Investigating Impact of Use of Agrochemicals in Golf Courses on Water Turbidity and Water Quality

Gavin Nicholls, Iris Metz, Jens van der Laan, Joy van Houten, Shirsho Roy Chowdhury

Environmental Project Studies ETE25812

Environmental Project Studies ETE 25812 (2024)

Research Report

Investigating Impact of Use of Agrochemicals in Golf Courses on Water Quality

Group 4

Gavin Nicholls (1236814)
Iris Metz (1149393)
Jens van der Laan (1297694)
Joy van Houten (1272926)
Shirsho Roy Chowdhury (1185888)

3 July 2024

Environmental Technology
Wageningen University and Research
Bornse Weilanden 9
6708 WG Wageningen

Commissioner: Hugo Hoofwijk, Wageningen Science Shop

Supervisor: Hanh Tran

This report is the final result of a study carried out by 2nd year students of Environmental Sciences at Wageningen University. It was conducted in the framework of the subject Environmental Project Studies.

Summary

In the Netherlands, quality of surface water is under stresss. This study investigates to which extend (historical and present) use of agrochemicals on golf courses influences the turbidity and the water quality both on the golf courses as well as water bodies in the vicinity.

The following research questions were composed: *What agrochemicals used in golf courses in the Netherlands are likely to be found in adjacent lakes? What are the possible effects of these agrochemicals?* To answer these questions, sub-questions had to be answered first. The sub-questions were: *Which agrochemicals are most likely to have been used by golf courses in the Netherlands? What is the probability of these agrochemicals being present in adjacent lakes? What impacts are these agrochemicals known to have?* To answer these questions policy, literature, databases, and interviews were used.

With these sources, a list of 29 agrochemicals that were probably used between 2015-2024 was created. In these agrochemicals, 24 different active ingredients were found. These active ingredients were analysed based on several characteristics, selected by their relevance for risk, and was backed by the work of Roberts (1996). Their boundaries are also set from the work of Roberts (1996).

The three most important factors were found to be mobility and lifespan in both soil and water, measured in DT50. Each compound was given a rank of 1 to 4, 4 being the highest mobility or persistence and 1 being the lowest. These values are multiplied across the three categories to give a final risk value.

The risks and effects of fertilizers were investigated separately. Pesticides and fertilizers are quite different, making the two incomparable. The active

ingredients in fertilizers are nitrogen, phosphorus and potassium compounds. Both substances are mobile in soil and in water. Their lifetime is uncertain as they cycle through the environment in different forms. Irrespective of the type, nitrogen and phosphorus compounds often cause eutrophication. There are application laws to lower the amount of fertilizer in water bodies, but due to drainage and runoff, this does not always help prevent leakage.

Lastly, the possible effects of agrochemicals were researched. Ecotoxicity and human toxicity were considered. Several risks to humans were found. Certain agrochemicals are endocrine disrupters, neurotoxicants, genotoxins, carcinogens and/or pose risks to reproduction and development. The final risk value for possible effects is the highest value the agrochemical obtained in either the ecotoxicity or human toxicity field.

The results have some uncertainties. The agrochemical list is based on literature research which is not one hundred percent reliable. There is always a possibility for human error leading to not including chemicals that are allowed. Furthermore, lifetime and mobility are calculated without considering the specific local environmental conditions which are sure to play a role. Even though a good estimation is made, local conditions will eventually dictate the actual results which cannot be predicted easily. This is also an issue with fertilizers as they can easily react to form new compounds under certain environmental conditions.

Furthermore, the effects of the agrochemicals that are mentioned are general effects. The effects will also be subject to local conditions. Besides that, the effects also depend on the dosage of chemicals that are present which is outside the scope of the paper to determine.

Even if the list is accurate and these are the chemicals in the water, it does not mean that they are the cause of turbidity. Over the past years, the use of agrochemicals has gone down significantly. This would suggest that the quality of the water should have got better. On the other hand, if the tipping point of the aquatic ecosystem has already been crossed, then the case would be different.

It is not possible to say with this research if the agrochemicals are causing the turbidity. What can be said is the likelihood that any of these 24 active compounds from agrochemicals are probably in the water. The research concludes that some of them do pose a risk and may affect turbidity. For further research, it is advised to first look at the water in the golf course itself – if the quality is poor, Lake Berendonck should be tested for agrochemicals, especially the most dangerous ones.

Contents

Introduction

For this research, agrochemicals that are used for managing golf courses, and their possible effects on the environment, will be investigated. Agrochemicals refer to pesticides, biocides, insecticides, herbicides, fungicides, nematicides, synthetic fertilizers and growth regulators (Jastrzębska et al., 2022). These may affect flora and fauna which in turn cause turbidity through sediment resuspension (van Hal, M., & Lürling, M. F. L. L. W., 2004).

Using agrochemicals, especially fertilizers, may lead to increased nutrients in neighbouring water bodies. This can result in eutrophication and an increase in turbidity (van Hal, M., & Lürling, M. F. L. L. W., 2004).

The structure of the report is as follows: the report starts with investigating the policies surrounding agrochemical use on golf courses. It details the agrochemicals which are still allowed, and which are banned, and looks at how and when the regulations changed. Following this policy review, there is a comprehensive agrochemical list with all the agrochemicals that have been used in the past 10 years.

Subsequently, the report shows a ranking system on the probability of the presence of agrochemicals in the research area. This ranking system contains multiple factors that influence the likelihood of contamination. Following the ranking system, the report shows the potential effects on the research area. Finally, the report summarizes the results in a discussion, followed by a conclusion.

Introduction

For this research, agrochemicals that are used for managing golf courses, and their possible effects on the environment, will be investigated. Agrochemicals refer to pesticides, biocides, insecticides, herbicides, fungicides, nematicides, synthetic fertilizers and growth regulators (Jastrzębska et al., 2022). These may affect flora and fauna which in turn cause turbidity through sediment resuspension (van Hal, M., & Lürling, M. F. L. L. W., 2004).

Using agrochemicals, especially fertilizers, may lead to increased nutrients in neighbouring water bodies. This can result in eutrophication and an increase in turbidity (van Hal, M., & Lürling, M. F. L. L. W., 2004).

The structure of the report is as follows: the report starts with investigating the policies surrounding agrochemical use on golf courses. It details the agrochemicals which are still allowed, and which are banned, and looks at how and when the regulations changed. Following this policy review, there is a comprehensive agrochemical list with all the agrochemicals that have been used in the past 10 years.

Subsequently, the report shows a ranking system on the probability of the presence of agrochemicals in the research area. This ranking system contains multiple factors that influence the likelihood of contamination. Following the ranking system, the report shows the potential effects on the research area. Finally, the report summarizes the results in a discussion, followed by a conclusion.

Chapter 1. Methodology

The goal of the study is to have a strong understanding of what agrochemicals may be present in water bodies on and adjacent to golf courses. To achieve adequate understanding, policies surrounding the use of agrochemicals within the Netherlands and the real-life use and application of agrochemicals were considered. A variety of historical data was collected and processed. Both governmental policies and scientific papers were analysed.

The research is a descriptive study. An attempt has been made to describe what agrochemicals may be present in water bodies adjacent to golf courses. It is also important to note that within the case study, there is no theory to be tested or proved. A variety of golf courses were looked into over the last ten years, to gain a general understanding of how golf courses operate around the use of agrochemicals.

The goal was to get a comprehensive list of all the agrochemicals used over the past ten years that could influence water quality and turbidity. The characteristics of the identified agrochemicals were researched to know if they would be transported to the lake and if they would persist. To gather this data, websites from Rijksoverheid were used. These websites were chosen because they are from the national management of regulations and the implementation of agrochemicals. They also monitor adherence to regulations. Therefore, the source is credible.

Besides literature research, several expert interviews were conducted. The maintenance of the golf courses is often done by big companies which would lose their credibility and face fines if they use prohibited agrochemicals or apply them incorrectly. Thus, policies were used as the starting point in preparing the agrochemical list. Policy changes over the past decade were also looked into to identify agrochemicals that are no longer allowed but might still persist in the environment.

The effects and characteristics of agrochemicals were found with the help of scientific databases. To compare the active ingredients of agrochemicals, a ranking system based on the categories of Roberts (1996) was used. A novel ranking system was not created owing to a limited understanding of how to identify and rank the most important factors affecting mobility and persistence in the environment. The information was sourced from the Pesticide Properties Database of the University of Hertfordshire, an academic database that has compiled information on most pesticides and other agrochemicals used in Europe. All the data is from academic peer-reviewed sources. Within the site, each piece of information has the academic validity of the data placed in the neighbouring column. The ranking system works with a letter and number system, with the letter indicating the type of source and the number validity of the data (University of Hertfordshire, 2024).

Chapter 2. Agrochemical Use on Dutch Golf Courses

Not all golf courses are transparent about their agrochemical use, which makes it difficult to create an accurate list. To make a most likely agrochemical-use list, maintenance practices must be discussed first. After that the regulations will be explained and then eventually a list will be compiled.

Golf Course Maintenance

The Netherlands has around 250 golf courses (Koninklijke Nederlandse Golf Federatie, 2024). These golf courses must be maintained. This can be done by a greenkeeping company or by people from inside the golf company. *Hollandsche Greenkeeping Maatschappij* is an example of a greenkeeping company. This company does the greenkeeping on many golf courses (Hollandsche Greenkeeping Maatschappij, 2024).

Golf courses require a high-quality golf course year-round. A golf course is used intensely, which can cause a lot of damage to the course. This results in the need for intensive maintenance. There are several requirements a golf course must meet, for instance, the quality of the course should be the same every season. Furthermore, the surface of the greens should be reliable, and the ball should be easy to find in the rough. Besides that, the aesthetic of the golf course is also important.

The maintenance of the grass depends on the purpose of the grass. A golf course has different areas: the tee, the fairway, the green, the rough, the foregreen, and the driving range. These areas have different functions and thus need to be maintained differently. To make the maintenance easier specific types of grass are used for the various areas. For instance, the green must be very short, sickness-resistant, and able to recover quickly. So, for the green, the grass species *Red Fescue* and *Creeping Bentgrass* are used (Willem de Haes, n.d.).

Using specific grass species helps lower the damage rate but it still happens and thus maintenance is needed. The golf course maintenance has various aspects: physical maintenance, water and nutrient supply, and agrochemical use. Examples of physical maintenance are cutting the grass, aerating the grass, and adding sand slats to increase drainage. The grass is cut at different heights depending on the area for instance, greens are cut very short. The golfers walk on the grass, which compresses the grass. This reduces the air flow, while grass needs a good airflow to grow. Greenkeepers increase the airflow again by aerating the soil with machines. Lastly, the grass needs to be well drained. To increase the drainage slats are created and then filled with sand (Flevo green support, n.d.).

The grass needs to grow fast to keep up with the damage. To grow fast the grass needs the right amount of water, air, nutrients, and protection against pests. Drainage is done as mentioned by sand slits and sometimes drainage pipes are added. However, too little water can also cause problems. When the grass becomes too dry it is irrigated. Grass also needs nutrients to grow, the greenkeepers add fertilizers to provide extra nutrients. With fertilizers, they add nitrogen, phosphate, and potassium. Generally, they use 100 kg nitrogen and potassium per and 30 kg phosphate per hectare. The greens are fertilized 6 times a year and the rough is fertilized twice a year (Ernst Bos, 2019).

Even when provided with the necessary growing conditions the grass growth can be hindered by pests, rodents, fungi etc. Greenkeepers use different types of pesticides to keep the quality of the grass high. Pesticides are agrochemicals that kill, regulate pests, or sometimes regulate the plant itself. A variety of agrochemicals fall under the term pesticides. Some of the most well-known are herbicides, fungicides, insecticides, and rodenticides. These chemicals all kill a certain type of organism (Jastrzębska et al., 2022). Besides chemicals that protect the plant, there are also agrochemicals like growth hormones which can stimulate or inhibit plant growth. Pesticides have one or more active components. There are a variety of agrochemicals on the market, with different dosages or active components that tackle the same issue. So, for every problem different kind of pesticides can be used (RIVM, n.d.).

Regulations on Agrochemical Use on Golf courses

Golf courses use several types of agrochemicals to maintain their course. Before a certain chemical can be used legally, it must be deemed safe. Agrochemicals are first researched by the European Authority for Food Safety (EFSA). After that, the agrochemical is researched again by a national authority. In the Netherlands, this is done by the board for the authorization of plant protection products and biocides (Ctgb). The Ctgb evaluates the effect of the chemical on humans, animals, and nature. After the evaluation, the Ctgb decides if a product may be used and sold or not. Besides that, they also decide which dosage may be used and how/when the chemical should be applied (Ctgb, n.d.-a).

The Ministry of Agriculture, Nature, and Food safety makes laws about agrochemical use: they decide who can use them and how often. So, sometimes even if a chemical is allowed by the Ctgb, the Dutch government can decide that the chemicals may not be used (Ctgb, n.d.-b). Lastly, the Dutch Food and Product Authority (NVWA) monitors companies to ensure they follow the agrochemical use laws. The NVWA randomly inspects companies like golf courses and if they find violations several things can happen. Depending on the severity of the case, a warning can be given, a fine or a trial in court can be started (NVWA, n.d.).

This is how agrochemicals are regulated now, but this procedure was not always the case. Before 1962 agrochemicals were not tested by or regulated by the government. Eventually, the government became worried about faulty agrochemicals being sold on the market. In 1947 the law: of Pesticides and Fertilizers came about (PLANTENZIEKTEN KUNDIGE DIENST TE WAGENINGEN, 1948). In 1975 the law was expanded, and from then on it became mandatory that agrochemicals were tested for their effect on humans and the environment. After this law there were still problems, the government wanted less agrochemical use and more skilled users. This resulted in a new law in 1994, the Law of Knowledge and Competence Requirements for pesticides (Wettenbank, n.d.-a). Eventually, more and more things were added to this law, which made it unclear. So, in 2007 the law was replaced by the law "Pesticides and Biocides"(Wettenbank, n.d.-b).

The new law made the regulation clearer and stricter, but the government eventually wanted less pesticide use. In 2011 the Green Deal started, this initiative was to help companies, organizations or other governmental bodies become more sustainable (Rijksoverheid, n.d.). In 2015 the green deal for sports fields was made and signed by big parties in the golf sector. This Green Deal had 3 main points. Pesticide use should no longer be used in 2020. Other solutions instead of pesticides should be found, like integrated pest management. Lastly, if pesticides are used, they should be low risk (Linde Kruese & Hein van Iersel, 2019). Shortly after this, in 2017 the government made a law that pesticide use is no longer permitted outside agricultural sites. However, sports fields were still excluded (staatscourant, 2016;Corine Komen et al., 2020). In 2020 the law was changed; golf courses and other sports fields were included. The law now states that they could use some pesticides but only if they first used integrated pest management and it should be the last possible solution. But they could not just use whatever was allowed by the Ctgb. The government has made a detailed scheme that dictates which pests can be treated and where and how much pesticide may be used (*Table 2.1*). This scheme was changed slightly in 2024. So, as can be seen in the scheme and from the new law, golf courses can now only use very small amounts of agrochemicals. Besides that, the goal is to eventually use 0 agrochemicals on golf courses (Staatscourant, 2024).

Table 2.1: Government scheme depicting allowed pesticide use in different parts of a golf course (Staatscourant, 2024).

Scientific Name of Organism	**Green**	**Fringe, Collar**	**Forgreen, Apron**	**Tees**	**Fairways**	**Maintain-ed Rough**	**Golf Rough**
Plantago spp.	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Veronica filiformis	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Veronica arvensis	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no

Taraxacum officinalis	no	max 20% per year subject to damage threshold	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Bellis perennis	no	max 20% per year subject to damage threshold	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Trifolium repens	no	max 20% per year subject to damage threshold	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Polygorum aviculare	no	max 20% per year subject to damage threshold	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Hypochaeris radicata	no	max 20% per year	max 20% per year subject to	max 20% per year	max 20% per year	max 20% per year subject to	no

		subject to damage thresh-old	damage threshold	subject to damage thresh-old	subject to damage thresh-old	damage threshold	
Ranunculus repens	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Achillea millefolium	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Cerastium fontanum	no	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	max 20% per year subject to damage thresh-old	max 20% per year subject to damage thresh-old	max 20% per year subject to damage threshold	no
Cirsium arvense	no	no	no	no	no	no	spot-wise
Jacobaea vulgaris *subsp. Vulgaris*	no	no	no	no	no	no	spot-wise
Rumex obtusifolius	no	no	no	no	no	no	spot-wise

Sagina procumbens	10%	no	no	no	no	no	no
Growth regulator	no	no	no	no	no	no	no
Melolontha melolontha	yes	yes	yes	yes	yes	yes	no
Amphimallon solstitialis	yes	yes	yes	yes	yes	yes	no
Tipula spp	yes	yes	no	no	no	no	no
Clarireedia spp. (vml. Sclerotinia homoeocarpa)	2x a year subject to damage thresh-old	2x a year subject to damage thresh-old	no	no	no	no	no
Microdochium nivale, Fusarium nivale	1x a year subject to damage thresh-old	1x a year subject to damage thresh-old	no	no	no	no	no

Agrochemical Use on Golf Courses in the Netherlands in the Past 10 Years

In *Table 2.2*, a list of probable agrochemicals can be found. This list consists of agrochemicals that have probably been used in the last 10 years on golf courses in the Netherlands. Their market name, active ingredients, agrochemical type and dosage are mentioned.

Table 2.2: List of Agrochemicals used in Dutch golf courses over the past 10 years (Corine Komen et al., 2020; Vos Capelle, 2024).

Agrochemical Name	**Active Ingredient(s)**	**Agrochemical Type**	**Dosage**
Aamix	2,4-D	Herbicide	6 litre per ha, once a year.
Acelepryn	Chlorantraniliprole	Insecticide	0,6 litre per ha, once a year.
Basagran	Bentazone	Herbicide	1,5-3 litre per ha, once a year
Caramba	Metconazole	Fungicide	1,5 litre per ha, once a year.
Chipco Green	Iprodione	Fungicide	20 litre per ha, with intervals of 4

			weeks.
Delfin	*Bacillus thuringiensis* Subsp. *aizawai* strain GC-91	Insecticide	0,75 kg per ha, 6 times a year
Dicophar SL	Dicamba, Mecoprop-P	Herbicide	7,5 litre per ha, once a year
Exteris Stressgard	Fluopyram, Trifloxystrobin	Fungicide	10 litre per ha, twice a year
Fox 480 SC	Bifenox	Herbicide	1,5 litre per ha, once a year not in September-may.
Frupica SC	Mepanipyrim	Fungicide	0,9 litre per ha, twice a year.
Harmonix Turf Defense	fosetyl-aluminium	Fungicide	25 litre per ha, 10 times a year.
Heritage	azoxystrobin	Fungicide	0,5 kg per year, twice a year.
Interface	Iprodione	Fungicide	1 litre per ha, 4 times a year.
Merit Turf	Imidacloprid	Insecticide	30 kg per ha, once a year
Primstar	Saccharin	Herbicide	1,9 litre per ha, once a year.
Primo maxx	Trinexapac-ethyl	Growth Regulator	0,4 litre per ha, 8 times a year
Primus	Florasulam	Herbicide	99 mL per ha, once a year
Roundup evolution	Isopropylamine salt of glyphosate	Herbicide	2,4-5 litre per ha, once a year
Signature Xtra Stressgard	Fosetyl-aluminium	Fungicide	0,5 kg per ha, 3 times a year
Signum	Boscalid, Pyraclostrobin	Fungicide	1,5 kg per ha, twice a year
Sirena	Metconazole	Fungicide	1,5 litre per ha, once a year
Starane Top	Fluroxypyr-MHE	Herbicide	0,6 litre per ha, cannot be used September-march
Sumicidin Super	Esfenvalerate	Insecticide	0,3 litre per ha, once a year
Tapir	Clopyralid, Florasulam, Fluroxypyr-meptyl	Herbicide	1, 5 litre per ha, once a year
Touchdown quattro	Glyphosate	Herbicide	6 litre per ha, once a year
Turex WG	*Bacillus thuringiensis* Subsp. *aizawai* strain GC-91	Insecticide	1 kg per ha, 3 times a year
Xentari	*Bacillus*	Insecticide	1 kg per ha, 8 times a year

	thuringiensis Subsp. *aizawai* strain GC-91		
Fertilizers	Nitrogen, phosphate, potassium	Artificial fertilizer	No maximum

Chapter 3. Likelihood of Agrochemicals to be Found in Water Bodies

To estimate the probability of what agrochemicals are present in the target area it must be understood how they can arrive there and how long they can persist. Therefore, the information on what routes they may take into the water bodies and their lifespans in soil and water was complied. From there the information was used to calculate a simple value used to represent the risk of a certain agrochemical being found in water bodies (both on the golf course as well as neighbouring water bodies). The categories and rankings used to calculate the agrochemical risk, are based on the paper Assessing the Environmental Fate of Agrochemicals (Roberts, 1996).

This information is summarized and used to calculate the likelihood that each agrochemical is found in the environment (*Table 3.1)*. The information for "Mobility" and time to degrade to 50% "DT 50" times in both field and water is sourced from The University of Hertfordshire Pesticide Properties Database (Lewis et al., 2016).

Explanation of Ranking System

The system to indicate what agrochemicals are most likely to influence water quality uses a points-based system with 3 categories – mobility, DT50 in soil and DT50 in water. Within each category, a compound can be awarded a value from 1 to 4 with 4 representing the highest likelihood of being found in the environment and 1 the lowest. Then each score in the three categories is multiplied across, generating the final value and rank. Therefore, the values range from a minimum of 1, with a compound being minimal risk in every category to a maximum of 64, a compound that is the highest risk in each category.

Table 3.1: Mobility and persistence of active ingredients of pesticides.

S. No.	**Common Name of Active Ingredient**	**Mobility Value**	**DT 50 (Field) Value**	**Water Photolysis DT50 Value**	**Final Risk Value**
1	2,4-D	3	3	3	27
2	Azoxystrobin	3	4	2	24
3	*Bacillus thuringiensis* Subsp *aizawai* strain GC-91	2	4	4	32
4	Bentazone	3	2	1	6
5	Bifenox	2	2	1	4
6	Boscalid	3	4	4	48
7	Chlorantranili-prole	3	4	1	12
8	Clopyralid	4	2	4	32
9	Dicamba	4	1	3	12
10	Esfenvalerate	2	2	1	4
11	Florasulam	3	2	4	24
12	Fluopyram	3	4	2	24
13	Fluroxypyr-meptyl	2	1	4	8
14	Fosetyl-aluminium	4	1	3	12
15	Glyphosate	2	2	3	12
16	Imidacloprid	3	4	1	12
17	Iprodione	2	2	4	16

18	Isopropyl-amine salt of glyphosate	2	2	1	4
19	Mecoprop-P	3	2	2	12
20	Mepanipyrim	2	4	2	16
21	Metconazole	3	4	4	48
22	Pyraclostrobin	2	3	1	6
23	Trifloxystrobin	2	1	1	2
24	Trinexapac-ethyl	2	2	4	16

Explanation of Category Choice

When deciding what categories to consider when making the ranking system, it was important to consider the scope, accuracy, and availability of data. It was decided that the greatest accuracy would be achieved if the research was focused on a limited number of factors. To calculate risk, the three categories, mobility and DT50 in both soil and water are used. It was decided to only consider the most relevant factors, to ensure the ranking system is easily interpretable and as accurate as possible within the limits of the paper.

Mobility

Mobility encompasses the relevant information that describes how a compound is transported from the location of application to a different location in the environment (Steinheimer et al., 2000). Within the categorizing of the active chemicals the table in the appendix two mobility options are used to describe the possible paths the compound may take and how mobile it is. The paths are broken down into surface flow and leaching.

Surface flow is the sum of all water runoff that occurs when rainfall exceeds soil infiltration capacity. Surface flow can proceed to collect both soluble in solution and suspend insoluble agrochemicals that are transported into the neighbouring water bodies (Steinheimer et al., 2000).

Leaching comprises the vertical component of agrochemical movement. Agrochemicals are washed down into the groundwater and can be transported by groundwater flow. This may result in contamination of surrounding water bodies and groundwater (Steinheimer et al., 2000).

Ranking

Each agrochemical has a rank from either low mobility (1), moderate mobility (2), mobile (3) or very mobile (4). These categories using the 1-4 system are used to convey the mobility and therefore, are a part of the likelihood that a substance could make its way to local water bodies. It was chosen not to include any non-mobile substances as they are unable to be transported into water bodies.

Lifespan in Soil

Looking at the lifespan of agrochemicals in soil when investigating agrochemicals in water bodies seems counterintuitive as the paper is focused on the probability of finding agrochemicals in water bodies and not soils. However, it is a crucial factor in understanding how likely an agrochemical is to be found in water bodies (Steinheimer et al., 2000). For agrochemicals to be found in significant amounts in water bodies, the agrochemicals must be persistent enough in soil while they undergo transport. To compare soil lifespan the number of days it takes the compounds to decay to 50% of their original value (DT 50) in soil is being used.

The lifespans (in days) that were described in Roberts (1996) are used to rank agrochemical persistence (*Table 3.2*).

Table 3.2: Category boundaries (Roberts, 1996).

Persistence	DT 50 (days)
Non-persistent	<5
Slightly persistent	5-21
Moderately persistent	22-60
Persistent	>60

Lifespan in Water

Understanding how persistent agrochemicals are in water is vital in understanding how potentially impactful those agrochemicals are in aquatic ecosystems. The longer the compounds are present in the water body, the greater their potential impact is. Therefore, two key factors have been complied to compare risk – the compounds' susceptibility to photolysis and to hydrolysis in water bodies (Steinheimer et al., 2000).

The same approach was taken as with soil using the DT 50 factor, specifically for photolysis of agrochemicals, to rank its longevity. Photolysis is the process in which a compound is broken down into smaller constituents by light (Díez et al., 2019). This means the DT50 for photolysis is how rapidly the compounds break down when exposed to light.

There is an important factor that may be relevant to the research – when dealing with water bodies, the more the depth, the lower the light level (Nababan et al., 2021). This of course is more pronounced in more turbid waters. This will decrease the rate of compound breakdown to a point where there is no light left and therefore, degradation will no longer occur (Nababan et al., 2021).

This may lead to an interesting result, with agrochemicals that are more prevalent in deeper and darker areas possibly prevailing for a longer time. This would be due to a lack of light for photolysis. However, this would also be heavily impacted by currents that may resuspend agrochemicals and take them closer to the surface and result in their degradation. Therefore, this factor is not able to be quantified although it is important to understand they will have an impact.

Results and Recommendations

The 24 different active compounds have been compiled from their agrochemicals. The results of the ranking system for the most mobile and persistent agrochemical are presented in *Table 3.3*. The results vary from 48 to 2, showing a wide range of possible risks that each compound may pose. Due to this ranking system being based on comparing risk between compounds and not to a set standard level, it is difficult to set give a recommendation of acceptable risk level. However, chemicals with a risk ranking over the 16.84 average have the greatest likelihood of being present in neighbouring still water bodies and therefore are recommended to be tested for. The recommendation is also given to de-priorities any agrochemical with a risk rating below 6, this is due to such a compound having a ranking of 1 in at least 1 category, making it their immobile or non-persistent. The chemicals that are recommended for testing are given more discussion in the conclusion, to also consider the compounds potential impacts.

Table 3.3: Active ingredients most likely to be found in water bodies on and adjecent to golf courses

Risk	**Chemicals**
48	Boscalid, Metconazole
32	*Bacillus thuringiensis* Subsp *aizawai* strain GC-91, Clopyralid
27	2,4-D
24	Azoxystrobin, Florasulam, Fluopyram
16	Iprodione, Mepanipyrim, Trinexapac-ethyl

12	Chlorantraniliprole, Dicamba, Fosetyl-aluminium, Glyphosate, Imidacloprid, Mecoprop-P
8	Fluroxypyr-MHE
6	Bentazone, Pyraclostrobin
4	Bifenox, Esfenvalerate
2	Isopropylamine salt of glyphosate, Trifloxystrobin

The average risks are presented below in *Table 3.4*.

Table 3.4: Average risks.

Mean Average	Median Average	Mode Average
16.84	12	12

Chemical to Note

It is interesting to know *B. thuringiensis*, which had a score of 32, is not a chemical pesticide, but a biological one. Biological pesticides are defined as pesticides that are derived from naturally occurring sources such as plants, animals, bacteria and so on (Marrone, 2007). *B. thuringiensis* produces proteins that are toxic to a variety of pests (Sansinenea, 2012). It was difficult to place within the system as it is a living organism and consequently does not have a DT50 time. This is because when it is applied as a pesticide, it is a mix of protein crystals and spores that can mature into bacteria (Osman et al., 2015). The living aspect leads to no finite DT50. Therefore, it was decided to assume that a value of 4 in the DT50 categories was appropriate. This is an assumption and should be taken into consideration.

Limitations with Available Information

The required information was obtained for most chemical compounds except for one chemical, isopropyl-amine salt of glyphosate (serial number 18). It was not possible to obtain the DT50 time for photolysis. it was decided not to remove the chemical from the list despite limited information, this is due to the possible risk they may hold. It received a value of 1 for DT50 in water via photolysis which was decided to be appropriate.

Fertilizers

As explained earlier, fertilizers often have nitrogen, phosphate and potassium as their active ingredients. These compounds are vital to ecosystem health and growth. However, fertilizers are often used in abundance and that can result in negative side effects (Vitousek et al., 2002; Hasanuzzaman et al., 2018).

The mobility of nitrates and phosphates is dependent on the form they are in. Overall, these substances are soluble in water. This solubility results in high mobility especially when the soil is wet. This also makes these substances susceptible to leaching or surface flow when there is a lot of rainfall. Potassium also has a relatively high mobility (Roger H. Bray, 1963; Gächter et al., 2004).

Both nitrogen and phosphorous undergo chemical reactions naturally within the environment (Gächter et al., 2004; Pierrou, 1976). Within this cycle they are converted to various compounds used for plant and animal growth. Due to this cycle, defining a "lifespan" for these compounds is difficult. These elements can go through multiple cycles between a variety of compounds. Nitrogen and phosphate can leave the water in gas form but, a notable portion stays in the water. Potassium is not very susceptible to transformations, and this increases the life span. Therefore, these three groups of agrochemicals are likely to be present in still water bodies neighbouring golf courses.

Chapter 4. Effects of Agrochemicals

It is not enough to characterise the mobility of agrochemicals – their effect on human health and the environment also needs to be understood.

Fertilizers

It is very difficult to categorise and rank the potential risk that nitrates, potassium and phosphates pose using the same system that will be used for the other agrochemicals being evaluated. However, they cannot be ignored when it comes to their possible impacts on turbidity. Eutrophic water bodies have reduced visibility due to the abundance of algae and other rapidly growing flora and fauna (Sheferaw Ayele & Atlabachew, 2021). It could be that these substances are contributing to the turbidity. The advice would be to research the concentrations of these substances.

Pesticides

Unfortunately, no clear correlation could be found between the presence of pesticides in water bodies and turbidity. However, this is not to say that the other pesticides are harmless. *Table 4.1* lists the eco and human toxicity details of the agrochemicals discussed in the previous chapter. Once again, the data is primarily based on the Pesticide Properties Database (Lewis et al., 2016).

The terms used are defined below:

- Acute toxicity: Ability of a substance to cause adverse effects within a short period after dosing or exposure.
- Carcinogen: A substance capable of causing or inducing cancer.
- Chronic toxicity: Capacity of a chemical to cause harm following chronic exposure – that is, persistent exposure over an extended period – or to produce effects that are persistent.

- Genotoxicity: Ability of a chemical to cause damage to the structure or function of genetic material.
- Neurotoxin: A chemical that can destroy or damage nerve tissue.
- Reproductive effects: Changes which may occur during the reproductive process such as mutagenesis, diminished fertility and growth retardation, including damage to or early death to offspring.

Table 4.1: Agrochemical toxicity.

S. No.	**Chemical**	**Ecotoxicity**	**Human Toxicity**	**Overall Toxicity**
1	2,4-D	Moderate risk	High risk: Endocrine disrupter, Neurotoxicant	High risk
2	Azoxystrobin	-	Moderate risk: Genotoxic, Reproductive/ Development risk	Moderate risk
3	*Bacillus thuringiensis* Subsp aizawai strain GC-91	Moderate risk: Aquatic systems	-	Moderate risk
4	Bentazone	Moderate chronic and acute toxicity in mammals	-	Moderate risk
5	Bifenox	High risk, Moderate mammal chronic toxicity	Moderate risk	High risk
6	Boscalid	Moderate risk	Moderate risk: Reproduction/ Development effects	Moderate risk
7	Chlorantraniliprole	High risk: Daphnia acute and chronic toxicity	-	High risk

8	Clopyralid	Moderate risk	Moderate risk: Reproduction/ Development effects	Moderate risk
9	Dicamba	Moderate risk, Moderate mammal acute toxicity	-	Moderate risk
10	Esfenvalerate	High risk	High risk: Reproduction/ Development effects	High risk
11	Florasulam	Moderate risk	Low risk	Moderate risk
12	Fluopyram	High risk, Moderate mammal chronic toxicity: Reproduction/ Development effects, neurotoxicant	Moderate risk	High risk
13	Fluroxypyr-meptyl	Moderate risk	Moderate risk: Reproduction/ Development effects	Moderate risk
14	Fosetyl-aluminium	Moderate risk	Moderate risk	Moderate risk
15	Glyphosate	-	High risk: Genotoxin	High risk
16	Imidacloprid	High risk	High risk: Reproduction/ development effects	High risk
17	Iprodione	Moderate risk	High risk: Endocrine disrupter, Reproduction/ Development effects	High risk
18	Isopropylamine salt of glyphosate	Moderate chronic risk	Moderate risk: Endocrine disrupter	Moderate risk

19	Mecoprop-P	High risk	High risk	High risk
20	Mepanipyrim	Moderate risk	Moderate risk: Possible carcinogen, Endocrine disrupter, Reproduction/ Development effects	Moderate risk
21	Metconazole	High risk: Birds	Moderate risk	High risk
22	Pyraclostrobin	High risk	High risk: Reproduction/ Development effects	High risk
23	Trifloxystrobin	High risk	High risk: Reproduction/ Development effects	High risk
24	Trinexapac-ethyl	Moderate risk	Low risk	Moderate risk

Based on these values, an overall toxicity score can be assigned. The toxicity score corresponds with the highest risk value. Thus, if an agrochemical has a high ecotoxicity and a low human toxicity, the overall toxicity risk is high. The implicit assumption here is that risk to the environment is considered at the same level as risk to humans, with neither given priority over the others.

Based on this, certain chemicals have been identified as posing a great threat to aquatic life and those who use the water where these chemicals are found. Even if their chance of being present in the lake is low, it is still urged that they be searched for, owing to their high toxicity value.

This list of agrochemicals is as follows:

1. 2,4-D.
2. Bifenox.
3. Chlorantraniliprole.

4. Esfenvalerate.
5. Fluopyram.
6. Glyphosate.
7. Imidacloprid.
8. Iprodione.
9. Mecoprop-P.
10. Metconazole.
11. Pyraclostrobin.
12. Trifloxystrobin.

Discussion

The result of this research is a list of 24 active pesticide ingredients, phosphate and nitrogen. The problem however is that this is done by literature research, which makes the list not fully credible. One of the issues is that not much research is done on agrochemical use on golf courses. Besides that, people are often not fully transparent on what they use. Though unlikely, some golf courses might use illegal pesticides. Lastly, the list is based partly on policy but, it could be that some of the allowed agrochemicals are not used often. This means that there are some uncertainties about the comprehensiveness of the list.

The agrochemicals on this list were analysed to find out the likelihood of their presence in the water body. The lifetime and mobility in the water and soil were researched. These factors were then quantified and ranked. To calculate their score a scientific ranking system was used. However, lifetime is a general characteristic. The lifetime can be quite different under certain conditions. In this situation, the chemicals are in water which can change the reactions and the reaction rate of the agrochemicals. As explained before, the water is also quite turbid which lowers the photolysis and thus increases the lifetime. It is difficult to estimate a precise lifetime due to various conditions.

This is also the case with determining mobility, a standardized value but also depends on the environment. A different type of soil, weather or fauna could change the mobility. So, a good ranking system is used, but it still cannot predict the real-life situation with a hundred percent certainty.

A simplified approach to calculating the risk agrochemicals pose had to be taken. Three categories which academic literature placed the greatest emphasis on were used. This has invariably lost some of the important factors for the risk. This issue is continued with the ranking system, though it was most appliable to our level of expertise. There is also no clear cut-off point of acceptable risk within the ranking system. The data can be presented to the commissioner. After which the Wageningen science shop can decide what they want to test for.

For the research, only the chemicals that might be in lakes due to agrochemical use on the golf course were researched. The reactions and resulting impacts of the chemicals mixing are not easy to quantify, even though they may have an important impact. Broken-down or combined compounds could be even more toxic to the environment. It is important to further investigate this process. The possible effects of transformation products are often overlooked in favour of analysing the effects of parent chemical compound products in ecological and health risk assessments for pesticides (Beyond Pesticides, 2021).

Agrochemicals can have a direct effect on water quality. However, there are also indirect factors which might influence turbidity. Think of this as a domino effect. With fertilizers, there is an impact on plants and especially on algae growth. With more nutrients available to grow it may increase the density of the algae. This has various effects, such as decreased incoming sunlight or decreased oxygen dissolved in the water after an algae bloom. Decreased light makes it harder for the predator fish to hunt for food. They might die, leading to an increase in smaller fish population. The smaller bottom fish can now resuspend the sand on the bottom which leads to an increase in turbidity (Ecoshape, 2020). It can also be that the ecosystem has reached its tipping point which means that the ecosystem has gotten to a state that it requires major change to revert. If this is the case, then it would mean that the water will never be as clean as before, without undergoing major work. With smaller inputs they might increase the visibility a bit however, they will have limited impacts.

Conclusion

Currently, there are very strict policies pertaining to the use of agrochemicals by golf courses in the Netherlands. According to the Green Deal, signed by major stakeholders in the golf sector in 2015, the use of pesticides should have been nearly eliminated by 2020. Instead, other solutions, like integrated pest management, were to be practiced. Laws passed in 2020 and 2024 further restrict the use of agrochemicals in sports fields. Thus, the current use of agrochemicals in golf courses is very little.

This is not to say agrochemicals have not been used in the past. Due to the persistence of agrochemicals in the environment, even those banned a few years ago may be found in neighbouring still water bodies. The list of agrochemicals, both in use and banned, includes Chipco Green, Delfin, Harmonix Turf Defense, Primo Maxx, Xentari and so on.

It should be noted that different agrochemicals have different dosage guidelines in the amount that can be added per hectare and the frequency at which the agrochemical can be added. Both these factors influence the concentration of the agrochemical in the environment, which in turn affects the likelihood of the agrochemical to be found in neighbouring water bodies.

Furthermore, it is unlikely that all the listed agrochemicals have been used by a single golf course. The probability of finding an agrochemical increases with an increase in the sampling size of the number of lakes.

The likelihood of agrochemicals being present in neighbouring lakes can be better estimated by studying their persistence. In the case of pesticides, mobility, DT50 in the field and DT50 in the water were considered. Based on these three factors, a final risk value (theoretically going from 1 to 64, with the higher the number the greater the likelihood of the pesticide being found in the water) was assigned. The mean average value is 16.84 while the median and mode average values are 12.

Pesticides that scored above the mean average are (in decreasing order of their score): boscalid, metconazole, clopyralid, 2,4-dichlorophenoxyacetic acid, azoxystrobin, florasulam and fluopyram. It is highly recommended that lakes neighbouring golf courses be tested for these pesticides.

On the other hand, any pesticide that scored a 6 or below in their final risk value must have scored a 1 (non-persistent or non-mobile) in any of the three factors. This makes it unlikely for the pesticide to be present in neighbouring still waters, but not impossible. Pesticides which fall under this group are: bentazone, bifenox, esfenvalerate, pyraclostrobin, trifloxystrobin and isopropylamine salt of glyphosate.

Of unique importance is *B. thuringiensis* Subsp *aizawai* strain GC-91, as it is a biological pesticide. It is a bacterium that produces the BT toxin. Consequently, it cannot be assigned DT50 values like the other pesticides. To be on the safer side, it was assumed that this biological pesticide is persistent in both soil and water.

In addition to pesticides, fertilizers are also used in golf courses. Thus, it is highly likely that nitrogen and phosphorus compounds will be present in neighbouring bodies of water, especially because nitrates and phosphates are soluble in water and mobile in soul and water. These can cause eutrophic conditions. Due to the abundance of algae and other rapidly growing flora, fertilizers may also be responsible for increasing the turbidity of still water bodies.

While no direct link between pesticides and turbidity was found, pesticides nonetheless have a harmful effect on the environment and on human health. The effect on human health includes disrupting the endocrine system and posing risks to reproduction and development. Certain pesticides are carcinogens, genotoxins and/or neurotoxins.

Based on ecotoxicity and human toxicity, the following pesticides have been identified as high-risk chemicals: 2,4-dichlorophenoxyacetic acid, bifenox, chlorantraniliprole, esfenvalerate, fluopyram, glyphosate, imadicloprid, ipropdione, mecoprop-P, metconazole, pyraclostrobin and trifloxystrobin.

In conclusion, it is recommended that the water of lakes neighbouring golf courses be tested for the following agrochemicals (mentioned in brackets is whether they have a high persistence and/or toxicity):

1. 2,4-dichlorophenoxyacetic acid (persistence, toxicity).
2. Azoxystrobin (persistence).
3. Bifenox (toxicity).
4. Boscalid (persistence).
5. Chlorantraniliprole (toxicity).
6. Clopyralid (persistence).
7. Esfenvalerate (toxicity).
8. Fluopyram (persistence, toxicity).
9. Florasulam (persistence).
10. Glyphosate (toxicity).
11. Imadicloprid (toxicity).
12. Ipropidione (toxicity).
13. Mecoprop-P (toxicity).
14. Metconazole (persistence, toxicity).
15. Pyraclostrobin (toxicity).
16. Trifloxystrobin (toxicity).

Authorship Statement

Gavin Nicholls: Data curation (Chapter 3 and Appendix), Original draft preparation (Chapters 1 3), Reviewing and Editing. **Iris Metz:** Data curation (Chapter 1, Methodology), Original draft preparation (Chapter 1, Discussion), Reviewing and Editing. **Jens van der Laan:** Data curation (Chapter 1), Original draft preparation (Introduction), Reviewing and Editing. **Joy van Houten:** Data curation (Chapter 2), Original draft preparation (Chapter 2 and Summary), Reviewing and Editing. **Shirsho Roy Chowdhury:** Data curation (Chapters 3, 4 and Appendix), Original draft preparation (Chapter 4, Conclusion and Appendix), Reviewing and Editing.

References

Corine Komen, Joke Wezenbeek, & Connie Posthuma. (2020). *Green Deal Gewasbeschermingsmiddelen Sportvelden*. https://www.rivm.nl/sites/default/files/2020-09/Memo%20Monitoring%20GD%20Sport_RIVM_1.0.pdf

ctgb. (n.d.-a). *Geschiedenis in het kort*. Ctgb. Retrieved June 27, 2024, from https://www.ctgb.nl/over-ctgb/organisatie/geschiedenis-in-het-kort#:~:text=In%201962%20neemt%20de%20Tweede,gewasbeschermingsmiddelen%20en%20biociden%20(Ctgb).

ctgb. (n.d.-b). *Toelating en gebruik*. Ctgb. Retrieved June 27, 2024, from https://www.ctgb.nl/toelating-en-gebruik#:~:text=Gewasbeschermingsmiddelen%20en%20biociden%20zijn%20toegelaten,Leefomgeving%20en%20Transport%20op%20controleren.

Ernst Bos. (2019, September). *Factsheet Duurzaam golfbaan beheer Bemesting*. Koninklijke Nederlandse Golf Federatie.

Flevo green support. (n.d.). *Goed onderhoud is essentieel*. Flevo Green Support. Retrieved June 26, 2024, from https://flevogreensupport.nl/onderhoud-golfbanen/

Holandsche Greenkeeping Maatschappij. (2024). *Welkom bij HGM*. Holandsche Greenkeeping Maatschappij. Holandsche Greenkeeping Maatschappij

Jastrzębska, M., Kostrzewska, M., & Saeid, A. (2022). Conventional agrochemicals: Pros and cons. In *Smart Agrochemicals for Sustainable Agriculture* (pp. 1–28). Elsevier. https://doi.org/10.1016/B978-0-12-817036-6.00009-1

Koninklijke Nederlandse Golf Federatie. (2024). *Contact met de NGF voor pers en media en feiten en cijfers over golf in Nederland*. Koningklijke Nederlandse Golf Federatie. https://www.ngf.nl/over-de-ngf/pers

Linde Kruese, & Hein van Iersel. (2019, January). *Green Deal 2020: nadert de nullijn?* Greenkeeper.Nl. https://www.greenkeeper.nl/upload/artikelen/gk119greendeal2020.pdf

NVWA. (n.d.). *Hoe werkt een inspectie van de NVWA?* NVWA. Retrieved June 27, 2024, from https://www.nvwa.nl/ondernemers/toezicht-maatregelen-en-boetes/hoe-werkt-een-inspectie-van-de-nvwa#:~:text=Onze%20inspecteurs

%20kijken%20of%20u,de%20dierenwelzijns%2D%20en %20diergezondheidsregels%20houden.

PLANTENZIEKTEN KUNDIGE DIENST TE WAGENINGEN. (1948). *De bestrijdingsmiddelenwetgeving*. https://edepot.wur.nl/419876

Rijksoverheid. (n.d.). *Green Deal aanpak*. Rijksoverheid. Retrieved June 27, 2024, from https://www.rijksoverheid.nl/onderwerpen/duurzame-economie/green-deal#:~:text=In%20een%20Green%20Deal%20probeert,administratieve %20lasten%20voor%20bedrijven%20terugdringen.

RIVM. (n.d.). *Gewasbeschermingsmiddelen*. RIVM. Retrieved June 26, 2024, from https://rvs.rivm.nl/onderwerpen/stoffen-en-producten/Gewasbeschermingsmiddelen

staatscourant. (2016, March 23). *C-189 Green Deal Gebruik van gewasbeschermingsmiddelen op sportvelden*. Overheid.Nl. https://zoek.officielebekendmakingen.nl/stcrt-2016-14025.html

Staatscourant. (2024, April 19). *Regeling van de Staatssecretaris van Infrastructuur en Waterstaat en de Minister van Landbouw, Natuur en Voedselkwaliteit, van 11 april 2024, nr. IENW/BSK-2024/97273, tot wijziging van de Regeling gewasbeschermingsmiddelen en biociden*. Overheid.Nl. https://zoek.officielebekendmakingen.nl/stcrt-2024-10202.html

Steinheimer, T. R., Ross, L. J., & Spittler, T. D. (2000). *Agrochemical Movement: Perspective and Scale-of-Study Overview*. https://pubs.acs.org/sharingguidelines

Wettenbank. (n.d.-a). *Besluit vakkennis- en vakbekwaamheidseisen bestrijdingsmiddelen*. Overheid.Nl. Retrieved June 27, 2024, from https://wetten.overheid.nl/BWBR0006814/2001-07-28

Wettenbank. (n.d.-b). *Wet gewasbeschermingsmiddelen en biociden*. Overheid.Nl. Retrieved June 27, 2024, from https://wetten.overheid.nl/BWBR0021670/2024-01-01

Willem de Haes. (n.d.). *Gras en greenkeeping*. Golfmeester. Retrieved June 26, 2024, from https://www.golfmeester.nl/site/grassoorten-golfbaan

Conley, D. J., Paerl, H. W., Howarth, R. W., Boesch, D. F., Seitzinger, S. P., Havens, K. E., Lancelot, C., & Likens, G. E. (2009). Ecology - Controlling eutrophication:

Nitrogen and phosphorus. In *Science* (Vol. 323, Issue 5917, pp. 1014–1015). https://doi.org/10.1126/science.1167755

Díez, A. M., Sanromán, M. A., & Pazos, M. (2019). New approaches on the agrochemicals degradation by UV oxidation processes. *Chemical Engineering Journal*, *376*. https://doi.org/10.1016/j.cej.2018.09.187

Gächter, R., Steingruber, S. M., Reinhardr, M., & Wehrli, B. (2004). Nutrient transfer from soil to surface waters: Differences between nitrate and phosphate. *Aquatic Sciences*, *66*(1), 117–122. https://doi.org/10.1007/s00027-003-0661-x

Hasanuzzaman, M., Fujita, M., Oku, H., Nahar, K., & Hawrylak-Nowak, B. (2018). Plant nutrients and abiotic stress tolerance. In *Plant Nutrients and Abiotic Stress Tolerance*. Springer Singapore. https://doi.org/10.1007/978-981-10-9044-8

Lewis, K. A., Tzilivakis, J., Warner, D. J., & Green, A. (2016). An international database for pesticide risk assessments and management. *Human and Ecological Risk Assessment*, *22*(4), 1050–1064. https://doi.org/10.1080/10807039.2015.1133242

Marrone, P. G. (2007). Barriers to adoption of biological control agents and biological pesticides. In *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* (Vol. 2). https://doi.org/10.1079/PAVSNNR20072051

Nababan, B., Ulfah, D., & Panjaitan, J. P. (2021). Light propagation, coefficient attenuation, and the depth of one optical depth in different water types. *IOP Conference Series: Earth and Environmental Science*, *944*(1). https://doi.org/10.1088/1755-1315/944/1/012047

Osman, G., Assaeedi, A. S. A., Organji, S., & El-Ghareeb, D. K. (2015). *Bioinsecticide Bacillus thuringiensis a comprehensive review*. https://www.researchgate.net/publication/279699661

Pierrou, U. (1976). *The Global Phosphorus Cycle*. https://about.jstor.org/terms

Roberts, T. R. (1996). Assessing the environmental fate of agrochemicals. In *Journal of Environmental Science and Health - Part B Pesticides, Food Contaminants, and Agricultural Wastes* (Vol. 31, Issue 3, pp. 325–335). Taylor and Francis Inc. https://doi.org/10.1080/03601239609372993

Roger H. Bray. (1963). Phosphate mobilty. *Soil Science*, *95*(2), 124–130.

Sansinenea, E. (2012). Bacillus thuringiensis Biotechnology. In *Springer 4* (Vol. 9789400730212). TUT Press. https://doi.org/10.1007/978-94-007-3021-2

Sheferaw Ayele, H., & Atlabachew, M. (2021). Review of characterization, factors, impacts, and solutions of Lake eutrophication: lesson for lake Tana, Ethiopia. *Environmental Science and Pollution Research*, *28*, 14233–14252. https://doi.org/10.1007/s11356-020-12081-4/Published

Singh, S., Anil, A. G., Kumar, V., Kapoor, D., Subramanian, S., Singh, J., & Ramamurthy, P. C. (2022). Nitrates in the environment: A critical review of their distribution, sensing techniques, ecological effects and remediation. In *Chemosphere* (Vol. 287). Elsevier Ltd. https://doi.org/10.1016/j.chemosphere.2021.131996

Steinheimer, T. R., Ross, L. J., & Spittler, T. D. (2000). *Agrochemical Movement: Perspective and Scale-of-Study Overview*. https://pubs.acs.org/sharingguidelines

Violante, A., Huang, P. M., Bollag, J.-M., Gianfreda, L., De Nobili^, M., Francaviglia, R., & Sequi, P. (2002). *Developments in Soil Science, Volume 28A RETENTION AND MOBILITY OF CHEMICALS IN SOIL*.

Vitousek, P. M., Hättenschwiler, S., Olander, L., & Allison, S. (2002). Nitrogen and nature. *Ambio*, *31*(2), 97–101. https://doi.org/10.1579/0044-7447-31.2.97

Pesticides, B. (2021b, mei 5). *Breakdown Products (Metabolites) from Pesticides May Be More Toxic than Parent Compound*, Study Finds. Beyond Pesticides Daily News Blog. https://beyondpesticides.org/dailynewsblog/2021/05/breakdown-products-metabolites-from-pesticides-may-be-more-toxic-than-parent-compound-study-finds/

EcoShape. (2020c, juni 13). 3.*Turbidity and sediment dynamics* - EcoShape. EcoShape - EN. https://www.ecoshape.org/en/knowledge-articles/sediment-and-ecology-in-delta-lakes/3-turbidity-and-sediment-dynamics/

Van Hal, M., Lürling, M., & Rapport, W. W. U. (2004). Duikers in de mist. Wetenschappelijk onderzoek naar de mate van doorzicht rondom onderwaterhuis ‘Aquavilla’in een diepe duikplas [‘Divers in the fog’: scientific research into the degree of transparency around underwater housing of ‘Aquavilla’in a deep diving lake]. Wetenschapswinkel Wageningen UR Rapport, 195, 110. https://edepot.wur.nl/26188

Aquatic Ecology and Water Quality Management. (z.d.). WUR. https://www.wur.nl/en/research-results/chair-groups/environmental-sciences/aquatic-ecology-and-water-quality-management.htm

W

Appendix

S. No.	Active Ingredient (Common Name)	Agrochemical(s)	Mobility	Value (1)	DT 50 (Field) (day)	Value (2)	Water Photolysis DT50 (days)	Value (3)	Environmental Toxicity	Human Health Risk	Substance Group	Status	Final Risk Value
1	2,4-D	Aamix	Strong	3	28.8	3	38	3	Moderate	High	Phenoxy herbicide; Phenoxy PGR; Phenoxyacetic herbicide; Auxin PGR	In use	27
2	Azoxystrobin	Heritage	Strong	3	180.7	4	8.7	2	Moderate	Moderate	Strobilurin fungicide	In use	24
3	*Bacillus thuringiensis* Subsp *aizawai* strain GC-91	Turex WG, Delfin, Xentari	Medium	2	[redacted]	4	[redacted]	4	Moderate	Low	[redacted]	In use	32
4	Bentazone	Basagran	Strong	3	7.5	2	4	1	Moderate	Moderate	Benzothiazinone herbicide	In use	6
5	Bifenox	Fox 480 SC	Medium	2	17.3	2	2.2	1	High	Moderate	Nitrophenol ether herbicide	In use	4
6	Boscalid	Signum	Strong	3	254	4	Stable	4	Moderate	Moderate	Carboxamide fungicide; Anilide fungicide; Pyridine fungicide	In use	48
7	Chlorantraniliprole	Acelepryn	Strong	3	204	4	0.31	1	High	Moderate	Diamide insecticide; Pyridylpyrazole insecticide	In use	12
8	Clopyralid	Tapir	Very Strong	4	8.2	2	271	4	Moderate	Moderate	Pyridine herbicide; Picolinic acid herbicide	In use	32
9	Dicamba	Dicophar SL	Very Strong	4	3.9	1	50	3	Moderate	Moderate	Benzoic acid herbicide, Benzoic	In use	12

											acid PGR		
10	Esfenvalerate	Sumicidin Super	Medium	2	19.2	2	2	1	High	High	Pyrethroid insecticide	In use	4
11	Florasulam	Primus, Tapir	Strong	3	8.5	2	156	4	Moderate	Low	Triazolopyrimidine herbicide; Sulfonanilide herbicide	In use	24
12	Fluopyram	Exteris Stressgard	Strong	3	118.8	4	21	2	High	Moderate	Benzamide fungicide; Pyridine fungicide; Unclassified nematicide	In use	24
13	Fluroxypyr-meptyl	Tapir, Starane Top, Primstar	Medium	2	3	1	63	4	Moderate	High	Pyridine herbicide	In use	8
14	Fosetyl-aluminium	Signature Xtra, Harmonix Turf Defense	Very Strong	4	0.04	1	35	3	Moderate	Moderate	Organophosphate fungicide	SX in use; HTD cannot be used since April, leftovers can be used until 30.05.25	12
15	Glyphosate	Touchdown quattro	Medium	2	6.45	2	55	3	Moderate	High	Organophosphate herbicide; Phosphonoglycine herbicide	In use	12
16	Imidacloprid	Merit turf	Strong	3	174	4	0.2	1	High	High	Neonicotinoid insecticide; Guanidine	No longer in use	12

											insecticide	since 2019	
17	Iprodione	Chipico green, Interface	Medium	2	11.7	2	67	4	Moderate	High	Dicarboximide fungicide; Dichlorophenyl fungicide; Dichlorophenyl dicarboximide fungicide	Allowed on golf courses till 2018	16
18	Isopropylamine salt of glyphosate	Roundup Evaluation	Medium	2	6.25	2	[redacted]	1	Moderate	Moderate	Organophosphate herbicide; Phosphonoglycine herbicide	In use	4
19	Mecoprop-P	Dicophar SL	Strong	3	21	2	7	2	Moderate	High	Phenoxypropionic herbicide	In use	12
20	Mepanipyrim	Frupica SC	Medium	2	142.2	4	21.4	2	Moderate	Moderate	Anilinopyrimidine fungicide	In use	16
21	Metconazole	Sirena, Caramba	Strong	3	134.7	4	83	4	High	Moderate	Triazole fungicide; Conazole fungicide	In use	48
22	Pyraclostrobin	Signum	Medium	2	33.3	3	0.06	1	High	High	Strobilurin fungicide; Carbanilate fungicide; Phenylpyrazole fungicide	In use	6
23	Trifloxystrobin	Exteris Stressgard	Medium	2	1.69	1	2.7	1	High	High	Strobilurin fungicide; Methoxyiminoacetate strobilurin fungicide	In use	2
24	Trinexapac-ethyl	Primo Maxx	Medium	2	14.6	2	868	4	Moderate	Low	Cyclohexanecarboxylate compound	In use; cannot be used after Aug	16