Individual internship report

5th year

Water quality assessment of urban runoff into a protected peatland

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Acknowledgments

I am expressing my gratitude to all those who have contributed to my internship experience.

First, I want to thank my supervisor Christian Damm, for taking me as intern, entrusting me with his project and accompanying me throughout my internship.

I am grateful to the Karlsruher Institut für Technologie and more particularly in Aueninstitut for welcoming me as part of the team and for their continuous support. Working with them all has been a valuable learning experience and gave me a better understanding of their research projects. A special thanks to all my colleagues for their assistance and encouragement, Lars Gerstner, Gerda Fritz, Mareike Roeder, Isabell Becker, Ethan Householder, Erika Schneider, Timo Jäger, André Araújo da Paz, Beatriz Nieto Ariza, Astrid de Oliveira Wittmann, and the others. Their help, expertise, and simply their company made my time here more enjoyable and interesting.

A special thanks also to the colleagues and researchers from the Institut für Wasser und Umwelt, Jan Wienhöfer, for accompanying and helping me with the SWMM model, Stephan Fuchs and Karoline Morling, for their time and sharing their precious knowledge of chemical contamination and water treatment.

Thank you to my university professor Catherine Boisneau for her supervision and advice throughout this internship, and my second jury Nathalie Gassama, for meeting me and guiding me for my method and protocol of water analysis.

Finally, I would like to thank my family and friends for their constant support and encouragement throughout this journey. A big thank you to Arthur and Léa, for putting up with me all this time, supporting me and helping me with statistics and Python.

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Overview of the internship

This end-of-studies internship is part of the Ingénierie des Milieux Aquatiques (IMA) degree in the Aménagement et Environnement department at Polytech Tours. It was carried out from February 15 to August 15, 2024, at Karlsruhe Institute of Technology in Rastatt, Germany.

The internship took place in a research center that focuses on Floodplain research. I found this internship through my university, by asking one of my professors for contacts in Germany. I wanted to work on projects outside of France to witness the differences in legislations and practices. Thanks to the KIT, I was given the opportunity to discover the field of research and what it entails, from conceptual studies to field work. Several projects were proposed to me, and I ended up working on the rewetting of a small suburban wetland in the area of Rastatt.

I had the chance to have a multidisciplinary internship, where I was able to do field work, sampling, chemical analysis in a laboratory, and modeling with an American hydraulic software (StormWater Management Model). I enriched my knowledge on fen and more largely floodplain ecosystems, as well as chemical contamination, by experiencing it first-hand in the field, discussing it with my colleagues and other researchers specialized in the domain, and reading scientific literature on the topic. I was able to get successful and interesting results, but also had to question and adapt my methods to suit my work as my internship progressed and with my new findings.

The tasks I conducted were part of the conceptual study "Rastatter Bruch – Model development of a suburban wetland":

- Review the scientific literature on potential chemical contaminations from urban runoff of a residential area, as well as threshold and precautionary values for contaminants introduced into the environment,
- Propose and conduct a protocol for water sampling of a sewer system outlet discharging urban runoff into a protected wetland,
- Assess water samples for nutrients and physical parameters; interpret the results and identify trends related to time and precipitation,
- Execute a protocol for soil sampling, and interpret the results from the laboratory, to conclude on the need to filter the water before it enters the peatland,
- Have a first attempt with a rainfall–runoff simulation model to run long-term simulations and runoff quantity and quality,
- Search and propose technical solutions to integrate water treatment facilities into the city that are using soil bioengineering technologies, and take into account the future adjacent development project of a new residential area, will which also direct its stormwater into the peatland.

Presentation of the host organization

The Karlsruher Institut für Technologie

The Karlsruhe Institute of Technology, or KIT, is a public research university located in the city of Karsruhe, in the federal state of Baden-Württemberg, Germany. Created in 2009 from the merge between the former University of Karlsruhe and the Karlsruhe Research Center, KIT brings together a wide range of disciplines in engineering sciences as well as in natural sciences, economics, or human and social sciences, with its historical background still focusing on technical disciplines.

As presented in the Figure 1 below, KIT is a large entity categorized into five divisions, each of them organized into sub-institutes that each focus on one specific domain of science. The Institute of Geography and Geoecology investigates the response of social and ecosystems to environmental changes such as climate change, altered material cycles and species loss. Interconnecting, pedology, hydrology, vegetation science, climatology and social science, it strives for a sustainable interdisciplinary approach to our environment.

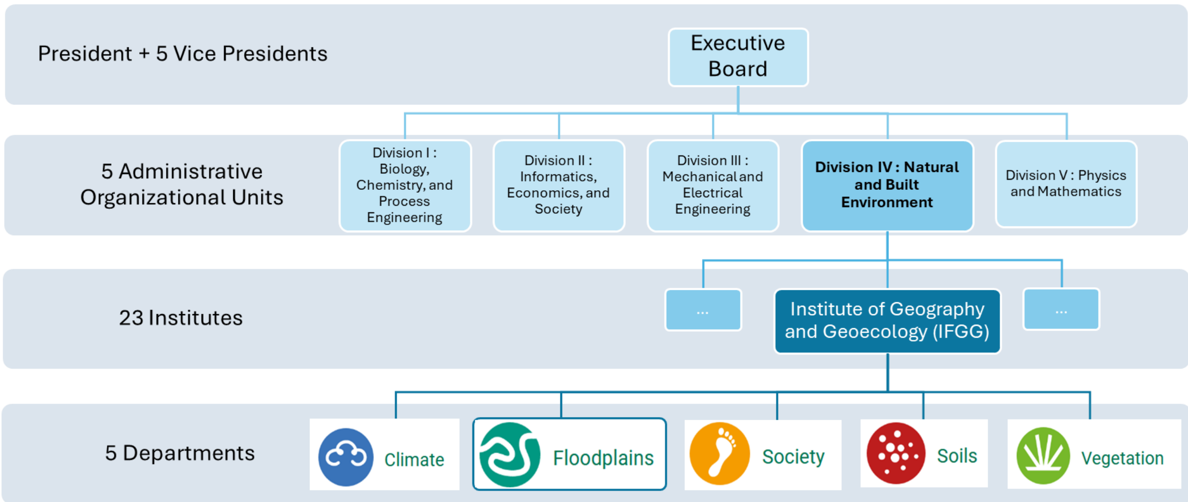

Figure 1 : Simplified organization chart of the Karlsruher Institut für Technologie to focus on the Floodplain department (Aueninstitut)

The Floodplain department

This internship takes place in the department of wetland ecology, which was initially founded in the city of Rastatt by the World Wildlife Fund (WWF) as the Floodplain Institute in 1985. Since then, it has conducted numerous study projects in various river landscapes around the globe, such as in the Upper Rhine Valley here in Baden-Württemberg, the Danube Delta in Romania, or the tropical floodplains in Amazonia.

After joining KIT in 2004, the department continued working on these topics, and is currently carrying out more in-depth research on these biodiversity-rich alluvial plains. Focusing on flood protection, floodplain development and renaturation, the team also develops and plans concrete management solutions for floodplain areas. One of the current projects at local scale involves the model development of a suburban peatland, which will be the focus of this internship.

1. Introduction

1.1. Global context: current environmental challenges

In 2023, “nearly 90 percent of the world’s wetlands have been degraded or lost”[1]. Human activities, particularly land use change, drainage and peat extraction have caused the loss of 25% of European peatlands, and Germany accounted in 2017 for more than 90% of peatland degradation (Tanneberger et al., 2021).

Peatlands are a type of wetland that is partially or completely waterlogged throughout the year, resulting in an accumulation of peat, organic matter that does not or only partially undergo decomposition processes due to anoxic conditions. In addition to the rich biodiversity that they foster, peatlands are the largest natural terrestrial carbon sink, and their water storage role greatly regulates annual water availability on a landscape scale. Their destruction is a major source of greenhouse gas release into the atmosphere, responsible for almost 5% of global anthropogenic carbon dioxide emissions, and drained peatlands lose their hydrological buffer function, increasing flood risks and lowering minimum flow levels (IUCN, 2021).

In this regard, peatland restoration is one of the carbon dioxide removal methods considered in the IPCC’s sixth report, and the only option that can sequester carbon indefinitely (Intergovernmental Panel On Climate Change (IPCC), 2023). Peatland restoration consists in rewetting the area, to restore anoxic conditions and prevent mineralization processes, trapping the carbon contained in dead organic matter. The Paris Agreement implies the rewetting of 50 million hectares worldwide of drained peatlands. Although restoration results in the first years in enhanced methane emissions, studies show that the long-term capture of CO_2 in rewetted peatlands more than compensates CH_4 radiative forcing (Günther et al., 2020; Renou-Wilson et al., 2019). Benefits also include the decrease of nitrous oxide emissions, enhanced infiltration and nutrient retention, improvement of water quality as well as recovery of original biodiversity (IPCC, 2023).

1.2. Context of internship: improved management of a wetland close to the city

The Rastatter Bruch nature reserve is a riverine peatland originating from an old side channel of the Rhine River, located on the outskirts of Rastatt. Classified as a nature and landscape conservation area, this nature reserve is of great ecological value, but has been threatened for decades by increasing desiccation, due to local drainage and climate change.

Funded by the Landesstiftung Naturschutzfonds Baden-Württemberg, the 3-year project, called “Rastatter Bruch – Modellhafte Entwicklung eines stadtnahen Feuchtgebietes” (Rastatter Bruch – Model development of a suburban wetland), led by Dr. Christian Damm, started in April 2022 with the main objective of a conceptual framework for the rewetting and restoring the peatland. The project assesses the water balance of the peatland, by measuring precipitation and groundwater, and creating a groundwater model. Technical solutions will be proposed for improved water management and carbon storage, to safeguard the fen ecosystem. Following guidelines for peatland restoration (IPS, 2002), drain blocking being tested to rewet the area, allowing longer water residence time within the wetland.

[1] Dr Musonda Mumba, Secretary General of the Convention on Wetlands for World Wetlands, 2023.

Blocking drains will be especially effective, considering the stormwater sewer system from a nearby residential area that runs alongside into the peatland through one outlet: instead of staying in the ditches and passing by the peatland, the stormwater might as well be diverted into the fen, to be absorbed by the soil and utilized by plants. However, this means that the quality of this stormwater must be pretested and monitored in the long run, as this introduces the risk of pollutant accumulation and potential damage to the peatland ecosystem.

The challenge of this internship will be to assess the potential of contamination using different methods and protocols, to answer the following question:

Does the stormwater coming from the Münchfeld area require filtration, in order to ensure the ecosystem's well-being and meet the legal criteria established in Germany?

If necessary, adequate technical solutions will then be proposed.

1.3. Missions assigned: water quality assessment of urban runoff into a protected peatland

During this internship, I was entrusted with several tasks as part of the Model Development project in the Rastatter Bruch, allowing me to take part in these investigations and evaluations.

1.3.1. Sampling in the peatland and analysis for pollutant detection

A significant part of my mission involved investigating pollutant concentrations from residential areas on runoff entering the peatland. This required firstly an extensive literature review on the types of pollutants typically found in stormwater runoff from residential zones, such as heavy metals, nutrients, organic compounds, plastics or microbial contaminants. Understanding these pollutants was crucial for assessing their potential effects on the peatland ecosystem.

With my tutor Dr. Christian Damm, we then agreed on a protocol to collect and analyze possibly contaminated samples from the Rastatter Bruch. It seemed apparent that water samples from the stormwater network outlet should be the focus of the analysis, but a meeting with Dr. Stephan Fuchs from the Department of Water Quality Management encouraged us to also sample the soil of the peatland to give to analysis, which we did in parallel of the water sampling. Throughout the six months, multiples water samples were collected and analyzed by me, and the protocol was modified with the improvement of our understanding of the challenges. Careful consideration was brought to environmental factors, such as weather conditions (rainfall events, temperature, evapotranspiration), seasonal variations, hypotheses on potential sources of pollution. The soil samples were collected only once and brought for a more detailed analysis to the TZW laboratory (Technologiezentrum Wasser Karlsruhe), enabling us to have a broader idea of the different types of pollutants present in the Rastatter Bruch.

I also had to interpret the results, and a comparison of the measured pollutant concentrations to established legal thresholds was conducting in order to assess the potential risks of contamination in the peatland habitat. This comprehensive approach, from literature research to protocol development, sample collection, analysis, and result interpretation, provided valuable insights into the quality of stormwater entering the peatland and informed recommendations for mitigating any identified risks.

1.3.2. Modelling of urban runoff with the StormWater Management Model

Another mission I was given was to use a modeling software called the StormWater Management Model (SWMM) to create a model and run long-term simulations to analyze the water quantity and quality entering the peatland. Because the peatland is receiving stormwater from a nearby residential area, each rainfall event leads to the washoff of pollutants that have built up on the ground surface, possibly impacting the peatland's ecosystem.

When I started this task, I had no prior knowledge of the SWMM software. Fortunately, I was not alone in this task as this mission was also assigned to Dr. Jan Wienhöfer, who also works on the Rastatter Bruch project but on the quantitative aspect. Together, we discovered the model and tried to navigate around understanding the basics and applications to urban runoff scenarios.

In the end, the model was only partially prepared, and my internship ended during the calibration step, which did not allow me to finish the model and provide any interesting simulation in terms of quality. At the request of my supervisor, I stopped working on the model to focus on my other missions, and decided not to present my work in this report.

1.3.3. Research into technical suggestions for filtering urban runoff water

In parallel to the mission, I was tasked with researching and prospecting technical suggestions for the filtration and treatment of urban runoff water. With an in-depth review of existing literature on stormwater management and treatment technologies, the objective was to identify effective solutions that could be applied in urban settings. My role required me to conduct a comprehensive survey of academic papers, technical reports, and case studies that addressed various aspects of stormwater treatment. This included exploring the effectiveness of different filtration methods, such as sedimentation tanks, constructed wetlands or bioretention systems. My research focused on finding sustainable and efficient solutions that not only meet regulatory standards but also contribute to the reduction of pollutants in urban runoff, thereby improving water quality in urban environments. The objective would be to then implement these facilities close to the stormwater outlet or within the residential area, and also to propose then for the future project of a nearby former military area that would be developed into another residential area.

1.3.4. Secondary missions

Finally, during this internship I occasionally could assist in the work of my colleagues, which was always an opportunity for me to learn more about their job and research subject. For example, I helped with the identification of endemic flora of the riverbanks in Kyrgyzstan, which will facilitate the work of on-field inventory, a necessary step to better understand the dynamics of the vegetation in the alluvial plains of the Naryn River. I also followed a team of forestry specialists to measure the height of different tree species in an area close to the Rhine River. These measurements will be of great importance to follow the growth and development of such species in a wetland. From June to August, I regularly went to the Rastatter Bruch to read the measures of the tensiometers set up at various locations of the peatland, as well as empty the rainwater station reservoir. All these devices will provide additional data to get a clearer overview of the seasonal hydrological dynamics of the Rastatter Bruch.

2. Methodology

2.1. Study area: the Rastatter Bruch and the suburban areas

The NSG-Rastatter Bruch is a 67.9-hectare protected wetland located in the western periphery of Rastatt, a city of the German region of Baden-Württemberg. It is situated approximately 6 kilometers away from the Rhine River, in the former Rhine floodplain (illustration Annex I). If "Bruch" loosely translates as "swamp", this wetland qualifies more as a floodplain peatland or a fen. The area was largely used as wet meadows and in parts even farmland until about 1980. Since then, it has been partly abandoned, turning into secondary moist willow-forest and being partly still maintained by extensive meadow use. In 1990, the suburban peatland gained its national protection status as a nature conservation area (NSG) and was classified by the IUCN in "Category IV – habitat or species management area" (Rhine Atlas, ICPR, 2020).

2.1.1. Geological and soil formation

The formation of the Rastatter Bruch is intricately tied to the geomorphological processes of the Upper Rhine Plain. This region is a graben, a tectonic rift stretching 300 km from Frankfurt to Basel and resulting in a vast depression in the landscape, in between the German Black Forest and the French Vosges mountains. The area's geomorphology has been shaped by significant sedimentation and erosion, particularly by the postglacial Rhine cutting into glacial gravel (*Erami R., 2023*). Located in the former floodplain of the Rhine River, the Rastatter Bruch is the result of an oxbow formation, that became a low peatland over time, due to the presence of a persistently high groundwater table (*SIGESRM BRGM, 2006)*.

Figure 2 shows a progression through various depositional environments, reflecting changes in hydrological conditions, sediment supply, and biological activity over time. The base layer of the profile consists of gravel and sand, coarser materials that indicate initial deposition under high-energy

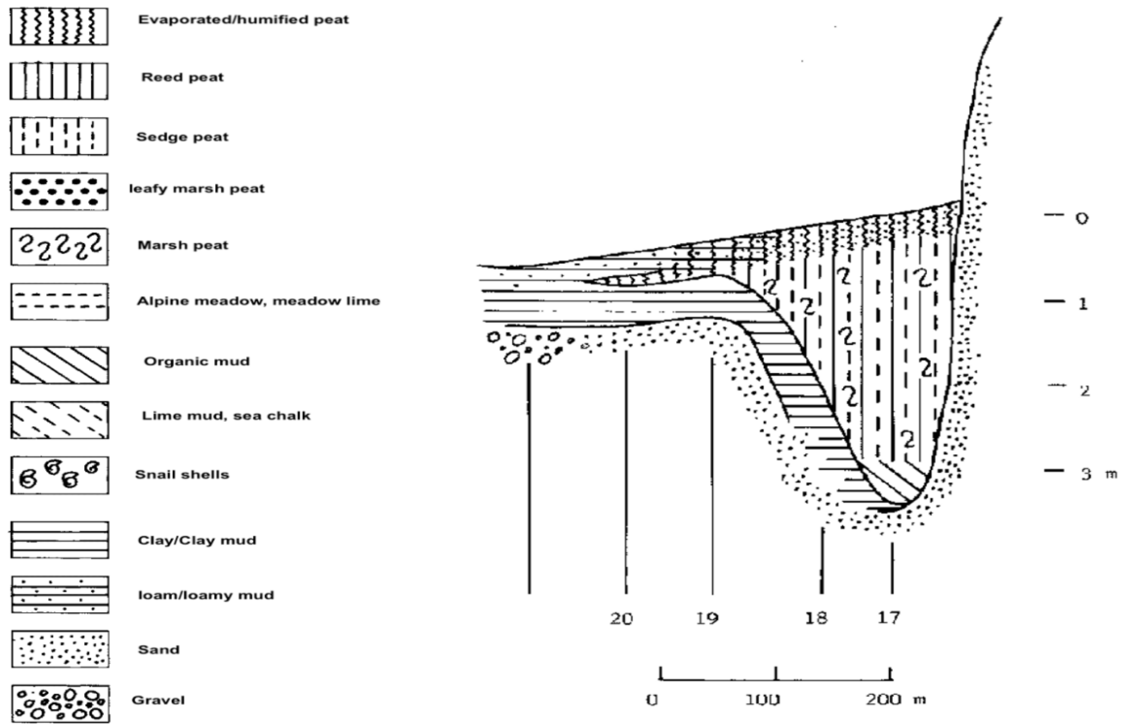

Figure 2: Profile section of the Rastatter Bruch presenting its different soil layers (Erami R., 2023; LfU, 2003)

conditions, such as a riverbed environment. The gravel and sand layers suggest a period when water flow was strong enough to transport and deposit larger particles.

Above the gravel and sand, there is a transition to finer sediments like clay and clay mud, alluvial deposits, typical in alluvial plains. This is evidence of a progressive decrease in water flow velocity and a slow sedimentation, where fine particles could settle out of suspension, typical of a floodplain environment. A river course cutting into the adjacent cut-slope entrenched a significant channel, which subsequently was filled with a series of sediments, starting with a conspicuous, fine mineral-organic layer of green-blue gyttja, a homogeneous mix of clay and organic material. Above this dense bottom layer, a long history of organic peat layer accumulated over a couple of thousand years. This simultaneous buildup of peat suggests an environment rich in organic material with periods of sustained waterlogging, which created anaerobic conditions favorable for the preservation of plant material. The uppermost layers are mineralized humified peat, most likely resulting from drainage for agricultural purposes over the last two hundred years. (LfU, 2003; Erami R, 2023).

Today, the Rastatter Bruch is a 3-meter-thick peatland located approximately 113 meters above the sea level. Located at the edge of the Rhine floodplain, the Bruch is settled next to a 10-meter elevation gain that is a former cutbank of the Rhine (as seen in Figure 3, with the location of the cross-section presented Annex II).

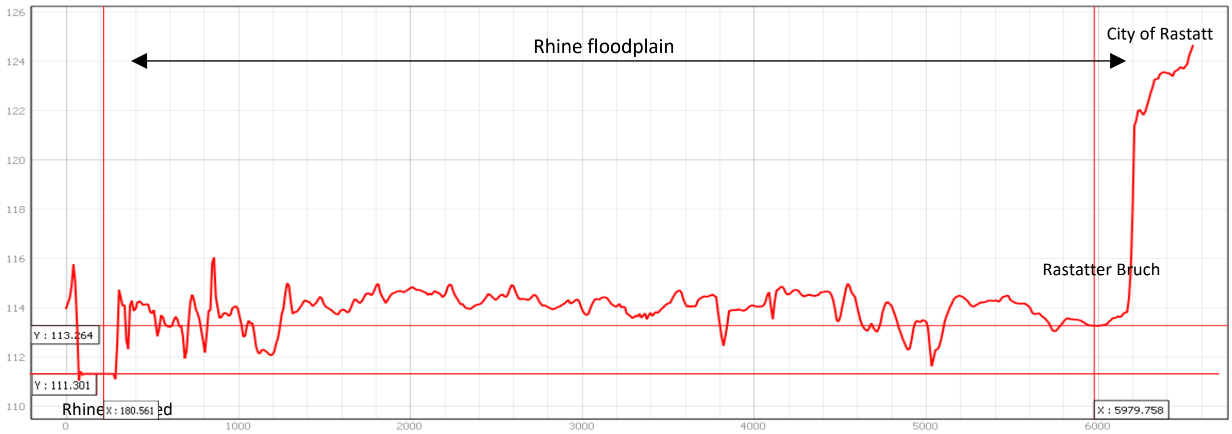

Figure 3: Topography of the Rhine floodplain from the Rhine River to the Rastatter Bruch (S. Gaudefroy, 2024)

2.1.2. Hydrology

Hydrogeological studies of the area reveal multiple aquifers, with significant groundwater resources in the Late Quaternary deposits. Groundwater plays a major role in the hydrology of the peatland, with additional contributions from local tributaries such as the Murg river, and precipitation. *Erami* (2023) states that groundwater levels depend primarily on winter precipitation, and typically rises between November and March, to then fall until October. According to the *Landesanstalt für Umwelt Baden-Württemberg* (LUBW), the distance of the groundwater varies between 0 and 4 meters below the ground surface depending on the location in the Bruch, often inferior to 1 meter, and is approximately 30 to 40 meters thick (see Annex III). This shallow aquifer, interacts with the surface, maintaining wetland conditions even during drier periods.

These conditions are very common in the "Ried" (meaning "reed" in German) or "Bruch" ("swamp") regions, where spongy wet and alkaline meadows develop on Holocene flood silts of the Rhine. The natural environment of the Ried is entirely conditioned by the presence of this abundant, nutrient-rich groundwater at a shallow depth in the soil, periodically rising and flooding the area (*SIGESRM BRGM, 2006*). This kind of minerotrophic peatland is called a fen.

Although secondary, precipitation also plays a role in the water supply of the wetland. The recording in a nearby rain station (ST4077) receives an annual average precipitation of approximately 900 mm (see Figure 4 below). Precipitation patterns in the area show a modest seasonal variation, with the lowest monthly average rainfall occurring in April (63 mm), and the highest in May (88 mm), sometimes even temporarily rising the groundwater in this period.

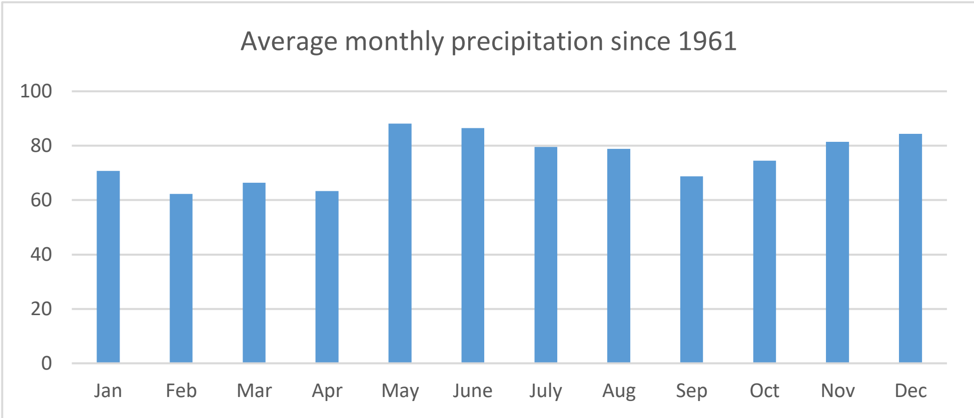

Figure 4: Average monthly precipitation in the Rastatter Bruch, calculated from data since 1961 (S. Gaudefroy, 2024)

Additionally, the Rastatter Bruch features numerous artificial ditches, once used to drain the wetlands. For now, this water does not enter the peatland, with the exception of high discharges which could lead to overflows in the fen, but with the new project of blocking the drains to rewet the Rastatter, stormwater runoff from adjacent residential areas should be considered. Indeed, this urban runoff would become a non-negligible water input for the wetland, especially during heavy rainfall events, and could be used to support the local water budget. Two ditches receive suburban runoff: one is supplied in water by a main inlet, the Merzeau pipe, which collects all the urban runoff of a neighboring residential area, the Münchfeld area. The other has two small inlets bringing minimal water, one being the result of rare spillovers from another stormwater infrastructure collecting water from industrial area and roads – although overflows only occur during extreme precipitation events –, the second, more diffuse, only bringing runoff from the L75 road. This runoff would also introduce additional nutrients and sediments, as well as pollutants into the wetland, affecting water quality and nutrient cycling within the ecosystem. Stormwater outlets are later illustrated in Figure 7.

2.1.3. Ecology

Today, the Rastatter Bruch is home to a wide variety of vegetation types, reflecting its varied hydrological conditions.

It presents a typical fen vegetation, as shown in Figure 2, with a marsh peat formed mainly from partially decayed sedges and reeds. Reed beds, dominated by *Phragmites australis Carex acutiformis* are prevalent in the wetter areas of the wetland, and are an indicator of nitrogen-rich locations. They are important for water filtration, sediment trapping, and providing habitat for a variety of bird and insect species. Other herbaceous species include *Glechoma hederacea*, *Phalaris arundinacea*, or *Urtica dioica*, which are indicators of nutrient-rich wetlands according to Ellenberg's indicator values and thrive in areas with fluctuating water levels such as wet meadows (Winarske A., 2024). Woody plants are also dominant in these swampy areas, particularly shrubs and alluvial forests, primarily composed of birch, alder and willow thickets. The black alder (*Alnus glutinosa*), the white willow (*Salix alba*), and the common ash (*Fraxinus excelsior*) are particularly adapted to periodic flooding. Other trees such as *Crataegus monogyna*, *Populus nigra*, and genera like *Prunus*, *Quercus*, *Rubus*, or *Sambucus* are typically associated with floodplain forests.

In addition to its diverse flora, the Rastatter Bruch supports a wide array of fauna, particularly insects, amphibians, and bats, many of which are also of conservation significance. The wetland provides breeding and feeding grounds for several amphibian species, such as *Rana temporaria* and *Hyla arborea*, both of which rely on the waterlogged conditions of the peatland for reproduction. Numerous species of dragonflies, damselflies, and other wetland-associated insects are also present, some of which are indicators of healthy wetland ecosystems. Birds and bats are also found in the area, taking advantage of the abundant insect population.

Some plant and animal species present in the Rastatter Bruch are listed under the UICN Red List of Threatened Species, as well as being of nature conservation significance (listed in Annex V). These species can be particularly vulnerable to pollution, which represents a major challenge to the mission.

Figure 5 presents the study area, and CORINE Land Cover 2018 (CLC 18) shows the different land covers and uses in the Rastatter Bruch and its surroundings.

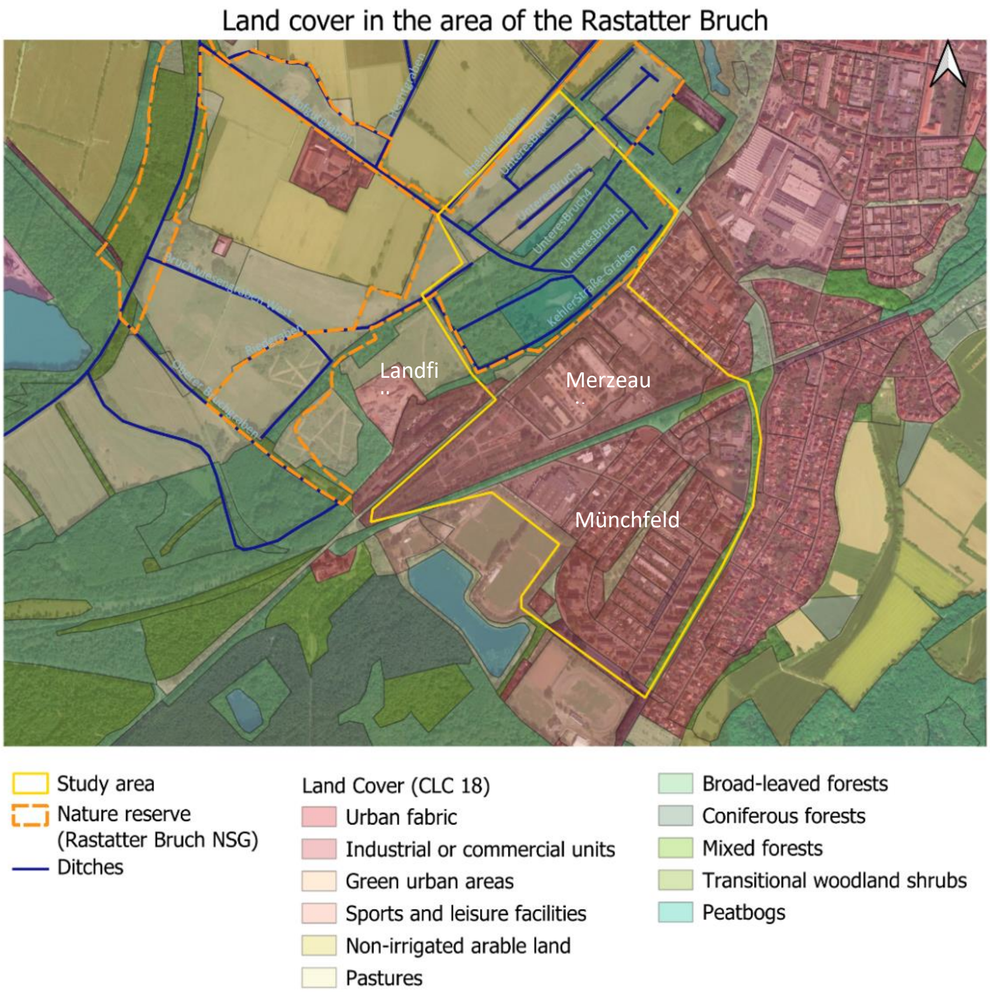

Figure 5: Land cover and study area in the Rastatter Bruch and its surroundings (S. Gaudefroy, 2024)

As can be seen, regarding land use, a large area in the southern side is a waste collection center, which can be a potential additional source of pollution. It is partly still operating, mainly for construction debris, but it is also a historic municipal landfill with uncertainties as to its imperviousness and the quantity of industrial residues buried. The western side is used for pastures and arable land.

2.1.4. The Münchfeld and Merzeau areas

The range of the study area also include a suburban neighborhood and a derelict area. The former is the Münchfeld area, origin of the runoff, and a standard residential area featuring a school and a supermarket. With an area of 32 hectares, about 50% is sealed, which is mainly the streets and the buildings. Most of the roofing here is gray roofs, although a few are green roofs, which will bring different types and quantities of pollutants. The stormwater sewer system supposedly flows entirely into the Rastatter Bruch, after collecting rainfall from the running track and sports fields at the periphery, although it might be only for sewage. Annex VI shows the Münchfeld area and its different surface sealing types and degrees. The Merzeau site is a former French military area that was abandoned but will be redeveloped over the next few years into another residential zone, of which the stormwater will also be directed to the fen. This opens the future chance to implement resource-efficient and environmentally-friendly techniques to use the precipitation from this catchment area for the rewetting, without adding pollution to the protected peatland.

2.2. Chemical and organic contamination

A first literature review is necessary to have a good overview of the potential compounds polluting the Rastatter Bruch. Chemical contamination from the surface runoff of residential areas arises from a variety of sources and encompasses a wide range of pollutants that can significantly impact environmental and human health. These contaminants, introduced into the environment through various anthropogenic activities, can be categorized into several key families.

Nutrients are natural compounds like nitrates, phosphates, and ammonium. They are essential for plant growth in small amounts, but excessive concentrations can lead to eutrophication in water bodies, depleting oxygen levels and harming aquatic life.

Heavy metals such as copper, zinc, but also lead or cadmium, are prevalent in residential areas due to the use of paints from surface coatings, certain construction materials, batteries, etc. These metals persist in the environment, binding strongly to soil particles and organic matter. Although some metal components such as zinc, copper, iron or manganese are essential micronutrients for plant metabolic activity, they can quickly become toxic when present in high concentrations.

Organic Pollutants are a group of toxic compounds that include petroleum hydrocarbons (oil/grease), pesticides, and synthetic chemicals like Polychlorinated Biphenyls (PCBs), Per- and Polyfluoroalkyl Substances (PFAS), and Polycyclic Aromatic Hydrocarbons (PAHs). Originating from anthropogenic sources, these pollutants are particularly concerning due to their persistence, low solubility, and potential to bioaccumulate, causing long-term health effects in the fauna.

Inorganic salts are chloride, sulfate, sodium, calcium, and magnesium are common in residential runoff and can alter the chemical composition of soil and water, impacting plants nutrient uptake and leading to salinization and reduced biodiversity, as it is toxic for freshwater biocenosis.

Other substances and organisms harmful to the ecosystem are plastics and pathogens, caused by anthropic activities, particularly improper disposal of waste, but will not be assessed in this project, due to the complexity of their detection.

Pollutants behave differently depending on their chemical nature. Soluble contaminants like nutrients and salts easily dissolve in water and can migrate through soil, potentially contaminating groundwater. In contrast, heavy metals and many organic pollutants tend to bind to soil particles and organic matter, making them less mobile but more persistent in the environment. Their solubility influences their toxicity: nutrients and salts, while necessary for life, can pollute the water and leads to eutrophication, depleting the environment of oxygen and creating a hostile habitat. Heavy metals and organic pollutants, often toxic even at low levels, contaminate the soil and food, and their ability to bioaccumulate and biomagnify within the food chain can cause severe reproductive and health issues with acute or prolonged exposure.

Annex VII classifies potential pollutants from a typical urban residential area and its natural and anthropic sources. Table 1 below cross-references the pollutants and their sources.

Table 1: Sources of pollutants from human-related activities and infrastructures (S. Gaudefroy, 2024)

<table>
<tr><th></th><th>Roofing material</th><th>Construction material</th><th>Plumbing material</th><th>Traffic /atmospheric emissions, spills</th><th>Vehicle material</th><th>Pavement and road-structure material</th><th>Households</th><th>Sewage, animal waste</th></tr>
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<tr><td>Zn</td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td></td><td></td></tr>
<tr><td>Organic pollutants</td><td></td><td style="background:#dae3f3"></td><td></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td></td><td style="background:#dae3f3"></td><td></td></tr>
<tr><td>Nutrients</td><td>Green roofs</td><td style="background:#dae3f3"></td><td></td><td></td><td></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td></tr>
<tr><td>Pathogens</td><td></td><td></td><td></td><td></td><td></td><td></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td></tr>
<tr><td>Plastics</td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td style="background:#dae3f3"></td><td></td><td style="background:#dae3f3"></td><td></td><td style="background:#dae3f3"></td><td></td></tr>
</table>

Sources: Ball et al., 1998; N. P. Miguntananna, 2009; Al Masum et al., 2022; Fuchte et al., 2022; Göbel et al., 2007; Huber et al., 2016; Jartun et al., 2008; Müller et al., 2020; Pamuru et al., 2022; Xu et al., 2021; Zanoletti & Bontempi, 2023

In this study, a focus will be made on common heavy metals found on roads and roofs, as well as PAHs, and nutrients.

2.3. Sampling methods

To assess the load and concentration of pollutants potentially contaminating the Rastatter Bruch, we employed two different sampling methods: soil sampling from the ditches near the stormwater outlet and water sampling from the same outlet. These methods were chosen based on the distinct behaviors of various pollutants in the environment, particularly in relation to their solubility and affinity for particulate matter. Soil sampling provides insights into the long-term accumulation and persistence of heavy metals and PAHs, while water sampling offers real-time data on the transport and concentration of soluble nutrients. Together, these methods enable a thorough assessment of the pollution levels and inform strategies for mitigating the adverse effects on the peatland ecosystem.

2.3.1. Soil sampling

If metals and PAHs are the pollutants with the highest probability of occurrence originating in the Münchfeld area, these are largely bound to soil particles and organic matter due to their low solubility in water and high affinity for particulate matter. Over time, the soil acts as a sink that stores these pollutants. A soil contamination analysis in the areas with the highest concentrations of these contaminants, i.e. the ditches, where most of the stormwater circulates, will provide a long-term overview of the accumulation of these pollutants.

To collect samples of ditch sediments, a standardized 31cm long and 8.5cm wide polypropylene cylinder is used. In the protocol, the first five centimeters of soil are always removed before starting the collection, as the uppermost layer of soil can be highly variable and may be influenced by recent deposition of dust, organic matter, or other contaminants that do not reflect the long-term accumulation of pollutants. Sampling below the surface layer is a way to obtain a more representative sample of the soil matrix where heavy metals and PAHs are more likely to have accumulated over time. The cylinder is then simply pushed into the soil until its 1L mark, and the shovel is used to close the cylinder underneath and take out the 1L of soil collected (illustrated in Figure 6 below).

Figure 6: Material and method used for soil sampling (S. Gaudefroy, 2024).

Picture A shows the standardized cylinder used; the 17.6cm mark is the limit for our soil collection, equivalent to 1L of soil. Pictures B show the protocol followed for soil collection: the removal of the 5cm of soil (left), the cylinder pushed into the soil until the mark (middle), the 1L of soil collected (right).

Taking financial limitations into account, the choice was made to analyze 5 samples from 5 different locations (see Figure 7). The sampling was carried out on May 15th, 2024, on a sunny day. The first sample was taken in the main ditch receiving the stormwater, close to the landfill, about a hundred meters from the Merzeau outlet. The bottom of the ditch was moist but without running water at the time of the sampling, the water table being just a few centimeters below the surface. For sample number 1, the composite sampling method was used, so five samples of 1L each were collected, about 50cm apart from each other along the ditch. These five "partial samples" were then mixed to obtain an individual sample. Composite sampling is interesting for a better representativeness of on-site pollutants, as well as for the spatial averaging of the concentration variability, while being more cost-effective for the analysis.

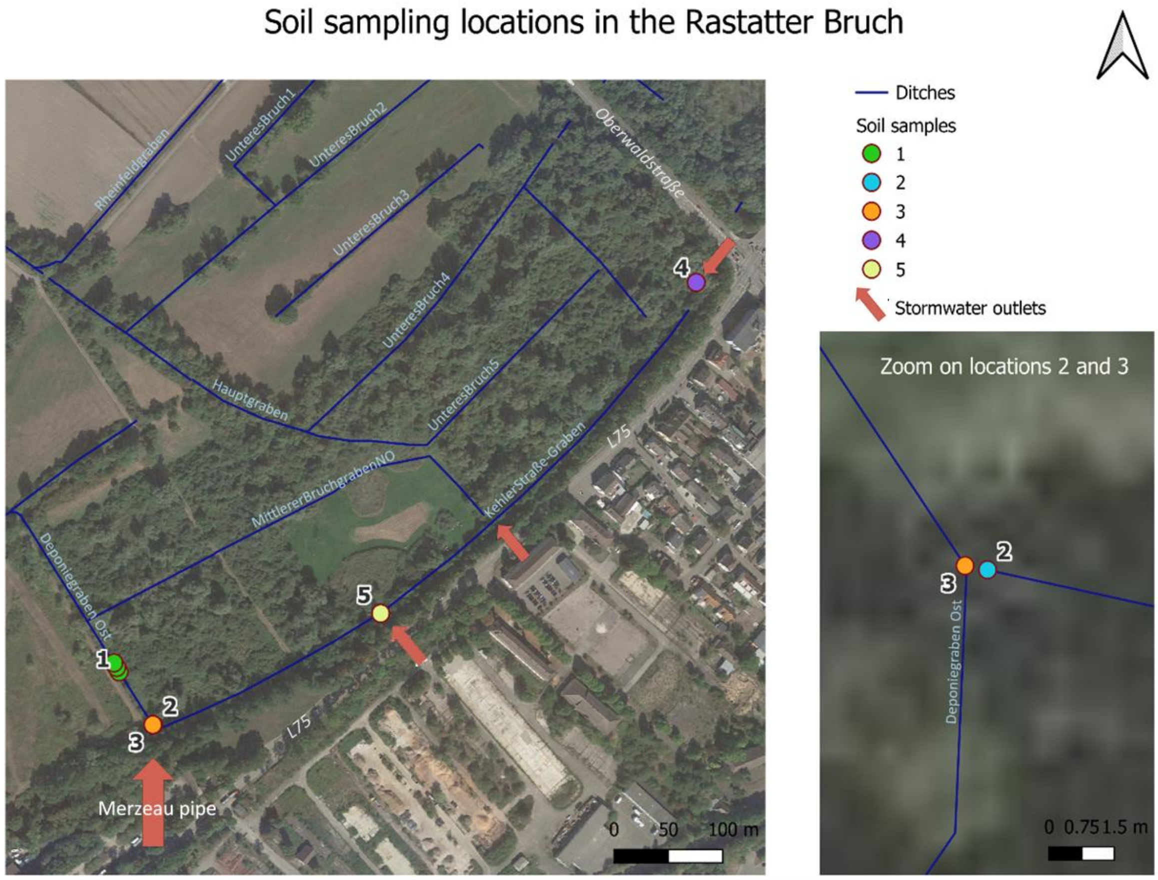


Figure 7: Soil samples locations in the Rastatter Bruch (S. Gaudefroy, 2024)
NB: The size of the arrows is not proportional to the amount of water supplied.

This method was however discontinued for the next samples for practical reasons. Samples 2 and 3 correspond to the stormwater outlet. Because the start of the ditch is paved, the samples start further where there is soil, so about 5 to 10 meters away from the pipe outlet. Sample 2 was taken in an alcove where there is less water circulation so potentially more sedimentation, whereas sample 3 was taken on the side of the main ditch where the main current passes by and sandy sediments is being deposited, particularly during rainfall events, when the water from the Münchfeld area is being discharged. Samples 4 and 5 were taken from “secondary outlets”. Both receive runoff directly running from the roads ten meters above (L75 and Oberwaldstraße), especially sample 5, near which there is a runoff water inlet that redirects the rainfall at that location (see Figure 8 below). Sample 4, although further away from the roads and protected by the forest, can receive additional polluted water from an adjacent combined sewer during overflow events.

After the collection, the five samples were placed in an oven at approximately 75°C for 48 hours to evaporate all the water that was present in the soil. Each of the samples was mixed to homogenize the different layers of soil and sieved to keep only the sediments under two millimeters. They were then weighed so that only 30 grams were brought for analysis to the Technologiezentrum Wasser laboratory (TZW), an institute conducting chemical analysis on water and soil.

The samples were tested for eleven heavy metals, two alkaline earth metals and sixteen PAHs. As seen previously, their presence results largely from anthropic activities, although metals can be found naturally in small amounts, which is why the results were compared to background values. Considering the available literature in Germany, these background values depend on the ecosystem present, therefore on the type of soil. No soil type analysis was carried out on our samples but considering the locations and physical aspects of the samples, background values for peat and sandy soils were used. Table 2 lists the components tested as well as typical background values found in the literature, primarily from German natural soil (more extensive results in Annex VIII). The results from the laboratory will be compared to these precautionary thresholds to determine the degree of pollution.

Figure 8: Runoff inlet into the Rastatter Bruch, at the location of sample 5 (S. Gaudefroy, 2024)

Table 2: List of metals and PAHs assessed by the TZW laboratory, their background values according to literature, and their share in particulate matter association (S. Gaudefroy, 2024)

		Standardized procedure of detection	Precautionary values				Particle-bound share in the water
			BBodSchV (2021) sand-clay	NLWK (2000)		LABO appendix (2017) peat and forest	
				Value	Fluctuation range		
Metals (mg/kg)	Aluminium (Al)	DIN EN ISO 17294-2:2017-01	-	-	-	-	-
	Arsenic (As)		10-20	-	10	9.2	-
	Cadmium (Cd)		0.4-1.5	0.3	0.15-0.6	0.5	46-59%
	Calcium (Ca)		-	-	-	-	-
	Chromium (Cr)		30-100	80	40-160	56	-
	Copper (Cu)		20-60	20	10-40	26	>81%
	Iron (Fe)		-	-	-	-	>87
	Lead (Pb)		40-100	25	12.5-50	48	>91%
	Magnesium (Mg)		-	-	-	-	-
	Manganese (Mn)		-	-	-	-	-
	Nickel (Ni)		15-70	30	10-60	22	>47%
	Thallium (Tl)		0.5-1	-	-	0.5	-
	Zinc (Zn)		60-200	100	50-200	54	>77%
PAHs (µg/kg)	Acenaphthene	**PV M 1500/F**	3,000-5,000	-		8,000	83-99%
	Acenaphthylene						
	Anthracene						
	Benzo(a)anthracene						
	Benzo(a)pyrene						
	Benzo(b)fluoranthene						
	Benzo(ghi)perylene						
	Benzo(k)fluoranthene						
	Chrysene						
	Dibenz(ah)anthracene						
	Fluoranthene						
	Fluorene						
	Indeno(1,2,3-cd)pyrene						
	Naphthalene						
	Phenanthrene						
	Pyrene						

“-“ = no value found

Table 2 shows that these background values can vary depending on local geology, soil type, and environmental conditions. Table 3 describes the samples' specific characteristics, which will determine the background values with which to compare.

Table 3: Summary of sample features (S. Gaudefroy, 2024)

	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*
Ditch	Deponiegraben Ost	Deponiegraben Ost	Deponiegraben Ost	Kehler Straße-Graben	Kehler Straße-Graben
Water table	Below surface	10cm above surface	10cm above surface	Below surface	Below surface
Dominant type of soil	Organic sediments	Sandy inorganic material	Sandy inorganic material	Organic sediments	Organic sediments

2.3.2. Water sampling

Water sampling performed at the stormwater outlet into the peatland is an efficient way to detect nutrients, typically more soluble in water and less likely to adhere to soil particles compared to heavy metals and PAHs, therefore undetectable in soil analysis. The advantage of water sampling is also immediate detection, compared to soil samples which accumulate over time: these water samples provide a snapshot of the current pollutant load entering the peatland, allowing for real-time monitoring of nutrient levels. Water sampling helps in assessing the immediate input of stormwater runoff on the aquatic ecosystem. A disadvantage of water sampling however is that concentrations of the studies substances vary over time, which is why continuous or at least regular measurements would be appropriate. For time and resource reasons this was not feasible in this case.

Nevertheless, in order to obtain a broader view on long-term stormwater quality, numerous water samples were collected throughout the internship, during dry and wetter periods. For the sampling frequency, two methods were used: in end of March and beginning of April, samples were collected three to four times a week for about three weeks, and then during the months of June and July, samples were collected weekly (sampling days related to daily rainfall depth illustrated in Annex IV). The first protocol was created to follow weekly variations of the pollutant input to try to establish a baseline understanding of the local water quality. Daily sampling increases the chances of capturing a wide range of weather conditions, such as long rainfall event or dry spells. The weekly protocol was then designed as a sustained monitoring solution to assess more broadly the seasonal variations over the spring and summer months. Longer-term trends can better show fluctuations of the different parameters over time. A third protocol was also suggested, an event-based sampling: following the weather forecast, sampling would be carried out at different times throughout a heavy rainfall event following a dry spell. It would provide a better view on the variability of pollutant concentrations in the timespan, from the dry period to the first-flush to the continued rain and total washoff of the nutrients. Unfortunately, not enough samples were taken with this method to perform a rigorous analysis. Further sampling will be carried out if necessary.

All samples were collected in the early or mid-afternoon at different days of the week, beginning in mid-February and ending in late July. Figure 9 presents the days sampled during the internship, in relation to daily precipitation. Daily rainfall depth was calculated from the recordings of the Aueninstitut rain station located in the Rastatter Bruch, which measures each raindrop with a system of tilting scale.

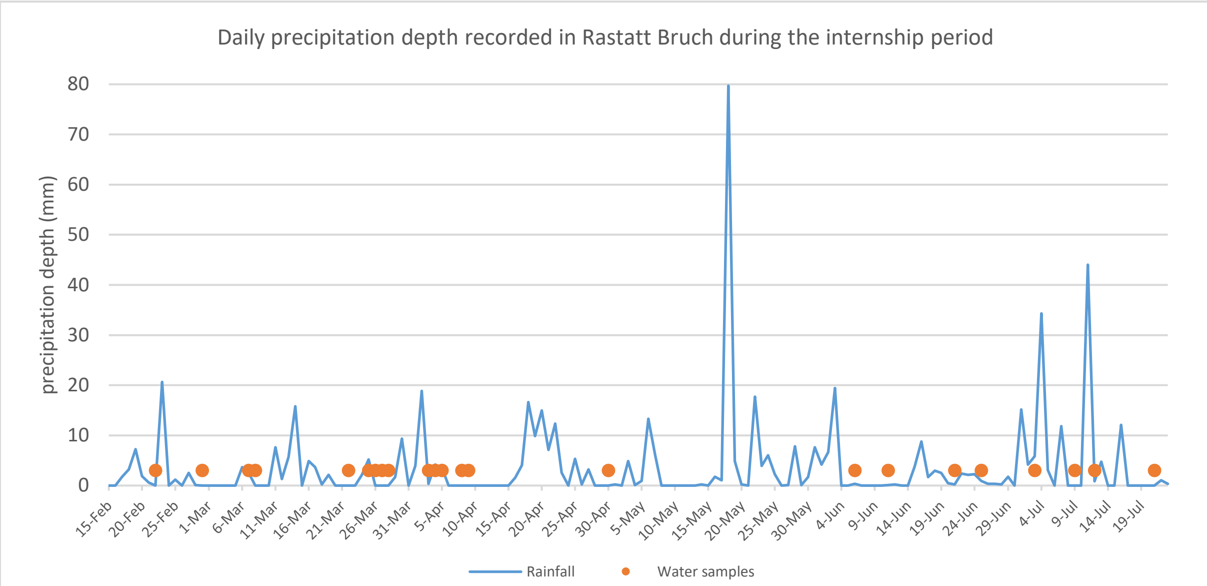


Figure 9: Daily precipitation and sampling days (S. Gaudefroy, 2024)

The Aueninstitut station is located approximately 800 meters away from the Münchfeld area.

All samples were analyzed manually in the lab. They were previously filtered using a 0.45µm syringe filter, to remove any suspended solid, which would alter the results of the photometry (see Annex IX for material). Using the photometer, the following parameters were measured:

- Nitrate (NO_3^-), a major form of nitrogen found in aquatic and terrestrial ecosystems. Although an important element for plant growth, high nitrate levels can lead to eutrophication.
- Ammonium (NH_4^+): another form of nitrogen, toxic to aquatic life at high concentrations and can convert to nitrate in water through bacterial nitrification originating mostly from sewage.
- Nitrite (NO_2^-): intermediate in the nitrogen cycle, it can indicate the presence of ongoing nitrification or denitrification processes. It is usually present in smaller quantities than nitrate and ammonium but is highly toxic to aquatic organisms.
- Phosphate (PO_4^{3-}): also a key nutrient that can contribute to eutrophication, it is usually a limiting nutrient in freshwater ecosystems, so even small increases have a large impact on water quality.
- Chloride (Cl^-): elevated chloride levels can be toxic to aquatic organisms and alter the chemical composition of water, affecting its quality and suitability for various uses.

Analyzing these parameters, as well as pH and electrical conductivity, provides a functional understanding of the nutrient and ionic composition of the stormwater entering the peatland. Monitoring these specific substances would help assess the potential for eutrophication, toxicity, and overall water quality degradation. Table 4 presents the range of detection of the photometer for each nutrient, as well as the German threshold values for each parameter in the water.

Table 4: Range of detection of the photometer for water analysis, and legal threshold values according to the legislation (S. Gaudefroy, 2024)

	Range of detection of the photometer		Unit	Threshold values for drinking water (mg/L)	Threshold values discharge into freshwater (mg/L)
EC	N/A		$\mu S.cm^{-1}$	2500	1000
pH			-	between 6.5 and 9.5	between 6.5 and 8.5
NO_3^-	Low Range	0.0 - 30.0	$mg.L^{-1}$	50	50
NH_4^+		0.00 - 2.50	$mg.L^{-1}$	0.5	0.2-2
NO_2^-		0.0 - 20.0	$mg.L^{-1}$	0.5-3.28	0.03-0.06
PO_4^{3-}	High Range	0 - 150	$mg.L^{-1}$	ca. 0.1	0.03-0.06
Cl^-	Low Range	0.00 - 3.00	$mg.L^{-1}$	250	200

N/A = non-applicable

Sources: Umweltbundesamt; Bundesverband der Energie- und Wasserwirtschaft; Bundesministerium für Umwelt, Naturschutz, nuckeare Sicherheit und Verbraucherschutz – Wasserhaushaltsgesetz; Trinkwasserverordnung; US EPA; Environment European Commisssion; Lehigh River watershed;

Results from water analysis will be compared to the thresholds, and descriptive and inferential analyses will be performed.

2.4. Water samples analysis methods

Concentration values of nutrients going into the Rastatter Bruch depend on the emissions of the pollutants but are also largely influenced by precipitation events. Specifically, the absence of rain (dry spells) allows an accumulation of pollutants on roads, roofs, and other impervious surfaces for a certain period of time. Then, during a storm event, the rain washes off these surfaces before entering the stormwater sewer system, now carrying the built-up pollutants. For this reason, results from water analysis were crossed with daily rainfall depth. Several methods were suggested:

- Descriptive statistics: both dataset, daily rainfall depth and pollutant concentrations, were first represented with descriptive parameters such as average, median, range, variance and standard deviation. Water quality parameters were summarized into box plots and compared with threshold values.
- Plot time series: time series charts were plotted to observe potential trends over time, such as wet/dry variations or seasonal patterns.
- Correlation Analysis: a correlation was sought between rainfall depth and nutrient concentrations. As a total of 22 samples were collected, the Spearman correlation is chosen. Spearman's rank correlation examines the relationship between two variables that do not follow a normal distribution, contrary to the Pearson correlation. Here, Kolmogorov-Smirnov tests were performed on every variable 2 by two to verify the non-parametric distribution, and only the nitrate-ammonium relationship could not reject hypothesis H0, that is that the 2 samples follow the same distribution. Different Spearman tests were then performed, varying the rainfall parameter to investigate possible delayed effects of rainfall on water quality (lag analysis): correlations are tested with the 24 last hours of rainfall data, then 48 last hours, etc until 7 seven days before.
- Event-Based Analysis: this approach would consist in define what constitutes a storm event, so rainfall above a certain threshold and/or during a certain period, a dry spell (also with duration), and categorize the water samples data based on whether they were taken during a dry spell or

during a storm event. Another parameter could be added, whether the sample was taken at the beginning of the event (first flush effect) or later. Then, comparison in water quality parameters between storm event days and non-storm days would be observed. The intensity of the rainfall within a storm event could also be related to the other parameters.

In the end, the event-based analysis was not carried out due to the limited number of data and representativity. Indeed, from the total 22 samples, 10 were collected during a dry period[2] and 11 during a wet period, however, during these storm events, only 2 samples were collected in the beginning of the rainfall, and the 9 others during the middle or the end of the event.

During the sampling period, each sample was collected in the early afternoon, typically between 2 and 3 p.m. As the correlation analysis assesses nutrient concentrations with the last 24*n hours, with n = ⟦1,7⟧, it was decided to use daily precipitation calculated to go from 2p.m. to 2p.m.

Only a comparison between rainfall depth and nutrients was investigated. Other parameters play a role in nutrient buildup, such as wind, which influences rainfall-runoff relationship (Gao et al., 2021), or temperature, which controls evaporation, but the choice was made to only focus on one parameter that influences nutrients concentrations: the rainfall.

[2] Here, the dry period was defined arbitrarily as 3 days without rain

3. Results & Discussion

3.1. Soil analysis

Table 5 shows the results from the laboratory. A value in bold means that it is in the upper range of the precaution values found in the literature review (Table 2); a value in red bold means that is exceeds the background values. Because only the background values for the total 16 PAHs was documented in the literature, the last row only should be compared.

Table 5: Results from the lab for soil analysis (TZW, 2024)

		QL*	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Metals (mg/kg)	Aluminium	20	19,000	7,700	7,400	14,000	13,000
	Arsenic	1	7.4	4.7	3.9	5.5	6.4
	Cadmium	0.1	**1.9**	**1**	0.3	**1.4**	0.5
	Calcium	500	8,200	5,400	9,900	15,000	5,000
	Chromium	1	**69**	25	20	**57**	55
	Copper	10	**600**	**150**	**69**	**240**	**150**
	Iron	10	16,000	8,800	11,000	15,000	14,000
	Lead	1	**220**	77	29	**170**	**50**
	Magnesium	500	3,500	2,200	2,700	2,900	2,800
	Manganese	5	190	84	130	200	220
	Nickel	1	**35**	19	14	**30**	**25**
	Thallium	1	< QL	< QL	< QL	< QL	< QL
	Zinc	10	**1,600**	**810**	**420**	**1,100**	**900**
	TOTAL		49,423.3	25,270.7	31,686.2	48,703.9	36,206.9
PAHs (µg/kg)	Acenaphthene	20	26	< QL	< QL	20	< QL
	Acenaphthylene	20	230	30	< QL	93	92
	Anthracene	20	300	61	33	180	120
	Benzo(a)anthracene	20	950	410	120	880	650
	Benzo(a)pyrene	20	1,400	430	100	1,000	760
	Benzo(b)fluoranthene	20	1,700	490	150	1,300	990
	Benzo(ghi)perylene	20	2,100	480	160	1,300	1,200
	Benzo(k)fluoranthene	20	770	220	63	620	430
	Chrysene	20	1,700	650	200	1,500	1,100
	Dibenz(ah)anthracene	20	370	90	28	270	190
	Fluoranthene	20	1,600	690	430	1,400	1,200
	Fluorene	20	54	20	< QL	54	27
	Indeno(1,2,3-cd)pyrene	20	1,400	330	120	1,000	730
	Naphthalene	20	46	< QL	< QL	< QL	< QL
	Phenanthrene	20	790	270	250	1,100	440
	Pyrene	20	1,300	570	250	1,100	990
	TOTAL		**14,736**	4,741	1,904	**11,817**	**8,919**

**QL = quantification limit*

Sediment concentrations of heavy metals and PAHs are variable across study sites: samples 2 and 3, which were taken closest to the main outlet, have overall lower concentration values for pollutants than the other samples, especially for PAHs. This can be attributed to two things: samples 2 and 3 are located close to the Merzeau pipe, receiving all the runoff from the Münchfeld area, especially inorganic particles, which explains the sandy material in the surface layer. As sand is chemically inert, pollutants tend to be less bound to these particles, compared to the other humic acid-rich locations, which is negatively charged and tend to attract positively charged heavy metals. Moreover, during storm events, the intensity of the rainfall creates a current, which prevent fine polluted-bound sediments from settling. Sample 1 is peaty and much further from the main outlet, where the water velocity is lower, and fine sedimentation takes place, accumulating pollution and explaining why it has overall higher values than the others. Sample 4 and 5 are similar, with both a peaty soil, a similar pollutant source (close to roads), and similar pollutant input, although sample 4 has slightly higher values. Sample 5 does not seem to receive significant pollution from the nearby stormwater system overflow.

The heavy metals cadmium, copper, lead and zinc are all exceeding the background values seen in the literature for at least two sample and represent therefore a potential threat for endemic species. Particularly, copper and zinc are far high above the recommended threshold, approximately 10 and 5.3 times higher respectively (when compared to the highest background value found in the literature). It was expected as copper and zinc are the most common metals used for roofs, buildings, plumbing and engine parts. Chromium and nickel approach the upper limit for precaution values and may also need more consideration and monitoring. Although PAHs can also occur naturally, the conditions remain extremely rare in a peatland: it can be argued that almost all the PAHs present in the Rastatter Bruch soil originates from the residential area. Here, three out of five samples exceed the precautionary value for PAHs, being almost 3 times higher for sample 1. Samples 4 and 5 are much further and isolated, only receiving little and diffuse runoff during strong storms, but the results still show high concentrations both for metals and PAHs, which means these outlets are not so secondary and require more consideration.

Arsenic, cadmium, chromium, lead, and mercury are rank among the most toxic metals (Tchounwou et al., 2012), of which two out of five exceed the threshold limit and one is in the upper limit of the normal range. Mercury was not evaluated here and could be subject of a potential future analysis. Nevertheless, these results are enough to prove the necessity of implementing a stormwater treatment facility. Aluminium, calcium, iron, magnesium, and manganese have much lower potential toxicity, and are more commonly found in nature, even utilized by plants (Arif et al., 2016), which can explain their high concentrations. Although no legal threshold was set for these pollutants (as seen in Table 2), scientific papers assessing background values from specific sites are comparable in values, which means there is not much concern about these metals.

Therefore, the Rastatter Bruch is contaminated in heavy metals and PAHs. The timespan of pollutant accumulation is unknown, that is the average concentration of these substances into the stormwater, but as the ditches are already well above the precautionary values, actions must be taken to prevent any additional pollution. It is worth noting that the nearby landfill could be the reason of such levels of pollution, as the Deponiegraben-Ost is located right next to it, especially considering that the sealing at the bottom of the landfill is questioned, due to its deterioration and the less strict environmental laws when it was built. If it could explain the higher pollution level in the area of sample 1, samples 4 and 5 confirm that road runoff is a hazard for environmental ecosystems, and the stormwater must be treated before entering the peatland.

3.2. Water analysis

3.2.1. Descriptive statistics

The results of the photometric analysis are presented in Annex X, summarized in Table 6 and illustrated with a box plot in Figure 10 (zoomed in Annex XI).

Table 6: Descriptive Statistics compared to threshold values for water analysis (S. Gaudefroy, 2024)

	Unit	Maximum	Minimum	Average	Median	Standard deviation	Threshold values for drinking water	Threshold values discharge into freshwater ecosystems
NO3-	(mg/L)	11.4	0.7	5.36	6.57	3.19	50	50
PO43-	(mg/L)	**4.32**	0.03	**1.77**	**1.56**	1.32	ca. 0.1	0.03-0.06
Cl-	(mg/L)	95	2.3	38.5	27.4	29.22	250	200
NO2	(mg/L)	**90**	**24**	**40.83**	**35**	15.30	0.5-3.28	0.03-0.06
NH4+	(mg/L)	**37.8**	0.27	**9.28**	**6.5**	9.46	0.5	0.2-2
EC*	µS/cm	**1145**	57.2	454.28	367	352.96	2500	1000
pH	none	8.35	6.51	7.55	7.54	0.45	from 6.5 to 9.5	from 6.5 to 8.5
Rainfall	mm	79.7	0	3.62	0.36	8.55	Total rainfall = 579.15 mm, i.e. 64% des of average annual precipitations	

**EC = Electrical conductivity*

Average values for phosphate, nitrate and ammonium far exceed thresholds values for both drinking water and discharge into the environment, being respectively 17, 12 and 4 times higher on average than the legal limit. This is concerning because ammonium and nitrite are toxic compounds for organism, only converted into nitrogen by O_2-demanding nitrification processes. High concentrations of nitrite and ammonium therefore lead to an increase in nitrate, and along with phosphate, to eutrophication. Moreover, if concentrations exceed nitrification rates, these toxic substances can have a longer residence time in the environment, harming aquatic life, particularly aquatic-dependent life stage such as insect larvae and tadpoles (Marco et al., 1999; Marco & Blaustein, 1999). Electrical conductivity, although not exceeding the threshold (on average), is quite high form stormwater, supposedly lower than 100µS/cm. This supposes a high concentration of ions, as well as dissolved metals.

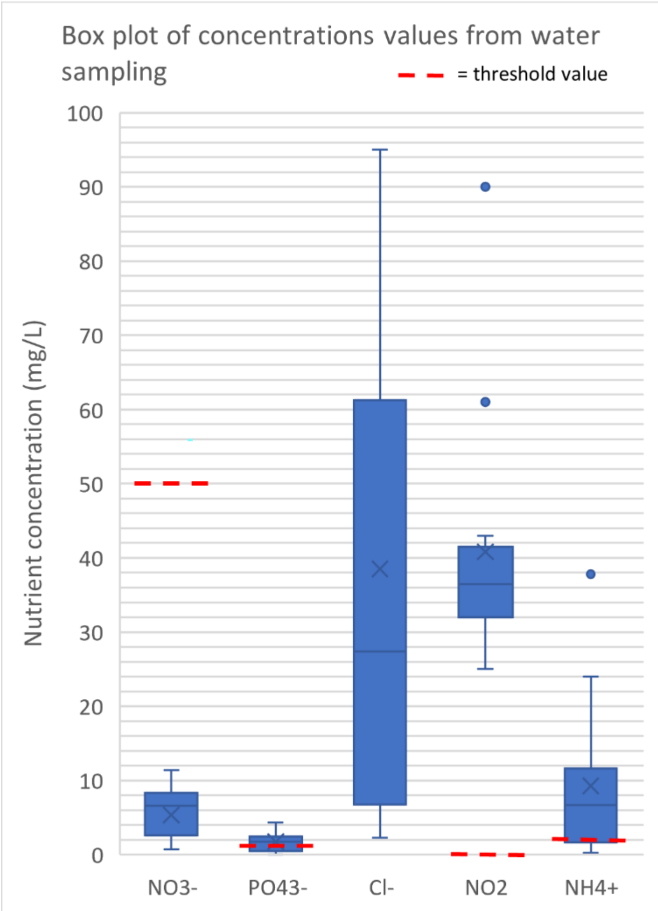


Figure 10: Box plot of nutrient concentrations for water analysis (S. Gaudefroy, 2024)

Such abnormally high results are evidence of a wastewater influence, which means that the stormwater is contaminated within the timespan between washing off the surface of the residential area and being discharged into the fen. Misconnected households can be a possibility, with their wastewater being redirected to the stormwater system instead of sewer.

3.2.2. Time series analysis

Plot time series, illustrating nutrient concentrations in relation to daily precipitation over time, is presented in Annex XIII. What can be said is that Electrical conductivity clearly shows a negative correlation with rainfall. Chloride, ammonium, and phosphate seem to also display a pattern of concentration decrease during a storm event and increase during drier periods. Phosphate particularly seems very sensitive to rainfall, dropping completely during the first flush. However, if the rain persists, concentrations seem to gradually increase again. Nitrite and nitrate do not seem to be correlated to rainfall.

Unfortunately, no significant trend was observed for nutrients. This can be explained by the limited number of samples over such a long period. A more systematic sampling method would perhaps show more clearly the behavior of dissolved substances in the runoff. As said previously, the sampling might also lack representativity. Although expected, chloride concentration values do not seem to vary between the end in winter, when road salts are used, and the spring and summer periods. On the contrary, chloride concentrations seem to have increased, suggesting another source of pollution, maybe acute but with slow and diffuse washoff.

A focus on one particular storm event was investigated to try and observe more precisely their behavior during transitions between dry and wet periods. Figure 11 illustrates the storm event between March 20th and April 10th, that happened during the regular sampling period tested.

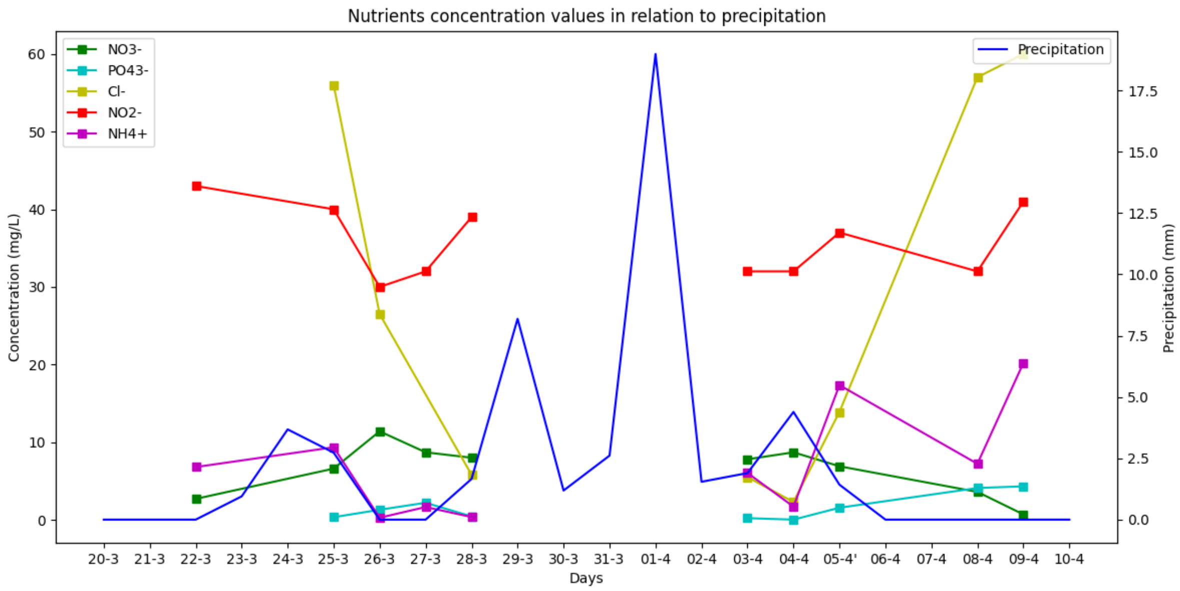


Figure 11: Storm event between March 20th and April 10th, and relation between nutrient concentration pattern and rainfall (L. Mesnil & S. Gaudefroy, 2024)

What is observed is not necessarily representative of every storm event, but it seems that a negative correlation could be detected for chloride and phosphate, but not for the other nutrients. A negative correlation to rainfall is expected due to the dilution effect.

To better comprehend the rainfall-nutrients relationship, correlation analysis is carried out.

3.2.3. Spearman correlation

Spearman correlations were performed on cumulated 24, 48, 72, 96, 120, 144 and 168 last hours of rainfall. Spearman's coefficients of each nutrient related to rainfall are represented Figure 12. Spearman's coefficients superior to 0.450 in absolute values correspond to a p-value inferior to 0.05 which means that a correlation between the two parameters exist. As can be seen, correlations cannot be observed for each cumulative days. Correlations peaks can be observed for the 48 last hours and then again, although smaller, for the 144 hours. The parameters with higher correlations are phosphate, ammonium, and electrical conductivity. Nitrite seems to be more and more correlated to stormwater with the accumulation of days. pH and nitrate show no correlation.

Correlation does not mean causality, and further research should be investigated on nutrients behaviors before making any assumptions. However, speculations can be made: strong negative correlations seem to exist for a short time span, between the last and three last days of rain. This could mean that nutrients such as phosphate and ammonium concentrations react quicky with rainfall and are washed off easily. On the contrary, nitrite, which only shows a correlation after 5 days of cumulated rain, could be washed off more slowly or undergo nitrification to be converted into nitrate. Nitrate does not follow any relation to rainfall which might be because the sources of pollution and multiple and diffuse, and that nitrates may accumulate in the soil and only be flushed into the stormwater system after prolonged rainfall or specific conditions that mobilize these nutrients. If correlations are still observed by cumulating several days of rainfall depth, it can be because of time lag effects, where water quality might not respond immediately to rainfall. Outliers should also be identified and considered because they can impact the statistical test. Outliers could not be identified here due to the limited number of samples taken in the first place.

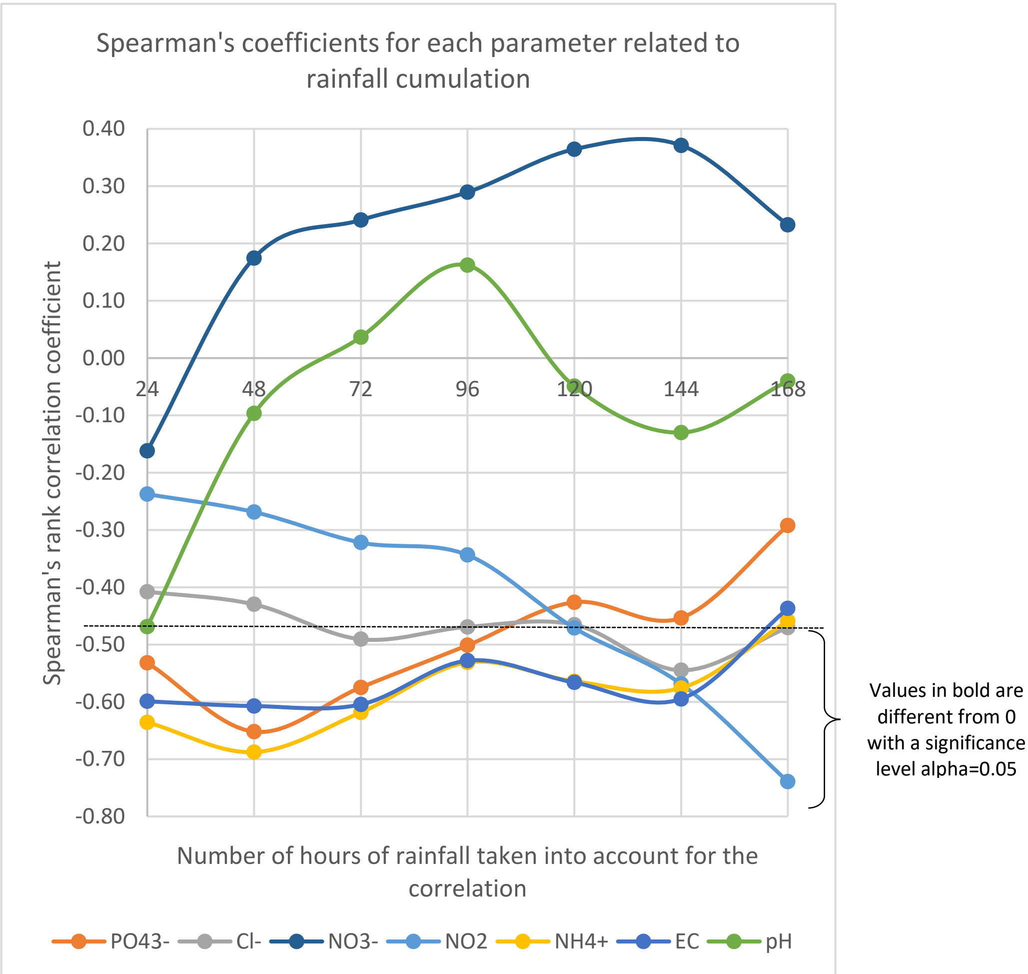


Figure 12: Spearman's coefficients for nutrients, pH and electrical conductivity in relation to rainfall cumulation (S. Gaudefroy, 2024)

4. Technical solutions and prospects

Given the results from soil and water analyses, it is evident that the urban runoff is polluted in PAHs, heavy metals, and nutrients, therefore necessitates filtration. This last part will introduce some technical solutions that aim at mitigating stormwater pollution. It does not make it any less important to reduce pollution at source, for example by making sure each household is well connected to prevent sewage input into stormwater.

4.1. Sedimentation tanks

Sedimentation tanks are a traditional and widely used method for treating stormwater runoff. The principle is to allow stormwater to enter a large tank where suspended particles can settle out at the bottom, leaving clear water at the top to be discharged into the environment.

Figure 13 shows how the infrastructure works. The stormwater enters the sedimentation tank through an inlet, with an inflow typically controlled to allow enough time for sedimentation to occur. As the water flows through the tank, its velocity decreases, enabling suspended solids (such as sand, silt, and other particulate matter) to settle at the bottom due to gravity. The clarified water then flows out of the tank through an outlet at the top, while the accumulated sediments remain at the bottom. Lamella settlers are tanks with vertically inclined sheets to increase sedimentation surface and therefore sedimentation efficiency.

Sedimentation tanks are effective at removing coarse sediments and particles. However, they are less efficient at removing finer particles and cannot remove dissolved pollutants, which requires an additional filter. They also require periodic maintenance, as removal of the settled material at the bottom of the tank is necessary to maintain its efficiency. This type of infrastructure is often used as a preliminary treatment step in a more comprehensive stormwater management system.

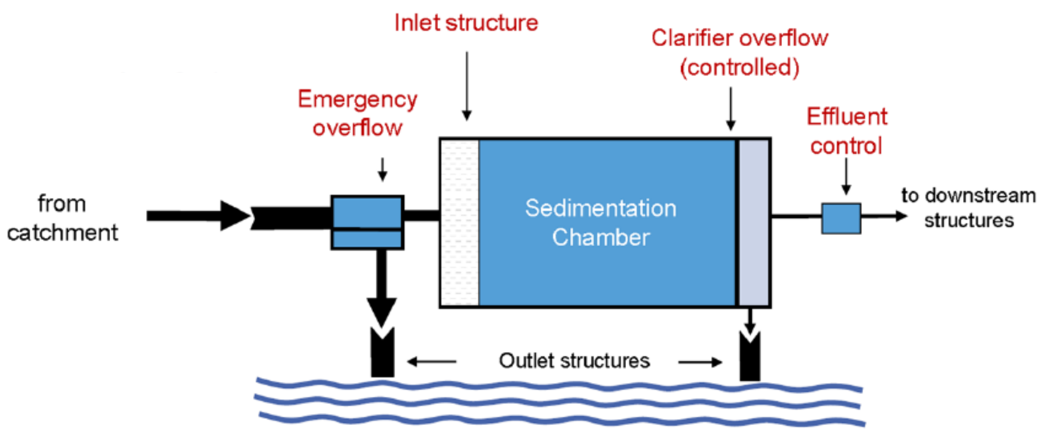


Figure 13: Schematic of a sedimentation tank (S. Fuchs, Institute for Water and Environment Water Quality Management, 2024)

4.2. Constructed wetlands for stormwater treatment

Constructed wetlands are engineering systems designed to mimic the natural water filtration processes of wetlands. These systems use a combination of soil, vegetation, and microbial processes to treat stormwater by filtering, absorbing, and breaking down pollutants. Unlike sedimentation tanks, it can remove even the finer particles and dissolved nutrients, absorbed by the present reed beds, and microorganisms.

Figure 14 illustrates a constructed wetland. Stormwater is distributed evenly across the wetland, composed of semi-aquatic plants that can tolerate both dry and wet conditions (reeds). There, sedimentation takes place, even for finer particles, due to the very slow current. The water infiltrates the soil, where the roots and substrate, often a mixture of gravel and soil (see Figure 14), filter out additional particles, debris and dissolved nutrients. Below the substrate, drains discharge the filtered water into the environment. Usually, before entering the wetland, the stormwater passes through a small space like a pit to remove the coarser sediments such as gravel and sand, which sediment quickly.

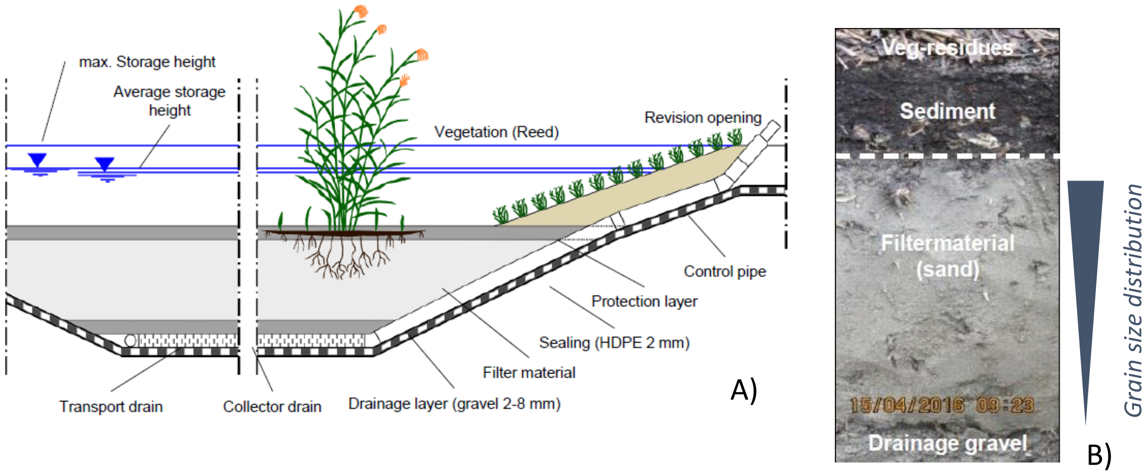


Figure 14: Representation of a constructed wetland (S. Fuchs, Institute for Water and Environment Water Quality Management, 2024)

A) is a cross section of the constructed wetland. B) is a cross section of the soil layers. The filtering material must be stable over time, which is why sand is the most common substrate used. The decreasing granulometry mimics the functioning of a sieve, retaining finer and finer particles.

Constructed wetlands have a high pollutant removal rate and can support a diverse range of plant and animal life. The constructed wetland is usually sealed below the substrate to control the environment, and maintenance is also rare, every decade or so (Lee & Scholz, 2007; Mickovski, 2021; Walaszek et al., 2016; Walton et al., 2020).

To implement such a system for the Rastatter Bruch, the wetland needs to represent 1% of the connected area. In this case, the Münchfeld area, which is approximately 32 hectares with about 50% of its surface sealed, the facility must be the size of is 1% of 16 hectares, that is, 1,600m². Proposed locations to build a constructed wetland are illustrated in Annex XII.

4.3. Decentralized water treatment plant

Decentralized stormwater management solutions are scale solutions that focus on treating stormwater at or near the source of runoff. These methods integrate landscape features with stormwater treatment, targeting specific pollution source and proposing an adequate solution, while reducing the need for large-scale infrastructure.

For example, for road runoff polluting the Kehler Strasse-Graben, bio-retention swales can be an adapted solution to directly reduce pollution runoff into the fen. Bio-retention swales consist in shallow, densely vegetated channels designed to slow, capture, and treat stormwater runoff. These small constructed wetlands come in the shape of a vegetated belt that can be integrated into urban landscapes, such as between roadsides and bike lanes. These systems also improve the visual appeal of urban areas while providing habitat for wildlife and contributing to urban green space.

Dirty and polluted water the road enters the bioswale, where the water is immediately slowed down by various plants, which greatly limit sewer overflow and runoff into the fen. Then, the water percolates through the soil as pollutants settle out, and clean water flows through the perforated pipe before being redirected to the standard underground sewer system. During heavy storm events, less water will run down the Rastatter Bruch, being absorbed in the soil, and even excess stormwater that might overflow will have lost some of its particulate matter and pollution.

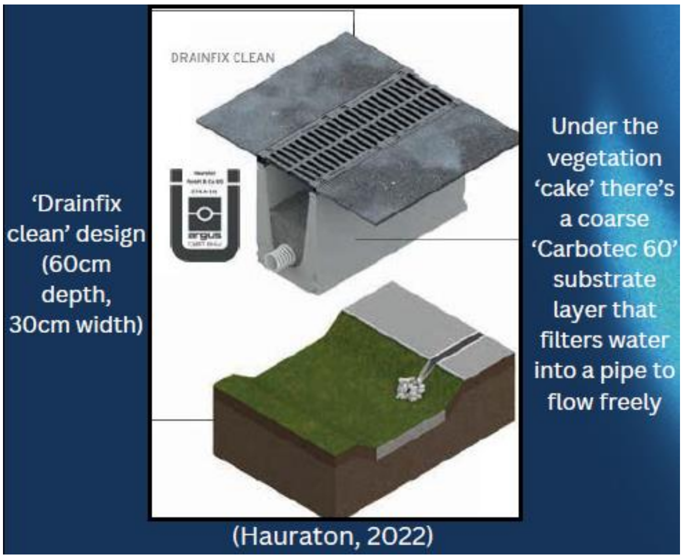
Figure 15: Proposed conversion of rainwater channels along the L75 into bio-retention swales (Dinic Brankovic M. et. al, 2018)

A) Photography of the L75 road next to a pedestrian/bike lane; the Rastatter Bruch is on the far right. B) Schematic of a bioswale published in the conference paper of the 2nd International Conference on Urban Planing - ICUP2018, Serbia

Bio-retention swales are particularly effective in reducing peak runoff volumes and removing pollutants such as sediments, nutrients, and heavy metals. They also enhance groundwater recharge and provide green space in urban environments.

Another solution is rainwater channels with vegetated "cakes", or infiltration layers below the surface. They follow the same idea as bioswales, except that they are smaller, have a less dense, more herbaceous vegetation, and are below ground (see Figure 16). They are not as efficient to mitigate overflow, but they take up much less space, and are much simpler to implement and maintain. The vegetation cakes can even add to the already existing rainwater channels, which facilitates work and reduces costs.

Stormwater flows through shallow the manhole covers lined with vegetation. The surface vegetation slows the flow, allowing for initial filtration and sedimentation. Beneath the channel surface, layers of 30 to 50cm thick soil, referred to as "vegetation cakes", are designed to capture and treat stormwater as it infiltrates downward. These vegetation cakes enhance pollutant removal through filtration, biological uptake, and chemical transformations. After infiltrating through these subsurface layers, the water goes down the perforated drains to join the existing sewer system. This system could be implemented on the top of the rainwater channels of the Münchfeld area, at least in the areas with the highest pollution potential, such as busy streets or parking lots. It could also be systematically employed for the future development project in the Merzeau area. Annex XII maps the different infrastructure and where they could be applied.



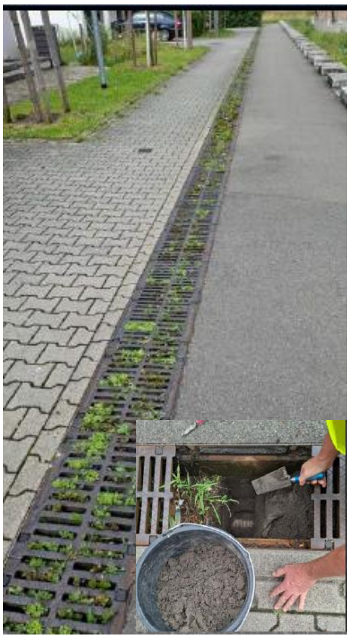


Figure 16: Rainwater channels with infiltration layers below ground (Institute for Water and Environment Water Quality Management, 2024)

Conclusion

The initial mission was to answer the following question: Does the stormwater coming from the Münchfeld area require filtration, in order to ensure the ecosystem's well-being and meet the legal criteria established in Germany? The soil sampling revealed important concentrations of heavy metals and PAHs that accumulated over the decades. Although the time span of accumulation is unknown, this is evidence that the Rastatter Bruch receives a certain quantity of pollutants. Moreover, stormwater analysis from the outlet shows a wastewater input, increasing nutrient concentrations, and altering the ecosystem chemistry and bioavailability. The development of a runoff simulation was started but not completed, due to the complexity of the model and the limited amount of time. Nevertheless, results from analyses are enough to assert that it is crucial for the well-being of the Rastatter Bruch and its wildlife. Technical solutions to filter the runoff was investigated, and first facilities were suggested.

In the near future, the project will continue. Additional soil sampling is planned for deeper analysis, from the Kehlerstrasse-Graben as well as from other ditches further into the Rastatter Bruch where there is no road contamination to compare with results. These will be tested only for a few contaminants, such as zinc or copper. The project of running long-term simulations to better comprehend the dynamics of stormwater entering the Rastatter Bruch is not abandoned, and will be pursued to hopefully quantify the water available for the rewetting of the area. Hopefully, filtrations systems will be implemented by the city like suggested. Urban runoff treatment is becoming increasingly crucial with urban development (phenomenon of soil sealing) and climate change, which will increase urban runoff (Gray et al., 2023; Climate Change Adaptation Resource Center - US EPA).

During this internship, I was given the chance to play an active role in model development research and get a good overview of the whole project in both quantitative and qualitative aspects, working alongside technicians and hydraulic engineers. Previously, I had been entrusted with the task of following a protocol and go in the field, focusing on application and interpretation of results in a swampy area, the Marais Poitevin, in France. Here, I was able to design a protocol from beginning to end, reflect and anticipate analysis, and was given a lot of autonomy to conduct my own experiments, to make mistakes and learn from them, which really helped me broaden my perspective and question myself and my work. This has been a great formative experience, and a good continuation of the Aquatic Environment Engineering training. Although lotic ecosystems are highlighted in this 2-year specialization, the theoretical lectures on wetlands have greatly helped me understand the dynamics of the fen, and this internship came to complete and strengthen my practical knowledge.

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Bundesministerium für Gesundheit: https://www.bundesgesundheitsministerium.de/en/topics/drinking-water

US EPA: https://www.epa.gov

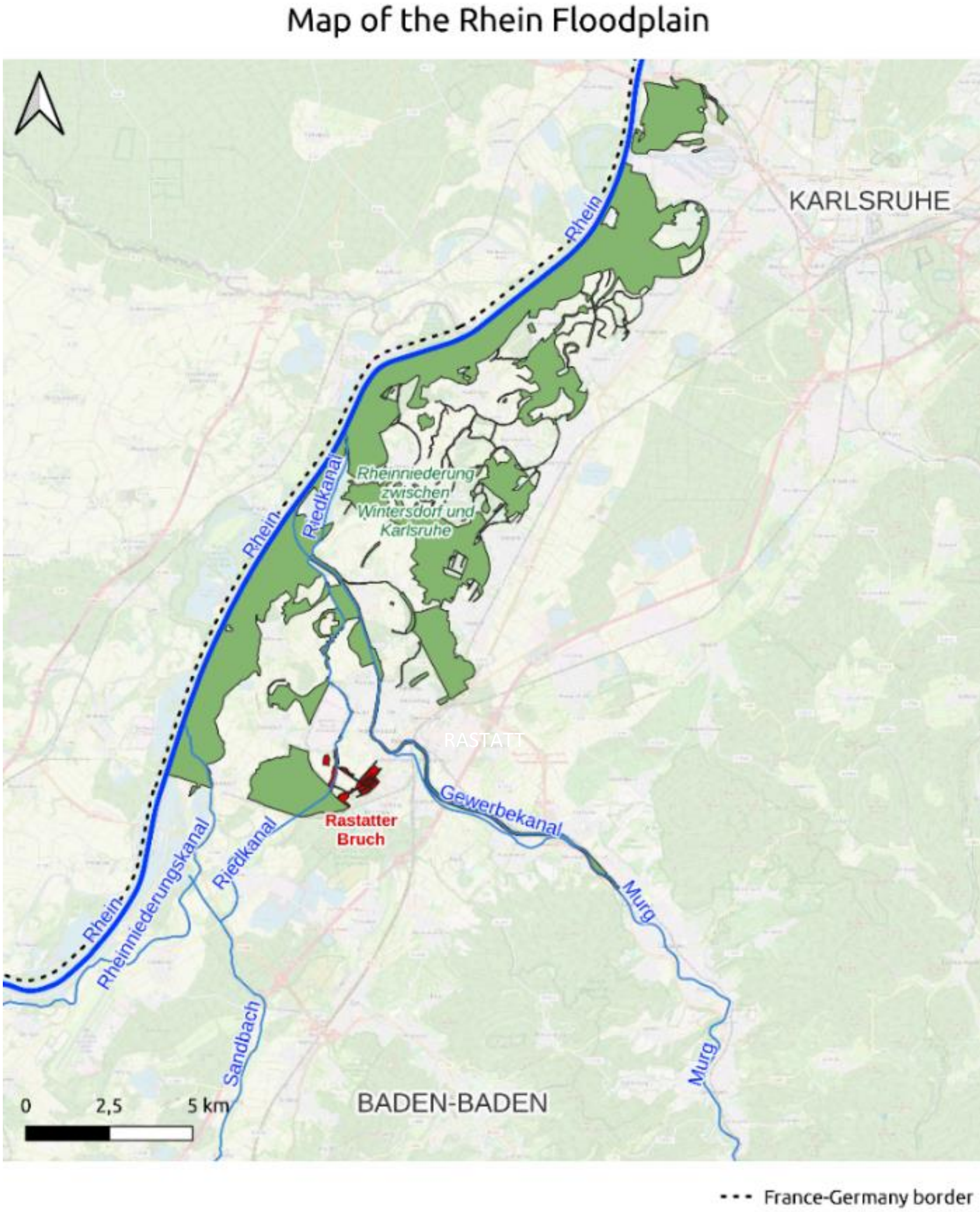
Environment European Commisssion: https://environment.ec.europa.eu/index_en

Lehigh River watershed: https://ei.lehigh.edu/envirosci/index.html

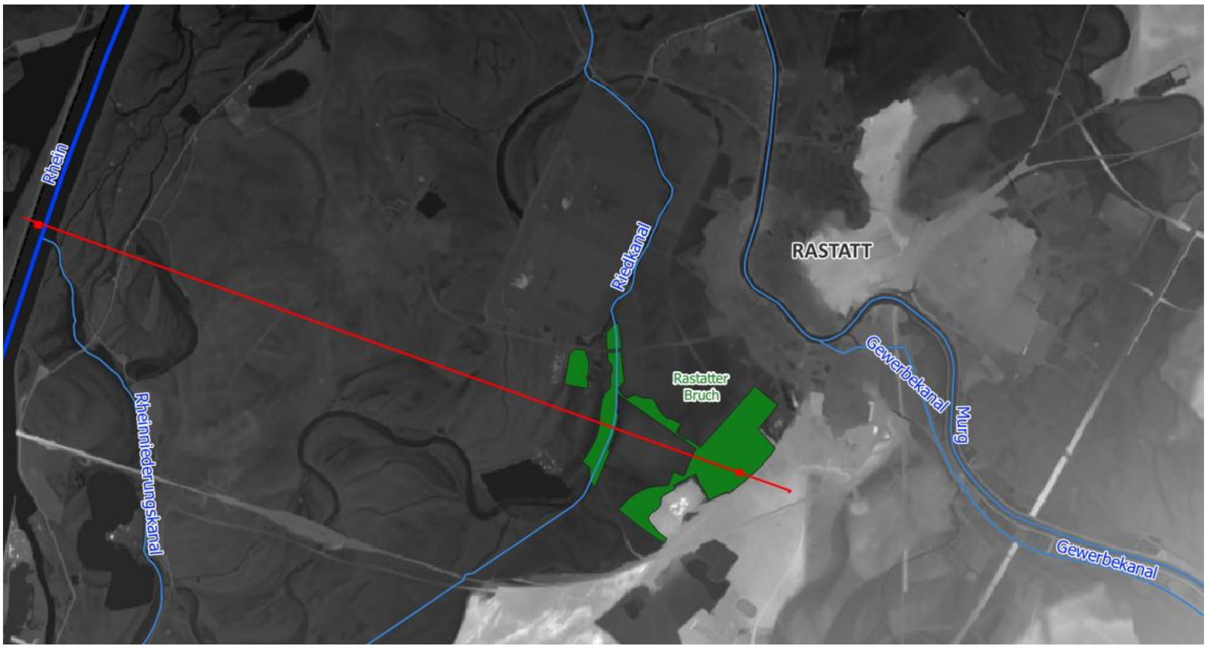
Bundesamt für Naturschutz: https://www.bfn.de/arten-nationaler-verantwortlichkeit

Appendix

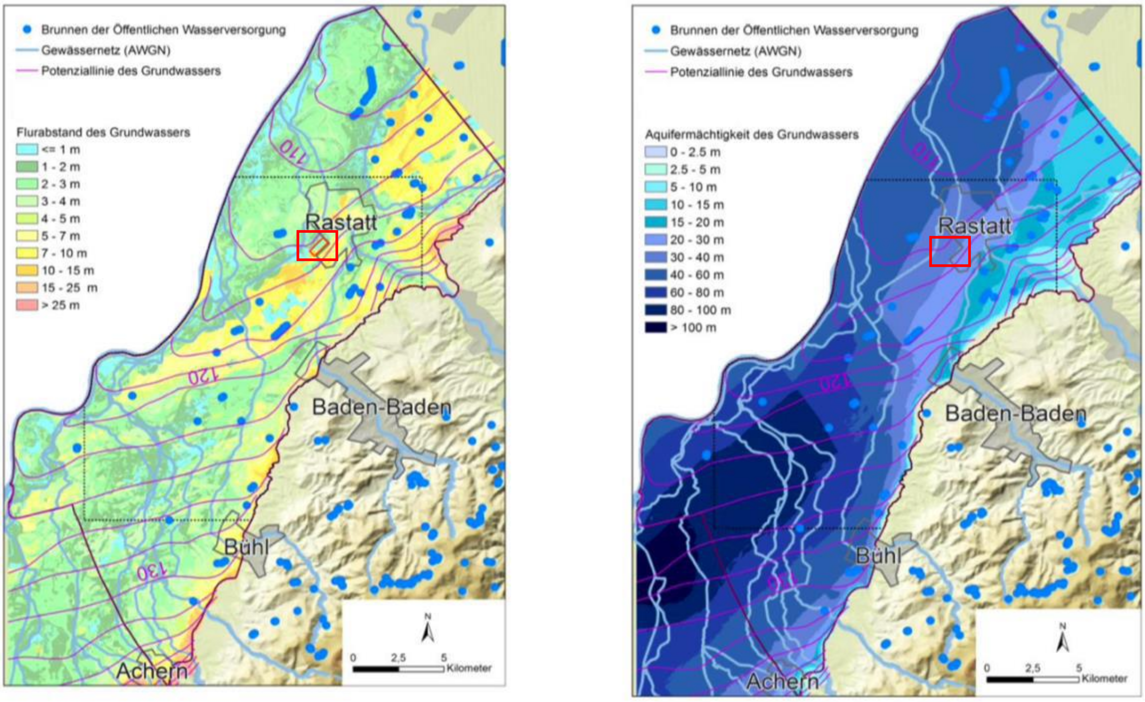
Annex I: Overview of the Rastatter Bruch location (S. Gaudefroy, QGIS, 2024). The green area is the name of the RAMSAR site.



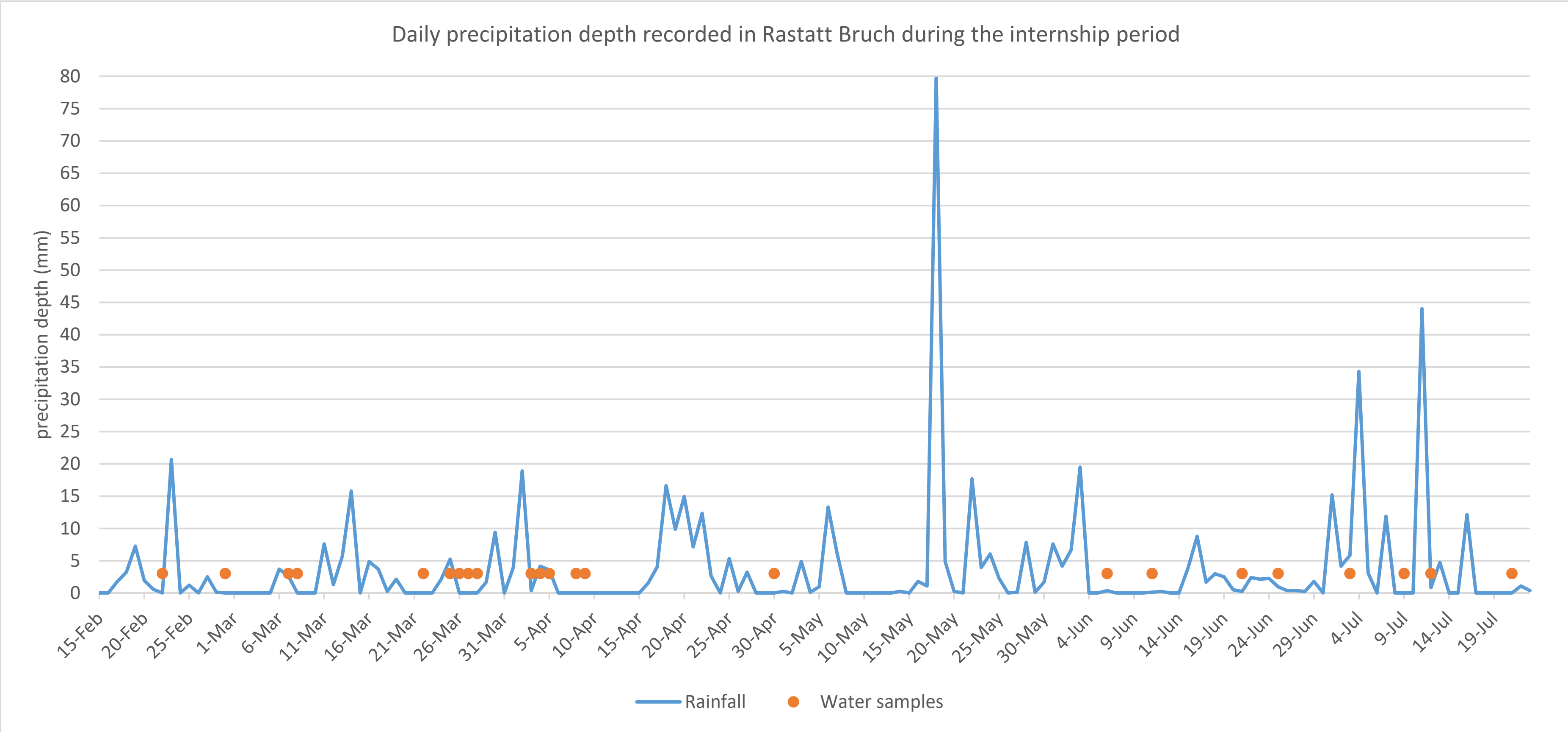
Annex II: Cross section of Figure 3 on QGIS



Annex III: Distance of ground water from the ground surface (left) and thickness of aquifers (right) in the area (Erami R., 2023; LUBW, 2021)



Annex IV: Daily precipitation recorded by the Aueninstitut station installed in the Rastatter Bruch, and sampling days (S. Gaudefroy, 2024)



Annex V: List of red list species present in the Rastatter Bruch

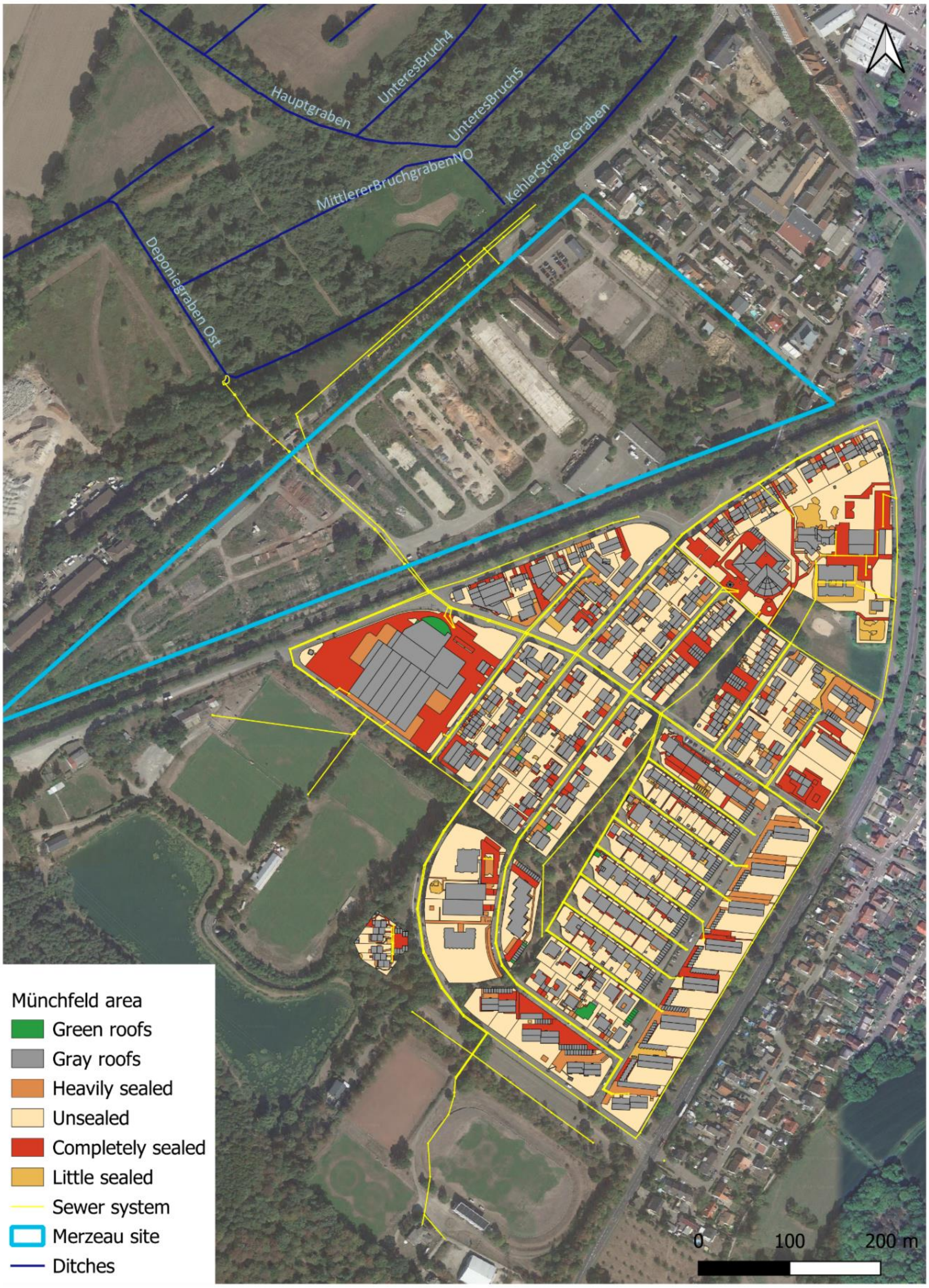
		UICN Red List f Threatened species	Nature conservation significance
Plants	Poa spec.	Early warning list	high to very high
Plants	Carex echinata cf.	Early warning list	high to very high
Plants	Saxifraga granulata	Early warning list	high to very high
Plants	Veronica serphyllifolia	Endangered	
Plants	Carex vulpina	Endangered	
Plants	Carex gracilis cf.	Extremely rare	medium
Plants	Carex spec.	Highly endangered	
Plants	Hypericum cf.	Highly endangered	
Plants	Juncus spec.	Insufficient data	medium
Plants	Ranuculus bulbosus	Threatened by extinction	
Plants	Arrhenaterum elatius	Threatened by extinction	high to very high
Amphibians	Rana temporaria	Endangered	
Amphibians	Rana dalmatina	Endangered	
Amphibians	Bombina variegata	Highly endangered	
Amphibians	Hyla arborea	Highly endangered	
Birds	Saxicola rubicola	Early warning list	
Birds	Oriolus oriolus	Endangered	
Birds	Rallus aquaticus	Highly endangered	
Birds	Streptopelia turtur	Highly endangered	
Birds	Saxicola rubetra	Threatened by extinction	
Insects	Coenagrion mercuriale (Dragonfly)	Endangered	
Insects	Lycaena dispar (Butterfly)	Endangered	
Insects	Cucujus cinnaberinus (Beetle)	Threatened by extinction	
Bats	Myotis myotis	Strictly protected*	
Bats	Myotis bechsteinii	Strictly protected*	

**According to FFH-Anhang IV*

Sources: KIT Aueninstitut data; ARTIS; LUBW; Natura 2000; Bundesamt für Naturschutz.

Annex VI: Map of the Münchfeld area by sealing types, and sewer system discharging stormwater into the Rastatter Bruch

Münchfled area sealing and its stormwater sewer system discharging into the Rastatter Bruch



Annex VII: Potential pollutants from the Münchfeld area and its natural and anthropic sources

The table describes shortly all existing natural sources but only focus on realistic possibilities for anthropic sources

Nature/ classification	Compound	Natural sources	Anthropic sources
Trace metals	Aluminium (Al)	Weathering of minerals containing said heavy metal	Diverse roofing and construction materials
	Arsenic (As)		Wood preservatives, traffic emissions, asphalt shingles
	Cadmium (Cd)		Roof shingles, motors, tires, batteries, pigments, plastic stabilizers, galvanized steel
	Chromium (Cr)		Metal plating, moving parts, brake lining wear, traffic emissions
	Copper (Cu)		Metal plating, bearing and brush wear, moving engine parts, brake lining wear, tires, roofing materials, copper plumbing
	Iron (Fe)		Automotive rust, corrosion of steel highway structures (e.g. guardrails), moving engine parts, tires
	Lead (Pb)		Exhaust gases, tire wear, lubricating oil and grease, bearing wear
	Manganese (Mn)		Moving engine parts, traffic emissions
	Nickel (Ni)		Diesel fuel and exhaust gases, lubricating oil, metal plating, ring wear, brake lining wear, asphalt coating, roofing material
	Thallium (Tl)		Cement
	Se, Hg, Co, Sb, Be, Ba		
	Zinc (Zn)		Tire wear, motor oil, grease, galvanized materials, roofing and plumbing materials
Organic pollutants	Oil, grease	Decayed organic matter, microbial activity	Spills, leaks or outgassing of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachates, cooking waste
	Polychlorinated biphenyls (PCBs)	None (synthetic)	Atmospheric background deposition, PCB catalyst in synthetic tires
	Polycyclic aromatic hydrocarbons (PAHs)	Forest fire	Asphalt surface leachate, fuel and oil, vehicle exhaust, household chemicals, paints and preservatives, electrical equipment
	Polyfluoroalkyl substances (PFAS)	None (synthetic)	Household furniture, firefighting foams
Nutrients	Nitrate (NO_3^-), Nitrite (NO_2^-), Ammonium (NH_4^+) …	Decomposition of organic matter, biological processes in plants	Fertilizers, gardens, green roofs roadside, sewage and animal waste, atmospheric and pollen deposition, soil erosion, industrial discharges
	Phosphate (PO_4^{3-})		Detergent, organic waste
Inorganic salts	Sulfate (SO_4^{2-})	Weathering of sulfate-bearing minerals, volcanic activity, atmospheric deposition, decomposed organic matter	Roadway beds, fuels, deicing salts
	Chloride (Cl^-), Sodium (Na^+)	Weathering of limestone, gypsum, dolomite, etc	Deicing agent on roads, construction lime, concrete, household chemical products, domestic wastewater
	Calcium (Ca^{2+}), Magnesium (Mg^{2+})		
Pathogenic microorganism	Escherichia Coli, viruses etc	Microbial and ecosystemic activity	Pet waste, improper waste disposal and failing septic systems
Plastics	Macro-, micro- and nanoplastics	None (synthetic)	household waste, synthetic fibers from laundry, personal care products, paints, littering, construction debris, automotive parts, tire wear

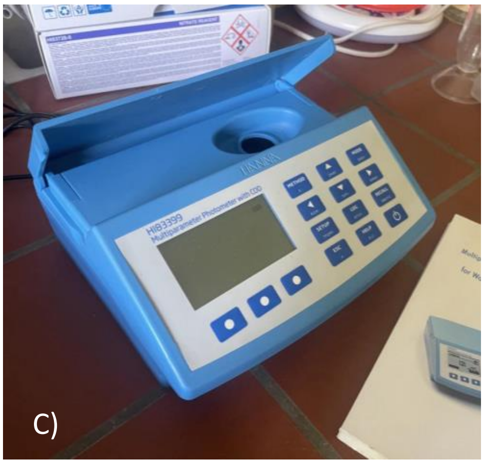
Annex VIII: Extensive literature research on precautionary and background values for heavy metals and PAHs

		Standardized procedure of detection	Precautionary values					Background values in specific sites		Upper limit	Particle-bound share in the water
			BBodSchV (2021) sand-clay	NLWK (2000)		LABO appendix (2017) peat /forest	BAST (2017)	Other sources			
				Value	Fluctuation range						
Metals (mg/kg)	Aluminium (Al)	DIN EN ISO 17294-2:2017-01	-	-	-	-	-	10,000-30,000	Lindsay (1979)	30 000	-
	Arsenic (As)		10-20	-	10	9.2	-	10-40	Agency for Toxic Substances and Disease Registry	40	-
	Cadmium (Cd)		0.4-1.5	0.3	0.15-0.6	0.5	0.19	0.01-1	Kubier, A. et al. (2019)	1.5	46-59%
	Calcium (Ca)		-	-	-	-	-	1,000-50,000	European Soil Data Centre (ESDAC)	50 000	-
	Chromium (Cr)		30-100	80	40-160	56	-	10-100	Yuxia, L. et al., 2021	160	-
	Copper (Cu)		20-60	20	10-40	26	12.3	2-50	Oorts, K. (2013)	60	>81%
	Iron (Fe)		-	-	-	-	-	20,000-550,000	Bodek et al. (1988)	550 000	>87
	Lead (Pb)		40-100	25	12.5-50	48	1.5	15-40	Center for Agriculture, Food, and the Environment	100	>91%
	Magnesium (Mg)		-	-	-	-	-	1,000-20,000	European Soil Data Centre (ESDAC)	20 000	-
	Manganese (Mn)		-	-	-	-	-	40-900	Agency for Toxic Substances and Disease Registry	900	-
	Nickel (Ni)		15-70	30	10-60	22		20-30	Echevarria, G et al. (2006)	70	>47%
	Thallium (Tl)		0.5-1	-	-	0.5	-	0.1-1	Fisher, M (2012)	1	-
	Zinc (Zn)		60-200	100	50-200	54	37.7	10-300	Noulas, C. et al. (2018)	300	>77%
PAHs (µg/kg)	Acenaphthene	**PV M 1500/F**	3,000-5,000	-		8,000	710				83-99%
	Acenaphthylene										
	Anthracene										
	Benzo(a)anthracene										
	Benzo(a)pyrene										
	Benzo(b)fluoranthene										
	Benzo(ghi)perylene										
	Benzo(k)fluoranthene										
	Chrysene										
	Dibenz(ah)anthracene										
	Fluoranthene										
	Fluorene										
	Indeno(1,2,3-cd)pyrene										
	Naphthalene										
	Phenanthrene										
	Pyrene										

Annex IX: Pictures of the material and method used for water sampling.

A) presents the bottles used to collect the samples. B) is the filter used along with a syringe to filter all samples. C) is the photometer used for the measures. D) is an example of the water samples tested for Chloride, after the chemical reaction.

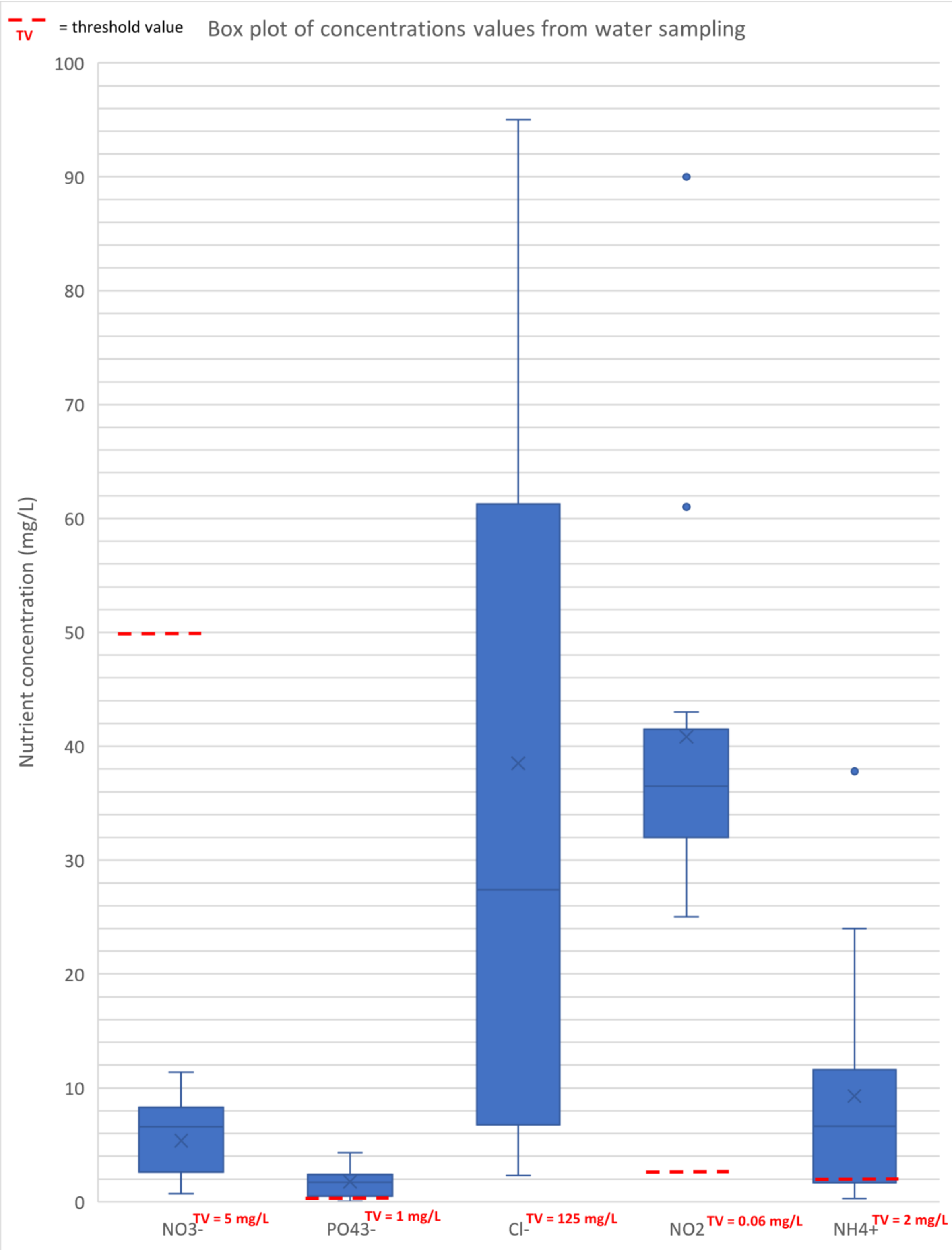
Reference of the photometer: Hanna Instruments COP-Photometer 83399 –Multiparameter Photometer with COD for Water & Wastewater.



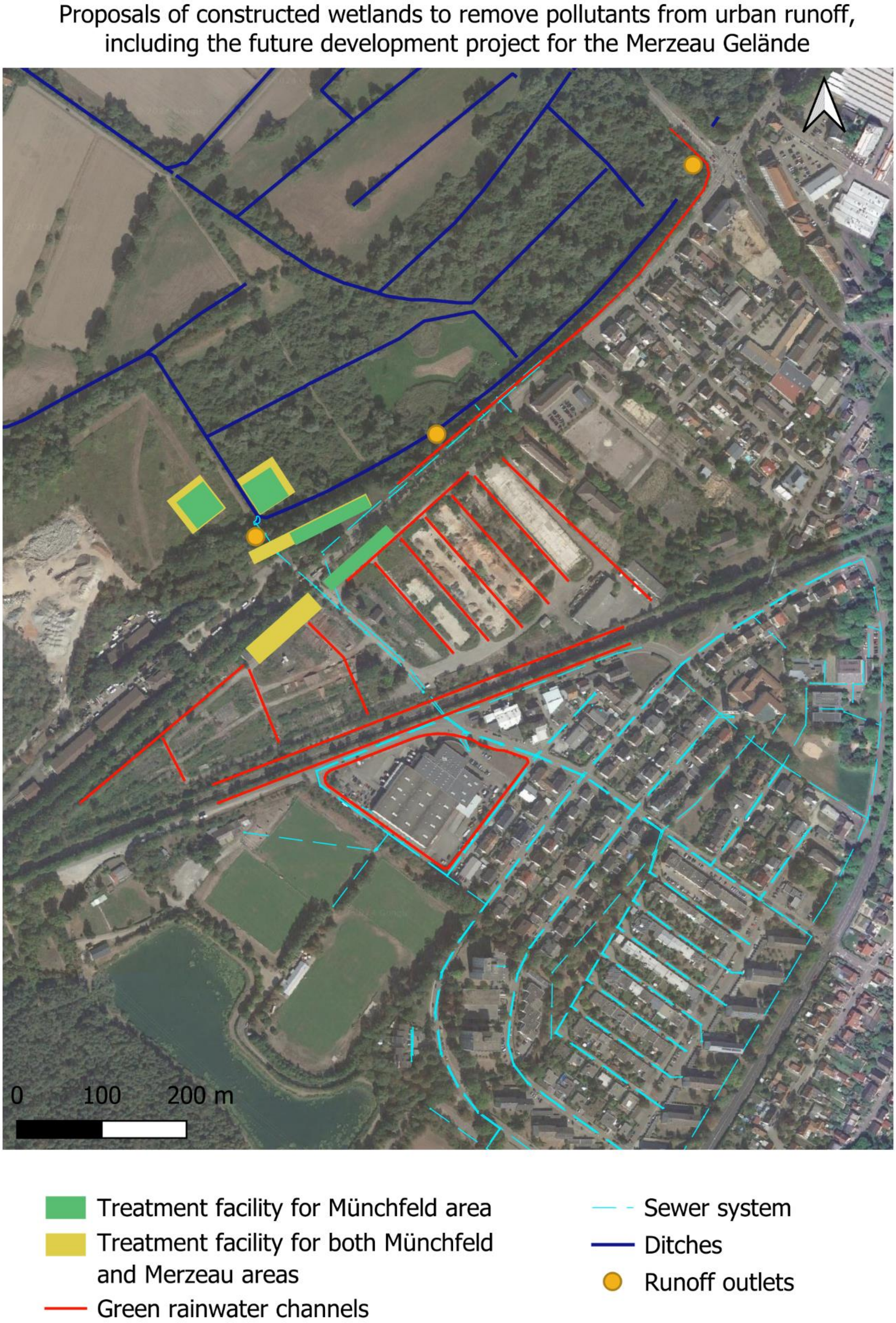
Annex X: Table showing the gross results from the water analysis

Day		NO3- (mg/L)	PO43- (mg/L)	Cl- (mg/L)	NO2- (mg/L)	NH4+ (mg/L)	EC (µS/cm)	pH
22-Feb		2.6	1.9	49.5			371	7.57
7-Mar		3.7	0.93	27.4	61	6.5	388	
8-Mar		3.7	0.93	27.4	61	6.5		7.85
22-Mar		2.7			32	7.22	933	7.44
25-Mar		6.6	0.34	56	32	1.7	149.8	7.54
26-Mar		11.4	1.3	26.5	43	6.8	363	7.82
27-Mar		8.7	2.2		40	9.35	532	7.72
28-Mar		8	0.44	5.8	32	1.65	99.8	7.24
3-Apr		7.8	0.22	5.5	39	0.36	75.2	7.47
4-Apr		8.7	0.03	2.3	30	0.27	58.7	7.4
5-Apr		6.9	1.56	13.9	32	6.04	279	7.73
8-Apr		3.6	4.1	57	37	17.35	800	7.83
9-Apr		0.7	4.32	60	41	20.2		8.03
30-Apr		8.6	2.64	88	90	37.8	1145	8.06
6-Jun		8.3	2.07	67.5	36	8.95	677	7.29
11-Jun		0.9	3.96	62.5	35	24	969	7.39
21-Jun		6.7	1.96	7.7	32	2.25	156.6	6.96
25-Jun		0.9	2.34	95	37	9.7	918	7.13
3-Jul		1.4	0.54	2.5	25	0.4	57.2	7.06
9-Jul		5.5	3.06	30.8	25	14.75	690	8.35
12-Jul		9.4	0.8	24.5	24	2.2	304	8.22
21-Jul		6.53	0.43	5.03	28.00	1.69	119.27	6.51

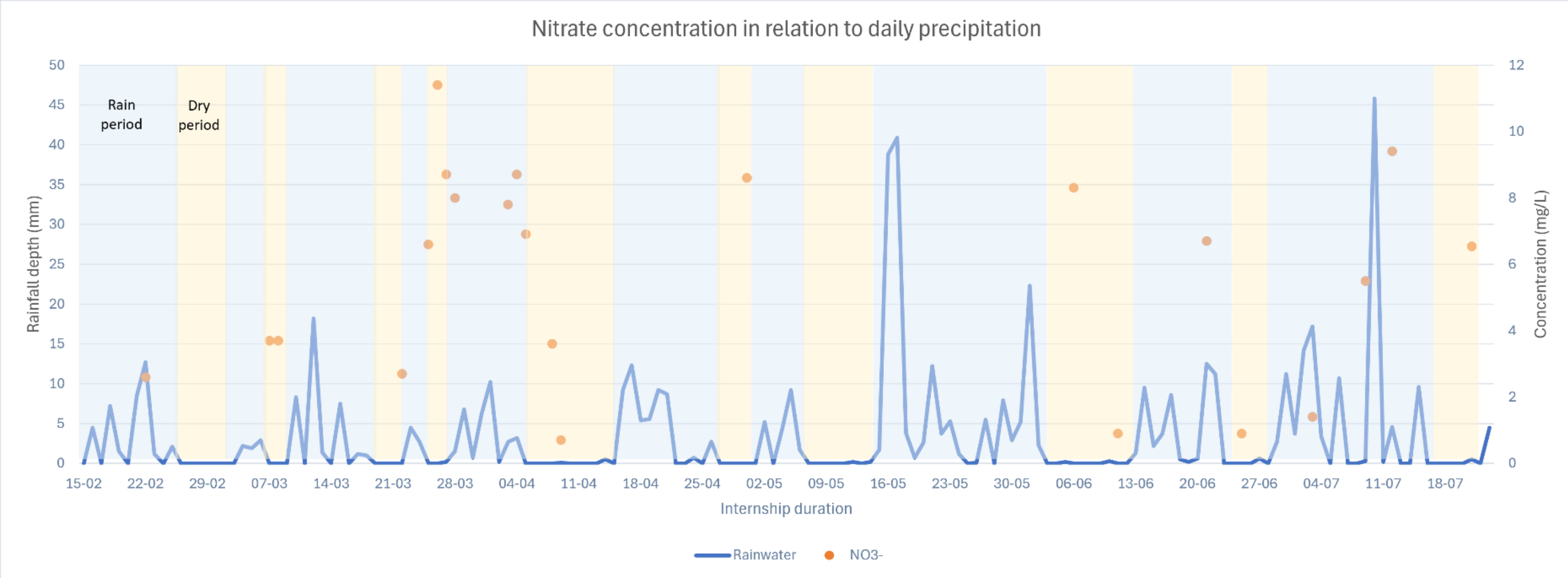
Annex XI: Box plot of nutrients with threshold values

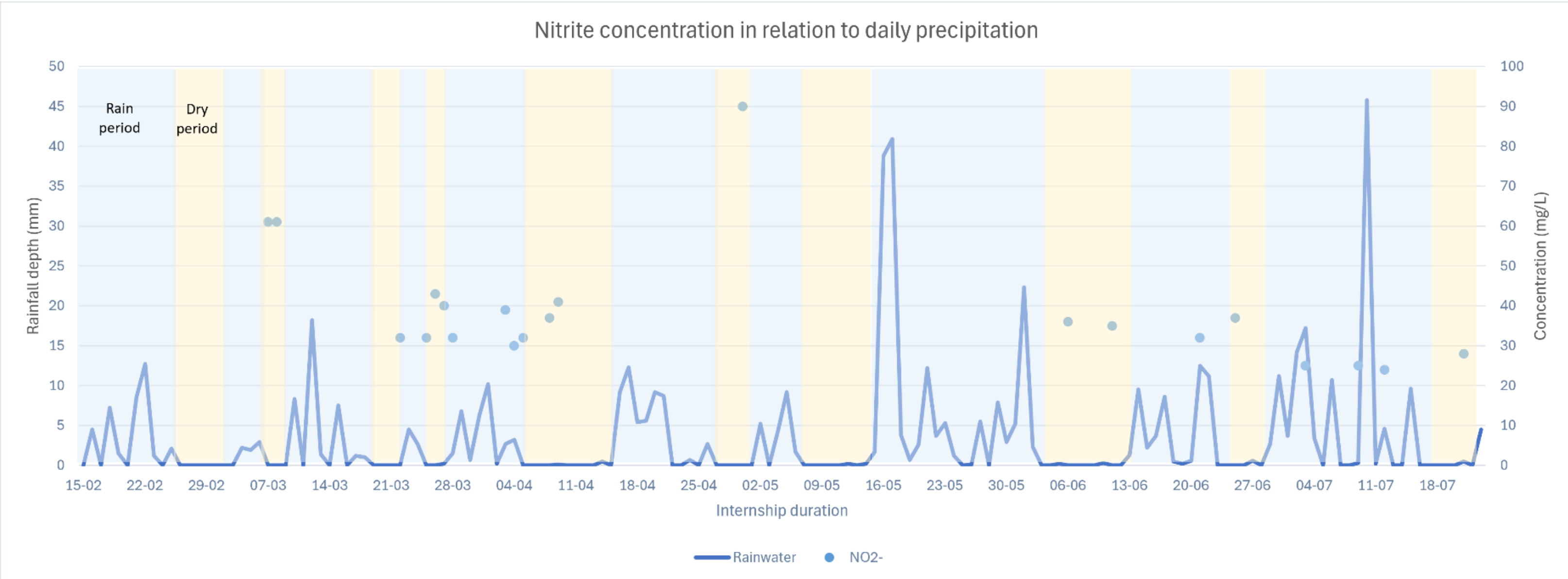


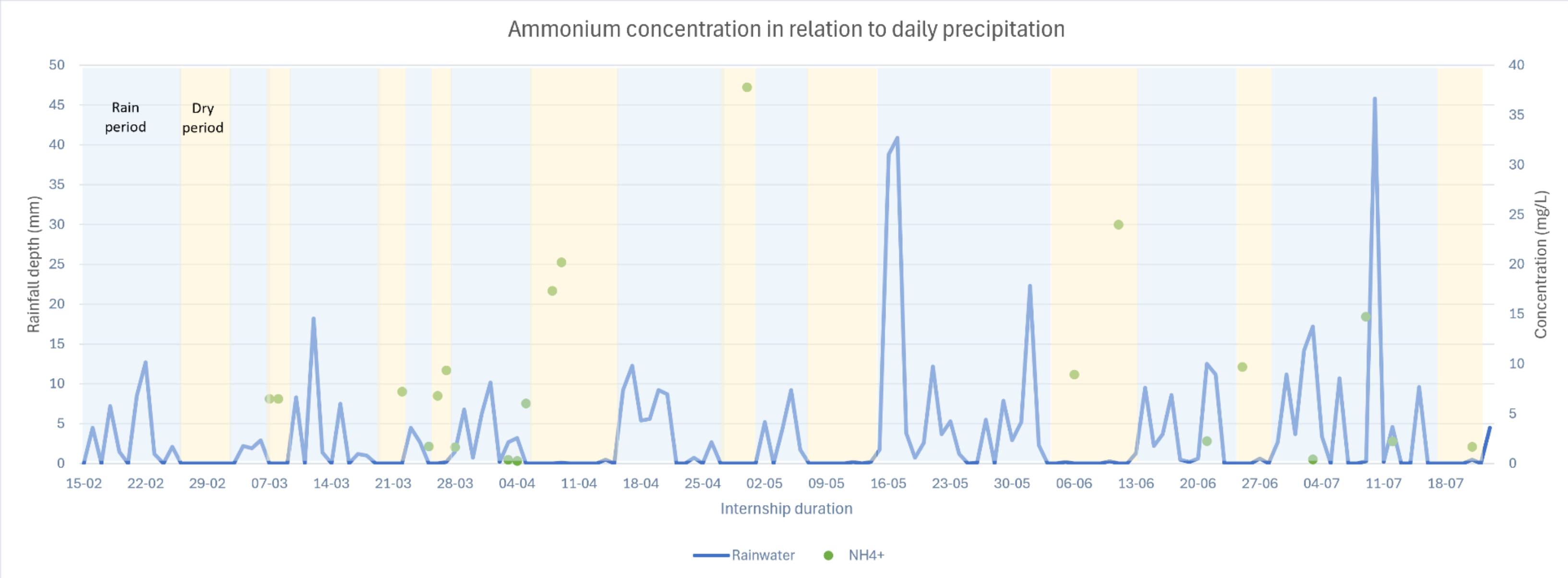
Annex XII: Proposals of water treatment facilities in the Rastatter Bruch area to mitigate urban runoff

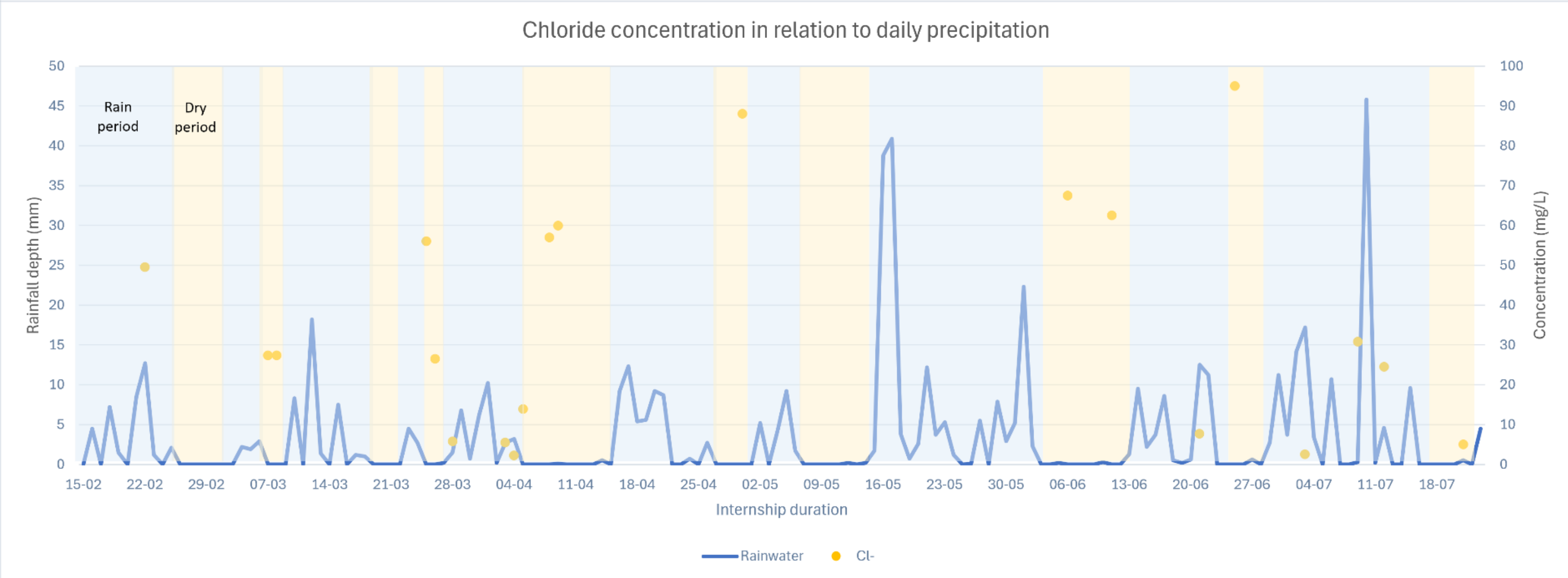


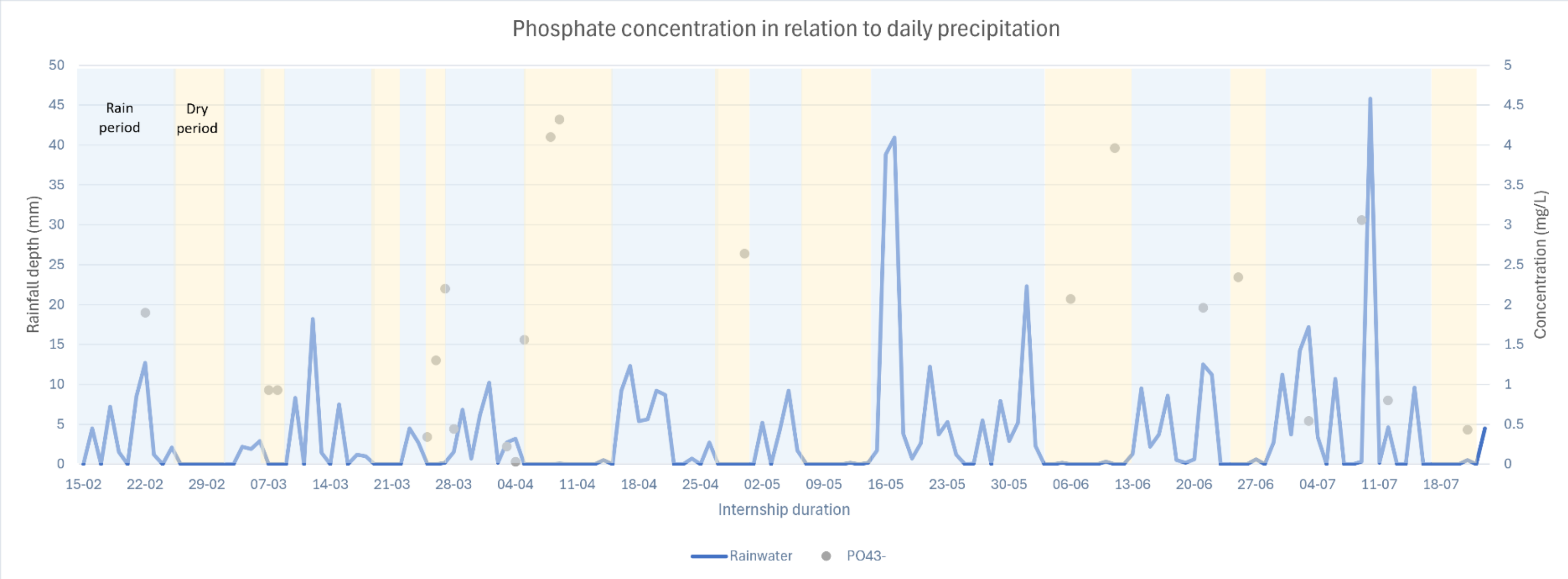
Annex XIII: Time series charts showing variations for each nutrient compared to rainfall


Nitrate concentration in relation to daily precipitation
Rainfall depth (mm)
Concentration (mg/L)
Rain period
Dry period
15-02
22-02
29-02
07-03
14-03
21-03
28-03
04-04
11-04
18-04
25-04
02-05
09-05
16-05
23-05
30-05
06-06
13-06
20-06
27-06
04-07
11-07
18-07
Internship duration
Rainwater
NO3-

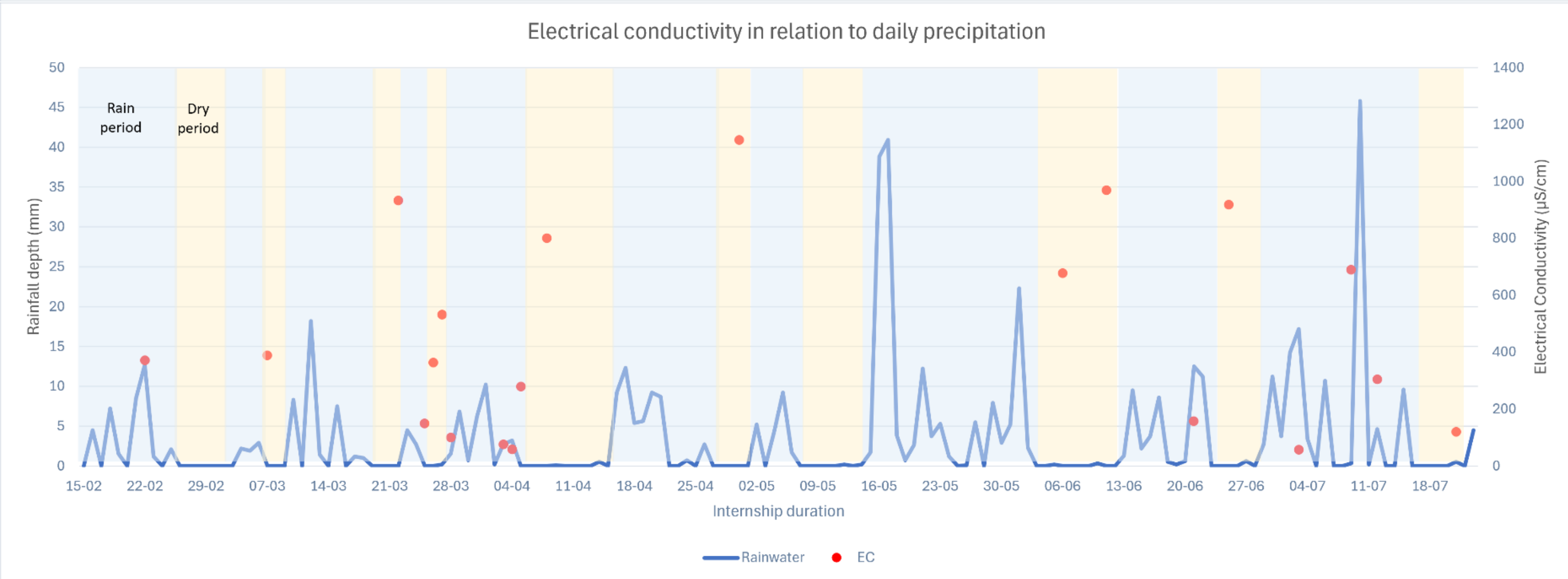

Nitrite concentration in relation to daily precipitation
Rainfall depth (mm)
Concentration (mg/L)
Rain period
Dry period
15-02
22-02
29-02
07-03
14-03
21-03
28-03
04-04
11-04
18-04
25-04
02-05
09-05
16-05
23-05
30-05
06-06
13-06
20-06
27-06
04-07
11-07
18-07
Internship duration
Rainwater
NO2-


Ammonium concentration in relation to daily precipitation
Rain period
Dry period
Rainfall depth (mm)
Concentration (mg/L)
Internship duration
15-02
22-02
29-02
07-03
14-03
21-03
28-03
04-04
11-04
18-04
25-04
02-05
09-05
16-05
23-05
30-05
06-06
13-06
20-06
27-06
04-07
11-07
18-07
Rainwater
NH4+


Chloride concentration in relation to daily precipitation
Rain period
Dry period
Rainfall depth (mm)
Concentration (mg/L)
Internship duration
15-02
22-02
29-02
07-03
14-03
21-03
28-03
04-04
11-04
18-04
25-04
02-05
09-05
16-05
23-05
30-05
06-06
13-06
20-06
27-06
04-07
11-07
18-07
Rainwater
Cl-



Phosphate concentration in relation to daily precipitation
Rain period
Dry period
Rainfall depth (mm)
Concentration (mg/L)
Internship duration
Rainwater
PO43-



Electrical conductivity in relation to daily precipitation
Rain period
Dry period
Rainfall depth (mm)
Electrical Conductivity (µS/cm)
Internship duration
Rainwater
EC

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37200 TOURS

Water quality assessment of urban runoff into a protected peatland

Servane Gaudefroy
2023-2024

Abstract: this report assesses the water quality of the Rastatter Bruch, a protected suburban fen that currently receives urban runoff from the nearby city of Rastatt. Several approaches have been explored, such as soil sampling to detect for heavy metals and PAHs, water sampling for nutrients, modeling of long-term simulations using a runoff simulation software. The drains of the Rastatter Bruch exceed the precautionary values for Cadmium, Copper, Lead, Zinc, and PAH-16, and is receiving water with phosphate, nitrite and ammonium exceeding the German threshold values for drinking water. Technical solutions are proposed to provide an adequate filtration of pollution, such as constructed wetlands, bioswales and rainwater channels with vegetated cakes.

Keywords: Rastatter Bruch, urban runoff, stormwater, pollution, constructed wetlands.

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