INDUSTRIAL STORMWATER TREATMENT AND REUSE: A CASE STUDY

by

Taylan Berke Yıldız

B.Sc. in Civil Engineering, The Ohio State University, 2017

Submitted to the Institute of Environmental Sciences

in partial fulfilment of the requirements for the degree of

Master of Science

in

Environmental Technology

Boğaziçi University

2024

INDUSTRIAL STORMWATER TREATMENT AND REUSE: A CASE STUDY

APPROVED BY:

Prof. Dr., Ferhan Çeçen Thesis Advisor	. . . . .
Prof. Dr. Nadim Copty	. . . . .
Prof. Dr. Kozet Yapsaklı	. . . . .

DATE OF APPROVAL: 11.01.2024

To my little sister Alara, who always makes me proud with her intelligence and kindness, and without whom I wouldn't find the strength to overcome the endless, mundane struggles of life.

ACKNOWLEDGEMENTS

First of all, I would like to thank my parents, Melek Yıldız and Harun Yıldız, for all the sacrifices they made to provide me with an outstanding education from kindergarten until graduate school. Without their unconditional love and support, I would never have reached this point in my academic life.

Secondly, I express my gratitude to my thesis and academic advisor, Prof. Dr. Ferhan Çeçen, who also taught many classes related to water treatment and wastewater treatment during my studies at Boğaziçi University, for sharing her vast knowledge in water and wastewater treatment.

I want to thank my co-workers at Meta Mühendislik, Ali Tanyeli, Cenk Çakal, and Gamze Özdemir for helping me during sample collection and laboratory analyses.

Finally, I want to thank Merve Günaştı for encouraging and motivating me to finish my thesis when I felt lost and hopeless.

ABSTRACT

INDUSTRIAL STORMWATER TREATMENT AND REUSE: A CASE STUDY

Stormwater drained from industries has adverse effects on receiving water bodies and sewer systems. Industrial facilities are usually built on large areas of land and receive a high volume of stormwater. Draining industrial stormwater to sewers is a waste of water that can otherwise be re-used in various processes within industries. Many different treatment technologies are studied and applied to minimize the negative effects of stormwater run-off on sewer systems, surface water bodies, and the water cycle in general. This study aims to review the pollutants found in stormwater collected from point sources in industries and evaluate their potential utilization for various on-site applications after proper treatment. Samples were collected from the warehouse of a logistics company during various rain events and parameters including COD, pH, TDS, and TSS were measured. Multiple treatment methods including sedimentation, coagulation, flocculation, sand filtration, and activated carbon filtration were used in a lab-scale experiments to evaluate the treatment efficiencies. It was tested whether stormwater can be brought to a quality that will be suitable for re-use in warehouses of logistics industries for technical purposes. The study showed that after proper treatment, stormwater collected from the warehouse of a logistic company can be brought to a quality suitable for reuse in technical applications.

ÖZET

ENDÜSTRİYEL YAĞMUR SULARININ ARITIMI VE GERİ KAZANILMASI: VAKA ANALİZİ

Endüstriyel tesislerden drene edilen yağmur suyu, alıcı su kaynaklarına ve kanalizasyon sistemlerine olumsuz etkiler bırakır. Endüstriyel tesisler genellikle geniş arazi alanları üzerine kurulur ve yüksek miktarda yağmur suyu alır. Yağmur suyunun kanalizasyona boşaltılması, çeşitli amaçlarla tekrar kullanılabilecek suyun israf edilmesi demektir. Yağmur suyunun kanalizasyon sistemleri, yüzey suları ve genel olarak su döngüsü üzerindeki olumsuz etkilerini önlemek için birçok farklı arıtma teknolojisi incelenmekte ve uygulanmaktadır. Bu çalışma endüstriyel tesislerdeki noktasal kaynaklardan toplanan yağmur suyunda bulunan kirleticileri analiz etmeyi ve uygun arıtma işlemleri sonrası çeşitli teknik amaçlarla yeniden kullanma potansiyellerini değerlendirmeyi amaçlamaktadır. Avrupa'nın önde gelen lojistik şirktetlerinden birinin deposundan çeşitli mevsimlerde yağmur yağışı sırasında toplanan numunelerde Kimyasal Oksiyen İhtiyacı (KOI), pH, Toplam Çözünmüş Madde (TÇM) ve Toplam Askıda Katı Madde (AKM) gibi parametreler ölçülmüştür. Dengeleme, koagülasyon, flokülasyon, çöktürme ve filtrasyon gibi çeşitli arıtma yöntemleri laboratuvar ölçeğindeki deneylerde uygulanarak arıtma verimlilikleri değerlendirilmiş ve lojistik endüstrilerinin depolarında teknik amaçlar için tekrar kullanılmak üzere yağmur suyunun uygun bir kaliteye getirilip getirilemeyeceği test edilmiştir. Yapılan çalışma, bir lojistik şirketinin depolama tesislerinden toplanan yağmur suyunun uygun arıtma teknolojileri kullanılarak teknik amaçlı kullanıma uygun hale getirilebileceğini göstermiştir.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iv

ABSTRACT v

ÖZET vi

TABLE OF CONTENTS vii

LIST OF FIGURES x

LIST OF TABLES xii

LIST OF SYMBOLS/ABBREVIATIONS xvi

1. INTRODUCTION 1

2. LITERATURE REVIEW 5

2.1. Stormwater Quality and Treatment 5

2.2. Stormwater Pollutants and Important Parameters 10

2.2.1. pH 11

2.2.2. Total Hardness 11

2.2.3. Conductivity 11

2.2.4. Total Dissolved Solids 12

2.2.5. Total Suspended Solids 12

2.2.6. Chemical Oxygen Demand 12

2.2.7. Oil and Grease 13

2.2.8. Total Iron 13

2.2.9. Temperature 14

2.2.10. Day Since Previous Rain Event – Time Internal Between Two Rain Events 14

2.3. Aim of The Study 14

3. MATERIALS AND METHODS 16

3.1. Sample Collection and Preservation 16

3.2. Laboratory Tests 19

3.2.1. Balancing……..... 21

3.2.2. Coagulation and Flocculation 21

3.2.3. Settling……. 27

3.2.4. Filtration……..... 28

4. RESULTS AND DISCUSSION 30

4.1. Sample Analysis Results 30

4.2. Experimental Results 36

4.3. Stormwater Yield Calculations..... 42

4.4. Annual Water Demand Calculations 44

4.5. Theoretical Demand Calculations for Natural Disaster Events..... 47

5. PROPOSED SYSTEMS AND RECOMMENDATIONS..... 49

5.1. Proposed System for Reuse in the Industry..... 49

5.2. Technical Specifications of Equipment 53

5.2.1. Coarse filter…… 53

5.2.2. Storage Tank… 54

5.2.3. Filter Apparatus..... 54

5.2.4. Booster Pump……..... 55

5.2.5. Flocculator…….. 55

5.2.6. Multimedia Filter..... 58

5.2.7. Activated Carbon Filter 59

5.3. Cost Analysis.. 60

5.3.1. Investment Cost..... 60

5.3.2. Operation Costs..... 61

5.4. Alternative Theoretical System for Natural Disaster Events 63

5.4.1. System Design.....64

5.4.2. System Components.....67

5.4.2.1. Feed pumps.....67

5.4.2.2. Dosing System. 67

5.4.2.3. Inline flocculator and inline mixers 67

5.4.2.4. Multimedia filter. 68

5.4.2.5. Activated carbon filter.....68

5.4.2.6. Reverse osmosis system. 68

5.4.2.7. Remineralisation system. 71

5.4.2.8. Booster set. 71

5.4.2.9. Final disinfection unit 72

5.4.2.10. Container. 72

5.4.2.11. Automation panel.....72

5.4.3. Cost Analysis…. 73

6. CONCLUSIONS…. 74

REFERENCES.....75

LIST OF FIGURES

Figure 1.1. Map of the location of the facility. 2

Figure 1.2. Sertrans warehouse in Samandira, Istanbul....3

Figure 1.3. Loading/unloading tracks for vehicles....3

Figure 1.4. Truck parking area....4

Figure 1.5. Container storage area....4

Figure 3.1. Sampling point 1....16

Figure 3.2. Tailor-made sampling rod used in the study for sampling....17

Figure 3.3. Sampling point 2....18

Figure 3.4. Sampling point 3....19

Figure 3.5. Samples 1 and 2 before lab tests....20

Figure 3.6. Jar test device. 21

Figure 3.7. Samples 1 and 2 during Jar test. 23

Figure 3.8. Samples 1 and 2 during flocculation phase....24

Figure 3.9. Sample 1 after mixing and 60 minutes of settling. 27

Figure 3.10. Filtration stage of the sample. 28

Figure 3.11. Top view of the filtration stage....29

Figure 3.12. Treated stormwater 29

Figure 5.1. Sample water quality comparison graph. 50

Figure 5.2. Stormwater collection and treatment system flow diagram. 52

Figure 5.3. Rainfilter produced by 3P Technik. 53

Figure 5.4. Water storage tank produced by Karmod Plastik. 54

Figure 5.5. Rainwater storage tank installation example by 3P Technik. 55

Figure 5.6. Flocculator example. 56

Figure 5.7. Inline static mixer example. 56

Figure 5.8. U-PVC pipe list by Pimtas. 58

Figure 5.9. Dosing pump by Seko for sodium hypochlorite dosing. 60

Figure 5.10. Sodium hypochlorite dosing 3D drawing by Meta Muhendislik. 60

Figure 5.11. Schematic configuration of reverse osmosis plant by Alghoul et al. 2009. 64

Figure 5.12. Drinking water treatment system flow schema. 65

Figure 5.13. Container design (top view). 66

Figure 5.14. Reverse osmosis system 3D Drawing by Meta Muhendislik. 69

Figure 5.15. Reverse osmosis membrane projection - 1. 70

Figure 5.16. Reverse osmosis membrane projection - 2. 71

Figure 5.17. Image of 40' standard shipping container. 72

LIST OF TABLES

Table 3.1. Sample preservation guide from industrial stormwater sampling guide by EPA. 20

Table 3.2. Lab test details for samples 1-3. 23

Table 3.3. Lab test details for samples 4-6. 24

Table 3.4. Lab test details for samples 7-9. 25

Table 3.5. Lab test details for samples 10-12. 25

Table 3.6. Lab test details for samples 13-15. 26

Table 3.7. Lab test details for samples 16-18. 26

Table 3.8. Lab test details for samples 19-21. 27

Table 4.1. Sample collection table. 31

Table 4.2. Analysis of samples 1-3. 32

Table 4.3. Analysis of samples 4-6. 32

Table 4.4. Analysis of samples 7-9. 33

Table 4.5. Analysis of samples 10-12 33

Table 4.6. Analysis of samples 13-15 34

Table 4.7. Analysis of samples 16-18 34

Table 4.8. Analysis of samples 19-21 35

Table 4.9. Statistical analysis of raw samples. 35

Table 4.10. Analysis of sample 1 before and after treatment. 36

Table 4.11. Analysis of sample 2 before and after treatment. 36

Table 4.12. Analysis of sample 3 before and after treatment. 37

Table 4.13. Analysis of sample 4 before and after treatment. 37

Table 4.14. Analysis of sample 5 before and after treatment. 37

Table 4.15. Analysis of sample 6 before and after treatment. 37

Table 4.16. Analysis of sample 7 before and after treatment. 38

Table 4.17. Analysis of sample 8 before and after treatment. 38

Table 4.18. Analysis of sample 9 before and after treatment. 38

Table 4.19. Analysis of sample 10 before and after treatment. 38

Table 4.20. Analysis of sample 11 before and after treatment. 39

Table 4.21. Analysis of sample 12 before and after treatment. 39

Table 4.22. Analysis of sample 13 before and after treatment. 39

Table 4.23. Analysis of sample 14 before and after treatment. 39

Table 4.24. Analysis of sample 15 before and after treatment. 40

Table 4.25. Analysis of sample 16 before and after treatment. 40

Table 4.26. Analysis of sample 17 before and after treatment.....40

Table 4.27. Analysis of sample 18 before and after treatment.....40

Table 4.28. Analysis of sample 19 before and after treatment.....41

Table 4.29. Analysis of sample 20 before and after treatment.....41

Table 4.30. Analysis of sample 21 before and after treatment.....41

Table 4.31. Laboratory test results statistical analysis. 42

Table 4.32. DIN 1989 yield coefficients.....43

Table 4.33. Yield calculations.....43

Table 4.34. DIN 1989 determination of the annual process water requirements.....45

Table 4.35. Demand calculations. 45

Table 5.1. Sample water quality comparison table. 50

Table 5.2. Investment costs.....61

Table 5.3. Energy consumption.....62

Table 5.4. Cost of consumables. 62

Table 5.5. Total annual operation costs. 62

Table 5.6. Regulation on waters intended for human consumption - indicator parameters (Republic of Türkiye Ministry of Health, 2005).....63

Table 5.7. Technical features of the reverse osmosis system. 69

Table 5.8. Cost analysis for alternative design. 73

LIST OF SYMBOLS/ABBREVIATIONS

Symbol	Explanation	Unit
A_A	The collecting area in square meters	m^2
BW_a	Annual Water Demand	L
E_R	The rainwater yield in liters per year	L/a
e	The yield coefficient in %	%
h_N	The quantity of precipitation	L/m^2
n	Number of Persons	-
η	Hydraulic Filter Efficiency	%
P_d	Demand per Person per Day	L/p/day
T	Temperature	° Celcius
t	Time	s
V	Volume	L
V_n	Useful Volume	L

Abbreviation	Explanation
AISI	American Iron and Steel Institute
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
BOD_5	Five-Day Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CHIAT	Chemical Hazard Identification and Assessment Tool
DIN	Deutsches Institut für Normung
EPA	Environmental Protection Agency
ISKI	Istanbul Su ve Kanalizasyon Idaresi
IT	Information Technology
ORP	Oxidation Reduction Potential
PAHs	Polycyclic Aromatic Hydrocarbons
R&D	Research and Development
RO	Reverse Osmosis
SM	Standard Methods
TDS	Total Dissolved Solids

TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TS	Total Solids
TSS	Total Suspended Solids
U-PVC	Unplasticized Polyvinyl Chloride
UV	Ultraviolet
WHO	World Health Organization

1. INTRODUCTION

Water stress is one of the most considerable environmental problems of the modern age. In a world where billions of people lack access to water with adequate quality, recycling water is an inevitable duty for the inhabitants of the planet earth. Therefore, water recovery systems are widely applied to save water in industries. One of the recovery systems applied in the world involves stormwater recovery systems. Environmental Protection Agency (EPA) defines stormwater as ‘’water from rain or snowmelt that does not immediately infiltrate into the ground and flows over or through natural or man-made storage or conveyance systems.’’ (Environmental Protection Agency, 2021a). Another definition is provided by Minnesota Pollution Control Agency. ‘’Stormwater refers to precipitation, snowmelt, surface runoff, and drainage.’’ (Minnesota Pollution Control Agency, 2015). Stormwater is a valuable resource and its utilization will benefit our ecosystem. Stormwater from roads differs from stormwater collected from roofs in terms of the pollutants it contains (Zhang et al., 2010).

Industrial facilities such as factories, foundries, construction sites, and warehouses are often built on large areas of land. In addition, they contain outdoor lots for parking and equipment storage. The high surface areas of these facilities receive a large volume of precipitation in total and the effect of them on the environment and the amount of water that can be recovered is much higher compared to residential facilities. A high surface area is a potential collection point for a high amount of stormwater which can be utilized for various applications including technical purposes such as plumbing, heating and cooling systems. To re-use stormwater, proper treatment techniques should be applied to increase the water quality and remove undesired pollutants. In this case study, stormwater was collected from outdoor impermeable surfaces of the warehouse of an internationally recognized logistics company and was analyzed. Lab-scale experiments were done to evaluate treatment efficiencies of various techniques.

Sertrans is a logistics company that has been operating successfully in the transportation field since 1989. In the early years of operation, Sertrans served its customers in international transportation. Today it is a reliable partner for supply chain operations with its strong vehicle fleet, warehouses in Türkiye and Germany, as well as its R&D Department and advanced IT infrastructure. One of the warehouses of Sertrans is located in Samandira Region, Istanbul, Türkiye. The facility is

used as a bonded warehouse where goods are unloaded from trucks arriving from various international destinations and stored. Customs clearance and inspection is also done at the facility. The warehouse has truck loading/unloading tracks, storage area for unloaded goods, container storage area, truck parking lot and an indoor storage facility. There is also an office building for the employees of Sertrans as well as the customs officials.

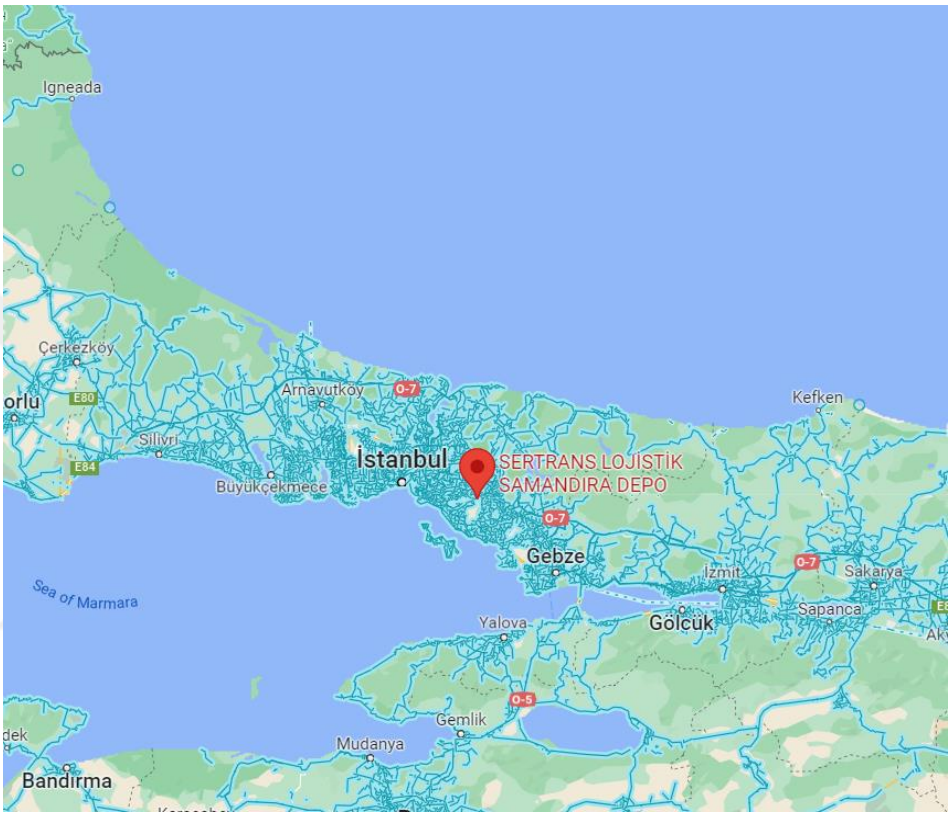


Figure 1.1. Map of the location of the facility.



Figure 1.2. Sertrans warehouse in Samandira, Istanbul.



Figure 1.3. Loading/unloading tracks for vehicles.



Figure 1.4. Truck parking area.



Figure 1.5. Container storage area.

2. LITERATURE REVIEW

2.1. Stormwater Quality and Treatment

Pollutants in stormwater from roofs and other impermeable surfaces such as roads, pavements, parking lots, and highways are analyzed in the literature. Treatment methods were also applied in lab-scale studies, pilot plants, and real-world case studies. This literature review aims to summarize and synthesize the information discussed in the literature in regards to the pollutants found in stormwater from road runoffs and possible treatment strategies to bring the stormwater to a quality to be reused. The quality of stormwater suitable for reuse will be provided from EPA standard as well as cooling tower and boiler manufacturers.

Stormwater is an important source of water. Many scientists research the pollutants present in stormwater from roof and road runoffs in detail. Zhang et al. (2010) examined the pollutant concentrations of stormwater runoff from roofs and roads in industrial, commercial, and residential areas in Zhengzhou City, China. Water samples from four separate rain events during the summer season were collected and the Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD) and 5-day Biochemical Oxygen Demand (BOD_5) parameters were measured. Characteristics of both road and roof runoffs were compared according to their pollutant concentrations. Zhang and co-workers found that the industrial stormwater runoff from roads contained the highest concentration of pollutants in each rain event (Zhang et al., 2010). Standard methods of APHA were used during sample analysis in the study. The pollutant concentrations measured as a part of the study were compared to previous data from the literature. Zhang et al. (2010) link the difference between measured pollutant concentrations and the data collected from another city in China to different precipitation patterns. According to Zhang et al. (2010), the time interval between rain events also affects the pollutant concentrations. Hence, pollutant concentrations may vary from one location to another. In addition to characteristics of stormwater in three different functional areas, Zhang et al. (2010) also investigated the treatment methods that are suitable for stormwater treatment. They argue that one important step in treating stormwater is the first flush application. ‘’Most pollutant loads were contained in the initial parts of runoff volume. Therefore, the initial runoff should be collected and treated separately before discharge or utilize to cut down the cost of treatment during utilization process and to control stormwater pollution’’ (Zhang et al., 2010). According to Zhang et al. (2010), COD and TSS are the main pollutants in stormwater runoff and all stormwater from road runoff

should be treated prior to reuse or discharge. They argue that sedimentation and filtration are effective methods to remove the undesired pollutants from stormwater.

Another study was done by Langeveld et al. (2012) about the characteristics of stormwater and the removal of pollutants in treatment facilities. The main focus of the study was to characterize stormwater and monitor pollutants. Langeveld et al. (2012) conducted a sample case study in which they monitored pollutants in stormwater for two years. Mean concentrations of specific pollutants were monitored in three locations in the Netherlands. Pilot plants were used to monitor the efficiencies of three treatment techniques including lamella settler, sand filter, and soil filter. Monitoring of pollutants was done by installing flow sensors and automatic sampling devices for collecting samples from the incoming stormwater and the treated stormwater. The water parameters that were analyzed as a part of the study were Total Suspended Solids (TSS), BOD, COD, Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), *E. coli*, and metals including lead, zinc, and copper. Langeveld et al. (2012) agrees with Zhang et al. (2010) that COD and TSS should be considered as the main pollutants. However, their concentrations differed from the international data (Langeveld et al., 2012). Langeveld et al. (2012) concluded that this difference was an implication that any stormwater treatment plant designed based on international data will be ineffective because the pollutant concentrations measured in this study were lower than the international data (Langeveld et al., 2012). Mean concentrations of phosphate and metals were measured to be higher than the discharge standards for stormwater. All pollutants except copper could be removed by sand or soil filter but lamella settler alone was not sufficient to bring the stormwater to an acceptable quality. One final aspect examined by Langeveld et al. (2012) was the uncertainties of data. ‘’The relative uncertainty strongly depends on the number of events sampled’’ (Langeveld et al., 2012). According to Langeveld et al. (2012) increasing the number of events will decrease the uncertainty in the obtained data of stormwater pollutants.

Scholz and Yazdi (2009) agree with Langeveld et al. (2012) that monitoring more rain events is advantageous in order to prepare for the worst-case scenario. In their article titled ‘’Treatment of Road Runoff by a Combined Storm Water Treatment, Detention and Infiltration System’’, Scholz and Yazdi (2009) evaluate the treatment performance of a combined system of filtration, detention, and infiltration for stormwater treatment. The stormwater is collected from a road and a car park with a combined area of 640 m^2. The flow modeling is done using the EPA Storm Water Management Model. A pilot plant was built so that the stormwater could pass through a three-layer filter that is composed of gravel, sand, and soil before flowing into the underground storm detention tank.

Stormwater is later infiltrated. This study was also based on samples collected on-site for a period of 16 months and samples were collected from the six separate locations including the inlets and outlets of the filter and the tank. Dissolved Oxygen (DO) and the temperature of the water are measured by portable instruments. Parameters such as Total Solids (TS), ORP, conductivity, pH, and Total Dissolved Solids (TDS) were also measured. One finding of the study that differs from previously discussed literature is the demonstration of the rainfall evaporation rate. According to Scholz and Yazdi (2009), half of the rainfall volume evaporates from the system. Thus, considering evaporation is critical during the design process (Scholz & Kazemi Yazdi, 2009).The treatment methods achieved high treatment efficiencies. Scholz and Yazdi (2009) considered biological degradation as one of the most important removal processes along with sedimentation and infiltration. In this matter, they somewhat contradict with Zhang et al. (2010) because in their study, Zhang et al. (2010) found that the BOD/COD ratio was low and implied that biological treatment is not a major process for stormwater treatment. However, both studies agree that Total Suspended Solids (TSS) and Chemical Oxygen Demand (COD) can be removed effectively with sedimentation and filtration. The Total Suspended Solids removal efficiency was %83 according to Scholz and Yazdi (2009) which is consistent with the data presented in previous studies. BOD and PO_4-P were also removed effectively but Nitrate (NO_3^-) removal performance was poor. They also agree that ‘’initial washout’’ or in other words the ‘’first flush’’ is significant in stormwater treatment (Scholz & Kazemi Yazdi, 2009). This study was important because it combined a filtration and detention tank whereas other studies often used a single technique and made a comparison between the treatment efficiencies of specific pollutants.

Another study was done by Eriksson et al. (2007) to identify the different types of pollutants that can be found in stormwater. A list that consists of 25 pollutants is proposed at the end of the study. Parameters include water quality parameters such as organic matter, pH, nutrients, and metals as well as pollutants caused by industrial activities such as herbicides and polycyclic aromatic hydrocarbons (PAHs). The study of Eriksson et al. (2007) is novel because it introduces additional pollutants to the pollutants listed on European Water Framework Directive. The study was done in five steps using a version of the Chemical Hazard Identification and Assessment Tool (CHIAT). First, the source characterization was done by identifying 680 compounds and metals as potential pollutants in stormwater. The main purpose of the study was to identify pollutants so the hazards of each pollutant were not assessed. When collecting the fates of pollutants, the focus was given on pesticides and PAHs. Finally, the final list was prepared with the involvement of other scientists working on relevant issues in regards to the environmental impacts on water bodies, stormwater management, and end-

users from various countries in Europe. Eriksson et al. (2007) agrees with Zhang et al. (2010) about the impact of surfaces and human activities on stormwater quality (Eriksson et al., 2007).In addition, both articles argue that the quality of stormwater varies based on on-site location and specific rainfall events.

As it is identified in the former studies in the literature and the international directive, heavy metals are often found in stormwater. ‘’For example, chemical pollutants such as heavy metals are primarily generated by motor traffic-related sources such as brake wear, tire wear and vehicle exhaust together with commercial and industrial activities’’ (Ma et al., 2016).Ma et al. (2016) emphasize the heavy metals in stormwater and their risk assessment on human health. According to Ma et al. (2016), stormwater is an important source that has a lot of reuse potential. However, heavy metals are a major setback in stormwater utilization. In their study, Ma et al. (2016) target to develop a quantitative path to evaluate the health risks associated with heavy metals present in stormwater. Ma et al. (2016) agree with previous research in literature that stormwater coming from roofs and roads has different characteristics and stormwater from industrial areas is the most polluted. Heavy metals are often found on road surfaces and therefore, a total of 40 samples were collected from roadways in 20 separate sites in Gold Coast, Australia. 9 heavy metals including aluminum, copper, zinc, manganese, iron, lead, cadmium, nickel, chromium were tested in the samples and a risk assessment procedure that consists of 4 steps were followed. Ma et al. (2016) conclude that heavy metal concentrations and the risk associated with them are strongly affected by the traffic volume on the roads (Ma et al., 2016). Land use also affects heavy metal risks. The heavy metal with the highest amount of contribution to human health risk was chromium (Ma et al., 2016). In addition to chromium, manganese and lead are toxic to human health even if they are present in stormwater at low concentrations. According to Ma et al. (2016), a combination of heavy metals being present in stormwater poses a higher risk to human health than a single heavy metal. This finding can be beneficial for designing a potential stormwater reuse system.

Moreover, Bratieres et al. (2008) conducted research for analyzing the biofilter performance in treating stormwater. A large-scale study was done to examine the pollutant removal efficiencies of biofilters. The study consisted of 125 biofiltration columns which allowed all important characteristics for the design of such filters to be analyzed. According to Bratieres et al. (2008), the main objective of the research study was to examine the impact of parameters such as pollutant concentration, vegetation type, biofilter area, and depth of media on the removal of solids and nutrients from stormwater. The experiment was done with an artificial mixture of stormwater from

an inlet pond and a water sample that was taken from a tap. Chlorine was removed from the tap water before it is added to the mixture. According to Bratieres et al. (2008), the artificial sample gives the opportunity to test the biofilters with a consistent composition which makes it easier to compare their performances in pollutant removal (Bratieres et al., 2008). 25 liters of water is dosed to the biofilters two times a week. This pattern of dosing is done in order to match the real-world pattern of Melbourne rainfall events. Bratieres et al. (2008) set up the sampling system so that samples with average concentration can be taken. In the study, Bratieres et al. (2008) found that all biofilters are capable of high solid removal. The findings match with the research presented in the literature. The average removal for suspended solids was higher than %95 in this study. Nutrient removal performance depended on the species contained in the biofilters. Bratieres et al. (2008) concluded that the biofilters should receive at least 2% of the stormwater in the catchment area, not contain any additional organic matter, contain sandy and loam media, and more importantly contain species with the highest nutrient removal performance in order to enhance the removal efficiency of the whole biofilter (Bratieres et al., 2008).

In addition to the research presented in the literature, Industrial Stormwater Management Guidebook prepared by Minnesota Pollution Control Agency presents a diverse list of topics and guidelines about stormwater management (Minnesota Pollution Control Agency, 2015). Common pollutants are presented in industrial stormwater in Chapter 2. According to the guidebook, the most common pollutants are Total Suspended Solids, Chemical Oxygen Demand, Biochemical Oxygen Demand, nutrients, and metals. Each pollutant and its impacts on water bodies were further explained. Additionally, best management practices including treatment applications for each pollutant are described. The guidebook goes beyond identifying pollutants and treatment strategies as it also provides practical information about preventing stormwater from getting polluted. According to Minnesota Pollution Control Agency, avoiding exposure to pollutants should be the first option (Minnesota Pollution Control Agency, 2015). Structural and non-structural best management practices are also described in the guidebook. Non-structural practices for stormwater consist of daily inspection and maintenance works that can be applied by operating personnel in industrial facilities to control stormwater pollution. Structural practices section includes treatment applications such as sedimentation, detention, infiltration, filtration systems, their design considerations and costs.

Environmental Protection Agency also presents a Pollution Prevention Plan which can be used as a guide by operating personnel in industries. The Pollution Prevention Plan by EPA describes control measures and management principles to control stormwater quality and more importantly to

eliminate pollution (Environmental Protection Agency, 2021a). The information provided by EPA is consistent with the stormwater management guidelines prepared by Minnesota Pollution Control Agency.

In the current literature, a wide range of research is available on stormwater quality, common pollutants, and effective treatment methods. The scientific articles analyzed as a part of this literature review acknowledge that stormwater from roads and other impermeable surfaces has high pollutant loads. The stormwater in an industrial area is more polluted than in residential and commercial areas. The most common pollutants are suspended solids and organic matter. In most cases, heavy metals and nutrients such as phosphorus and nitrogen are found in stormwater. However, stormwater from roads is usually not consistent in terms of its constituents. The quality of stormwater depends on many different variables and therefore the uncertainty in measurements is usually high. Physical treatment methods such as sedimentation and filtration are effective in stormwater treatment but additional treatment methods such as biological treatment and adsorption should be integrated to remove nutrients and metals.

In conclusion, the changing pollutant concentrations in industrial stormwater makes a standardized treatment method hard to apply. Pollutant concentrations in stormwater from the exact same collection point can vary among different seasons of the year. In order to come up with the most effective and economical solution, each facility should be considered unique, and specific treatment methods or a combination of methods should be applied to each facility in order to increase the quality of treated stormwater to the desired level.

2.2. Stormwater Pollutants and Important Parameters

The are many parameters that are important in stormwater reuse systems. The most significant parameters are selected according to prior research in the literature and the water quality requirements for water that will be used for reuse purposes. The main parameters are pH, Total Hardness, Conductivity, Total Dissolved Solids, Total Suspended Solids, Chemical Oxygen Demand, Oil and Grease and Total Iron. In addition to these parameters, temperature of the sample, days between rain events and precipitation rate is also analysed as a part of the present study. Each parameter is defined and discussed in further detail below in parts 2.2.1 through 2.2.10.

2.2.1. pH

pH is defined as ‘’a measure of the acidity or basicity of an aqueous solution’’ (Metcalf & Eddy Inc., 2003). It expresses the H^+ concentration and is one of the most important parameters in water quality studies in general. In the environment the pH of water bodies range between 6-9. However, wastewaters can have pH values out of this range. As a part of this study the Standard Methods are used for measuring pH in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8

2.2.2. Total Hardness

Total hardness primarily refers to the total amount of calcium and magnesium present in the water in dissolved form (Metcalf & Eddy Inc., 2003). Calcium and magnesium ions dissolve in water as it passes through soil and rocks. It is expected to have low hardness in rain and stormwater according to previous studies (Başak & Alagha, 2004). Total hardness is measured in milligrams per Liter of calcium carbonate. Total hardness is certainly an important parameter for water quality. Especially considering the use of water for technical purposes, hardness has direct relationship with scale formation in water networks and equipment (American Society of Plumbing Engineers, 2010). High level of hardness has negative impact on water infrastructures and water treatment processes (Metcalf & Eddy Inc., 2003). As a part of this study the Standard Methods are used for measuring total hardness in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8. The unit of hardness in this study is French hardness.

2.2.3. Conductivity

Conductivity in stormwater refers to the ability of the stormwater to conduct electrical current. This parameter is a measure of the total amount of dissolved ions, such as minerals and salts dissolved in water. If the amount of dissolved minerals and salts increase, the conductivity also increases (Metcalf & Eddy Inc., 2003). The conductivity of stormwater is typically measured in units of microsiemens per centimeter (μS/cm) or millisiemens per centimeter (mS/cm). It provides important information about the overall quality of the water. Higher levels of conductivity can indicate the presence of pollutants, such as road salts or fertilizers, which can have negative impacts on water body or water network. It also can indicate the source of water. For example, a water sample with high conductivity can indicate that the water source is groundwater as groundwater contains higher

level of dissolved minerals compared to surface water. Seawater also has very high conductivity as it contains large amount of dissolved sodium and chloride (Metcalf & Eddy Inc., 2003). In addition to providing indications about water sources, conductivity can also help track the type of pollutants present in water and effectiveness of stormwater collection and treatment applications. As a part of this study the Standard Methods are used for measuring conductivity in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.4. Total Dissolved Solids

Total dissolved solids parameter shows the amount of solids that is dissolved in the solution. According to the Standard Methods, ‘’The solids contained in the filtrate that passes through a filter with a nominal pore size of 2.0 micron or less are classified as dissolved’’ (American Public Health Association, American Water Works Association, Water Environment Federation, 1998). These dissolved solids can include minerals and salts such as Iron, Magnesium, Calcium, Sodium, Sulfate, Nitrate and Chloride. As a part of this study the Standard Methods are used for measuring total dissolved solids in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.5. Total Suspended Solids

Total suspended solid concentration is a physical characteristic of an aqueous solution. A paper filter is used to measure the suspended solids in a solution. The pore size of the filter can affect the result of the analysis. If the pore size of the paper filter is reduced, more TSS can be measured (Metcalf & Eddy Inc., 2003). A high concentration of suspended solids can cause sludge formation which is not desired in reuse plants. As a part of this study the Standard Methods are used for measuring total suspended solids in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.6. Chemical Oxygen Demand

‘’The COD is the estimate of oxygen required for the portion of organic matter in wastewater that is subjected to oxidation and also the amount of oxygen consumed by organic matter from boiling acid potassium dichromate solution.’’ (Khan & Ali, 2017). Chemical oxygen demand corresponds to the amount of oxygen required to oxidize organic pollutants in water. COD gives the load of all

organic pollutants including both biodegradable and non-biodegradable pollutants (Metcalf & Eddy Inc., 2003). It is commonly used to measure the organic matter in wastewaters. High oxygen demand indicates high level of organic matter presence in the water sample and it is an important parameter that is often monitored in wastewater treatment plants. The unit is mg/L O_2. The average chemical oxygen demand if found to be around 500 mg/L in medium domestic wastewaters (Metcalf & Eddy Inc., 2003). When it comes to stormwater a mean chemical oxygen demand value between 252.5 mg/L is measured in the previous research done by Han et al (Han et al., 2006). As a part of this study the Standard Methods are used for measuring chemical oxygen demand in stormwater samples.

2.2.7. Oil and Grease

Oil and grease refer to substances including oils, petroleum products, animal fats and vegetable fats and oils that are not soluble in water. Oil and grease pollution in wastewater, stormwater and other water sources are important because presence of oil and grease have various adverse effects on the environment. Oil and grease in water sources discharged to the environment affect aquatic life and microbial communities. Oil and grease is often not biodegradable because of its insoluble nature. Oil and grease form a film on the surface of water bodies and prevent its contact with air. This blocks water bodies direct contact with oxygen and therefore cause oxygen depletion (Metcalf & Eddy Inc., 2003). When used for technical purposes, oil and grease containing water damage equipment and clog pipes in the water networks of buildings and other industrial facilities (Pintor et al., 2016). Oil and grease has units of milligrams per Liter and is measured using laboratory techniques. As a part of this study the Standard Methods are used for measuring oil and grease in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.8. Total Iron

Iron is a natural element that can be found in rocks, soil, sediments and it mixes with stormwater over the roofs and grounds. Iron can also be found in groundwater and surface waters. ‘’It ranks fourth among the most abundant elements on earth’’ (Khatri et al., 2017). Iron can be present in stormwater in dissolved and particulate form due to various reasons. Iron is an important parameter as it contributes to the corrosion occurrence in pipes other metal equipment in water networks. It also has adverse effects on water bodies causing reduction in oxygen levels and increasing growth of aquatic plants such as algae. It is measured in units of milligrams per Liter. As a part of this study the Standard

Methods are used for measuring total iron in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.9. Temperature

Temperature is an important parameter that has major effects on the biochemical reactions that take place in water treatment processes. It also affects oxygen solubility in water. A higher temperature causes lower oxygen solubility which has direct impact on aquatic life. Rapid changes in temperature also affect water bodies and as a result the aquatic life (Metcalf & Eddy Inc., 2003). Another important effect of temperature is the effect on microbial activity in a water body. Bacterial activity is optimum between 25°-35° Celsius while changing temperatures have adverse effects on bacteria population and activity (Metcalf & Eddy Inc., 2003). As a part of this study the Standard Methods are used for measuring temperature in stormwater samples. The method used in the laboratory analysis is listed in Tables 3.2 through 3.8.

2.2.10. Day Since Previous Rain Event – Time Internal Between Two Rain Events

Rain intervals affect stormwater quality. As the time between two rain event increases, the pollutant load is also expected to increase as there will be more time for pollutants to accumulate on the roofs and ground surfaces where stormwater passes through. DIN 1989 Norms suggest the first flush method to eliminate the pollutants that mix with stormwater in the initial 1-2 minutes of the rain event. First flush prevents the heavier load of pollutants from entering the stormwater treatment system by collecting all pollutants that accumulate on the impermeable surfaces between rain events and draining them to the sewer (DIN Deutsches Institut für Normung, 2001).

2.3. Aim of The Study

The main objective of the study is to measure the average concentrations of important pollutants in stormwater collected from a logistics facility and testing if it is possible to bring it to a quality suitable for reuse. Stormwater quality is very inconsistent and it depends on many different parameters. In order to reach to an approximation of the quality of stormwater in an industrial logistics facility, 21 stormwater samples were collected from the facility in different seasons and important parameters were measured for each sample. The average concentrations were calculated. Each sample were tested in a laboratory scale treatment plant and the outlet concentrations of the important

parameters were measured. The concentration of the pollutants after treatment were compared to the water quality requirements for reuse. Finally, the study aims to estimate the investment and operation costs of the treatment plant that can be supplied to the facility and the investment cost of a theoretical plant that can be used in the event of a natural disaster.

3. MATERIALS AND METHODS

3.1. Sample Collection and Preservation

Three sampling points were selected as a part of the study. Sampling point 1 is a rainwater channel with metal grills that receive rainwater drained from impermeable surfaces including the parking lot, driveway and outdoor storage area. Sampling point 2 is the surface of the parking lot. Sample point 3 is also the surface of the driveway at the entrance of the facility. Surface run-off from the parking lot is drained to the sewer through the surface of the driveway. Currently, there is no active rainwater recovery plant in the facility. Rainwater that drops to the roofs and other impermeable surfaces such as the driveway, parking lot and the outdoor storage area flows to the grills by gravity. After passing through the grills, rainwater is drained to the sewers through a pipeline without any treatment or reclamation.

21 grab samples were taken from the rainwater channel during seven rain events. Sampling was carried out in accordance with the Industrial Stormwater Monitoring and Sampling Guide published by Environmental Protection Agency (Environmental Protection Agency, 2021). Grab sampling was applicable considering the dimensions of the channel where the samples were collected. A composite sampling device was not available at the facility and considering that the sampling point location and the lack of operating personnel at the facility, sample collection by an automatic sampling device would not be possible.



Figure 3.1. Sampling point 1.

Automatic sampling devices collect samples according to a timeline and set times. Considering the expected variation of rainwater quality during a rain event, an automatic sampling device would be beneficial to collect a composite sample which consists of the heavily polluted rainwater that is expected in the first minutes of the rain event and the comparably cleaner rainwater that is expected in the later minutes of the rain event. However, it was not possible in this case. The grab samples were collected by a telescopic swing sampler made of unplasticized polyvinyl chloride (U-PVC). The sampler that is shown in Figure 3.2. contained an 80 cm long rod made of U-PVC and a water dipper. The sampler was designed by the thesis student and is a tailor-made production.



Figure 3.2. Tailor-made sampling rod used in the study for sampling.

Sample collection was done according to Environmental Protection Agency's Industrial Stormwater Monitoring and Sampling Guide published in April 2021 (Environmental Protection Agency, 2021b). Samples were preserved according to the Sample Preservation and Hold Times Table presented in the Sampling Guide by EPA (Environmental Protection Agency, 2021b). Samples

were first tested for pH on site due to time limiting nature of pH measurement. Then they were placed in a cooler partially filled with ice. The temperature was set to approximately 4° Celcius in the cooler.



Figure 3.3. Sampling point 2.



Figure 3.4. Sampling point 3.

3.2. Laboratory Tests

Samples were first tested for pH on site due to time limiting nature of pH measurement. The holding time for pH is 15 minutes according to EPA Sample Preservation and Hold Times presented in Table 3.1 (Environmental Protection Agency, 2021b). Other parameters were tested in Meta Mühendislik Arıtma Laboratory and Çevre Analiz Laboratory. The measurement of each pollutant was done in accordance with Standard Methods for the Examination of Water and Wastewater. (American Public Health Association, American Water Works Association, Water Environment Federation, 1998) For measuring the water quality parameters, equipment was available in Meta Mühendislik Arıtma Laboratory and Çevre Analiz Laboratory. The treatment efficiencies and effectiveness of various methods were tested in the laboratory. Data collected through the lab-scale tests were compared to experimental and theoretical data presented in previous research. The water quality required for reuse was taken from the industry in the case study in order to check the treatability of the stormwater to the desired quality and the performance of each treatment method. The treatment purpose was to reach process water standards. Therefore, process water requirements were taken from the industry. Water quality was tested to treat to such quality for reuse. Following the arrival of the samples to the laboratory, common stormwater treatment methods such as balancing, coagulation, flocculation, settling and filtration steps were applied to bring the samples to desired quality. Samples were first put it a beaker for balancing. Then coagulation was applied, followed by

flocculation and settling. Finally, the sample was passed through a paper filter to achieve filtration of suspended solids present in sample. The final sample was tested for various parameters to check the treatment efficiency of the system.

Table 3.1. Sample preservation guide from industrial stormwater sampling guide by EPA.

Pollutant	Maximum Holding Time
pH	15 minutes (field test)
COD	14 days
Hardness	6 months
Total Suspended Solids	7 days

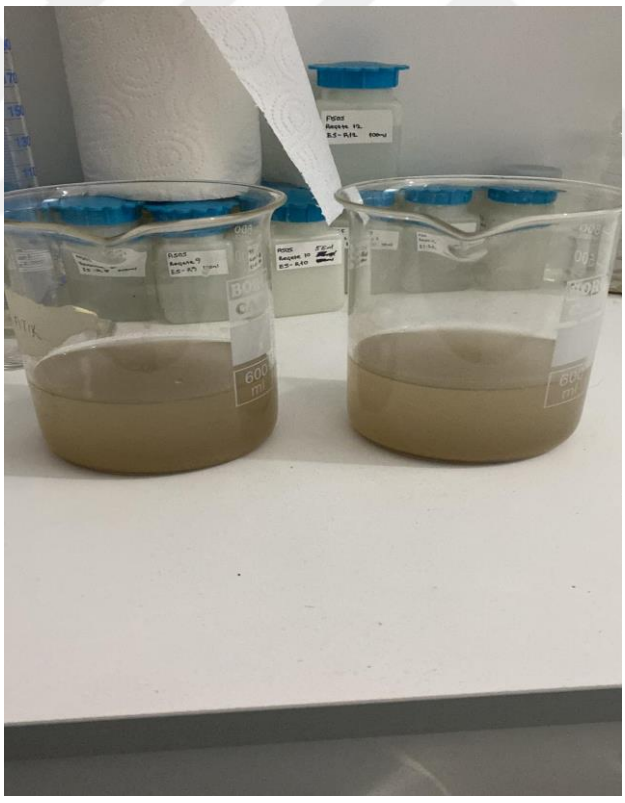


Figure 3.5. Samples 1 and 2 before lab tests.

3.2.1. Balancing

A 500 mL glass beaker was used as the balancing tank which is shown in Figure 3.5. The hydraulic retention time τ of 2 hours is selected from the Table 5-20. This is the typical design information for primary sedimentation tanks (Metcalf & Eddy Inc., 2003). A 500 mL of sample was put in the beaker and the sample was observed visually for 2 hours. No visual change was observed between time t=0 and t= 2 hours.

3.2.2. Coagulation and Flocculation

Chemical treatment methods including coagulation, flocculation and pH adjustment are widely used in the process of rainwater recovery for technical purposes (Philp et al., 2008).

In this study, coagulation and flocculation applications were done in the laboratory with a Jar test device. Jar tests are laboratory experiments that are done to find the optimized coagulant dosage, pH value and mixing conditions for chemical treatment systems (Pivokonský et al., 2022). Jar tests are used both for research and for preliminary design of industrial water treatment systems. A Jar tester with 2 reaction vessels was used in the experiment. The Jar tester was equipped with paddle stirrers, a timer and a speed control that allows for speed adjustment of the stirrer. The device is shown in Figure 3.6.

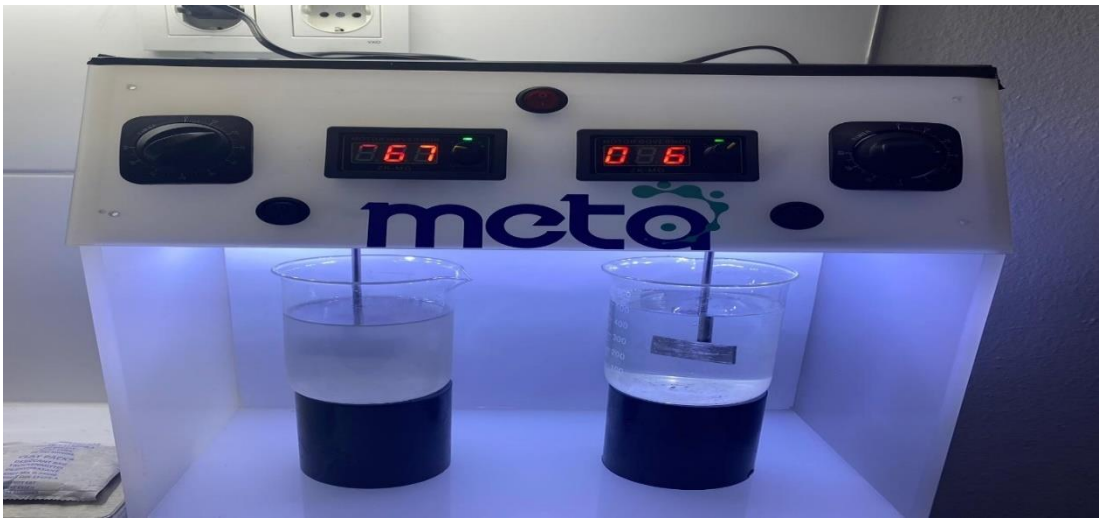


Figure 3.6. Jar test device.

After 2 hours of primary sedimentation and balancing, a Jar test was done. $FeCl_3$ was used as the coagulant and an anionic polyelectrolyte was used as the flocculating agent. $FeCl_3$ and $Al_2(SO_4)_3$ are the most common coagulants that are used in industry. These chemicals require instantaneous mixing.

For this study, $FeCl_3$ which is an iron salt is used because it was available in the laboratory. In addition, $FeCl_3$ is widely used in the industry due to its low price and easy supply. During the laboratory test, 0.10 mL of $FeCl_3$ with a 40% solution is used as the coagulating agent. The mixing was done at 80 rpm. After coagulation, flocculation phase started. 0.10 mL of anionic polyelectrolyte was added to the sample. The mixing for flocculation was done at 40 rpm for a duration of 20 minutes followed by a settling period of 60 minutes. When pH was below 7.5, 0.10 mL of 48% NaOH was added to the sample for pH adjustment before adding the coagulant.

One important factor of chemical processes is the addition of chemicals including coagulants and neutralizers to the samples. Addition of chemicals increase the concentration of dissolved solids in the samples which lead to an increase in the conductivity. When considering reuse for potable or non-potable purposes, conductivity is an important parameter because waters with high conductivity harm the pipelines and other mechanical equipment in buildings. Stormwater collected as a part of the study had very low conductivity. Considering the conductivity of the samples to the Istanbul City tap water which is published monthly at ISKI's website iski.istanbul, it can be seen that the samples had much lower conductivity than Istanbul city's tap water. This makes the concerns for increasing the TDS with chemical addition disappear.

Laboratory test details are provided in Tables 3.2 through 3.8. For samples 1 and 2 the pictures from the Jar tester during coagulation and flocculation phases are also provided in Figure 3.7 and Figure 3.8.

Table 3.2. Lab test details for samples 1-3.

Parameter	Lab Test on Sample 1	Lab Test on Sample 2	Lab Test on Sample 3
Sample No	1	2	3
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.08 g/L	0.08 g/L	0.08 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

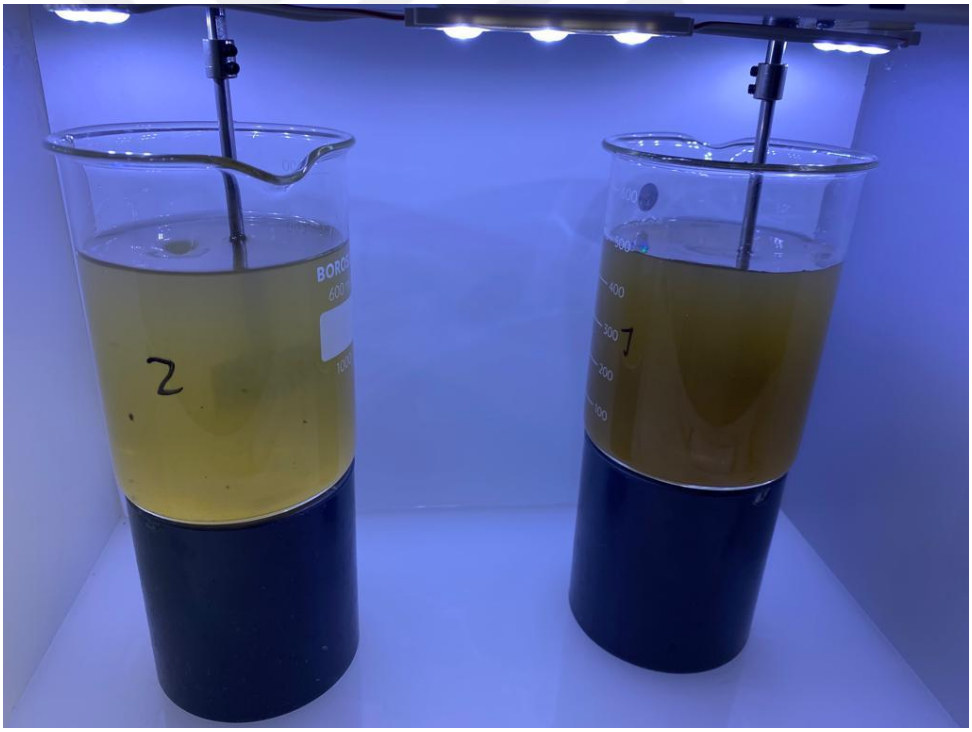


Figure 3.7. Samples 1 and 2 during Jar test.

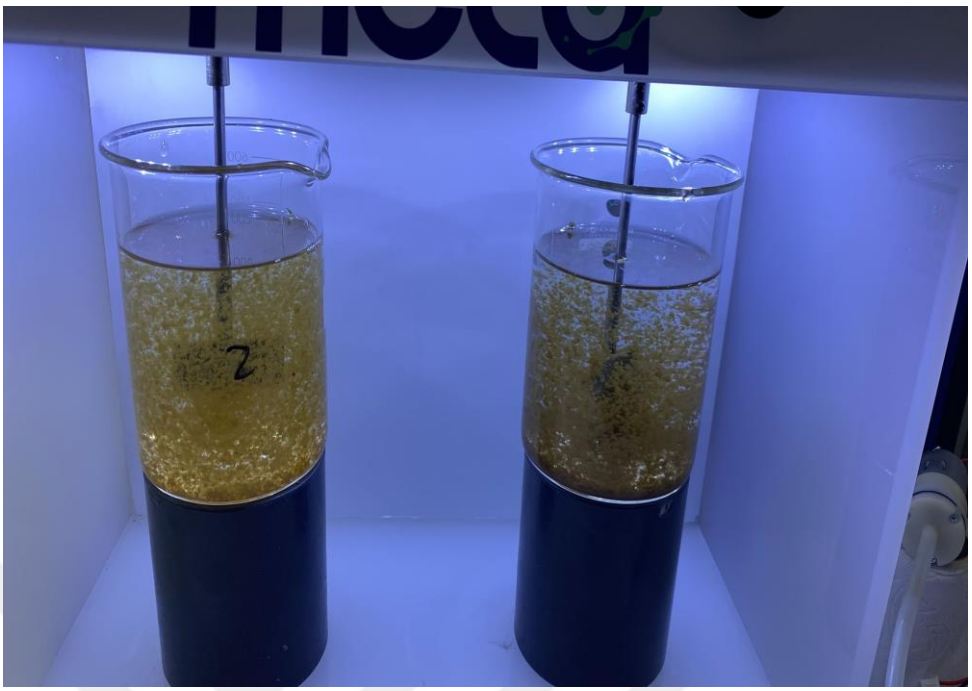


Figure 3.8. Samples 1 and 2 during flocculation phase.

Table 3.3. Lab test details for samples 4-6.

Parameter	Lab Test on Sample 4	Lab Test on Sample 5	Lab Test on Sample 6
Sample No	4	5	6
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.08 g/L	0.08 g/L	0.08 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

Table 3.4. Lab test details for samples 7-9.

Parameter	Lab Test on Sample 7	Lab Test on Sample 8	Lab Test on Sample 9
Sample No	7	8	9
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.08 g/L	0.08 g/L	0.08 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

Table 3.5. Lab test details for samples 10-12.

Parameter	Lab Test on Sample 10	Lab Test on Sample 11	Lab Test on Sample 12
Sample No	10	11	12
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.08 g/L	0.08 g/L	0.08 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

Table 3.6. Lab test details for samples 13-15.

Parameter	Lab Test on Sample 13	Lab Test on Sample 14	Lab Test on Sample 15
Sample No	13	14	15
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.08 g/L	0.08 g/L	0.08 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

Table 3.7. Lab test details for samples 16-18.

Parameter	Lab Test on Sample 16	Lab Test on Sample 17	Lab Test on Sample 18
Sample No	16	17	18
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.24 g/L	0.24 g/L	0.24 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

Table 3.8. Lab test details for samples 19-21.

Parameter	Lab Test on Sample 19	Lab Test on Sample 20	Lab Test on Sample 21
Sample No	19	20	21
Balancing Time	120 minutes	120 minutes	120 minutes
Coagulant	$FeCl_3$	$FeCl_3$	$FeCl_3$
Coagulant Dosage	0.16 g/L	0.16 g/L	0.16 g/L
Rapid Mixing Speed	80 rpm	80 rpm	80 rpm
Flocculant	Anionic Polyelectrolyte	Anionic Polyelectrolyte	Anionic Polyelectrolyte
Flocculant Dosage	4 mg/L	4 mg/L	4 mg/L
Slow Mixing Speed	40 rpm	40 rpm	40 rpm
Slow Mixing Time	20 minutes	20 minutes	20 minutes
Settling Time	60 minutes	60 minutes	60 minutes
Filtration Grade	100 µm	100 µm	100 µm

3.2.3. Settling

The same glass beaker was used as the settling tank after the coagulation and flocculation stages. After mixing is completed, the sample was left to settling. After 60 minutes of settling, sludge remained at the bottom of the beaker.

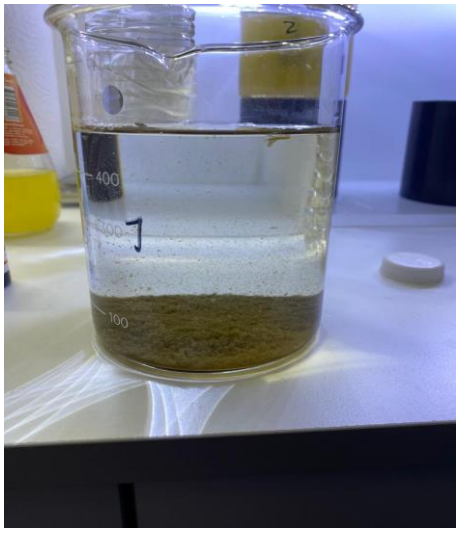


Figure 3.9. Sample 1 after mixing and 60 minutes of settling.

3.2.4. Filtration

The sample containing the settled sludge was then passed through a paper filter which had a filtration grade of 100 µm. A paper filter instead of filtration media such as quartz sand was used because it was available in the laboratory. After the filtration stage, it was observed that the sample was free from suspended solids and it was visually clear. Sludge that settled to the bottom of the beaker during settling phase was retained in the paper filter.

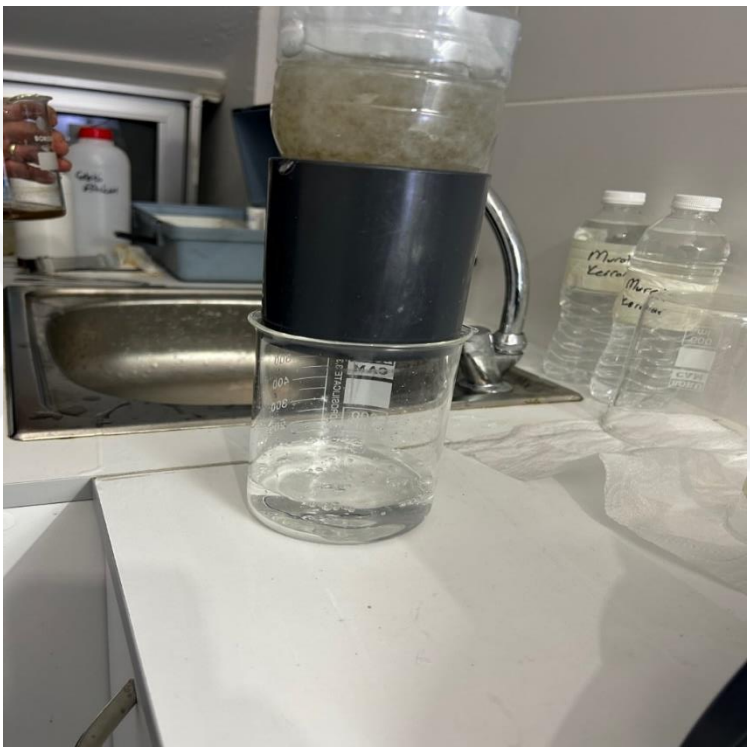


Figure 3.10. Filtration stage of the sample.



Figure 3.11. Top view of the filtration stage.

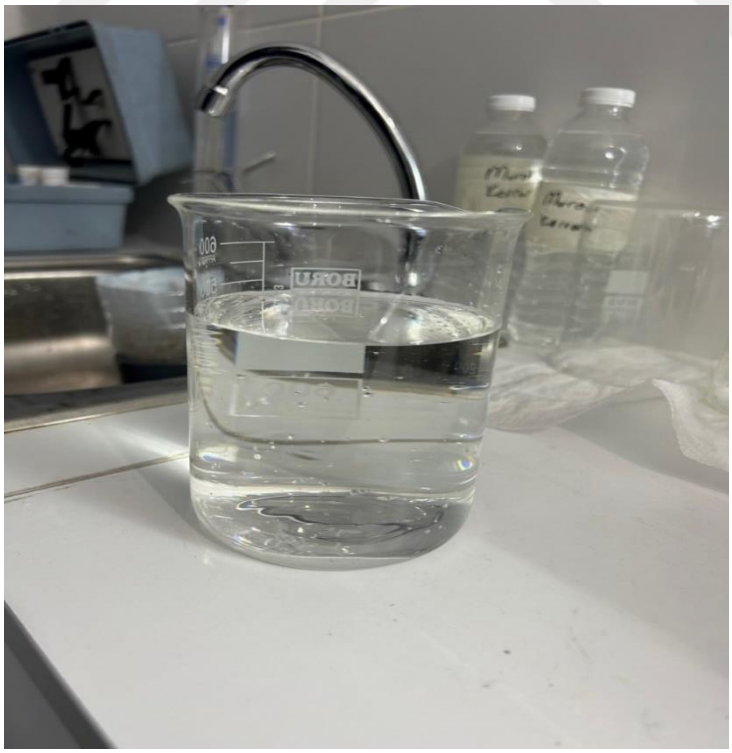


Figure 3.12. Treated stormwater

4. RESULTS AND DISCUSSION

4.1. Sample Analysis Results

21 samples were collected in different rain events. Dates, sampling points, sampling methods and sample volumes are listed in Table 4.1. As a part of the study, 10 parameters were tested and analysed. The results are listed in Tables 4.2 through 4.8. Table 4.9 shows the minimum, maximum, mean and standard deviation values for each parameter. The mean value is an important indication for assessing stormwater quality. It was seen that the main pollutants that were observed in the stormwater samples that were collected from the catchment points were Total Suspended Solids and Organic Matter. pH, Hardness, Conductivity and Total Dissolved Solids all had a lower concentration when compared to tap water provided by ISKI to the city of Istanbul. No oil and grease were observed in the samples. Iron was only observed at very low concentrations in a few samples. Temperature varied depending on the season and ambient temperature.

Table 4.1. Sample collection table.

Sample No	Collection Date	Location	Catchment Point	Sampling Method	Volume	Sample Package
1	13.12.2022	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
2	13.12.2022	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
3	13.12.2022	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
4	12.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
5	12.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
6	12.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
7	28.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
8	28.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
9	28.01.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
10	29.03.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
11	29.03.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
12	29.03.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
13	3.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
14	3.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
15	3.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
16	27.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
17	27.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
18	27.04.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container
19	18.05.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 1	Grab Sample	500 ml	Sterile Container
20	18.05.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 2	Grab Sample	500 ml	Sterile Container
21	18.05.2023	Sertrans Warehouse Samandira, Istanbul	Sampling Point 3	Grab Sample	500 ml	Sterile Container

Table 4.2. Analysis of samples 1-3.

No	Parameter	Analysis Method	Unit	Sample 1	Sample 2	Sample 3
1	pH	SM 4500, EPA 9040	-	7.19	7.20	7.20
2	Hardness	M 2340:C	mg/L	6.00	7.00	7.00
3	Conductivity	SM 2510:B	microsiemens/cm	119.50	116.10	117.00
4	TDS	SM 2540:C	mg/L	54.00	51.00	52.00
5	TSS	SM 2540:D	mg/L	538.00	550.00	550.00
6	COD	SM 5220:D	mg/L	112.00	180.00	177.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.00	0.00	0.00
9	Temperature	SM 2550:B	°Celcius	16.30	17.20	17.00
10	Day Since Previous Rain Event	-	days	2.00	2.00	2.00

Table 4.3. Analysis of samples 4-6.

No	Parameter	Analysis Method	Unit	Sample 4	Sample 5	Sample 6
1	pH	SM 4500, EPA 9040	-	7.80	7.80	7.90
2	Hardness	M 2340:C	mg/L	6.00	6.00	7.00
3	Conductivity	SM 2510:B	microsiemens/cm	124.00	127.00	133.00
4	TDS	SM 2540:C	mg/L	54.00	55.00	58.00
5	TSS	SM 2540:D	mg/L	490.00	490.00	498.00
6	COD	SM 5220:D	mg/L	54.00	66.00	67.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.00	0.00	0.00
9	Temperature	SM 2550:B	°Celcius	16.00	16.00	16.00
10	Day Since Previous Rain Event	-	days	0	0	0

Table 4.4. Analysis of samples 7-9.

No	Parameter	Analysis Method	Unit	Sample 7	Sample 8	Sample 9
1	pH	SM 4500, EPA 9040	-	7.15	7.13	7.15
2	Hardness	M 2340:C	mg/L	9.00	7.00	7.00
3	Conductivity	SM 2510:B	microsiemens/cm	128.00	133.00	136.00
4	TDS	SM 2540:C	mg/L	56.44	57.10	57.50
5	TSS	SM 2540:D	mg/L	477.00	466.00	499.00
6	COD	SM 5220:D	mg/L	58.00	62.00	74.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.00	0.00	0.00
9	Temperature	SM 2550:B	°Celcius	15.00	15.00	15.00
10	Day Since Previous Rain Event	-	days	1.00	1.00	1.00

Table 4.5. Analysis of samples 10-12.

No	Parameter	Analysis Method	Unit	Sample 10	Sample 11	Sample 12
1	pH	SM 4500, EPA 9040	-	8.30	7.80	7.80
2	Hardness	M 2340:C	mg/L	11.00	7.00	7.00
3	Conductivity	SM 2510:B	microsiemens/cm	183.00	87.00	87.00
4	TDS	SM 2540:C	mg/L	77.20	39.55	39.55
5	TSS	SM 2540:D	mg/L	613.00	443.00	773.00
6	COD	SM 5220:D	mg/L	68.50	54.00	112.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.00	0.00	0.00
9	Temperature	SM 2550:B	°Celcius	13.00	12.00	12.00
10	Day Since Previous Rain Event	-	days	2.00	2.00	2.00

Table 4.6. Analysis of samples 13-15.

No	Parameter	Analysis Method	Unit	Sample 13	Sample 14	Sample 15
1	pH	SM 4500, EPA 9040	-	8.02	7.77	7.90
2	Hardness	M 2340:C	mg/L	5.00	5.00	6.00
3	Conductivity	SM 2510:B	microsiemens/cm	166.00	176.00	104.00
4	TDS	SM 2540:C	mg/L	74.70	79.20	46.74
5	TSS	SM 2540:D	mg/L	158.00	166.00	201.00
6	COD	SM 5220:D	mg/L	45.00	43.00	58.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.05	0.30	0.20
9	Temperature	SM 2550:B	°Celcius	13.00	13.00	12.00
10	Day Since Previous Rain Event	-	days	0.00	0.00	0.00

Table 4.7. Analysis of samples 16-18.

No	Parameter	Analysis Method	Unit	Sample 16	Sample 17	Sample 18
1	pH	SM 4500, EPA 9040	-	6.83	6.65	7.10
2	Hardness	M 2340:C	mg/L	4.00	3.00	3.00
3	Conductivity	SM 2510:B	microsiemens/cm	138.90	142.00	133.00
4	TDS	SM 2540:C	mg/L	88.90	64.10	59.01
5	TSS	SM 2540:D	mg/L	601.00	558.00	563.00
6	COD	SM 5220:D	mg/L	0.00	0.00	0.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.30	0.00	0.00
9	Temperature	SM 2550:B	°Celcius	17.00	16.00	19.00
10	Day Since Previous Rain Event	-	days	0.00	0.00	0.00

Table 4.8. Analysis of samples 19-21.

No	Parameter	Analysis Method	Unit	Sample 19	Sample 20	Sample 21
1	pH	SM 4500, EPA 9040	-	6.92	6.50	5.44
2	Hardness	M 2340:C	mg/L	2.00	5.00	4.00
3	Conductivity	SM 2510:B	microsiemens/cm	98.30	100.30	94.30
4	TDS	SM 2540:C	mg/L	43.11	45.91	42.44
5	TSS	SM 2540:D	mg/L	522.00	533.00	444.00
6	COD	SM 5220:D	mg/L	32.00	45.00	75.00
7	Oil and Grease	SM 5520:B	mg/L	<10	<10	<10
8	Fe	SM 3030:D	mg/L	0.50	0.50	0.50
9	Temperature	SM 2550:B	°Celcius	17.00	19.00	16.00
10	Day Since Previous Rain Event	-	days	7.00	7.00	7.00

Table 4.9. Statistical analysis of raw samples.

No	Parameter	Unit	Min	Max	Mean	Median	Range	Standard Deviation
1	pH	-	5.44	8.30	7.31	7.80	2.86	0.65
2	Hardness	mg/L	2.00	11.00	5.90	6.00	9.00	2.07
3	Conductivity	microsiemens/cm	87.00	183.20	126.06	128.90	96.20	26.70
4	TDS	mg/L	39.55	77.20	56.92	55.00	37.65	13.44
5	TSS	mg/L	158.00	773.00	482.52	499.00	615.00	147.08
6	COD	mg/L	43.00	112.00	65.83	62.00	69.00	47.84
7	Oil and Grease	mg/L	0.00	0.00	0.00	0.00	0.00	0.00
8	Fe	mg/L	0.00	0.50	0.11	0.00	0.50	0.19
9	Temperature	°Celcius	12.00	19.00	15.36	16.00	7.00	2.14
10	Day Since Previous Rain Event	days	0.00	7.00	1.71	2.00	7.00	2.37

4.2. Experimental Results

Water analysis was done for each sample after they are passed through various lab-scale treatment applications described in Section 3. Following parameters are measured after treatment applications:

- pH
- Hardness
- Conductivity
- TDS
- TSS
- COD
- Temperature

Parameters such as Oil and Grease and Iron were not measured because they are not found in the raw water samples. Number of days since previous rain event were also not included in the analysis considering that this parameter value is already provided with the raw water analysis. Analysis of post-treatment samples are provided in Tables 4.10 through 4.30.

Table 4.10. Analysis of sample 1 before and after treatment.

No	Parameter	Unit	Sample 1	Sample 1 Post-Treatment
1	pH	-	7.19	5.88
2	Hardness	mg/L	6.00	21
3	Conductivity	microsiemens/cm	119.50	585.00
4	TDS	mg/L	54.10	254.8
5	TSS	mg/L	538.00	26.5
6	COD	mg/L	112.00	39
7	Temperature	°Celcius	16.30	20.4

Table 4.11. Analysis of sample 2 before and after treatment.

No	Parameter	Unit	Sample 2	Sample 2 Post-Treatment
1	pH	-	7.20	6.12
2	Hardness	mg/L	7.00	22
3	Conductivity	microsiemens/cm	116.10	549.30
4	TDS	mg/L	51.50	235.5
5	TSS	mg/L	550.00	28.7
6	COD	mg/L	180.00	55
7	Temperature	°Celcius	17.20	20.5

Table 4.12. Analysis of sample 3 before and after treatment.

No	Parameter	Unit	Sample 3	Sample 3 Post-Treatment
1	pH	-	7.20	5.45
2	Hardness	mg/L	7.00	22
3	Conductivity	microsiemens/cm	117.00	582.8
4	TDS	mg/L	52.30	254.1
5	TSS	mg/L	550.00	29.4
6	COD	mg/L	177.00	50
7	Temperature	°Celcius	17.00	20.5

Table 4.13. Analysis of sample 4 before and after treatment.

No	Parameter	Unit	Sample 4	Sample 4 Post-Treatment
1	pH	-	7.80	6.15
2	Hardness	mg/L	6.00	21
3	Conductivity	microsiemens/cm	124.30	588.2
4	TDS	mg/L	54.10	255.3
5	TSS	mg/L	490.00	25.3
6	COD	mg/L	54.00	18
7	Temperature	°Celcius	16.00	21.2

Table 4.14. Analysis of sample 5 before and after treatment.

No	Parameter	Unit	Sample 5	Sample 5 Post-Treatment
1	pH	-	7.80	6.35
2	Hardness	mg/L	6.00	22
3	Conductivity	microsiemens/cm	127.50	592.2
4	TDS	mg/L	55.60	254.4
5	TSS	mg/L	490.00	29.5
6	COD	mg/L	66.00	21
7	Temperature	°Celcius	16.00	21

Table 4.15. Analysis of sample 6 before and after treatment.

No	Parameter	Unit	Sample 6	Sample 6 Post-Treatment
1	pH	-	7.90	6.4
2	Hardness	mg/L	7.00	22
3	Conductivity	microsiemens/cm	133.80	604.3
4	TDS	mg/L	58.80	268.9
5	TSS	mg/L	498.00	29
6	COD	mg/L	67.00	21
7	Temperature	°Celcius	16.00	21.5

Table 4.16. Analysis of sample 7 before and after treatment.

No	Parameter	Unit	Sample 7	Sample 7 Post-Treatment
1	pH	-	7.15	5.56
2	Hardness	mg/L	9.00	24
3	Conductivity	microsiemens/cm	128.40	595.6
4	TDS	mg/L	56.44	265.6
5	TSS	mg/L	477.00	22.1
6	COD	mg/L	58.00	18
7	Temperature	°Celcius	15.00	20.5

Table 4.17. Analysis of sample 8 before and after treatment.

No	Parameter	Unit	Sample 8	Sample 8 Post-Treatment
1	pH	-	7.13	5.99
2	Hardness	mg/L	7.00	23
3	Conductivity	microsiemens/cm	133.10	600
4	TDS	mg/L	57.10	259.3
5	TSS	mg/L	466.00	27.4
6	COD	mg/L	62.00	20
7	Temperature	°Celcius	15.00	20.4

Table 4.18. Analysis of sample 9 before and after treatment.

No	Parameter	Unit	Sample 9	Sample 9 Post-Treatment
1	pH	-	7.15	5.94
2	Hardness	mg/L	7.00	21
3	Conductivity	microsiemens/cm	136.10	609.2
4	TDS	mg/L	57.50	265.1
5	TSS	mg/L	499.00	24.9
6	COD	mg/L	74.00	24
7	Temperature	°Celcius	15.00	20.4

Table 4.19. Analysis of sample 10 before and after treatment.

No	Parameter	Unit	Sample 10	Sample 10 Post-Treatment
1	pH	-	8.30	6.45
2	Hardness	mg/L	11.00	29
3	Conductivity	microsiemens/cm	183.40	640.1
4	TDS	mg/L	77.20	280.5
5	TSS	mg/L	613.00	35.3
6	COD	mg/L	68.50	22
7	Temperature	°Celcius	13.00	20.2

Table 4.20. Analysis of sample 11 before and after treatment.

No	Parameter	Unit	Sample 11	Sample 11 Post-Treatment
1	pH	-	7.80	6.31
2	Hardness	mg/L	7.00	22
3	Conductivity	microsiemens/cm	87.90	552.5
4	TDS	mg/L	39.55	240.5
5	TSS	mg/L	443.00	33.2
6	COD	mg/L	54.00	26
7	Temperature	°Celcius	12.00	20.3

Table 4.21. Analysis of sample 12 before and after treatment.

No	Parameter	Unit	Sample 12	Sample 12 Post-Treatment
1	pH	-	7.80	6.29
2	Hardness	mg/L	7.00	22
3	Conductivity	microsiemens/cm	87.60	551.2
4	TDS	mg/L	39.55	240.3
5	TSS	mg/L	773.00	44.5
6	COD	mg/L	112.00	47
7	Temperature	°Celcius	12.00	20.2

Table 4.22. Analysis of sample 13 before and after treatment.

No	Parameter	Unit	Sample 13	Sample 13 Post-Treatment
1	pH	-	8.02	6.44
2	Hardness	mg/L	5.00	18
3	Conductivity	microsiemens/cm	167.20	630.4
4	TDS	mg/L	74.70	274.9
5	TSS	mg/L	158.00	12.7
6	COD	mg/L	45.00	13
7	Temperature	°Celcius	13.00	20.4

Table 4.23. Analysis of sample 14 before and after treatment.

No	Parameter	Unit	Sample 14	Sample 14 Post-Treatment
1	pH	-	7.77	5.4
2	Hardness	mg/L	5.00	16
3	Conductivity	microsiemens/cm	176.40	632.1
4	TDS	mg/L	79.20	275
5	TSS	mg/L	166.00	12.2
6	COD	mg/L	43.00	12
7	Temperature	°Celcius	13.00	19.2

Table 4.24. Analysis of sample 15 before and after treatment.

No	Parameter	Unit	Sample 15	Sample 15 Post-Treatment
1	pH	-	7.90	6.54
2	Hardness	mg/L	6.00	19
3	Conductivity	microsiemens/cm	104.40	577.3
4	TDS	mg/L	46.74	254.9
5	TSS	mg/L	201.00	10.3
6	COD	mg/L	58.00	19
7	Temperature	°Celcius	12.00	19.7

Table 4.25. Analysis of sample 16 before and after treatment.

No	Parameter	Unit	Sample 16	Sample 16 Post-Treatment
1	pH	-	6.83	5.53
2	Hardness	mg/L	4.00	20
3	Conductivity	microsiemens/cm	138.90	811
4	TDS	mg/L	88.90	354.3
5	TSS	mg/L	601.00	30.1
6	COD	mg/L	0.00	0
7	Temperature	°Celcius	17.00	20.3

Table 4.26. Analysis of sample 17 before and after treatment.

No	Parameter	Unit	Sample 17	Sample 17 Post-Treatment
1	pH	-	6.65	5.39
2	Hardness	mg/L	3.00	18
3	Conductivity	microsiemens/cm	142.10	825.7
4	TDS	mg/L	64.10	361.7
5	TSS	mg/L	558.00	28.8
6	COD	mg/L	0.00	0
7	Temperature	°Celcius	16.00	20.4

Table 4.27. Analysis of sample 18 before and after treatment.

No	Parameter	Unit	Sample 18	Sample 18 Post-Treatment
1	pH	-	7.10	4.97
2	Hardness	mg/L	3.00	18
3	Conductivity	microsiemens/cm	133.50	800.2
4	TDS	mg/L	59.01	342.5
5	TSS	mg/L	563.00	28
6	COD	mg/L	0.00	0
7	Temperature	°Celcius	19.00	20.5

Table 4.28. Analysis of sample 19 before and after treatment.

No	Parameter	Unit	Sample 19	Sample 19 Post-Treatment
1	pH	-	6.92	4.74
2	Hardness	mg/L	2.00	14
3	Conductivity	microsiemens/cm	98.30	514.7
4	TDS	mg/L	43.11	223.2
5	TSS	mg/L	522.00	27.4
6	COD	mg/L	32.00	10
7	Temperature	°Celcius	17.00	22.8

Table 4.29. Analysis of sample 20 before and after treatment.

No	Parameter	Unit	Sample 20	Sample 20 Post-Treatment
1	pH	-	6.50	3.31
2	Hardness	mg/L	5.00	17
3	Conductivity	microsiemens/cm	100.30	516.1
4	TDS	mg/L	45.91	235.5
5	TSS	mg/L	533.00	27.5
6	COD	mg/L	45.00	15
7	Temperature	°Celcius	19.00	22.9

Table 4.30. Analysis of sample 21 before and after treatment.

No	Parameter	Unit	Sample 21	Sample 21 Post-Treatment
1	pH	-	5.44	3.35
2	Hardness	mg/L	4.00	15
3	Conductivity	microsiemens/cm	94.30	505.3
4	TDS	mg/L	42.44	220.1
5	TSS	mg/L	444.00	22.6
6	COD	mg/L	75.00	24
7	Temperature	°Celcius	16.00	23.3

In addition to sample results, a statistical analysis is done for the data set. Minimum, maximum, mean, median, range and standard deviation values are calculated and presented in Table 4.31. It can be seen that hardness and conductivity increased after treatment while TSS and COD were decreased. The increase in conductivity was caused by the addition of $FeCl_3$ and NaOH to the mixture for coagulation and pH adjustment. The increase in hardness was not expected because no calcium or magnesium ions were added to the mixture. However, after discussing with the producer of the chemical, it was detected that the %40 $FeCl_3$ solution contained city tap water. Calcium and Magnesium ions that are present in city tap water may cause the increase in hardness.

Table 4.31. Laboratory test results statistical analysis.

No	Parameter	Unit	Min	Max	Mean	Median	Range	Standard Deviation
1	pH	-	3.31	6.54	5.65	5.94	3.23	0.90
2	Hardness	mg/L	14.00	29.00	20.29	21.00	15.00	3.31
3	Conductivity	microsiemens/cm	505.30	825.70	612.53	592.20	320.40	89.35
4	TDS	mg/L	220.10	361.70	267.45	255.30	141.60	38.38
5	TSS	mg/L	10.30	44.50	26.45	27.50	34.20	7.54
6	COD	mg/L	0.00	55.00	21.62	20.00	55.00	14.93

4.3. Stormwater Yield Calculations

Stormwater yield calculations are done according to the data provided by Sertrans in order to find the correct stormwater collection tank volume and the capacity of the treatment system. Total Surface Area of the Facility is 13,700 m^2. 5,500 m^2 of the total area is covered by roofs amd 1,500 m^2 of the area is covered by sheds. The roofs of the buildings are flat and made of gravel. Total number of employees that work in the facility is 20. The annual rainwater amount that can be collected from the roofs is calculated theoretically according to the DIN 1989-1:2001-10 Standards Equation (1) (DIN Deutsches Institut für Normung, 2001).

$$E_R = A_A \times e \times h_N \times \eta \quad (4.1)$$

Where;

E_R The rainwater yield in liters per year (L/a)

A_A The collecting area in square meters (m^2)

e The yield coefficient in %

h_N The quantity of precipitation in liters per square meter (L/m^2) or millimeters (mm)

η The hydraulic filter efficiency.

Table 4.32. DIN 1989 yield coefficients.

Composition	Yield Coefficient % *e*
Slanted hard roof [a]	0.8
Flat roof, without gravel	0.8
Flat roof, with gravel	0.6
Green roof, intensive	0.3
Green roof, extensive	0.5
Paved surface/compound paved surface	0.5
Asphalt covering	0.8
[a] Deviations depending on the absorbency and roughness	

Table 4.33. Yield calculations.

Yield Calculation					
Collection Point	Composition	Projected Roof Surface (m^2)	Discharge Coefficient e	Annual Rainwater Yield (L/m^2)	Hydraulic Filter Efficiency η
Building Roofs	Flat Roof Without Gravel	5,500	0.8	648.1	0.9
Shed	Slanted Hard Roof	1,500	0.8	648.1	0.9
Parking Lots	Asphalt Covering	3,350	0.8	648.1	0.9
Other	Paved Surface/Compound Paved Surface	3,350	0.5	648.1	0.9

Total Yield E_R (liter/year)	5,806,651.95

$E_R = A_A \times e \times h_N \times \eta$

= (5500 m^2 x 0,8 x 648,1 L/m^2 x 0,9) + (1500 m^2 x 0,8 x 648,1 L/m^2 x 0,9) + (3350 m^2 x 0,8 x 648,1 L/m^2 x 0,9) + (3350 m^2 x 0,8 x 648,1 L/m^2 x 0,9) = 5.806.651,95 liters/year

Total Annual Rainwater Yield for the facility is 5.806.651,95 liters.

4.4. Annual Water Demand Calculations

Annual water demand should be calculated before determining the design capacity of the stormwater treatment system. Common reuse areas are irrigation, toilet flushing and cleaning. In this study, toilet flushing is the main concern because the facility has no green area. This makes the need for irrigation disappear. In addition, the amount of cleaning water used in the facility is very low because no water is supplied to the trucks at the warehouse according to the maintenance manager of the facility. The stormwater that will be collected in the facility will therefore only be reused for toilet flushing. Only the water demand for toilet flushing is considered in the calculations. According to the DIN 1989-1:2001-10 standards, the daily water demand for toilets in office areas is 12 L/person/day. The annual demand can be calculated with Equation (2) provided in the standards (DIN Deutsches Institut für Normung, 2001)**.**

$$BW_a = P_d \times n \times 365 \quad (4.2)$$

BW_a: Annual process water demand

P_d: Demand per person per day

n: Number of persons

Table 4.34. DIN 1989 determination of the annual process water requirements.

The following requirement values are provided for the individual calculations:			
Consumers		Daily Per-Person Requirements	Specific Annual Requirements
Toilets in the household[a]		24 L/ person × day	—
Toilets in office areas[a]		12 L / person × day	—
Toilets in schools[a]		6 L / person × day	—
Garden watering per 1 m² useful garden area of green spaces		—	60 L/m²
Watering or sprinkling amounts during the vegetation period of April to September			
For sports facilities	Total amount for 6 months	—	200 L/m²
— For meadow land			
With light soil	Total amount for 6 months	—	100 L/m² to 200 l/m²
With heavy soil	Total amount for 6 months	—	80 L/m² to 150 L/m²
NOTE If washing machines are connected, the daily personal requirements would be increased by 10 L.			

Table 4.35. Demand calculations.

Demand Analysis			
Source	**Average Annual Demand Values Per Person (L/personxday)**	**Number of people**	**Total Demand Value (L/year)**
Toilets	12	20	87,600

$BW_a = 12\ L/person/day \times 20\ persons \times 365 days/year = 87{,}600\ L/year$

The amount of water needed for toilet flushing in commercial buildings such as offices can also be calculated according to American Society of Plumbing Engineers Design Handbook (American Society of Plumbing Engineers, 2010). It is assumed that genders are distributed equally among the total number of people. This means, 10 men and 10 women should be considered during the design phase in this study. Number of toilet usage per day is assumed 3 on average. Women are expected to use the toilet %100 of the times they visit the restrooms, whereas men are expected use the toilet %25 of the times, and the urinal %75 of the times. Reservoir water consumption per flush is 6.06 L and urinal water consumption per flush is 1,89 L (American Society of Plumbing Engineers, 2010).
Women daily water consumption per person for flushing: 3 flush/day x 6.06 L/flush = 18.18 L/day
Men daily water consumption per person for flushing: 3 flush/day x 6.06 L/flush x 0.25 + 3 flush/day x 1.89 L/flush x 0.75 = 8.80 L/day.
Total water consumption: (10 x 18.18 L) + (10 x 8.80 L) = 269.90 L/day.
Total annual water consumption: 98,514 L/year.

When designing a stormwater treatment and reuse system it is necessary to calculate both demand and yield values for each facility. In the case of Sertrans Warehouse, the annual calculated stormwater yield is approximately 5,806,652 L and the annual calculated water demand is approximately 98,514 L. For reuse plants the design should be based on the smaller value. In this case the demand is quite smaller than the yield value and treating the stormwater that will not be used would be a waste of energy and as a result not sustainable. Therefore, the design should be based on the annual demand value of 98,514 L. But, if other facilities have a demand for water, this value would increase.

The stormwater collection tank is calculated according to the useful volume procedure presented by the DIN 1989-1:2001-10 standards. For commercial facilities, the standards make the assumption that the useful volume is the 6% of the design value.

V_n = Minimum of (BW_a or E_R) × 0.06 (4.3)

Where;

V_n Useful volume

BW_a Annual process water requirements

^{E}R Rainwater yield in liters per year (L/a)

V_n= 98,514 x 0.06 = 5,910 L

For Sertrans Warehouse, the adequate volume for the stormwater collection tank is approximately 6,000 L. This volume corresponds to the amount of water that is required for toilet flushing for three weeks (DIN Deutsches Institut für Normung, 2001). Daily water demand for non-potable uses and the roof area required to collect stormwater to meet daily non-potable water demand is calculated below.

Total water consumption: (10 x 18.18 L) + (10 x 8.80 L) = 269.90 L/day

Required surface area (from yield calculation formula: 98,514 L / (0.9 x 648.1 L/m^2 x 0.9) = 211.12 m^2.

It would be sufficient to only collect rainwater from a roof area of 212 m^2 in this facility.

4.5. Theoretical Demand Calculations for Natural Disaster Events

Türkiye is a located in a zone where major natural disaster such as earthquakes and forest fires occur frequently. Since there is available space in the Sertrans Warehouse, a much bigger rainwater storage tank can be built underground to store water for use in the face of natural disaster and destruction. An alternative design is prepared for further use of the stormwater that is collected at the facility. The current water demand for technical purposes is low. In the alternative design, the total water that can be collected from the facility is considered as the basis for design calculations. In this case, the total impermeable surface area of 13,700 m^2 is used for calculations of the total stormwater that can be harvested per year. According to the rainwater yield calculations presented in Section 4.3, total annual rainwater yield for the facility is 5.806.651,95 L. This means that if all rainwater that drop to the impermeable surfaces of the facility, including roofs and pavements is considered, almost 6,000 m^3 of water per year can be collected and stored for further reuse. This is equal to the annual potable water demand of 100 people assuming a daily consumption of 150 L per/person. The German

Standards recommend an optimum storage tank volume that corresponds to 6-8% of the total rainwater yield per year.

5.806.651,95 liters x 0,08 = 464.532,15 liters

Because the alternative design aims to store rainwater for natural disasters, a higher volume will be selected. In this case, a volume of 500 m^3 is selected as the volume of the stormwater collection tank. This means that when a rain event occurs, all stormwater collected from the impermeable surfaces at the facility will be sent to the underground rainwater tank and stored there.

5. PROPOSED SYSTEMS AND RECOMMENDATIONS

5.1. Proposed System for Reuse in the Industry

A simple stormwater collection system that consists of a coarse filter, a storage tank, pumps, flocculator, dosing systems, filters for advanced treatment and a disinfection system is designed as a part of the study. The system is designed so that it contains sufficient equipment and treatment to meet the requirements for non-potable use. The design can be further optimised. There are two main concerns associated with stormwater reuse for non-potable use; the health risks due to pathogen concentrations and the adverse effects of stormwater to the water networks due to its chemical composition. Jiang et al., compares the human health risks caused by non-potable use of stormwater to WHO's and EPA's water risk benchmarks (Jiang et al., 2015). Stormwater is suitable for toilet flushing according to the Jing et al., and the risk benchmarks. However, pathogens should be removed by disinfection methods which are listed in WHO's Guidelines for Drinking-Water Quality (World Health Organization, 2017). Furthermore, EPA's Guidelines for Water Reuse classifies reuse of stormwater in toilet flushing in an office building as ''restricted urban reuse'' and according to EPA, the reclaimed water should have a pH value between 6-9, a TSS value ≤ 30 mg/L and 200 detectable fecal coliform per 100 mL (Environmental Protection Agency, 2004). Chemical composition of stormwater that will be reused for non-potable reasons is also important as it causes corrosion and scale formation in water networks and has adverse effects on equipment. Companies that produce valuable equipment such as sanitary ware, boilers, cooling towers recommended a certain water quality in their user manuals. Baltimore Aircoil Company has a section for corrosion and scale control in their Operation and Maintenance Manual (Baltimore Aircoil Company). Recommended water properties are listed by Baltimore Aircoil Company for equipments made of various types of materials including galvanized steel, hybrid polymer, stainless-steel grade 304 and stainless-steel grade 316. The recommended TDS value is below 1,500 mg/L. The recommended pH range is between 6,5-9 and the recommended TSS is below 25 mg/L (Baltimore Aircoil Company). A comparison between raw water sample quality, treated water sample quality and the recommended water quality for technical reuse is provided in Table 5.1. and Figure 5.1.

Table 5.1. Sample water quality comparison table.

No	Parameter	Unit	Raw Samples Mean Values	Treated Samples Mean Values	EPA Guidelines	Baltimore Aircoil Company Requirements
1	pH	-	7.31	5.65	6-9	6.5-9
2	Hardness	mg/L	5.9	20.29	-	-
3	Conductivity	microsiemens/cm	126.06	612.53	-	-
4	TDS	mg/L	56.92	267.45	-	1500
5	TSS	mg/L	482.52	26.45	<30	<25
6	COD	mg/L	65.83	21.62		

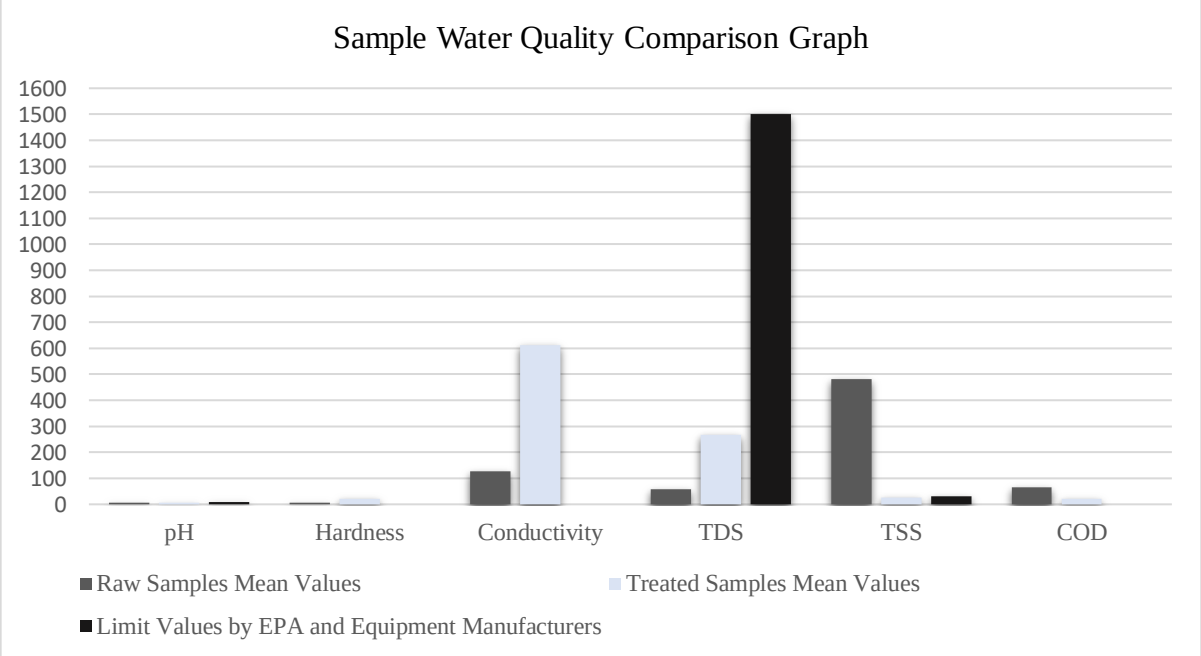


Figure 5.1. Sample water quality comparison graph.

The equipment selected for the case study to meet the minimum requirements recommended by equipment manufacturers, EPA and WHO is described below in Section 5.2. in detail. Stormwater collected in the facility will be transferred to the rainwater storage tank through gravity. A rain filter will be installed in the inlet of the rainwater tank to prevent large solids such as leaves, animal residues

and tree branches from entering the tank. The rainwater tank will act both as a settling tank and a storage tank. Pumps will be used to transfer the rainwater stored in the tank to the flocculator. The rainwater tank will be disinfected by dosing sodium hypochlorite through an automatic dosing system. No microbiological analysis was done in the study. But stormwater may be microbiologically polluted as shown by previous studies. H. J. Albrechtsen found that rainwater and stormwater contain pathogens that city water networks do not have (Albrechtsen, 2002). In addition, the previous research done by Lim et al., also investigates the health risks associated with microbiological pollutants in stormwater and their effects on non-potable use (Lim et al., 2015). The dosing system will measure the amount of residual chlorine in the tank and automatically dose the required amount of sodium hypochlorite to keep the chlorine concentration in the tank within the desired range. This is done in order to prevent growth of bacteria and viruses. Water in the tank is then pumped to the flocculator. The flocculator is a pipe-type flocculator that has inline mixers for homogeneous mixing of chemicals. A coagulant, a flocculant and a pH adjusting chemical will be dosed using automatic dosing pumps. Coagulation and flocculation will take place in the flocculator and the flocs will be formed with the help of flocculant. The water mixture containing the flocs will then pass through the sand and activated carbon filters in order to remove the flocs physically. The flocs will be held in the sand filter and then will be removed during the backwash phase. This way an additional settling tank will not be needed for removal of flocs. After the sand filter the stormwater will pass through the activated carbon filter where organic matter, turbidity, color and unpleasant odors will be removed. A coal based activated carbon specifically produced for organic matter removal will be used in the filter column. The main reason for selecting a coal based activated carbon is its availability in the market and cost advantage. At the end of the plant, sodium hypochlorite will be re-dosed to the system because the chlorine in the raw water is removed by activated carbon. This time, the dosing will be done according to the flow that passes through the flowmeter. A flowmeter with pulse output will be installed inline to the pipeline. The dosing pump will operate according to the pulse signals it will receive from the flowmeter. This way the recommended minimum concentration of chlorine will be supplied to the system to avoid bacterial growth in reservoirs. A flow diagram of the system can be seen in Figure 5.

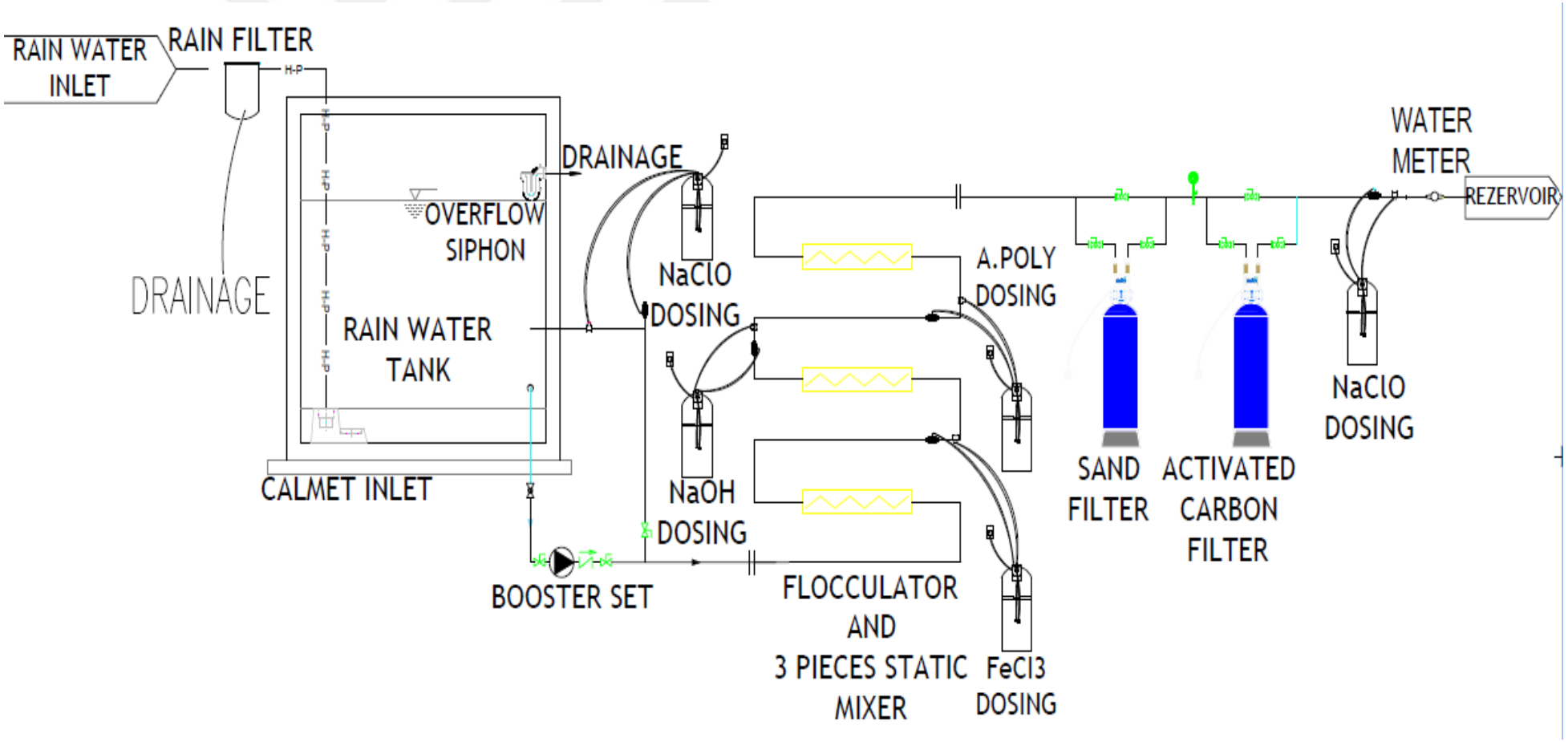


Figure 5.2. Stormwater collection and treatment system flow diagram

5.2. Technical Specifications of Equipment

5.2.1. Coarse filter

A rain filter will be used in the inlet of the storage tank to prevent solids such as animal residues, leaves, tree branches from entering the tank. The filter consists of a cascade system where the incoming water is balanced. The water then flows through the cascades. Eventually, water passes through a sieve inside the filter, and all solids with diameter above 0.65 mm are retained in the filter. Then the water flows to the sewer. The filter is specifically designed for treating rainwater and stormwater. It is manufactured according to DIN 1989-2. Housing material is polyethylene. Filter cartridge is made of stainless steel 1.4301.



Figure 5.3. Rainfilter produced by 3P Technik.

5.2.2. Storage Tank

A continuous-flow reactor will be used. This means that rainwater will enter and leave the reactor during the balancing phase. It is assumed that the reactor has uniform mixing and uniform hydraulic conditions. A storage tank of 6 m^3 is selected for the facility. The volume is determined according to the calculations presented in Section 4.4. The storage tank has a small volume and the facility has available open areas above ground where it can be installed. Therefore, it is not necessary to install it below ground which will increase the investment costs. A standard vertical water tank which is made of low-density polyethylene can therefore be used in the facility. The tank has a diameter of 208 cm and a height of 268 cm. The working temperature of the tank is between 5-50° Celsius and the total empty weight of the tank is 160 kg. This type of tanks is widely used in water treatment systems and also in other facilities for various purposes. The filter can be installed in the tank which will optimize the use of space. An example installation can be seen in Figure 5.5 below.



Figure 5.4. Water storage tank produced by Karmod Plastik.

5.2.3. Filter Apparatus

A calmed inlet and overflow siphon will also be installed in the tank. These apparatuses are a part of the filtering system. The calmed inlet apparat will prevent turbulence in the tank when fresh stormwater enters the tank. With calmed inlet the water will enter to the tank smoothly from the bottom and will not create a turbulence. This way, solids settled to the bottom will not move and a potential increase in the turbidity inside the tank will be prevented. In addition, oxygen rich and fresh incoming water will be supplied to the bottom area of the tank. The overflow siphon will periodically remove the pollutants that flow on the surface of the water inside the tank. Some pollutants such as

pollens and leaves have a lower density than water and when they get the chance to pass through the filter, they float on the surface of the water inside the tank. Overflow siphon will pull these pollutants from the surface of water and direct them to the sewer. This ensures that water inside the tank is in contact with oxygen.



Figure 5.5. Rainwater storage tank installation example by 3P Technik.

5.2.4. Booster Pump

The booster pump will be used to transfer the rainwater that is inside the rainwater tank to the usage points in the building when needed. The pump should have a capacity of 1 m^3/h according to the design calculations and a pressure of 6 bars. The pressure is selected according to the operating pressure of the multimedia and activated carbon filters because the pumps will also be used for feeding these filters. The booster pump will be equipped with a floating intake which will prevent solid particles in the rainwater tank from harming the booster pumps during suction of water. The floating intake will have a suction filter and a floating ball which helps the pump set to receive the cleanest water from 5-10 cm below the surface.

5.2.5. Flocculator

A pipe type flocculator will be used to provide optimum and efficient application of chemicals. Coagulation and flocculation applications will take place inside the flocculator. Coagulant and flocculant will be dosed to the flocculator. Inline mixers will be installed on the flocculator to ensure

mixing of the chemicals that will be dosed.The minimum detention time for the flocculator should be between 2-20 minutes according to EPA (Environmental Protection Agency, 2002). In their study, Nurul Anggraeni found the optimum detention time for pipe flocculator to be 19.3 minutes (Nurul Anggraeni et al., 2020). In this design, 10 minutes of detention time is selected as the design value.



Figure 5.6. Flocculator example.



Figure 5.7. Inline static mixer example.

The pipe diameter is selected to be 2'' which corresponds to 63 mm. U-PVC pipes are classified according to their outer diameter. 63 mm pipes with PN16 pressure class are selected. The total volume of the flocculator is calculated according to the hydraulic detention equation presented by Metcalf and Eddy Inc. (Metcalf & Eddy Inc., 2003).

Hydraulic detention equation

$Q=V/T$ (5.1)

$1\ m^3/h = V/10\ min$

$V= 1/6\ m^3$

Volume of the pipe flocculator equals to π * ((Pipe Diameter)^2/4) * h

In this case considering the design pipe diameter of 63 mm, the length of flocculator will be 53.4 meters. The flocculator will be made of U-PVC pipes.

U-PVC BORULAR / PIPES

PİMTAŞ

U-PVC Yapıştırma Muflu Borular
U-PVC Solvent Cement Socketed Pressure Pipes





PN 10

Çap Dia	Basınç PN	Kod / Code 6 m	Kod / Code 3 m	Fiyat (metre) Price (meter)	Ağırlık (Kg/m) Weight (Kg/m)	S(mm) Et kalınlığı Wall Thickness
Emniyet kat sayısı (safety factor) C = 2,5						
25	10	100 10 025 1	150 10 025 1	0,96 €	0,165	1,5
32	10	100 10 032 1	150 10 032 1	1,40 €	0,241	1,6
40	10	100 10 040 1	150 10 040 1	2,04 €	0,353	1,9
50	10	100 10 050 1	150 10 050 1	3,24 €	0,561	2,4
63	10	100 10 063 1	150 10 063 1	5,03 €	0,871	3,0
75	10	100 10 075 1	150 10 075 1	7,20 €	1,245	3,6
90	10	100 10 090 1	150 10 090 1	10,29 €	1,784	4,3
Emniyet kat sayısı (safety factor) C = 2,0						
110	10	100 10 110 1	150 10 110 1	12,48 €	2,160	4,2
125	10	100 10 125 1	150 10 125 1	16,08 €	2,782	4,8
140	10	100 10 140 1	150 10 140 1	20,28 €	3,512	5,4
160	10	100 10 160 1	150 10 160 1	26,60 €	4,607	6,2
200	10	100 10 200 1	150 10 200 1	41,13 €	7,123	7,7
225	10	100 10 225 3	150 10 225 3	51,72 €	8,957	8,6
250	10	100 10 250 3	150 10 250 3	64,22 €	11,119	9,6
280	10	100 10 280 3	150 10 280 3	80,88 €	14,007	10,7
315	10	100 10 315 3	150 10 315 3	100,50 €	17,404	12,1
355	10	100 10 355 3	150 10 355 3	128,04 €	22,171	13,6
400	10	100 10 400 3	150 10 400 3	161,78 €	28,014	15,3
450	10	100 10 450 3	150 10 450 3	②	35,640	17,2
500	10	100 10 500 3	150 10 500 3	②	43,976	19,1

PN 16

Çap Dia	Basınç PN	Kod / Code 6 m	Kod / Code 3 m	Fiyat (metre) Price (meter)	Ağırlık (Kg/m) Weight (Kg/m)	S(mm) Et kalınlığı Wall Thickness
Emniyet kat sayısı (safety factor) C = 2,5						
20	16	100 16 020 1	150 16 020 1	0,78 €	0,138	1,5
25	16	100 16 025 1	150 16 025 1	1,25 €	0,213	1,9
32	16	100 16 032 1	150 16 032 1	2,00 €	0,345	2,4
40	16	100 16 040 1	150 16 040 1	3,08 €	0,530	3,0
50	16	100 16 050 1	150 16 050 1	4,76 €	0,823	3,7
63	16	100 16 063 1	150 16 063 1	7,59 €	1,313	4,7
75	16	100 16 075 1	150 16 075 1	10,74 €	1,860	5,6
90	16	100 16 090 1	150 16 090 1	15,38 €	2,663	6,7
Emniyet kat sayısı (safety factor) C = 2,0						
110	16	100 16 110 1	150 16 110 1	18,87 €	3,268	6,6
125	16	100 16 125 1	150 16 125 1	24,08 €	4,169	7,4
140	16	100 16 140 1	150 16 140 1	30,24 €	5,237	8,3
160	16	100 16 160 1	150 16 160 1	39,50 €	6,839	9,5
200	16	100 16 200 1	150 16 200 1	61,31 €	10,616	11,9
225	16	100 16 225 3	150 16 225 3	77,61 €	13,441	13,4
250	16	100 16 250 3	150 16 250 3	95,43 €	16,524	14,8
280	16	100 16 280 3	150 16 280 3	120,21 €	20,424	16,6
315	16	100 16 315 3	150 16 315 3	152,00 €	26,815	18,7
355	16	100 16 355 3	150 16 355 3	194,24 €	33,635	21,1
400	16	100 16 400 3	150 16 400 3	247,25 €	42,812	23,7
450	16	100 16 450 3	150 16 450 3	②		
500	16	100 16 500 3	150 16 500 3	②		

Figure 5.8. U-PVC pipe list by Pimtas.

5.2.6. Multimedia Filter

The multimedia filter is selected with the guidance of the sales engineers of Gel Hydrotechnology, an Italian water treatment filter producer. Standard products for the determined flow rate of 1 m^3/h are selected. Tank diameter will be 13 inches which corresponds to 33 cm. A fiber-reinforced polypropylene tank will be used as the filter bed. The filtration velocity is 12 m/h (Nassar & Hajjaj, 2013).

5.2.7. Activated Carbon Filter

The multimedia filter is selected with the guidance of the sales engineers of Gel Hydrotechnology, an Italian water treatment filter producer. Standard products for the determined flow rate of 1 m^3/h are selected. Tank diameter will be 13 inches which corresponds to 33 cm. A fiber-reinforced polypropylene tank will be used as the filter bed. he filtration velocity is 12 m/h (Nassar & Hajjaj, 2013).

5.2.8. Sodium Hypochlorite Dosing Unit

A dosing set consisting of a metering pump, chemical tank, ORP sensor and a sensor holder will be used in the system. ORP sensor will measure the residual chlorine in the tank and dosing will be done to the tank by the dosing pump when the chlorine concentration drops below the recommended value of 0.5 ppm (Galal-Gorchev, 1996). The pump will have dosing capacity of 5 L/h and a dosing pressure of 6 bars. The pump is a magnetic diaphragm type pump with a digital screen which ensures easy operation. The suggested brand is Seko. The commercial product that is available and commonly used in the market is sodium hypochlorite with a concentration of %14-15. The required dosage is determined according to World Health Organization’s Guidelines for Drinking Water Quality (Galal-Gorchev, 1996). 0.5 mg/L of chlorine is needed in water to achieve the desired level of disinfection. The dosage point is selected so that the sodium hypochlorite dosed to the system can be evenly mixed and the contact time is ensured. In this case, the dosing is done directly to the top of the storage tank. A 3D dosing schema is shown in Figure 5.10.



Figure 5.9. Dosing pump by Seko for sodium hypochlorite dosing.

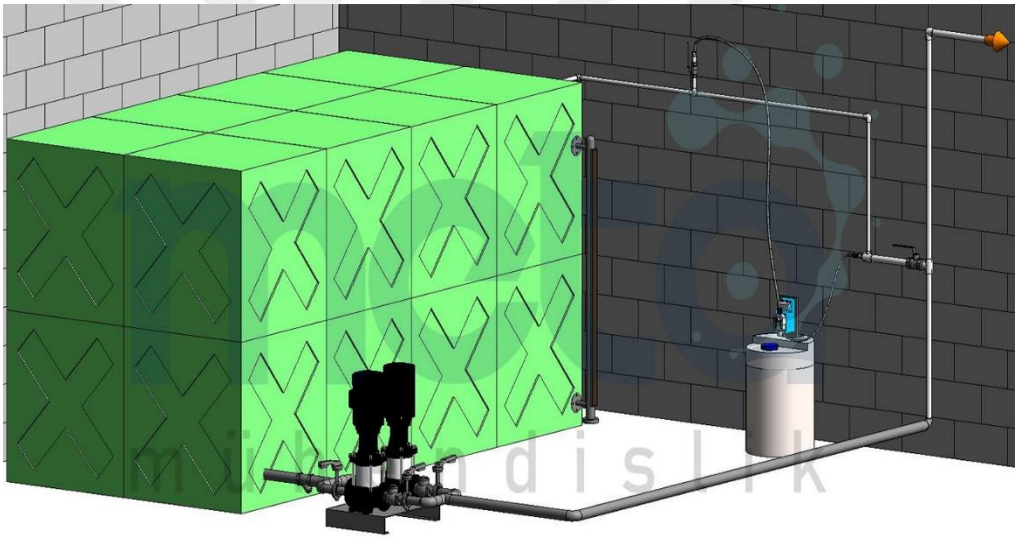


Figure 5.10. Sodium hypochlorite dosing 3D drawing by Meta Muhendislik.

5.3. Cost Analysis

5.3.1. Investment Cost

First, cost of investment for each equipment is listed on Table 5.2. The prices are up to date prices gathered from official suppliers and distributors of the brands. In order to calculate the total cost of investment, a component list of the system is prepared. Each component is analysed in detail and quotations were received for each of them. Description of the products, unit cost excluding taxes,

suggested brands and required quantities are provided in Table 5.2 below. Mechanical and electrical installations and infrastructure costs are not included in the prices. The table only provides the cost of equipment including shipping and excluding the taxes.

Table 5.2. Investment costs.

No	Equipment	Description	Suggested Brand	Quantity	Unit Cost	Total Cost
1	Rainfilter and Accessories	Volume Filter VF1 Set, Body Material: PP, Filter Material: Stainless Steel	3p Technik	1	€ 330.00	€ 330.00
2	Storage Tank	Volume: 6000 L, Material: Low Density Polyethylene	Rotaplast	1	€ 450.00	€ 450.00
3	Filter Booster Set	1 m^3/h 4-6 bar, Horizontal Centrifugal Pump with AISI304 Body	Wilo	1	€ 750.00	€ 750.00
4	Sodium Hypochlorite Dosing Unit	Automatic, ORP controlled	Seko	1	€ 500.00	€ 500.00
5	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	1	€ 35.00	€ 35.00
6	Flocculator	U-PVC Pipe Type Flocculator, Diameter: 63 mm, Pressure Class: PN16	Pimtaş	1	€ 650.00	€ 650.00
7	Static Mixers	U-PVC, Inline, Diameter: 63 mm, Pressure Class: PN16	Pimtaş	3	€ 150.00	€ 450.00
8	Coagulant Dosing Pump	Automatic, On/Off controlled	Seko	1	€ 150.00	€ 150.00
9	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	1	€ 35.00	€ 35.00
10	Flocculant Dosing Pump	Automatic, On/Off controlled, with digital screen	Seko	1	€ 150.00	€ 150.00
11	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	1	€ 35.00	€ 35.00
12	NaOH Dosing Pump	pH controlled, with digital screen	Seko	1	€ 500.00	€ 500.00
13	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	1	€ 35.00	€ 35.00
15	Multimedia Filter	Flow Rate: 1 m^3/h, Fully Automatic	GEL Hydrotechnology	1	€ 420.00	€ 420.00
16	Activated Carbon Filter	Flow Rate: 1 m^3/h, Fully Automatic	GEL Hydrotechnology	1	€ 450.00	€ 450.00
17	Sodium Hypochlorite Dosing Unit	Automatic, Flow Controlled	Seko	1	€ 500.00	€ 500.00
18	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	1	€ 25.00	€ 25.00
					NET TOTAL	€ 5,465.00

5.3.2. Operation Costs

Total energy consumption and consumable lists are shown in Tables 5.3 and 5.4. Currently, 1 m^3 of Istanbul City tap water supplied by ISKI costs the company approximately 1.90 Euros. According to the calculations below, the unit cost of the treated stormwater for the facility is 5.35 Euros excluding the first investment costs. The design can be further optimised. The cost per 1 m^3 of

treated stormwater will be lower for facilities that have a higher water demand for technical purposes because the same design is capable treating a higher volume of stormwater at the same operation cost.

Table 5.3. Energy consumption.

Equipment	Electric Consumption (kWh)	Quantity	Operation Time (hour)	Total Daily Energy Consumtion
Chlorine Dosing Pump	0.0122	2	12	0.1464
Automatic Sand Filter	0.012	1	12	0.144
Activated Carbon Filter	0.012	1	12	0.144
Booster Set	0.75	1	12	9
Coagulant Dosing Pump	0.0122	1	12	0.1464
Flocculant Dosing Pump	0.0122	1	12	0.1464
NaOH Dosing Pump	0.0122	1	12	0.1464
			Total Daily Electric Consumption (kWh)	9.8736
			Unit Electric Price per kWh (Commercial)	€ 0.08
			Total Annual Electric Cost	€ 233.13

Table 5.4. Cost of consumables.

Equipment	Consumable	Unit Price per L	Consumption	Total Annual Cost
Chlorine Dosing Pump	Sodium Hypochlorite %14-15	€ 0.60	0.5 mg/L	€ 0.33
Coagulant Dosing Pump	%40 FeCl3	€ 0.50	0.2 mL/L	€ 9.85
Flocculant Dosing Pump	Anionic Poly. %100	€ 2.00	0.2 mL/L	€ 39.41
NaOH Dosing Pump	%48 NaOH	€ 1.00	0.2 mL/L	€ 19.70

Table 5.5. Total annual operation costs.

Cost	Total Price
Annual Electric Cost	€ 233.13
Annual Consumable Cost	€ 69.29
Periodic Maintenance (3 times/year)	€ 225.00
Total Annual Cost	€ 527.42

Cost per 1 m3 of treated water = Total Annual Operation Cost/Total Treated Water

= 527.42 € / 98,514 L

= 0.00535 € / L

= 5.35 € / m^3

5.4. Alternative Theoretical System for Natural Disaster Events

In the face of natural disaster, water becomes the most prominent commodity for helping victims survive. In addition to the system designed to bring the water to a quality suitable for non-potable use, a mobile drinking water treatment plant can be designed according to the stormwater analysis. The mobile plant can be brought near the facility and treat water from the stormwater storage tank when needed. The flow rate of treated water is selected to be 4 m^3/h. The system is designed so that it can meet the drinking water quality and guidelines published by WHO and Regulation on Waters Intended for Human Consumption published by Republic of Türkiye Ministry of Health. Regulation on Waters Intended for Human Consumption Indicator parameter list can be seen on Table 5.6 (Republic of Türkiye Ministry of Health, 2005). The system will therefore be equipped with more advanced technology.

Table 5.6. Regulation on waters intended for human consumption - indicator parameters (Republic of Türkiye Ministry of Health, 2005)

No	Parameter	Value	Unit
1	Aluminum	200	µg/L
2	Ammonium	0,50	mg/L
3	Chloride	250	mg/L
4	C. perfringens (including spores)	0	count/100 mL
5	Color	No abnormality	
6	Conductivity	2500	µS /cm at 20 °C
7	pH	6.5 – 9.5	
8	Iron	200	µg/L
9	Manganese	50	µg/L
10	Odor	No abnormality	
11	Oxidizability	5.0	mg/L O_2
12	Sulfate	250	mg/L
13	Sodium	200	mg/L
14	Taste	No abnormal change	
15	Colony count at 22 °C	No abnormal change	
16	Coliform bacteria	0	count/100 mL
17	Total Organic Carbon (TOC)	No abnormal change	
18	Turbidity	No abnormal change	

5.4.1. System Design

The system designed for treating stormwater to drinking water quality when needed is shown below in Figure 5.12. It is similar to the system designed for stormwater reuse but is more advanced. The main addition to the previous design is a reverse osmosis (RO) system. Reverse osmosis is an advanced water treatment technology that uses the natural osmosis principle to remove dissolved solids from water (Eisenberg & Middlebrooks, 1986). A semipermeable membrane is used to remove undesired particles. Raw water is pressurized and passed through semipermeable membranes with high pressure. Membranes have a very small pore size and are able to remove salts, bacteria, metals and organic matter. Pure water free from dissolved solids, minerals, salts, and organic matter is produced at the outlet of the plant while water with high concentration of salts and minerals is discharged from the system (Alghoul et al., 2009). An example flow schema provided by Alghoul et al. in 2009 is shown in Figure 5.11.

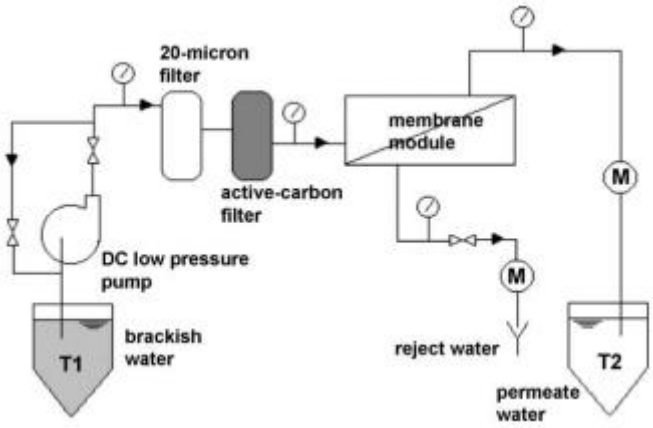


Figure 5.2. Schematic configuration of reverse osmosis plant by Alghoul et al. 2009.

In this study, 21 samples of stormwater collected from the facility have a mean TDS value of 267,45 mg/L. According to World Health Organization (WHO), water with TDS value below 500 mg/L is considered drinking water. In this case, the TDS of stormwater is suitable for drinking purposes without treatment with reverse osmosis. However, considering that stormwater is in direct contact with microorganisms on the surface of the parking lot pavements, it is necessary to apply reverse osmosis for safety concerns.

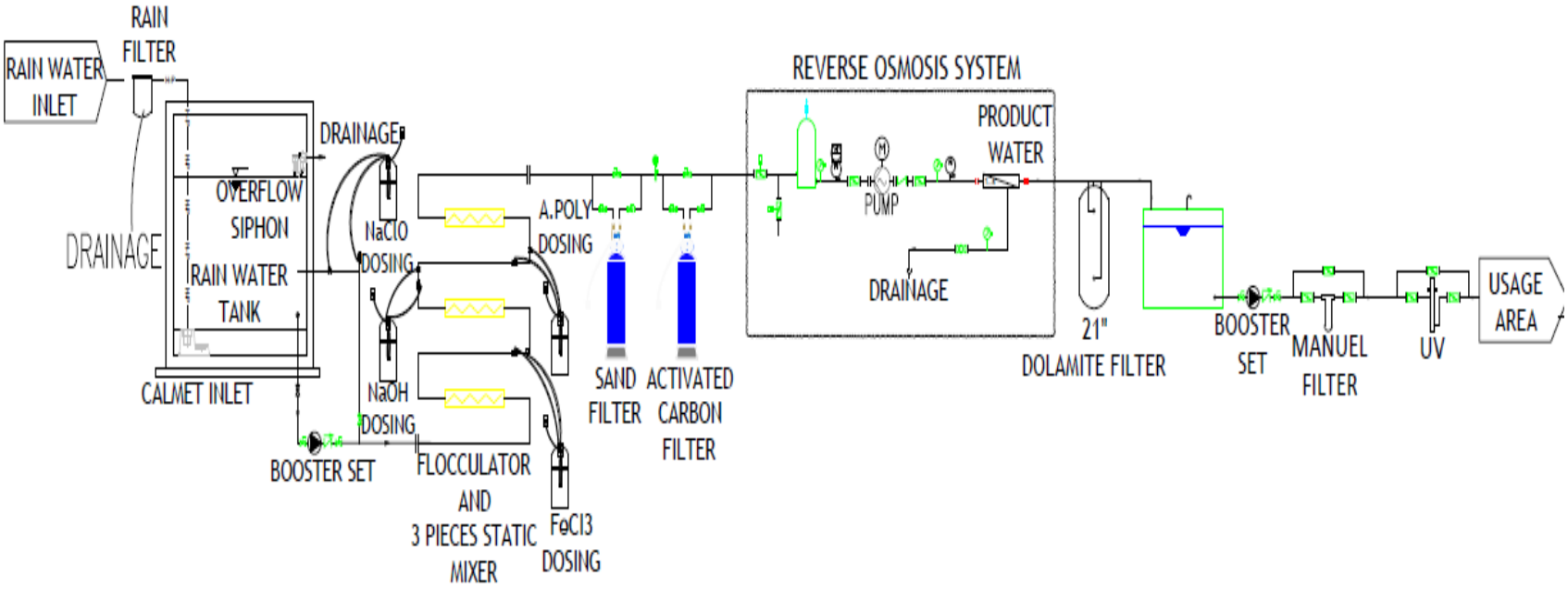


Figure 5.12. Drinking water treatment system flow schema.

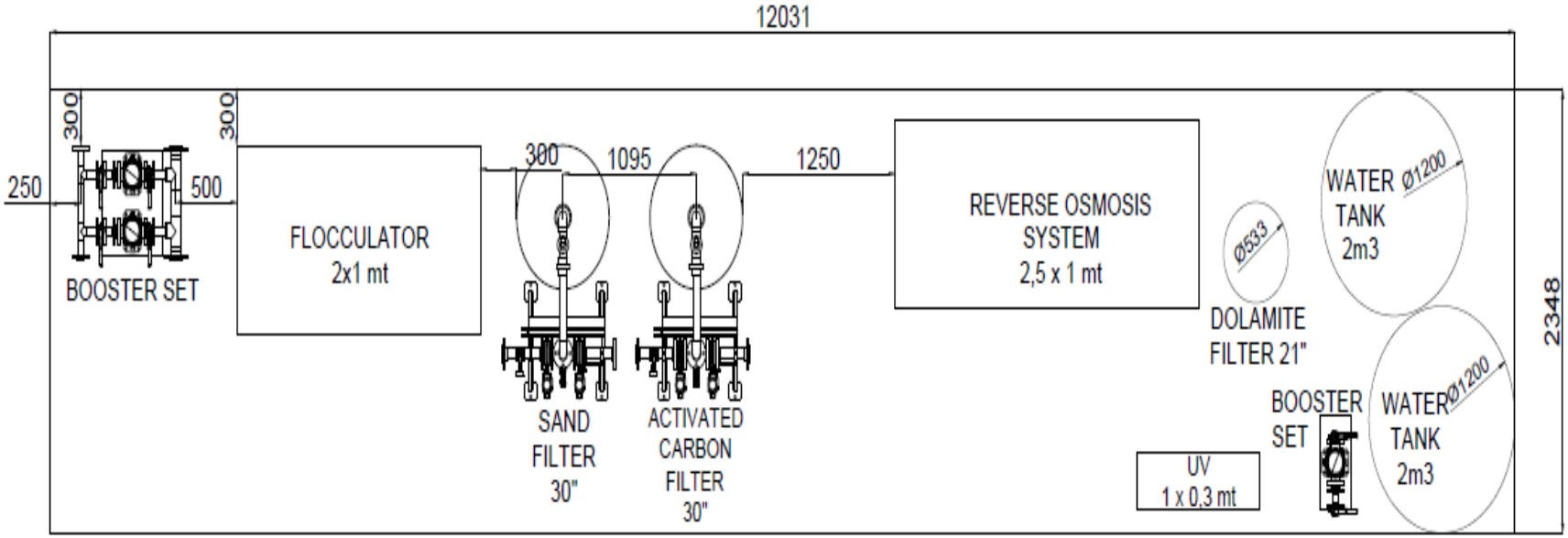


Figure 5.3. Container design (top view).

5.4.2. System Components

The system consists of the following components.

5.4.2.1. Feed pumps. Feed pumps will be used to transfer the stormwater in the stormwater tank to the treatment system. Horizontal centrifugal pumps will be used with AISI304 stainless steel bodies. The suggested brand of the pumps is Lowara. Feed flow rate will be 6 m^3/h and the pressure will be between 4-6 bars.

5.4.2.2. Dosing System. A dosing set consisting of a metering pump, chemical tank, ORP sensor and a sensor holder will be used in the system. ORP sensor will measure the residual chlorine in the tank and dosing will be done to the tank by the dosing pump when the chlorine concentration drops below the recommended value of 0.5 ppm (Galal-Gorchev, 1996). The pump will have dosing capacity of 5 L/h and a dosing pressure of 6 bars. The pump is a magnetic diaphragm type pump with a digital screen which ensures easy operation. The suggested brand is Seko. The commercial product that is available and commonly used in the market is sodium hypochlorite with a concentration of %14-15. The required dosage is determined according to World Health Organization's Guidelines for Drinking Water Quality (Galal-Gorchev, 1996). 0.5 mg/L of residual chlorine concentration is needed in water to achieve the desired level of disinfection. The dosage point is selected so that the sodium hypochlorite dosed to the system can be evenly mixed and the contact time is ensured. In this case, the dosing is done directly to the top of the storage tank. A 3D dosing schema is shown in Figure 5.10.

5.4.2.3. Inline flocculator and inline mixers. A pipe type flocculator will be used to provide optimum and efficient application of the chemicals. Coagulation and flocculation applications will take place inside the flocculator. Coagulant and flocculant are dosed to the flocculator. Inline mixers will be installed on the flocculator to ensure mixing of the chemicals that will be dosed. The detention time for the flocculator should be between 2-20 minutes according to EPA (Environmental Protection Agency, 2002). In their study, Nurul Anggraeni and co-workers found the optimum detention time for pipe flocculator to be 19.3 minutes. (Nurul Anggraeni et al., 2020). In this study, 10 minutes of detention time is selected as the design value. The pipe diameter is selected to be 2'' which corresponds to 63 mm. U-PVC pipes are classified according to their outer diameter. 63 mm pipes with PN16 pressure class are selected. The total volume of the flocculator is calculated according to the hydraulic detention equation presented by Metcalf and Eddy Inc. (Metcalf & Eddy Inc., 2003)

Hydraulic detention equation

$Q=V/T$ (5.1)

$1\ m^3/h = V/10\ min$

$V= 1/6\ m^3$

Volume of the pipe flocculator equals to π * ((Pipe Diameter)^2/4) * h

In this case considering the design pipe diameter of 63 mm, the length of flocculator will be 320.4 meters. The flocculator will be made of U-PVC pipes. pH adjustment will also be done by dosing NaOH to the flocculator. An inline pH sensor will be used to measure the pH of the raw stormwater that enters the flocculator and NaOH solution will be dosed automatically according to the desired pH value.

5.4.2.4. Multimedia filter. The multimedia filter is selected with the guidance of the sales engineers of Gel Hydrotechnology, an Italian water treatment filter producer. Standard products for the determined flow rate of 6 m^3/h are selected. Tank diameter will be 30 inches which corresponds to 77 cm. A fiber-reinforced polypropylene tank will be used as the filter bed. The filtration velocity is 13 m/h (Nassar & Hajjaj, 2013).

5.4.2.5. Activated carbon filter. The multimedia filter is selected with the guidance of the sales engineers of Gel Hydrotechnology, an Italian water treatment filter producer. Standard products for the determined flow rate of 6 m^3/h are selected. Tank diameter will be 30 inches which corresponds to 77 cm. A fiber-reinforced polypropylene tank will be used as the filter bed. The filtration velocity is 13 m/h (Nassar & Hajjaj, 2013).

5.4.2.6. Reverse osmosis system. The reverse osmosis system is the key component that brings water to the drinking water quality by eliminating undesired dissolved solids, bacteria and viruses (Alghoul et al., 2009). The design of the reverse osmosis system is based on the projection softwares of membrane producers and raw water analysis data. The design information of the reverse osmosis system is provided in Figure 5.15 and 5.16.

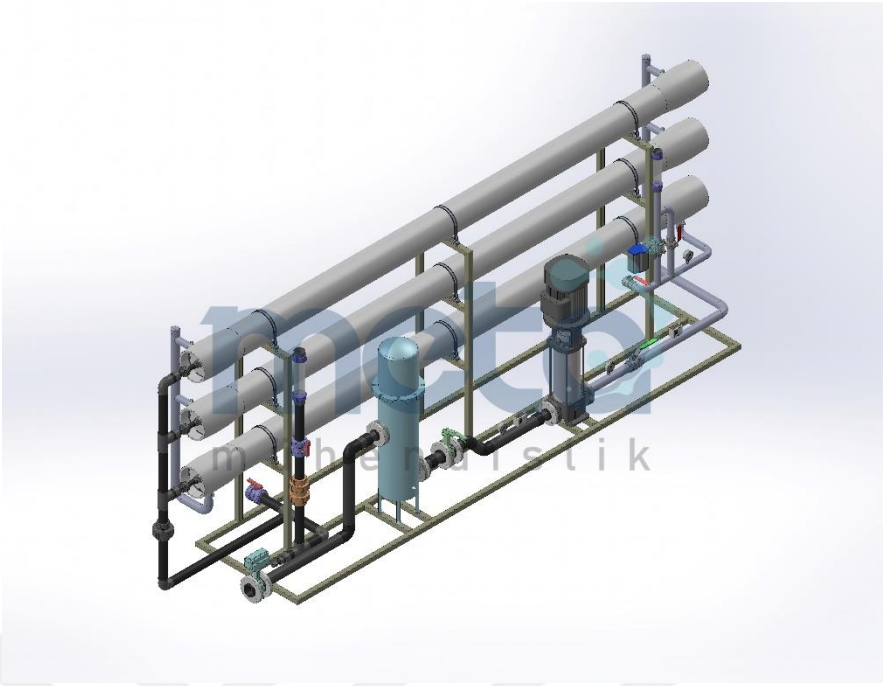


Figure 5.14. Reverse osmosis system 3D Drawing by Meta Muhendislik.

A reverse osmosis system among the standard models produced by Meta Muhendislik was selected as the unit that will be used. An example 3D drawing is provided in Figure 5.14. Technical details of the system are provided below in Table 5.7.

Table 5.7. Technical features of the reverse osmosis system.

Technical Features	
Brand	Meta
Model	ARORA BW 8-4 H2
Body Material	Epoxy Coated ST-37 Carbon Steel
Membrane Quantity	4 pieces
Membrane Model	8040
Membrane Vessel Quantity	2 pieces
Pump Pressure	8.86 bar
Feed Flow	6.00 m^3/h
Product Flow	4.20 m^3/h
Concentrate Flow	1.80 m^3/h
Efficiency	70 %
Design Temperature	20 °C
Max. TDS	1500 ppm

LG Chem

2023-01-09 22:24:00
v3.2.0.2

Project name: Standart8	Water type: NaCl, 1,500 ppm	Membrane age: 0
Customer:	Flux loss per year: 7.00%	Safety factor: 1
Username:	Salt passage increase: 7.00%	

Overall System

Total permeate flow: 4.2 m3/hr	Water source: Well Water (SDI<3)	Feed pressure: 8.86 bar (1P)
Raw water flow: 6 m3/hr	Raw water TDS: 1,500 mg/L	
Total concentrate flow: 1.8 m3/hr	Feed osmotic pressure: 1.18 bar	
Overall recovery: 70 %	Concentrate osmotic pressure: 3.9 bar	

System - Pass1

Permeate flow: 4.2 m3/hr	Average flux: 25.69 lmh	Temperature: 20 °C
RO feed flow: 6 m3/hr	Water source: Well Water (SDI<3)	Average NDP: 4.81 bar
Concentrate flow: 1.8 m3/hr	Feed TDS: 1,500 mg/L	Specific energy: 0.44 kWh/m³
Recovery: 70 %	Feed osmotic pressure: 1.18 bar	Feed pressure: 8.86 bar
Number of elements: 4	Concentrate osmotic pressure: 3.9 bar	Permeate TDS: 19.43 mg/L
ERD type: None	Pump efficiency: 80 %	Fouling factor: 1
Recirculation:		

	# of vessels	# of elements	RO feed flow	Permeate flow	Conc. flow	RO feed pressure	Conc. pressure	Vessel DP	Boost pressure	Back pressure	Inter-stage pressure loss	Average flux	Perm. TDS
			m3/hr	m3/hr	m3/hr	bar	bar	bar	bar	bar	bar	lmh	mg/L
Stage 1	1	2	6	2.49	3.51	8.86	8.59	0.27	0	0	0	30.52	8.87
Stage 2	1	2	3.51	1.71	1.8	8.59	8.48	0.11	0	0	0	20.9	34.84

Figure 5.4. Reverse osmosis membrane projection - 1.

The raw water parameters and their concentrations shown in the design of the reverse osmosis system are from standard design values. The standard systems by Meta Muhendislik are designed to treat water with TDS up to 1500 mg/L. Considering the maximum TDS of the stormwater samples in the study is 361.70 mg/L, the standard reverse osmosis systems can be used for stormwater treatment.

Water Analysis - Pass1

Species	Raw water	Adjusted feed	Conc. Stage1	Stage2	Composite	Permeate Stage1	Stage2	Composite
Ammonium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium	590.09	590.09	1,007.58	1,952.61	1,952.61	3.49	13.70	7.64
Potassium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Magnesium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Barium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chloride	909.91	909.91	1,553.67	3,010.87	3,010.87	5.38	21.13	11.78
Sulfate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbonate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bicarbonate	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bromide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silica	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TDS	1,500.00	1,500.00	2,561.25	4,963.48	4,963.48	8.87	34.84	19.43
pH	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00

Within Vessels - Pass1

	Position	RO feed flow	Permeate flow	Flux	Element recovery	Element DP	Net driving pressure	Polarization	Feed TDS	Perm. TDS
		m3/hr	m3/hr	lmh	%	bar	bar		mg/L	mg/L
Stage 1										
LG BW 440 ES	1	6.00	1.32	32.29	22.00	0.16	7.07	1.29	1,500.00	6.73
LG BW 440 ES	2	4.68	1.17	28.74	25.10	0.11	6.34	1.33	1,921.15	11.28
Stage 2										
LG BW 440 ES	1	3.51	0.98	23.97	27.95	0.07	5.36	1.36	2,561.25	22.91
LG BW 440 ES	2	2.53	0.73	17.83	28.86	0.04	4.07	1.36	3,545.79	50.85

Figure 5.16. Reverse osmosis membrane projection - 2.

5.4.2.7. Remineralisation system. Dolamite is used after treatment with reverse osmosis because WHO recommends a certain magnesium concentration in drinking water and a pH value (Birnhack et al., 2009). After reverse osmosis (RO) the remineralisation filter is used to add magnesium, calcium to water and increase alkalinity (Birnhack et al., 2009). The remineralisation filter consisting of dolamite is selected with the guidance of the sales engineers of Gel Hydrotechnology, an Italian water treatment filter producer. Standard products for the determined flow rate of 4 m^3/h are selected. Tank diameter will be 21 inches which corresponds to 54 cm. A fiber-reinforced polypropylene tank will be used as the filter bed. The filtration velocity is 18 m/h.

5.4.2.8. Booster set. The booster pump will be used to transfer the treated water that is inside the treated water tanks to the usage points. The pump should have a capacity of 4 m^3/h according to the design calculations.

5.4.2.9. Final disinfection unit. Final disinfection is provided by an inline Ultraviolet Device. This is done in order to remove any virus or bacteria that may grow in the treated water tanks. A standard unit with a capacity of 5 m^3/h will be used. The body of the unit is made of stainless steel AISI304.

5.4.2.10. Container. A 40’ standard shipping container will be used in the system to store all equipment. The container will be equipped with an air conditioner to protect the system from extreme temperatures. In the event of a natural disaster the complete system will be ready to use inside the container. The container is mobile and can be moved to any location when needed.



Figure 5.17. Image of 40' standard shipping container.

5.4.2.11. Automation panel. The automation panel will control all electronic equipment in the system. A touch screen will be provided and all equipment will be controlled from the screen.

5.4.3. Cost Analysis

Table 5.8. Cost analysis for alternative design.

No	Equipment	Description	Suggested Brand	Quantity	Unit Cost	Total Cost
1	Feed Pumps	Flow Rate: 6 m^3/h Pressure: 4 bar, Type: centrifugal feed pumps, Material: AISI304 Stainless Steel	Wilo	2	€ 1,000.00	€ 2,000.00
2	Dosing System for NaOH	pH controlled, with digital screen	Seko	1	€ 150.00	€ 150.00
3	Coagulant Dosing System	Automatic, On/Off controlled	Seko	1	€ 150.00	€ 150.00
4	Flocculant Dosing System	Automatic, On/Off controlled, with digital screen	Seko	1	€ 150.00	€ 150.00
5	Chemical Tank	Volume: 100 L, Material: Low Density Polyethylene	Rotaplast	3	€ 35.00	€ 105.00
6	Inline Flocculator	U-PVC Pipe Type Flocculator, Diameter: 63 mm, Pressure Class: PN16	-	1	€ 1,000.00	€ 1,000.00
7	Inline Mixers	U-PVC, Inline, Diameter: 63 mm, Pressure Class: PN16	-	3	€ 150.00	€ 450.00
8	Multimedia Filter	Flow Rate: 6 m^3/h, Fully Automatic	GEL Hydrotechnology	1	€ 1,500.00	€ 1,500.00
9	Activated Carbon Filter	Flow Rate: 6 m^3/h, Fully Automatic	GEL Hydrotechnology	1	€ 1,800.00	€ 1,800.00
10	Reverse Osmosis System	Fully Automatic, Treatment Capacity: 4 m^3/h	Meta Mühendislik Arıtma	1	€ 14,000.00	€ 14,000.00
11	Remineralisation System	Flow Rate: 4 m^3/h	Meta Mühendislik Arıtma	1	€ 650.00	€ 650.00
12	Treated Water Tank	Volume: 2000 L, Material: LDPE, vertical water storage tank.	Rotaplast	2	€ 350.00	€ 700.00
13	Automation Panel	Automation Panel with Touch Screen	Bilgi Otomasyon	1	€ 2,500.00	€ 2,500.00
14	Treated Water Booster	Flow Rate: 4 m^3/h Pressure: 1 bar, Type: Booster Pump Set, Material: AISI304 Stainless Steel	Wilo	1	€ 1,200.00	€ 1,200.00
15	Ultraviolet Disinfection Unit	Flow Rate: 4 m^3/h, Material: AISI304	Meta Mühendislik Arıtma	1	€ 500.00	€ 500.00
16	Container	40' Standard Shipping Container, Used, Equipped with Air Conditioner	-	1	€ 4,500.00	€ 4,500.00
17	Mechanical Installation	Piping between equipment, Material: U-PVC PN16	Pimtaş	1	€ 1,500.00	€ 1,500.00
18	Electrical Installation	Cabling between equipment and the automation panel.	-	1	€ 1,000.00	€ 1,000.00
					NET TOTAL	€ 33,855.00

6. CONCLUSIONS

The study that consisted of thorough research of the literature and industry, on-site sample collection for 6 months, laboratory-scale tests and water analyses showed that stormwater has a very inconsistent quality. The main pollutants in stormwater appear to be organic matter and suspended solids. Stormwater is a free source that can be utilized and used for various purposes after proper treatment. It was shown in this study that companies in the logistic industry can collect stormwater from the impermeable surfaces of their facility and use it after treatment. Especially facilities with a high number of employees can benefit from stormwater treatment and reuse system because a higher water demand can be supplied from treated stormwater. It was seen in this study that after balancing, coagulation, flocculation, pH adjustment, settling and filtration stages, stormwater can be brought to a quality suitable for reuse in reservoirs. A microbiological analysis is not done in this study but it is assumed that microbiological pollution is present in all samples. Therefore, the proposed system also consists of a disinfection unit.

A cost analysis was also conducted as a part of the study. Investment and operating costs of a water treatment plant that can bring stormwater to a quality suitable for reuse were estimated. In addition, an alternative design, a mobile treatment plant, aiming to achieve potable water quality to aid cities during post-natural disaster periods was presented, including the technical specifications of the components and the initial investment cost. Stormwater can serve as a potential water source in the aftermath of natural disasters such as earthquakes. When city water networks are damaged by natural disasters, stormwater can emerge as a resilient alternative, helping the cities recover in the early post-disaster period.

Stormwater is a source of water that should be carefully handled. Industries should prevent the waste of stormwater in their facilities and reuse it, at least for technical purposes. Natural disasters and the damages they may cause in water infrastructure of cities should also be considered when handling stormwater. The problem of water scarcity is becoming an increasingly significant threat to the future of the planet Earth and humanity. Despite its inconsistent nature, stormwater, once treated, is a valuable source whose reuse should be embraced. Through careful design and implementation, the potential of stormwater reuse can be revealed. Stormwater reuse is sustainable, economically profitable and environmentally friendly solution to fight against water scarcity.

REFERENCES

Albrechtsen, H.-J. (2002). Microbiological investigations of rainwater and graywater collected for toilet flushing. Water Sci Technology, 46(6-7):311-6 http://iwaponline.com/wst/article-pdf/46/6-7/311/42547/311.pdf

Alebic-Juretic, A., & Sojat, V. (1998). Chemical composition of rainwater collected at two sampling sites in the city of Rijeka. Arhiv Za Higijenu Rada i Toksikologiju, 49(3) https://pubmed.ncbi.nlm.nih.gov/10376356/

Alghoul, M. A., Poovanaesvaran, P., Sopian, K., & Sulaiman, M. Y. (2009). Review of brackish water reverse osmosis (BWRO) system designs. Renewable and Sustainable Energy Reviews, 13(9), 2661–2667. https://doi.org/10.1016/J.RSER.2009.03.013

APHA, AWWA, WEF, 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition, Washington, D.C., U.S.A.

American Society of Plumbing Engineers, 2010. Plumbing Engineering Design Handbook Volume 2 Plumbing Systems. Des Plaines, IL, U.S.A

Aryal, R., Vigneswaran, S., Kandasamy, J., & Naidu, R. (2010). Urban stormwater quality and treatment. In Korean Journal of Chemical Engineering (Vol. 27, Issue 5). https://doi.org/10.1007/s11814-010-0387-0

Baltimore Aircoil Company. FXV and FXV3 Closed Circuit Cooling Tower Operation & Maintenance Manual. Jessup, MD., U.S.A. https://baltimoreaircoil.com/download_api_endpoint/5330/RGOMALL-03-M248_R5.0_20220926.pdf

Başak, B., & Alagha, O. (2004). The chemical composition of rainwater over Büyükçekmece Lake, Istanbul. Atmospheric Research, 71(4). https://doi.org/10.1016/j.atmosres.2004.07.001

Begum, S., Rasul, M., Rasul, M. G., & Brown, R. J. (2008). Stormwater treatment and reuse techniques: A review Article in WSEAS Transactions on Environment and Development · Solar Photovoltaic Power Forecasting View project Optimization of Biodiesel Feedstocks View project Stormwater treatment and reuse techniques: A review. https://www.researchgate.net/publication/267242625

Birnhack, L., Fridman, N., & Lahav, O. (2009). Potential applications of quarry dolomite for post treatment of desalinated water. Desalination and Water Treatment, 1(1–3). https://doi.org/10.5004/dwt.2009.132

Bratieres, K., Fletcher, T. D., Deletic, A., & Zinger, Y. (2008). Nutrient and sediment removal by stormwater biofilters: A large-scale design optimisation study. Water Research, 42(14). https://doi.org/10.1016/j.watres.2008.06.009

Chow, M. F., Yusop, Z., & Shirazi, S. M. (2013). Storm runoff quality and pollutant loading from commercial, residential, and industrial catchments in the tropic. Environmental Monitoring and Assessment, 185, 8321–8331. https://doi.org/10.1007/s10661-013-3175-6

Cook, E. A. (2007). Green Site Design: Strategies for Stormwater Management. Journal of Green Building, 2, 46-56 https://meridian.allenpress.com/jgb/article/2/4/46/199983/Green-Site-Design-Strategies-for-Storm-Water

DIN Deutsches Institut für Normung, 2001. Rainwater harvesting systems — Part 1: Planning, installation, operation. Berlin. Germany.

Eisenberg, T. N., & Middlebrooks, E. J. (1986). Reverse Osmosis Treament of Drinking Water. Butterworth Publishers.

Eriksson, E., Baun, A., Scholes, L., Ledin, A., Ahlman, S., Revitt, M., Noutsopoulos, C., & Mikkelsen, P. S. (2007). Selected stormwater priority pollutants - a European perspective. Science of the Total Environment, 383(1–3), 41–51. https://doi.org/10.1016/j.scitotenv.2007.05.028

Feng, W., Liu, Y., & Gao, L. (2022). Stormwater treatment for reuse: Current practice and future development – A review. Journal of Environmental Management, 301. 10.1016/j.jenvman.2021.113830

Galal-Gorchev, H. (1996). Chlorine in water disinfection. In Pure & App/. Chem (Vol. 68, Issue 9). IUPAC. https://publications.iupac.org/pac/68/9/1731/index.html

Ghawi, A. H. (2018). Optimal design parameters for hydraulic vertical flocculation in the package surface water treatment plant. In Scientific Review Engineering and Environmental Sciences (Vol. 27, Issue 4, pp. 438–451). WULS - SGGW Press. https://doi.org/10.22630/PNIKS.2018.27.4.42

Goonetilleke, A., Liu, A., Managi, S., Wilson, C., Gardner, T., Bandala, E. R., Walker, L., Holden, J., Wibowo, M. A., Suripin, S., Joshi, H., Bonotto, D. M., & Rajapaksa, D. (2017). Stormwater reuse, a viable option: Fact or fiction? Economic Analysis and Policy, 56. https://doi.org/10.1016/j.eap.2017.08.001

Han, Y., Lau, S.-L., Kayhanian, M., & Stenstrom, M. K. (2006). Characteristics of Highway Stormwater Runoff. Water Environment Research, 78(12), 2377–2388. https://doi.org/10.2175/106143006x95447

Helmreich, B., & Horn, H. (2009). Opportunities in rainwater harvesting. Desalination, 248(1–3), 118–124. https://doi.org/10.1016/j.desal.2008.05.046

Jang, Y. C., Jain, P., Tolaymat, T., Dubey, B., Singh, S., & Townsend, T. (2010). Characterization of roadway stormwater system residuals for reuse and disposal options. Science of the Total Environment, 408(8). https://doi.org/10.1016/j.scitotenv.2010.01.036

Jiang, S. C., Lim, K. Y., Huang, X., McCarthy, D., & Hamilton, A. J. (2015). Human and environmental health risks and benefits associated with use of urban stormwater. Wiley Interdisciplinary Reviews: Water, 2(6), 683–699. https://doi.org/10.1002/WAT2.1107

Khan, S., & Ali, J. (2017). Chemical analysis of air and water. In Bioassays: Advanced Methods and Applications (pp. 21–39). Elsevier. https://doi.org/10.1016/B978-0-12-811861-0.00002-4

Khatri, N., Tyagi, S., & Rawtani, D. (2017). Recent strategies for the removal of iron from water: A review. In Journal of Water Process Engineering (Vol. 19, pp. 291–304). Elsevier Ltd. https://doi.org/10.1016/j.jwpe.2017.08.015

Kim, L. H., Ko, S. O., Jeong, S., & Yoon, J. (2007). Characteristics of washed-off pollutants and dynamic EMCs in parking lots and bridges during a storm. Science of the Total Environment, 376(1–3). https://doi.org/10.1016/j.scitotenv.2006.12.053

Langeveld, J. G., Liefting, H. J., & Boogaard, F. C. (2012). Uncertainties of stormwater characteristics and removal rates of stormwater treatment facilities: Implications for stormwater handling. Water Research, 46(20). https://doi.org/10.1016/j.watres.2012.06.001

Leecaster, M. K., Schiff, K., & Tiefenthaler, L. L. (2002). Assessment of efficient sampling designs for urban stormwater monitoring. Water Research, 36(6). https://doi.org/10.1016/S0043-1354(01)00353-0

Lim, K. Y., Hamilton, A. J., & Jiang, S. C. (2015). Assessment of public health risk associated with viral contamination in harvested urban stormwater for domestic applications. Science of the Total Environment, 523, 95–108. https://doi.org/10.1016/j.scitotenv.2015.03.077

Llopart-mascaró, A., Ruiz, R., Martínez, M., Rusiñol, M., Gil, A., Suárez, J., Rio, H., Paraira, M., & Rubio, P. (2010). Analysis of rainwater quality : Towards sustainable rainwater management in urban environments - Sostaqua Project. Novatech.

Ma, Y., Egodawatta, P., McGree, J., Liu, A., & Goonetilleke, A. (2016). Human health risk assessment of heavy metals in urban stormwater. Science of the Total Environment, 557–558. https://doi.org/10.1016/j.scitotenv.2016.03.067

Maeda, M., Nakada, K., Kawamoto, K., & Ikeda, M. (1996). Area-wide use of reclaimed water in Tokyo, Japan. Water Science and Technology, 33(10–11). https://doi.org/10.1016/0273-1223(96)00406-4

Matilainen, A., Vieno, N., & Tuhkanen, T. (2006). Efficiency of the activated carbon filtration in the natural organic matter removal. Environment International, 32(3), 324–331. https://doi.org/10.1016/j.envint.2005.06.003

Mendez, C. B., Klenzendorf, J. B., Afshar, B. R., Simmons, M. T., Barrett, M. E., Kinney, K. A., & Kirisits, M. J. (2011). The effect of roofing material on the quality of harvested rainwater. Water Research, 45(5). https://doi.org/10.1016/j.watres.2010.12.015

Metcalf and Eddy, 2004. Wastewater Engineering, Treatment Reuse. McGraw Hill, New York, U.S.A.

Minnesota Pollution Control Agency, 2015. Industrial Stormwater Best Management Practices Guidebook. https://www.pca.state.mn.us/sites/default/files/wq-strm3-26.pdf

Mitchell, V. G., McMahon, T. A. (Thomas A., Mein, R. G., & Cooperative Research Centre for Catchment Hydrology. (1999). The reuse potential of urban stormwater and wastewater. CRC for Catchment Hydrology.

Mukherjee, M., & Jensen, O. (2020). Making water reuse safe: A comparative analysis of the development of regulation and technology uptake in the US and Australia. Safety Science, 121. https://doi.org/10.1016/j.ssci.2019.08.039

Nassar, A. M., & Hajjaj, K. (2013). Purification of Stormwater Using Sand Filter. Journal of Water Resource and Protection, 05(11), 1007–1012. https://doi.org/10.4236/jwarp.2013.511105

Nurul Anggraeni, R., Ki Hajar Dewantara, J., Jababeka, K., Utara, C., & Barat, J. (2020). The optimum of detention time on flocculation unit using a laboratory scale prototype. 05(02), 101–112. https://doi.org/10.33021/jenv

Philp, M., Mcmahon, J., Heyenga, S., Marinoni, O., Jenkins, G., Maheepala, S., & Greenway, M. (2008). Review of Stormwater Harvesting Practices. https://publications.csiro.au/rpr/download?pid=procite:6057d2b6-42b7-4d03-9fd7-ddd451b9d269&dsid=DS1

Pintor, A. M. A., Vilar, V. J. P., Botelho, C. M. S., & Boaventura, R. A. R. (2016). Oil and grease removal from wastewaters: Sorption treatment as an alternative to state-of-the-art technologies. A critical review. In Chemical Engineering Journal (Vol. 297, pp. 229–255). Elsevier B.V. https://doi.org/10.1016/j.cej.2016.03.121

Pivokonský, Martin., Novotná, Kateřina., Čermáková, Lenka., & Petrícek, Radim. (2022). Jar Tests for Water Treatment Optimization. IWA Publishing.

Republic of Turkey Ministry of Health, 2001. Regulation on Waters Intended for Human Consumption.

Rodak, C. M., Jayakaran, A. D., Moore, T. L., David, R., Rhodes, E. R., & Vogel, J. R. (2020). Urban stormwater characterization, control, and treatment. Water Environment Research, 92(10). https://doi.org/10.1002/wer.1403

Scholz, M., & Kazemi Yazdi, S. (2009). Treatment of road runoff by a combined storm water treatment, detention and infiltration system. Water, Air, and Soil Pollution, 198(1–4). https://doi.org/10.1007/s11270-008-9825-6

Silva Vieira, A., Weeber, M., & Ghisi, E. (2013). Self-cleaning filtration: A novel concept for rainwater harvesting systems. Resources, Conservation and Recycling, 78, 67–73. https://doi.org/10.1016/j.resconrec.2013.06.008

Song, H., Qin, T., Wang, J., & Wong, T. H. F. (2019). Characteristics of stormwater quality in Singapore catchments in 9 different types of land use. Water (Switzerland), 11(5). https://doi.org/10.3390/w11051089

Sonstrom, R. S., Clausen, J. C., & Askew, D. R. (2002). Treatment of parking lot stormwater using a StormTreat system. Environmental Science and Technology, 36(20). https://doi.org/10.1021/es020797p

Thomas, R. B., Kirisits, M. J., Lye, D. J., & Kinney, K. A. (2014). Rainwater harvesting in the United States: A survey of common system practices. Journal of Cleaner Production, 75. https://doi.org/10.1016/j.jclepro.2014.03.073

Trowsdale, S. A., & Simcock, R. (2011). Urban stormwater treatment using bioretention. Journal of Hydrology, 397(3–4), 167–174. https://doi.org/10.1016/j.jhydrol.2010.11.023

U.S. Environmental Protection Agency, 2002. Water Treatment Manuals - Coagulation, Flocculation & Clarification. Wexford, Ireland. https://www.epa.ie/publications/compliance--enforcement/drinking-water/advice--guidance/EPA_water_treatment_mgt_coag_flocc_clar2.pdf

U.S. Environmental Protection Agency, 2012. Guidelines for Water Reuse https://www.epa.gov/sites/default/files/2019-08/documents/2012-guidelines-water-reuse.pdf

U.S. Environmental Protection Agency, 2015. Sampling and Analysis Primer For Water Quality Surveillance and Response Systems Sampling and Analysis Primer. https://www.epa.gov/sites/default/files/2015-06/documents/sampling_and_analysis_primer.pdf

U.S. Environmental Protection Agency, 2021a. Developing Your Stormwater Pollution Prevention Plan: A Guide for Industrial Operators https://www.epa.gov/sites/default/files/2021-03/documents/swppp_guide_industrial_2021_030121.pdf

U.S. Environmental Protection Agency, 2021b. Industrial Stormwater Monitoring and Sampling Guide. https://www.epa.gov/sites/default/files/2015-11/documents/msgp_monitoring_guide.pdf

Vogel, J. R., & Moore, T. L. (2016). Urban Stormwater Characterization, Control, and Treatment. Water Environment Research, 88(10), 1918–1950. https://doi.org/10.2175/106143016x14696400495938

World Health Organization, 2017. Guidelines for Drinking-water Quality.

Xu, J., Wei, D., Wang, F., Bai, C., & Du, Y. (2020). Bioassay: A useful tool for evaluating reclaimed water safety. In Journal of Environmental Sciences (China) (Vol. 88). https://doi.org/10.1016/j.jes.2019.08.014

Yi, L., Jiao, W., Chen, X., & Chen, W. (2011). An overview of reclaimed water reuse in China. Journal of Environmental Sciences, 23(10), 1585–1593. https://doi.org/10.1016/S1001-0742(10)60627-4

Zhang, M., Chen, H., Wang, J., & Pan, G. (2010). Rainwater utilization and storm pollution control based on urban runoff characterization. Journal of Environmental Sciences, 22(1), 40–46. https://doi.org/10.1016/S1001-0742(09)60072-3