Master's Thesis

Master:
Water Science and Management

RELATION OF RIVER DISCHARGE AND PRECIPITATION WITH WATER INTAKE STOPS: THE MEUSE CASE

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Abstract

Surface Waters are important in the provision of drinking water, food production, the industry sector and nature. However, their quality has been deteriorating due to direct discharges from industrial and sewage water treatment plants, and the low dilution of contaminants during dry periods. Chemicals of Emerging Concern (CEC) such as pharmaceuticals and pesticides are becoming more occurrent in the Meuse. This river is an important drinking water source; therefore, it is crucial to guarantee surface water quality for the supply of high-quality drinking water. When signaling values of CEC are exceeded, drinking water companies stop their intake of water. Dry scenarios, lower discharge in the Meuse and higher concentrations of CEC are expected in the future. Thus, intake stops might increase as well.

The key objective of this project was to find the relation between river discharge, water quality, precipitation and water intake stops. For that, five intake stations which are part of the drinking water production companies: Vivaqua and Water-Link from Belgium; and WML, Dunea and Evides, from the Netherlands were considered. Their respective data on water quality, river discharge, precipitation and registered water intake stops were compared and statistically analyzed with the Pearson and Spearman Rank correlation test. A significant relation between discharge and water quality was found. Relations between intake stops and discharge and precipitation were significant for the Dutch drinking water companies. In addition, it was found that decision rules of each company have big influence in the frequency and duration of the intake stops.

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Content

Abbreviations

CEC Chemicals of Emerging Concern

CP Chemical Pollution

DA *Daphnia* Alarm

DIPE Diisopropylether

ERM European River Memorandum

FA Fish Alarm

IWTP Industrial Wastewater Treatment Plant

KNMI The Royal Netherlands Meteorological Institute

MA Mussels Alarm

PI Preventive Interruption

TBP Tributyl Phosphate

TCEP Tris(2-chloroethyl)phosphate

THMs Trihalomethanes

OS Organic Substances

PC Polar Compound

RIWA Association of Maas/Meuse Waterworks

STP Sewage Treatment Plant

WWTP Wastewater Treatment Plant

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1. Introduction

Surface waters are important in the provision of drinking water, food production, the energy sector, industry, recreation and nature. However their quality has been deteriorating due to direct industrial discharges via industrial waste water treatment plants (IWTP) and industrial and household discharges via Sewage Treatment Plant (STP) effluents (Coppens et al., 2015; van Wezel et al., 2018). These effluents contain Chemicals of Emerging Concern (CEC) such as pharmaceuticals and pesticides, which are becoming more occurrent in the aquatic environment (Luo et al., 2014). STPs are not designed for the removal of these substances, and their reduction efficiency can vary widely depending on the physico-chemical properties of the CEC. These point sources are reflected in the occurrence of CEC on surface waters (Luo et al., 2014; Michael et al., 2013).

CEC often lack information on their hazardous properties, hampering the assessment of which concentration is safe for drinking water sources. As a matter of prevention, a so-called signaling value is proposed in the Dutch implementation of the European Drinking Water Directive and the Water Framework Directive. A concentration of 1 µg/L and 0,1 µg/L is used as this value for drinking water and drinking water sources respectively, and when exceeded, further research is mandatory (Drinkwaterbesluit, 2011). This signaling value allows the drinking water utilities to be aware of the presence of these chemicals, and leads to more intense monitoring of the source waters for the drinking water production (RIVM, 2017).The European River Memorandum (ERM) intends to guide the decisions regarding surface waters used for the production of drinking water and assure a sustainable and safe provision of drinking water with the necessary protection of water bodies (IAWR et al., 2013).

For the Meuse river, the memorandum is followed by the Association of Maas/Meuse Waterworks (RIWA-Meuse) which at the same time is in charge of monitoring the water intake points along the river (RIWA-Meuse, 2017). According to RIWA-Meuse, the water quality of the Meuse does not always meet the surface water quality standards, and the presence of some pharmaceuticals and industrial compounds exceeds the signaling value. The intensive monitoring at drinking water intake points facilitates the identification of several relevant compounds such as glyphosate, metformin or fluoride (RIWA-Meuse, 2017).

In the Netherlands, 40% of the total drinking water comes from surface waters. The river Meuse provides water to six million people, in both Belgium and the Netherlands. Hence it is crucial to guarantee surface water quality for the supply of high-quality drinking water. The constant water quality fluctuations and presence of CEC in the Meuse river have led drinking water companies to stop their intake of water, in order to find solutions or adjust the water treatment process on time (Baken et al., 2016; Hoogh et al., 2006; RIWA-Meuse, 2017). For instance in the summer of 2015, the Dutch drinking water utilities along the Meuse had a long term intake stop due to the high concentrations of pyrazole (Baken et al., 2016; Sjerps et al., 2017).

Climate change, with more and longer extreme conditions, influences water quality. During dry periods the water quality deteriorates with low river discharge, as there is less dilution of the contaminants in the water (Wuijts et al., 2012). Heavy rainfalls can cause sewage overflows and thus, more pollution can make its way into the surface waters (Cox, 2016). In addition, effects on the Meuse water quality can be severe with extreme weather conditions, like heavy precipitations or droughts, as the Meuse is a rain-fed river. Sjerps et al., (2017) projected concentrations of pharmaceuticals and pesticides that exceeded the signaling values, especially during very dry scenarios which are expected in summer. This leads to the hypothesis that more water intake stops will happen in the future, due to the more frequent periods of low river discharge.

The key objective of this project is ***to gain more insight in the relation between river discharge, water quality, precipitation, and the water intake stops.*** We aim to fill the gap that exists in literature related to drinking water intake stops and the reasons behind them.

The central research question is:

- What is the relation between the Meuse discharge, water quality, precipitation and the frequency and duration of water intake stops of the drinking water companies in the past seven years?

In addition, the following sub-question is proposed:

- What are the current decision rules (according to parameters, thresholds and duration) in the Meuse drinking water utilities to start and end intake stops?

This study was performed along the Belgium and Dutch Meuse river basin. It considers five intake stations, which are part of the drinking water production companies: Vivaqua and Water-Link from Belgium; and WML, Dunea and Evides, from the Netherlands. Their respective data on water quality, river discharge, precipitation and registered water intake stops were compared and statistically analyzed, in order to find any significant relation between the frequency and duration of the water intake stops and the other previously mentioned parameters.

2. Theory

2.1 Contamination of Surface Waters

Surface waters can be found in large quantities in rivers, lakes and canals, providing a good source for drinking water supply. Due to the increase of industrialization and population growth, surface water quality has been deteriorating and therefore, more advance drinking water treatment such as membrane filtration, oxidative techniques and active carbon filtration are being used (Sharma & Bhattacharya, 2017; van Wezel et al., 2018). Different human activities such as industry, agriculture, shipping and chemical use in households have introduced many contaminants to the waters (Luo et al., 2014).

The pollutants input can be classified as incidental, structural or diffuse emissions. Events that cannot be overseen (e.g. industrial accidents, sewage overflows) are considered incidental emissions. The continuous discharge of industrial and sewage treatment plants is classified as structural emission from a point source. The agricultural activities or road run-off, which can vary according to the season, are considered diffuse emissions and mainly from a non-point source (Carpenter et al., 1998; Houtman, 2010).

Chemicals of emerging concern (CEC), which are agents with unknown effects on the health and the environment, can be found among these emissions (Halden, 2015). CEC come amongst others from the Sewage Treatment Plants (STPs), and their removal efficiency depend on the treatment plant's technology. However most of the STPs are not designed for the removal of CEC, and a high portion of the emerging compounds can enter easily to the environment through the sewage effluents (Bolong et al., 2009; Hamza et al., 2016). Discharges from Industrial Wastewater Treatment Plants (IWTPs) have received less attention than STPs, although these effluents can also have serious effects on surface water's quality. Pollution of the water bodies can come from textile, pharmaceutical or chemical industries among others, which can discharge via IWTPs (Bolong et al., 2009; Lee et al., 2011; Rivera-Utrilla et al., 2013; van Wezel et al., 2018). Discharges composition varies depending on the input sources and the changes that can occur during the industrial production process, along with the removal efficiencies and treatment processes through which the large number of compounds have to pass (Lee et al., 2011; van Wezel et al., 2018).

CEC are increasing in quantity, diversity and geographic expansion. Their rate of change is exceeding the rate of nutrient pollution or land use change, which leads to the recognition of emerging substances as a global environmental problem (Bernhardt et al., 2017). Within CEC, compounds like pharmaceuticals, personal care products, pesticides, hormones, nanomaterials and flame retardants can be found (Hamza et al., 2016).

2.2 Meuse River Basin

The Meuse River has a total length of 935 km. It starts in Poilly-en-Bassigny in France and drains in the Haringvliet mouth in the Netherlands. Its basin covers parts of Belgium (41%), France (26%), the Netherlands (22%), Germany (11%) and Luxembourg (<1%), comprising a total area of 34.548 km^2 (de Wit et al., 2007; van Vliet & Zwolsman, 2008). The Meuse basin is mainly used for agricultural purposes, which occupies around 55% of the land, including the pastures. The remaining land is represented by forests (35%) and built up area (9%) (Pyka et al., 2016; van Vliet & Zwolsman, 2008). The average annual precipitation in the basin can range from 700 mm to 1200 mm, with the highest values (1000-1200mm) found in the Ardennes (France), and the lowest values (700-800mm) in the Dutch and Flemish lowlands. The Meuse river is considered a rain-fed river, meaning that it has a fast response to precipitation, being affected by floodings and droughts. This can be seen in the extreme discharge values of 10 m^3/s during dry periods and more than 2500 m^3/s during wet periods. It also counts with important tributaries as the Rur and Niers rivers from the region of Düsseldorf and Cologne, and the Dieze river from the province of Brabant, which contribute to rapid rises of the water level when there is heavy precipitation in the basin (de Wit et al., 2007; van Vliet & Zwolsman, 2008).

The Meuse river basin can be divided in three geomorphological areas: 1) The Lorrain Meuse area, that goes from its origin to Charleville-Mézières and it is characterized by sedimentary and porous rock, a narrow basin, no navigation and little industrialization and urbanization, which leads to a low pressure in the environment; 2) the Ardennes Meuse area, that goes from Charleville-Mézières to Liège, and it is composed by low porosity rocks, a wider basin, which allows navigation and more urbanized and industrialized areas; and 3) the Dutch and Flemish lowlands, that goes from Liège to the mouth, and it is characterized by unconsolidated sedimentary rocks, dense population, industrial installations and intense agriculture (de Wit et al., 2007; International Meuse Commission, 2005).

2.2.1 Water Quality of the Meuse

Historically the quality of the Meuse has been changing over the years. In the decade of the 1960s the water quality started to deteriorate and in the 1970s the water was considered extremely polluted. Since then, the water quality has improved thanks to the construction of wastewater treatment plants and the implementation of more policy measures (van Vliet & Zwolsman, 2008). Currently, the Meuse shows high concentrations of nutrients, salts and metals. Additionally the presence of emerging substances like pharmaceuticals, industrial compounds and plant protection products has increased, due to the new compounds introduced in the market (e.g. glyphosate (pesticide), metformin (pharmaceutical) or acetone (Industrial compound)), and their detection has been possible due to the improved analytical techniques. (RIWA-Meuse, 2017; van Vliet & Zwolsman, 2008).

Since the Meuse is an important drinking water source for the Netherlands and Belgium, it is crucial to constantly monitor and protect the river. Concentration measurements of different pollutants, and water general parameters are taken at least 13 times per year (depending on the parameter) in nine monitoring stations along the Meuse (RIWA-Meuse, 2017). CEC shall not exceed the signaling values proposed by the Water Framework Directive, which can also be found as “Target values for rivers and watercourses” in the European River Memorandum (ERM). For anthropogenic substances the target value for drinking water sources is 0,1 µg/L (Drinkwaterbesluit, 2011; IAWR et al., 2013).

The Association of Maas/Meuse Waterworks (RIWA-Meuse) oversees this monitoring by using detection frequency, occurrence of concentrations above the target value, scores according to their removal by water treatment, toxicity and public perception variables to classify drinking water relevant compounds in 1) drinking water relevant compounds, 2) candidate drinking water relevant compounds and, 3) no longer drinking water relevant compounds (see Annex 1). (RIWA-Meuse, 2017; van der Hoek et al., 2015).

2.3 Biomonitoring of Surface Waters

Due to the large number and different chemical characteristics of substances it is impossible to detect and analyze all by only using chemical techniques. Because of that, biomonitors are used to detect the presence of chemicals that affect water quality (Wagenvoort et al., 2010). In combination of chemical techniques such as HPLC-UV, biomonitors are used to monitor river waters and have the advantage of measuring the direct toxicity effect of the substances. Furthermore, biomonitors are not expensive and are sensitive to various types of compounds (de Hoogh et al., 2006; Wagenvoort et al. , 2010).

Different biomonitors such as fish, *Daphnia*, mussels and algae are used in the monitoring of water quality. For the Meuse river the *Daphnia* and mussels are the most common.

- Mussels Monitor

To monitor the water and detect the presence of pollutants, the change of the mussel's behavior is observed. Each mussel is evaluated individually. Normally the mussels remain open 70-80% of the time for the intake of food and oxygen, and shells occasionally close and reopen after a short period.

As result of contamination the mussels can remain close for a longer period, increase their activity by opening and closing more frequently, or have no further movement. When the shell remains more open than usual and reaches the maximum open position, it means that the mussel died. When several mussels show an unusual behavior, for instance if five out of eight mussels are closed for more than 5 minutes simultaneously, then an alarm occurs. If only one show this behavior it is not catalogued as unusual (de Hoogh et al., 2006; Wagenvoort et al. , 2010).

Image 1 *Closed Mussel Monitor*

Image 2 *Open Mussel Monitor*

- *Daphnia* Monitor

The *Daphnia* monitor or toximeter, uses *Daphnia magna* as the test organism. With digital image processing the behavior of the *Daphnia* is observed and evaluated. Ten Daphnia are normally observed, and measures of movements velocity, number of active organisms, distribution in chamber, distance between the Daphnia and growth are taken (Wagenvoort et al., 2010). In normal conditions, the organisms describe calm movements with a constant speed. As result of pollution in the water, the behavior of the Daphnia may change depending on the concentration and reaction time of the pollutants. An alarm is activated if an unusual behavior such as mortality of 50% of the Daphnia, or increased velocity occur (de Hoogh et al., 2006; Wagenvoort et al., 2010).

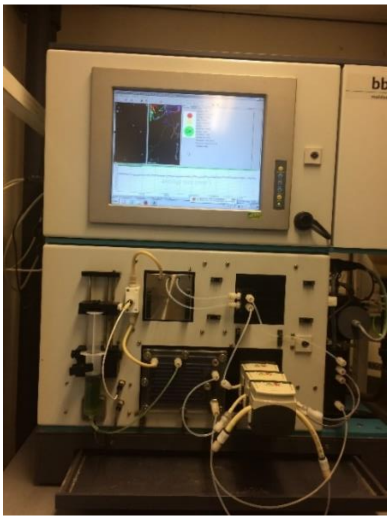

Image 3 *Daphnia Monitor*

Image 4 *Daphnia*

2.4 Climate change, river discharge and water quality

Climate change is an increasing and continuing global issue. Because of it, land and sea temperatures are increasing and precipitation patterns are changing. In Europe, the wet regions are becoming wetter, especially in winter and, the dry regions are becoming drier in summer. In addition, the frequency and intensity of extreme weather events like heavy precipitation or droughts are increasing (European Environment Agency, 2017). The hydrological cycle is related to the climate and hence, the spatial and temporal distribution of freshwater resources are affected by the climate variability. River flows, which depend mainly on precipitation, temperature and catchment characteristics such as vegetation or soil moisture, have been affected by this fluctuation. Water availability is therefore affected, being a major concern for ecosystems and the socio economic sectors that depend on surface waters (European Environment Agency, 2017).

Four different climate scenarios were developed based on global temperature rise, air circulation patterns, socioeconomic scenarios and historical measurement records. The scenarios represent different economic, technological, socio-economic and population developments. 1)intensive globalization, 2) intensive regionalization, 3) sustainable globalization and 4) sustainable regionalization (IPCC, 2007). In all scenarios global temperature and sea levels are expected to rise, summer droughts are expected to increase, and wet periods will become wetter (IPCC, 2007, 2013).

With climate change, rain fed rivers will be mainly affected and with low precipitation, the river discharge will tend to decrease. Wit et al., (2007) or Sjerps et al., (2017) have found that climate change may decrease the average discharge during the low flow season, due to the increase of temperature and decrease of summer precipitation.

Water quality which depends on climatic variability, and hydrological and anthropogenic influences, is also showing a decrease. Droughts are one of the reasons for the diminishing water quality. When the water levels are reduced, and the temperatures are elevated, the processes of respiration and reaeration in water bodies change. In addition, low discharges diminish the dilution of substances present in the water, and this combined with continuous and rising pollution discharges lead to a higher degradation of water quality (Delpla et al., 2009; Mosley, 2015; Sjerps et al., 2017). Studies made in the Meuse and the Rhine have found that with future climate change projections, the peak concentrations of CEC compounds may increase during the low flow periods, and if future emissions are not reduced and water efficient removal techniques are not improved, drinking water supply will be affected, as the thresholds are being exceeded (Coppens et al., 2015; Delpla et al., 2009; Sjerps et al., 2017).

3. Methods

Literature review was done using databases such as Scopus or the literature provided by my supervisors, in order to identify the knowledge gaps. Literature related to water quality in surface waters, effects of climate change on water, drinking water production and historic data of the Meuse was reviewed.

3.1 Study area

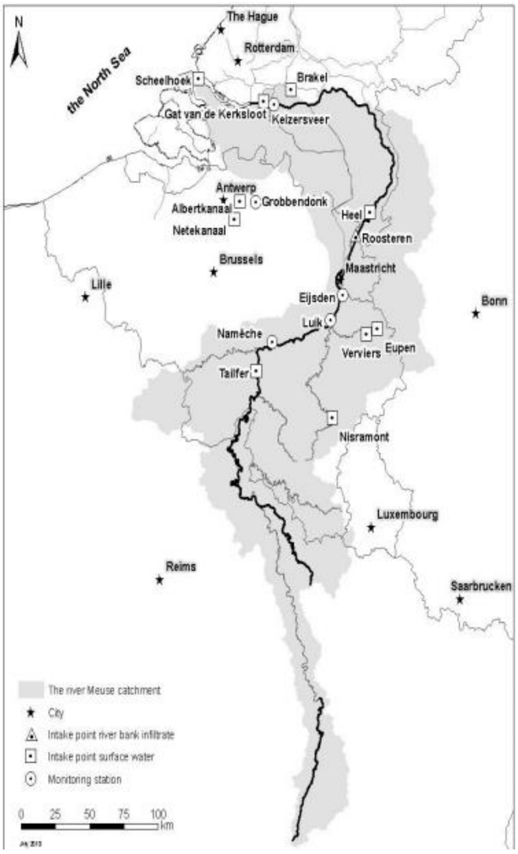

Figure 1 *Stations along the Meuse river Catchment* (van der Hoek et al., 2015)

The study area is the Meuse river basin in Belgium and the Netherlands. Five intake water points were considered: Tailfer, Luik, Heel, Brakel, and Keizersveer (Figure 1), corresponding respectively to the five contacted drinking water companies: Vivaqua and Waterlink from Belgium, and WML, Dunea and Evides from the Netherlands.

- Vivaqua

Vivaqua is in charge of the abstraction, treatment, supply, storage and distribution of the drinking water in Brussels and some Walloon regions. The abstraction of water consists of 70% of groundwater and 30% of surface water that comes from the Meuse river. The company provides water to around 2.25 million people (Vivaqua, 2018).

- Water-Link

Water-Link provides drinking water to around 198.000 people. It uses water from the Meuse river and supplies water to the Antwerp region (Water-Link, 2018).

- WML

WML is located in the Limburg region. It provides drinking water to around 500.000 people and 14.000 companies. It uses mainly groundwater (75%) in the production of drinking water. The other 25% comes from the Meuse river (WML, 2018).

- Dunea

Dunea provides drinking water to around 1.3 million people in the western part of South Holland. It uses a unique method to produce drinking water, which consists of filling the dune area with the pre-treated Meuse water. This is used to treat the water in a natural way (Dunea, 2018).

- Evides

Evides provides water to around 2.5 million people in the regions of Zeeland, South Holland and Brabant. It mainly uses surface water from the Meuse (80%) for the production of drinking water (Evides, 2018).

3.2 Data Collection

- Interviews

  To understand how the water system intake and the decision rules of each company work, an interview was concluded and visits to water intake points (Image 1) and to the drinking water companies took place. The Laboratory Managers at Vivaqua and Water-Link, the Senior Hydrologist at WML, the Senior Strategist of Water Resources at Dunea and the Process technologists at Evides were interviewed. Information about the water treatment used in the utilities, alternative sources, monitoring and alarm methods and how intake stops happened was required. The interviews to Vivaqua and Water-Link were answered through email and the interviews to WML, Dunea and Evides were personally (Annex 2).

- River Discharge

  The Meuse discharge data was collected for each of the water intake points. Data was obtained from the RIWA database and was provided as daily discharge in m^3/s, meaning it was continuous data for a chosen period of seven years (2010-2017). This period was chosen according to the data availability.

- Precipitation

  Precipitation data was provided by Vivaqua and the meteorological institute in the Netherlands (KNMI). Data was taken from the meteorological stations of Uccle in Belgium (provided by Vivaqua) and Beek, Herwijnen and Rotterdam in the Netherlands (KNMI, 2018). They were chosen based on their distance to the water intake points. The data was provided as daily precipitation in mm, and it comprises a continuous dataset for the seven years period.

- Water intake stops

Data of water intake stops was obtained from each of the drinking water companies and the RIWA annual reports. The data was registered continuously, with a “YES” if an intake stop happened and with a “NO” when there were no stops. The data described how many stops occurred, how long the stop took and the parameter or reason that caused the stop. The data was obtained for a period of seven years (2010-2017). Before 2008 intake stops were not registered properly (personal communication with Evides).

- Water Quality

Water quality data was obtained from the RIWA database. It included more than 1000 measured parameters, including emerging substances, as well as general parameters such as pH or turbidity. identification of the most important substances for this study followed an update list with compounds relevant to the drinking water production from the river Meuse (van der Hoek et al., 2015). The compounds found on the list already passed selection criteria made by RIWA, which include:

- Detection at two or more monitoring stations for a minimum of two years, with a frequency of at least 8% of the measurements per year.
- Exceedance of ERM target values from the Dutch regulation on at least two different monitoring stations in the past 5 years.
- Exceedance of ERM target values at least once in the past 3 years.
- If benchmark quotient is 1 or higher.

From this list ten parameters were selected, based on the reasons of water intake stops retrieved from the Intake stops data, and the 2015 RIWA list of relevant compounds. If a parameter did not appear frequently as a reason for an intake stop (at least in 20% of the intake stops), it was discarded. If a parameter initially did not appear in the list but was occurrent in water intake stops, it was considered. The parameters data was taken from the Keizersveer intake station, which contained the most complete dataset.

Image 5 *Keizersveer intake point*

3.3 Data Analysis

- Relation Concentration and River Discharge

Following Sjerps et al., (2017), I studied the specific relation between the river discharge and the chemical concentration of the selected compounds at the station Keizersveer, which contained the most complete data for water quality.

The Pearson correlation[1] coefficient (*r*) and p value were found with the function *cor.test* (1) in R studio. A p value below 0,05 indicates a significant correlation, and the squared correlation (r^2) indicates how good is the fit of the linear regression model. The values of chemical load (*a*) and background concentration (*b*) were found according to the Q-C Relation Equation (2). These values were fitted using the function *lm* (3) in R studio

$$cor.test(glyphosate\$Q, glyphosate\$C) \quad (1).$$

$$c = \frac{a}{Q} + b \qquad (2).$$

Where c= concentration (µg/L), a= chemical load (mg/s), Q= discharge (m^3/s), b= background concentration (µg/L).

$$lm(C \sim I\left(\frac{1}{Q}\right), data = glyphosate) \quad (3).$$

As the water quality parameters and periods used in this study differed from the ones used in Sjerps et al., (2017), the Pearson correlation test was also used to assure that a significant correlation exists between the selected parameters and the Meuse discharge. The script used in R studio is found in Annex 3.1.

- Relation water intake stops with discharge and precipitation

In order to know the main reasons of the intake stops in each of the water utilities, the frequency of each reason of stop was found. The functions *prop.table* was used to find the reasons frequencies and the *barplot* function was used to plot the results in R studio. The proportion of number of stops within a specific discharge and precipitation condition and the frequency of every duration were found using the same functions.

The accumulation of days with a certain discharge was plotted in excel, as well as the intake stops and discharge to allow a clearer view of the stops behavior with discharge. A ratio (4) of the number of stops within a certain range of discharge to the number of days within the certain discharge range, was also found. The number of days for each range have similar sizes, hence the ranges of discharge varies.

$$Ratio = \frac{\#stops\ between\ range}{\#days\ between\ range} \quad (4).$$

The duration of the intake stops was also related to the river discharge using boxplots. The function *boxplot* was used in R studio as follow (5).

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[1] Pearson Correlation: Measures the statistical relation between two quantitative and continuous variables. Its coefficient (r) measures the strength of this linear relation (UWE, 2018a).

$$yesduration = data.frame(data\$Duration, data[data\$Duration > 0, "Discharge"])$$

$$boxplot(yesduration\$Discharge \sim yesduration\$data.Duration \quad (5).$$

To find a significant relation between the intake stops and the data of precipitation and river discharge, the Spearman rank correlation test[2] was used. This test was chosen, as the relation was between an ordinal variable (Intake stop) and a continuous variable. A p-value under 0,05 indicates a significant relation between discharge and the intake stops. The correlation test was done for each of the intake stations. Complete scripts used in R studio for the analysis of the data can be found in Annex 3.

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[2] Spearman Rank test: is the non-parametric version of the Pearson correlation test. Measures the statistical relation between the rankings of two variables. For this test at least one variable has to be ordinal (UWE, 2018b)

4. Results

4.1 Interviews

Interviews made to each of the drinking water companies included four topics: 1) Water treatment, 2) Alternative sources, 3) Monitoring and alarm system and 4) Intake stops.

4.1.1 Water Treatment

Each drinking water companies follows a different treatment scheme of the extracted surface water. The presence of reservoirs, dunes or different technologies might be the cause of the treatment differences. The following water treatment processes are used in each company:

***Table 1**. Water treatments used at water utilities*

Treatment	Vivaqua	Water-Link	WML	Dunea	Evides
Pre-ozonation	x				
Aeration		x	x	x	x
Softening				x	x
Pre-purification with sand filters				x	
Infiltration lakes (dunes system)				x	
Flocculation	x	x			x
Sedimentation	x	x			
Filtration	x				x
Quick Sand Filtration		x	x		
Activated Carbon Filtration		x	x	x	x
Slow Sand Filtration				x	
UV Disinfection		x	x		x
Ozonation	x				

4.1.2 Alternative Sources

All drinking water companies, except Dunea, use groundwater for their drinking water production, being their main alternative source from surface water. Evides counts with three reservoirs that are filled with the Meuse water. When the reservoirs are not receiving water, the reservoirs can still be used for a maximum of five to six weeks for drinking water production. Dunea has the possibility to extract water from the Lek river, when it cannot use water from the Meuse river.

4.1.3 Monitoring and Alarm system

All companies make use of a continuous monitoring of chemical, microbiological and general parameters. They use HPLC UV technology for the chemical monitoring. Evides, Dunea, WML and Water-Link use biomonitoring for detecting pollution in the water. *Daphnia*, mussel, algae and fish are used as bioindicators (Table 2).

Table 2 *Biomonitoring used at the water utilities*

Biomonitoring	Vivaqua	Water-Link	WML	Dunea	Evides
Daphnia			x	x	x
Mussel			x		x
Fish		x			
Algae				x	

The five drinking water companies are part of the Meuse Alarm. Warnings are given among the companies, when one finds high concentrations of any substance during the monitoring process. Countries' governments also conduct continuous monitoring of the river Meuse. When something irregular is found, a communication to each drinking water company is sent, in order to take pertinent actions. For instance, in the Netherlands exists *Aqualarm*, a system that determines the water quality of the Rhine and the Meuse. When signaling values are exceeded, it is reported, and an alert is created.

Every time *Daphnia* or mussel start behaving differently for a continuous period, an alarm is activated and the water intake is stopped automatically at WML, Dunea and Evides. As soon as an alarm is announced, water samples are taken immediately. When an intake stop occurs, or an alarm is triggered, monitoring is more frequently done.

4.1.4 Intake Stops

Based on the water treatment, monitoring and the alarm systems, the number and possibility of intake stops can vary. Vivaqua does not have intake stops, since they consider their water treatment robust enough. They would consider, however, stopping the intake (manually), if it is not possible to remove a substance that can affect human health.

After an alarm is triggered, models are used to calculate when a substance will arrive to the intake points, helping to decide whether it is necessary to stop or continue the intake. A manually intake stop will occur, if the company is determined to do so. On the other hand, if *Daphnia* or mussel alarms are activated, the intake stops will happen automatically in the WML, Dunea and Evides intake stations.

The decision to restart the intake is also based on biological monitoring. When the *Daphnia* and mussel's behavior and the water quality parameters are back to normal, the intake is opened again. If the company is not able to keep using the alternative source, the intake should also start again. In very exceptional cases, the company must inform the government and ask for a permit, when the company requires to continue with the intake even with high concentrations of a substance in the Meuse river.

4.2 Reasons of Intake Stops

It was possible to determine the number and the main reasons of the stops in each of the companies with the collected data of the intake stops. The number of intake stops per utility are shown in Figure 2. WML presented the highest number of stops, followed by Evides, Water-Link and Dunea. Each company presented respectively 230, 64, 21 and 6 stops during the studied period. The frequency for each of the reasons in Water-link, WML, Dunea and Evides is depicted in Figure 3.

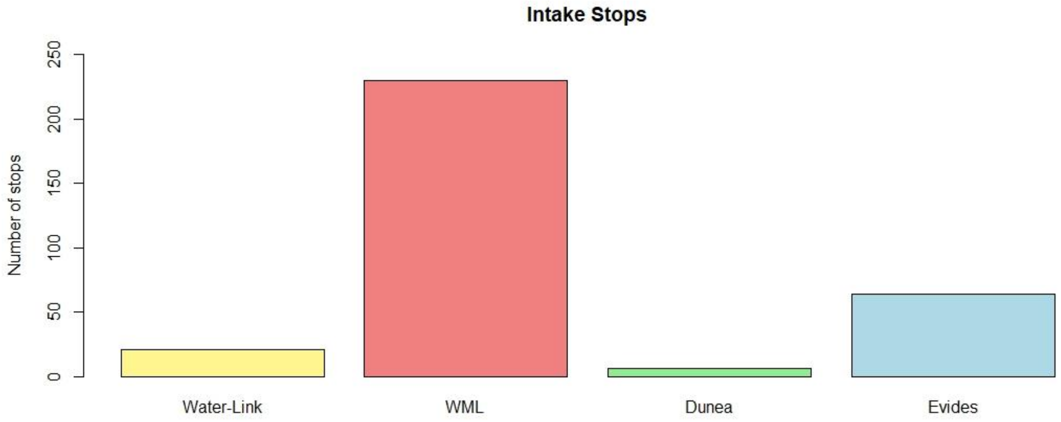


Figure 2 *Number of intake stops per water utility*

At Water-Link the stops were mostly triggered by the presence of fuels, causing 52% of the stops, followed by pesticides and conductivity with less than 10% of the stops, respectively. Other reasons like the presence of fertilizers and sodium chloride, or turbidity can be found.

At WML, although specific substances like tributyl phosphate, melamine or DIPE were found as the reasons for some intake stops, more than 40% of the stops were triggered by the mussel's alarm, followed by turbidity and chemical pollution with 18% each. Chemical pollution indicates a high concentration of substances that were not possible to identify. The *Daphnia* alarm caused 6% of the stops.

In the case of Dunea, Dimethomorf leads the reasons of stops with 33%. The remain percentage includes other CEC like dimethoate, naphthalene or pyrazole, causing around 17% of the stops each.

For Evides, the intake stops were mainly caused by the *Daphnia* and mussel's alarm, with 52% and 9% respectively. As in the other intake points, chemical pollution was present and triggered 3% of the stops. Some substances were only possible to classify them as organic or polar compounds, causing 3% and 2% of the stops respectively.

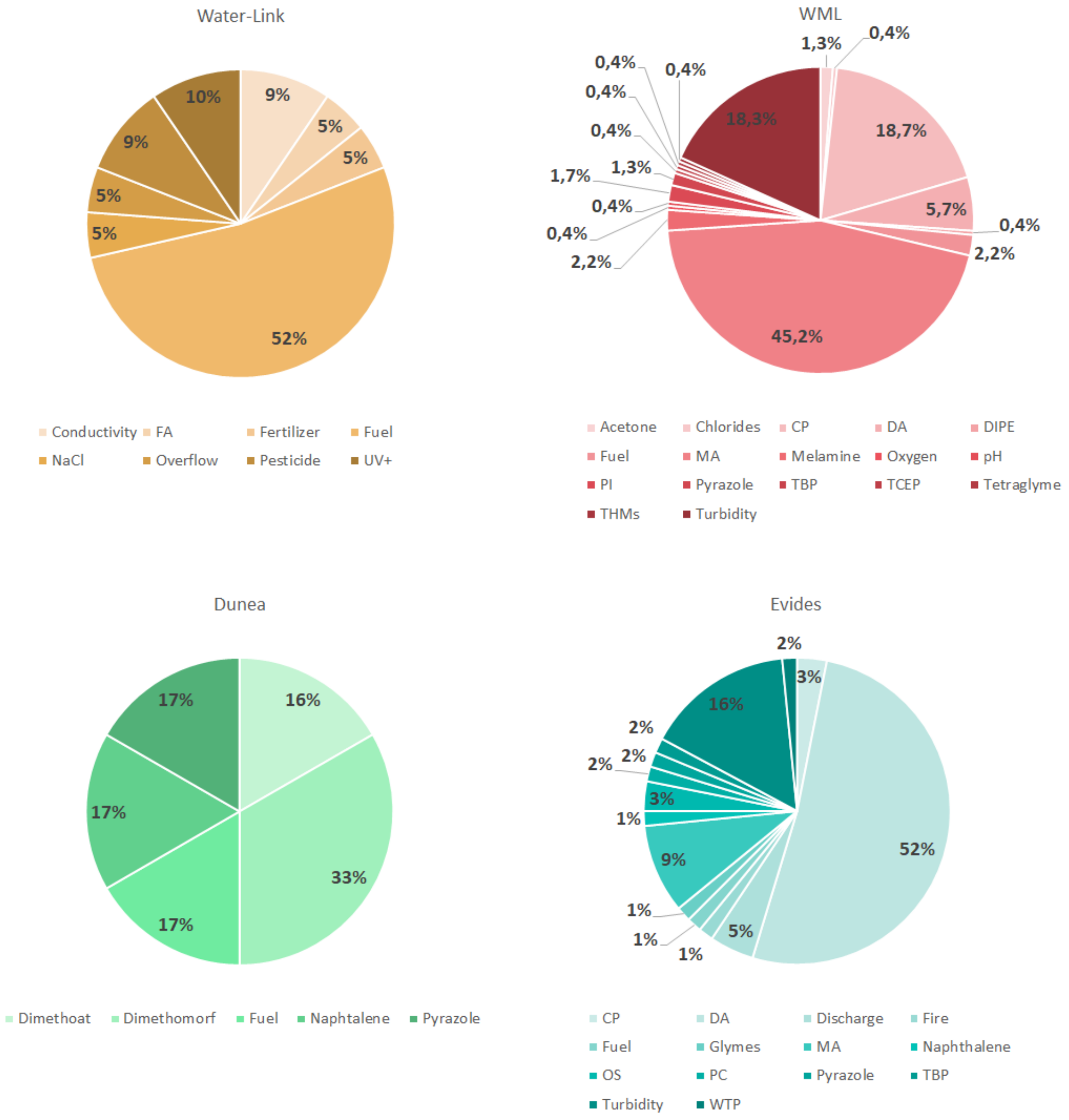


Figure 3 *Reasons frequency for intake stops in each company. FA=Fish Alarm, CP=Chemical Pollution, DA=Daphnia Alarm, DIPE= Diisopropylether, MA=Mussels Alarm, PI=Preventive Interruption, TBP=Tributyl phosphate, TCEP= Tris(2-chloroethyl)phosphate, THMs=Trihalomethanes, OS=Organic Substances, PC=Polar Compound, WTP=Water treatment Plant.*

4.3 Q-C Relations

Based on the intake stops information and the list of relevant compounds, the following substances and parameters were chosen: AMPA, caffeine, Diatrizoic Acid, DIPE, EDTA, glyphosate, guanylurea, jomeprol, metoprolol and tributyl phosphate. Some of these parameters caused intake stops (DIPE and tributyl phosphate), as previously mentioned in section 4.2. The other parameters were chosen based on their relevance in the production of drinking water from the river Meuse.

The Q-C relation for each of these substances was performed, using the water quality and discharge data from the Keizersveer intake station (Evides), as it provided the most completed data.

Table 3 *Relation of discharge with the chosen substances. Significant values in bold*

Compound	Type	r^2	p value	Number of measurements	Years with measurements	a=chemical load (mg/s)	b=background concentration (µg/L)	Standard Deviation Q-C
AMPA	Pesticide	0,44	**<0,01**	225	2009-2017	64,16	0,48	0,51
Cafeine	Pharmaceutical	0,03	**0,04**	121	2010-2017	5,33	0,30	0,18
Diatrizoic Acid	X-ray contrast agent	0,04	**0,03**	97	2009-2016	3,02	0,07	0,08
DIPE	Industrial Compound	0,21	**<0,01**	142	2009-2017	23,29	0,43	0,30
EDTA	Industrial Compound	0,04	**0,03**	118	2009-2017	275,38	17,13	9,69
Glyphosate	Pesticide	0,04	**<0,01**	225	2009-2017	1,14	0,06	0,71
Guanylurea	Pharmaceutical	0,02	0,26	50	2014-2017	11,69	1,54	10,24
Jomeprol	X-ray contrast agent	0,11	**<0,01**	112	2009-2017	4,55	0,13	0,09
Metoprolol	Pharmaceutical	0,05	**<0,01**	136	2009-2017	2,03	0,06	0,05
Tributylphosphate	Industrial Compound	0,085	**<0,01**	116	2009-2017	3,2	0,15	0,07

The chosen compounds showed a significant correlation (p value < 0,05), except for the guanylurea (Table 3). The explained variability is however low to medium with r^2 varying from 0,03 for caffeine to 0,44 for AMPA (Figure 4). Some graphs, such as caffeine do not show the expected behavior. This might be due to the low r^2 or the larger standard deviation found for the *Q-C* relation.

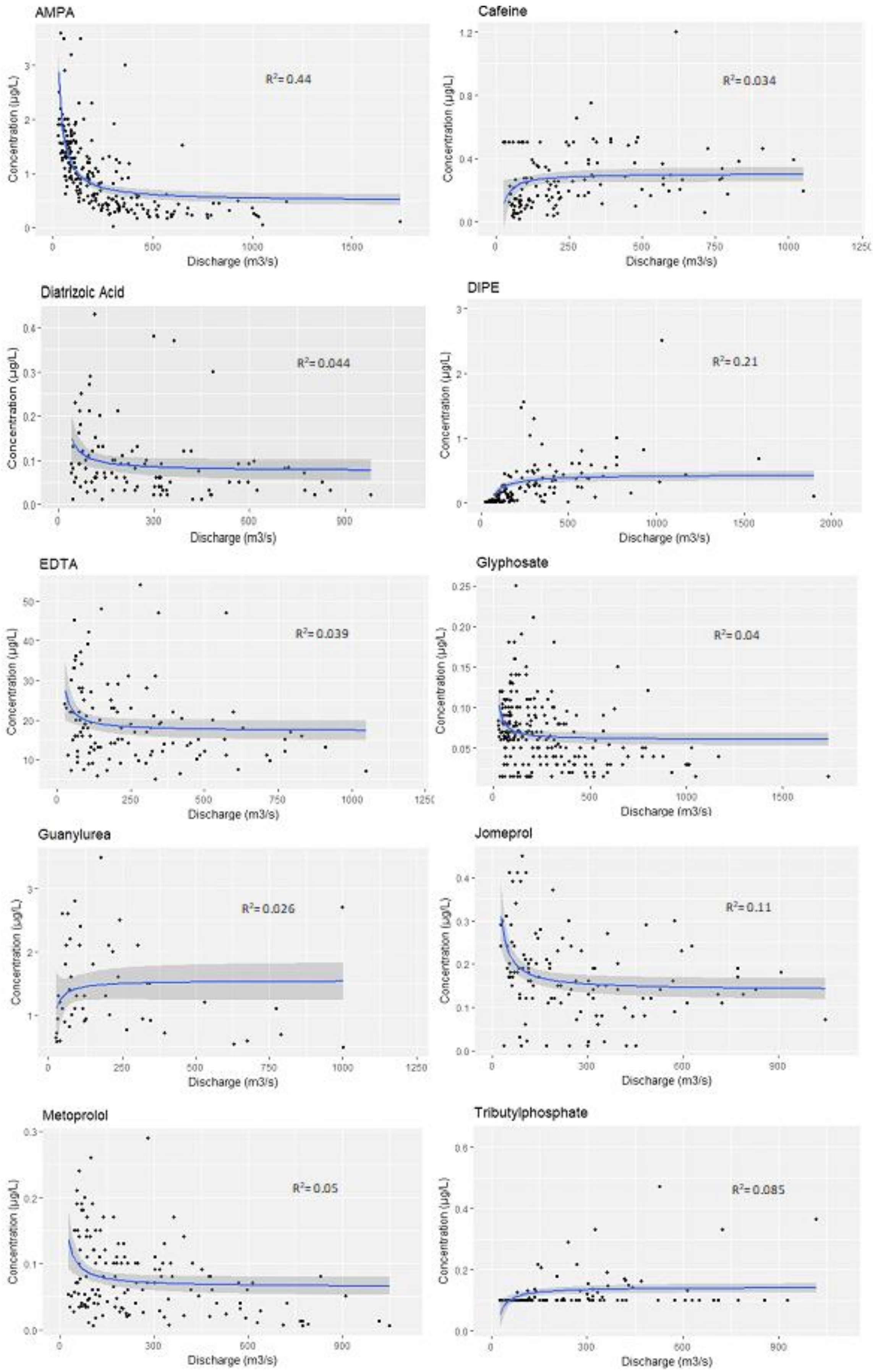


Figure 4 Q-C Relation for each of the selected substances.

4.4 Relation Discharge and Intake Stops

The proportion of stop events according to low (<270 m^3/s), medium (<800m^3/s) or high (>800m^3/s) discharge was calculated for each drinking water company, in order to find the relation between river discharge and intake stops,. The low river discharge was chosen based on the discharge percentiles on Heel and Keizersveer (Figure 15 in Annex 4). Values below 270 m^3/s, which is the average of the river, were considered low discharge.

At WML and Waterlink most of the intake stops (over 60%) occurred when the river Meuse presented discharges under 270 m^3/s. In the same intake stations, over 20% of the stops happened with medium discharge conditions (between 270 and 800 m^3/s). Contrary to this, in the intake station of Dunea, 50% of the stops happened with medium discharge conditions and the other 50% with low discharge. While in Evides more than 40% of the stops happened during low and medium conditions. For all companies, the lowest number of intake stops occurred during high discharge conditions (Figure 5).

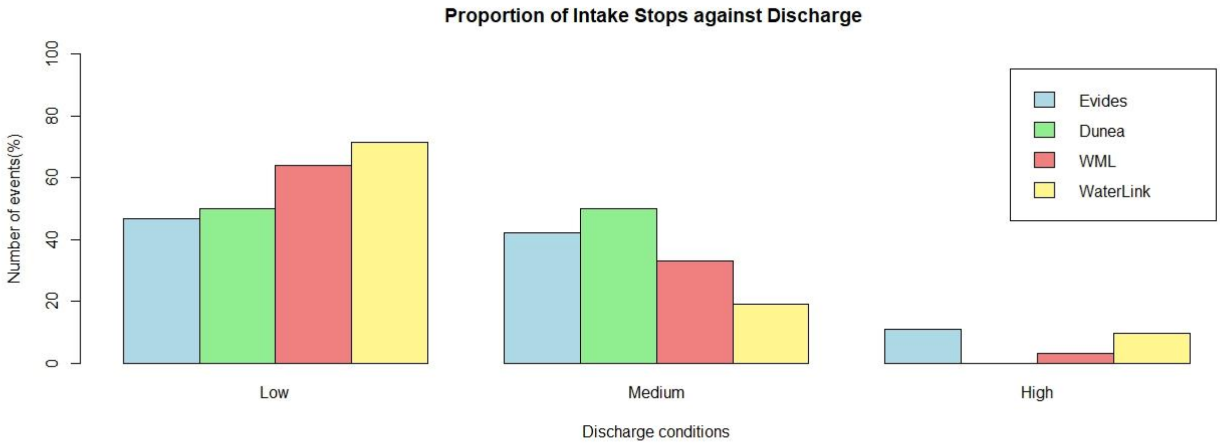
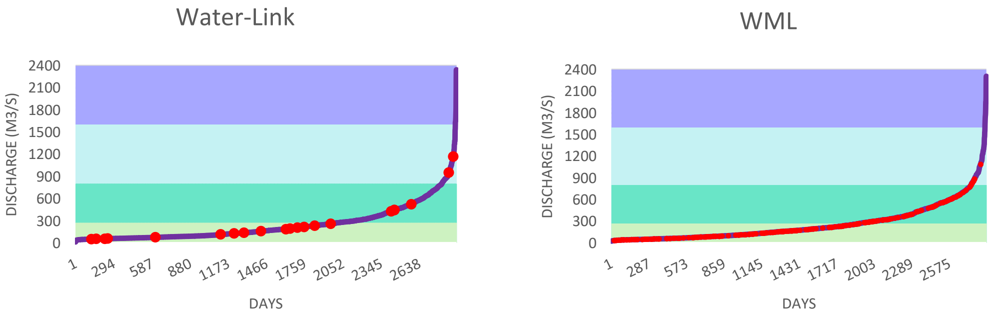


***Figure 5** Proportion of intake stops with Discharge. Low discharge<270, Medium discharge>270 & <800, High discharge>800*

A clearer view of the intake stops behavior within the different ranges of discharge is showed in Figure 6. It is possible to see that most of the studied period presented low discharge conditions, where ca. 1700 days (59%) of the time had discharges below 270 m3/s.



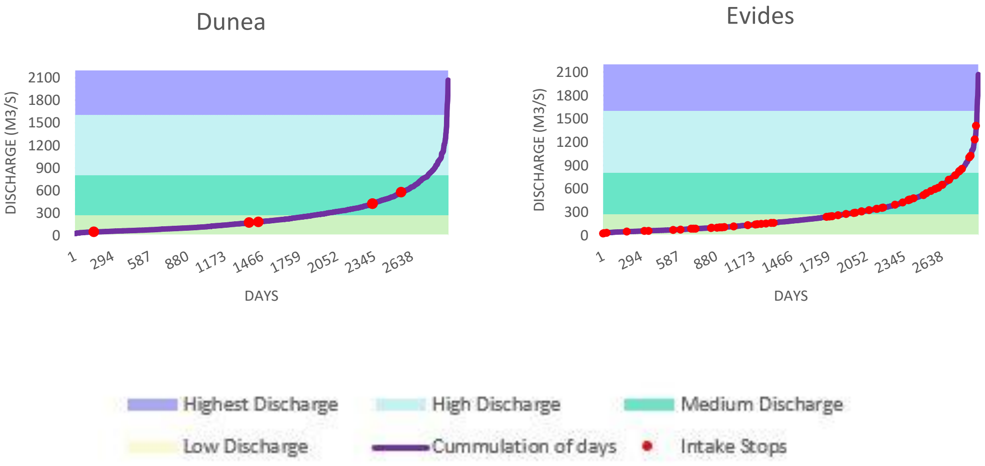


Figure 6 *Cummulation of days with certain discharge and intake stops per utilitie.*

A Spearman rank correlation test was performed to find whether a significant relation exists between the intake stops and the river discharge. With this test is possible to correlate an ordinal variable (intake stops) and a continuous variable (discharge) (Table 4).

Table 4 *Spearman Rank correlation test between intake stops and discharge. Significant values are in bold.*

Company	p value	Spearman Rank
Water-Link	0,69	-0,0072
WML	**0,019**	-0,044
Dunea	**<0,01**	0,13
Evides	**<0,01**	0,19

According to the results, a significant correlation between the intake stops and discharge can be found in the intake stations of Evides, Dunea and WML, as their p-values are below 0,05. In the case of Water-Link there is no significant relation between the two variables (p-value=0,69), probably because the number of stops and their duration at this intake point are too small. According to the Spearman rank values, the intake stops can be best explained by discharge for Evides and Dunea.

The ratio between number of days with intake stops to the total days per discharge range is shown in Figure 7 for each of the drinking water utilities. The graphs were used with a comparable number of days per range. All of them showed high peaks, specially Water-Link, WML and Evides. These peaks might be due to the large number of ranges used, which are mostly found below the low discharge conditions. Although there are peaks in the ranges of medium and high discharge, the quantity is too little compared with the number presented with low discharge ranges.

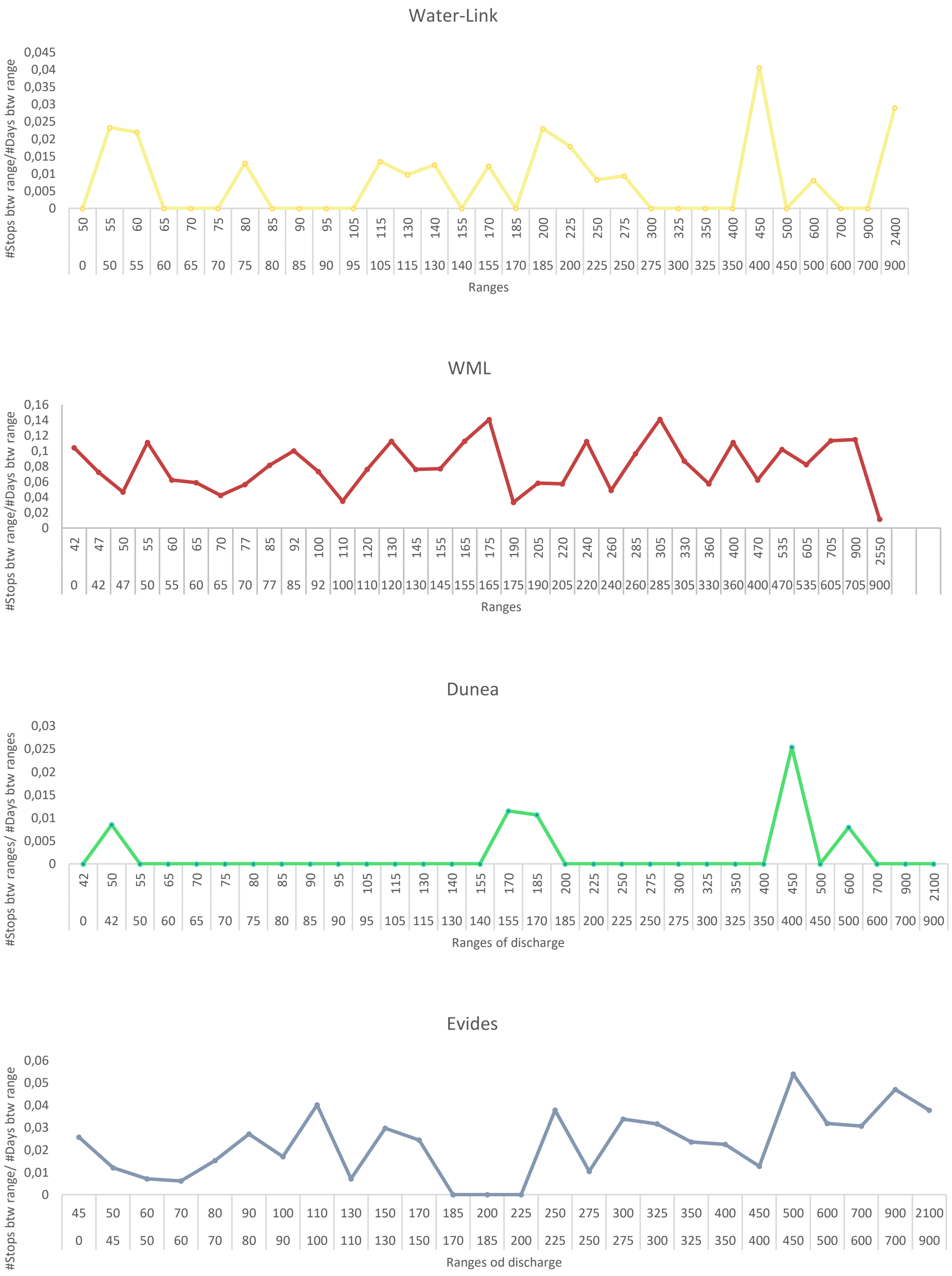


Figure 7 *Ratios between number of stops within the discharge range and number of days within the range. For each of the drinking water utilities.*

4.5 Relation duration of stops and discharge

To find the relation between the duration of the stops and the river discharge, it was first determined the frequency of the presented durations of the intake stops at each drinking water company (Figure 8).

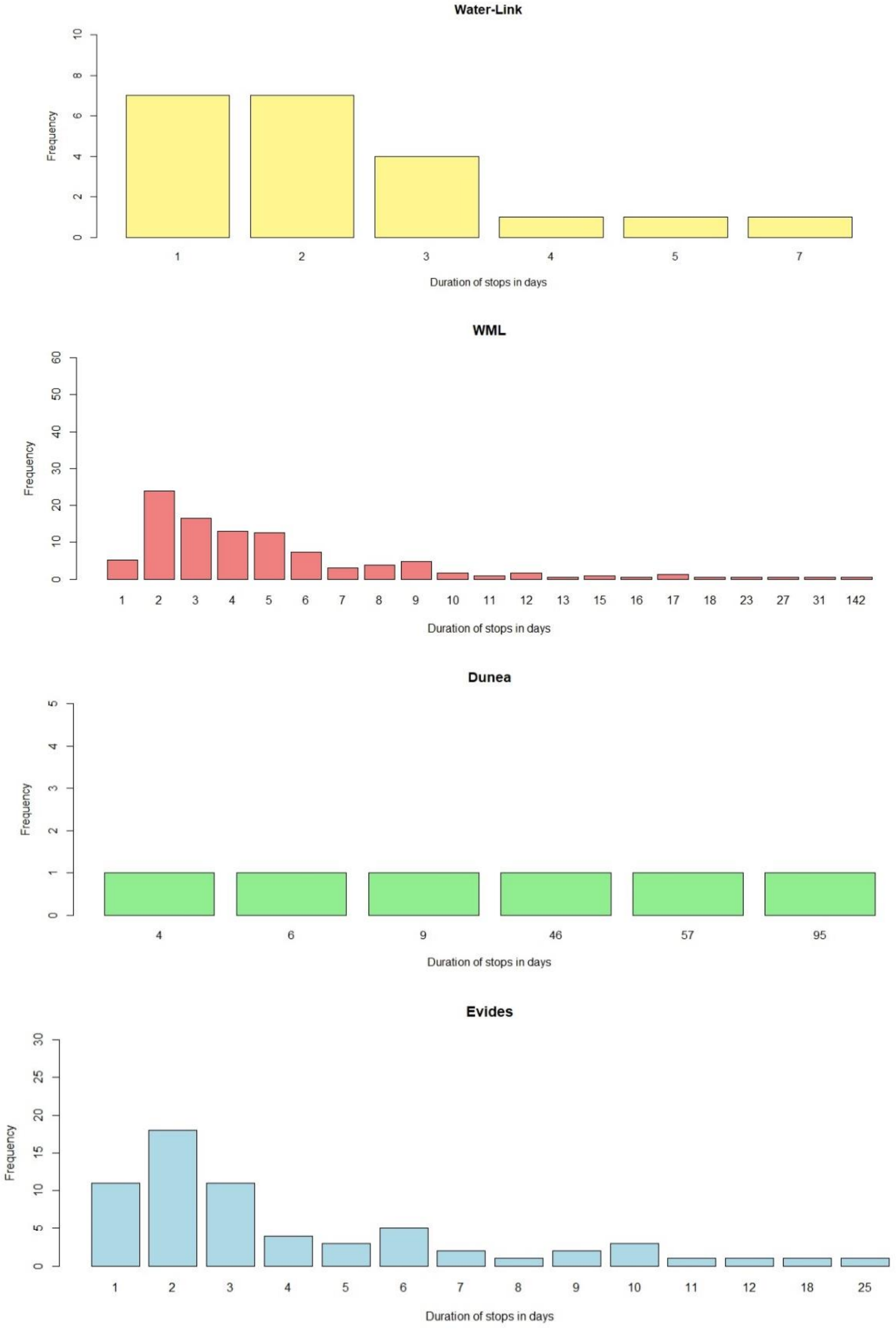


Figure 8. *Frequency of the stops duration for each drinking water company.*

Most intake stops did not last for a long time for all drinking water companies. At Water-Link the majority only lasted one or two days, and the longest intake stop lasted seven days. In WML the range of durations increased, but still most of the intake stops lasted between two and five days. The longest intake stop lasted 142 days which happened during the high concentration of pyrazole in 2015 (Baken et al., 2016). This event also caused the longest stops of 95 and 25 days for Dunea and Evides, respectively.

At Dunea, not many intake stops occurred. Hence, the frequency of the durations is the same either for the short and long stops. Like WML, Evides showed a wider range of duration and most of the intake stops lasted between one and three days.

On average, most of the durations happened during the low discharge conditions at Water-Link, WML and Evides, especially the ones that lasted between one and three days that are the most frequent ones. The long stops are mostly presented with low discharge (<100m^3/s). In the case of Dunea, the intake stops and their durations varied more between the low and medium the discharge, and the shown behavior might be related to incidental pollution, like illegal spills of pesticides (Figure 9).

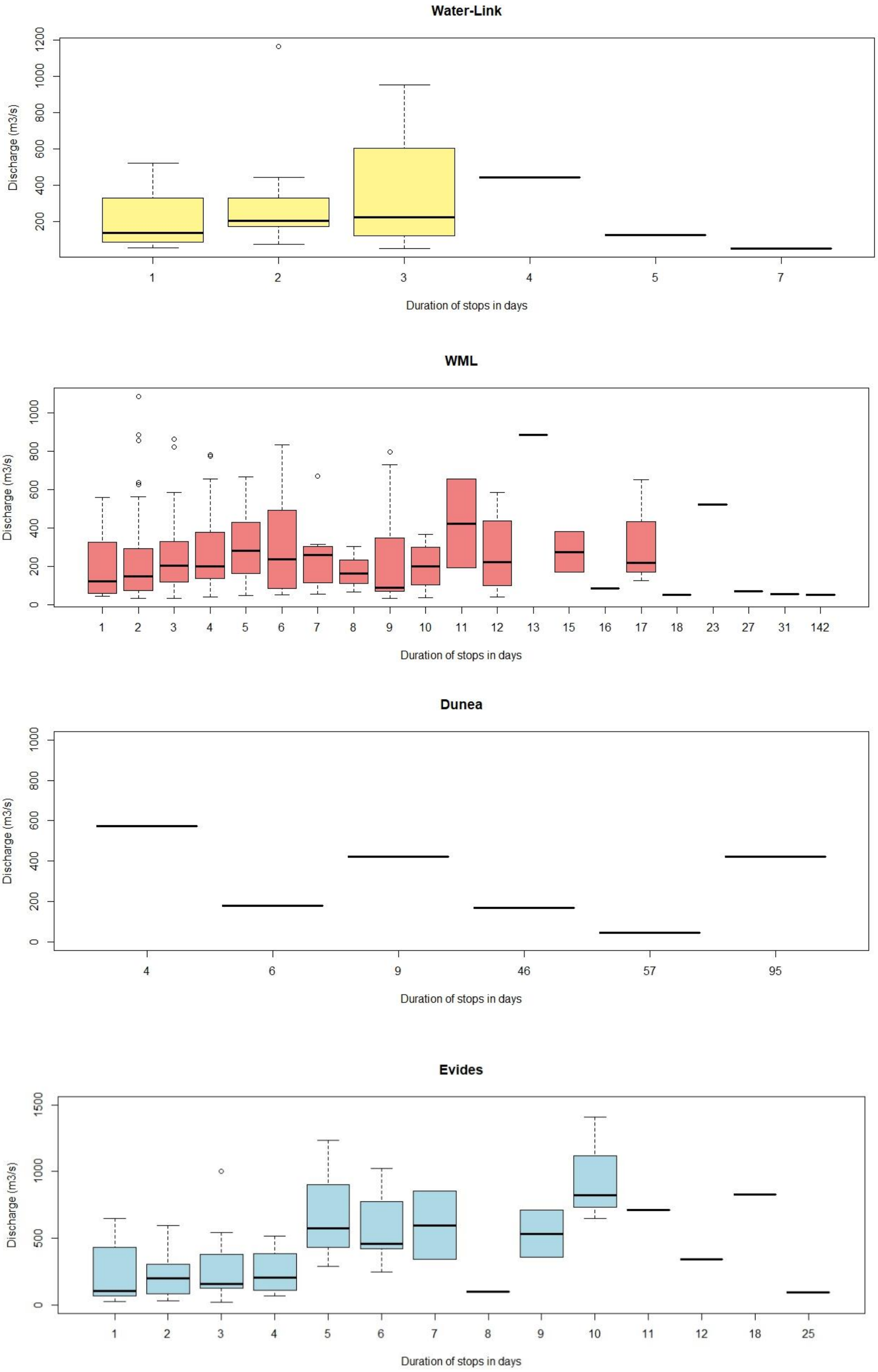


Figure 9 *Distribution duration of stops and discharge for each drinking water company.*

4.6 Relation Precipitation and Intake Stops

The proportion of stop events according to low(<8mm), medium(<20mm) or high(>20mm) precipitation were determined per drinking water company to find the relation between precipitation and the intake stops. Over 60% of the events happened during low precipitation conditions (<8mm) in all the intake stations. In Dunea, all stop events happened with low precipitation. Between 20% and 30% of the stops happened with medium precipitation conditions in the other intake stations,. With high precipitation (>20 mm) less than 10% of the stops occurred in all intake stations (Figure 10).

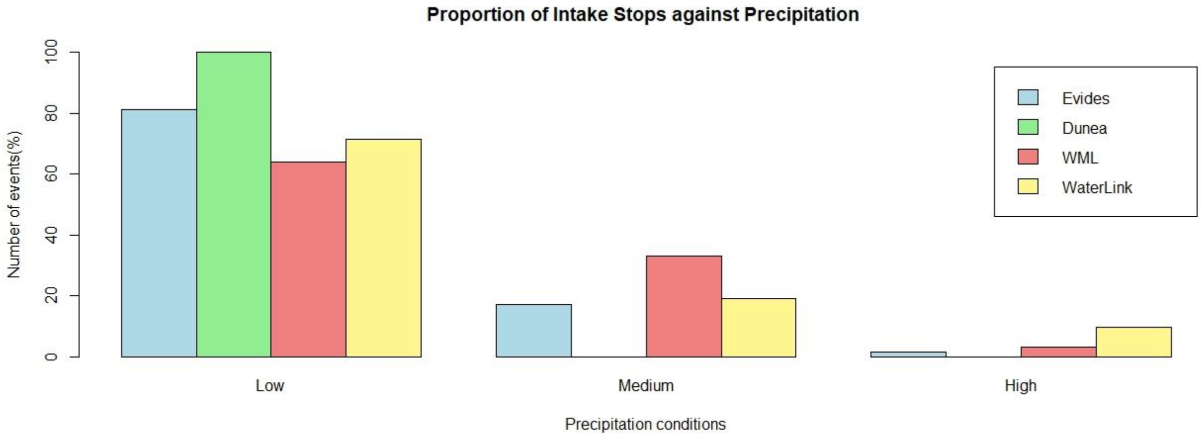


Figure 10 *Proportion of intake stops and Precipitation (Low <8mm, medium <20mm, High>20mm)*

A Spearman rank correlation test was performed to find whether a significant relation exists between the intake stops and the precipitation (Table 5).

Table 5 *Spearman Rank correlation between precipitation and intake stops. Significant values are in bold.*

Company	p value	Spearman Rank
Water-Link	0,76	0,005
WML	**<0,01**	0,049
Dunea	**<0,01**	0,057
Evides	**<0,01**	0,070

According to the results, a significant correlation but with low explained variability between the intake stops and precipitation can be found in the intake stations of Evides, Dunea and WML, as their p-values are under 0,05. In the case of Water-Link there is no significant relation between the two variables.

On average, all stop durations happened during the low precipitation condition at Water-Link, WML and Dunea. In Evides, durations varied more within the precipitation, but the most frequent stops duration happened during low precipitation. All long stops occurred during low precipitation (between 0 and 5mm). Thus, the resuspension of the substances during heavy rainfall are apparently not relevant in the duration and presence of intake stops (Figure 11).

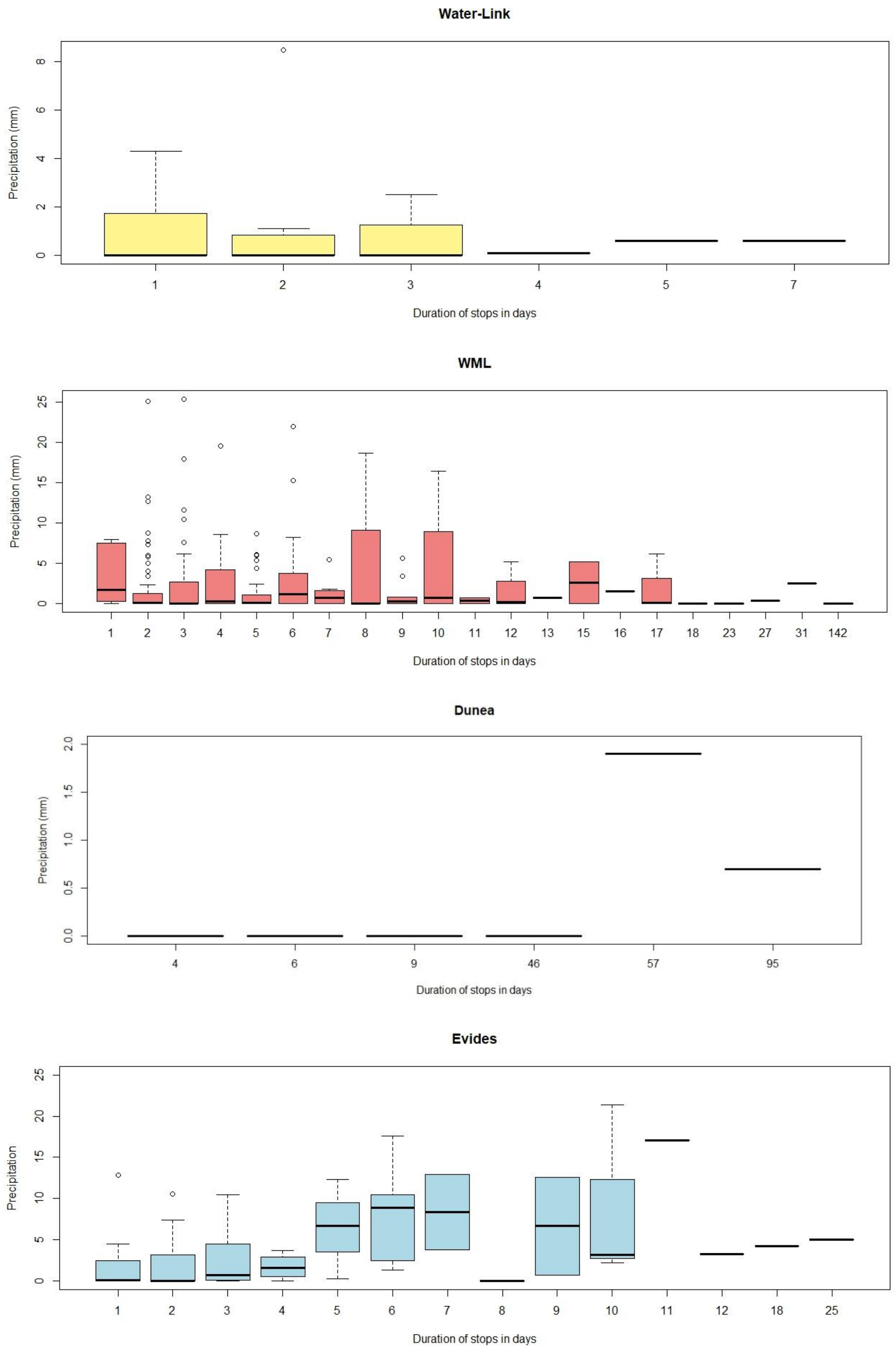


Figure 11 *Distribution duration of stops and precipitation for each drinking water company.*

5. Discussion

5.1 Influence of decision rules on intake stops

Each of the companies manages a different scheme regarding the production of drinking water. Their differences start from their preferred source of water, difference in redundancy between sources, the different water treatments they follow, up to the different techniques used to monitor the water. These differences are also reflected in the number and duration of interruptions of water intake that have occurred in the studied time.

WML with the largest number of interruptions and Vivaqua with no intake stops have in common that the two use mostly groundwater (more than 60%), as their source to produce drinking water. Unlike the other companies, intake stops do not hamper the provision of drinking water, although the quality that can be produced from the redundant groundwater sources has a higher water hardness than the normal surface water sources. WML has a large percentage of groundwater intake, meaning that it can carry out several interruptions of surface water intake and for longer periods. The opposite can be seen in Evides. As it uses less groundwater for their production, intake stops cannot last as long as at WML. Furthermore, the water taken from the Meuse passes through three reservoirs, which can have their water level affected, if the interruption is too long. In the interview with Evides was stated that as soon as the water level from the reservoirs begins to get lower, the mussels and other aquatic organisms start dying, leading to unwanted organic contamination and the eutrophication of the water systems. Therefore, stops of the intake can happen but with a maximum duration of three to four weeks, which is reflected in the results of Figure 8.

The water treatment and the quality of the Meuse in the upstream and downstream, is also an important aspect for taking the water intake stop decision. For instance, Vivaqua has a robust and complete water treatment. It was able to remove most of the CEC, hence the produced water quality complies with all the standards, as stated in the interview. In addition, the Meuse river quality is better in the upstream than in the downstream, as it can be seen in Annex 5 where most of the chosen substances showed lower concentrations in the Belgian intake points of Tailfer and Luik, making the water treatment process much easier for the Belgian water utilities than for the Dutch ones.

The aspect that might have the most influence in the intake stops is the type of monitoring used and, whether the stops activation is done manually or automatically in each company. For instance, the Belgian companies, who make the stops manually are the ones with the less and shorter intake stops. Furthermore, biomonitoring is not used in Vivaqua, which can lead to the non-detection of some CEC and consequently not having intake stops. Water-Link, on the other hand, uses a fish monitor, which is classified not as sensitive as the *Daphnia* bioindicator, being the latter more suitable for monitoring pollution events at low concentrations during short terms (Ren & Wang, 2010).

On the other hand, the Dutch WML and Evides, with 230 and 64 stops respectively, presented a higher frequency of stops due to the mussel and *Daphnia* monitor as seen in Figure 3. Since their stops occurred automatically, as the biomonitoring alarm is activated and they both possess two types of biomonitoring, the possibility of having an intake stop is higher than in the rest of the water utilities. Therefore, with these results, it is clear that the rules and management inside the companies highly influence the decisions and ways of handling an intake stop.

5.2 Relation of Intake stops with river discharge and precipitation

Intake stops can be considered the result of a series of events within the Meuse river basin. The Meuse is a rain-fed river, thus the variations in its flow depend on the dry or wet season. More than 70% of the days in each of the intake stations, presented low flow conditions which means that the precipitation was also low throughout the period studied. These low levels are suitable for less dilution of substances in water. This study as well as Sjerps et al., (2017) , van Vliet et al., (2008) and de Wit et al., (2007) found that water quality decreases at low flow rates. With the increase of pollutant concentrations, especially of CEC, the signaling values are frequently exceeded and detected during the monitoring, which generates alarms and therefore the decision of intake stops.

It is clear the significant correlation, between intake stops and the discharge and precipitation data. Water-Link was the only drinking water company that did not show a correlation between these two variables. The reasons of this might be the few intake stops during the seven-year period, as well as the company decision-making of having or not a stop. Water-Link also does not make the intake directly from the Meuse river, but from the Canal Albert. Pre-treated waters from the Meuse are discharged to this canal, thus the concentrations of CEC are lowered and, it is less probable that an intake stop happens. Dunea also showed few stops but did show a significant relation between discharge and intake stops. The reason behind might be the duration of the stops, although few, some of them were long enough to influence the results of the correlation.

Dunea showed different results in the proportions of intake stops with different discharge conditions. Most of their stops happened with both medium and low flow conditions, which might be due to the area of water abstraction. Dunea uses water from the dunes. When low discharge or and intake interruption occur, water does not flow through the dunes, leading to low water tables and ecological damages (e.g. loss of biodiversity)(Stuyfzand & van der Schans, 2018). When the area reaches medium discharge conditions, Dune areas may have recovered from the low discharge conditions, and thus might be easier to stop the intake.

Intake stops also occurred during high discharge and precipitation conditions as seen in Figure 5 and Figure 10. Heavy rainfalls during these periods can lead to sewage overflows or to a rapid increase of discharge, which can reduce the efficiency of the WWTPs and thus increase the surface water pollution (Mailhot et al., 2015).

In the boxplots relating duration of the intake stops and the discharge and precipitation, it was clearly showed (especially with precipitation) that on average all durations happened during low conditions. Since the discharge conditions were mainly low, the process of dilution of the CEC found in the Meuse must have taken longer and thus, starting the intake might have not been possible as higher concentrations keep appearing in the Meuse with low discharge conditions.

Regarding the Q-C relations, most of the chosen compounds showed a significant correlation with river discharge, as it was expected based on other studies mentioned (Sjerps et al., 2017). As it was found that concentrations are related with discharge, and they increase with low discharge conditions, it can be suggested that concentration also influences the intake stops. Furthermore, the high concentration of pollutants is the main trigger of alarms along the Meuse river. Hence water quality, discharge and the intake stops of the drinking water utilities are related.

6. Conclusions

- A significant relation exists between the intake stops and low discharge and precipitation conditions. Most of the stops and specially the long stops occurred during these conditions.
- Decision rules inside each company are of high importance for the way intake stops are handled. For instance, the stops will depend on the type of monitoring and water treatment used in each company, and for how long they can rely on alternative sources to provide drinking water.
- The increased of dry periods and low discharges in the Meuse has led to the deterioration of its water quality, which could be determined with the Q-C relation. It can be suggested that water quality has a big incidence in the intake stops, and as drinking water target values are more often exceeded with low discharge conditions a higher risk of alarms and stops exist.
- Dutch drinking water utilities presented more intake stops than the Belgian ones. The higher pollution in the downstream of the river lead to more risk of alarms and hence more risk of intake stops.

7. Recommendations

- To standardize information of the intake stops for all drinking water companies using the Meuse. Most of the collected information was not equally organized and complete, thus the use of a same format to fill the intake stops every year will be advantageous. For instance, each of the companies should fill the date of the stops, duration, which alarm triggered the stop and the reasons behind the alarm (with the specific substance if detected). Information will be distributed within the companies along the Meuse river in an easier way and, the understanding of the data will be better for further research.

- Monitoring should be intensified in all drinking water companies. In the case of the Belgian water utilities, biomonitoring (specially *Daphnia* or mussels' monitoring) should be implemented or further developed, as it has shown to be more sensitive to river pollution. In addition, chemical monitoring and samples analysis should be performed more often. Consequently, water utilities will have more time to respond to alerts and, deeper information about substances present in the Meuse might be generated to increase the knowledge of CEC.

- Relations between river discharge and the change in behavior of bioindicators as *Daphnia* or mussels should be considered for further research.

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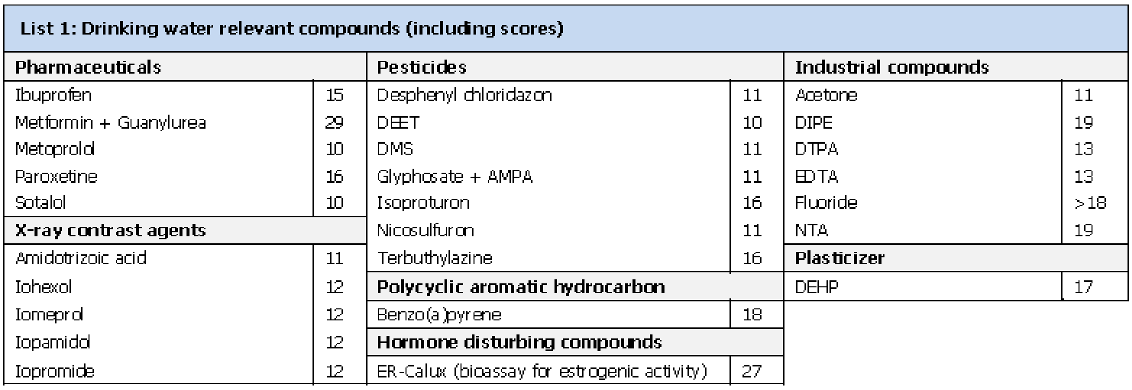
Annex

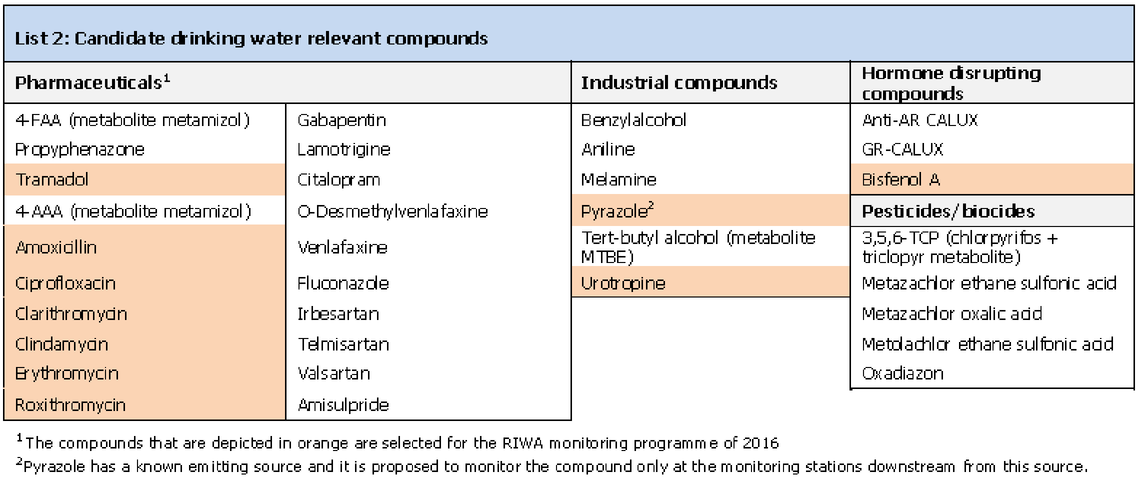
1. List of relevant compound for the drinking water production from the Meuse.



List 1: Drinking water relevant compounds (including scores)

Pharmaceuticals		**Pesticides**		**Industrial compounds**	
Ibuprofen	15	Desphenyl chloridazon	11	Acetone	11
Metformin + Guanylurea	29	DEET	10	DIPE	19
Metoprolol	10	DMS	11	DTPA	13
Paroxetine	16	Glyphosate + AMPA	11	EDTA	13
Sotalol	10	Isoproturon	16	Fluoride	>18
X-ray contrast agents		Nicosulfuron	11	NTA	19
Amidotrizoic acid	11	Terbuthylazine	16	**Plasticizer**	
Iohexol	12	**Polycyclic aromatic hydrocarbon**		DEHP	17
Iomeprol	12	Benzo(a)pyrene	18		
Iopamidol	12	**Hormone disturbing compounds**			
Iopromide	12	ER-Calux (bioassay for estrogenic activity)	27		

***Figure 12** List of Relevant Compounds, taken from An update of the lists with compounds that are relevant for the drinking water production from the river Meuse* (van der Hoek et al., 2015)



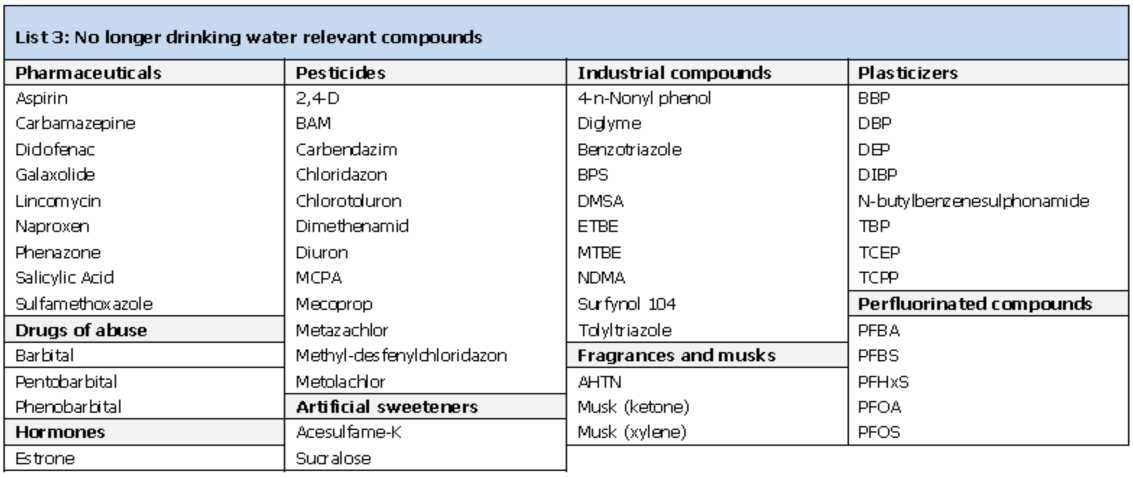
List 2: Candidate drinking water relevant compounds

Pharmaceuticals[1]		**Industrial compounds**	**Hormone disrupting compounds**
4-FAA (metabolite metamizol)	Gabapentin	Benzylalcohol	Anti-AR CALUX
Propyphenazone	Lamotrigine	Aniline	GR-CALUX
Tramadol	Citalopram	Melamine	Bisfenol A
4-AAA (metabolite metamizol)	O-Desmethylvenlafaxine	Pyrazole[2]	**Pesticides/biocides**
Amoxicillin	Venlafaxine	Tert-butyl alcohol (metabolite MTBE)	3,5,6-TCP (chlorpyrifos + triclopyr metabolite)
Ciprofloxacin	Fluconazole	Urotropine	Metazachlor ethane sulfonic acid
Clarithromycin	Irbesartan		Metazachlor oxalic acid
Clindamycin	Telmisartan		Metolachlor ethane sulfonic acid
Erythromycin	Valsartan		Oxadiazon
Roxithromycin	Amisulpride		

[1] The compounds that are depicted in orange are selected for the RIWA monitoring programme of 2016

[2] Pyrazole has a known emitting source and it is proposed to monitor the compound only at the monitoring stations downstream from this source.

***Figure 13** List of Candidate Relevant Compounds, taken from An update of the lists with compounds that are relevant for the drinking water production from the river Meuse* (van der Hoek et al., 2015)



List 3: No longer drinking water relevant compounds

Pharmaceuticals	**Pesticides**	**Industrial compounds**	**Plasticizers**
Aspirin	2,4-D	4-n-Nonyl phenol	BBP
Carbamazepine	BAM	Diglyme	DBP
Diclofenac	Carbendazim	Benzotriazole	DEP
Galaxolide	Chloridazon	BPS	DIBP
Lincomycin	Chlorotoluron	DMSA	N-butylbenzenesulphonamide
Naproxen	Dimethenamid	ETBE	TBP
Phenazone	Diuron	MTBE	TCEP
Salicylic Acid	MCPA	NDMA	TCPP
Sulfamethoxazole	Mecoprop	Surfynol 104	**Perfluorinated compounds**
Drugs of abuse	Metazachlor	Tolyltriazole	PFBA
Barbital	Methyl-desfenylchloridazon	**Fragrances and musks**	PFBS
Pentobarbital	Metolachlor	AHTN	PFHxS
Phenobarbital	**Artificial sweeteners**	Musk (ketone)	PFOA
Hormones	Acesulfame-K	Musk (xylene)	PFOS
Estrone	Sucralose		

***Figure 14** List of No longer Relevant Compounds, taken from an update of the lists with compounds that are relevant for the drinking water production from the river Meuse* (van der Hoek et al., 2015)

2. Interviews

2.1 Questions Interview:

1. How is the process of the water intake at the company?
2. How much water is abstracted per hour/daily? For how many persons?
3. Is there any treatment (e.g screens) during the intake of the water?
4. Do you usually have intake stops? What are the main reasons for these stops?
5. If you don’t have intake stops, what are the reasons for not having?
6. What do you do when the water quality of the Meuse exceeds the signaling value?
7. In which cases would you consider having an intake stop?
8. Do you count with alternative sources of water? If so, do you use them at the same time with the River or just in case of emergency?
9. In case of drought what is your emergency plan for the intake of water?
10. How you respond to the actions or alerts of the government or other drinking water companies, when the water quality is bad?
11. What monitoring procedures do you use? (e.g Biomonitoring: *Daphnia*)
12. After the intake, what treatment do you give to the water?
13. In the last years the presence of emerging substances (pharmaceuticals, pesticides etc..) has increased in the Meuse. How do you approach this problem in order to comply with the standards of drinking water sources?
14. In case of high concentration of emerging substances, do you usually ask for permits to the government or water boards to keep the intake? If so, how do you determine for which substances you can omit the alarm?

2.2 Summary of the interviews

Table 6 *Summary Interviews.*

	Vivaqua	Water-Link	WML	Dunea	Evides
Alternative Sources	Groundwater	Groundwater	Groundwater	Reservoir of groundwater, leg of the Rhine.	Reservoirs Emergency case: Water from the Rhine.
Monitoring	Risk analysis, in case of need chemical and biomonitoring	HPLC, Biomonitoring	HPLC, Biomonitoring	HPLC, Biomonitoring	HPLC, Biomonitoring
Alert system	Alerts from government or DW companies.	Fish Alarm, Alerts from government or DW companies.	Daphnia and Mussels alarm. Government or DW companies alarms.	Daphnia and Mussels alarm. Government or DW companies alarms.	Daphnia and Mussels alarm. Government or DW companies alarms.
Intake Stops	No	Yes	Yes	Yes	Yes
Decision of stops	Employees make decision.	Chemical monitoring. Alerts from companies and government.	Automatically when daphnia or mussel alarm is activated. Alerts from companies and government.	Automatically when daphnia or mussel alarm is activated. Alerts from companies and government.	Automatically when daphnia or mussel alarm is activated. Alerts from companies and government.
Start Intake	-	Water quality values are back to “normal”.	Water quality values are back to “normal”. Daphnias or mussels behave normally again.	Water quality values are back to “normal”. Daphnias or mussels behave normally again. No more alternative source.	Water quality values are back to “normal”. Daphnias or mussels behave normally again. No more alternative source.

3. Script

3.1 Q-C Relation

```
#GLYPHOSATE
glyphosate <- read_excel("Utrecht/RIWA/Substances.xlsx",  sheet = "Glyphosate")#Read excel file
fit1  = lm(C~I(1/Q), data=glyphosate)#Linear regression Q-C data
r2glyphosate = format(summary(fit1)$r.squared, digits = 2)#Save r2 value
library(ggplot2)
ggplot(glyphosate, aes(x=Q, y=C) ) +geom_point(size = 1)+ xlim(0,1800)+ labs(title="Glyphosate",
       x ="Discharge (m3/s)", y = "Concentration (µg/L)") +
  stat_smooth(method = "lm", formula = y ~  I(1/x), size = 1) #Plot Q-C relation
summary(fit1) #Find values of a,b, std, r
cor.test(glyphosate$Q,glyphosate$C)# Pearson
```

3.2 Analysis Intake Stops

```
library(readxl);
Evides <- read_excel("~/Utrecht/RIWA/Evides.xlsx", sheet = "Data"); #Read data of Evides
dataevides=Evides;
stopsevides=c(dataevides$Stops); #Column stops evides
dischargekei=c(dataevides$Dischargek); #Column discharge at Keizersveer
flowtypekei=c(dataevides$Type); #Classification discharge (Low, medium, high)
classrainkei=c(dataevides$Class); #Classification Rain
Instops=factor(stopsevides,labels=c(0,1)); #Label stops in yes and no

dfevidesQ=data.frame(Instops,flowtypekei);#Data just with stops and type of flow
dfevidesP=data.frame(Instops,classrainkei);#Data with stops and rain
tabQevides=prop.table(table(dfevidesQ),1)*100 ;#Proportions of type of flow for Yes/No(stops)
tabPevides=prop.table(table(dfevidesP),1)*100 ;#Proportions of type of flow for Yes/No(stops)

tablView(tab);
```

```
proportionsevidesQ=data.frame(tabQevides);#Set proportions of Q as data frame
proportionsevidesP=data.frame(tabPevides);#Set proportions of P as data frame

freqQ=c(proportionsevidesQ$Freq); #Substract frequencies from data frame
freqP=c(proportionsevidesP$Freq); #Substract frequencies from data frame
yesfreqQ=proportionsevidesQ[proportionsevidesQ$Instops==1,"Freq"] ;#Frequencies Q for Stops=yes
yesfreqP=proportionsevidesP[proportionsevidesP$Instops==1,"Freq"] ;#Frequencies P for Stops=yes

propallQ=data.frame(yesfreqQ,yesfreqdunQ,yesfreqWmlQ, yesfreqWaterlinkQ); #Join all frequencies of the dw companies
proptQ=as.data.frame(t(propallQ)); #Set as data frame
View(proptQ)
proptableQ=as.matrix(proptQ)
colnames(proptableQ)=c("High", "Low", "Medium") #Set names of columns
row.names(proptableQ)=c("Evides", "Dunea", "WML", "WaterLink") #Set names of rows
proptableQ=proptableQ[,c("Low","Medium","High")] #Organize in ascendant order
barplot(proptableQ,ylim=c(0,100),xlab="Discharge conditions",
    legend.text= TRUE,  ylab="Number of events(%)",
    main="Proportion of Intake Stops against Discharge ",
    beside= TRUE, col= c("lightblue", "lightgreen", "lightcoral","khaki1")) #Plot proportions of intake-discharge as barplot

propallP=data.frame(yesfreqP,yesfreqdunP,yesfreqWmlP, yesfreqWaterlinkP);
proptP=as.data.frame(t(propallP));
View(proptP)
proptableP=as.matrix(proptP)
colnames(proptableP)=c("High", "Low", "Medium")
row.names(proptableP)=c("Evides", "Dunea", "WML","WaterLink")
proptableP=proptableP[,c("Low","Medium","High")]
barplot(proptableP,ylim=c(0,100),xlab="Precipitation conditions",
    legend.text= TRUE,  ylab="Number of events(%)",
```

```
      main="Proportion of Intake Stops against Precipitation ",

      beside= TRUE, col= c("lightblue", "lightgreen", "lightcoral","khaki1"))
```

###Frequencies of durations of stops

```
dutableWml=prop.table(table(dataWml$Duration))*100

 barplot(dutableWml, ylim=c(0,60), xlab="Duration of stops in days",

       main="WML",ylab="Frequency", col="lightcoral")
```

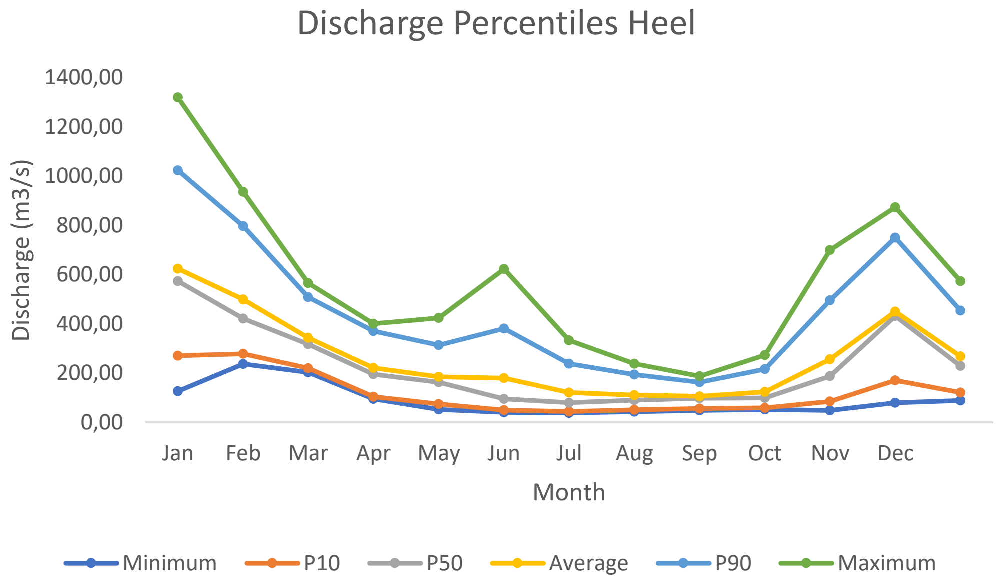
#####Frequency Reasons

```
 reasonsdunea=prop.table(table(datadunea$Reason[datadunea$Stops %in% 1]))*100 #Find proportions of reasons

 reasonsdunea=round(reasonsdunea, digits=2) #Round results with two digits

 labsdu<- paste("",names(reasonsdunea),"","", reasonsdunea, "%",sep=" ") #Join reason with percentage for labeling

 pie(reasonsdunea, labels=labsdu, col=rainbow(length(reasonsdunea),s=0.5),border= "White", main="Dunea",
cex=0.7, clockwise = TRUE) #Plot pie chart
```

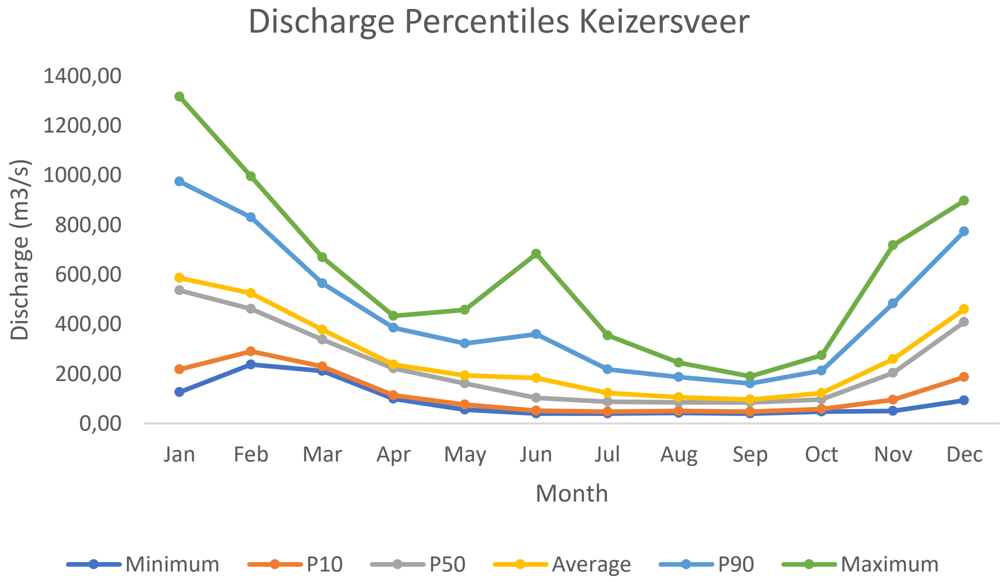
####Boxplots Discharge vs Duration of stops.

```
yesdurwaterlink=data.frame(dataWaterlink$Duration,

                    dataWaterlink[dataWaterlink$Duration>0, "DischargeL"])

duwaterlink=boxplot(yesdurwaterlink$DischargeL~yesdurwaterlink$dataWaterlink.Duration,

              col="khaki1", ylab="Discharge (m3/s)",

              xlab="Duration of stops in days", main="Water-Link")
```

4. Discharge Percentiles



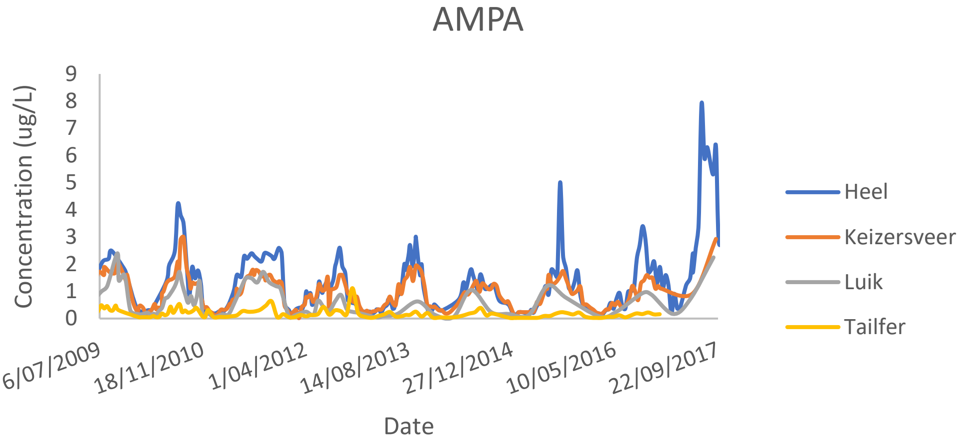
a)



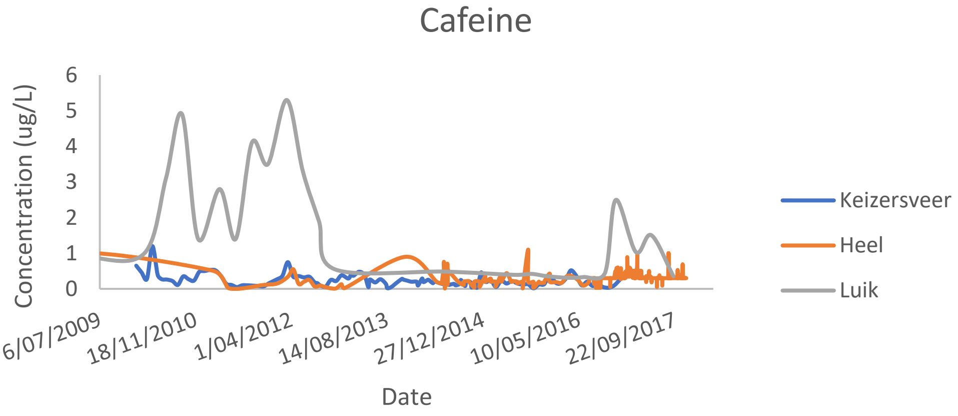
b)

***Figure 15** Discharge percentiles for the stations Heel (a) and Keizersveer (b).*

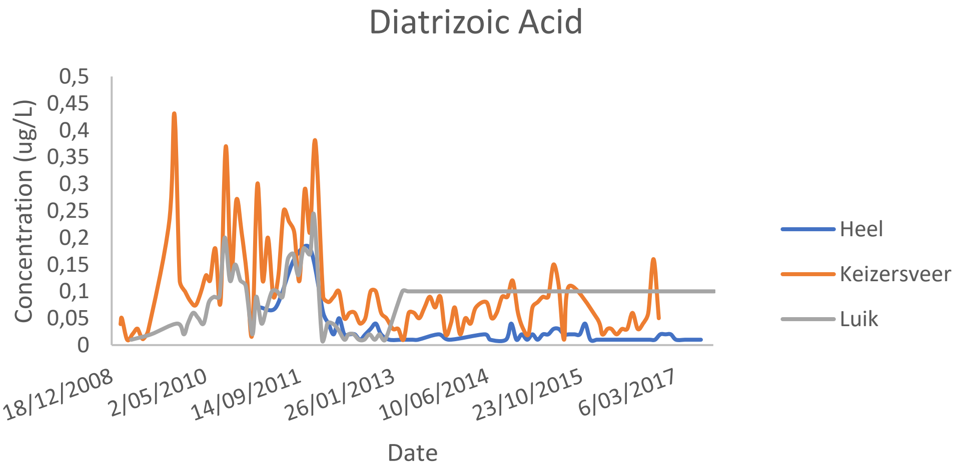
5. Comparison of substances concentrations in the different intake stations



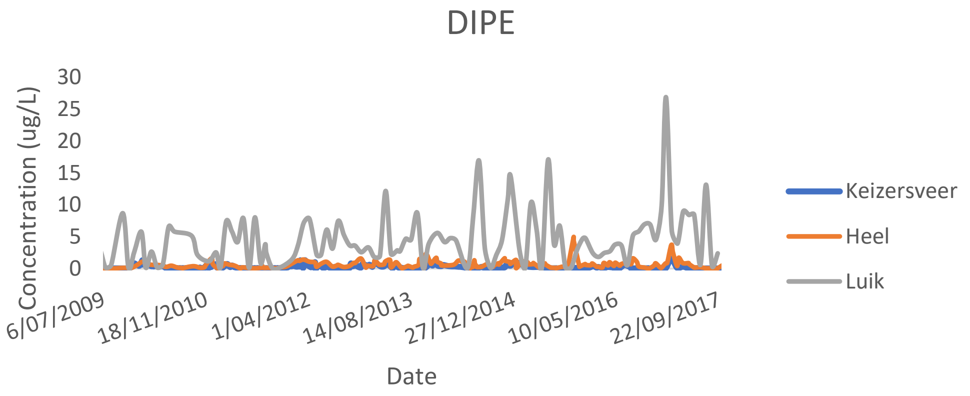
a)



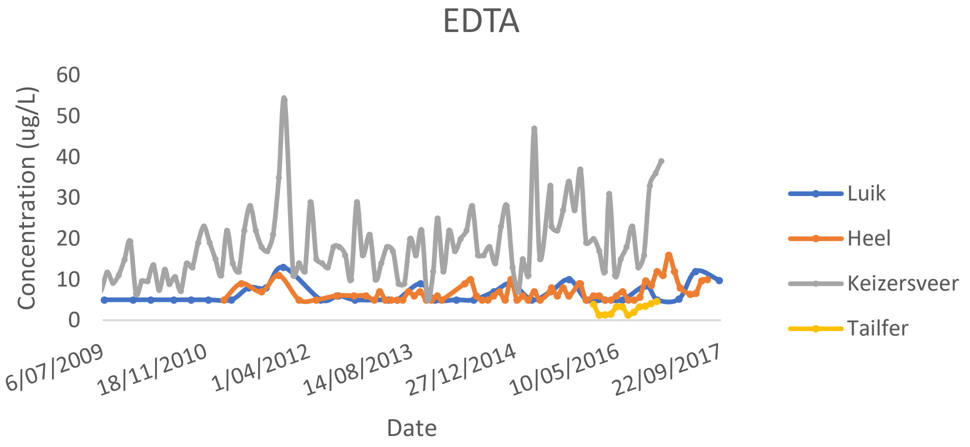
b)



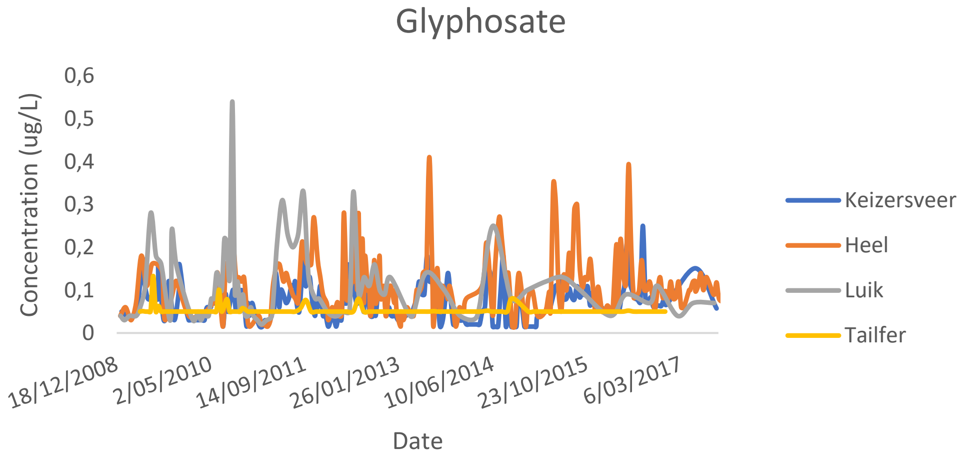
c)


DIPE
Concentration (ug/L)
30
25
20
15
10
5
0
6/07/2009
18/11/2010
1/04/2012
14/08/2013
27/12/2014
10/05/2016
22/09/2017
Date
Keizersveer
Heel
Luik

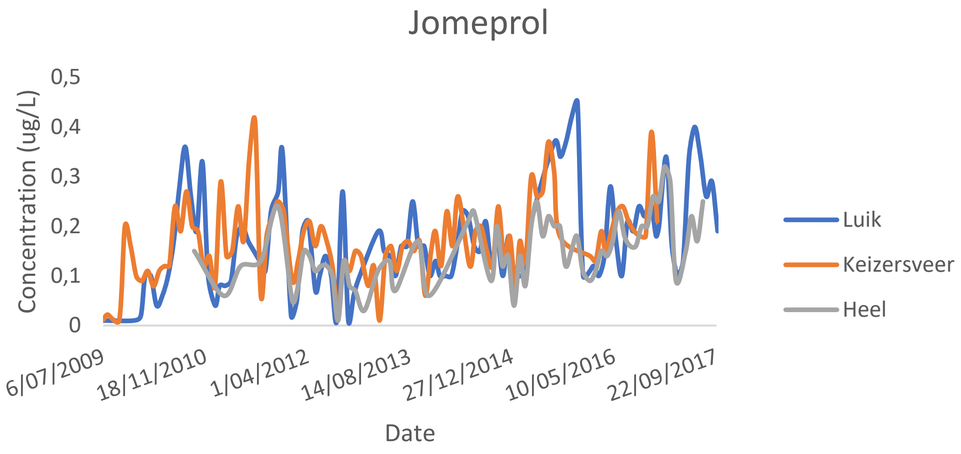
d)


EDTA
Concentration (ug/L)
60
50
40
30
20
10
0
6/07/2009
18/11/2010
1/04/2012
14/08/2013
27/12/2014
10/05/2016
22/09/2017
Date
Luik
Heel
Keizersveer
Tailfer

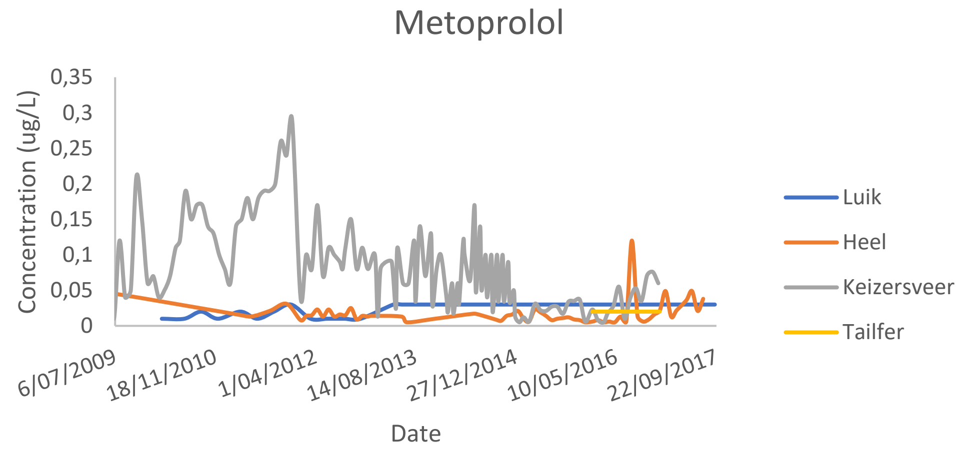
e)


Glyphosate
Concentration (ug/L)
0,6
0,5
0,4
0,3
0,2
0,1
0
18/12/2008
2/05/2010
14/09/2011
26/01/2013
10/06/2014
23/10/2015
6/03/2017
Date
Keizersveer
Heel
Luik
Tailfer

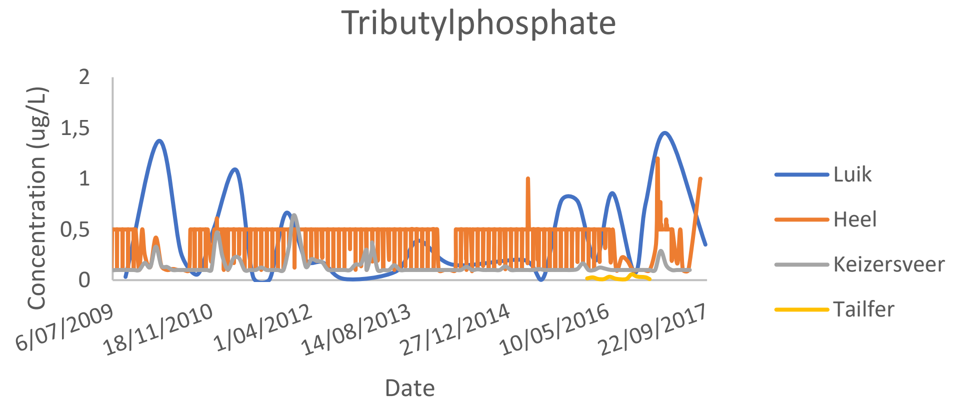
f)



g)



h)



i)

Figure 16 *Comparison Concentration of susbtances in the different intake stations. Tailfer data for Cafeine, Diatrizoic Acid, DIPE and Jomeprol was not available.*