Table 2: A comparison of current USEPA aquatic benchmarks to proposed benchmarks by Canada's PMRA (in µg/L)

Compound	USEPA acute benchmark[a]	PMRA acute benchmark	USEPA chronic benchmark[a]	PMRA chronic benchmark
Imidacloprid	0.385	0.36[b]	0.01	0.041[b]
Thiamethoxam	17.5	9.0[c]	0.74	0.026[c]
Clothianidin	11	1.5[d]	0.05	0.0015[d]

a USEPA 2019.

b PMRA 2016.

c PMRA 2018a.

d PMRA 2018b.

In an earlier assessment, Mineau and Palmer (2013) proposed that the toxicity of clothianidin and thiamethoxam should be assumed to be similar to that of imidacloprid because of similar test results when the same species were exposed to the different neonics. Morrissey et al. (2015) reached similar conclusions, arguing that "differences in relative toxicity among the various individual neonicotinoids are minor." Indeed, the main difference between imidacloprid and the other newer neonics is the amount of available toxicity data. Where toxicity data for the same species tested with multiple neonics are available, they show remarkably similar toxicity.

From this perspective, USEPA's benchmarks for clothianidin and thiamethoxam are untenable. Other benchmarks have been proposed that better account for the similarities in toxicity among neonics. Morrissey et al. (2015) proposed 0.035 µg/L as a chronic exposure benchmark for all neonics in order to "avoid lasting effects on aquatic invertebrate communities." PMRA's analysis suggests that a scientifically-defensible chronic benchmark for thiamethoxam is slightly lower than that for imidacloprid, while the clothianidin benchmark should be radically lower at 0.0015 µg/L (Table 2).

In light of these uncertainties, we propose that benchmark values for all neonics should be in the range of 0.01–0.04 µg/L. For the purpose of this report, we will use the more protective value of 0.01 µg/L given that this is now the value accepted by USEPA for imidacloprid, although PMRA's much lower benchmark for clothianidin (0.0015 µg/L) suggests that our chosen benchmark may not be protective enough.

1.3.4. How do we account for neonic mixtures? – the need for a proper cumulative assessment

Although neonics have similar modes of action, USEPA does not appear to assess their impacts cumulatively, stating that it has not made "a common mechanism of toxicity" finding for either imidacloprid or thiamethoxam (USDA Forest Service 2016, USEPA 2011). While highly questionable for imidacloprid, this finding is clearly unsupportable when applied to thiamethoxam, given that the neonic clothianidin is actually the primary breakdown product of thiamethoxam. Contamination studies in agricultural environments have shown that several neonicotinoid insecticides are often found in the same water samples. Hladik and Kolpin (2015) in the first USGS national survey of neonics recorded that 26% of their samples contained more than one neonic and 11% contained three or more.

In an ecological context, there is no valid reason not to consider the registered neonics as a group. Morrissey et al. (2015) proposed that their benchmarks be applied to the sum of all neonic residues. Bayer Crop Science (2010), the main neonic manufacturer, has even argued that neonics can act synergistically—meaning that their combined impact might be greater than the action of each separately. This raises the possibility that we are under-protecting by merely adding concentrations of the various neonics found in the same water sample.

For these reasons, we propose that the USEPA benchmark of 0.01 µg/L be the benchmark we apply to all neonics separately or to the combined concentration of neonics in any one sample. This is the level of contamination to which we will compare all water samples to in order to better predict the ecological harm of the residue levels detected.

1.3.5. Drinking water standards

As early as 1994, when imidacloprid was first registered, USEPA expressed concerns about its potential to contaminate drinking water supplies (USEPA 1994a, b). Comparing imidacloprid to aldicarb, another highly soluble pesticide, USEPA found imidacloprid's potential to leach into groundwater to be three times higher—a finding of particular relevance to New York given the long history of aldicarb contamination in Long Island aquifers.

Recent research shows USEPA's initial fears were well-founded. Klarich et al. (2017) showed that neonics can survive standard water treatments and Sultana et al. (2018) found that neonics are near ubiquitous drinking water contaminants in agricultural areas. Clearly, the human population is now potentially exposed to neonics in a chronic fashion.

USEPA recently updated its guidance document for setting human health drinking water benchmarks (USEPA 2017b). The process starts by noting the lowest No Observable Adverse Effect Levels (NOAELs) from various mandated toxicological studies, and deriving appropriate Reference Doses (RfDs) or population adjusted doses (PADs) through the application of various safety factors reflecting the type and severity of the effects, and completeness of the database. Although USEPA determines both acute and chronic drinking water benchmarks, we will concentrate here on the chronic benchmarks for the reasons discussed above.

Table 3 shows the chronic or lifetime reference dose or adjusted reference dose as well as the water concentration that should not be exceeded in order to remain below this lifetime dose. Included in the table are the toxicology endpoints (adverse effects) that served as the departure point for these drinking water benchmarks.

Table 3: A summary of current Human Health Benchmarks for Pesticides (HHBPs) in drinking water				
Name	**Chronic or lifetime PAD (RfD) (mg/kg/day)[a]**	**Chronic or lifetime HHBPs (µg/L)[a]**	**NOAEL in relevant chronic study (mg/kg/day)**	**Effect seen in study from which NOAEL established[c]**
Imidacloprid	0.057	360	5.7	NOAEL for two year rat study. Thyroid effects at higher doses.
Clothianidin	0.098	630	9.8	NOAEL for two generation rat study. Effects seen include decreased body weight gain, delayed sexual maturation, decreased thymus weight in first generation offspring and increased stillbirths at higher doses.
Thiamethoxam	0.012	77	1.2	NOAEL for two generation rat study. Effects seen on sperm counts and testis weight in first generation offspring at higher doses.
Thiacloprid	0.004	0.8[b]	1.2	NOAEL for two year rat study. Liver and thyroid histopathology, nervous system degeneration, and carcinogenicity seen at higher doses.
Acetamiprid	0.071	450	7.1	NOAEL for two year rat study. Liver and kidney toxicity, body weight and body weight gain effects seen at higher doses.

a USEPA 2019b.

b Different calculation to account for carcinogenicity of compound. The value of 0.8 µg/L is based on an estimated increased cancer risk of one in a million.

c Complete review mammalian toxicology available in Mineau and Callaghan 2018.

The same industry studies were reviewed by other regulatory bodies, notably in California, Canada, and Europe. Concurrence amongst jurisdictions provides additional weight to the review of the toxicological studies provided by industry, even if the methods of deriving water concentration benchmarks vary somewhat. However, it should be noted that some independent published research has resulted in lower NOAELs in some cases (Mineau and Callaghan 2018), but this research has not yet been incorporated into formal regulatory assessments.

The choice of NOAELs reported above met with general concurrence with the exception of acetamiprid. The European Union (2004) identified a slightly lower NOAEL of 6.5 mg/kg/day based on a two generation rat study. However, both USEPA and PMRA identified the NOAEL as 18 mg/kg/day in the same study. This difference is slight and would not lead to a substantial difference in the resulting drinking water benchmark.

The California EPA (2018) calculated an imidacloprid acute reference water level for non-nursing infants of 283 µg/L. This is lower than the 360 µg/L level chronic calculated by USEPA. They recommended using this as the official California reference level for imidacloprid.

Drinking water standards do not take pesticide degradates into account and it is known that some of these are much more toxic to mammalian systems than the parent material. Recently, Klarich Wong et al. (2019) identified not just the known metabolites of imidacloprid (imidacloprid-urea and desnitro-imidacloprid) in drinking water supplies, but also four novel chlorinated products following water treatment. These compounds have not yet been characterized toxicologically and may present human health concerns.

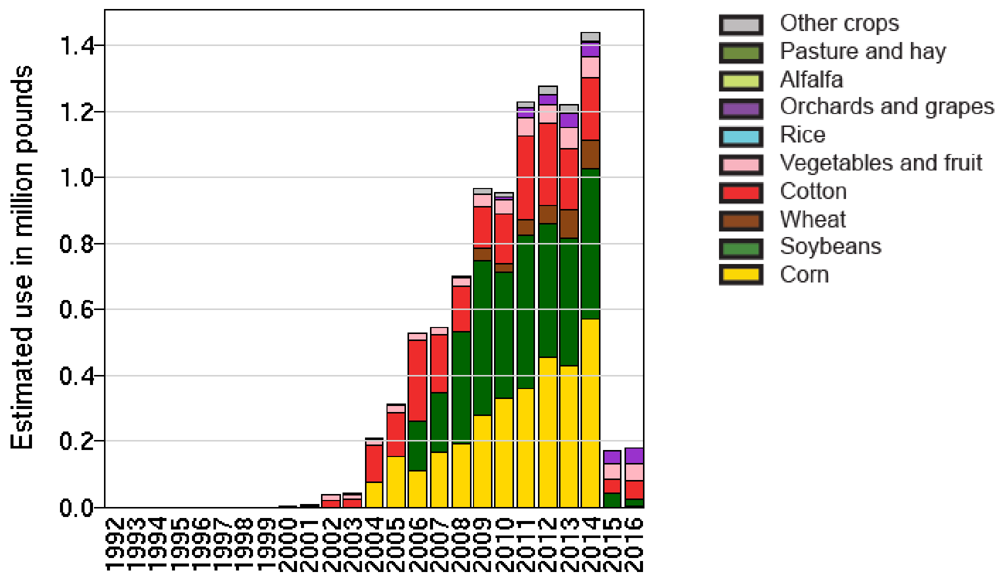
2. NEW YORK STATE AND NEONICS

2.1. How Much Are Neonics Used in New York?

We calculated the total neonic use in New York by using data from USGS (Thelin and Stone 2013); they used confidential surveys of pesticide use patterns on different crop types and extrapolated these use rates by the recorded crop acreages for each U.S. state and county. In cases where the USGS use rate data for a county was lacking, we opted for the USGS method of interpolating from use rates in nearby counties rather than assuming no use—a much more realistic approach. Importantly, USGS estimates reflect the agricultural use of the pesticides only—not domestic, landscape, or industrial uses—meaning imidacloprid use is likely greatly underestimated given its extensive use in residential and commercial settings.

We report on three separate years of estimated use: 2004, 2009, and 2014 (Table 4). The year 2004 was chosen because it falls at the midpoint of intensive surface water sampling for imidacloprid in New York and corresponds with the highest reported frequency of detection (see section 2.2.1.). The year 2014 is the last year when USGS incorporated seed treatment uses in its pesticide estimates. This is critical given that imidacloprid, clothianidin, and thiamethoxam are used, to a large extent, in seed treatments. For example, Figure 1 shows the sharp drop off in estimated thiamethoxam use for 2015 when USGS stopped tracking seed treatment uses.

Figure 1: National estimates[a] of thiamethoxam use, by year and crop



a Downloaded February 2019 from: https://water.usgs.gov/nawqa/pnsp/usage/maps/.

Finally, 2009 was chosen as the midpoint between those two time points to illustrate any trends.

Table 4: USGS-derived estimates of agricultural neonic use for New York State in 2004, 2009, and 2014

	2004 quantity (lbs)	2009 quantity (lbs)	2014 quantity (lbs)
Acetamiprid	218	8,265	6,464
Clothianidin	432	17,317	38,561
Dinotefuran	0	0	88
Imidacloprid	4,855	6,279	26,444
Thiacloprid	154	8,234	7,676
Thiamethoxam	2,156	3,893	12,707
Total neonics	7,818	43,989	91,941

This ‘snapshot’ of pesticide use for New York echoes the trends seen worldwide with respect to the increasing dominance of neonics in insecticide markets (Jeschke et al. 2010). It also suggests that neonic use in New York increased 12-fold in the 2004-2014 decade, and that clothianidin has become the dominant agricultural neonic, despite the fact that New York has effectively prohibited non-seed treatment uses of that chemical in agriculture (Serafini 2007).

The New York State Department of Environmental Conservation (NYSDEC) also oversees state pesticide reporting requirements in collaboration with Cornell University, which collects several types of data (PSUR 2019). Prior to 2013, data were reported by USEPA product registration number, making tabulation difficult without access to the machine-readable records. Starting in 2013, however, data were amalgamated by active ingredient.

Two NYSDEC data categories are useful to build a full picture of neonic use in New York State (Robert Warfield, Cornell pers. comm.). The first is "Sales by Commercial Permit Holders" of pesticides intended for agricultural crop production. This data should best correspond with USGS estimates for agricultural use, with the exception of neonic-treated seeds, which are not considered pesticides by NYSDEC (Dan Wixted, Cornell University pers. comm.). Given the fact that a large proportion of the insecticide applied to seeds escape to the environment, either through runoff or during seeding, and that the contamination of terrestrial invertebrates is higher following seed treatment use than during foliar application (Mineau and Callaghan 2018), the notion that seed treatment use is not a pesticide application is clearly one based on convenience rather than sound science. The second is "Use Data by Commercial Applicators," which tallies applications by commercial applicators required to report annually. Since farmers are exempt from this reporting requirement, this second category should capture non-agricultural neonic uses. Importantly, however, this number excludes all uses of neonic consumer products (e.g., lawn care products available at a hardware store or nursery). The other two types of data collected by NYSDEC—"Sales Data to End Users" and "Sales Data to Resellers"— are likely encompassed in the first two categories.

For comparison, USGS estimates, as well as the estimates generated from the NYSDEC-collected data for the year 2014, are presented in Table 5.

Table 5: Selected data from NYSDEC for neonic sale and use in 2014

	USGS Estimate of Agricultural Use (lbs)	DEC -Sales by Commercial Permit Holders (lbs)	DEC - Use Data by Commercial Applicators (lbs)
Acetamiprid	6,464	1,193	3,911
Clothianidin	38,561	0	4
Dinotefuran	88	0	0
Imidacloprid	26,444	10,842	49,939
Thiacloprid	7,676	7,233	33
Thiamethoxam	12,707	4,314	1,825
Total	91,941	23,583	55,713

Although the "Sales by Commercial Permit Holders" category best estimates agricultural use, instances where farmers contract out their spraying to a commercial applicator would appear in the "Use Data by Commercial Applicators" category (Robert Warfield, Cornell pers. comm.). The thiacloprid estimates (USGS vs. NYSDEC-recorded sales) are in good agreement, suggesting that few non-farmer commercial applicators apply thiacloprid on agricultural land. The case, however, is different for acetamiprid, suggesting a substantial contribution by non-farmer commercial applicators.

We can estimate the proportion of imidacloprid, thiamethoxam, and clothianidin applied in the form of seed treatments based on a graphical extrapolation of the USGS use data plots for those chemicals used nationwide from 2010 to 2014 (when seed treatments were included in the estimates) to 2015 (when seed treatments were excluded) and comparing this extrapolated value to the reported value for 2015 (see full report for details). This provides a rough estimate of the proportion of the chemicals used in seed treatments–58%, 75%, and 92% for imidacloprid, thiamethoxam, and clothianidin, respectively. We will assume these proportions hold for New York State.

These estimates allow us to correct the NYSDEC sales data to account for seed treatment use. For example, assuming that 75% of agricultural thiamethoxam use is not captured in the "Sales by Commercial Permit Holders" category, the corrected total would be approximately 17,196 lbs or 35% higher than the USGS estimated use. Likewise, the corrected agricultural use of imidacloprid is approximately 25,794 lbs—essentially the same as the USGS estimate. The strong agreement between NYSDEC-recorded sales and USGS estimates for thiacloprid and imidacloprid and the fair agreement for thiamethoxam suggest that the USGS estimates for clothianidin are reasonable also, despite the lack of NYSDEC-recorded sales. It is not surprising that no sales of clothianidin were recorded given that this chemical is almost exclusively used as a seed treatment and not otherwise permitted for sale or use for agricultural purposes in the state.

One difficulty with sales data is that a sale in any given year does not necessarily reflect use in that same year. However, over a number of years of data collection, the supply and demand equations should equilibrate to reflect the turnover of various products. However, this remains an uncertainty.

We believe that the best overall estimate for neonic use in New York is a combination of the USGS and/or NYSDEC estimates of sale for agricultural use corrected for seed treatment use. The non-agricultural use is best captured by the NYSDEC use data by commercial applicators. As mentioned earlier, some of these applicators might be applying the pesticides on contract to farmers. However, the generally strong agreement between USGS estimates and NYSDEC sales data corrected to include seed treatments and the fact that imidacloprid represents 90% of the neonics applied by commercial applicators suggest that the "Use Data by Commercial Applicators" category captures the extensive turf, ornamental, and industrial site neonic use rather than a major part of the agricultural use.[1] The recent work by Nowell et al. (2017; but samples were taken in 2013) in the Midwest confirms that imidacloprid is now being detected more frequently and at higher levels in surface waters with urban inputs. Based on our assumptions and correcting for seed treatment applications, the only neonic where application to agricultural land by commercial applicators appears to be happening to any significant extent is acetamiprid. Not knowing how much of the commercial applications overlap with USGS estimates for agricultural land leads to a higher uncertainty for this chemical.

Accordingly, Table 6 provides what we believe to be the best estimate of neonic use for New York in 2014.

Table 6: Best estimates of neonic use for New York in 2014 (see text for data sources and assumptions)

Chemical(s)	Best estimate (or range) of agricultural use (lbs)	Best estimate of non-agricultural use (lbs) (may include some application to agricultural land by commercial applicators, for acetamiprid especially)	Best estimate of neonic use in New York 2014 (lbs) excluding any consumer product use
Acetamiprid	1,193 – 6,464	3,911	5,104 – 10,375
Clothianidin	38,561	4	38,561 – 38,565
Dinotefuran	0 – 88	0	0 – 88
Imidacloprid	25,814 – 26,444	49,939	75,753 – 76,383
Thiacloprid	7,233 – 7,676	33	7,266 – 7,710
Thiamethoxam	12,707 – 17,258	1,825	14,533 – 19,083
Total Neonics	85,508 – 93,491	55,712	141,217 – 152,205

As can be seen, despite the fact that clothianidin likely predominates in agriculture, imidacloprid remains the dominant product sold and used in the state. It should be noted, however, that the estimated 70-76 U.S. tons of neonic active ingredient used in New York excludes consumer products containing neonics. As such, the imidacloprid use totals, especially, underestimate actual use given the hundreds of imidacloprid consumer products registered for use in the state.

USGS estimates suggest that the use of neonics has increased exponentially in the last decade. As of 2015, NYSDEC reported that there were 335 imidacloprid products alone registered for use, 252 of which could be used on Long Island (NYSDEC 2015). Based on the same use data source reported in Table 5 above, NYSDEC estimated that the number of applications of imidacloprid on Long Island had increased from 39,007 in 2003 to 46,316 in 2012. However, based on the combined NYSDEC data (Sales by Commercial Permit holders; and Use Data by Commercial Applicators—as per Table 5 above) for the period 2013-2016, imidacloprid use may have peaked in 2015 and may now be declining.

As of 2017, the main thiacloprid product (Calypso) appears to have been suspended. According to the NYSDEC list of registered products, it was not registered for use on Long Island.

1 Nevertheless, it is believed that applications by commercial applicators on farms is high (Dan Wixted, Cornell University, pers. comm.), although this is a general impression not specific to any particular product.

2.2. What Is the Evidence of Contamination?

We have estimated that at least 70-76 U.S. tons of neonic active ingredients are applied in New York every year, at least based on 2014 data. We believe that number is probably increasing still (based on national trends)—even if imidacloprid use has peaked. The next relevant question is whether we can detect any contamination of either surface or groundwater as a result.

2.2.1. Surface water samples.

All relevant and available New York water quality data from the USGS's National Water Information System (NWIS 2019) were downloaded in early February of 2019 following guidance provided in Shoda et al. (2018).

USGS started reporting imidacloprid residues in 2000, but with minimum reporting levels (i.e. detection limits) of 0.1 µg/L only. In 2001, reporting levels dropped to 0.007 µg/L or just below the USEPA and our benchmark for ecological damage (0.01 µg/L). Unfortunately, reporting levels then changed over time, making detection more difficult. The minimum reporting level of 0.007 µg/L increased to 0.02 µg/L partway through 2004 and then to 0.06 µg/L partway through 2006. Accordingly, results for these years were often labeled as trace levels (t), below formal detection levels, and values were mostly given as estimates. Sampling effort dropped dramatically from 2008 to 2015 with few detections; this interval is therefore presented as a single time period in the analysis below. From 2013 on, reporting levels were given as 0.011 µg/L on an interim fashion and then 0.016 µg/L once the use of new calculation software was in place. The current detection levels are above the USEPA benchmark—clearly inadequate to fully detect harmful biological effects or allow for summation of residues with other neonics.

The variation in reporting levels in the last two decades makes it difficult to attach much importance to the proportion of samples showing detections. However, we can provide a rough estimate: in the years 2001 to 2007 and in 2016, the proportion of surface water samples analyzed from New York State that showed detections of imidacloprid varied between 15% and 50% of samples—despite variable minimum reporting levels as reported above. The proportion of imidacloprid detections peaked at 50% in 2004. Drawing meaningful conclusions from this high level estimate, however, is difficult because the samples lack context: whether they originated from an area of pesticide use, or from an agricultural, urban, or mixed use environment. In addition, samples were taken at various times of the year and from various types of waterbodies, including large rivers where the dilution factor can be extreme.

To understand the actual ecological consequences, it is more meaningful to look at samples where imidacloprid was in fact detected, indicating some use in the watershed. There is clear evidence from the literature that, where neonics are used on crops, they will be detected in nearby bodies of water at a high frequency (Morrissey et al. 2015). Reported values of imidacloprid are summarized in Table 7. The data represent all positive samples reported for any given year, with some sites being sampled more than once (i.e., the values from which the tabulation was made are not strictly independent).

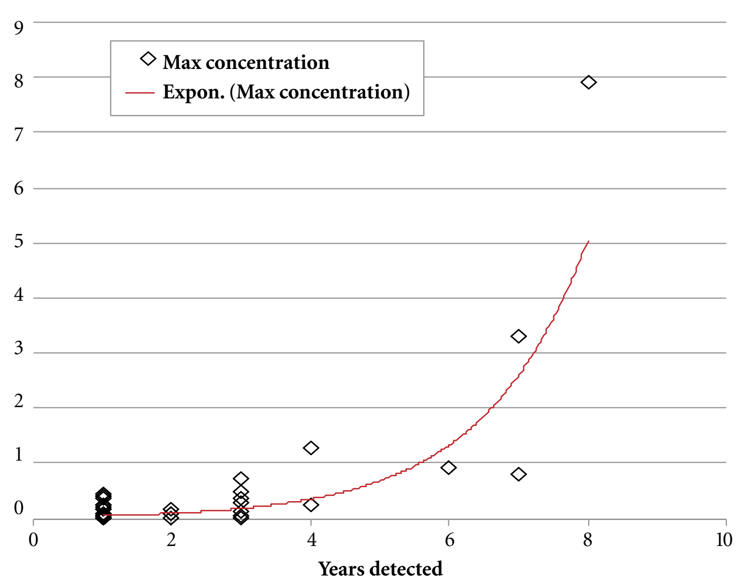
A number of observations can be made from these results. With the exception of the 2008-2015 period of reduced sampling intensity, it can be seen that, when detected, imidacloprid was present at levels above our benchmark level for ecological damage 90-100% of the time. A very high proportion of samples (up to 60% of samples in at least two years) had imidacloprid levels that were over 10 times this critical benchmark. This suggests that impacts to aquatic invertebrate fauna in New York State from imidacloprid alone have been substantial.

As high as those values are (relative to biological impact levels), they cannot be assumed to be true maxima. There are serious limitations to ascertaining maximum levels of contamination from routine water sampling. Samples are often taken from large streams, after significant dilution has occurred, whereas impacts to aquatic life are expected where most of the aquatic productivity is taking place—in small drainage ditches and ponds bordering field areas or in small feeder streams. Grab or spot samples taken at a single moment in time are also unlikely to capture peak concentrations. Indeed, it has been shown that, even when taken weekly, water samples will underestimate peak concentrations by one to three orders of magnitude (Xing et al. 2015). Many of the New York sampling sites we examined for this report were sampled only once in the 15-year period.

Table 7: A summary of New York State imidacloprid detections from the USGS NWIS database						
Year	**Number of detections**	**Mean concentration (µg/L)**	**Median concentration (µg/L)**	**High value recorded (µg/L)**	**Proportion of values above the 0.01 µg/L benchmark**	**Proportion of values at least 10 fold higher than the 0.01 µg/L benchmark**
2001	50	0.197	0.132	1.30	98%	60%
2002	31	0.238	0.077	1.84	97%	45%
2003	93	0.271	0.074	7.94	99%	42%
2004	83	0.347	0.085	4.93	99%	60%
2005	63	0.373	0.092	4.64	100%	48%
2006	57	0.144	0.029	5.13	100%	12%
2007	49	0.146	0.033	1.40	90%	22%
2008-2015	8	0.025	0.018	0.073	62%	0%
2016	122	0.082	0.041	0.460	93%	26%

Where a water source was sampled more often, higher levels of imidacloprid were most often detected. Figure 2 shows how the ability to detect higher levels of contamination in surface waters is directly related to the intensity of sampling. Here, the maximum observed concentration of imidacloprid at any given site (as high as 7.9 µg/L on one site) is plotted against the number of years imidacloprid was detected at that site.

Figure 2: Maximum concentration of imidacloprid (in µg/L) detected at a sampling site against number of years of detection at that site with exponential fit shown



The shape of the curve in Figure 2 suggests that high values of imidacloprid detected in routine water sampling are less a function of the specific site sampled, but rather, reflect sites with more intensive sampling. If correct, this means that most sites with imidacloprid detections will be exposed to these very high and extremely damaging levels of insecticide.

Outside of imidacloprid, the sampling for other neonics has been minimal. Based on the same NWIS data, a total of only fifteen samples were analyzed for clothianidin and thiamethoxam over the same 2001-2016 period—all from between 2012 and 2016—with reporting limits between 0.0039 to 0.0062 µg/L for clothianidin and 0.0034 to 0.0039 µg/L for thiamethoxam. Only one of the fifteen samples was taken in June, and therefore probably occurred post-seeding; this sample from Fall Creek near Ithaca contained 0.020 µg/L clothianidin and 0.0119 µg/L thiamethoxam, as well as trace levels of imidacloprid.

The last three neonics, acetamiprid, dinotefuran, and thiacloprid were analyzed only at three New York sites. Most of the sampling consisted of a monthly sample taken from the Genesee River in Rochester in 2015-2016. Minimum reporting levels were low (0.0032-0.0045 µg/L), but there were no detections from this limited sampling effort.

The low monitoring effort for neonics other than imidacloprid is unfortunate in light of the longer persistence and greater potential of the newer products to contaminate surface waters. Hladik et al. (2015) found that both clothianidin and thiamethoxam occurred more frequently than imidacloprid in Midwest streams fed from agricultural areas.

Apart from the regular USGS testing, the U.S. Fish and Wildlife Service (USFWS) conducted a standalone water testing project in New York (Secord and Patnode 2018). Eleven surface water samples were taken in July 2016 from streams downstream from, or in proximity to, potato fields with a limit of detection of 0.004 µg/L. For this sampling, four of eight sampled locations tested positive for neonics. Table 8 provides a summary of those detections.

Table 8: A summary of positive neonic detections in Secord and Patnode (2018)

Sample ID	Analytes	Concentration (µg/L)	Site description
NYP18	Imidacloprid Acetamiprid	0.114 0.005	Salmon Creek 1, Wayne County, NY - Downstream of potatoes, corn, beans, orchards
NYP19	Imidacloprid Thiamethoxam	0.309[a] 0.005	Salmon Creek 2, Wayne County, NY - Downstream of corn, beans, potatoes, orchards
NYP20	Imidacloprid	0.006	Flint Creek, Yates County - Downstream of potatoes, corn, beans
NYP23	Imidacloprid	0.018	Cohocton River, Steuben County, NY - Downstream of potatoes, corn, beans, wetland

a Average of two measurements.

Of these, three of the four sample locations had neonics above the 0.01 µg/L benchmark, with the combined neonic concentration at one site exceeding the benchmark by a factor of 30. Half of the sites with positive detections had residues of multiple neonics.

In the same project, USFWS also took five aquatic invertebrate samples described as "mostly crayfish." Given the high detection limit of 3 µg/L, only one of five invertebrate samples tested positive for neonics: 7.3 µg/L of thiacloprid. This is an interesting finding in light of the low estimated amount of thiacloprid used in New York.

Finally, Carpenter and Helbling (2018) included imidacloprid as one of a large number of "micro-pollutants" analyzed in the Hudson River Estuary. Of the 127 water samples taken in 2016-2017 from 17 sites, imidacloprid was detected in 36 samples with a median concentration of 0.012 µg/L and a maximum of 0.103 ug/L; therefore, slightly over half of the detected levels were above the biological harm benchmark. Interestingly, these authors found that imidacloprid detections tended to cluster with samples affected by wastewater outlets (and sewage treatment plants in particular), again suggesting the importance of urban landscape uses in the overall contamination picture for that neonic.

2.2.2. Groundwater and drinking water samples

Based on the same search of NWIS records, 1,023 groundwater samples were tested by the USGS for imidacloprid between 2001 and 2016, with detection limits as described above for surface water samples. Of those, only 46 detected neonics, ranging from trace levels to 5.3 µg/L. All but three detections had values above the ecological harm benchmark, but none approached the drinking water benchmark set by USEPA.

An exchange between NYSDEC (NYSDEC 2003, 2004) and Bayer Corporation (Bayer Corp. 2004) mentions the detection of imidacloprid in approximately 20 monitoring and private wells on Long Island. Imidacloprid was reported from well clusters down gradient from farms and, in some cases, trees injected with imidacloprid, with the highest reported value at 0.0067 µg/L. There were concerns expressed over the fact that some wells with detections were well away from use sites and others were deep (85-90 feet) community supply wells.

In 2014, NYSDEC (NYSDEC 2014) summarized drinking water quality on Long Island based on analyses carried out by the Suffolk County Department of Health Services and Water Authority between the years 1996-2010 (Table 9). Imidacloprid was the only neonic analyzed. It was the sixth most frequently detected pesticide in Long Island groundwater, whether as part of the public water system or in private wells.

Table 9: Imidacloprid data (µg/L) from the Suffolk County Department of Health Services (1996-2010) from NYSDEC (2014)

Drinking water supply				Monitoring wells			
Number of detects (wells)	Minimum	Maximum	Median	Number of detects	Minimum	Maximum	Median
549 (60)	0.1	12.9	0.4	341	0.04	407	0.7

Imidacloprid urea, a degradate, was also detected in six monitoring well samples at a maximum of 1.3 µg/L. The guanidine and olefin degradates were not detected.

A 2015 NYSDEC (NYSDEC 2015) report summarized ground and well water data from Long Island from 2001 to 2013. This report cited 0.2 µg/L as the lowest concentration detected (at odds with the previous report). Using that higher detection limit, the proportion of wells where imidacloprid was detected in the last year of sampling (2013) was 8.4% for monitoring wells and 7.5% for private wells with maximum levels of 6.2 µg/L and 2.8 µg/L respectively. That same report pointed out that detection levels from 2010 to 2013 were lower than from 2005 to 2009.

The latest USGS information available for Long Island (2016-2017) provides results for 88 groundwater samples. Twenty-seven of those samples (31%) had detections of imidacloprid ranging from 0.005 µg/L to a maximum of 5.3 µg/L.

NYSDEC with the help of Cornell University investigated well water for pesticide contamination in several upstate New York counties from 2006 to 2010 (Whitbeck 2006, 2008, 2009a,b, 2010). Wells were chosen on the basis of intensity of nearby pesticide use and vulnerability. Imidacloprid was analyzed from year two of the program onwards, but with a detection limit of 1 µg/L only. However, in one of the years, samples were tested with a commercial enzyme-linked immunosorbent assay (ELISA) for imidacloprid and related compounds (degradates as well as thiacloprid and acetamiprid) with a detection limit of 0.07 µg/L and quantification limit of 0.2 µg/L. This resulted in a single detection estimated to be between those two values.

2.3. Are Reported Neonic Levels in New York Water Causing Harm to the Environment or Human Health?

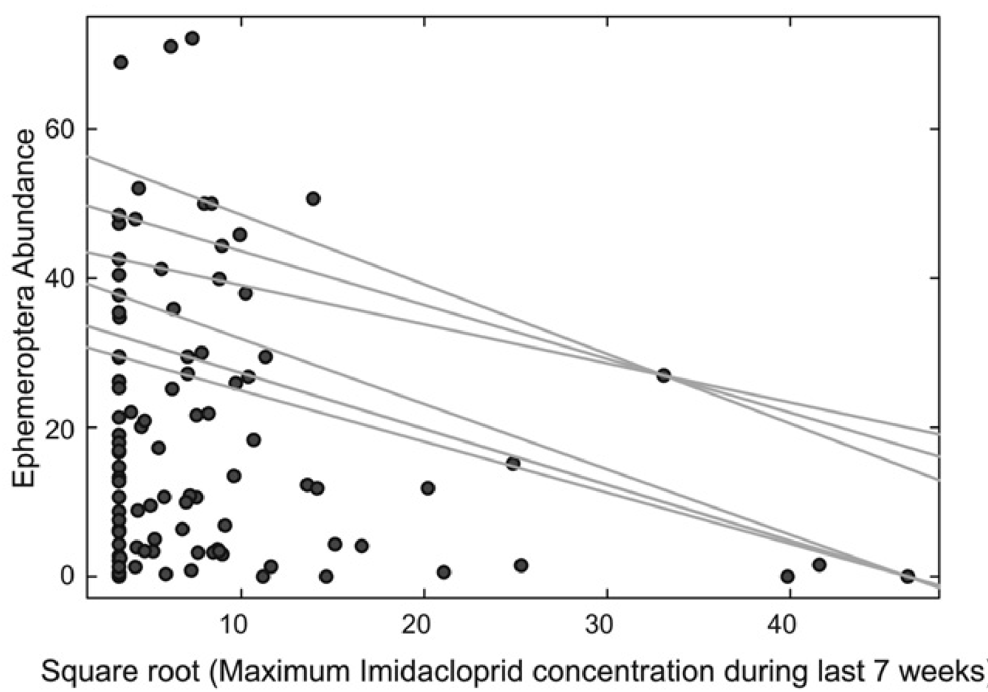
The data available for New York indicate that, when detected, neonic levels are likely to be above the ecological harm level of 0.01 µg/L, and frequently above 0.1 µg/L. There already is an indication that, with more intensive sampling, contamination levels above 1 µg/L would regularly be encountered. Levels of 8 µg/L have already been seen in routine monitoring efforts, which, as discussed above, are unlikely to detect true maximum pesticide concentration levels. Directed studies (reviewed in the full-length version of this report) have shown much higher concentrations of neonics measured in and around treated fields.

The USEPA (2017a) has already concluded that, nationwide, imidacloprid levels are frequently above the level (0.01 µg/L) at which they believe some aquatic invertebrate species will be harmed. In fact, they conclude that several key taxonomic groups of aquatic invertebrates, not merely the most sensitive ones, are likely to be adversely affected (USEPA 2017a). They arrived at this conclusion after reviewing nationwide imidacloprid contamination values as well as modeled water concentrations. The latter approach allowed them to differentiate between different types of use for imidacloprid. USEPA (2017a) thus estimated that 60% of seed treatment applications, 90% of soil applications, and 100% of foliar applications of imidacloprid are expected to produce surface water contamination levels above the 0.01 μg/L benchmark for ecological harm. Moreover, the loss of dust from treated seeds at planting, an important route of environmental contamination (see Mineau and Callaghan for an extensive review), was not included in the estimated water contamination levels following seed-treatment use. The 60% estimate for the proportion of seed-treatment uses that produce contamination levels above the aquatic benchmark is therefore a clear underestimate.

Morrissey et al. (2015) following an exhaustive review of water measurements worldwide similarly concluded that their higher estimated injury level of 0.035 μg/L was exceeded of the neonic, not just imidacloprid.

Nowell et al. (2017) were able to show the consequences of imidacloprid detection on mayfly abundance in their monitored streams. Mayflies are known to be sensitive to neonics and are a key component of the benchmark levels established in all jurisdictions. Although a correlation is not proof of causation, their data suggests that neonics are indeed having deleterious effects on stream ecology in the Midwest. In that study, the highest recorded concentration of imidacloprid was 2.2 μg/L. Because concentrations as high as 8 μg/L have been recorded in New York streams, the presumption of ecological damage in New York is very high. Given the levels at which imidacloprid was detected in groundwater, impacts to streams and wetlands receiving groundwater recharge are also likely.

Figure 3: Relationship between mayfly (ephemeroptera) abundance and maximum imidacloprid concentrations in Midwest streams according to Nowell et al. 2017 (in ng/L or 1/1,000th of 1 μg/L)



Hallman et al. (2014) demonstrated possible broader ecological impacts of neonic contamination by showing a convincing correlation between neonic use and declining insectivorous bird populations in the Netherlands. They divided the time period of their analysis into pre-and-post-neonic periods, showing that not only did neonic concentrations explain bird declines, but these site-specific declines were not seen before the introduction of neonics, despite the use of other insecticides of high aquatic toxicity. Regional bird declines were observed starting at estimated neonic concentrations of about 0.2 μg/L.

Scientists and independent experts are now convinced of the broad impact of the whole class of neonics on ecosystems. Curiously, the USEPA (2008) in one of its early reviews of thiamethoxam predicted "structural and functional changes of both the aquatic and terrestrial ecosystems," an unprecedented assessment and prophetic warning. Others followed suit, including: Tennekes (2010b), a Dutch scientist and naturalist who predicted a "disaster in the making;" the "Task Force on Systemic Pesticides," a large group of independent scientists under the auspices of the International Union for the Conservation of Nature (IUCN) (van der Sluijs et al. 2015, Pisa et al. 2015, 2017); the European Academies Science Advisory Council (2015) made up of 29 independent scientists nominated by their respective countries; as well as several other independent scientists (Morissey et al. 2015; Sánchez-Bayo et al. 2016).

Regulatory agencies including Canada's PMRA, and the European Food Safety Authority (EFSA) agree that imidacloprid as currently allowed to be used, presents unacceptable risks to the aquatic environment. USEPA (2017a) concludes that their "risk findings … are in general agreement" with those two agencies. Clothianidin, thiamethoxam, and imidacloprid were re-evaluated recently by PMRA, which recommended a complete phase out of all outdoor uses of these three neonic on food and feed crops, including seed treatments and outdoor ornamentals, due to the evidence of serious harm to aquatic species and ecosystems (PMRA 2016b; PMRA 2018a, b). Likewise, the European Union banned outdoor uses of the same three neonics at the end of 2018—although this was largely as a result of pollinator impacts. USEPA's re-evaluation of these neonics had not concluded at the time of publishing this report.

Clearly, New York State is not unique. A broad scientific consensus from around the world suggests that the levels of neonic contamination reported in New York are indicative of clear damage to aquatic environments and terrestrial consumers, such as birds, amphibians, and mammals.

3. CONCLUSIONS

Neonic use in New York has increased dramatically in the last two decades, and neonics now frequently appear in the state's water supplies. Given the very high probability that the neonic levels found are causing significant harm to aquatic ecosystems, substantial reductions in outdoor neonic use are recommended.

Imidacloprid residues appear frequently in New York surface water testing, with nearly all detections exceeding USEPA's and our chosen 0.01 μg/L benchmark for harm to aquatic ecosystems, and many exceeding it by a 10-fold margin or more. The highest water concentrations (typically 6-8 μg/L) tend to be from sampling locations where imidacloprid has been detected over multiple years, suggesting that more frequent monitoring would uncover other significant spikes. Imidacloprid groundwater detections, while less frequent, were common on Long Island—with 2016-2017 USGS testing revealing the chemical in ~31% of samples.

Sparse sampling for the other five neonic chemicals provides limited insight into their presence in and effect on New York water, but given their significant use and high runoff potential, regular monitoring for these chemicals is recommended. While the aggregate neonic presence in water is the relevant measure of concern, imidacloprid data alone indicate a very high probability that neonics are causing ecosystem-wide damage—including depletion of aquatic invertebrate populations as well as possible harms to consumer species, such as birds, fish, and mammals.

Although detected imidacloprid levels did not exceed current USEPA drinking water standards, emerging research on neonics and their toxic breakdown products in drinking water, as well as the lack of comprehensive monitoring for the other neonics suggests that risk to the human population has been underestimated. New York should monitor water sources for the presence of all neonics (down to detection levels of 0.01 μg/L or lower), especially where surface waters are used for drinking water and on Long Island or other areas with heavy neonic use and vulnerable aquifers.

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