The potential of the Urban Wastewater Treatment Plants in the Netherlands to remove the contemporary contaminant microplastics from the inflow wastewater

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Abstract

The entrance of new contaminants on the water quality policy agenda initiates matter of concern for managers of wastewater treatment plants. This research outlines a capacity analysis of the Dutch urban wastewater treatment plants (UWWTPs) to treat these new contaminants. The research focuses on the contemporary contaminant, microplastics, for analyzing the removal capacity of the UWWTPs. This contaminant is selected because of its high impact on the environment, which led to its entrance on the water quality policy agenda. This research categorizes the UWWTPs in the Netherlands based on their basic wastewater treatment capacity. Presence of secondary and tertiary technology in the UWWTPs and the need for additional technology to remove microplastics are the basis of this categorization. Furthermore the study uses qualitative methodology to collect information on the biochemical nature of the contaminant and evaluates the technical performance of the known removal processes. It also looks at required policy and regulation to upgrade the UWWTPs for microplastics removal. Overall a situation analysis of the UWWTPs depicts their capacity to treat such contemporary contaminants. The situation analysis founds that the UWWTPs of the Netherlands are removing high amount of microplastics with their primary treatment system but they release small but significant amount of microplastics which is harmful for the marine environment. The case analysis of emerging chemical contaminants indicates that regulation change is required to upgrade the UWWTPs for microplastics removal and that is a time-consuming process.

Key word: wastewater treatment, emerging contaminants, microplastics

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List of abbreviations

BAF	Biologically Activated Filter
BAT	Best Available Technology
BOD	Biochemical Oxygen Demand
CE	Circular Economy
CEC	Contaminants of Emerging Concern
CSO	Combined Sewage Outflow
CSS	Combined Sewage System
DESAR	Decentralized Sanitation and Reuse
EPA	Environmental Protection Agency
EUWARENESS	European Water regimes and the Notion of a Sustainable Status
EQS	Environmental Quality Standards
EU	European Union
GAC	Granulated Activated Carbon
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GSI	Green Stormwater Infrastructure
IPPC	Integrated Pollution Prevention and Control
IWA	International Water Association
IWM	Integrated Water Management
IWRM	Integrated Water Resources Management
LID	Low-Impact Development
MBBR	Moving Bed Biofilm Reactor
MBR	Membrane Bio Reactor
MEEM	Masters in Environment and Energy Management
MSFD	Marine Strategy Framework Directive
MP	Microplastics
NF	Nano Filtration
NGO	Non-Governmental Organization
PAC	Powdered Activated Carbon
PE	Population Equivalent
POP	Persistent Organic Pollution
REA	Rapid Evidence Assessment
REFIT	Regulatory Fitness and Performance Programme
RSF	Rapid Sand Filtration
RO	Reverse Osmosis
SUDS	Sustainable Drainage System
TSS	Total Suspended Solids
UK	United Kingdom
UN	United Nations
WSUD	Water-Sensitive Urban Design
WFD	Water Framework Directive
USA	United States of America
UWWTD	Urban Waste Water Treatment Directive

UWWTP	Urban Waste Water Treatment Plant
UV	Ultra Violet
UNESCAP	United Nations Economic and Social Commission for the Asia and Pacific
WWTP	Waste Water Treatment Plant

1 Introduction

1.1 Background

The journey of water contamination has started parallel with water extraction, water use and thus water exploitation. It started in the early phase of the human civilization. The problem was not acute then due to ample water resources and small population. With the migration of humans from one place to another, water contamination has spread over the world (Berekoven, 2006). Population boom has caused overexploitation of water. Then with the entry of the industrial era, water contamination rate started increasing exponentially (Hobsbawm, 1963). This led to reduction in water sources and water contamination to become a problem all over the world. The natural hydrological cycle failed to manage the overburden of contaminated water.

Specialized water treatment plants then were built to treat this contaminated water, or "wastewater." Initially, it followed primary treatment (physical separation of solids) to wastewater. In the late 19th century, septic system based water treatment technology evolved. It included the biological treatment along with physical separation of solids. In the early 20th century, more efficient secondary treatment (biological method) of water purification was introduced (Lofrano & Brown, 2010). Till then, wastewater treatment systems made gradual advancements. With more knowledge of the impact of wastewater on health and environment, new technologies were evolved to tackle the new contaminants. Various forms of contaminants introduced to water have very different chemical and biological properties. However, due to the change in lifestyle, industrialization and urbanization, many new contaminants are entering the water cycle and help sustaining the need for development in wastewater management technology and practice.

The Netherlands has always been the forerunner in wastewater management. Water quality management started in the country with the development of sanitation and sewer systems. After 1900, the water closet system and sewer network were introduced to it. Along with that, end of the pipe treatment of sewer water also started. However, the treatment was limited to physical separation of contaminants and aerobic digestion (Angelakis & Snyder, 2015). The sewer network and wastewater management advanced equally in the country. Gradually, more and more cities started operating the network of sewer system and in 1970, a general management system of wastewater treatment plants (WWTPs) was integrated in the policy (Meijer, 1993; Hegger, Vilet & Spaargaren, 2017). With time the number of water boards decreased to gain more efficiency. But the number of WWTPs increased. Between 1970 and 1980 the biological treatment capacity of the WWTPs increased from 5 million person-equivalent to 17 million person-equivalent (Mostert, 2006). In 1981, the number or WWTPs reached 505. After that the number started reducing due to better connection and pumping system (CBS, 2017). There were also changes in the technology installed, practice and volume of wastewater. With the rise of population, wastewater generation has increased (Dutch Water Authority, 2013). Industrialization and urbanization spread over, which causes changes in lifestyle and consumption pattern. Due to that, more complex contaminants were introduced to the water. To tackle the situation, most of the WWTPs updated with secondary treatment from early primary treatment technologies. Some of them are equipped with modern tertiary treatment technologies to fight new generation contaminants. Alongside a new dimension has been added to the wastewater management situation. Due to the presence of different elements in the wastewater, it started being considered as resource (Unie Van Waterchappen, 2013). WWTP managers started to recover energy and material from wastewater and the treatment plants are considered as energy factory. The country received its recognition for its work in wastewater management in 2013, when European Union declared the Netherlands as one of the three countries (the other two are Germany and Austria) that fully complied with the EU Urban Wastewater Treatment Directive (Dutch Water Sector, 2013). However, the impacts of these contaminants on the environment and health are being gradually identified. Thus, the need for upgrading the WWTPs becomes part of the water quality policy agenda. New contaminants such as pharmaceutical residues, like antibiotics, different forms of plastics, complex hydrocarbons are considered difficult to tackle at this moment. The literature review section will elaborate the situation and also explain the available technologies to express the gap between contemporary contaminants and operational technologies in the system. This gap identification is the key to elaborate the importance of the study this document is proposing.

1.2 Problem statement

The WWTPs of the Netherlands treat wastewater from different sources. It includes the black and grey water from domestic and commercial sources. Industries also discharge their wastewater to WWTPs through sewer system. Industries need to treat their wastewater for few specific parameters before discharging it to the sewer (Hegger et al., 2017). According to the EU wastewater treatment directive they are termed as Urban Wastewater Treatment Plant (UWWTP). There are 327 UWWTPs in the country (CBS, 2018). Many new products are being introduced to the society such as new foods, beverages, medicines etc. As an impact of that many contaminants are being exposed to the wastewater stream. These contemporary contaminants include hormones, antibiotics, several pesticides, antioxidants etc. The consequences of these contaminants are diverse. They have impacts on the environment and human health in different ways. Each of them follows different chemical and biological pathways to influence the water quality, hence influence the marine and aquatic biodiversity as well in different pathways. Microplastics is one of them. They are small particles of plastics that are mainly coming from different plastic products. The traditional primary and secondary treatments are not always capable of trapping and recovering these contaminants in the UWWTPs. An article published on 22 June, 2018 in the newspaper NRC titled “Filters with miniscule holes for plastic particles smaller than a grain of sand” elaborates the microplastics situation in the Netherlands. The report states that microplastics particles are available in the surface water of the Netherlands. The report cited an interview of Hielke van der Spoel, policy advisor at Waterschap Rivierenland, where he clearly mentions that the sewage is not specifically filtered for microplastics in the UWWTPs (NRC, 2018). Thus, the discharge water from UWWTPs can contain them in considerable amount and results in damage to the quality of the natural water stream and anything depending on this quality. Development and addition of technologies in the wastewater treatment plant can change the situation. Removal of these microplastics at the point of generation can be one alternative as well. These technologies are not widely used but their technical capacity to deal with specific contemporary contaminants has made them alternative option to deal with the contemporary contaminants.[1]

1.3 Research Objective

The two objectives of the research are 1) to analyze the potential of the Urban Wastewater Treatment Plants of the Netherlands to treat the contemporary contaminant microplastics, and 2) to analyze the present policy and regulation of EU and the Netherlands for microplastics removal at Urban Wastewater Treatment Plants.

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[1]The problem statement takes some of the knowledge gained from the literature review as presented in chapter 2 into consideration.

2 Literature Review

This section elaborates the background of wastewater and wastewater management. It consists of the evolution of wastewater management technologies and practices over the world with special emphasis on the Netherlands. This section also explains the research works and methodological developments done on contaminants identification, their impact assessment and technology development for removal and recovery. It discusses the position of wastewater management in the EU and Dutch policy. This section will act as a knowledge platform for the proposed research by serving necessary information from secondary sources.

2.1 Wastewater

In general, wastewater can be defined as water that lost its natural quality by human use. This general definition demands the specification of natural quality of water. Thus it requires more specific definition. Tilley, Ulrich, Lüthi, Reymond & Zurbrügg, (2014) defined it as "used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff or stormwater, and any sewer inflow or sewer infiltration" (Tilley et al., 2014, p. 175). Households produce wastewater from sink, shower, bathtub, flush toilet and urinals. This can be classified into three different sections. They are grey water, black water and brown water. The grey water is the total amount of water generated from washing food, cloths, dishware and bathing but doesn't include the water from toilets. Black water is the mixture of feces, urine and flush water. Brown water generation is less occasional than the other two. It represents the feces and flushing water but excludes the urine (SSWM, 2016). Black water contains high organic load and needs complex secondary treatment technology. Grey water contains less organic load and can be reused following simple treatment. Most sewer system collects the mixture of grey and black water which contains less solid and high water but still requires secondary treatment due to presence organic and pathogen load from black water (Hegger et al., 2017).

Industrial wastewater comes from different industrial processes. Thus, in most cases it is diverse in properties compare to household wastewater. It can be categorized based on the source and quality. The major sources of industrial wastewater are complex organic chemicals industry, electric power plants, food industry, Iron and steel industry, mines and quarries, nuclear industry, pulp & paper industry and textile Dyeing (Hanchang, 2002). Based on quality they can be divided into three categories, wastewater with high organic load; wastewater with high chemical load and cooling water with high temperature (Azizi, Valipur & Sithebe, 2013). Different treatment methods need to be applied depending on the physical and biochemical properties of the wastewater.

2.2 Wastewater and sanitation

The sanitation system is the producer of highest amount of wastewater. Although it contains 99% water and 1% soiled, its huge volume has given sanitation an important position for discussion in wastewater management (Unwater, 2017). In general, sanitation means the system which manages the human excreta and flushing water from the point of generation to the point of use or ultimate disposal. Tilley et al., (2014) defined sanitation system as a "context-specific series of technologies and services for the management of these wastes (or resources), i.e., for their collection, containment, transport, transformation, utilization or disposal" (Tilley et al., 2014, p. 10). The association of sanitation with water and hygiene has made the issue much broader. Sanitation management is closely linked with water management (Nguyen-Viet et al., 2009). Drinking water, cleaning water and wastewater management circulates around sanitation system. Hygiene practice secures the water quality from contamination (Unwater, 2016).

Based on the collection and transportation of feces and wastewater to the treatment system, sanitation can be divided into two types, centralized and decentralized sanitation. A centralized system depicts an urban sewer network system with treatment of the wastewater in a central treatment plant. It collects the feces and wastewater from the commode/squat pan and channels it to the treatment system. However, other solutions exist, namely 'decentralized sanitation'. They are also termed as on-site systems (Wilderer & Schreff, 2000). It includes septic systems and also other types of treatment systems. It also includes composting toilets, aeration systems and compendium sewer based mini treatment systems to service a group of structures. Wastewater whether it is central or decentral, a WWTP can be owned and managed publicly and privately. In the Netherlands, almost all collective treatment plants are owned and managed by the water authorities, some central treatment plants were owned and operated by private companies, for instance DSM (Koninklijke DSM N.V.) operates a central treatment plant for many factories (Paques, 2018).

Different kinds of sewer systems are being used in the Netherlands. In a mixed sewer, waste and rainwater flow together in one piped network to the sewage treatment plant (WWTP). Mixed sewer can also be termed as combined sewer (discussed in the next section). There are separated systems that drain wastewater and rainwater into two separate tubes. Most of them uses the gravity to pass the water to the treatment plant. In some systems, a pump pushes the wastewater into the pipe with force (Riool, n.d.). The water flows further into the piped network as a result of this pressure. Most of the cities of the Netherlands use mixed sewer. Some part of Amsterdam uses separated sewer system. In Europe, Sweden and Germany are forerunners in using decentralized sanitation. However, the country is also implementing demonstration pilot projects on decentralized sanitation. "Decentralized Sanitation and Reuse" (DeSah) project has been implement in few towns of the Netherlands which includes Groene Dak (Utrecht), Waterland (Groningen), Lanxmeer (Culemborg), Swichum (Friesland) (Hegger et al., 2017).

2.3 Wastewater and drainage management

Stormwater is the other source of wastewater that runs into a mixed sewage system as mentioned in the previous section. The drainage system of cities contains the stormwater and transports it to the wastewater treatment plant. Parkinson & Taylor (2003) defined drainage system as "an engineered infrastructure for urban runoff, focusing on actions to prevent and mitigate problems related to flooding, as well as those related to pollution and deterioration in environmental health conditions" (Parkinson & Taylor, 2003, p. 77) It indicates that along with flood management, another intention of drainage management is to manage the contaminants in the water and pass it to the treatment plant. Drainage system for only stormwater carry physical contaminants like dust, sand and similar other particle matters. Contaminants from mixed untreated water in combined sewer system (CSS) negatively affect water quality in a wide range of receiving waters. The contaminants include oil, grease and toxic substances picked up as rain washes across roads or fields. In this situation, combined sewage outflows (CSOs) were created to directly discharge into receiving waterborne environment during extreme precipitation event and CSOs include a wide range of contaminants, which affect public health and aquatic species. EPA (1994) claimed that CSOs can result in waterborne infections such as hepatitis, gastroenteritis, as well as skin, respiratory or ear infections in human. Last but not least, CSOs discharge brings about economic burdens, including cleanup expenses, emergency repairs, lost tourism revenue, lost productivity, and medical treatment.

2.4 Material recovery from wastewater

Resource recovery from wastewater is another aspect of wastewater management. Since, the wastewater is diversely rich in organic and inorganic components, resource recovery from it has the potential to supplement the overarching cost of wastewater treatment. At the moment water is used in a linear way. It is extracted upstream, treated, used, treated again, and discharged. The water becomes more and more polluted during this usage. This way of using water is quite inefficient. Not much is done with all the resources that get extracted from the wastewater during the treatment processes. In changing this linear usage, the concept of 'waste' should be eliminated. This is possible by extracting energy, nutrients, and materials (Jeffries, 2017). The recovery of these resources is the aspect of circular water on which a part of this research will focus. The exact definition of recovery in this case is: extract resources (other than water) out of the wastewater and put them to use again (Wbcsd, 2017).

Wastewater comes from three different sources. One of these is households. The main resources which are present in wastewater from households are organics, nutrients (nitrogen, phosphorus and potassium), pathogens, pharmaceuticals residues and hormones (Zeeman, 2009). These mainly come from feces and urine. Another source of wastewater is agriculture, the main resources present in this water are fertilizers and nutrients. The third source is industry, here water is mainly used as cooling water, boiler makeup water, and process water. These applications do not require a really high quality of water. Therefore water in industry can, in contrast to households and agriculture, be reused several times (Mo & Zhang, 2013). Wastewater from industry contains for example metals and chemicals.

To implement efficient resource recovery there is need for research and practices on integrated resource recovery in wastewater treatment plants (Mo & Zhang, 2013). This can be incentivized through regulations, policy instruments and funding. Another important aspect to make the recovery of resources from wastewater work efficiently and effectively is cross sector collaboration. There has to be good collaboration between government, agriculture and industry (Wbcsd, 2017).

2.5 Wastewater treatment: technology evolution

Technology to treat the wastewater has evolved with time. Initially it followed physical measures to separate large contaminant particles. Later more complex techniques were introduces to remove micro particles and pathogens. In general the technologies can be divided into three stages. They are: Primary, Secondary and tertiary technologies. A short description for each of them is given below:

Primary treatment: Primary treatment is the method for the removal of heavier solids by gravity sedimentation (Metcalff & Eddy, 2008). Trenches and pits were used in many centuries to remove heavier solids from water before use (Vuorinen, Juuti & Katko, 2007). More advanced form of primary treatment record was found in Minoan Tylissos, Palace of Knossos and Hagia Triada in Greece (Chatzakis, Lyrintzis, Mara & Angelakis, 2006). They used large sedimentation tank for removal of heavy articles from water. L.H. Mouras designed a cesspit in 1860. It had provision for inlet and outlet pipe beneath the water surface to form water seal. Donald Cameron developed the design of septic tank in 1895, for treating the sewage sludge using the soil as filter. The Imhoff tank, designed by Karl Imhoff in 1906 illustrated further advancement to septic tank method and still used as basic of on-site sanitation (Imhoff & Mahr, 1932).

Secondary treatment: Secondary treatment uses micro-organisms to convert the organic materials in the wastewater to generate carbon dioxide, water and energy. There are two basic types of Secondary treatment: attached growth (biofilms) and suspended growth (activated sludge) (Metcalff & Eddy, 2008). In the first method, rock or plastic is used as a place for the microbes to stick on and grow to form a biofilm. Wastewater flows over this aerated biofilm and digests the organic material of the wastewater. In a suspended growth system, the biomass and wastewater are constantly agitated and mixed. The digestion of the organic material continues and generated residues are separated by sedimentation.

Tertiary treatment: The impact of wastewater on health and environment was gradually revealed. Higher concentration on research identified many contaminants of water and need for advanced treatment technology was established. Secondary treatment mainly reduces the carbonaceous material of the wastewater, but many other elements like nitrogen and phosphorus remains in the treated water. That poses the risk of bacterial and algal growth in the water called eutrophication. Depending on the receiving waters, many treatment plants need to remove nitrogen and in some cases phosphorous also. Studies carried done by Downing, Painter & Knowles, (1964) proposed a design methods of biological nitrification which is in practice now. In 1962, Lutdzack and Ettinger developed the idea of using anoxic zone to achieve biological denitrification in activated sludge process (Lutdzack & Ettinger, 1962). Sludge system was updated later by James Barnard (Barnard, 1975).

2.6 Wastewater policies

2.6.1 EU Policy

Wastewater management has been considered as priority area in European Union (EU) from its beginning. It adopted the council directive 91/271/EEC concerning urban waste-water treatment in 1991. The objective of the directive was to protect the environment from the impact of urban wastewater discharges. It selected three sources as area of concern. They are the collection, treatment and discharge of: domestic wastewater; mixture of wastewater and wastewater from certain industrial sectors (Council Directive, 1991). Later EU developed an integrated water management plan, when it has finalized the Directive 2000/60/EC of the European Parliament and established a framework for the community action in the field of water policy in 2000 (WFD, 2000). It is popularly known as EU Water Framework Directive. It concerns about integrated water management and contains direction about prevention of groundwater and surface water sources from wastewater. EU commissioned its Marine Strategy Framework

Directive in 2008 (MSFD, 2008). Its major objective is to protect the marine environment of Europe. It illustrates the protocol for prevention of marine and other aquatic habitats from the exposure of wastewater. EU has more focused concern about the contemporary and emerging contaminants in the water. Directive 2013/39/EU of the European Parliament, 2013 pointed the priority substances in the water. In 2015, the directive adopted a watch list of new contaminants to be monitored in the water. The list includes, the natural hormone oestrone; three (macrolide) antibiotics; several pesticides; a UV filter (a chemical that prevents UV light getting though, as used in sun cream); an antioxidant used as a food additive (Marek, Baun & Dąbrowski, 2017).

2.6.2 Dutch Policy

Regional Water Authorities are in charge of wastewater treatment in the Netherlands. Municipalities share responsibility here since wastewater collection and transport through sewer is their duty. The wastewater chain has developed as the country has adopted successive plans which includes national level instruments for strategic planning. Wastewater treatment is the responsibility of the water authorities. Municipalities also share responsibility, since they are in charge of management of the sewer network. Water quality policy and the planning and building of WWTPs really started on national level when the law on pollution of surface water (Dutch Pollution of Surface Waters Act - WVO) was issues in 1970. Since then the water boards started building and operating WWTPs nationwide. The wastewater management was governed under the renewed Regional Water Authorities Act, 1992 (Dutch Water Authorities, 2015) that managed some constitutional aspects. More than a decade later, meanwhile eight water laws were in operation, there was a quest for coordination and integration. The integration of eight water laws of the country has generated the National water act, 2009. As directed, the water authorities and municipalities jointly sharing responsibilities for wastewater management. A new and more integrated Environmental Planning Act has been developed and presented to the Dutch parliament by the Netherlands Ministry for Infrastructure and Environment. After adoption by the parliament the draft final Act was published on March 2016. It is expected that the Act will enter into force in 2019 (MIW, 2016).

2.7 Wastewater Management Practice in the Netherlands

Wastewater treatment plant operation started in the Netherlands in early 20th century. The Integrated operation of WWTP in the country has started in 1970, after the adoption of Dutch Pollution of Surface Waters Act (WVO) (Meijer, 1993). From that time, treatment technology became a sector of industry. The WWTPs started with the vision to treat wastewater to discharge quality but the new technologies made the WWTP not only a plant for wastewater treatment but also for energy generation since early this century. Most of the WWTPs in The Netherlands consist of at least two stages of treatment, primary and secondary (discussed in section 2.5). Nowadays and for stricter regulations in the future, in some of the WWTPs and special sector pollution focused treatment plants, tertiary treatment. It includes an extra treatment which uses physical and biochemical measures to get high-quality water such as distillation, evaporation, adsorption and reverse osmosis (Gupta, Ali, Saleh, Navak & Agarwal, 2012).

Anaerobic digestion: The process of the anaerobic digestion is much similar to that in the aerobic digestion. It bacteria that survives and grows without oxygen, in which microorganisms break down biodegradable material. After the primary stage, the sludge is transferred into the anaerobic digestion reactor (Bachmann, 2015). In the anaerobic digestion, the microorganisms are treated the organic compound and produce biogas which consisted mainly of Methane, CO_2 and small amount of other gases. The biogas produced from the anaerobic digestion is not ready for combustion, it needs to be dried and remove unwanted substances and gases.

Nereda©: The Nereda© technology was invented by the University of Delft in 1993, the difference between this technology and the traditional digestion is that the Nereda© technology bacteria grow in granules while the traditional purification bacteria grow in flocs. The granulate includes two layers; the outer aerobic layer takes care of biological oxidation and oxidation of ammonium to nitrate, while the inner anoxic/anaerobic layer reduces nitrate to nitrate gas and takes care of the phosphate removal. This technology shows that the processes of nitrification, de-nitrification and removal of phosphate are done in one tank while the traditional treatment needs multi-tanks. That is the main reason why using the Nereda© technology can save about 70% on required space (Lulofs & Bressers, 2017).

DEMON®: The DEMON® is a treatment system for removal of nitrogen during the purification of the sewage water in the WWTP. The DEMON® technology is an upgradation of the biological nitrification process. The biological nitrification process oxidizes the ammonia and convert it into nitrite and nitrate. Aerobic autotrophic bacteria carry out the chemical conversion. The final product of the nitrification is nitrite. Then it is converted into nitrogen gas through the de-nitrification process. Nitrogen gas is easy to remove from the sludge (Kutty, Isa & Leong, 2011).

Several advanced technologies are being developed following the success of these two technologies. Moving-Bed Biofilm Reactor (MBBR) uses different types of growth media for deammonification of high-strength, ammonium-rich recycle streams. Purac/Läckeby AB (Sweden) developed this system in collaboration with the University of Hannover and Ruhrverband. The commercial name is DeAmmon(r). (Plaza, Stridh, Örnmark, Kanders, 2011; Thöle, 2007). Similar one is developd by AnoxKaldnes/Veolia. It is called ANITA(tm)Mox. It is a single-stage deammonification MBBR system. Clariant/SÜD-Chemie AG (Munich, Germany) has developed the same system using bentonite instead of plastic as support medium for biofilm growth. The commercial name is Terra-N(r) Process. Several other commercial processes are in the process of development (Capodaglio, Hlavínek & Raboni, 2016).

2.8 Contemporary Contaminants

A report of United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) on wastewater has mapped the situation of contemporary contaminants in the wastewater (Unwater, 2017). They are mainly organic compounds such as: pesticides, pharmaceuticals and personal care products. It also includes hormones, plasticizers, food additives, wood preservatives, laundry detergents, surfactants, disinfectants, flame retardants, and other organic compounds that were found recently in natural wastewater stream generated by human and industrial activities. The conventional primary and secondary water treatment plants cannot recover or remove these toxic pollutants efficiently and depicts the need of cost effective tertiary treatment method (Sophia A. & Lima, 2018). Gogoi et al., (2018) has evaluated the treatment options and found that the design of existing treatment plants are not suited to remove most of these contaminants. Thus many contemporary contaminants are being exposed to the environment without detection and removal (Gogoi et al., 2018). A group of contemporary contaminants has been termed as “Emerging contaminants”, sometimes referred as “contaminants of emerging concern” (CECs) which includes different compounds that pose risk to human health and/or the environment (Schnoor, 2014). They are not commonly monitored in the environment. They have potential to enter the environment and cause known or suspected adverse ecological and/or human health effects. This includes antibiotics, estrogenic compounds, PAHs (poly-aromatic hydrocarbons), Reproductive hormones and many other similar compounds (Templeton, Graham, & Voulvoulis, 2009). Among them antibiotics are considered as a sensitive group due to their wide and significant use. Antibiotics represent a long list of natural and synthetics secondary metabolites that are found in the hospital and household wastewater stream. It is generated due to excretion of used antibiotics and disposal of unused antibiotics compounds. The worldwide increment of antibiotics use as drug is believed to be one reason for its high presence in the wastewater. The occurrence of antibiotics in the marine environment believed to promote the selection of antibiotic resistance genes and antibiotic resistant bacteria (Lien et al., 2016). They are of interest in this study since some advancements have been made to upgrade the regulations and so upgrade the UWWTPs to treat these compounds. Thus it can act a lighthouse to bring the microplastics issue into regulation for removal at UWWTP.

2.9 Microplastics

Microplastics are small particles of plastic present in the environment. They are categorized as microplastics based on their size. According to U.S. National Oceanic & Atmospheric Administration, plastics less than 5 mm in size is classified as microplastics (Arthur, Baker & Bamford, 2009). They can be manufactured and found on products like facial cleanser or cosmetics. It is called the primary microplastics (Patel, Goyal, Bhadada, Bhatt, & Amin, 2009). They can be generated by the breakdown of larger plastic particles or as by product of different industrial or metabolic process. Then it is called the secondary microplastics ((Cole, Lindeque, Halsband, & Galloway, 2011). Figure 1 show different sources of microplastics and their percentage of contribution to the overall microplastics generation.

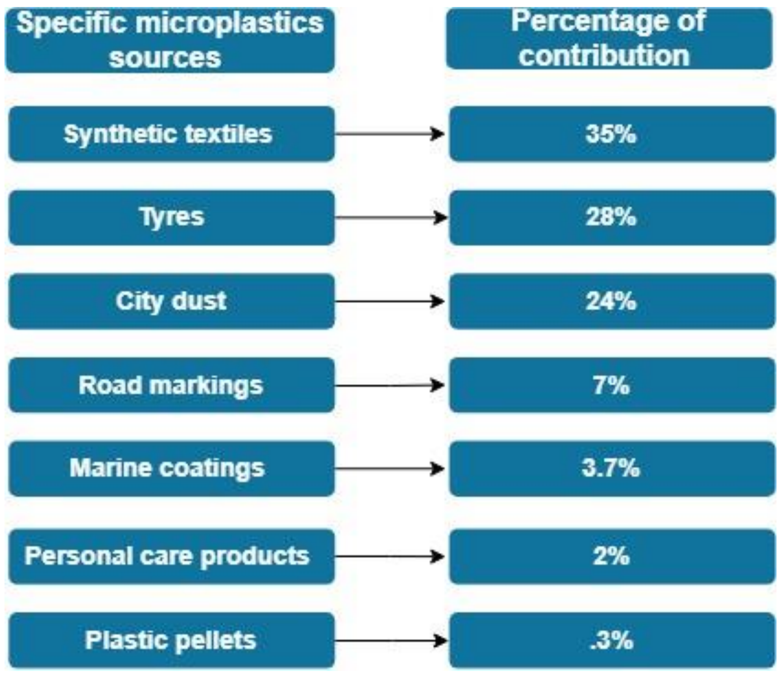

Figure 1: Contribution of microplastics by different sources (modified by author from IUCN, 2017)

It has significant environmental impact, especially in the marine environment. Due to their chemical structure, they sustain in the environment for long time and disrupts the ecological chain. Secondly, they are ingested by marine organisms and causes death (IUCN, 2017). For instance, a study done by a group of Swedish scientists found that microplastics particle from the food web can induce behavioral disorder and brain damage in Fish (Mattsson et al., 2017). Figure 2 shows the mechanism of microplastics to disrupt the marine eco-system.

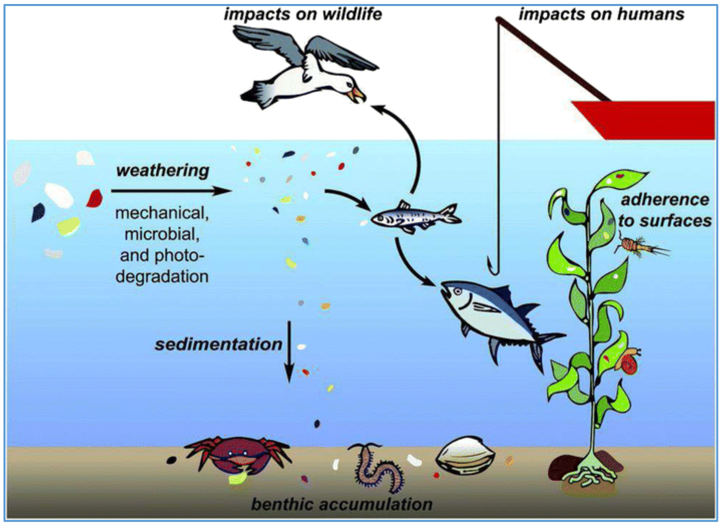

Figure 2: Marine eco-system breakdown by microplastics (Ogunola, Onada, & Falaye, 2018)

In last few years the microplastics issue has come into the concern of the people. Not only the scientific community but also the mass media is showing great concern for microplastics release. The released microplastics from different products ends up in the ocean following the wastewater flow (Prata, 2018). They are not just disrupting the marine environment but entering the drinking water as well. An investigation done by Orb media on drinking of water of more than 12 countries has found alarming result. Overall 83% of the collected water samples were contaminated with plastic fibers. 94% of the samples from the USA have found the presence of microplastics. In the Europe it was 72% which is lower than USA but alarming indeed (The Guardian, 2017). Thus efficient microplastics removal is necessary. That can be done by preventing the process of microplastics generation through brining change in the generation process. Another one is removing the generated microplastics which can be done in the wastewater treatment plant or in the point of generation. This study looks at the wastewater treatment plant (centralized treatment) option for its potential analysis and also compares it with removal at point of generation (decentralized treatment).

3 Research Methodology

This section has outlined the research strategy of the study. A research strategy has explained the pathway between the objective and the result of the study. It has helped to design the data collection and analysis procedure of the study (Verschuren & Doorewaard, 2010). It has given direction to achieve the objective of the study by a step by step pathway. The data collection process has been divided into two sources. One was literature review and the other one was key personnel interview. The research and theoretical framework has guided the data collection and analysis process to connect it to the research objective.

3.1 Research Philosophy

The study has used the research process onion concept for research design, which was developed by Saunders, Lewis & Thornhill, (2009). It provides an excellent way to visualize and categorize the scientific path from research idea to specific methods. Saunders et al. (2007) split the research process onion into six stages: 'philosophy', 'approach', 'strategy', 'choice', 'time horizon' and 'techniques'. The concept is visualized in figure 1**.** This is a pragmatic research in philosophy and followed mixed method to carry it out.

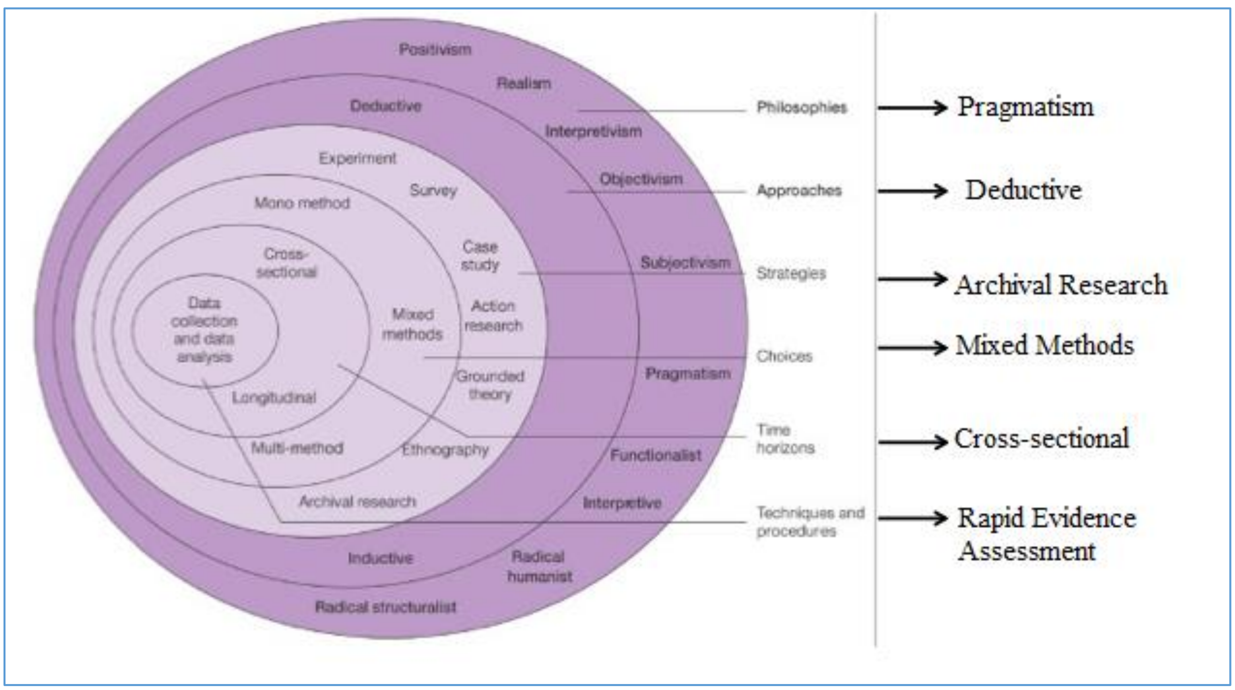

Figure 3: Schematic presentation of the research philosophy (Saunders et al., 2009, p. 138)

3.2 Research Framework

The purpose of the research framework is to establish the theoretical background of the research. It also helps to connect the theoretical framework with the objective of the research. The conceptual model developed by Verschuren and Doorewaard, 2010 has been used to illustrate position of this study in the overall research scenario of wastewater management (Verschuren and Doorewaard, 2010). Stepwise elaboration of the framework is given below.

Step 1: Characterize briefly the objective of the research project:

To identify the present capacity of the urban wastewater treatment plants of the Netherlands to treat and recover contemporary water contaminants

Step 2: Determining the research object:

The research object of this research it the capacity of the urban wastewater treatment plants to deal with microplastics.

Step 3: Establishing the nature of the research perspective:

This is a research which looks into the general technology followed in the urban wastewater treatment plants following mixed method. The research perspective is to compare this technology with the advanced technology for treating and recovering microplastics described in the conceptual model. It also looks into the present regulation and required changes in the regulation for upgrading the wastewater treatment plants. This uses rapid evidence assessment on that based on the information from the literature and key personnel interview.

Step 4: Determining the sources of the research perspective:

The research perspective of the comparison of UWWTP technologies with advanced technologies for microplastics removal uses the theory on new contaminant and advanced treatment technologies as the sources of the research perspective.

Key concept	Theory
Comparing the technology to treat microplastics with the technology available in the wastewater treatment plants of the Netherlands	Theory on contaminants Theory on treatment technology for microplastics

Table 1: Sources of the Research Perspective

Step 5: Making a schematic presentation of the research framework

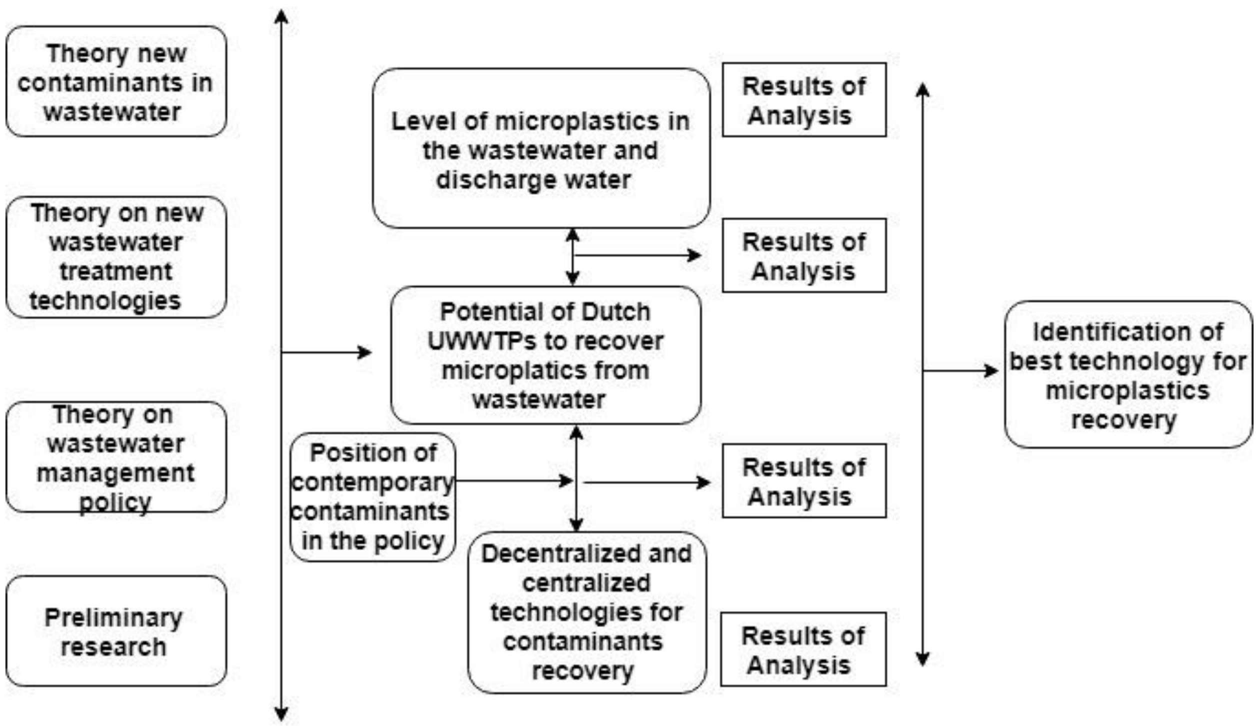

Figure 4: Schematic presentation of the research framework (developed by the researcher)

Step 6: Formulating the research framework in the form of arguments which are elaborated

(a) An analysis of the theories of water contaminants, new wastewater treatment technologies and preliminary research on the present technology of the UWWTPs
(b) By means of which the research object will be identified
(c) Confronting the result of the analysis as the basis of situation analysis of the UWWPs

(d) Limitations and prospects of the UWWTPs to manage contemporary contaminants in wastewater

Step 7: Checking whether the model requires any change

3.3 Research Questions

What is the potential of the Urban Wastewater Treatment Plants in the Netherlands to remove the contemporary contaminant, microplastics from the inflow wastewater?

Sub Questions

- What is the general process (technology) being followed by the UWWTPs of the Netherlands?[2]
- What addition (retrofitting) is needed to treat microplastics at the UWWTP level?
- What is the position of microplastics and other contemporary contaminants in the policy and regulation?
- To what extent can the decentralized technology help better to treat this contaminant?

3.4 Definitions

Potential: technical capacity of the urban wastewater treatment plant to fully treat a specific contaminant to comply with the discharge water quality regulation.

Urban wastewater treatment plant: An urban wastewater treatment plant, abbreviated as UWWTP, treats wastewater and is usually operated by public authorities or by private enterprises working by order of public authorities. It does not include the treatment of wastewater from specialized industrial sources (EU, 1991). In this thesis, the acronym UWWTP is used to indicate the wastewater treatment plants that are run under the EU Urban Waste Water Treatment Directive (UWWTD). Acronym WWTP is used to refer the wastewater treatment plants in general sense.

[2] UWWTPS will be categorized based on their technology as stated in the literature review section (not all 327 UWWTPs, rather the basic technology of those 327 will be evaluated in the study).

Contemporary contaminants: Contaminants that are not listed in the Directive 2013/39/EU of the European Parliament (EU, 2013).

Treat: Removal or recover any contaminant from wastewater

Decentralized treatment technology: add-on technology that are used in source to treat and recover any specific contaminant instead of applying any technology to target the overall quality of water.

Boundary

The boundary of this study is limited to the discussion of urban wastewater treatment. To set the perimeter of study, industrial and other wastewater that are pretreated before entering the municipality wastewater system kept out of the discussion. Also for the intensity and magnitude analysis of the contemporary contaminants, their health and environmental impact will be considered. Their financial implications has not been considered as factor for analysis in the study. However, during the technology analysis of the treatment methods, their retrofitting cost has been discussed as a part of the technology analysis but their long term financial implications have been avoided. For literature review on contemporary contaminants and their removal technology, literatures that are published after 2000, has been considered and reviewed[3].

3.5 Research Material and Accessing method

Research material for this study are literatures available on this relevant topic and selected expert interviews based on a semi-structured questionnaire. Information from multiple sources of literature will be uses. They can be categorized into three major classes:

- Peer reviewed paper
- Published reports
- Official website of EU and Dutch departments

[3] For other parts of the study, literature published prior to 2000 are also reviewed

It selected 52 peer reviewed scientific literatures and 54 grey literatures. The grey literatures includes 12 reports published by consultancy farms, 21 reports published by EU and EU countries, 12 webpage publications and 9 news articles[4].

In depth interviews has been held with several position holders which will be mainly focused on evaluation of the findings from the literature sources and also to get direction for the future steps to upgrade the UWWTPs of Netherlands. The key potential respondents include the following:

1. Three respondents from water authorities, with technical and policy portfolio on wastewater treatment
2. Three respondents from academia, with research experience on wastewater policy and management
3. Three respondents from other stakeholders of wastewater treatment such as commercial technology support companies and consultancy firms

The list given below contains the name of the experts that are interviewed.

Name	Organization and position	Target information
Dr. Stefan Kools	KWR Water team leader	Latest technologies and their applications for contaminants removal specially microplastics
Michaël Bentvelsen	Union of Waterboard Policy Officer International	Policy regarding the wastewater management and national approach towards that
Dr. Andrea Keessen	Department of Law , University of Utrecht	Position of emerging contaminants in the policy and regulation of EU and the Netherlands
Dr. Erik Roesink,	Honorary professor (University of Twente)	Technical advancement in membrane tech for microplastics removal
Andreas Giesen	Nereda Director Technology, Water	The possibility of Nerada for emerging contaminants and required add-on for the WWTPs
Dr. Kees Roest	KWR Senior scientific researcher Programme coordinator	Future model of the UWWTPs and required policy, resource and technology to achieve that

[4] These papers were cited at the points of use, for microplastics removal technology selection 20 scientific paper were used, they have been cited separately in annex 1.

Dr. Ruud Steen	Research Manager The Water Laboratory	Microplastics in drinking water and treatment technologies
EU secretariat (EDCC)[5]	Environment desk	EU regulation and future plan for upgrading them
Dr. Cora Uijterlinde	STOWA Programme Manager	Latest technologies and their applications for emerging contaminants removal

Table 2: List of the experts that are interviewed

The data and information required and its accessing method in this research are identified through the set of sub-research question, as displayed in Table 2.

3.6 Data Collection and Analysis Matrix

Research sub questions	Data required	Source of Data	Research method applied
Present technology practice of the UWWTPs in the Netherlands	Small medium and large UWWTPS of the Netherlands	Policy document Published report	Literature review
	Categorized technology of the UWWTPs based on the size, water quality and age	Published report	Literature review
		Process/system analysis	
Retrofitting required to treat microplastics in the UWWTP	New technology selection and categorization	Scientific literature	Literature review
	Retrofitting selection based on new technology and present situation of the UWWTPs	Key personnel interview	Qualitative Data Analysis
Regulation on microplastics in the EU and the Netherlands	EU and Dutch wastewater regulations	Policy document Scientific literature	Literature review
	Other directives that are connected with water and emission management	Key personnel Interview	Qualitative Data Analysis

[5] Environment desk of the EU secretariat collected the questions from the researcher and sent the answers through their official email. Other experts have given their comments in face-to-face interviews.

Decentralized technology application for microplastics removal and their capacity	Available decentralized technology to treat microplastics	Scientific literature	Qualitative Data Analysis
	Technical and systemic feasibility information of decentralized technologies	Key personnel interview	Qualitative Data Analysis

Table 3: Data collection and analysis framework

3.7 Conceptual framework

The research has not followed any single concept as conceptual framework. To answer different sub-questions, it will follow different concepts as its conceptual framework. The research questions are more focused on exploration and theory building rather than theory testing by accepting or rejecting hypotheses. Thus, the conceptual framework will support to explore knowledge on the contemporary contaminants and UWWTPs. Performance measurement tool of wastewater treatment plant described by Guerrini, Romano, Ferretti, Fibbi, & Daddi, (2016) will be used as concept to help understand the potential of the UWWTPs in the study. It was illustrated in figure3.

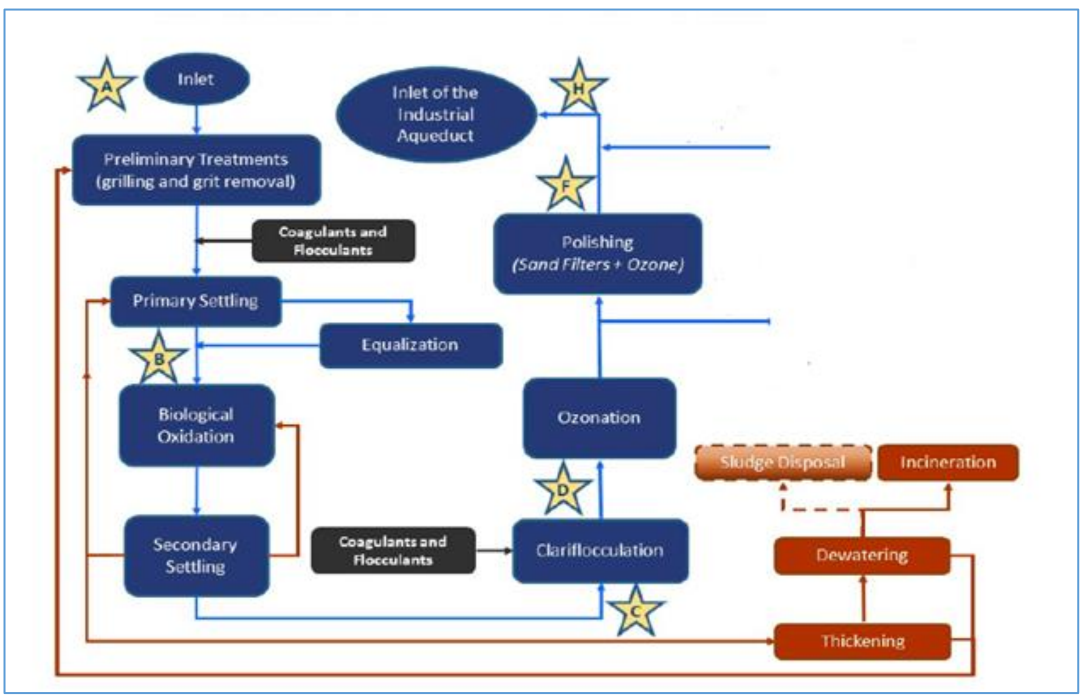

Figure 5: Key technologies for wastewater treatment (source: Guerrini et al., 2016, p. 3)

The second source of concept will be the US-EPA report on performance of the secondary treatment technologies (Buchanan & Seabloom, 2004). This report explains the performance of secondary treatment in UWWTPs. These technology performance report analyzes the performance of suspended growth aeration methods (activated sludge) to reduce the total suspended solids (TSS) and biochemical oxygen demand (BOD).

3.8 Data analysis

Considering the short period of the thesis, this study has followed rapid evidence assessment (REA) in the data collection and analysis (Barends, Rousseau & Briner, 2017). Figure 4 illustrates the REA with similar other data analysis methods. As mentioned earlier, this study used two sources for data collection, literature and expert interview. For the both sources, the following pattern of REA has been used.

- Searching: consulting a limited number of literature and excluding unpublished research.
- Inclusion: only including specific research designs (e.g. studies related to contemporary contaminants treatment and their policy only)
- Data Extraction: only extracting a limited amount of key data, such as, emerging contaminants, microplastics in discharged wastewater, new treatment technologies, policy change in wastewater etc.
- Critical Appraisal: limiting quality appraisal to methodological appropriateness and quality.

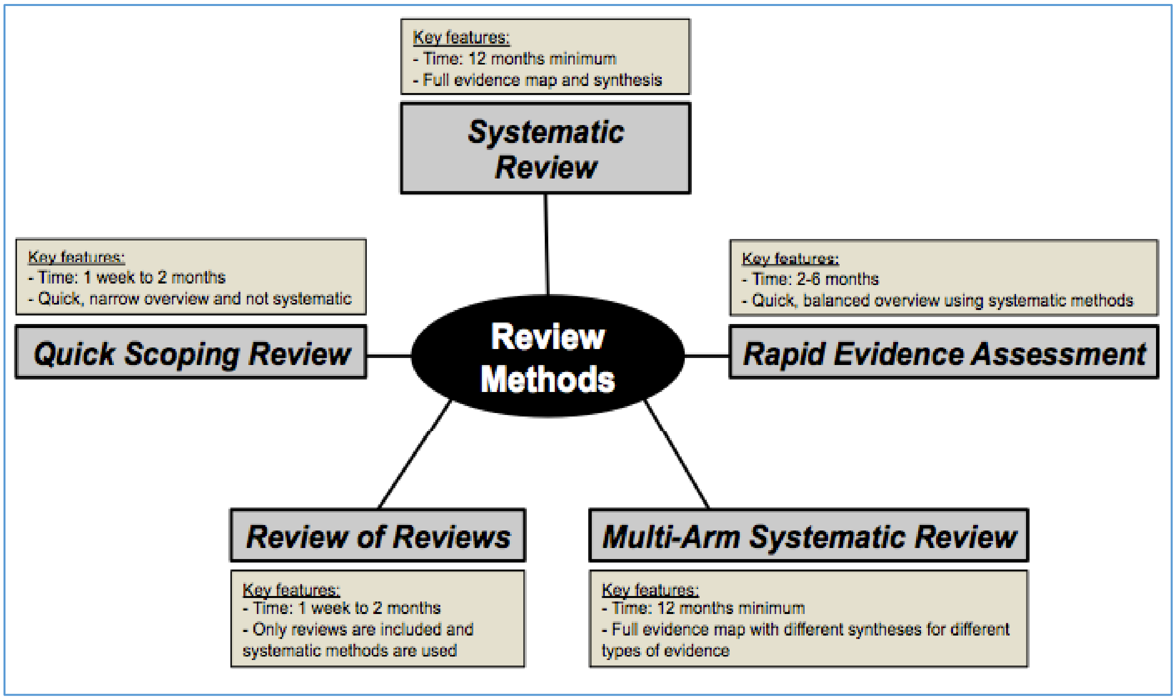

Figure 6: Different qualitative data analysis approach (source: UK Civil Service, 2014, para-3)

Work Plan

Table 4 illustrates the initial work plan followed to carry out the research.

Activities	March	April	May	June	July	August
Idea and Proposal development	X					
Proposal revision based on tutor's remarks	X	X				
Literature Review		X	X			
Interviews		X	X	X		
Results of interview and analysis			X	X	X	
Drafting the preliminary section of the report					X	
Final submission						X

Table 4: Work plan for data collection, analysis and report development

3.9 Ethical review

The study has collected information from two sources. One is existing literature and policy documents & reports. The second one is expert interviews. The collected information has been analyzed following the stated framework to find out the present situation and potential of the UWWTPs of the Netherlands to treat and remove microplastics. The research has given insight for future changes and upgradation of UWWTP technology and policy. Experts those who have been interviewed, responded voluntarily to the interview request. The interviews have been carried out after getting the consent from the supervisor and BMS ethical review committee. Respondents have been informed about the consequences of the research and their written consent have been taken before using the information provided by them. The questions for the interview kept limited to technology and policy issues only thus posed no physical or psychological harm to the expert respondents. Besides, the confidentiality of the information has been considered with high priority and irrelevant texts from the interview transcripts have been removed following the advice from the expert interviewees. The study is an academic research with the sole objective to gain knowledge in the field of water and wastewater management and contribute to the policy for better practice. The researcher has no commercial objective or conflict of interest with the sector players. Thus, the researcher has independently carried out the research.

4 Results

At this moment, plastic litter contamination is considered as one of the serious threat to natural specially marine environment. It is mostly manmade and its impacts are very diverse (Eerkes-Medrano, Thompson, & Aldridge, 2015). Plastic litters are of different size. Among them the one smaller than 5 mm is considered as microplastics. They are the deadliest among the different categories of plastic litters due to their easy access inside the aquatic plants and animals (Chang, 2015). Sometimes a sub-category of microplastics is also considered. They are called the nanoplastics when found in the size of less than 0.2 mm (Cole et al., 2011). Because of their smaller size, microplastics can be ingested by aquatic animals more easily than larger particles. They pose serious physical harm to those animals. Alongside this microplastics can adsorb some persistent organic pollutants (POPs). Thus introduces toxicity to the food web. Global studies found the presence of microplastics in very remote marine habitats as well (Eriksen et al., 2013; Watters, Yoklavich, Love & Schroeder, 2010).

The largest share of marine plastic derives from terrestrial sources (Andrady, 2011). They are released from different industries, construction sites, personal care products, city dust and different other sources. They are released at different stages but the ultimate destination of it is the ocean. Figure 5 illustrates the basic points and pathway of microplastics emission. In this pathway, they go through wastewater treatment plants which are the main tactical points to capture before being discharged to the surface water then to the ocean. This section analyzes the selected scientific and grey literatures to answer the questions of this study. It also utilizes the expert interviews to answer some of the analytical questions. The expert interviews also helped to verify some of the hypothesis made from the analysis of the literatures. This section discussed the technical capacity of the UWWTPs of the Netherlands to capture the microplastics, adjustment needed for their upgradation to capture microplastics and policy/regulation changes required to make the upgradation. In this process, this section also discusses the research on emerging chemical contaminants and progress achieved so far to translate the findings into regulation and practice. The study on emerging contaminants helps to understand the pathway for tackling microplastics in the future.

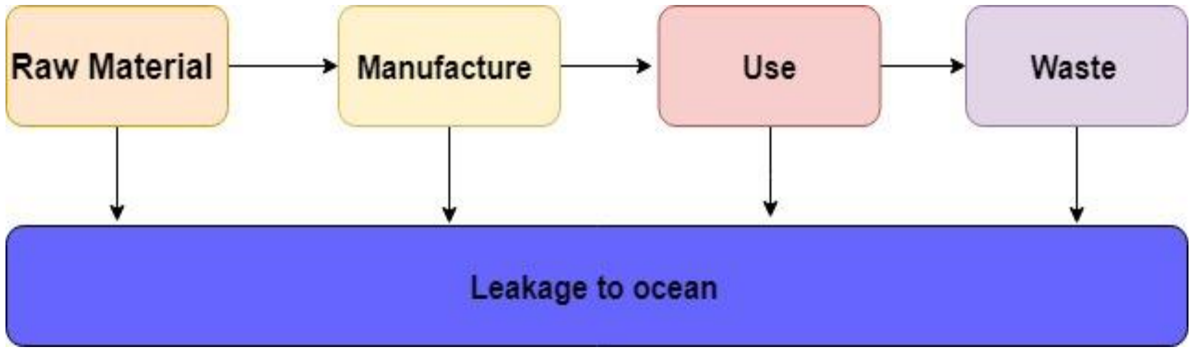

Figure 7: Microplastics transmission pathway (Original by P.J. Kershaw, modified by author)

4.1 WWTPs of the Netherlands

This sub-section analyzes the WWTPs of the Netherlands, their position and the general technology they follow. Based on the technology they use, the capacity of the WWTPs to remove microplastics can be calculated. Based on that the rate of discharge of microplastics to the surface water and the need for capturing those microplastics can be identified. The first sub-question of this study is “what is the general process (technology) being followed by the WWTPs of the Netherlands?” Section 4.1 answers that question.

4.1.1 Position and technology

The wastewater treatment plants of the Netherlands are spread over different locations of the country. The municipal wastewater treatment plants are run by the water authorities of the country. Besides, there are specialized water treatment plants for the industrial water treatment to be discharged in the public sewer. This study considered the municipal WWTPs. As per the European Union directive, they are termed as Urban Wastewater Treatment plant (UWWTP). They are run by the EU regulation of Urban Wastewater Treatment Plant Directive (UWWTD). In the Netherlands, the number of treatment plants started decreasing after 1990. Whereas the capacity and coverage of them have increased significantly. Now there are 327 UWWTPs functional in the country. Two database were reviewed to get information on the UWWTPS. They are the Dutch national statistics database (CBS, 2018) and EU database for UWWTD (Oieau, 2018). Processing the information found from these two websites, the locations of the UWWTPs of the Netherlands are shown in fig 6.

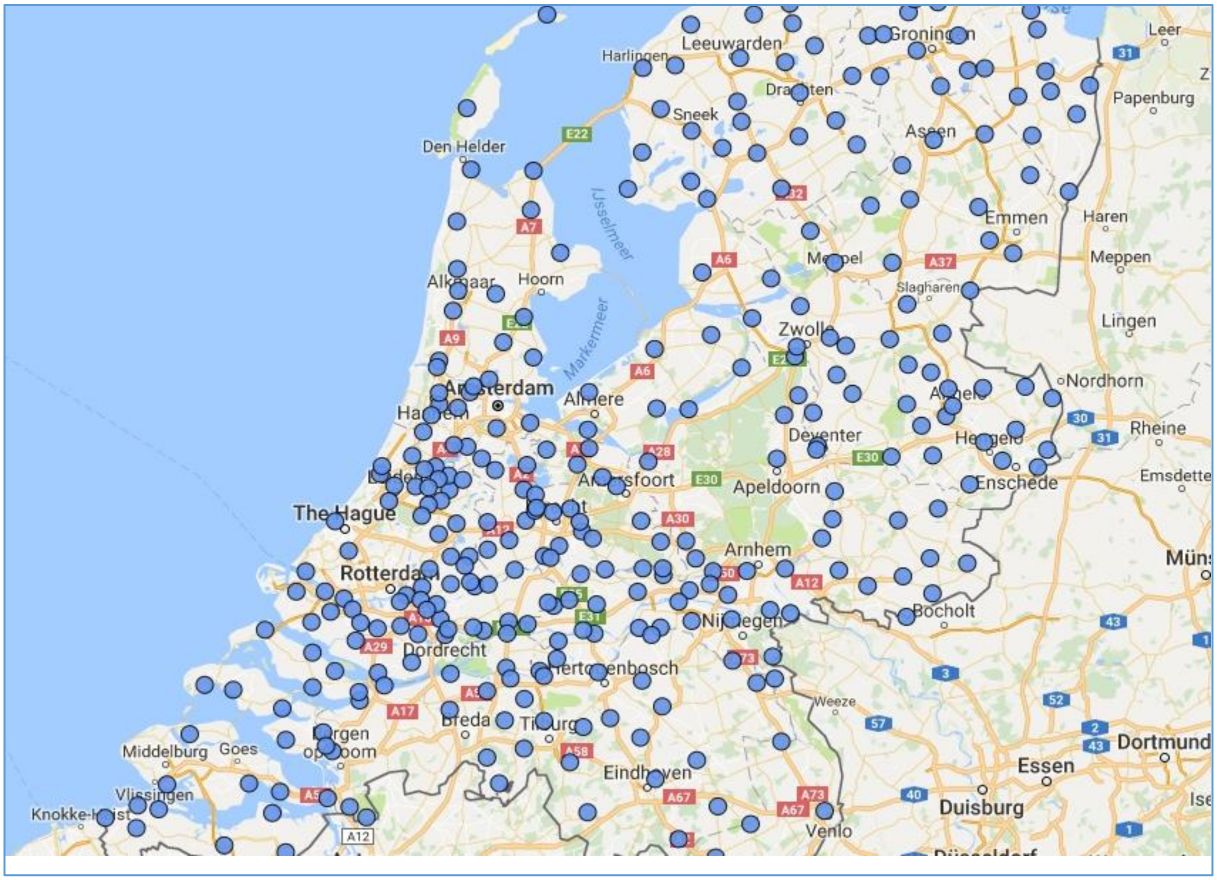

Figure 8: Location of the UWWTPS of the Netherlands (collected from http://uwwtd.oieau.fr)

All the UWWTPs of the Netherlands have primary and secondary treatment facility. The primary treatment system works through physical separation and secondary treatment system works through biological treatment. The physical separation is almost same for all the UWWTPs.

Type of technology		Number of Treatment plants	Percentage
Total number of plant(operational)		327	100%
physical separation(primary treatment)		327	100%
	Oxidation bed	2	0.7%
	Aeration tank	61	19%
	Oxidation tank	66	20%
	Oxidation ditch	50	15%
	Carrousels	115	35%

Biological treatment (activated sludge-secondary treatment)	Discontinue systems	2	0.7%
	Parallel installations	14	4%
	Two-stage installations	15	5%
	Compact installations	1	0.3%
	Membrane bioreactors	1	0.3%
Plants with P removal technology (tertiary technology)		298	91%
Plants with N removal technology (tertiary technology)		312	95%

Table 5: Type of technologies used in the UWWTPs of the Netherlands. (Developed by author)

The secondary treatment has minor differences in different UWWTPs. The difference mostly lies in the structure of the oxidation system since most of the secondary treatments follow the activated sludge method. Only one treatment plant uses the membrane bioreactor (MBR) system which is significantly different from the other secondary treatments. Membrane bioreactor is a combination of physical and biological separation where wastewater is treated with aerobic digestion followed by membrane separation (Lares et al., 2018).

Nutrient separation is the basis of tertiary treatment which is also a requirement of UWWTD (UWWTD, 1991). 312 of the 327 plants have Nitrogen removal technology. 298 of these 312 have Phosphorus removal technology as well (Oieau, 2018).

4.1.2 UWWTP for microplastics discharge

To understand the capacity of WWTPs of similar technology, several scientific literature were reviewed. Leslie et al. did a study on 7 UWWTPs of the Netherlands (Leslie, Brandsma, Velzen, & Vethaak, 2017). They found that raw sewage influents, effluents and the sludge of these UWWTPs contained mean microplastics particle concentrations of 68–910 L^{-1}, 51–81 L^{-1} and 510–760 kg^{-1} wet weight (ww), respectively (particle sizes between 10 and 5000 µm). After treatment, the discharge water constitutes a source of microplastics pollution of surface waters, and via fertilizer applications in agriculture, microplastics retained in sewage sludge can be transferred to terrestrial environments. The UWWTPs investigated in the study showed a mean microplastics retention efficiency of 72% in the sewage sludge.

More recent study done by Talvitie, analyzed the UWWTPS of the Netherlands along with Dutch river delta, Amsterdam canals and North Sea sediments (Talvitie, Mikola, Setälä, Heinonen, & Koistinen, 2017). It analyzed the microliter removal at different treatment stages such as mechanical, chemical and biological treatment (activated sludge) and biologically activated filter (BAF). It found that most of the microplastics are removed during pre-treatment and activated sludge treatment stages. The study found that the primary treatment is removing 97% of the microplastics present in the influent water. Secondary treatment (activated sludge) removes (7%-20%) of the remaining microplastics. This raises the overall capacity of the microplastics removal 99%. BAF and other tertiary treatments for nutrients removal have little impact to the microplastics removal capacity of the microplastics. The study looked at the balance analysis of the microplastics and found that more that 20% of the microliter removed from the process can be recycled back with the discharged water. But 80% of the microplastics is contained in the dried sludge.

Earlier, similar study was done by Carr, Lie & Tesoro, 2016 in Southern California, USA. The Study sampled seven tertiary treatment system containing UWWTPs and one secondary treatment containing UWWTP. The secondary treatment was biological oxidation and the tertiary treatment was chlorination and Sulphur Di Oxide application. It checked over 0.189 million litter of effluent at different stages of treatment. It found that the microplastics are mainly removed at the settling and skimming treatment process. These studies indicate that tertiary treatment (nutrient removal step) has no significant impact on microplastics retention.

These studies shows that UWWTPs are removing microplastics from the wastewater in good amount. For a typical UWWTP the range of removal could be (70-99) %. Still the amount of microplastics being released from the UWWTDs could be very harmful for the environment. Murphy, Ewins, Carbonnier & Quinn, 2016 did a study on a UWWTD of Glasgow. The UWWTD had a removal capacity of 98.41%. In this capacity, it releases 65 million pieces of microplastics per year which is a significant amount to cause harm to the environment. Talvitie et al., 2017 also found that the each UWWTP sampled in their study is releasing 1.7×10^6 to 1.4×10^8 microplastics particles per day. 99% of these microplastics beads and particles are expected to form sediment in the ocean floor and cause significant disruption to the plants and animals residing in the ocean floor (Gallo et al., 2018). This indicates the critical positioning of the UWWTPs in the microplastics generation and discharge pathway (presented in figure 7).

4.2 What addition (retrofitting) is needed to treat microplastics at the UWWTP level?

The discussion in section 4.1 clearly explains the capacity of the presently working UWWTPs to remove microplastics from the wastewater. It also explains the need of the UWWTPs to increase the capacity of microplastics removal though they are already removing it to a substantial level. This section discusses the technologies that can efficiently remove microplastics from the wastewater and also discusses the best fit for the UWWTP to increase the capacity of microplastics removal in the future. This way, section 4.2 answers the second sub-question of this study "What addition (retrofitting) is needed to treat microplastics at UWWTP level?"

4.2.1 Which technologies can remove microplastics from the wastewater?

This study analyzes 20 scientific literatures from the University of Twente database network that are published after 2000 and precisely looked at technologies for microplastics or similar contaminants removal from the wastewater[6]. The technologies are shown in table 5 below.

Sl. No.	Removal technology	Short description	Applicable for	Technology type	Remarks
1	Adsorptive material	Chemical adsorption of target inorganic/ organic material	Microplastics	Decentral/ central	Can be used at source and also as a retrofit solution to UWWTP
2	liquid membrane	Wastewater treatment using hollow fiber	Microplastics and other	Decentral	Can be used at source

[6] The 20 scientific literatures are cited in a separate reference list in annex 1 since table 5 presents organized information from those literatures.

		supported liquid membrane	micropollutants		
3	Ozonation	O_3 application in the effluent for digestion of micro/trace pollutants	Micro-pollutants	Central	Can be used at UWWTP as add-on
4	RO/NF	Reverse osmosis and tight nano-filtration membrane application	Antibiotics and microplastics	Central	Can be used as an additional treatment at UWWTP level
5	Dynamic membrane (DM)	DM are made up of non-woven fabric, and woven filter cloth, and stainless-steel mesh with large pore size	Microplastics	Central/ decentral	Can be used at source or as an additional technology at UWWTP level
6	MBR	Membrane based filtration followed by anaerobic digestion	Microplastics and other contaminants	Central	Being applied in the UWWTPs
7	Rapid sand filter (RSF)	Sand filtration with pump based flow	Microplastics and other contaminants	Central	Used for water polishing, can be added in the UWWTP as additional step
8	Dissolved air flotation	Physical separation of micro particles	Microplastics and similar other small particles	Central/ decentral	Primary treatment being practiced in the UWWTPs
9	Heat and Bleach	Physio-chemical separation from return activated sludge (RAS)	Microplastics	Central	Can be used as add-on the UWWTPs

Table 6: Technologies capable of removing microplastics in the UWWTP

4.2.2 Which technology can fit into the presently working UWWTDs as an add-on

The selected technologies in table 5 are technologies that can remove microplastics efficiently. However, close look at those technologies signals that technology 2, 5 and 9 are difficult to apply in UWWTPs. Liquid membrane and dynamic membrane are difficult to use in UWWTP because the passing substrate is water. Heat and bleach is difficult to apply because wastewater is a combination of many other contaminants and this technique can change the composition and may form some active compounds. Technology 1 and 8 are physical separation method and sometimes used as primary treatment technology. Ozonation can be used as potential add-on but it has the capacity to produce chemically active intermediate substances from the other compounds present in the wastewater. Thus, Ozonation will require additional treatment technology for those active intermediates. Thus technology 4, 6 and 7 can be considered as add-ons for UWWTDs in the Netherlands as a shortlist of options to consider.

4.2.3 What is the technical impact of these retrofitting in the forward and backward process?

Section 4.3.2 selected technologies 3, 4, 6 and 7 from table 5. Talvitlie et al., 2017 conducted study on MBR and RSF with disc filter and dissolved air flotation. It found that MBR can remove 99.9% of the microplastics present in the wastewater (from 6.9 to 0.005 MP L-1), rapid sand filter 97% (from 0.7 to 0.02 MP L-1), disc filter 40-98.5% (from 0.5 - 2.0 to 0.03-0.3 MP L-1) and dissolved air flotation 95% (from 2.0 to 0.1 MP L-1). Which clearly depicts that among the four technologies MBR has shown the best performance. RSF's microplastics removal capacity increases to 99.9% if used as additional treatment technology to primary and secondary treatment (Michielssen et al., 2016; Steen, 2018, personal communication).

While study by Roesink et al. from Membrane Science and Technology department of the University of Twente (unpublished research) shows that nanofiltration has equal capacity of MBR to remove microplastics from the wastewater. Study showed that it could remove microplastics at a rate of 99.9%. This clearly shows that from the technical capacity aspect, nanofiltration can be considered as add-on for the UWWTPs (Roesink, 2018, personal communication). A model proposed by research organization Stowa for water factory idea (producing clean water from the

UWWTP) has similarity with these findings though the water factory model hasn't considered microplastics as a contaminant. The model is:

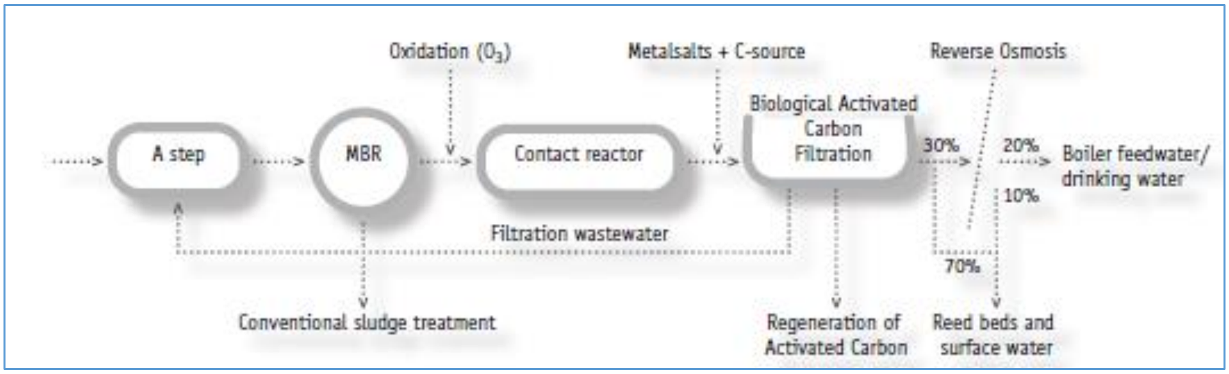

Figure 9: Future UWWTP layout for water factory idea (Stowa, 2010)

The overall analysis of these three technologies depicts a future scenario for microplastics removal. RSF and NF can be used as add-on to the existing UWWTPs. They can remove (97%-99%) of the microplastics that are presently being discharged to the surface water from the UWWTPs after primary and secondary treatment. This will increase the overall microplastics removal capacity of the UWWTPs to 99.9%. Whereas MBR can act as a sole secondary treatment technology with similar microplastics removal capacity (99.9%).

4.2.4 Financial impact of this retrofitting the UWWTD.

This study has looked at technical implication of microplastics removal at UWWTP and necessary policies & regulations for that. Thus, the study hasn't looked at the overall financial impact of upgrading or retrofitting the UWWTDs and limited itself on the financial impact of the upgrading process only. Section 4.2.3 illustrates that MBR, RSF and NF are the three technologies that can efficiently remove the microplastics from the wastewater. Amec Foster Wheeler study looked at the cost needed to include these systems to the conventional UWWTPs. For MBR the cost per plant will be between €111,700 and €1,700,000. For RSF the cost is between €60,000 and €1,100,000. The cost is higher for NF, which is between €300,000 and €1,400,000 (Amec Foster Wheeler, 2017). The calculation included not only the capital expenditure but the operation and maintenance expenditure as well. Considering the cost and ease of operation, RSF is the possible choice because it can be easily added to the UWWTP as an extra step (Kools, 2018 personal communication). Another plus point of the RSF is its capacity to remove other emerging chemical contaminants to a certain extent (Roest, 2018, personal communication; Uterlinde, 2018, personal communication). Most of the UWWTPs of the Netherlands have sufficient space to add extra technologies (Bentvelsen, 2018, personal communication). Converting the UWWTPs to MBR is not an addition rather the UWWTP need to be retrofitted which is little more complicated than adding an extra step. But there is no regulatory standard available on microplastics content in the discharge water. Even more scientific evidence is needed to specify the harmful level of microplastics in the sea water (Kools, personal communication). Without developing standards for that, selecting the appropriate technology to upgrade/retrofit the UWWTPs is difficult.

4.3 Regulations

This section looks at the regulation at EU and Dutch level for wastewater management. It tries to find the answer of the third sub-question of this study "What is the position of the microplastics and other contemporary contaminants in the policy and regulation?" It analyzes the provisions available for new contaminants like the microplastics. The objective of this section is to look at the level of burden from the policy and regulation to upgrade the wastewater management system. At this moment, concern is visible for emerging chemical contaminants removal from the wastewater. This section analyzes the pathway of regulation development for emerging chemical contaminants and tries to figure out the future pathway of regulation development for microplastics removal.

4.3.1 Present regulation in the Netherlands for wastewater management

In 1970, The Netherlands got the Wet Verontreininging oppervlaktewater (WVO) (surface water pollution act). The purpose of the act was the protection and management of surface water specially the ditches, canals, rivers and lakes. Other objectives were to help the drinking water supply, irrigation water supply and better ecological management. This act specifically directed the authority formation for wastewater management. As per the legislative framework there are official bodies of state entitled with the task to treat collected wastewater, sometimes as a province, or as a treatment authority. The industries can purify their own wastewater prior to discharge it into the sewer system together with the domestic wastewater for treatment. The (WVO) act makes it possible to tax the discharge of contaminants which follows the "polluter pays principle (Bressers & Lulofs, 2002). Waste materials that are being taxed as a result of discharge into the sewer are:

- Oxygen consuming components to calculate the levies a unit accounting for the oxygen consuming components is used: the population equivalent (PE); that is the average oxygen consuming components' capacity from the waste produced, within a 24 hour period per person that gets discharged with the wastewater (WVO, 1970, p. 3).
- Other materials (e.g. heavy metals) the "contamination unit" is employed in the Netherlands to account for other compounds. Aside from oxygen consuming components since the 1980s much attention is being increasingly paid to fertilizing compounds, such as phosphates and nitrogen (WVO, 1970, p. 3).

Present regulation at EU for wastewater management

At EU level, three different directives are connected with the wastewater management. One is the Water Framework Directive (WFD) which is the umbrella directive for water management at EU (Keessen, 2018, personal communication). The other two are Urban Waste Water Directive, the Integrated Pollution Prevention and Control Directive/Industrial Emissions Directive. The Urban Waste Water Directive 91/271/ EEC (UWWD) was commissioned in 1991 to protect the surface waters, from the toxic effects of the discharge of urban wastewater. The UWWD precisely focuses the collection, treatment and discharge of municipal wastewater, industrial wastewater discharged to municipal sewers, and some direct industrial wastewater discharges (UWWTD, 1991, p. 6). The UWWD explicitly requires:

- Collection and treatment of all wastewater streams >2000 p.e.,
- Secondary treatment of all discharges from waste streams > 2000 p.e.,
- Advanced treatment for streams >10 000 p.e. discharging to sensitive areas,
- Pre-authorization of all discharges of urban wastewater, from the food-processing industry and industrial discharges into urban wastewater collection systems
- Performance monitoring of treatment plants and receiving waters status
- Sewage sludge disposal and re-use controls
- Treated wastewater re-use whenever it is possible and appropriate.

Integrated Pollution Prevention and Control Act (IPPC) was commissioned in 1996 as Directive 96/61/ECC. The IPPC directive provides a regulatory framework for industrial discharges. Later the Industrial Emissions Directive was compiled to further control the emissions from industrial installations. Another intention was to simplify the permitting, reporting and monitoring requirements of the Directives it. The concept of integrated pollution control was included in the IPCC. The key characteristic of the IPCC is that it includes the best available technology (BATs) based Emission Limit Values (ELVs) in the industrial permitting process (IPCC, 1996). The Water Framework Directive 200/60/EC was adopted in 2000. It is the integrated policy for European water management. Specific goals of the WFD include the protection of surface and groundwater, achieving good status for all water by a set deadline, water management based on river basins, combined approach for emission limit values and quality standards, getting the prices right and getting the citizens involved more closely for good water management.

4.3.2 Position of the new contaminants in the regulation

Upgradation of the wastewater treatment system requires policy and regulation changes that direct the system to be changed. To check the policy and regulation, the three directive and their changes were analyzed. The study found change in the WFD. In August 2013, the Directive 2013/39/EU has published a revised list of priority substances for the European aquatic environments. 12 new substances were identified through a procedure of prioritization based on a risk assessment (RA) methodology with the use of monitoring and modelling data (Europa, 2018). The study collected data for a period of 4 years to finalize the list. Of the 12 new substances, emerging chemical contaminants and some biocides are included. The Commission has established a watch list of substances for which EU-wide monitoring data will be collected. The list includes diclofenac, beta-estradiol (E2) and 17-alpha-ethinylestradiol (EE2), for them the directive has foreseen a monitoring obligation. The objective is to gather data to the appropriate measures to address the risk to surface waters posed by those substances. Furthermore, on the basis of the outcome of a study on the risks posed by pharmaceutical products, the commission will develop a strategic approach to pollution of water by pharmaceutical substances (Carere, Polesello, Kase, & Gawlik, 2015).

The list and the joined activities are connected with the EU Marine Strategy Framework Directive (MSFD). Because the MSFD requires that, the member states should run a strategy contaminants that may have polluting effects in marine regions. The Watch list is supporting that task by using an integrated nomenclature for the unambiguous identification of contaminants (Europa, 2015).

However, no change has been made so far on the UWWTD. Thus, no regulation push is there to the UWWTPs to upgrade the removal technology for the new contaminants (Keessen, 2018, personal communication).

4.3.3 Position of the microplastics in the regulation

Microplastics pollution and its environmental effects have achieved attention from different sectors. But limited attention has been translated into regulation in order to limit and prevent environmental exposure and hazards of macro- and microplastics. Most important regulations that showed sensitivity towards microplastics are: the EU chemical Regulation, the Packaging and Packaging Waste Directive, the Waste Framework Directive and the Directive on the Landfill of Waste. But no change has been made on the UWWTD so far to target the microplastics (Keessen, 2018, personal communication). Although one of the objectives of the UWWTD is to ensure the protection of aquatic life and the environment (UWWTD, 1991). Steensgaard et al., 2017 carried out a study on the EU regulations for plastics emission management. It looked at MSFD and WFD as well. In the WFD microplastics is not included yet. The MSFD has looked into the microplastics issue and defined 11 descriptors to achieve "Good Environmental Status" Descriptor 10 identifies marine litter as a harmful agent to the coastal and marine environment. But the term "harm" has not been defined. Although Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) has already documented 250 species that are affected by marine plastic litter (Steensgaard et al., 2017).

4.3.4 Future change in the regulation for microplastics

The future course of tackling microplastics in the water is not yet set. But the appeared approaches by the EU indicate that source control will be prioritized over treatment at the end. Section 4.2.3 depicted that the MSFD is focusing on preventing marine litter to enter to the ocean. In January, 2018 EU published its Plastic Strategy. Its broad objective is to ensure all plastic packaging to be recyclable by 2030 and consumption of single-use plastics is decreased (Chemicalwatch, 2018). Earlier in 2017, EU commissioned a study on “Intentionally added microplastics in products”. Peter Fisk Associates carried out the study. As a solution to the microplastics problem, it evaluated the option of upgrading the UWWTPs. It counted that the upgrading will cost several billion euro in the EU to upgrade all the UWWTPs. They also indicated that upgrading the UWWTPs would not be consistent with the principle of controlling pollution at source (Amec Foster Wheeler, 2017). But another study done by FIDRA SCIO has different opinion. It considered UWWTPs as the final barrier for the environment. It concluded that source control should be the basic strategy to deal with microplastics but wastewater treatment should be made as effective as possible. Thus, it recommended the EU for upgrading the UWWTD for effective removal of microplastics at UWWTP level. The WFD and UWWTD are currently being evaluated in accordance with the European Commission’s REFIT programme (Regulatory Fitness and Performance Programme). The WFD is being evaluated along with the EQS (Environmental Quality Standard) Directive, the Groundwater Directive and the Floods Directive. The evaluation will assess the effectiveness, efficiency, relevance, coherence and EU-added value of the legislation. Consideration will be given to whether, among other things, the directives address the "right” pollutants. A public consultation will be done as a part of that. The outcomes of the evaluation, which is also being supported by a study, will affect the Commission's decision on whether and if relevant, how, to propose revising the legislation. Revision could include changes to the list of priority substances (EDCC, 2018, personal communication).

In the evaluation of the UWWTD, the European Commission will assess whether the directive has reached its objective of protecting the environment from the adverse effect of urban wastewater discharges and discharges from certain industrial sectors over the past decades. In this context the commission will also assess whether there are gaps in the directive, for example as regards microplastics and pharmaceuticals. The recently published plastics strategy included a follow-up action to assess the effectiveness of UWWTPs as regards microplastics capture and removal. The findings from the evaluation will inform the Commission’s decision on whether to revise the directive (EDCC, 2018, personal communication).

However, a country can take initiative to make its regulations stringent without waiting for the upgradation of the EU regulation (Keessen, 2018, personal communication). For emerging contaminants like antibiotics, Switzerland's has already made regulation for stringent wastewater treatment. The new law passed in 2016 to remove 12 selected emerging contaminants by 80% from the water. They will do it by upgrading 100 large UWWTP in next 25 years (admin, 2017). German Federal Environment Agency (UBA) has also decided to add a fourth step in the UWWTPs of the country to battle the micropollutants (Chemicalwatch, 2018). Both the countries are applying Ozonation, granular activated carbon (GAC) and powder activated carbon (PAC) dosing as the fourth step. These technologies have been used in laboratory scale in the Netherlands and practically being applied in Switzerland and Germany as fourth treatment step. These add-ons can work with both conventional and newly developed process. For instance, the GAC or PAC can be used with Nereda technology which is replacing the conventional activated sludge based biological treatment. Nereda has established such combined system in the Switzerland but not yet in the Netherlands (Giesen, 2018, personal communication). These indicate the technical and legislative ease of adding fourth treatment step in the Netherlands. However, some plans were developed in the Netherlands for future wastewater management. Stowa published a report on Dutch WWTP road mapping for 2030 (Stowa, 2010). This report has categorized the future UWWTP system into three streams. They are energy factory, resource factory and water factory. This report has proposed different technology models for these three streams as well. The water factory model considered the option of getting full treated water from the WWTP for reusing. The report has not considered microplastics as contaminant but the proposed technology model for future WWTP considered reverse osmosis as final step of treatment which is capable of removing microplastics at a rate of 99.99% from the wastewater. Uni Van Waterschappen published a vision brochure on that roadmap in 2013 (Uni Van Waterschappen, 2013). But bringing it into practice is yet far from reality. Although there is pressure from different group of activists to the Dutch government to take immediate steps to control the microplastics. Maria Westerbos, the director of the Plastic Soup Foundation in her article "We eten drinken en ademen plastic" published in the NRC on 20 June, 2018 clearly mentioned that following the precautionary principle, the Dutch government should take the lead to fight against the plastic tsunami (NRC, 2018). Before upgrading the UWWTPs, bringing the water authorities into one platform is necessary. Since they are sovereign bodies, it is sometimes difficult to reach into consensus. There are other issues like rainwater management and pesticide treatment in the wastewater are more prioritized by the Uni Van Waterschappen at this moment (Bentvelsen, 2018, personal communication).

4.4 Decentralized treatment

This section attempts to find the answer of the question "To what extent can the decentralized technology help better to treat microplastics." To find the answer, the researcher looked at the inventory of the literature to find the source and route of transmission of microplastics in the Netherlands and commonly in the Europe. It also looked at available decentral technologies and the possibility of them to efficiently capture microplastics at source.

4.4.1 Source and route of transmission of microplastics in the system (schematic presentation)

Section 4.2 discusses the "end of the pipe" solution to deal with the microplastics discharge to the surface water. However, the issue can be dealt with two other ways. One is definitely the prevention of microplastics emission from different products. The other one is capturing the microplastics at the point of emission (capturing at source). This is the key to answer the fourth sub-question of this study "To what extent can the decentralized technology help better to treat this contaminant?" The prevention issue is not inside the boundary of this study but the capturing at source is an important point to answer the fourth sub-question. Section 4.4 discusses these the microplastics sources, their pathway and available decentralized technologies to answer the fourth sub-question.

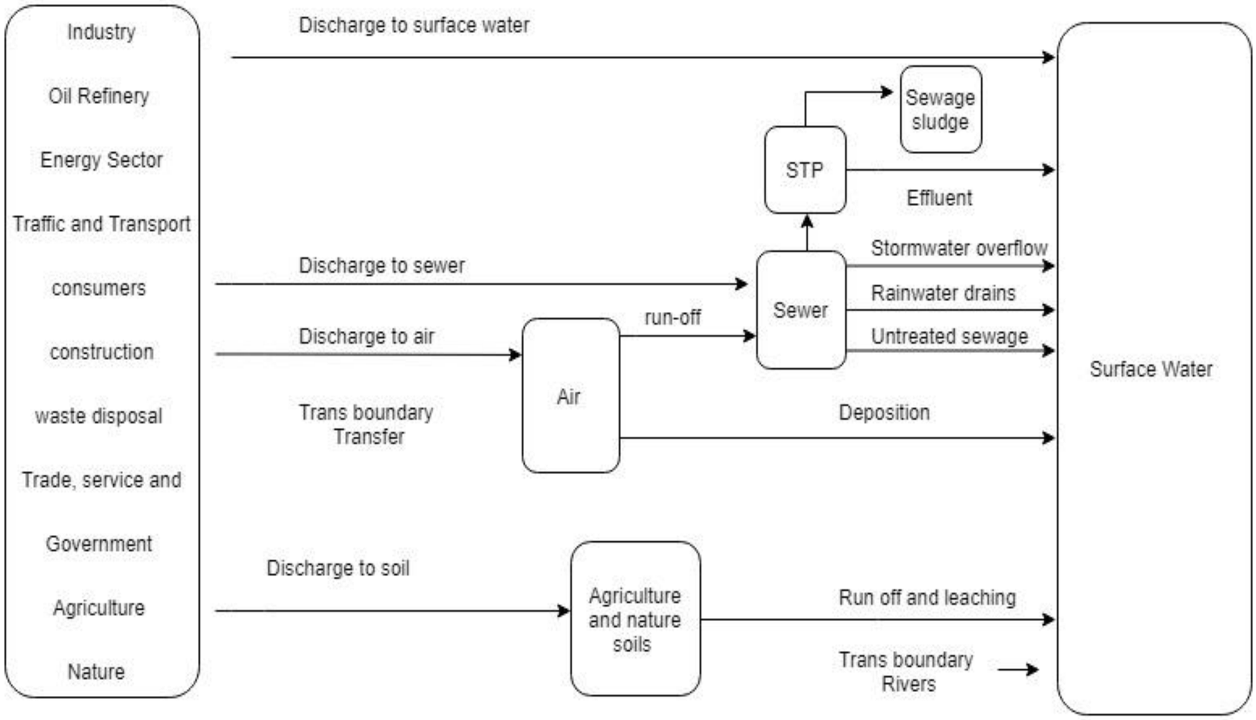

Figure 10: Sources and route of transmission of the microplastics (RIVM, 2014)

Fig 8 shows that microplastics has different sources. Some of them are discrete and diverse whereas some of them are well organized and easy to add technology/process to capture microplastics at point of release.

A study was commissioned by RIVM (Netherlands National Institute for Public Health and the Environment) on microplastics, where Verschoor, Poorter, Roex, & Bellert, 2014 identified different sources of microplastics and their route of transmission to the surface water. A study by Eriksen et al., 2017 has done similar analysis with updated information and scientific knowledge. Both study identifies the general consumers along with mainstream industries as the key sources of microplastics generation. The main stream industries include the oil refinery, energy sector, transport industry, etc. Consumer products includes the personal care products, cosmetics, etc. Some less focused sectors are also contributing to microplastics generation such as waste disposal, agriculture and some natural process.

4.4.2 Amount of microplastics generated from macro sources compared to micro sources

Microplastics capture at sources depends on the sources and their rate of contribution to the generation process. Thus, sources of microplastics and the rate of microplastics generation by different sources were analyzed by different researchers. The study done by Eunomia applied a basic extrapolation for European primary microplastics release (Eunomia, 2016). As per that the primary microplastics releases are between 0.5 and 1.41 million MT/year. Among them, more than one-third is coming from synthetic textiles (35%). Tires holds the second position with 28%. Although this considers the synthetic rubbers and excludes the natural rubber. IUCN, 2017 report estimated that inclusion of natural rubber would give it the top position in microplastics release. City dust holds the third position with 24%. It is not a single source rather a combination of different sources. As it is difficult to detect each source, it is also difficult to detect their route of transmission as well.

4.4.3 Source control Vs wastewater treatment

It is an issue of debate at this moment, what is the ideal strategy to deal with the microplastics problem, controlling at source or targeting the end products? Amec Foster Wheeler study (A study commissioned by the EU to develop its plastic strategy) preferred the source control strategy as better option. It is very logical to prefer the source control strategy since it helps to get rid of the problem itself whereas microplastics removal from the wastewater is only a temporary solution since the microplastics is going to remain in the sludge. The changes in the MSFD and the new EU "Plastic Strategy" indicate the preference of the policy makers for source control. However, that cannot nullify the need of microplastics removal from the wastewater as a temporary solution. The emerging chemical contaminants case clearly depicts that it takes a long time for a contaminant to enter into the regulation from the discussion stage. A study done by Eriksen, identified the possible steps need to be taken to deal with the microplastics issue in a holistic way (Eriksen et al., 2017). The measures proposed in that study are: Removing microplastics from the products, regulation for plastic pellet handling, improvement of containment and recovery system for industrial abrasives, biodegradable plastic use for agricultural purposes, road surface change for tire dust control, enforcement of fines for littering, Laundry was with to-lead machines and use of single-fiber textiles, improved waste management for UV and chemically degraded waste products; and valorization of waste products. The measures clearly show that they require regulatory, economical, societal and behavioral changes.

Till achieving those changes, UWWTPs will act as the last line of defense to prevent microplastics from exposing to the environment.

5 Discussion and Conclusion

With the passage of time, agricultural and industrial processes are changing. These changes are influencing the life style of human being as well. Due to that new contaminants are entering into the water and wastewater stream. Depending on the magnitude of the problem, some contaminants are getting the attention of the researchers and media whereas some are getting less priority. Some contaminants like the pesticides, antibiotics, hormones are in the discussion for last 3 decades and several researches have been done on them. Still, strong regulation for upgrading the wastewater treatment system for these contaminants is not visible. In this situation, this study has looked into the case of microplastics which is a relatively new contaminant compare to the ones mentioned above. Although it is new but its adverse effect on the marine environment has been established by different researches. Thus, it is necessary to find out scientific evidence on the standard for its safe emission rate and make policy & regulation for that. Removal of microplastics from the wastewater is a part of the overall microplastics management. This study has looked into the UWWTPs of the Netherlands, their capacity to remove microplastics from the wastewater and presently available regulations for that. The study was a situation analysis thus the attempt has focused on analyzing the process and its associated policies & regulations. The study has come up with a couple of findings. The study was built on four questions. The first two questions were about the technology analysis of the Dutch UWWTPs and their capacity of microplastics removal. The technology analysis of the UWWTPs reveals that the operational primary treatment is removing a significant amount of microplastics, secondary treatment also contributes but tertiary treatment has no or little contribution to microplastics removal. The UWWTPs in the Netherlands can remove 70% to 99% of the microplastics present in the influent water. But the scientific evidences suggest that the remaining amount of the microplastics present in the UWWTP discharge is capable enough to affect the marine environment. Different studies found that, in this rate of removal, one UWWTP can discharge more than 65 million particles of microplastics in a year and 99% of these particle form sediments in the ocean floor. This sedimentation has significant impact on the marine ecosystem. Upgrading the UWWTPs can increase the removal capacity of the microplastics to 99.9% which will decrease the particle discharge from 65 million to 6 million. This reduction can substantially improve the marine eco-system. Thus, upgradation of the UWWTPs is necessary. The study analyzes potential technologies for microplastics and shortlists MBR, RSF and NF for retrofitting the UWWTPs. Their suitability to fit into the presently operational treatment technologies reveals the potential of the Dutch UWWTPs to be upgraded. Most of the Dutch UWWTPs are located outside the city areas with available space. That is also strengthening the potential of them for upgradation.

For the upgradation, policy initiative is required. The third question of this study was about position of microplastics in the policy and required changes in the regulation for better removal of it in the UWWTPs. Policy level changes have been seen at EU level for source control of the microplastics. Modification of the MSFD and development of a new EU Plastic Strategy are examples of this. But for wastewater treatment, no visible change in the regulation is observed. Along with the UWWTD, no change for microplastics management has been seen in the WFD as well. This study founds a loophole there. The directive for industrial management (IPCC) follows the BAT principle. But the UWWTD is not following the BAT principle. This is a factor that hindering the change of the UWWTD for upgrading the UWWTPs.

At country (the Netherlands) level, the observation is same. No regulation change for microplastics removal at UWWTP is yet in progress. However, a roadmap for wastewater treatment has been developed by Uni Van Waterschappen. The roadmap proposed different technology combinations for different types of influent water. For highly contaminated water, it proposes combination of technologies like MBR, BAF and RO. This can increase the rate of microplastics removal to 99.9%. Although no visible progress has been seen so far to implement that model, but the presence of the roadmap indicates the concern of the authority on the contemporary contaminants and also can act as a lighthouse for future progress.

This study finds that some progress has been achieved to bring the emerging chemical contaminants removal into regulation. Switzerland and Germany spontaneously changed their UWWTP regulation to treat some of these emerging contaminants and EU has also shown their sensitivity by including some of these contaminants into the watch list. That indicates possible change in the UWWTD for these contaminants removal in near future. The microplastics issue is not yet connected with the movement for emerging chemical contaminants management. But if the UWWTPs are upgraded only for the emerging chemical contaminants, then another upgradation might be required for the microplastics. It will have technical and economic consequences as well. Thus, consideration of microplastics removal together with the emerging chemical contaminants removal can be an efficient approach for long term sustainability of the UWWTPs.

The fourth question of the study was about decentralized removal of microplastics and its benefit over centralized removal at the UWWTPs. Decentralized technologies can be an alternative to upgrading the UWWTPs by capturing contaminants like the microplastics at the point of generation. Such technology for pharmaceutical residues removal has been proven effective. But the sources of microplastics are diverse and spread over the whole society. Thus, decentralized technology from microplastics removal is not an effective solution. For the long run, source control of microplastics has been considered as the best solution. EU has already published their strategy to enhance the use of biodegradable plastics and limit the use of products that release microplastics. But acquiring full success through this strategy will take time since it requires behavioral changes as well. Till then, UWWTPs remain as the last line of defense to protect the marine environment from microplastics. Overall, this study reveals the present potential of the Dutch UWWTPs for microplastics removal and also reveals the technical and policy requirement to improve the removal capacity.

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Annex 1

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Annex 2

Interview Transcript 1

Interviewee:

Dr. Stefan Kools

Team leader and project manager

KWR

D.D: Thanks for giving me the time to interview you. The reason to interview you because my thesis topic is how we can upgrade the wastewater treatment plants in the Netherlands for removal of antibiotics and microplastics. Of course I tried to reach you because of your expertise in the field of microplastics. But I would like to start with your general opinion about WWTPs in Netherlands, how they're working at this time, what's your perception.

S.K: There's are two ways of approaching it. One is dealing with the Dutch perspective [which is quite advanced, e.g. a high level of household connections], and then the other perspective where one may say it can always be better than current practice. If you look at the European or the global perspective, I believe in general, sewage treatment plants in The Netherlands are quite well organized. Most of the water which is used from households is treated well according to its basic principle. The basic principle is "Removing nutrients, reducing Nitrogen and Phosphorous" and some priority compounds. So the main goal is meeting standards.

The other story is that more and more, other compounds are getting attention [compounds of emerging concern]. So, while the current practice is of reducing nutrients, treatment of micropollutants, antibiotics or microplastics it's a positive side effect, not the main aim. To my knowledge not many sewage treatment plants are specifically designed for removing microplastics but maybe upgraded or piloted towards the extend removal of micro pollutants. Mind that upgrading STPs is a big debate at the moment (due to high costs involved).

This must also be the reason why you are doing this interview.

Talking about the governance in the Netherlands, I think it's quite OK organized via the water boards because that makes it clear who's responsible and from this how it is paid for.

Having said that, the impact of industrial wastewater treatment plants is less known and recent examples (as the pyrazole case) have shown that this system needs some tweaking. Here, the main attention is paid to the way governments take care of 'discharge licenses'. Currently, a license for discharge from a complicated industrial process may involve only rather simple or bulk parameters that are asked for (e.g. in monitoring). So, these factories may not be licensed towards production of harmful chemicals. For example we know that there are some factories are producing harmful chemical Y but in the license this harmful chemical Y is not licensed, thus you don't have to measure it. Also, the fact that downstream of industry, drinking water production makes use of the same river is underlining the urgency of meeting stringent standards. The problem is that for many chemicals, no standards (safety thresholds) exist, making risk assessment quite difficult.

D.D: So if I mean what I have got your perception, if we consider the technical aspects technical aspects up in the field is there a scope of improvement I guess

S.K: Yes, next to technical aspects, it's a governance issue as well. In my opinion there are two schools. One is following the 'precautionary principle' and the other one is to follow guidelines and focus on existing safety levels. So in case no safety level exist, nothing is exceeded, no problem exists. What comes firsts? The chicken or the egg? So I would rather hope that people do not wait for the environmental standard and then comply with it but take precautionary steps. The latter is very common in Dutch drinking water practice by the way.

D.D: Of course from the perspective of the conditions, it makes sense that they will prefer the second thought but they will break up with the regulation. But what about organizations and academics here what they're thinking about the new contaminants:

S.K: As a scientist I would say we like to give the scientific evidence as such and leave others to decide. For example, I am very reluctant to speak about 'problems', for example on the topic microplastics (I rather call it an 'issue'). For example, we may to want to discuss only the effect of microplastics and micropollutants but also the direction in which all concentration are developing. Act before all is clear, again: the precautionary principle.

As a researcher it's a wonderful time because you have all these big questions getting a lot attention (climate change, micropollutants, antibiotic resistance). Also in the latter, question arise whether one should upgrade sewage treatment plants to control the resistant genes or control the substances themselves. As I am trained in 'the substances' rather than genes my opinion is that to control the resistance, one should focus on the emissions of the substances first.

D.D: It's more like a precautionary approach you are actually proposing…

S.K: Yes. One may act when you already know something in which direction things develop (so the direction is more important than the actual level of impact for taking measures).

D.D: But I mean, can we put one hypothesis in that debate because we think that we are very concerned about the antibiotics because of amr whereas the effect of microplastics are subtle

S.K: I am concerned about microplastics. I'm concerned that it ends up in the ocean. Yes. Actually I'm more concerned about what ends up in the ocean floor. Some plastics may float as an island (the pastic soup). But plastics on the sea floor will never be removed by any ocean cleanup project. So yes I am concerned. To compare different issues is quite difficult as they have many dimensions but as such, plastics seem to be a more ecological problem rather than AMR (yet). But, in my opinion, all ecological problems become human problems in the end.

D.D: Yes I agree that it has a different dimension. So you have already told me that there was only a few treatment plan in Netherlands that are removing microplastics.

S.K: Yes. Floating plastics may easily stay on the surface and will walk through the suits. If it has the tendency to settle and end up in the sewage sludge, as research shows. Scientist now start to model the spread of plastics also based on the density of particle size.

D.D: It's because this morning I had one discussion with one guy from the water authority Michael Bentvelsen. Also I was actually asking the same question how the WWTPs can be upgraded to manage this problem. Actually what I have found exactly the way you have explained if they were following the natural processes they are trapping a certain amount of plastic but any dedicated technique to grab these is not present

S.K: Membranes may be applied to remove plastics, yes. But it is not many times applied for wastewater treatment as far as I know.

D.D: I was actually coming to talk about that technique if you have just mentioned that membrane technology which can grab the microplastics but is it feasible at this moment to use that at WWTP level?

S.K: No, it don't specifically target microplastics. And especially when it comes out the wastewater and it will be complicated and very expensive also. I find it understandable that the water authority is more on source control.

D.D: Exactly and they articulate what they were actually trying to frankly explain to me what kind of mitigation measures, can be taken how the building activities, can be taken which is very good. But from the researches point of view, it is pretty evident that microplastics is in the water and wastewater treatment plants are kind of acting like source to expose this to environment? Thus some responsibility goes to those WWTPs right?

S.K: Yes, I think they see it but what is the value that we should achieve? What is the efficiency that we could achieve? What is the benchmark, since microplastics are very fuzzy.

D.D. If we can use Nano filtration, that can catch the microplastics. If we use RO that can catch the other micro particles of water as well. So in that case from the ground of feasibility, it is pretty evident that reverse osmosis shouldn’t be used as a means of microplastics removal. But you mentioned the combination of techniques. If we consider that or think about a combination of techniques how would you like to be designed that?

S.K: I know how it should not be designed (laughing). I mean in a perfect world we would be able to see the best from the good in. So in my, I've been writing a report about the pros and also the cons from advanced oxidation. So it decreases toxicity, but we don’t know what compounds may form and these compounds are we lack detection methods for polar compounds. This is why ozonation needs also activated carbon behind it. So it's an extra safeguard to have an activated carbon behind it. So learning from the experience of being used in drinking water production I would say this is advice for the wastewater as well. To have ultrafiltration or nanofiltration or any ceramic or whatever high sense filtration techniques, there is still the issue of brine and in which you check all the organic to me and maybe also some essentials like the minerals. So in a large scale wastewater treatment plant, I would say this is very difficult to build because you end up with a lot of solid waste and you have to deal with that and most probably it will contain all kinds of nasty things, so you have to treat basically as contaminated waste thing. So you end up from one problem to another.

D.D: That also implies that applying NF or RO is actually going to cause a little more of a problem, right. But if we just consider the combination you have proposed, ozonation then activate carbon application.

Can we combine these two techniques to presently running wwtps because a regular one following the primary and secondary treatment which is physical separation then aerobic or anaerobic digestion?

S.K: I think it's done in pilots in Leiden even across plants in Germany and Switzerland.

D.D: So, I mean if we think that of course not all there all the 327 plants. Can we propose any kind of pilot project for the Netherlands?

S.K I mean our research and other research have clearly shown which plants have the highest impact. It's also done for pharmaceuticals recently. We have done a similar study in 2015 using a previous version of the water explorer, we recently published a paper on the same approach on industrial wastewater. So identifying which one that suits most likely to have an effect on the receiving water I think, we have the tools to identify them. Whether they apply your system or not, that is a political choice.

D.D: what about the microplastics in the drinking water? For instance, the report published in the Guardian.

S.K: It was not the Guardian who published the report. It was the Guardian who cited the report. This is basically why I am disturbed by the news item, because the moment the guardian cited this research, it got some spotlight and also a stamp of quality, but if you look at it from a scientific view, the research has some faults, although they did good work but it didn't proof that it was the drinking water which contained the plastics, it found plastics in water. I also emailed the author, why did you target drinking water, and they admitted, they didn't want to target drinking water, they wanted to target plastics, that it is everywhere. That is what it has proven but the sources are not clear. Here it was suggested that the drinking water was a major pathway of that. At this moment we, are doing research with students, what kind of criteria you would select to judge this papers. What kind of control they used. We can use glove hood control or fume hood and let's see how it compares. That is quite interesting. Contamination is quite likely. I interrupted you while talking about the Guardian. But this is interesting that the Guardian said, hey this is a big thing, that is how internet works.

D.D: But looking more into policy, how do you suggest or prescribe to change the policy to deal with microplastics in the future? The EU or the Dutch policy for the emerging contaminants, do you think they are ok or they need any change?

S.K: I see in the European Parliament, everybody is quite willing, I am an optimistic person and I would say it's really good. Because the intention is to really do something. The skeptical part, the research always has this part, the mitigation efforts are the most wanted, it is little bit symbolic to target small household plastic items, that is in one side and not targeting t the big industrial sources who are little bit difficult to target, I don't know, but they do exist too, dye, paints, single use plastics which is not going to be regulated, the big discussion in the Netherlands, there should be refund system for the plastic bottles, for example, makes me very skeptical. We the Dutch government and some other governments tend to not regulate as much as possible?

D.D: is that because of the preference for industrial and economic proliferation?

S.K: Well, I don't know!!! Obviously the easy answer is yes, there is belief that if you can provide big financial incentives, the market will change itself. And it works for quite a while. And it is true that if you ask this sector to organize itself, they will likely, that the sector is quite willing to adopt these measures. There should be they advanced steps. One should be always cautious about, they will not cut themselves.

D.D: Apart from the political issues, do you scientists have enough data at this moment to propose the politicians to set an emission or discharge standard for microplastics?

S.K: On both fields, I would say, you have never enough, but for the microplastics it is very hard to get a standard. Plastic is really diverse, but I am very happy that at some point there is definition for what microplastics are quite adopted. There is no lower limit, and also no definition for where dose the nanoplastics end and where the molecules begins.

D.D: there are some advancements, in 2015, EU published a watch list of 10 contaminants 6 antibiotics were there, for monitoring?

S.K: Right, that was for monitoring no threshold limit was there.

D.D: But we were saying that at least for antibiotics, at least we have some science to propose some standard like that, but for microplastics we are yet not in a state to propose something?

S.K: Yes, that’s what I am saying. I would like to be proven wrong,

D.D: In that case what’s your suggestion for the future research on microplastics, what should be the ideal next step?

S.K: I think there are lot of evidence known, that plastics is everywhere, I think there is lot of information ready on sources, So my advice would be, make that analysis, like I just said, try to think of all the possible sources and also try list all the possible actions and I am pretty sure that some of them are easy to take. This is the general flow of action from the science which I see in many cases, in which I believe there is a momentum, because the European parliament and other people are talking about it, antibiotics, I am not sure about it. There are some advancements on safety limits of antibiotics by some Swedish scientists, I can send you a link if you want.

D.D: That would be great. And thank you for sharing all the information and your feeling in that issue. I will make a transcript out of the audio and send it to you for check. If you think that’s ok and give you your consent to use that my thesis only then I will use it.

S.K: Good, I will love to see that. After having my consent use it however you wish in your thesis because that’s how research works, at least that’s how it should be.

DD: Thank you.

Interview Transcript 2

Interviewee:
Michaël Bentvelsen
Policy Officer International
Union of Waterboard (Unie Van Waterschappen)

DD: I would like to start with knowing more about your general impression about the wastewater treatment plants of the Netherlands. How it is doing at this moment?

MB: Well, I think, in general we are doing fine according to the standards we have at this moment. The Netherlands is one of the few countries that is complying with the regulation of the European Union's Urban Wastewater Directive. So, we have more or less complete removal of BOD, COD, nutrients that we have fairly good removal like N and P. So I think according to the standards we have set for ourselves in the past, we are doing very well for modern range of treatment plants, but of course there are new developments, you are familiar with the water framework directive. We see that, locally, recently there is, we have seen there must be an extra effort to remove nutrients. And of course we are discussing now about micro pollutants, from pharmaceutical industries, microplastics. I this these are our concerns. And also sewer overflows. You know, we have a very flat country, while during heavy rainfall. This is manageable, but in the long run, we need to do something for it because they are causing locally some problems. I think that could be better as well. They are very costly, we have invest in the sewer system itself. It is very hard to do that in one, so we are doing that step by step. For the coming time, overflows and micro pollutants are our concern, sometime little bit extra removal of nutrients of course. One other recent development is that, since we see that climate is changing, we expect more periods of drought in the Netherlands, the effluents for instance from irrigation, there is European regulation is on way, for minimum level for pathogens, for water reuse in irrigation, that could be one development that we are more and more closing the cycle of water, for our effluents directly to the field. So that's actually, new development in the procedure.

DD: Thanks you, I will ask more technical questions about the micro pollutants, but since you have raised the point, struggling with the overflow of the sewers?

MB: There are housing areas, with combined sewers, but new houses with separated sewers. When somebody is working on the ground, and do wrong connections, there is also some problem. We are thinking about, what is the ideal situation here. In the old towns, there are frequently overflows, this is not a big problem, because nobody is going to swim there, but it is some pollution and we like to see better.

DD: If you consider that from the public perspective this is a nuisance but not a big problem. But is it commercially and economically feasible to treat the rainwater that is going to the WWTPs most of which is almost clean?

MB: There is an economic optimum I think when you consider the pick flow, the dry weather flow always treated, the cost are very high, so we always have to keep a certain gap, also in the transport system itself, but also in the treatment plant. Probably the most limiting system is the collecting sewer itself, because we cannot make the pipes wider and wider, if we really have very intensive rainfalls like yesterday, there always be overflow, but it is considered as small that that we have control over now. Basically you would like to have a separate sewer, for infiltration to the ground or irrigation, basically it is clean. Historically it has grown like this. In the old times, when nobody cared so much, so it's gradually developed. At this moment the problems that our drinking water industry is facing are the micro pollutants, and organic material,

DD: What about the micro pollutants, or more precisely the emerging contaminants, what about their presence in the wastewater stream of the Netherlands?

MB: It's a difficult problem, we have asked our national institute of health to make a report whether this a problem or not and they said it is a reason for concern which is a bit between yes and no, a bit diplomatic, they made an inventory of all the measurements and we see that many of these pharmaceuticals are below scientific toxicity levels, because there is no legal standard. Thus we have to go with scientific standard. Most of them in our surface water are below standard, diclofenac and some other are sometimes higher, they said there is no acute problem there, but this mixture of substances are relatively low concentrations, not from pharmaceuticals, but coming from other products, we don't know exactly, how they are affecting the ecosystem. But we just can't leave the problem alone, should do something. The drinking water industry and our ministry, we jointly took action, in terms of research to getting to know the problem better. We did a study on removal techniques. In Germany, they are little bit ahead of us. They are implementing some removal techniques, in some treatment plants. We are now developing some instruments like we call it bioassays or effect based monitoring, which not about analyzing all the substances, but we try to assess the whole mixture of substance in water, their activities and other metabolic functions. We hope this instrument can be of use, to assess more objectively the safe level of micro pollutants and what is not safe. But sometimes we are talking about nanograms. As the analysis techniqies in the laboratories are getting better and better all the time, there is always has to be a certain level that is ok now. Our treatment plants are removing 50%-60% of these micro pollutants now, if we do better may be it will reach 90%, will that be enough, or should we need to reach 99%, would that be enough, so nobody knows where the cut off value should be. So that's also a point in the coming years need to assess. Evaluating the cost and also need to check the sustainability of all those new techniques like UV or ozone or activated carbon, they are sustainable on energy consumption or so on, so we also want to know the cost in terms of money, and energy and so on and what are the benefits, so what we try to do, there is some money from the government, 80-90 million euros to start a lot of pilot plants and what we want is the specific sites, specially those treatment plants that are discharging to relatively small rivers, there are areas where 40% or 30% of the water in the river are effluents, if we can improve the water then we will be able to see if there are improvement in the ecosystem as well, the insects and the animals are betting better. That's what we do and not too quick and not jump to big investments and see what we can get. That's our strategy at this moment. Getting more knowledge on the impacts of these micro pollutants, developing technology and see how argent the problem is. And other issue of the technology is we want to warn the society as a whole, that every chemical you use actually ended up in our wastewater, so for certain categories of chemicals, you won't want them in the wastewater at all. Also can we just be little more careful producing these substances or not. Of course for pharmaceuticals it is hard because people need the drug but even there are new perspectives, we think, we hope, we can be able to reduce the production of pharmaceuticals but that is of course very long perspective, and that is very difficult because if you are sick, your family wants you be cured. We realize that. So, that's more or less our strategy. I think that is shared with the drinking water industry and with the departments of Government and we are operating the treatment plants thinking about big investment schemes. There are people in the government think that stop these researches and just do it, you know, but we are a bit careful because we have to explain why these extra costs and we are more close the field and we are more practical. It is easy to say, all treatment plants should be adapted to extra treatment schemes but they are costly of course. So there are some differences but mainly we are going in the same directions.

DD: so we can say that you are at this moment very much concerned about the micro pollutants?

MB: Ya, very much concerned, but it's not the top priority, because what we see, we think, the pesticides the plant protection products, do have more impacts on the water quality and the ecosystem as a whole, may be you have read the articles that the insects are decreasing, that is our priority at this moment, and the second one is general impact in the agriculture sector, but the pharmaceuticals are our concern but on the top priority.

DD: Yes, I can understand, in the Netherlands, agriculture is the big economic sector, so that's make sense, but you have also explained very well that the micro pollutants are also in the list. You have also explained the strategy of yours very well, which is very realistic. But I would like to know, you have just mentioned that Germany and Switzerland are a bit more advanced in that field. Is that because the problem is acute in those two countries.

MB: well, I don't know for sure. In Switzerland, they have many pharmaceuticals. And they have so many mountains there. Traditionally the water quality is very high. And they don't have any other problem with water. So at this moment the pharmaceuticals could be the most important issue, also they are trying to protect their pharmaceutical industry a bit, so that's also a point. And they are the richest country in the world, so they can have few cups of coffee less, and they can solve the whole problem. And Germany is also relatively wealthy country although I think there is not much differences with the Netherlands. But I think why there are a bit ahead of us, it's part of the culture, traditionally they are very efficient people, if there is a problem they solve it. The country of engineers, the country of very practical people. And in the Netherlands, I think our culture is, you know, it doesn't have to be 100% clean I think it is little bit part of our perception as well. We have now for 10 years, the government from the right wing, which is very much focused on economic growth, and we still have to struggle in the Netherlands with the environmental issues, the agenda, the airport should grow and grow, Schiphol, you have been there, but it's so big and everybody is complaining about the noise and sound pollution, and that's typically Dutch, we want everything you know, economic growth and in that case we are very careful about spending our money on environment, but on the other hand we are relatively ahead of many other countries in the Europe.

DD: Now if I want to turn our discussion to the technology part, what do you think, what kind of modifications can be done the WWTPs for these kind of contaminates?

MB: Ya, we hope to develop new technologies that are efficient and not require high energy, may be biological removal at the moment, no view on that, so may be activated carbon and ozone treatment. I think those are the two common techniques that are also being used in the Germany and Switzerland. When you use ozone, there is chance that you might have intermediate substance, half degraded and may be potentially very active again, but the Germans have shown that it can work and also with activated carbon, can be a good extra treatment step, and we also have this new technology, not so new actually, powder activated carbon, can be used in activated sludge the Paques project. So we have these technologies and also have intention to pilot them in demonstration scale, and see what cost are what are the effective doses, what is the impact on the effluent, and I hope that there could be number of new technologies as well, of course it is hard for these pharmaceuticals because they are very inactive for the biological treatment, but who knows, there might be some new technologies ahead of it,

DD: Yes, Activated carbon can be one tertiary technique to be used for pharmaceuticals, I have already talked with Dr. Cora from Stowa and Dr. Rene from Paques, But why ozone, they are more powerful to kill the biological agents?

MB: They also attacks the molecules the big molecules. UV also, these kinds of technologies can help starting the breakdown of the pharmaceutical products. Depending on the dose, may be you need something extra like sand filtration, because if you discharge it and it has compound with high redox potential, then the fish and other animal and plants will also suffer from that again. So you need some extra balancing step.

DD: I can have more technical details, from Dr. Cora, but at this moment I am interested to know about the overall process. So you are seriously thinking about pilot implementation of this process, have you ever considered the membrane technology to use as a tertiary process?

MB: Ya, that's a good question, the stowa report has kind of list of all the techniques, and also theprose and cons of all the techniques. I think its somewhere there. The membrane technology can catch the cells, the big molecules, for catching smaller molecules it requires higher electricity and increases the cost as well. And cleaning is also a problem. So I can imagine for smaller molecules it is a problem and there are other molecules in the effluent, humic acid and rest product of the big molecules that are not causing any problem anymore. So, if you use membrane technology, that is a separation process only, you will have concentrated waste which is a new problem.

DD: There are 327 WWTPs in the Netherlands, some are small and some are big and applying more modern resource recovery techniques such as the one in Amsterdam or Epe. Is it possible to bring them under one basic technology system?

MB: Ya, interesting question, I think we have them to certain level, because all them are using the activated sludge system with oxic-anoxic and anerobic process with N and P recovery. So they are very much comparable. But given to our very much decentralized nature, we have 21 water boards, they are autonomously functioning, and they make the decision of themselves, what kind of technology they need, of course we are looking at each other, but there is always circumstance that you want make your own choices. There are plants with small and large space, about recovery, the P is clogging the pipes and we are making not much money out of it. So there is always a balance of one uniform technology you can apply everywhere and of developing new technologies and specific demands of specific locations or specific situations. There is always a trade of. If you have 327 exact same treatment plants then you have less possibilities to improve your insights on how to develop the technologies and so on. But the plants are big enough to allow some diversity as well.

DD: That means there is enough space in the treatment plants to upgrade or add tertiary technology?

MB: In many cases, yes. Most of them are located outside the cities. In many circumstances there are extra space available for adding compact technologies. But there could be problem sometimes, some of them have no additional space and anything you would like to do will be extra, for instance the one in Rotterdam, everything is underground there in concrete boxes, you can't do anything there, because anything you will do will be very costly. So space is being a problem here, how much the population is growing, so space is a problem.

DD: on the contrary, there are some techniques that are saving space as well. Such as the Nereda technology?

MB: Ya, but the Paques project, you can more easily adjust it to the conventional activated sludge system, but I don't know whether it will work with the Nereda technology, because there is the up-flow motion. But ya, we should check, if Nereda can work with that, specially if Nereda can be used with a post treatment technique in that.

DD: Now, I want to ask something about the policy as regulation as well. In the opening remarks, you have talked about the water framework directive. So, what is the national stand for the merging contaminants at this moment?

MB: The national policy is in the stage of development. For pharmaceutical industry there is no strict regulation at this moment. Our national government is always in discussion with the pharmaceutical industry and with hospitals. So, basically what we want to reduce the use of these chemicals, on the voluntary basis, also from the hospitals, the antibiotics thing, may be for other substances as well, but specially for antibiotics, because the hospitals are very keen on cleaning the operation room and other areas, so they use a lot of antibiotics. So probably for these kind of substances and also for instance the pharmaceuticals that are not being used by people, you can bring them back to the pharmacy and the chemical waste can be treated in a safe way. These are the things we are very much advocating, and also for controlling the emissions. This is for microplastics as well. For one time use plastic bottles return scheme and also advocating for the plastic bottles that can be used for more than 100 times. The PET bottles are thrown away randomly. So for plastic bottles the society has to change a little bit. So they should not try to use one time plastic things. There is also a European initiative from the European commission, that is not official yet, but that's the basis. Avoid pollution as much as possible at source. And make producers as much as responsible, take back scheme, if that doesn't work we should think about better removal, we are in an interesting period of moments, life of pharmaceuticals, that also true for microplastics, how far they can go and what is the safe limit for it that we really don't know, so in the coming years, we need to know the impact of micro pollutants, what exactly there are doing in the environment, whether they are really toxic or not, another issue is to get to the public and the politicians, being used to those ideas and also look for any other methods for better measurement and also getting support from the public and the politicians because one can say that I want the water clean! But it cost 30-40 billion euros then he will certainly have another opinion. So they are not always willing to pay for it. So becoming aware of this kind of processes also takes a year. Our progressive politicians are asking for measures at this moment but if we say it would cost as a society, 200 million euro/year, they would say well, that's a bit too early, let's think about it for little more time. So that also takes time, the process nobody is in charge of them, not the minister, not we, not even the people, it is more or less a process the whole society is going through, the scientists they publish their scientific papers, the newspapers write about it, so its whole complex process and everybody is trying to steer a little bit, so let's see how that will go, at least we are doing what we can, we as a water sector writing letters about it, publishing articles, responsible care means not doing so much works at a time, and slowly and slowly finding out what we can do, I think personally, we shouldn't wait too long, because there is only one earth to protect, but we need little more time to get the full grip on the position, I think these pilot projects they are really good and we should see how far we can get with that.

DD: These pilot projects, when do you actually like to initiate them?

MB: Ya , that is bit of a problem, because our central government has send us a plan of fund something between 30-90 million euros, the exact value is changing all the times, but that could be spent for pilots. They also said that if you want to apply for that money, you have to keep the plant running for 10 years, so you can hardly think about a pilot installation, it would be a full scale operation with permanent installations. I think there are two problems with that, think many of the water boards are not ready with that to commit themselves for 10 years because the subsidy will be 10 or 20% of the overall exploitation sum of over 10 years, so then why do it for the money, it’s not a very interesting financial offer and secondly we don’t know whether it is interesting enough to do it for 10 years specially when know so little about the technology and its impact. So what we are discussing with the government at this moment, if they can reduce the 10 years condition a bit and if they can come up with the regulation a bit quickly, because we are talking about it for years, but apparently the legal and financial people in the government are agreeing with it, so we are waiting for it, we are waiting for the central government to make their steps, and in the meantime we are trying to develop this effect based monitoring, we are looking for data set on good impacts on the ecology of these micro pollutants. And get a good understanding, how big is the impact, what are the hotspots and what is the relative urgency of this micro pollutants.

DD: so this effect based monitoring, also called bioassay, how you are carrying this out, alone or with any research partner?

MB: The water boards are doing that. And we have STOWA, they have developed a tool for it, AFS in English it is ecological key factor. We have 9 of this key factor, toxicity is one factor, and the other ones are turbidity, the morphology of the canals, the key factors for good aquatic environment and toxicity is of course the important one, there are two kinds of measurement in it, one is the measurement of all kind of toxic substances in the surface water and give them a kind of value and the second one is six kinds of VOCs, all kinds of estrogenic activities, the volatile compounds, that are done by bio assays, if you combine them all, then you will have idea about the more or less toxicity of the wastewater, the test is quite expensive, approximately 2000 euro for each, so you are not going to do that on daily basis. And I know, lot of this water authorities are working with it, to get with this experience factors, 2 or 3 reports have been made on this new methodology and that gives you a good idea how clear your water is. Basically the reports were not so bad, for instance the toxicity of our effluents are not so high, that also gives us the impression, that the extra treatment for these micro pollutants that might not be necessary everywhere, specially if you have dilution in the surface water, may be you don’t need all your treatment plants to upgrade, and secondly the toxicity in the water is sometimes less than the areas of agriculture where a lot of pesticides are used, may the pesticides are more harmful than the pharmaceutical residues, we are in the middle of the process, we want to finish this process before we decide the general regulation for all the wastewater treatment plants for extra treatment or 10% or maybe who knows. Ya, that’s how we see the future, may in next 10-20 years all the treatment plants have extra treatment facilities, or may be a few of them and we will come to the conclusion that the problem is acceptable actually.

DD: It is pretty clear that you are in the middle of the process for developing a roadmap for it. But for the regulations, how much time it might take to develop something, for antibiotics or microplastics discharge to the wastewater?

MB: I think the European Union is developing a set of regulations for the microplastics and a voluntary scheme for the antibiotics, these might take 1 or 2 years, because there is election on the European parliament next year. So the current parliament probably will not intent to make any big decision. So probably in 1 or 2 years we will have something in the European scale, and the Dutch government will follow that, may be try to take a lead in that, but there is not very much strict regulation in it, it would be more or less on awareness and voluntary measures and discussions on what pharmaceuticals can do. But for really strict measures I don't know, it could be 5 years, it could be 10 years, and it could be never.

The water framework directive has a list of priority substance and there is a commitment that the member states must do everything they can do to reduce the emissions, but mainly the substance on that list, they have been discussed it to so long that most of the industries have already taken measures for them, and there is a watch list, the substances on that list, the objective is to do measurements of them together to have better understanding, it can remain there for a certain moment, it will be monitored in the environment, its toxicity levels, then it can go off or it can be included in the priority list. There are few antibiotics in the watch list. They can be upgraded to the priority list. There is also diclofenac, which can be also upgraded but the member states need to think about it. Because the diclofenac is still available in the supermarket, so if it goes to the priority substance, one of the first step would be get diclofenac out of the supermarket and get it only available by the prescription of the doctors. I don't know the market of the diclofenca but that might lead to reduction of 50-60% of its which might be enough for now. Then we will obligatory removal of dilofenac from all treatment plants. Then we will remove diclofenac but what about the other 30 substance. I personally I think to have a holistic view than looking at a particular substance. And also I consider the estrogenic activity should be considered more that the toxicity of them. And also all those kinds of cleaning agents, my wife used to buy a lot of them from the market, earlier we used to buy biological cleaning soaps, but these new stuffs, you don't know, all kinds of chemical substances are there and they all lead to the sewer. You don't the impact of these mixed substances.

DD: So apart from European regulation, can Dutch government do something of its own?

MB: Well, yes they can, like the German government did, but they will face political resistance because if they impose any financial mechanism or standards, then the industries will resist. But still we can do, like the Germans and Swiss did. Depending on the election and some other things. At this moment there is quite a lot of money in that. But climate change agenda is there. So there are people in the water boards who think that climate change is an issue of more priority and pharmaceutical issues are not that acute, but that of course a political issue as well. I am in charge of the micro pollutants issue and let's stick to that. As you have asked me about the required time, I can expect it would be done in 5 years. But I really don't have any clue. But if I have to put my money on somewhere, I would say between 5 and 10 years, there will be some kind of regulation. For the 327, maybe 30-40 will have extra treatment systems. You have heard about the hotspot analysis, maybe we will start with them but who knows.

DD: These were my questions and you have answered the explicitly. I must that you for that. I will make a transcript out of it and send to you for your consent to use that in my thesis.

MB: I wish you best of luck for your thesis.

Interview Transcript 3

Interviewee:

Dr. Andrea Keessen (AK)

Assistant Professor

University of Utrecht

DD: Thanks a lot Dr. Keessen for the time. I am a student of University of Twente, doing my masters their on Energy and Environmental Management. My specialization is on water and I am working on my master's thesis which is on future upgradation of Dutch WWTPs for emerging contaminants like antibiotics and microplastics. And as part of that I would like to know about the legal process, the regulations present at EU and Dutch level and the future pathway of stricter regulations.

AK: At this moment, the Dutch WWTPs are at III level of technologies and discussion is going on to upgrade them to IV. The technology is there.

DD: Yes, the technology is there, what we require is the regulation or policy for them.

AK: Yes, the reason is they are expensive. Actually two reasons, one the cost and another is, there are no standards that oblige to remove or reduce emergent substances such as microplastics and antibiotics in the Urban Waste Water Directive, therefore it is not obliged. You know, if there is no standard, you don't need to meet any standard. So it is like a voluntary process to upgrade to level IV.

DD: Here comes the question of regulation. Before we proceed any further on that, I would like to know a bit about the directives. For my thesis the important ones are the Water Framework Directive (WFD) of course and Marine Strategy Framework Directive (MSFD). But the most important one is UWWTD. What is the connection of Urban Waste Water Treatment Directive (UWWTD) with WFD?

AK: It is an independent and separate directive. But they call it daughter directive. WFD is an umbrella directive, a framework directive. So, all the other directives are equally important but the WFD is more over-arching, all the other directives were already there and the EU added the water framework directive and revised and updated many of the others but not all; not the UWWTD.

DD: Yes, there was no change in the UWWTD.

AK: And I think there is one more directive that might be interesting for you, the so called Industrial Emission directive (IED; 2012/75 EU), previously called the IPPC Directive, and wastewater treatment plants fall within the scope of this Directive. This directive obliges the member counties to issue permit to highly polluting activities, make sure they reduce pollution or they do not pollute at all. The whole idea of this directive is reduce the harm of industrial emissions. It takes an integrated approach. It integrates emissions to air water and soil and prescribes the use of best available techniques. And that's where it is interesting because you could say, the UWWTD doesn't prescribe the antibiotics to be removed but the IED prescribes that the best available techniques (BAT) should be used, perhaps there is BAT available on wastewater treatment but the thing is BAT implies that should be technically feasible but also financially affordable. But I have no idea, that to what extent this fourth step is actually affordable or too expensive.

DD: So what about the WFD, does it also mentioned the BAT in its approach?

AK: No, but it prescribes monitoring. From this monitoring obligation, pollution with microplastics or antibiotics comes up, then the authorities that monitor should discuss the data, should there be standards. Once you have the standards it would be easy to include that in the UWWTD. So there is possibility that it would be revised and updated. But currently it doesn't prescribe that level of treatment. I know that experiment is needed and it is necessary to do these experiments in the pilot phase. Then it can be found out that it makes sense to make it mandatory. Because it should be feasible and affordable before everybody has to install such a thing.

DD: But professor, isn't it a bit difficult to do that, because we have to agree on the toxic level of the emissions and then the procedural change?

AK: Yes, here comes the precautionary principle, authorities do not have to wait until they are certain, before they take action.

DD: So for antibiotics, the issue is in discussion for years but still we couldn't make standards for that. Isn't it a bit of deviation from the precautionary principle?

AK: Well (laughing), I want you to discuss that in your thesis.

DD: Could it be possible that the industrialization and economy have been over rated on the environment issue.

AK: Yes, That's always a difficult thing, the balance between environment (public health) and the economy. So I think as soon as you figure out that it also a public health fact, then that might be fit into the economy until then no. I mean, you are right, it's a long discussion, as long as you are very extensive, it is very difficult to take up new technology. But I know that, in the Netherlands, the water authorities are discussion about up grading the technology. On the other hand, discussing on the precautionary principle, and the principle that pollution should be rectified at source, the microplastics shouldn't be in the shampoos. And antibiotics and other medicines should be made in such a way that they become degradable.

DD: But Switzerland and Germany have already started implementing this kind of processes. What could be the reason? Is it because changing the regulation is a bit easy there?

AK: Well, this is difficult to say. May be they are more concerned about this; it's also about the production facility. May be the problem is bigger in Switzerland or it is because pharmaceutical companies are located in Switserland, that could be one reason why they started implementing it.

DD: of course, but if we look from the regulation side, how often we could see an EU country or state to make the regulation stricter?

AK: oh yes, that's possible, unless it hinders the market access for the others, but in this case the plants are located in one place. So free movement is not a problem for them. EU law allows for stricter national laws especially if they don't affect the internal market and in this case they don't. It has a special name. That is called 'gold plating'. It means adding something to the EU law. This terminology has a negative connotation, but you can also consider it as something positive.

But it is difficult to say, how it could take place in the Netherlands. Strict regulations on the emission standard of antibiotics and microplastics depend on the willingness of the policy makers and many other things. It is a political process. If there is a shared feeling of urgency, things will go fast. In particular, if the technology is not that expensive, the uptake will be very big. Once it is taken over in Germany, it will be taken over elsewhere because it will become cheaper then. And once a technology is taken up widely, it becomes more difficult to say that it is something very new and expensive.

DD: Of course. These were my questions and you have answered them all and explained the legal issues. Thanks a lot for that. Thanks for sharing the report as well. I will make a transcript out of the audio of this interview and send that to you for your look and consent. Thanks again.

AK: Thank you and best of luck for your thesis.

Interview Transcript 4

Interviewee:

Dr. Erik Roesink,
Honorary Professor
Faculty of Science and Technology
University of Twente

DD: Thank you Dr. Roesink for the interview time. My main question will be on membrane technology wastewater treatment but I would like to start with your general opinion about the wastewater treatment plants of the Netherlands. How they are working at this moment?

ER: Before I start, let me first conclude, I am a professional in the field of Membrane technology, not formally in the water treatment. Before I answer the question, let me tell you a bit about my background. I was a student of this University in 70. I have started my PhD in 1985. Then I started a company named X-Flow (audio not clear) now it's part of Pentair (audio not clear). I left this company 5 years ago. I formed my own company, NXFiltration, you may know, it's all in my LinkedIn profile. Since 2012, I am a part-time or honorary professor here in this department. And my main task here is to develop hollow fiber nanofiltration membranes, and the main application is the removal of micropollutants. Since I have positioned my membranes in this application, I came across antibiotic-resistant bacteria and micro or nano-plastics. If you have come across the report of STOWA, it is either powder activated or granular activated carbon which is absorption. Or you can use Ozone or UV which is oxidation. And the third is membrane filtration. One of the drawback of membrane filtration is its costly. And since it is a separation, you have the permeate which is water and you also have the concentrate. (Drawing a diagram)

In the present wastewater treatment process, the tertiary effluent, is going into the river, lakes, so we can use the membrane as a tertiary treatment process and the membrane concentrate will go back to the treatment plant. The concentrate will be full of micropollutants. And the permeate water, you can discharge to the river or lakes. It is good in quality, better than one you have in most areas of e.g. Bangladesh. It can be used for industrial purposes. Even for drinking water, if you add an extra filter or polisher in it. For all the micropollutants activated carbon application can be effective, however for microplastics and antibiotic resistant bacteria that is not so good. With ozone you can kill the bacteria but you have to be sure, you really need a strong dose. But for nanofiltration that is a piece of cake. I don't know, how familiar you are with membrane technology, Ultrafiltration means using membrane filters with a pore size less than 30 nm and nanofiltration is with the pore size of less than 1nm. For granular and powder activated carbon the cost of treatment is 15-25 euro cent but for nanofiltration which is a new technology could cost between 20 and 30 eurocent. But since it is more efficient, if the volume is big enough we can do it for the same price compared to oxidation or adsorption processes. So price wise that is comparable and technology wise that is much more efficient, since it also removes the antibiotics resistant bacteria and microplastics as well, and in addition the permeate quality is superior to the water after adsorption and/or oxidation.

DD: So professor if I may ask, for removal of these micropollutants by nanofiltration seems have potential but the concentrate still has to be treated by the WWTP again. Wouldn't that increase the cost of treatment to another fold?

ER: well, what you are trying to say (following the diagram), if the concentrate stream from the membrane is 10%, assumable that the WWTP has to treat 110 %(adding 10% extra). But as you may know, that the WWTPs of the Netherlands are prepared to take the load of the rainwater. So, I think they are capable of taking the extra load. But the micropollutants they will go back to the WWTP again. So the biological process has to be capable enough to process them. We not sure whether this will work as good as we expect. So what we can do? The concentrate stream can be treated with little amount of ozone. So it breaks down the compound, and biological degradation process becomes faster, more efficient. That what we are trying to find out at this moment. Since we also remove the bivalent ions, Ca^{2+} and Mg^{2+}, so the wastewater treatment plant will be also full of bivalent ions, or salts in general. That means, we also need to find, how these microbes doing when it is full of salts. So as you know from your knowledge in biochemistry, there is certain sensitivity but also certain flexibility of biological processes in salt. This is not like we are filling the treatment plant with sea water but we need to find not only how it is dealing with high amount of micro-pollutants but also how it is dealing with high amount of salts. But don't forget a wastewater treatment plant is a biological system where we remove/dispose microorganisms from time to time. But we keep on growing new microorganisms in it. There is a continuous production of microorganisms here. They will be disposed every so many times. This disposal, you also remove extra salts, extra micro-pollutants and that can go to incineration.

DD: So I was wondering, the WWTPs are treating almost the clean water during the rainy season. Thus pushing the concentrate stream back to the wastewater treatment plant from nanofilter might increase the treatment capacity and also increase the recovery rate because the concentrate will also contain some N and P.

ER: yes yes, all the phosphates, carbonates and N are going back to your system, that's a good point absolutely, we haven't touched it too much.

DD: So we can think that if adding the nanofiltration system in the WWTP increases the cost of wastewater treatment, then it could be also true that by recovering the extra nutrients that extra cost can be neutralized?

ER: We can create a business case out of it. But what I have touched already, that in the Netherlands we are disposing the water to the nature for free. After nanofiltration this water could be of great value. Unfortunately this wastewater treatment plants, most of them are located in areas, where this water has no value, nobody is willing to pay too much for it. But if it is requiring 30 cent then the business case is closed. But if you are willing to pay for cleaner environment and if you can recover resources then we can make a business case out of it. I am discussing it with another professor, he is a drinking water and also a membrane specialist. Because the drinking water companies are being more and more interested in this kind of things. You can have a look on our country (drawing). Here is the Meuse and here is Rhine. And the Meuse in the drying season, is containing a lot of industrial wastewater from Germany, France and Belgium. The drinking water guys are already thinking about that. Because 50 to 100 days a year, actually 50 days a year, this water is impossible to drink due to too high concentration of chemicals. So here in the Netherlands we are having more problems with it. So in these areas, it is better to use the discharged water from the WWTPs to prepare drinking water than taking it from river because it is more clear. Now the question is who should pay the bill, you, me or the government which is you and me again or by the water boards, or by the companies.

DD: the water companies in the northern part of the country are having good water from the ground sources. I have interviewed Vitens there, they told me that the surface water quality is worse in the southern part of the country.

ER: yes, and they should be honest on that, pesticides and other industrial wastes are gradually increasing in those areas:

DD: yes and along with that they have the brackish water intrusion problem from the North Sea. And the pesticides problem, I guess is due to the agriculture practice in those areas. The pesticides and other industrial wastes are percolating and contaminating the groundwater sources.

ER: The water companies are using membrane technologies. Some are using anaerobic techniques and membrane also. Sometimes we think that we are wet country and we have plenty of water. But I keep warning people. The drinking water companies have started working on that. We need to use different sources of water, rainwater, and wastewater, whatever water is available.

DD: we have entered into the technical discussion, you have explained NF but what about RO and UF? What's your opinion about them?

ER: well, yes, depending on what you want. Let's start with reverse osmosis. It's an existing technology. We can fit that into the model I propose. That can catch everything even the minerals. And it requires more pressure that means more energy. And the membrane, the spiral bound elements, it is more prone to fouling, the ideal model would be UF then RO. That means more costs required to it. Capillary nanofiltration is relatively new, brand new and unique that means your pretreatment can be relatively simple, then it is more affordable, if we can do that 25 cents per cubic meter, RO would then cost double. But in theory RO can do that as well, but it would have more sodium and potassium in the sludge which we are disposing at this moment. You can you UF. That is a nice solution for microplastics and antibiotics resistant bacteria but the micropollutants will go through it.

DD: In RO the wastewater volume will be much higher, 40-50% I Guess.

ER: No you are not treating sea water. It would be around 80% recovery. But the cost will increase for sure.

DD: Son in ideal condition of the Netherlands you think, NF will perform better than RO and Uf

ER: yes I have and it's not only because professor Roesink is saying that, I am an entrepreneur and professor but other engineering companies like Haskoning are also saying that. But what I have told and draw in the diagram are based on respecting the existing technology. Considering NF with a polishing step, considering there is lot of capital investments there and require some extra space. But I don't know whether you are considering the Dutch political issues into it or not, because the political parties are also discussing whether they will do that or not because it needs a lot of money, people's money and it is an end of the pipe solution. But I don't think this is an end of the pipe solution. Because the microplastics and the micropollutants are coming from you and me. Perhaps you can stop that by changing regulations and practice, but that would take 30-40 years. And the antibiotics, they will also remain, because people need them, thus I see we need the WWTPs at least for 50 more years. And in circular economy, they are going back to the nature or industry. The same concept can be presented by picture. But if we look at the future of the WWTPs, I appreciate and respect the existing model of the WWPTs, (Drawing), you have already started to work on the same thing, we take the municipal wastewater, then we take two filtration steps then nanofiltration, then it will take the solids here then the digestion, you can do it anaerobic, you can burn them, this would be a very compact installation then nanofiltration, you can do the same game, again you can digest the concentrate anaerobically or whatever. This will be replacing the wastewater treatment system by some simple filtration steps, the simple flirtation steps they can be electro-coagulation, can be sand filtration, so here we are simply separating the waste, the solid waste and the liquid waste, the liquid waste will go to nanofiltration, you can send the solid waste to digester, make green gas or you can whatever you want to do with it. You ca use san filtration as one of the steps. You have to separate the organics from the wastewater, then step by step you can use sand filtration or any other mechanical filtration then nanofiltration.

DD: This model, compare to the existing model, does add any extra value?

ER: yea, do you know how much CO2 the WWTPs are producing. The new model can stop doing that. Then you have CH4, you can still argue that it is a green gas or not but you can use that as a building block in the chemical industry. It is like wood which is not fossil fuel but coming from the waste. Only a few WWTPs are using anaerobic digestion but only for treating the sludge, the end residue.

DD: But the activated sludge system is radiating all the CO2 to the nature, right?

ER: let's go back to your questions, "what do you think about the emerging contaminants? Have you seen any change of pattern? That's an interesting question. What my colleague from the drinking water company say, every day we find a new contaminants that could be dangerous, could be toxic, and we don't know what to do and everyday something new pops-up. A question to me, perhaps you can help me here, for the micro pollutants nobody wants to pay, for them it's like one aspirin in the swimming pool, they keep on saying, its low concentration, and it's nothing, so how can we argue for the wastewater and the effluent in the wastewater.

DD: For antibiotics, there are already some policy level initiatives like the EU watch list, but for microplastics there is no such thing yet, scientists are still confused about its sources and impact, what do you think on this?

ER: (showing a picture) microplastics are already in the bodies of the aquatic animal, they are in the food chain and we don't know its impact. I am so pissed off with this kind of things. Everybody is trying to cover this up, everybody is trying to avoid investment and asking for more investigation, they need more time, more research, there is also one affect, specially in the western part of the country, we have no bees there, the bees are dying, we have insecticides and pesticides and no bees. There us one insecticide called nicotine that is killing bees, and we are arguing and arguing and arguing. Albert Einstein told that, guys, if the bees are dying, we the humans are dying too, and you are from the cost of Bangladesh, you can see all the plastics in the sea, they are degrading, all the whales and other animals, everyone can see that they are dying because of the plastics and still the stupid Dutch researchers, they need more time and research. You can count, in every minutes how many tons of plastics are going to the sea. The good news is that in couple of years we will be able to go the halfway of the United States by walk. You mentioned a key word, legislation, I can tell you a bit about the legislation in the membrane industry, we have started a company in the mid-80s called EXLO (need to be checked-audio not clear), looking for all kinds of application with the membranes, it was not easy, started with the wine filtration, manure, blood, dairy products, but precisely in 93, we have the cryptosporidium outbreak in the US, 90 people died which is very sad but sometime that helps. I don't want to be rude but the legislation came and water treatment plants ware forced for proper treatment. Cryptosporidium can hide themselves against chlorine which was the antimicrobial agent used at that moment. They pass the chlorine treatment and people died. So filtration come such as membrane technology, you can also use UV or peroxide. But legislation came and given enormous boost to technology.

DD: Apart from the model you have proposed, which is to be used at central level, can we use the membrane at source specially in industries?

ER: yes that's possible, specially in your part of the world. I was in an exhibition in Germany, I was talking with people from Indian and Pakistan, for the textile industry. Indigo can be recovered from it. So membrane can be used to treat the process water in textile industry. The funny thing is, we are very civilized people or that's what we think we are, but people specially in the southern part are discharging industrial waste to the Rhine because it ended up in the sea. But ya, these can be tackled with NF or RO. But you need to have a strong legislation there to prevent them going to the sea. Because we consider the sea as a big membrane bioreactor, we think the microorganism will be able to digest everything you put on the sea. That shouldn't be done, at least I think that shouldn't be done. Because I have small children and grandchildren and I want them to live. Look at the Great Barrier Rife, even the planktons there are dying. If the scientists have to investigate, they should do it now. It's like the cancer due to nuclear radiation, if you have cancer in half an hour, everybody cares but if you have in 20 years nobody cares.

DD: so, for industrial areas WWTP with retrofitted NF can perform better I guess since it can serve the industries with treated water?

ER: well yes, but that is being performed in the Netherlands already, we call it industrial water or grey water but that is not performing very well because water here in the Netherlands are very cheap and sometime the WWTPs are located far from the industrial areas. To use water from those plants you have to build infrastructure with piping system. That's often a discussion. But what we can do, that could be interesting for your master's thesis as well, where we have new city, then we need to adjust the WWTPs, we need to think of what kind new technology we can install, and yes, we should immediately incorporate reuse of the water that's the way of thinking and since we are an exporting country, what I have depicted not a biological treatment but filtration technique followed by nanofiltration and anaerobic digestion should be the ideal decentral one. You will have water and you will have energy. In the western part of the country, the drinking water companies are really discussing about that to close the chain.

DD: but the number of WWTPs in the Netherlands are shrinking. Now it is 327 and 5 years ago it was 395...

ER: I would say that's a stupid approach because the water should be treated in peripheral areas in a more decentral way, but I don't know that much, probably because for biological treatment you need to have a certain volume, less than that will not work. But the problem I have depicted, it can work from 1 cubic meter/hour to 10,000 cubic meter/hour. That is not a problem.

DD: How do you envision wastewater treatment system after 30 years?

ER: I wonder, it would be still biological. I think, biological treatment will not be the main technology rather be part of the technology as anaerobic digestion for the sludge for biogas and kind of like immobilized biological reactor (MBBR), to treat the concentrate of the NF, but the primary technology should be mechanical separation.

DD: Thank you very much. You have covered all of my questions. I will prepare transcript out of the audio and send to you for your consent to use that in my thesis.

ER: wish you best of luck.

Interview Transcript 5

Interviewee:

Andreas Giesen
Director (Technology),
Royal HaskoningDHV

DD: Mr. Andreas Giesen, thanks a lot for allocate the time for the interview. I understand your busy schedule. And I am very thankful to you for the time. My thesis is on upgradation of the Dutch wastewater treatment plants for emerging contaminants. I am working with two, antibiotics and microplastics.

AG: and you are from WETSUS….

DD: Actually I am from University of Twente. I am doing my masters on Environmental and Energy Management. My specialization is on water. Our main campus is in Enschede but for this masters they have a satellite campus in Leeuwarden with the WETSUS. So yes, it's pretty linked with the WETSUS.

And the reason to approach you for the interview is linked with the invention and application of the Nereda technology. It is a fast technology with space and energy saving capacity. Thus it is replacing the conventional activated sludge systems. So we can consider its expansion in the future. It is also necessary to consider its capacity to deal with the emerging contaminants or capacity to cope up with the technologies that can deal with these contaminants. Let's start with a general overview of the Nereda technology.

AG: yes, we are doing very well. It started in 2006, so it's been around 12 years, we are working in 5 continents and I think around 50-60 projects have been implemented so far. So the new and modern technology is replacing the old and conventional systems.

DD: yes, I have tried to look into the website. There is a map with all the locations of the plants there. It is great to look at the spots, the system is operational in many countries of the world.

What about the emerging contaminants. How they are growing in the country or over Europe.

AG: I think, countries that have established wastewater treatment system, for them, micropollutants or microplastics etc. etc. are a new concern, in Europe they are growing and growing, Switzerland is already way ahead in it, we have interests for the micropollutants in the Netherlands you know, and we see that happening also in countries where water reuse is an issue whether its direct reuse or indirect reuse of wastewater, so I think that's probably the future issue in the wastewater treatment after dealing with the nutrient issue of course. The nutrient issue is already being taken care of so I guess in the coming years micropollutants will be hot topic in the market.

DD: Apparently the scientists, researchers and technology developers like you are very much concerned about these things. But what about the policy makers, do you think they are equally concerned?

AG: That's a very general question, yes there are people in the government who are concerned about that but politics is really difficult to see, what it important and what is driver, but I think most governments are giving attention to it, you know Switzerland government have clear referendum for it and majority of the population are motivated and in favor of that.

DD: But what about the concentration of these micropollutants? Have you noticed any change or upsurge of them in the Netherlands compare to its neighboring countries?

AG: no, not really. But I also have to say that not much data available on that. But it is difficult to compare because analysis protocols are not reliable, so I don't see any striking difference between the neighboring countries, I guess they are pretty similar. They are originates from things like the medicines, even in the Netherlands people are more, I mean we are not in the top of consuming medicines, people here are more careful about prescribing and consuming medicines.

DD: I guess, comparatively agriculture has more contribution of micropollutants in the country, right?

AG: correct, I don't have data but that wouldn't surprise me.

DD: Since this country is in downstream of Switzerland and Germany, the micropollutants load could be possibly higher here?

AG: well, I don't know that idea really holds or not, certainly in the surface water there will be more because we are at the end of the delta so we get all the pollutants in but a large part our drinking water comes from the ground sources that will be free or extremely low in micropollutants, surface water we use to drink are also properly treated so I think the import of micropollutants in our wastewater is relatively limited. That is my idea.

DD: Let's get back to the technology discussion, the plants that have adopted the Nereda, how are they functioning?

AG: well, all the treatment plants are performing like they should perform. This is also extremely important, that since we have exported that technology to many countries so, we have a lot of check and balances in play, because any problem can quickly damage the image and in Netherlands we are of to project number 7 if I can recall the municipal clients, they all talk to each other, they share information's, they sit together so ya.

DD: that means they are doing pretty well. There are 327 municipal WWTPs here, so for the small WWTPs that are in the periphery, do you think the Nereda can perform there as well?

AG: Oh ya, sure size does not really matter, relatively small WWTP can adapt to Nereda technology, for example we are going to have our first two projects in the USA, one of them I would say is relatively small, so size is not really of importance, and using this technology is partly decentral type of treatment, but we are currently targeting the larger projects because this is the first move in the market, all the smaller projects will be there in a few years' time and there are more competitors, so at this moment we are really looking at large and sexy type of projects.

DD: What is the capacity of Nereda technology itself to remove the micropollutants?

AG: that's also our interest currently to investigate. Part of the advantage we see about Nereda, it's actually look like part of biofilm system, so there will be adsorption and there will be sufficient sludge residence time more precisely microbes for micropollutants, so that positive, partly the components will be not removed, just like the activated sludge system. I think the good option would be to add activated carbon in the cycle as well, of course you can apply advanced oxidation like normal activated sludge system or also can place membrane behind it. Already validated in pilot scale, in our program for micropollutants removal, but we need a lot of data to claim and backup guarantee.

DD: I am asking this because if Nereda can perform better with any specialized technology for micropollutants removal then the duo can act like a package for the future?

AG: Well, I think that due to the adsorption and higher sludge residence time it will not perform less than the conventional activated sludge system and there are some other options that can be added to it as well. You can do that just like the activated sludge system.

DD: and what about investment,

AG: Well, if you establish membrane filtration system that would certainly cost extra money?

DD: Of course, but would that require any retrofitting to the Nereda system?

AG: oh no, anything you do downstream to the Nereda will not have any impact but if you consider activated carbon etc. to the Nereda you can get maximum benefit out of it. There could be little tie in there but it's not like you really need to redesign the Nereda reactor to do it.

DD: So as a single design Nereda is performing great, and it can work with additional technologies as well.

AG: you have referred to the projects in the Netherlands, but we have quite international portfolio, in few of them, tertiary filtration is already engaged, the project we are implementing in Switzerland, is actually part of the retrofit is activated carbon oxidation, in many plants in the UK you will have UV, so there is already quite some experience building up some, how to have tertiary and polishing type of technologies can be added, there really not difficult compare to activated sludge systems. We don't have any reports available on that. But I think I have seen a brochure with flow scheme. If I can get that I will scan and try to share that with you.

DD: that would be very helpful. You have answered all my questions and I don't want to take any more moment from your busy schedule. I will make a transcript from the audio and share that with you. After having your concern on that I will use it in my thesis.

AG: that is even perfect. Any I would love to see your report when ready.

DD: That would be an honor for me. I will share it with you. Thank you.

AG: Wish you best of luck for your thesis.

Interview Transcript 6

Dr. Ruud Steen
Main Market and Advice
The Water Laboratory

DD: Thanks a lot Dr. Steen for accepting the interview request. I would like to start with the presence of microplastics in the drinking water of the Netherlands?

RS: Well, we are asked by the drinking water company to check that situation because they use the surface water as source. And microplastics are present in the surface water. We are collecting samples and developing methods for detection. But yes more to do.

Drinking water companies have good treatment technologies for treating the source water. We have visited one plant. But of course, different plants may vary in the performance. Thus we suggested them to use micro sieves for physical separation of the microplastics. It can be followed by sand filtration. In another plant, they are using nanofiltration which is designed for capturing even smaller particles than the micro and nanoplastics. So basically after these physical separations, we don't expect them to be present in the drinking water.

But, of course, you interest is more on sewerage and other wastewater treatment system.

DD: yes, and what kind of additional technology do you think, can help?

RS: Well, the most easy solution is to use the membrane. But that is costly. In this regard, sand filtration can be a better solution. It is relatively cheap and also efficient. You can think about something in between such as ceramic filter or ultrafiltration but they are costly too. But microplastics is not the only problem. There are other contaminants. And you need something that can remove the microplastics and other contaminants like the antibiotics as well.

DD: So, we need a combination of techniques, to target these kind of contaminants?

RS: Yes, we are following a technique actually, powder activated carbon application followed by rapid sand filtration. The powder activated carbon form a layer on the top of the filter which gives a sieving effect and adsorption effect. This kind of combination can perform better. You can talk about Reverse Osmosis or Nanofiltration but firstly they are costly and secondly they produces a lot of brine. Thus I would say a combination of adsorption and sieving would be a good solution. May be sand filtration or you can use ceramic filtration.

DD: What about the research of PWN?

RS: Yes, they are working on wastewater as well. They are researching on using UV, Ozone, peroxide technologies to treat the wastewater. But for microplastics I would say, using RSF as pretreatment could be good followed by other treatment methods for wastewater it can be used as a last step or polisher. But yes we need to standardize methods for that.

DD: another question, the drinking companies those who are using surface water, do they all use NF?

RS: No, No, of course some of them are using NF but there are other techniques. Some are using sand filtration, ozone and uv-peroxide combination, some are using powder activated carbon, there are multi barrier you know. But, we need more knowledge for the microplastics. We are working with other organizations to do that.

DD: Thank you Dr. Steen, along with the drinking water issues you have also informed me about the wastewater treatment techniques. It has been very helpful to my work.

RS: Good luck with your thesis.

Interview Transcript 7

Interviewee: Dr. Cora Uijterlinde[7]
Programme Manager
STOWA

DD: I look at the report developed by Stowa on 2010, more like a vision work plan for 2030, they are not limited to energy and resource recovery, they are trying to make the water factory.

CU: When you have advanced wastewater treatment for your WWTPs, it can also be easier to use that water for all the purposes, for instance for industries or drinking water, it's all possible. It's more possible than before. But it's all in transition and at the moment, we are only researching advanced WWT. We have some pilots and we are experimenting with activated carbons and ozone and UV for the treatment of effluence for the pharmaceutical. We have all the organics – we call CECS – contaminants of emergent concerns. I have a few topics in my research program and one of them is the energy recovery on WWT system, the resource recovery, effluence in quality and cost production – four topics, the wastewater quality is now increasing because of the medicine residues and at the moment also resource recovery with all the resources which we could recover from the WW, it's also expanding.

DD: For WWPT, the load of inflow water is increasing or decreasing if you have any information on that?

CU: There are a lot of initiatives to separate rain water from sewage water. That makes how much rainwater you also treat. In fact, the population is increasing, there is also the addition in going in the toilet, you know population equivalent (P.E). Last year, we did a research to see if the P.E was changed so we measured in a small part of a sewage system, only household no industries. We measured how much WW the area produced to recalculate P.E. Because, if you look back historically, we start with a very 180 sometimes it's changing – the amount of water used for showering and food preparation, they are all influencing the quality of water. We saw that it's quite stable for now. P.E is important to calculate how much people or industries have to pay for their treatment of WW.

DD: We can generally consider that in general, overall quality and quantity of the water is remaining the same.

CU: For COD, nutrients, but if you look pharmaceuticals, there is an assumption, we don't know yet but that it will increase in the future. Because people get older they consume more medications but also from the industry, all the kinds of prescriptions and medicines more focused at ill part than the whole body. Its pros and cons so the quality of pharmaceuticals and all the CECs will increase as it's also – we know a lot but there are also unknown components: micro plastics.

DD: The number of WWTPs are reducing at the moment. Isn't it also meaning that more pressure on the WWTPs? Or their efficiency is increasing?

CU: The number of WWTPs is decreasing, because a small number of WWTPs are closed down and WW is transferred to other plants and then because of efficiency reason, especially when you look at development like medicine removal, then it will be very expensive to treat all the small WW stream in particular way. So it will be more efficient to have large plants. On the other hand, when you have some places with new areas that it's considered to install new sanitation concept. Because of on the long term,

[7] Interview taken as a part of the MEEM case study work.

you don't want to transport lots of water or wastewater, so it's a little … from the urban environment, if you see it now, you cannot implement new sanitation concept. It will be difficult as you have to be very creative to implement those. We have some historical infrastructures and all the sewage systems so it takes a lot of efforts and a lot of time in the coming decades or centuries.

DD: We have some questions about your idea how we can make drinking water and sanitation systems more efficient. But before that, we want to know a bit more about resource and energy recovery that you explained a little bit already.

CU: As we speak, the national government is thinking about how to determine or remove efficiency of WWTPs and for now it will not be in some kind of a law, that it will be discharged limit or so but they have a range of subsidies and ways of influencing/treating WW. If you want some of subsidies, you have to show you have some kind of removal efficiency. And, if that removal efficiency is 70% or 80% now on the construction, it's also implication for the technique that we are going to use in the future. Also last year, we also did a research on hotspots of pharmaceuticals and we look at all the WWTPs, how they influence the quality of surface water and how they could influence the resources for Drinking water consumption, because we have the drinking water production site using surface water, the treatment of discharged of WWTP can be implemented. So with all WWTP, how they implement the local quality of surface water and some of the WWTPs are located in highly sensitive area with high nature value and then it's also important to remove sediments and residues.

At the figures, sometimes you see a map with red dots, importance of these plants.

DD: The question I got from your explanation, you use the technique like activate carbon or similar technique, would it be easy that can be interpreted into present structure of WWTP, but if we are going to use more complex methods like ozone or something like that, some electronic method, then it might be a problem to fit into present running WWTPs, right?

CU: Activate carbon, especially activate carbon in activate sludge, is more simple, it is easy to apply, because it's only …. (26s23) equipment, if ozone is so complicated, only when, at the moment, we are looking at the byproduct of ozone dosing, because sometimes you have the contaminants of emergent concerns or pharmaceuticals, but when you treat them with ozone, you have to look after dosing whether you need another treatment. Sometimes, it is expensive and it also has to be possible that you have … (27s36 – sorry I don't understand what she was talking about in this part). However, sometimes, it's difficult to install those kinds of equipment. So it's more a problem of local situation, which makes a choice of a certain technique at a certain place. And the efficiency rate, the removal rate.

DD: And the standard?

CU: Yes, when the effluent is discharged, at the surface water, which also function of swimming water, then you also have to remove your pathogens. Then also determines the technique you apply.

DD: We have discussed about more decentralized technology. For specific contaminants, do you think we can use decentralized technology as well, for instance, for antibiotics, can we use the decentralized technology? What do you think?

CU: Decentralized technology, I think it can be a good opportunity because you have concentrated waste stream, and it can be adjusted especially through the discharged of the effluent of the filter. On the other hand, you have other decentralized system like new sanitation concept. You can add a lot of techniques in decentralized concept.

Decentralized system can be used in one households, or ten households. And all the systems can be diverse. I don’t think the system in the small scale can treat COD and CAPS and that will be very complicated because you need expertise, you need monitor. It will be easier to install some kind of treatment for small group of people or small group of households. In Sneek project, that’s the concept of decentralized system and it’s still in progress, how to imply, do you discharge on surface water or do you discharge on sewage system?

So it will be a challenge, still have to look on what is the loading of CAPs at the surface water? If you have decentralized system, you’ll have quite small but if they discharge at a very large system, then the impact will be not that much. Then you’ll have to look at the impacts or so.

DD: Thank you

Interview Transcript 8

Interviewee:

Environment Desk[8]

EU secretariat

DD: What is the policy available at this moment, for surface water quality and wastewater treatment monitoring? How it is considering the emerging contaminants like antibiotics and microplastics?

ED: The Water Framework Directive (2000/60/EC) addresses chemical pollution in three ways. First, it requires the identification of priority substances (relevant at EU level), for which Environmental Quality Standards (EQS) are set in Directive 2008/105/EC as amended by Directive 2013/39/EU; second, it requires Member States to identify pollutants relevant at national level (river basin specific pollutants) and set EQS for them; third, it uses the watch list mechanism to gather data on pollutants which are suspected to pose a risk but for which insufficient good quality monitoring data are available, so that a decision can be made about their regulation. Some pharmaceuticals including antibiotics are in the watch list, recently updated (Commission Implementing Decision (EU) 2018/840), and some Member States monitor pharmaceuticals as river basin specific pollutants. As far as we are aware, microplastics are monitored only as part of monitoring campaigns, e.g. as reported here:

https://www.researchgate.net/profile/Jan_Koschorreck/publication/318128423_Conference_on_Plastics_in_Freshwater_Environments/links/595b4f84458515117740ee0c/Conference-on-Plastics-in-Freshwater-Environments.pdf

The Urban Waste Water Treatment Directive (91/271/EEC) requires treated urban wastewater to meet strict standards as regards organic load, phosphorous and nitrogen, which are more stringent for discharges in sensitive areas. It requires performance monitoring of wastewater treatment plants and receiving waters (Article 15). Antibiotics and microplastics are not considered in this Directive.

DD: What could be the upcoming step to upgrade the directives?

ED: The WFD and UWWTD are currently being evaluated in accordance with the European Commission's REFIT programme (Regulatory Fitness and Performance Programme).

The WFD is being evaluated

(http://ec.europa.eu/environment/water/fitness_check_of_the_eu_water_legislation/index_en.htm) along with the EQS Directive, the Groundwater Directive and the Floods Directive. The evaluation will assess the effectiveness, efficiency, relevance, coherence and EU-added value of the legislation. Consideration will be given to whether, among other things, the Directives address the "right" pollutants. A public consultation will be launched in the next few months. The outcomes of the evaluation, which is also being supported by a study, will affect the Commission's decision on whether and, if relevant, how, to propose revising the legislation. Revision could include changes to the list of priority substances. In the evaluation of the UWWTD (http://ec.europa.eu/environment/water/ water-urbanwaste

[8] The environment desk of EU, Brussels has sent the answers of the interview questions through email. Thus name of the interviewee person is unknown.

/legislation/index_en.htm), the European Commission will assess whether the Directive has reached its objective of protecting the environment from the adverse effect of urban wastewater discharges and discharges from certain industrial sectors over the past decades. In this context the Commission will also assess whether there are gaps in the Directive, for example as regards microplastics and pharmaceuticals. The recently published Plastics Strategy included a follow-up action to assess the effectiveness of UWWTPs as regards microplastics capture and removal. The findings from the evaluation will inform the Commission's decision on whether to revise the Directive. A public consultation has just been launched to support the evaluation: https://ec.europa.eu/info/consultations/public-consultation-evaluation-urban-waste-water-treatment-directive_en

DD: Some of the contaminants are at watch/monitoring list. What is the possibility to develop certain standard for their emission at industry level?

ED: The purpose of the watch list (for most of the substances on it) is to gather high-quality monitoring data to determine whether they pose a risk. Only once sufficient data have been gathered can a decision be made about whether to set an EQS at EU level, which might then trigger the derivation of emission limits for industry, and influence permit conditions in Member States.

DD: For developing such standards, it is important to have guidance from the scientific community. What is there stand for tackling the emerging contaminants at this moment.

ED: A number of academic and other research institutions have been involved in research on emerging contaminants. The SOLUTIONS project, funded by the European Union over nearly 6 years, is a good example. The Commission's Directorate General Joint Research Centre (JRC) is also working on emerging pollutants, partly in cooperation with Member State and stakeholder experts in the context of the Common Implementation Strategy (CIS) for the WFD. There is an activity on investigating the possibility of Effect-Based Methods to better assess the risks from chemical pollutants, in particular from their presence as mixtures. See: https://circabc.europa.eu/w/browse/26fd8014-faa3-4312-8895-1ef23f507346. Member States are also involved when EQS are set for priority substances under the WFD, and draw on the expertise of their relevant environment agencies and other technical support services. The development of Best Available Techniques (BAT) Reference Documents and BAT-Associated Emission Levels under the Industrial Emissions Directive also involves Member State and stakeholder experts.

DD: What do EU expect from its member countries to tackle these emerging contaminants?
ED: As mentioned above there is a legal requirement for Member States to identify and set standards for pollutants of national concern, i.e. the river basin specific pollutants. They are required to establish and implement programmes of measures to address pollutant discharges so that water bodies reach good status. The CIS process under the WFD engages Member States in discussions and technical work to advance the implementation of the Directive and the level of protection of water bodies.

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Interviewee:

Dr. Kees Roest
Senior Scientific Researcher
KWR

DD: Thanks a lot Dr. Kees Roest for giving me the time between your busy schedules. I will try to make it fast. I would like to know start by knowing your perception on the wastewater treatment plants of the Netherlands. How we can upgrade them in the future. And what about the emerging contaminants? Let's start with your general perception about that?

KR: Let's start with a general discussion. I have been through your questions. I don't know whether I can answer all of them, I don't have a crystal ball and I can't predict all of them. But yes, I know micropollutants and removal of micropollutants from wastewater is a hot topic and there are lot of intentions for removal of these compounds. The water boards and the industries are challenged to deal with these compounds and to remove them further. But that would be good for the water quality and for the drinking water companies. If a new technology can deal with these compounds that would tackle a lot of problems. So the current focus is more on removal of medicinal residues from the municipal wastewater, microplastics are still in its early infancy, I think. And probably there are some of the techniques in the picture for the removal of pharma residues, they cannot tackle bioplastics that count also for antibiotic resistance, antibiotic resistance genes that can cancer the environment. So still a bit need for lot of researchers actually, pilots and demonstrations, the characteristics of the lot of technologies, and need monitoring which can be quite expensive, but that is required to take good decisions by comparing technologies. We are doing several projects in this topic but sometimes it is difficult to get funding on comparative studies, so quite recently we have a proposal for comparing the environmental benefits, efficiencies of different technologies and make a guideline on them, that was not funded yet but I think these kinds of studies are important to make it good in the end. There are some differences among the water boards, but in general nearly all water boards are working on this topic intensively. There is a big will to improve the water quality. The water boards are working together with STOWA, KWR, TKI board of technology and STW, now they are part of NOW. They called joint forces and there is a programme called contaminants of emerging concerns, they are working on better prediction, better removal, new technologies development. It is important to have all kinds of opportunities and practice, there is lot of realm in all kinds of water parties in the cycle, in society to tackle this kind of problem.

DD: So Dr. Roest, what you have discussed is a brief overview of the efforts on wastewater treatment and micropollutants. But what about the treatment plants. How they are functioning at these moment?

KR: I think the Dutch Water boards including the drinking water companies, they are quite innovative. They are open for new innovations. They are also more and more open towards working with the commercial companies, to test new solutions. So, the circumstance are quite positive. But sometimes they are a bit conservative, so full implementation is sometimes difficult because of their structure. Because the water boards are public bodies, they have elections so that can take time. It also depends on political stature and composition of the water board, some water boards are less innovative than the others. But in general we have quite innovative environment here in the Netherlands and we have done quite well in water technology. And we have worked together. In many countries, cooperation among water boards, water companies and knowledge institutes is not always logical. Here sometimes we work together, sometimes we compete with the same organization that is quite unique and positive to work here.

DD: So we can assume that the water boards and the water companies are quite motivated. Perhaps the water boards have little bureaucracy inside but apart from that they are positive towards changes?

KR: yap, there are several pilot projects running and research that are partly executed by water boards.

DD: let's come to the issue of emerging contaminants. From when, they have been issue of concern for the water researchers?

KR: well, I think from 10 years, there are these contaminants in the water, maybe longer because the industrial contaminants and the contaminants from agriculture are there in the water. But it is also an issue of law and regulation. Meantime some solutions have been tested. I think, Switzerland is little bit ahead of us in it. For the Netherlands, I think we should follow the regulations of the EU in that. The water boards of the Netherlands have also tested some solutions for emerging contaminants removal.

DD: here comes the issue of Regulation. Along with Switzerland, Germany is also advanced in it. What could be the reason for that?

KR: I don't think the situation is more argent in Germany than the situation in Netherlands. I think the same water that passes though Switzerland and Germany, ends up in the sea through the Netherlands. So we are the sewer pit or final telltale. Even we remove all the contaminants here, still the water will not be good if they don't take action in Switzerland and Germany. So it is logical for Switzerland take action then Germany take action and then we take action. And they are rich countries so it is easy for them to do so.

DD: so, geographically Netherlands is at the end of the pipe. Thus the WWTPs here are the barrier before discharging the contaminants to the sea. It's a huge responsibility. In your opinion, how are the performing at this moment?

KR: there are some data revealed by the Dutch statistical body, CBS, there are improvements in the wastewater quality that is a positive sign. But if you look at the water framework directive, then there are lot to do, because a lot of water here are not according to the specs, that is quite difficult for a densely populated country like the Netherlands with quite a lot of animals. And we are receiving water from different countries, so there are charge of contaminants. So there is two signs. We are doing quite well and trying our best. On the other hand it is not quite enough to reach the water quality we needed. So there is still need to improve further.

DD: So how we can upgrade the WWTPs, for removal of those pollutants like antibiotics and microplastics?

KR: for microplastics and nanoplastics I am not even completely sure, which technology can deal with it, because it is relatively new and I am not even sure about the measures of microplastics and nanoplastics in the effluent. For antibiotics there are some advanced oxidations that can catch, the bacteria and the antibiotics resistant genes and membrane technology can stop the spread of antibiotic resistant microorganisms. So there are some technologies tested. But for nanoplastics it is still evolving. I don't know whether its membrane technology or advanced oxidation? But yes they are in development. And that also implies the need for more research, monitoring and development.

DD: so there are couple of techniques available at this moment. For instance UV or Ozonation or nanofiltration. But how can we retrofit the WWTPs with any of those?

KR: yap, it's possible. But it is yet not clear, which technology or technologies are better and that also depends on the effluent quality. With ozone you can have side products, each technologies have advantages and disadvantages. One technology can use more energy compare to another technology. And also not all WWTPs are of equal size besides different WWTPs and water companies use different technology. You have already summarized several technologies, some of them have been practiced in pilots, but often it is about costs because extra treatment costs extra money. So it requires legislation or clear stimulation to apply these technologies. It depends on the water boards to apply these technologies and industries as well, if they are not obliged by the legislation, their willingness to invest in these kind of technologies is difficult to achieve.

DD: so it's about legislation also. At this moment, do you think, the scientists have enough evidence to push the government for more strict regulation?

KR: I think they have lot of knowledge that lot of contaminants are entering the water and polluting it. It's also true for the drinking water, I think it's a matter of time that legislation will be more strict on this. It takes time but I think at the end it will come up with strict regulation. It has happened in the past. At the beginning wastewater treatment was about separating the solids, then comes the nutrients such as N and P so if you extrapolate it will only become stricter and tighter with discharge limits.

DD: So at this moment we are trying to convert the WWTPs into resource factory and water factory. How this agenda takes the emerging contaminants issue into consideration?

KR: Indeed we have the energy recovery and resource recovery, sort of network of the water boards, but yes the treatment plant can be the source of fresh water with energy may be less but nutrients like P in the form of struvite, cellulose and other products and water of course. In it, the contaminants of emerging concern is a big topic. If you want to reuse the water it depends on the reuse application but in general you don't want contaminations so these contaminants have to be removed may be with membrane or advanced oxidation so that the water fits for purpose, such as agricultural reuse or reuse in the industry, not so much for drinking water purpose in the Netherlands. Although worldwide it's a topic because water is very important for people, industry an economic development.

DD: so how can we bring the water factory issue strongly to the water policy agenda so that it strengthens the contaminants removal discussion as well?

KR: at this moment circular economy is a hot topic because we are thinking about reuse a lot. But the economy is also important because the solutions have to be cost effective as well. In these case you have to remove the contaminants if you want to compare the reused resource with the virgin resource. But it's also not true that virgin resources are always clean for instance, phosphorus, in some places of the world, it's collected from the earth and found very much polluted. So if you recover it from water than it is better. This way you can achieve sustainability. This also helps tackling the climate change because you can recover energy. But recovering resources needs energy and if you want to remove emerging contaminants that requires more energy. Thus we need to have energy from renewable sources but we need the resources and water as well.

DD: Since there are so many pilot projects conducted and some are going to start. So when should we expect a strong regulation to come for this?

KR: that's a difficult question, it also depends on the politicians, I think it is possible to use lot of this compounds that means regulations can be implemented in quite short notice. I think it is better to work in the EU level and it might also be better to work in steps. For next few years a certain level of certain contaminants should be removed then in the few years extra contaminants should be removed on the water board level, first tackle the big installations then the small installations. I think without regulation a lot of contaminants removal process will not perform. But if it can be implemented in next 2 years, 5 years or 10 years, sooner the better for our well beings.

DD: Is there any pilot done on the feasibility analysis of these technologies? May be financial feasibility or limited to technical feasibility only?

KR: for technical feasibility, yes. The technical feasibility has been checked. But analyzing financial feasibility is difficult because it requires extra money. I am not sure about the number but probably it require few euros/person/year to apply effluent polishing. So it's a decision for the organizations or the politicians because at the end the inhabitants have to pay in a way or the other. It depends whether the people will pay it to the water boards, or the pharmaceuticals will pay it even then the people that works in the pharmaceuticals have to pay this or by the tax to the national government. But at the people has to pay the extra money.

DD: But the extra cost going to be incurred by the extra treatment, can it be neutralized by more efficient use of water?

KR yes, I can give one example of the drinking water company, more than 20 years ago they established aqua minerals, this organization was run by the drinking water companies to get rid of their waste streams in a cheaper way and during these period up to now, most of these waste streams have been converted to resources so they get money out of it. On the other side to get resources you need to invest. I don't know if we can do all sorts of resource recovery in an energy neutral way, sewage has lot of money which is not easy to recover, because you need a lot of investment in technology, lots of sensors. If you use less you will pollute less, and then it would be more concentrated. And it is easier to make energy and resource out of it. So yes, that's how it is.

DD: So Dr. Roest, you have answered all my questions and also given some valuable remarks on this issue. I very much appreciate your help. I will make a transcript out of the audio and will send it you. If you think that's ok, then please give your consent to use that in my thesis. Thanks again.

KR: Sounds good. I will you best of luck for your thesis and for the masters as well.