Additional MSc Thesis Project

Urban Wastewater Management of Willemstad, Curaçao, and Environmental Implications

A qualitative and quantitative investigation on urban wastewater fluxes

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MSc Environmental Engineering
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Additional MSc thesis in Environmental Engineering

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A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering

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Abstract

Curaçao's coral reefs are subjected to a deteriorating momentum risking the health and therefore sustainability of this vital ecosystem. Despite the dependency of the Islands prosperity on the condition of the ecosystem, research suggest that the wastewater management is likely be a significant contributor to this effect. Incorporating both open literature results and information obtained from an extensive constructed research network, this study demonstrates essential aspects of the urban wastewater management system of Willemstad regarding quantity and quality of the urban wastewater fluxes and its potential environmental implications. The system, which merely connects 33% of Curaçao's population, is concluded on to be outdated and insufficient with respect to capacity as well as treatment efficiency. Although it is solely designed for pure domestic wastewater, this study concluded on and demonstrated the significant impact of illegal discharge onto this system by industrial sectors leading to both high contamination loading and increased wastewater volumes. The combination of these features is the major cause of wastewater discharge pathways into marine environments. Arising from the constructed urban wastewater flux model, which visualizes the wastewater management system, 14 discharge locations correlated to significant environmental contamination pathways are identified with Piscadera Bay, Rif Mangrove area, Playa Kanoa and Shut concluded upon as the utmost important. Furthermore, the model revealed that the urban wastewater is predominantly directed towards treatment plant Klein Hofje via either the norther trajectory (Bonam - Suffisant F - Garipitoweg - Argentianweg - Klein Hofje) or the southern one (SVB - Klein Hofje). Also the quantity and quality of the fluxes are estimated for based on the connected area and the potential industrial activities within it. However, validation of these estimations are recommended for since no water quantity and quality analysis was performed or available for conducting the modeled estimations. Furthermore, since the system is partly combined sewage system, hence harvesting stromwater fluxes as well, its effect is recommended to incorporate in the model and estimations for accuracy purposes. Lastly, the government reports that at least 90% of all industrial wastewater is discharged either directly into the ocean or onto the sewer system. Since the actual ratio as well as the water quality is remains unknown this is recommended for future research. Overall, this study enables tailored future research programs overcoming the discussed limitations and with that significantly contributing to eliminating the current existing white spot concerning the effect of urban wastewater fluxes on the marina ecosystem of Curaçao.

Keywords

- Urban Wastewater Management
- Environmental Implications
- Curaçao Coral Reefs

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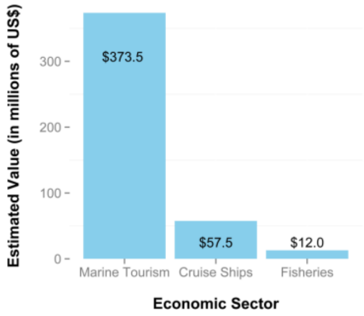
1 Introduction

Coral reefs are essential ecological entities of high complexity inextricably linked with the stability and functionality of both marine- as well as coastal-ecosystems. Despite its ocean coverage percentage being less than one per cent, it harbours over 25% of all marine species resulting in an extraordinarily high level of biodiversity [Coral Reef Alliance, 2016]. These marine biodiversity 'hotspots', which are among others described by Reid [1998] as "areas particularly rich in species, rare species, threatened species, or some combination of these attributes", are crucial in the providence of life-supporting, or even life enabling, ecosystem services. With these coral reefs, Mother Nature accommodates, along with others, food provision, storm surge protection, carbon sequestration, cultural and aesthetic value, tourism attraction, and functions as extreme climate event buffer [Cinner et al., 2016; Hughes et al., 2017; Worm et al., 2006; Eddy et al., 2021; Bellwood et al., 2004]. Regardless of the extreme dependence of global human societies on the functionality and therefore health and sustainability of these ecosystems, research increasingly conclude on alarming signals pointing towards the destabilizing effects of a multitude of external stressors. Such stressors are widely studied and originate both from natural origins, such as hurricane damage and fresh terrestrial water input, as well as anthropogenic induced sources such as pollution by wastewater and global climate warming. Correlated to these stressors, research performed by Eddy et al. [2021], highlighted that currently, compared to the year 1950, the global coverage of living coral has declined by approximately 50%, the capacity to provide the mentioned ecosystem services has halved, and the total coral reef-associated fish yields has decreased by 60%.

Research performed by Wilkinson and Souter [2008] shows that similar decreasing trends are present among the coral reefs within the Wider Caribbean Region (WCR) showing an average living coral coverage decrease of approximately 50% over the course of the last 40 years. Adding to that, the trajectory of this ecosystem decline is expected to continue, leading to a total loss of the Caribbean coral reef ecosystems of 60% in the next 30 years as a result of ongoing external anthropogenic stresses [Estep et al., 2017]. Putting this in an economical perspective; the annual yield of these coral reefs is estimated to be $1.5 million per kilometre of healthy Caribbean reef solely based on tourism and fisheries [Estep et al., 2017]. This estimation is supported by Diez et al. [2019] which estimated a total annual gross revenue for the WCR to be close to 60 billion US dollars directly produced by marine and coastal tourism. Additionally, they assume that inaction, hence losing large parts of these coral reefs,

Habitat	Direct Value ($/ha/year)	Indirect Value ($/ha/year)	Total Value ($/ha/year)
Coral Reefs	$28,300	$29,200	$57,500
Mangroves	$500	$30,100	$30,600
Seagrasses	$6,200	$29,300	$35,500

(a)



(b)

Figure 1.1: (a) Estimated values for economic sectors relying on marine and coastal resources, including marine tourism and associated expenditures in the hotel sector; cruise tourism, and fisheries. (b) Estimated values of three coastal marine habitats in Curaçao. Direct values refer to values captured in the formal economy; indirect values are those that support human and economic health but are not formally reflected in the. Source: Waitt Institute et al. [2016]

could therefore put a significant amount of people, as well as governments, in economic jeopardy and is very likely to be significantly more costly compared to costs associated with pollution prevention and management strategies. Primarily, one out of four jobs within the WCR is directly dependent as well as impacted by the health of marine ecosystems [De Paulo, 2016]. Furthermore, research indicates that the loss of other ecosystem services accompanied by coral reef degradation, such as shoreline protection services, adds besides the extreme intrinsic value depletion to an instrumental value loss between US $700 million to US $2.2 billion [Austen et al., 2019; De Paulo, 2016]. Moving towards a sustainable ocean economy, i.e. the Blue Economy, and establishing mutualism between society and ecology, encompasses enormous potential for development, income growth, poverty reduction, and environmental protection [Diez et al., 2019].

The increasing trend of loss of coral reefs and the significant accompanied impacts is one of the major, both current and future, issues the government of Curaçao is facing. Economically, the Waitt Institute in collaboration with the organisations Blue Halo Curaçao and the Sustainable Fisheries Group UC Santa Barbara has estimated that healthy coral reefs support the Island's economy by approximately $57.000 (ha/year) translating to an approximated $375.5 million annual total economic value contribution as indicated by Figure 1.1 [Waitt Institute et al., 2016]. Even though the coral reefs surrounding Curaçao are argued to be significantly more healthy compared to reefs in the WCR, owing to relatively minim freshwater input originating from terrestrial surface runoff due to the combination of low annual rainfall levels and little topography, coral reef degradation occurs and is likely to worsen [Estep et al., 2017]. Anthropogenic external stressors are enhancing this deteriorating momentum within these marine ecosystems. Literature concludes that especially the South Coast of the Island in particular shows this coral reef decline as depicted in Figure 1.2, hence suggesting a higher sensitivity or greater environmental implication effect [Estep et al., 2017]. One of the key characteristics in this trend, yet still in need of a sound scientific foundation, is indicated by among others Diez et al. [2019] to be directly correlated to Curaçao's wastewater management protocols, resulting in high amounts of source pollution via sewage systems effluent discharge outlets. One of the research programs investigating the linkage between terrestrial pollutants and input in the growth and survival of nearshore coral reefs in the Dutch Caribbean is the SEALINK Program [Vermeij, 2021]. An important 'white spot' currently relates to the urban wastewater management concerning potential pollution fluxes directed towards the ocean. To this end, this additional master thesis project intents to provide valuable insight through investigating the urban wastewater management of the capital city, Willemstad, and its potential environmental implications. This thesis report elaborates on the research focused on estimating the magnitude of urban wastewater fluxes directed towards the ocean, indicating the respective water quality of the fluxes, and pinpointing both the origin as well as endpoints of potential contamination within these fluxes.

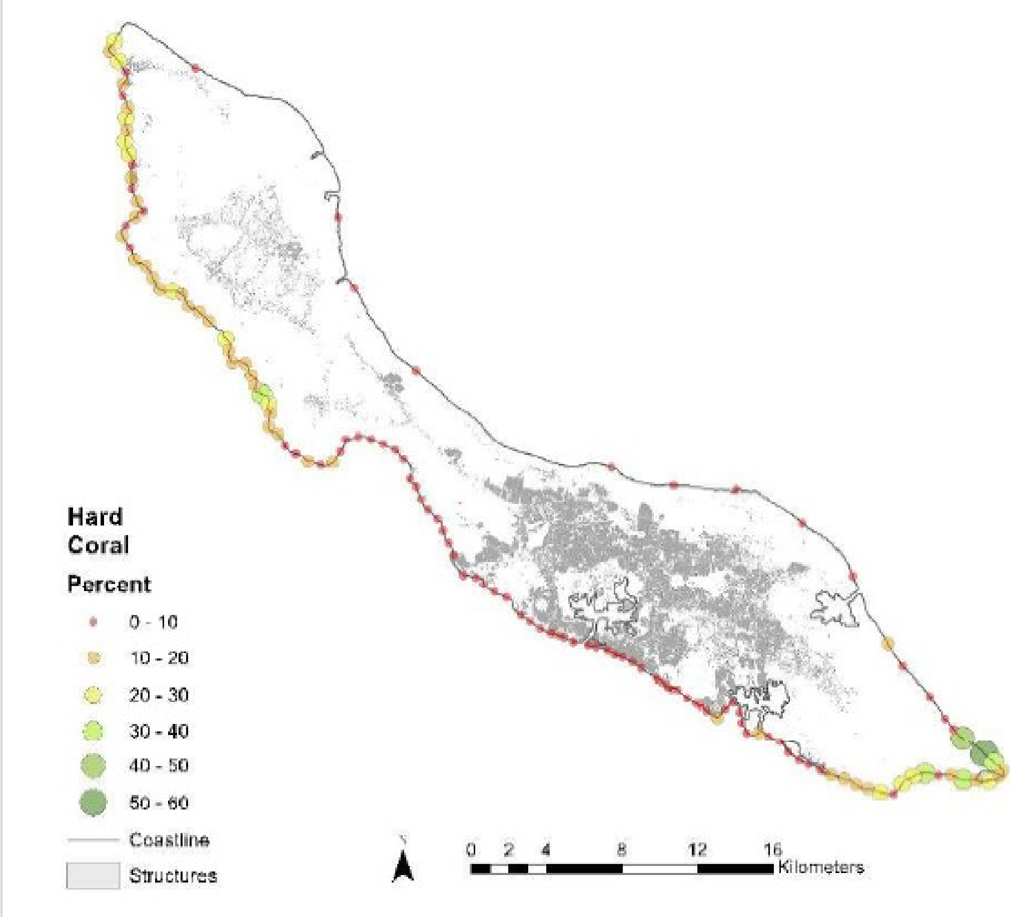


Figure 1.2: Average coral cover of 148 sites. Source Estep et al. [2017]

1.1 Objective, Relevance & Research question

This additional master thesis project is aiming to produce a sound estimation on the quantity and quality of urban wastewater fluxes originating from Willemstad, Curaçao, to gain valuable insight in the management cycle of domestic and industrial wastewater fluxes. Its relevance is directly coupled to a currently existing 'white spot' within the SEALINK Program. This program aims to asses terrestrial water fluxes affecting the growth and survival of nearshore coral reef in Curaçao. One of those fluxes suspected of potentially causing significant negative effects are the urban wastewater fluxes. To this end, this research contributes to resolving this gap and promote better understanding of linkage between terrestrial water fluxes and environmental implications. Additionally, this research aims to successfully identify significant urban wastewater management bottlenecks. At one end, these bottleneck aspects identify where system difficulties could arise whilst on the other end provides locations estimated to be of significant environmental impact. Ultimately, these aspects pinpoint aspects which are convenient for further and more thorough water quality analysis contributing to the efficiency of future research programs as well as better understanding of the origin of stressors causing ecosystem degradation effects.

Arising from this objective the research scope is limited to urban wastewater fluxes, defined as domestic wastewater and industrial wastewater, and does not include other elements crucial to the hydrological functioning of the capital such as infiltration capacity, groundwater flow, drainage, and stormwater management. However, since the latter is hypothesized to be highly entangled with the management of urban wastewater fluxes, its functionality will be discussed superficially and its estimated effects will be elaborated on.

The main research question of this project is captured in the following sentence:

Research Question

"How does the urban wastewater management of Willemstad, Curaçao, function with respect to the quantity and quality of wastewater fluxes directed towards the ocean?"

As a means to answer this research question the following sub-questions are stated:

1. *What is the current state of the wastewater management system?*
2. *Estimation of potential quantity & quality parameters of urban water fluxes?*
3. *Which discharge locations could potentially have large contamination effects on the marine environment?*

Overall, stated sub-questions are sought to be answered through literature study and information congregation from collaboration with local institutes and peer researchers. Predefined limiting factors for this research are:

- Information availability on current water management systems might be scarce or not open due to privacy laws and sensitivity of the material.
- The time frame of the research (10-15 weeks) is relatively short with respect to the complexity of the material.
- There could potentially exist a language, as well as, cultural barrier between researcher and local sources of information. This could potentially challenge collecting the required information.

Assumption that have been made carrying out this research are:

- The gathered information provided by government entities is assumed to accurate.
- It is assumed that all available information within the government concerning urban wastewater management, which is cleared for usage within this research, has been shared. Hence, it is assumed that there is no intentional information withhold.
- It is assumed within the constructed urban wastewater flux model that, under normal flowing condition, i.e. no overloading due to stormwater drainage input, fluxes are unpartitioned. Hence, fluxes are either fully flowing according to their 'main trajectory' or fully discharged via the plotted emergency discharge pathways.

1.2 Report structure

The report structure of this thesis project is displayed in table Table 1.1.

Table 1.1: Report structure

Chapter	Section	Content
Chapter 1: Introduction	Section 1.1	Objective, Relevance & Research Question
	Section 1.2	Report structure
Chapter 2: Research Area	Section 2.1	Topography, Climate, and Demography
	Section 2.2	Site Boundary
Chapter 3: Methodology	Section 3.1	Research strategy
	Section 3.2	Information Network
	Section 3.3	Urban Wastewater Flux Model
Chapter 4: Literature Results - Current Situation	Section 4.1	Foul Sewer System
	Section 4.2	Governmental Involvement
	Section 4.3	Industrial Wastewater
	Section 4.4	Drinking Water Production
Chapter 5: Modelled Results - Wastewater Flux Map	Section 5.1	Urban Wastewater Flux QGIS Model
Chapter 6: Discussion	Section 6.1	Key Results
	Section 6.2	Result Interpretation
	Section 6.3	Limitation Acknowledgement
Chapter 7: Recommendation	Chapter 7	Recommendation
Chapter 8: Conclusion	Chapter 8	Conclusion

In the text above the subject of this research is introduced, the objective is described, the relevance is elaborated, the research questions are presented, and lastly the report structure is constructed and visualised.

The second chapter, Chapter 2 *Research Area*, of this report presents and elaborates on the topography, climate and demography of Curaçao which is essential to the overall understanding of this report. Furthermore, it presents the defined site boundary as well as depicts a visual presentation of it.

Chapter 3 *Methodology* describes the applied methodology. This chapter is constructed out of three sections elaborating the specific research strategies applied on the sub-research questions, describing the developed information network, and explaining how the Urban Wastewater Flux Model is constructed respectively.

The fourth chapter, Chapter 4 *Literature Results - Current Situation*, presents the results arising from both open literature and the information gained through the developed information network. In particular, this chapter is crucial to answering the first and second stated sub-questions by extensively describing the current state of the urban wastewater management system of Curaçao.

Chapter 5 *Modelled Results - Wastewater Flux Map* presents the constructed QGIS model incorporating results arising from the previous chapter. Ultimately, it visualizes the urban wastewater management of Curaçao as well as forms the foundation for answering the third sub-question.

Chapter 6 *Discussion* firstly recapitulate the key research results. Next, it carefully discusses how the results should be interpreted. This chapter finalizes with a section dedicated to the acknowledgement of the research limitations.

The seventh chapter of this report, Chapter 7 *Recommendation*, presents recommendations for further research.

Lastly, this reports finalizes with the concluding chapter presented in Chapter 8. This chapter answers the main research question, draws conclusions from the obtained results and argues the scientific contribution of this study.

2 Research Area

This chapter provides additional information concerning the topography, climate and demography of Curaçao which is crucial to the overall understanding of this research. Furthermore, it elaborates on how the research area is defined as well as gives a visual representation of it.

2.1 Topography, Climate & Demography

Curaçao is located within the Southern Caribbean Dry Zone (SCDZ) approximately 40 miles north of the coast of Venezuela [Meteorological Department Curaçao, 2021; Ministry of Health, Environment and Nature, 2014]. The prevailing climate is characterized as semi-arid to arid and has distinguishable dry and wet seasons stretching from February to June and September to January respectively [Jager, 2021]. The Meteorological Department Curaçao [2021] reports that the annual average air temperature in Curaçao is approximately 28 °C with fluctuations of roughly -2 °C and +4 °C as portrait in Figure 2.1. This temperature is indicated by Girigori de Flores Martinez [2020] to be extremely likely (95% certainty) to increase accompanied by increased frequency of hot days, warm spells, and heat waves. Furthermore, the Island receives on average 600 [mm] of cumulative rainfall annually with absolute peak rainfall intensities in December with a monthly precipitation level of 100 [mm]. Precipitation events are generally characterized by relatively high intensities and short duration, also revered to as 'isolated showers', often exceeding the immediate infiltration capacity of urban areas due to their high ratio of paved surfaces and causing additional challenges with respect to efficient surface runoff drainage management [Meteorological Department Curaçao, 2021]. The frequency, as well as the intensity, is estimated to significantly increase with certainties of 50% and 90% [Girigori de Flores Martinez, 2020]. The total territory belonging to the domain of Curaçao is 444 [km2], contains a total coral reef coverage of approximately 7.85 [km2], and is called home by roughly 153.066 registered inhabitants [Jager, 2021; Ministry of Health, Environment and Nature, 2014; Government of Curaçao, 2017; Cordilia, 2018]. The island population is grossly concentrated in the capital city Willemstad, which is located around the natural harbour Schottegat, accommodating nearly 90% of the total population. Additionally, Curaçao has a flourishing tourism domain, bringing on average over 460.000 tourists to the Island annually [Jager, 2021].

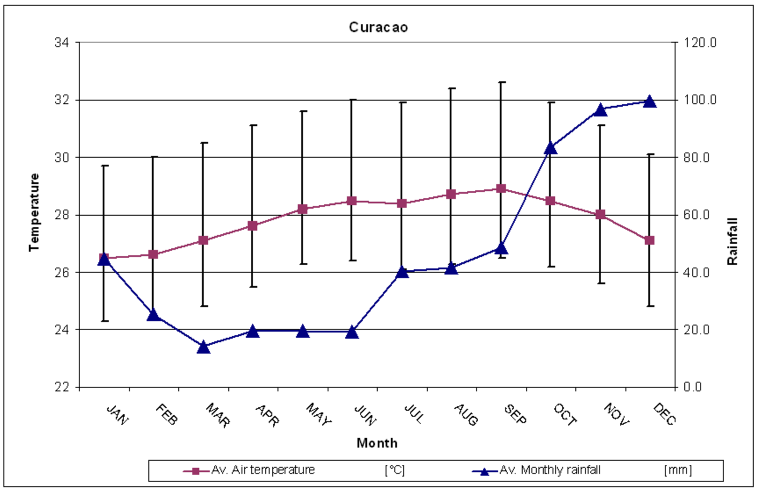


Figure 2.1: Overview of climate parameters Curaçao. Source [Meteorological Department Curaçao, 2021]

2.2 Site Boundary

Despite the fact that inadequacy of wastewater management poses a significant threat to both Curaçao's ecosystems and society over the entire Island as a whole, this research focuses on the role of the urban wastewater management of Willemstad within this dilemma. For the situation of Willemstad, it is expected to find the highest ratio of the population connected to the central sewage system as result of the historical development of system along side the economy, industry and housing on the Island. Consequently, the largest wastewater fluxes are expected to be located within this urban area. However, detailed information describing the actual number of connected households is scarcely available nor up to date with recent developments as pointed out by U. Cordilia [1] and C. Profas [2]. The domestic wastewater from households located within Willemstad but which are not connected to the central sewage system are stored within septic tanks or cesspits. Furthermore, how and if the surface drainage system, which is visible as gullies throughout the area, is connected to the central sewage systems remains partially undescribed in the open literature. Research performed by van der Molen and Ruth [2000] indicates that the original system, which was built between the years 1940 till 1960, handled domestic, industrial, agricultural, and surface runoff, i.e. a combined sewage system. However, despite the prevailing climate in Curaçao involving high-intensity rain events in combination with a high ratio of paved surfaces in the urban area, often causes the exceeding of the storage capacity of the sewage system, resulting in emergency discharge onto the streets or into marine and terrestrial environments. More detailed

[1]District chief and Project leader Public Works section Water Management. Personal interviews July and August 2022

[2]Senior Policy Officer within the Ministry of Health, Environment and Nature. Personal interview August 2022.

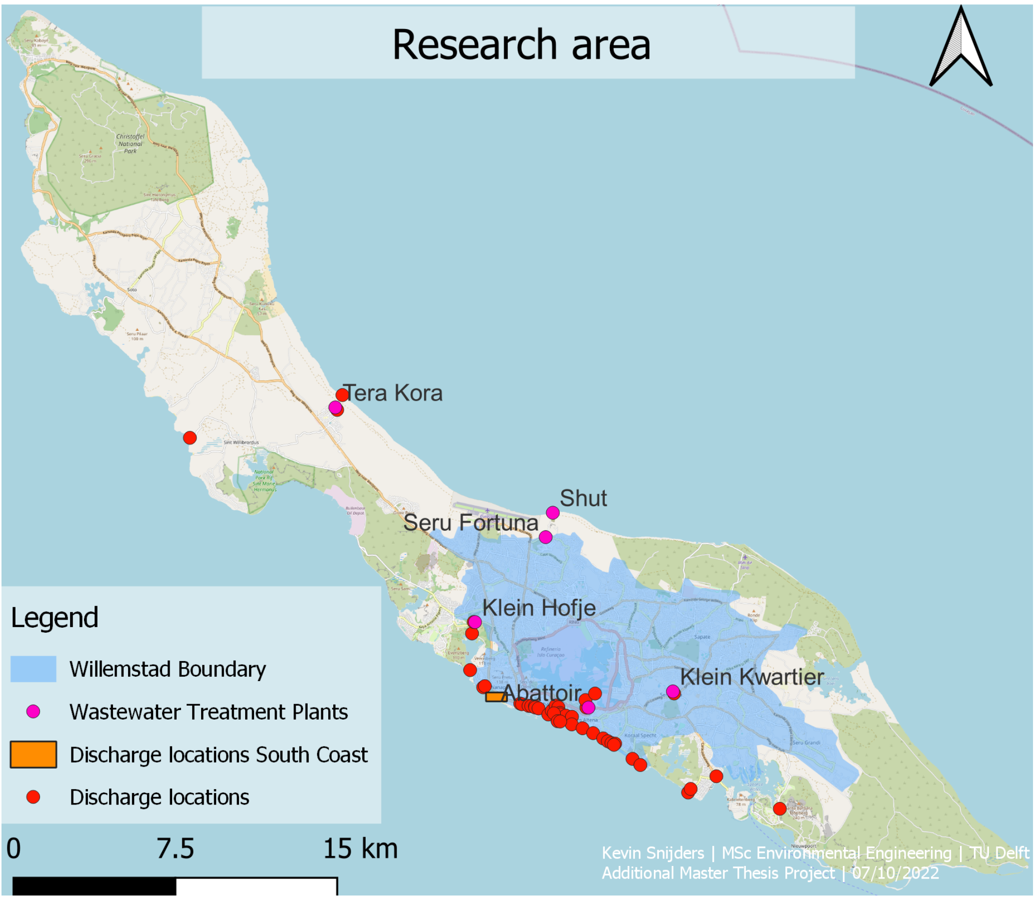


Figure 2.2: Visualisation of research area. Authors' own figure produced using QGIS. October 2022

information concerning the current state of the central sewage system is presented in the fourth chapter of this report.

The site boundary constructed for the purpose of this research is illustrated in Figure 2.2. This figure presents a Geographic Information System (GIS) model visualizing the study area and presents the unmodified information provided by SEALINK initial to this research. This information includes effluent discharge locations as well as the locations of WWTP's. The defined site boundary, however, should not be interpreted as an absolute research boundary. As mentioned earlier, most of the domestic and industrial wastewater volumes as well as the contamination loads originate from this area but could potentially be discharged outside the constructed site boundary. Therefore, discharge locations that correlate to Willemstad's activities, but are geographically situated outside of the city, will still be included in this research.

3 Methodology

This chapter presents the applied methodology. First of all, Section 3.1 briefly describes the specific research strategy to find answers to the individual sub-questions. Next, as part of the presented strategies, Section 3.2 elaborates on the established information network. Lastly, this chapter finalizes with the method applied to construct an Urban Wastewater Flux Model, which is described within Section 3.3.

3.1 Research strategy

Satisfying the research objective and answering the stated research question required different strategies that have been applied throughout the execution of this research. The core of these strategies focused on the aggregation of available information and building upon them in order to safeguard both the validity as well as the scientific value of this research. Concerning the first stated sub-question; '***What is the current state of the wastewater management system***', an extensive information network has been established and utilized to gather the latest details with respect to the Wastewater Management System (WWMS). This network, presented in Section 3.2, consists of government ministries, research organisations, individual researchers, Non Governmental Organisation (NGO), and teaching staff of the University of Curaçao. It has proven to be of utmost value to this research in general and for closing the knowledge gap existing within WWMS research. Moreover, the information emanated from this network offered essential insight into the potential quantity and quality parameters of urban wastewater fluxes required to answer the sub-question; '***Estimation of potential quantity & quality parameters of urban water fluxes?***'. Yet, in order to fully answer this, open-source literature has been consulted as well. On top of that, these open sources have been used to gather general information supporting the understanding of the WWMS. Lastly, the final sub-question, which is stated as; '***Which discharge locations could potentially have large contamination effects on the marine environment?***', has been answered based on a constructed GIS model representing the essential information obtained by the first and second sub-questions. Overall, the constructed answers to these sub-questions, which are presented in Chapter 4 and Chapter 5, formed a solid foundation that enabled the answering of the main research question being '***How does the urban wastewater management of Willemstad, Curaçao, function with respect to the quantity and quality of wastewater fluxes directed towards the ocean?***'.

3.2 Information Network

The established information network aims to provide valuable insight into the currently available information with respect to the sewage system and close the existing knowledge gap. As mentioned, it consists of multiple entities each individually responsible for, or connected to, an aspect of the system. In favour of complete information transfer as well as to support future research programs this network and its information will be shared openly. However, since some information is defined as sensitive, this transferring process will be in consensus with both the author of this report, as well as the author of the original informative documents. The figure below gives a visual representation of this network, whereas Table 3 gives an overview of the gathered information with acknowledgement to its original author(s).

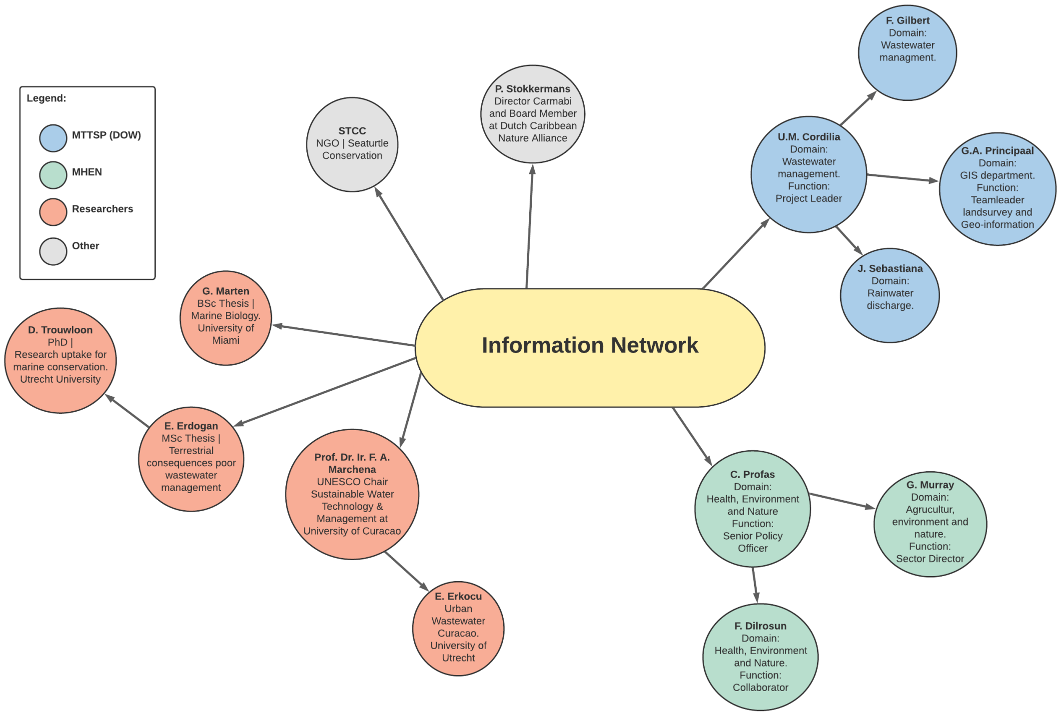


Figure 3.1: Information network diagram. MHEN: Ministry of Health, Environment and Nature. MTTSP: Ministry of Traffic, Transportation and Spatial Planning. DOW: Domein Openbare Werken (Dutch acronym). Personal contact information sharing in consensus of author and information source.

3.3 Urban Wastewater Flux Model

Constructing an answer to the second stated sub-question resulted in a deliverable in the form of a GIS model. This model encompasses all of the most essential information concerning wastewater quality- and quantity-fluxes and presents a summarising visualization. This result is constructed in the following order. First of all, the discharge locations known by the SEALINK project are compared and complemented with the information on discharge locations provided by the research of Cordilia [2018]. This resulted in an overview of every documented discharge location situated or correlated to the area of Willemstad. Each discharge point is thereafter analyzed and categorized based upon activity (continuous- or discontinuous discharge), estimated water quality, and estimated water quantity which is represented by symbol form (circle or triangle), colour (red, orange, burgundy), and size respectively. This categorization is based upon the results constructed by Cordilia [2018] as well as flux diagram provided by Ministry of Traffic, Transportation and Spatial Planning (VVRP, Dutch acronym) (MTTSP). All discharge locations are labelled numerically which corresponds to the overview described by Cordilia [2018] and presented in Table 1. The estimated water quality and quantity are based upon gathered information from both the Ministry of Health, Environment and Nature (GMN, Dutch acronym) (MHEN) and the MTTSP. The full attribute table of this model layer is presented in Table 5 in the appendix of this report. Secondly, a model containing all digitally documented pump-station locations, provided by G.A. Principaal [1], is plotted. Again these pump stations are categorized on estimated water quality and quantity which is represented by a colour (light green and dark green) and size differences. Again the specific attributes are presented in the appendix in Table 6. Next, the WWTP's and the location of the documented industrial areas are visualised a by blue and red areas respectively. Both attribute tables can be found in the appendix Table 9 and Table 10 respectively. Thereafter, the discharge locations, pump-stations, WWTP's, and industrial areas are connected based on the flux scheme provided by MTTSP, MHEN, and the information presented in Table 1. The orientation of these fluxes was indicated by the orientation of the arrowhead, water quality is represented by a colour (light blue, dark blue, purple), and the flux quantity was roughly indicated by its size/thickness. Additionally, emergency fluxes, which are determined as fluxes that only flow during pump-station failure mechanisms, were represented by a dashed orange line. To support the clearness of the map, the models present the flow for each known flux with a numerical value plotted against a white transparent background. The full attribute of this flux model layer is presented in Table 7. The final layer added to the model is called 'potential fluxes' and represents fluxes that are very likely to exist, but which are not documented in any of the information provided by the government. These fluxes are represented by a yellow dashed line and mainly form the potential foul sewer system orientated to WWTP Klein Kwartier. The full attribute table is presented by Table 8 in the ap-

[1] Teamleader LandSurvey and Geo-Information at Public Works Curacao

pendix. Lastly, unknown quantity fluxes of wastewater at discharge locations, pump stations, and flow streams are represented by the number -999 indicating that there is likely to be a flux but numerically undefined. Moreover, within the attribute table the level of confidence is described according to four levels; high, medium, low, and very low. The highest level is given when the information is provided by the governmental agency responsible for the WWMS being MTTSP. A medium confidence level still provides a very likely representation of reality, however, data is only implicitly described within the gathered information. The lowest levels of confidence, Low and Very low, are considered when little to no information was available and the author used implicit sources of information; incomplete data from government, narratives from local people, personal experience from living on the Island, or logical reasoning.

Since the model is merely a simplified representation of reality aiming to visualize the urban wastewater fluxes, it does not take into account the actual location of the situated pipelines within the existing sewage system. Moreover, the model is based upon information provided by the government of Curaçao which roughly dates back to the year 2018. Therefore, most recent developments could potentially not be included within this model due to the fact that these are either not yet documented by the government, or deemed sensitive and not cleared to be used within this report. Validation of the model could be performed by MTTSP since they are the responsible Ministry for the wastewater management system but has yet to be performed due to the limited time frame of this research.

4 Literature Results - Current Situation

This chapter aims to present the first results arising from a literature study and the information gathered throughout the mentioned information network. It will elaborate on the current state of WWMS on the Island Curaçao. The chapter is constructed of four paragraphs describing the overall functionality of the wastewater network, the influence of the stormwater drainage system on the central sewage system and the governmental influence on the management protocols respectively. Ultimately, the information presented in this chapter answers the first stated sub-question "*What is the current state of the Wastewater treatment management system?*". Moreover, this information provides textual elaboration with respect to the quality and quantity fluxes within this sewer system which form in combination with the results presented in Chapter 5 the answer to the second stated sub-questions. Ultimately, these literature results provide a crucial foundation for purpose of answering the main research question.

4.1 Foul Sewer System

A general trend that has been described and elaborated through research performed by Ministry of Health, Environment and Nature [2014] and Fuldauer et al. [2019] emphasizes the increased difficulty of Small Island Developing States (SIDS) to effectively, sustainably, and sufficiently manage their waste streams due to their characteristics regarding remoteness, high input due to tourism, limited resources, and high per-capita infrastructural costs. Focusing on the management systems of Curaçao concerning processing and directing wastewater, it is subjected to additional characteristics amplifying the burden of the problem, causing high rates of partially treated or untreated effluent to directly be discharged into natural environments [Luff et al., 2013; Diez et al., 2019]. First and foremost, one of the key factors for this sewage system deficiency is described by Cordilia [2017], in the latest Evidence-Based Infrastructure report published by the Government, indicating that 67% of the population is not connected to the sewage systems. These unconnected wastewater sources are generally stored within cesspits and septic tanks or directly discharged into the environment. The tanks typically allow for infiltration of the stored water into the soil, hence facilitating natural groundwater recharge. However, when the capacity of the tank is exceeded it needs to be emptied by a vacuum collection truck and the wastewater is thereafter either transported to WWTP's or transported and directly discharged into marine environments at the government-designated location Shut

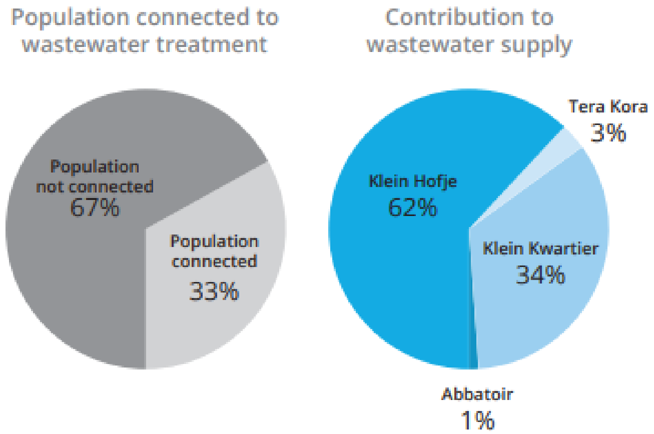


Figure 4.1: Overview of wastewater management in Curaçao and partitioning of the connected wastewater to the different WWTP's. Note, Treatment plan Tera Kora is no longer operational since 2019 and directly discharges into the natural environment. Figure obtained from [Ministry of Traffic, Transport and Urban Planning et al., 2018]

[Ministry of Traffic, Transport and Urban Planning et al., 2018; Civil Engineering Caribbean N.V., 1991]. The total amount of cesspits and septic tanks is estimated to be 42375 and 1703 respectively [Jager, 2021]. Furthermore, Cordilia [2018] concludes in his research that at least 84% of all produced wastewater is not treated and directly discharged to the ocean. Of the remaining one-third (33%) of the population, which are connected to the central sewage system, the effluent is transported, via either pressure pipes or gravitational pipes, to four sewage plants as indicated in Figure 4.1. Of this network, which was predominantly constructed in the early 1980s, Cordilia [2018] states that 85% is in direct need of improvement, maintenance, or even total replacement primarily due to the usage of old materials such as iron, concrete, and asbestos, as well as the fact that it substantially exists of a combined sewage system which is defined as problematic due to high stormwater flux inputs. Altogether the current cumulative treatment capacity of the sewage network is calculated by the Department of Public Works to be approximately 5.617 cubic meters per day but is often exceeded resulting in direct discharge or insufficient treatment due to this overloading [Ministry of Traffic, Transport and Urban Planning et al., 2018; Jager, 2021; Cordilia, 2018]. Moreover, despite that C. Profas [2] as well as U.M. Cordilia [1] both confirm that industrial water is deemed to be too polluted to be treated by the current WWTPs, these fluxes are often illegally discharged onto the central domestic sewage lines contributing overloading the system both quantitatively and qualitatively. The role of industrial wastewater fluxes will be discussed more thoroughly in paragraph Section 4.3.

4.1.1 Wastewater Treatment Plants

This paragraph presents the most recent and officially documented state of all four WWTP's as presented in the last version of the 'Wastewater structure plan' constructed by Civil Engineering Caribbean N.V. [1991] and the research performed by Cordilia [2018]. The sequence of presentations is based on the order of significance within the overall wastewater network. Moreover, the required effluent quality requirements to meet standards of safely discharging into environmental bodies or reuse within the agricultural domain are presented in Table 4.1. Lastly, Table 2 in the appendix presents what types of wastewater are suitable for treatment by the current state of the WWTP's.

Table 4.1: Effluent Requirements. Table information obtained from Cordilia [2018]

Parameter	Value	Unit
Chemical Oxygen Demand (COD)	<100	mg/l
Biological Oxygen Demand (BOD)	<30	mg/l
Kjeldahl Nitrogen	<40	mg/l
Total Suspended Solids (TSS)	<100	mg/l
Ammonium (NH_4^+)	<40	mg/l
Chloride (Cl^-)	<250	mg/l
E-coli	<1000CFU/100	mg/l
Electric Conductivity (EC)	<2250	µS/cm
pH	6-8.5	-

Klein Hofje

The most significant WWTP, cleaning the bulk of the collected wastewater, is 'Klein Hofje' which is built in 1986 with an design capacity of 2.300 [m^3/day]. Later, it is expanded to treat 40.000 inhabitant equivalent, i.e. 3.500 [m^3/day], with a peak capacity of 350 [$m^3/hour$] and approximated influent design parameters as presented in Table 4.2 DOW [1991b]. However, research performed by [Cordilia, 2018] suggests that, due to the combination of including more neighbourhoods on the sewer system as well as increased population density, this treatment plant currently operates at overcapacity of approximately 15 to 20 percent. Additionally, in line with future developments, it is expected that the daily wastewater load will increase to approximately 4.349 [m^3/day] accompanied by an estimated additional load of 600 [m^3/day] originating from vacuum truck companies Cordilia [2018]. To meet future needs a minimum capacity expansion of 218%, i.e. the total hydrological capacity of 5.000 [m^3/day], will be required.

Primarily the wastewater is treated mechanically whereafter secondary biological treatment is initiated. By comparing the effluent quality of the treated water to the influent quality of the wastewater, an approximation of the individual treatment efficiency for the specified WWTP has been determined and is presented in Table 4.2.

Table 4.2: Influent design parameters of WWTP Klein Hofje combined with the effluent quality (June - November, 2018) of WWTP Klein Hofje to determine specific treatment efficiency. Information obtained from MIC N.V. [2016]

Parameter	**Influent Value**	**Effluent Value**	**Unit**	**efficiency**
COD	350	101.6	mg/l	70.97%
BOD	870	43.1	mg/l	95.05%
Kjeldahl Nitrogen	170	46.4	mg/l	72.7 %
TSS	1040	12.1	mg/l	98.84%
Ammonium (NH_4^+)	Not specified	25.5	mg/l	-
Chloride (Cl^-)	Not specified	196.6	mg/l	-
E-coli	Not specified	>1000 CFU/100	mg/l	-
EC	Not specified	1341.8	µS/cm	-
pH	6.5	7.3	-	-

Research performed by Cordilia [2018] as well as Civil Engineering Caribbean N.V. [1991] both indicate that the treatment facility does not meet the required effluent standards as presented in Table 4.1. One of the key aspects of this inadequate treatment capacity is the insufficient functioning of the constructed effluent ponds due to algae growth and overloading the treatment capacity of the treatment plant [Civil Engineering Caribbean N.V., 1991]. Presently, U.M. Cordilia [1], states that, despite the insufficient quality parameters, all effluent is presently reused within the domain of agriculture,

Klein Kwartier

The second to most important treatment plant 'Klein Kwartier' with a design capacity of 3.875 inhabitant equivalent, an average load of 160 [m^3/day] and a maximum peak capacity of 25 [$m^3/hour$]. After an expansion of the plant in the year 2000, the hydraulic capacity increased to 1.752 [m^3/day] and currently operates at an average flow rate of 1.300 [m^3/day] mainly treating effluents originating from the southeast side of the Shottegat region [DOW, 1991a; Cordilia, 2018]. This treatment plant is designed as a biological treatment facility utilizing an oxidation pond. The treated effluents contain relatively high levels of nutrient loading and are therefore determined to be suitable for irrigation purposes to stimulate plant growth. A numerical overview for influent and effluent quality, as well as specific treatment efficiencies, are bundled within Table 4.3

Table 4.3: Influent design parameters of WWTP Klein Kwartier combined with the effluent quality (June - November, 2018) of WWTP Klein Hofje to determine specific treatment efficiency. Information obtained from MIC N.V. [2016]

Parameter	Influent Value	Effluent Value	Unit	efficiency
COD	Not specified	70.2	mg/l	-
BOD	590	26.8	mg/l	95.46%
Kjeldahl Nitrogen	350	97.7	mg/l	72.09%
TSS	1040	12.1	mg/l	98.84%
Ammonium (NH_4^+)	Not specified	46	mg/l	-
Chloride (Cl^-)	Not specified	199.8	mg/l	-
E-coli	Not specified	740 CFU/100	mg/l	-
EC	Not specified	1236.8	µS/cm	-
pH	6.5-8.5	7.4	-	-

Tera Cora

Tera Cora is the third largest treatment system put into operation back in 1984. The plant was originally designed to treat the domestic wastewater of the neighbourhood of Tera Cora with a hydraulic capacity of 4.140 inhabitant equivalents, an average daily load of 300 [m^3], and a maximum capacity of 15 [$m^3/hour$] [Civil Engineering Caribbean N.V., 1991; Cordilia, 2018]. An overview of the influent parameters is presented in Table 4.4 whilst effluent quality research coming from this plant has not been conducted. Moreover, WWTP Tera Cora often suffers from vandalism and theft due to its remote and unserveillanced location causing it to be completely shut down since 2019 as explained by U.M. Cordilia [1]. Since this current state of condition, all influent water is directly transported via a discharge pipe to be discharged onto the norther limestone terraces where it infiltrates and seeps towards the ocean rather than be treated and than discharged as it is designed to be Cordilia [2018].

Table 4.4: Influent parameters WWTP Tera Cora. Information obtained from Cordilia [2018]

Parameter	Value	Unit
COD	5.000	mg/l
BOD	415	mg/l
Kjeldahl Nitrogen	350	mg/l
TSS	2.000	mg/l
pH	6.5-8.5	-

Abattoir

Lastly, WWTP Abatoir was put into operation in 1983 aiming to treat the highly contaminated wastewater from the slaughterhouse in Parera. Its system combines mechanical and biological treatment aspects to purify the water from the blood, meat, fat, and other animal grease-orientated substances. In its current state, which is determined by Cordilia [2018] to be in need of thorough maintenance, it has a hydraulic capacity of 2700 inhabitants equivalents, and a maximum allowable daily flow of 65 [m^3/day]. Furthermore, its specific influent parameters are presented in Table 4.5. Effluent parameters of the treated water have not been documented.

Table 4.5: Influent parameters WWTP Abattoir. Information obtained from Cordilia [2018]

Parameter	**Value**	**Unit**
COD	5.000	mg/l
BOD	2.500	mg/l
Kjeldahl Nitrogen	350	mg/l
TSS	2.000	mg/l
pH	6.5	-

4.2 Governmental Involvement

The pressing weight of negative effects correlated to the inadequacy of the current water policy have become increasingly heavy and is in desperate need of immediate action to preserve the marine ecosystem functionality Curaçao is dependent on. To this end, the Ministry of Health, Environment and Nature [2014] reports that intergovernmental frameworks such as Barbados Programme of Action (BPoA) and Mauritius Strategy Implementation (MSI), which address the principles and commitments to sustainable development embodied in Agenda 21 and translated these into specific policies, actions and measures to be taken at national, regional and international levels, are pre-eminently opportunities to do so. Within these frameworks, in line with emerging challenges, significant improvement of waste management, both solid waste as well as wastewater, is stated to be the key factor of highest urgency [Ministry of Health, Environment and Nature, 2014]. The government of Curaçao has acknowledged the significance of this challenge and has incorporated this within its published policy plan 'Future of Water'. Moreover, this policy plan states that the current capacity of the WWTP's of Klein Hofje, Tera Cora, and Klein Kwartier are insufficient for current, let alone, future contaminated water fluxes. To support the future economic prosperity of the island, this policy framework identifies the fine balance between the economy, nature, and society as key role in a sustainable future. This paragraph elaborates on the role of the different governmental agencies with respect to this dilemma, points out the current legislative framework, and briefly touches upon the future perspective as designed within the 2020 policy plan.

Ministry of Traffic, Transportation & Spatial Planning

Within the latest policy plan, it is described that the MTTSP has been, and will continue to be, responsible for the collection and transportation of all "grey water" via its executive agency Public Works. This responsibility incorporates the development and maintenance of the sewage system and the management and maintenance of the WWTP's. The specific department within Public Works responsible for wastewater management is the Department of Public Facilities, section Wastewater Management, which aims to ensure efficient management of wastewater as part of the whole water chain [Cordilia, 2018].

Ministry of Health, Environment and Nature

The MHEN is generally responsible for creating and assuring a healthy living environment for both human societies as well as natural entities. With respect to the wastewater dilemma, this ministry is designated to supervise and carry out (open)water management and water conservation [Public Policy consultation Curaçao, 2016]. Additionally, as wastewater fluxes directly discharge directly to open water bodies, hence natural environments, problems associated with these activities are situated within the domain of this ministry. Lastly, this ministry is responsible and striving towards a more descriptive legislation framework encompassing maximum allowable contamination parameters for direct discharge activities as explained by C. Profas [2].

Ministry of Economic Development

Another crucial governmental entity within this dilemma is the Ministry of Economic Development (EO, Dutch acronym (MED). The main responsibility of this ministry within the Islands' water cycle concerns the production of drinking water and the provision of adequate economical capacity to substantiate required development.

Commission Integral Water management Curaçao

The distribution of responsibilities in this current policy framework often fails to construct complementary strategies, reach mutual agreements, and parallelize ministry trajectories. The overarching commission, called the Commission Integral Water-management Curaçao (CIWC), is created to overcome this development impediment and aims to secure intergovernmental collaboration by focusing on three key elements being; advising the engaging ministries, realizing an integral, adequate, and sustainable trajectory to resolve the water dilemmas on Curaçao, and lastly to construct a sound integral water management policy plan [Girigori de Flores Martinez, 2020]. The absolute necessity of a strong water management policy was already incorporated in and signed for within the coalition agreement of 2017-2021 striving for among others an ecologically sustainable society [Rhuggenaath et al., 2017]. Additionally, the long-term vision, constructed within the development trajectory of the United Nations (UN), explicitly states the need for adequate sewage management to meet the needs of the Sustainable Development Goals (SDG) number 6 [UN Water, 2022]. To visualise this long-term vision, the government of Curaçao has created Figure 2. indicating the individual future tasks and responsibilities of all responsible entities.

Legislation Framework

The prevailing legal and regulatory framework with respect to wastewater management is constructed by four complementary laws. First and foremost, the 'Nuisance Ordinance Curaçao 1994 - Permitting Industrial Pollution' was initiated to control and monitor industrial pollution and prevent environmental hazards arising from commercial activities Cordilia [2018]. In essence, this law prohibits environmental harmful activities through discharging highly contaminated wastewater without an active nuisance license [Island Council of the Island of Curaçao, 1994]. Unfortunately, however, C. Profas [2], as representative of the MHEN, argues that the Government of Curaçao lacks resources to actively execute this legal framework causing over 90% of the companies producing these industrial wastewater streams, which are determined to be environmentally harmful, are not in possession of such an active nuisance license. Evidently, this has resulted in the actual volume and quality of this wastewater percentage not being monitored and will continue to harm the natural environment uncontrollably at the designated discharge location Shut. A second legal framework which aims to constrain any form of wastewater discharge into natural environments destitute of a permit given by the MTTSP is the Public Order Ordinance 2005. Thirdly, the MARPOL treaty-International Convention for the Prevention of Pollution from Ships 1978, is another legislation in place in Curaçao. This law aims to minimize the environmental pollution by ships. Especially with respect to the large number of cruise ships arriving at Curaçao and their highly polluted wastewater (see Table 2). This protocol is crucial to prevent environmental harm. Nevertheless, both C. Profas [2] and U.M. Cordilia [1] confirm that despite this legislation and due to both economical incentives and insufficient controlling resources, a lot of this type of wastewater is transported by vacuum truck companies and directly discharged at Shut. The next and fourth active legislation is the Cartagena Convention with its Protocols. These protocols aim to protect the whole marine environment of the WCR via a regional legal agreement focussing on the prevention of oil spills, Specially Protected Areas and Wildlife (SPAW), and Land Based Sources of Marine Pollution (LBS). Finally, two other crucial frameworks for future developments are the Wastewater Ordinance - Draft and the Waste and Chemicals Waste Ordinance 1995. The former aims to protect the environment by significantly reducing the harmful effects of wastewater discharges through several aspects. First, regulation rules will be constructed with respect to the construction, management and maintenance of public sewage systems and WWTP's in order to reduce discharge events and increase the total amount of collected wastewater Ministry of Health, Environment & Nature [2005]. Secondly, a permit obligation for wastewater discharging will be established wherein unapproved wastewater discharge will be eliminated. Moreover, this law aims to increase the governmental control of industrial wastewater via a new polluter pays principle system. This system will incorporate that commercial domains producing highly contaminated wastewater will be held financially accountable and responsible for either pre-treatment activities or environmental restoration costs. Lastly, the MHEN intends to utilize this new framework to produce new guidelines on maximum allowable quality parameters for the discharge location at Shut [UNOPS Curaçao, 2018; Girigori de Flores Martinez, 2020]. The latter potential framework, the Waste and Chemicals Waste Ordinance 1995, was already active historically but expired in 2010. Currently, this ordinance is therefore not active at the moment resulting in no official law with respect to hazardous waste legislation in Curaçao Cordilia [2018].

4.3 Industrial Wastewater

Currently, the WWMS is not equipped to purify highly contaminated wastewater streams originating from industrial activities as presented in Table 2. Due to this problem these waste fluxes are either directly discharged into marine environments at the Shut disposal area or illegally discharged onto the domestic sewage system without the crucially needed pre-treatment causing significant negative impacts within the entire water cycle UNOPS Curaçao [2018]; Cordilia [2018]. In purpose of improving this situation through scientific decision-making support, United Nations Office for Project Services (UNOPS) has developed an assessment report focusing on among others the industrial wastewater effects. They concluded upon 18 individual areas of relevance with respect to significant contamination effects on the marine environment and provided a map indicating their locations as presented in Figure 4.2. Moreover, in this report, in combination with reported findings by Civil Engineering Caribbean N.V. [1991] and Cordilia [2018], a general description of these areas are derived which are incorporated and summarized in Table 4 presented in the appendix.

4.4 Drinking Water Production

Drinking water production plays an essential role within the assessment of the wastewater management system of Willemstad. Especially, for constructing a overall water balance and estimating the produced domestic wastewater, information from this domain is of significant importance. The drinking water production is performed by Aqualectra, which is a government owned utilities company producing and distributing drinking water to 81.506 residents and 7.357 industrial consumers. Their two water plants perform reverse osmosis to treat the seawater and produce a total drinking water volume of 24.750 [m^3/day] [Aqualectra, 2021]. The specific location of the drinking water consumers remains undescribed within the openly

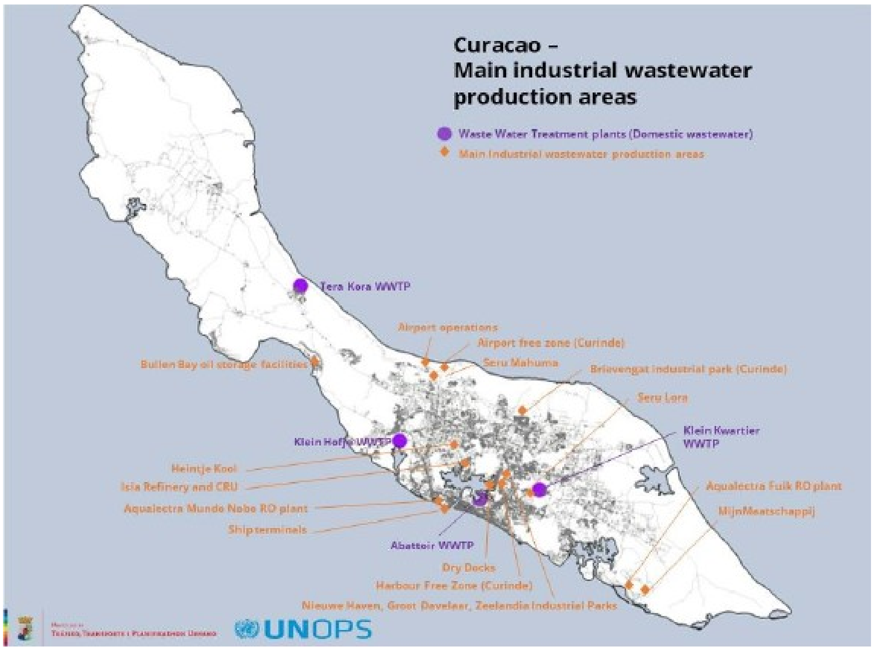


Figure 4.2: Overview of Industrial wastewater production areas in Curaçao. Figure obtained from UNOPS Curaçao [2018]

accessible literature provided by Aqualectra and, due to failing to retrieve this information via the information network, remains unknown within this research. For the remaining inhabitants (roughly 70.000) it is assumed that they are not connected to the drinking water distribution system, and with that are subjected to fetch their water demand from natural sources such as groundwater aquifers accessible via wells [Canon van Curaçao, 2020].

5 Modelled Results - Wastewater Flux Map

Within this chapter, a constructed QGIS Model is presented. This model is a simplified visualization of the urban wastewater fluxes on Curaçao with respect to quantity and quality. This visual representation in combination with the described information in Chapter 4 and the information incorporated within the attribute tables of the model layers give a complete answer to the second stated sub-question. Furthermore, the urban wastewater flux model indicates discharge locations of relevance with respect to potentially significant contamination loads which are identified in this chapter and with that answering the third stated sub-question.

5.1 Wastewater Flux QGIS Model

Based upon the literature results described in Chapter 4 and the obtained information depicted in Table 3 a QGIS model has been constructed. This model satisfies its purpose of enabling to answer the final stated sub-question of this research. Adding to that, since it is an integration of previously obtained results, it visualizes and indicates both water quantity and -quality fluxes within a topographical representation. Moreover, the model is constructed in a way which promotes and enables direct implementation of newly found results obtained by potential future research. This characteristic was actively created through specifically modelling each attribute set, i.e. future model users merely have to add newly found information to the attribute table of a layer and the model will automatically generate the correct symbology, colour, and size within the map. This feature advocates direct usage of the model and therefore safeguard information transfer, transparency, and scientific value which are in line with the core objective of this research. The methodology of the construction of the model is presented in Section 3.3.

The first layer, called 'Discharge locations', plots 42 identified discharge locations whereof more than half (57%) are discharged discontinuously. All of these discharge locations are directly linked to one or more pump-locations and discharge primarily domestic wastewater (71%), secondarily mixed wastewater (21%) and lastly industrial wastewater (8%). The remaining 43% is continuously discharging into the sea in terms of 39%, 28%, and 33% for wastewater fluxes of domestic, industrial and mixed character respectively. The largest absolute discharge fluxes are located at Piscadera

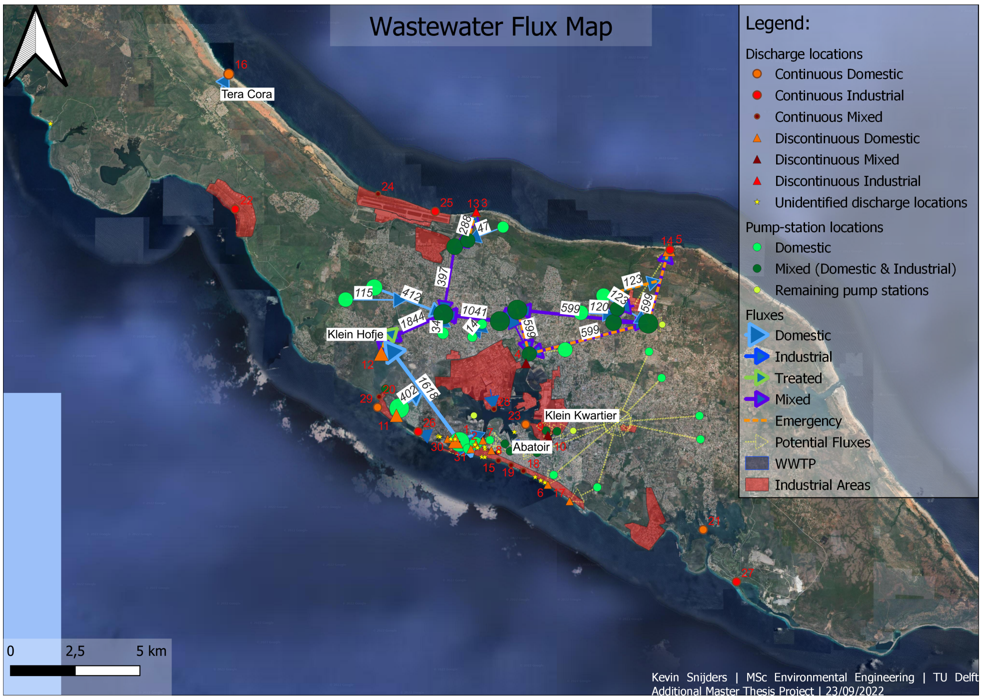


Figure 5.1: Wastewater Flux QGIS Model Map. Constructed by author. September 2022

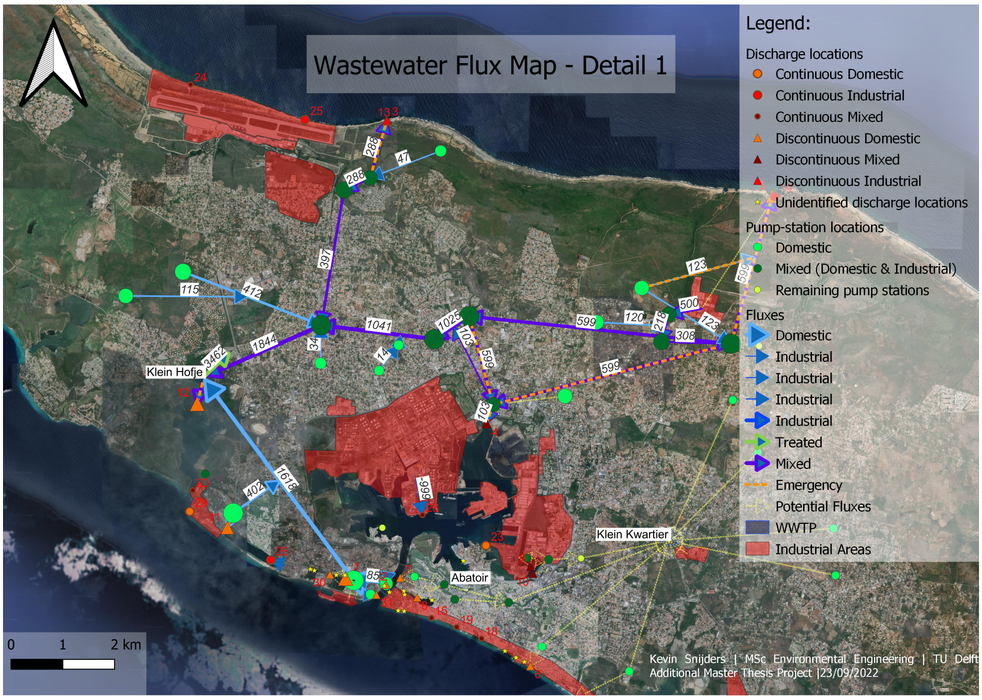


Figure 5.2: Wastewater Flux QGIS Model Map -Detail 1. Constructed by author. September 2022

bay (discontinuous, 3500 [m^3/d], domestic, discharge location 12), The Rif Mangrove area (discontinuous, 1216 [m^3/d], domestic, discharge location 1), and Playa Kanoa (discontinuous, 599 [m^3/d], mixed, discharge location 5). The largest continuous discharge location is found at discharge location Tera Cora (into the environment) (166 [m^3/d], domestic, discharge location 16). Furthermore, the largest contamination loads are expected at Playa Kanoa (discontinuous, 599 [m^3/d], mixed, discharge location 5) due to the combination of large volume and the likelihood of industrial contaminants and Piscadera bay (discontinuous, 3500 [m^3/d], domestic, discharge location 12) due to significant high volume. However, these fluxes are theoretically only discharged during emergency events such as expected extremes volumes due to weather events, energy blackouts, and system malfunctions. Moreover, discharge locations 5, 22, 25, 26, 27 and 28 show continuous discharge of industrial wastewater, unknown with respect to total volume, and are expected to be of high contamination loads. Discharge locations 13, 14 are designated discharge locations for 'unfit' wastewater, and locations 15, 18 and 20 are directly related to discharge of restaurants and hotels. Lastly, 16 discharge locations remain unidentified concerning water type as well as estimated quantity.

The pump-station locations layer consists out of 21 'domestic' pump-stations (55%), 14 'mixed' pump-stations (37%), and 3 'unidentified' pump-stations (8%). The largest volume is transported via Argentinaweg (mixed, 1844 [m^3/d]), SVB (domestic, 1216 [m^3/d]) and Garipitoweg (mixed, 1025 [m^3/d]). Moreover, the largest expected contaminations are expected with the highest fluxes of mixed water which are concentrated at Argentinaweg (mixed, 1844 [m^3/d]), Garipitoweg (mixed, 1025 [m^3/d]), Suffisant F (mixed, 922 [m^3/d], and Bonam (mixed, 599 [m^3/d]). These locations are together with Margrietlaan also the pump-stations with the most connected wastewater fluxes. Finally, based on the information presented in Chapter 4 pump-station Seru Fortuna could potentially collect large amounts of mixed wastewater as well.

Considering the fluxes, most volume is transported during emergency discharge events from WWTP Klein Hofje to the discharge location at Piscadera bay (discharge location 12). Furthermore, the fluxes between Argentinaweg - Klein Hofje, SVB - Klein Hofje, Garipitoweg - Argentinaweg, and Suffisant F - Garipitoweg are the most significant with respect to total volume conducting 1844, 1618, 1041, 1025 [m^3/d] respectively. Excluding the SVB - Klein Hofje flux, which transports domestic wastewater, all of these fluxes contain mixed wastewater indicating significant both domestic as well as industrial contaminant loading. Overall, 37 flux streams are plotted of which 49% domestic wastewater, 43% mixed wastewater, 5% pure industrial wastewater, and solely 3% which are documented to be treated. From those domestic and mixed wastewater fluxes, approximately 33% and 31% are characterized as emergency fluxes respectively.

6 Discussion

The outcomes of this research provide insight into the wastewater management of Willemstad with respect to the quantity and quality of wastewater fluxes directed towards the ocean and their environmental implications. This insight significantly contributes to closing the existing knowledge gap, identifies bottleneck system aspects, pinpoints significant marine contamination pathways, and constructs a valuable foundation for future research. However, due to research limitations, these results should be interpreted with caution. This chapter discusses the main results and reflects upon the research process. First of all, the research objective is emphasized and the key results supporting this will be summarized. Thereafter, the chapter elucidates how these key findings should be interpreted and argue their significance. The chapter finalizes with a short acknowledgement of the research limitations.

6.1 Key Results

Aiming to answer the main research question ***"How does the urban wastewater management of Willemstad, Curaçao, function with respect to the quantity and quality of wastewater fluxes directed towards the ocean?"*** both qualitative and quantitative methods have been carried out. Results obtained from the information network in combination with open source literature review conclude that 67% of the inhabitants of Curaçao are not connected to the central sewage system. This, in combination with industrial wastewater, sewage system malfunctioning and illegal discharge activities, results that at least 84% of all 'produced' wastewater being discharged into natural, typically marine, environments whilst remaining untreated. The remaining percentage (33%) of inhabitants, which are geographically concentrated within Willemstad, is connected to a WWMS with an estimated total treatment capacity of 5.617 [m^3/d]. Data suggests that this capacity is already exceeded and is expected to worsen due to population growth and an increased amount of connected inhabitants. Arising from the presented drinking water production only, which is approximately 4.4 times larger in volume, it becomes clear how sever this incapacity currently is. Additionally, the current state of this WWMS is described as outdated, unfit with respect to Curaçao's precipitation event intensities, hindering sustainable trajectories, and grossly (85%) in direct need of improvement.

Furthermore, research findings conclude that, in spite of existing legislative frameworks aiming to prevent industrial wastewater discharge activities, approximately 90% happen without the governments' legal approval and therefore remain unknown with respect to quantity and quality. However, research results have been successful in identifying the most significant industrial wastewater sources and connecting them to discharge locations modelled within the wastewater flux model. Essentially, these results give a valuable indication at which locations industrial contaminants are illegally entering the central sewage system or discharged into natural environments.

Finally, the modelled results identified that out of all discharge locations 43% continuously discharge domestic (39%), industrial (28%), and mixed (33%) wastewater, whilst 57% discharges domestic (71%), industrial (21%), or mixed (8%) wastewater solely during emergency events. The data suggest that, based on the modelled discharge location, Piscadera Bay, Rif Mangrove area and Playa Kanoa are expected to be the most significant with respect to volume and contamination loads. Additionally, these results identify fourteen discharge locations (ID numbers 1, 5, 12 till 16, 18, 20, 22, 25 till 28) to be of high contamination risk due to their water composition and/or flux volume. Next, data concludes that out of 38 modelled pump stations more than half (55%) transport domestic wastewater, whilst 37% and 8% handle mixed and unidentified wastewater respectively. These results point out six pump stations that are classified as most significant within the WWMS being Argentinaweg, SVB, Garipitoweg, Suffisant F, Bonam, and Margrietlaan. Lastly, the wastewater flux model concludes on four major and most significant fluxes Klein Hofje - Piscadera Bay, Argentinaweg - Klein Hofje, SVB - Klein Hofje, Garipitoweg - Argentinaweg, and Suffisant F - Garipitoweg. Moreover, data suggest that 49% of all fluxes contain domestic wastewater, whilst 43% and 5% are characterised as mixed and industrial respectively.

6.2 Result Interpretation

This section elaborates on how the presented key findings should be interpreted in relation to the scope, objective and limitations of this research. Furthermore, it provides the foundation for research recommendations and the conclusion of this research.

Current Situation

Overall, based on the obtained results, a general trend revolving around a significant and persisting data incompleteness and information gap within the domain of wastewater management has been highlighted. This trend firstly reflects within answering the sub-question which focuses on the current state of the WWMS. Although results conclude on crucial system facets such as capacity, the percentage of connected inhabitants and the ratio of treated versus untreated wastewater, it lacks the substantiation of detailed information causing the limitation of its implementation potential. Concerning the characteristics of the WWMS, it remains partly undocumented which parts of Willemstad are connected to the central sewage system and which are not, which parts are mixed with urban stormwater drainage and which are separated, and if there are dysfunctions such as leaks and blockages. Also, new developments, both completed or planned, have not been properly documented and are in need of revision as argued by U.M. Cordilia [1] and C. Profas [2]. Altogether, this information gap impedes accurately describing the functionality of urban wastewater management of Willemstad and with that hinders tailored development. At the heart of this problem lies a set of governmental and legislative issues. Primarily, the responsibility concerning the effects of (poor) wastewater management is distributed, or better formulated 'diluted', over multiple Ministries. Moreover, due to this, research performed by these ministries often lacks a holistic character essential to its implementation potential and causes poor intergovernmental information transmission. On top of that, results obtained within these studies are often classified as sensitive and therefore not openly shared with non-governmental external researchers preventing them from accurately performing research and potentially promoting development through external guidance. In spite of, initiatives and plans to construct an overarching governmental organisation uniting these responsibilities, overcoming this dilemma, and better the overall WWMS, developments often lack sufficient momentum and both financial and public support to be fully realized.

Quality & Quantity Fluxes

To correctly interpret the estimated quantity and quality results of the urban wastewater fluxes, which form the core of the second stated sub-question, The following points of discussion should be taken into consideration. Importantly, results, as well as points of discussion arising from them, should not be consulted independently from the constructed wastewater flux model. Since this model intrinsically contains large amounts of information, the aspects discussed within this section should be considered as supplementary guidance for the correct interpretation of the model and vice versa.

First and foremost, arising from the wastewater characteristics of the influent of each individual WWTP, presented in tables 4.2 till 4.5, the following points of discussion are raised. Influent values for treatment plant Klein Hofje display an extremely disproportionate BOD to COD ratio of approximately 2.5 whereas this ratio generally approaches a value of 0.4-0.6 for domestic sewage systems [Metcalf Eddy, Inc. et al., 2013; TU Delft , 2018]. This significant deviation is very likely to be correlated to external wastewater input from the industrial activities such as food processing and restaurant activities [Zulaikha et al., 2014; Sensorex, 2022]. Moreover, also rain events could potentially contribute to high BOD loading when organic matter is introduced into the system via stormwater. Furthermore, treatment plants Tera Cora and Abbattoir show high COD and high COD and BOD loading respectively compared to the other treatment plants. With respect to the latter, these high loads can be explained by the fact that this treatment plant purely purifies the wastewater originating from the slaughterhouse in Parera, which is in essence accompanied with significantly high COD and BOD loads. In case of Tera Cora however, the origin of the high COD load remains undescribed in the acquired literature since no extensive industrial activities are located here. The final discussion point arising from the influent characteristics regards to the striking similarity in influent values for different treatment plants. For example the value for the measured Kjeldahl Nitrogen in the influent for treatment plants Klein Kwartier, Tera Cora and Abattoir are all equal to 350 [mg/l]. Moreover, also the presented TSS value for Klein Kwartier and Klein Hofje are equal. The chance of these values being exactly equal for different and not connected treatment plants is extremely unlikely and with that harming the credibility of the presented values.

Also the treatment efficiencies should be discussed. Due to the combination of overcapacity and illegal industrial discharge to the central sewage system, the WWTP's do not fully meet the set effluent requirements. As can be concluded from Table 6.1, which compares the effluent results from the two major treatment plants and the set effluent requirements, especially the effluent quality of Klein Hofje suffers the most due to operating at overcapacity. Four out of nine tested quality parameters do not meet the required standards with the most significant exceeding parameter being BOD. High BOD levels at this facility could be explained due to the largest connected fluxes of domestic wastewater and the additional illegal industrial discharge of high levels of fats, oil, grease and food solids by restaurants and the hotel industry located at the South Coast of the Island. In contrast, effluent quality parameters from Klein Kwartier are exceeded on both ammonium and Kjeldahl Nitrogen, in particularly the latter. This significant exceedance is expected to cause excessive plant growth which is in line with its usage as irrigation water within the agricultural domain. High levels of Kjeldahl Nitrogen could be considered to be induced by domestic wastewater streams as well as industries discharging soaps and detergents such as Nieuwe Haven, Groot Davelaar, Zeelandia Industrial Parks and Seru Lora.

Thirdly, it is of utmost importance when focusing on quality and quantity fluxes that it is emphasised that the scope of this research excludes the urban water flows originating from the stormwater drainage system. This system, which is designed to quickly drain the urban environment from high-intensity precipitation events and mitigate flooding risks, often discharges onto the mixed sewage system. At these points, different fluxes are combined resulting in potentially significant alteration of the quantity and quality of the fluxes. Even though this research acknowledges the great influence of this system feature, the gathered information remains insufficient for scientifically substantiated estimations or conclusions. Nevertheless, it

Table 6.1: Wastewater Treatment Plant validation

Wastewater Treatment Plant	**Parameter**	**Validation**
Klein Hofje	COD	Exceeding factor 1.016
	BOD	Exceeding factor 1.44
	Kjeldahl Nitrogen	Exceeding factor 1.16
	TSS	Complies with limit
	Ammonium (NH_4^+)	Complies with limit
	Chloride (Cl^-)	Complies with limit
	E-coli	Exceeds limit
	EC	Complies with limit
	pH	Complies with limit
Klein Kwartier	COD	Complies with limit
	BOD	Complies with limit
	Kjeldahl Nitrogen	Exceeding factor 2.44
	TSS	Complies with limit
	Ammonium (NH_4^+)	Exceeding factor 1.15
	Chloride (Cl^-)	Complies with limit
	E-coli	Complies with limit
	EC	Complies with limit
	pH	Complies with limit

can, and should be, assumed that during heavy precipitation events the volume of the wastewater fluxes will increase due to the addition of stormwater flow and the wastewater fluxes themselves will be diluted. Potentially, these stormwater fluxes could also induce new hazardous elements originating from surface runoff flows. On top of that, during these events, it should be taken into consideration that, in addition to the already overloaded sewage system, it is likely that more emergency discharge locations will be activated causing untreated wastewater fluxes to enter natural environments. Based on the constructed wastewater flux model results it is evident that discharge locations 1, 5 and 12 are significantly bigger with respect to their flux quantities as portrayed in Figure 6.1 up and till 6.3. During heavy precipitation events, it is expected that discharge locations 12 and 5 will be major points of interest for discharging large wastewater volumes. The latter discharge location is indicated by U.M. Cordilia [1] and F. Gilbert [1] of MTTSP as important relieve mechanism for the bottleneck pump-station Bonam. This location is a central point for multiple other pump stations and forms the first possible discharge relief mechanism to prevent overloading of the sewage system orientated towards WWTP Klein Hofje. Moreover, due to the nearby industrial area indirectly connected to this pump station, these waters are often estimated to be of higher contamination loading. On the other hand, if the capacity of the system is exceeded and excessive

[1]Public Works section Water Management

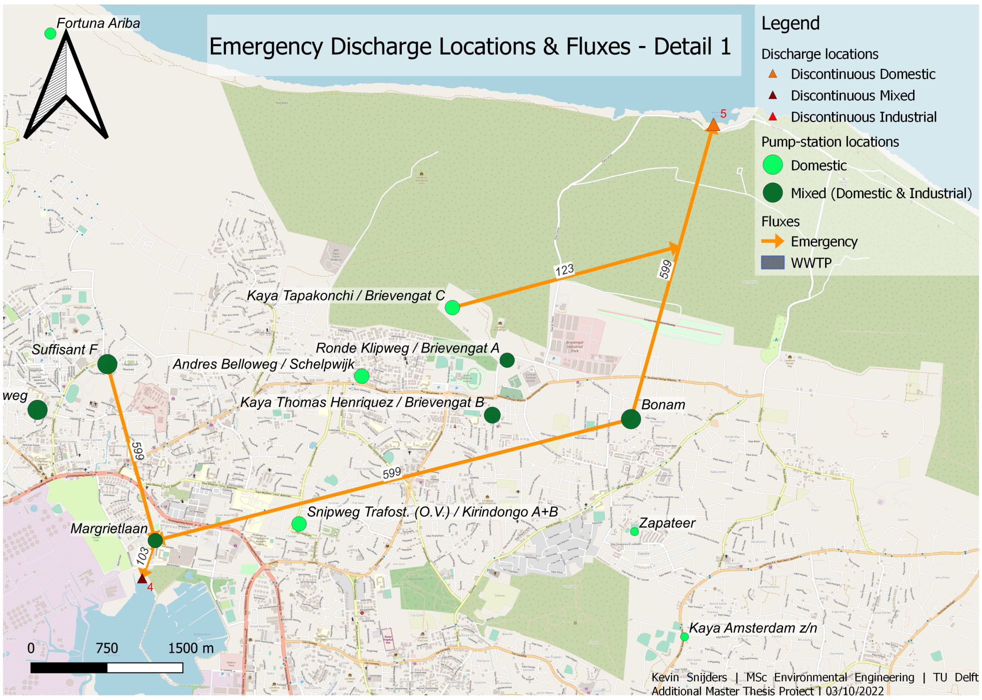


Figure 6.1: Emergency flux - Detail 1/5. Constructed by author. October 2022

quantities are directed towards WWTP Klein Hofje, it is assumable that these fluxes are bypassed towards discharge location 12 at Piscadera Bay to prevent overloading of the treatment plant and mitigate harmful effects on its biological characteristics such as organism wash-out. Due to this, in combination with the described constant exceedance of multiple effluent requirements, it is expected to find high levels of BOD, Kjeldahl Nitrogen, COD and E-coli at this discharge location especially during emergency events.

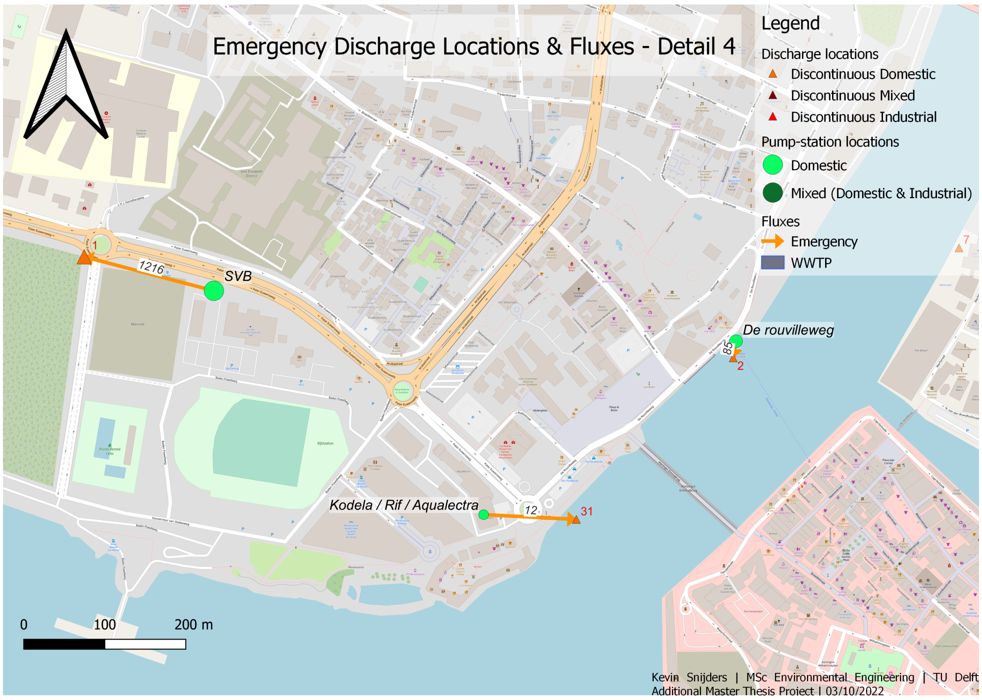


Figure 6.2: Emergency flux - Detail 4/5. Constructed by author. October 2022

Figure 6.3: Emergency flux - Detail 5/5. Constructed October 2022 by author

Another important point of interpretation revolves around the management of industrial wastewater. Arising from literature results is that, due to the characteristics of industrial wastewater, it cannot be connected to WWTP's and therefore requires specialized management. However, despite legislative frameworks and active laws, this wastewater is often illegally discharged onto the central sewage system, directly discharged into natural environments, or transported via vacuum truck companies to be discharged at designated locations. The urban wastewater flux model has successfully identified locations potentially containing and discharging these wastewater fluxes. Based upon the detailed presentation in Figure 6.4 the following pathways of industrial contamination can be grouped. Although the means of this research remained insufficient to establish numerical results regarding water quantity and water quality of these fluxes, the model descriptively concludes upon the estimated pollutants and potential flux size which is included within the attribute tables of the model. First of all, discharge locations 22, 25, 26, 27 and 28 are indicated by the government to continuously discharge wastewater fluxes directly originating from industrial activities. Other discharge locations specifically known for their extensive pollution effects are discharge locations 13, 14, 20 and 28. Especially discharge location 13 is infamous since the government has pinpointed this location for condoned illegal discharge of heavily polluted wastewater fluxes which are not treatable by the WWTP's. Based on this function within the WWMS it is expected to find wastewater containing high salinity, organic fat, oil, grease, mineral oil, and high toxic chemical loading. Furthermore, discharge locations 20 and 28, which are classified as continuous discharge of mixed wastewater, are estimated to discharge higher contamination levels than described within the provided sources due to the high activities of the connected industrial areas. This is in line with literature findings that conclude these water bodies to be the most contaminated and therefore advised against by the government to utilize for recreational usage. Next, discharge locations 15, 18 and 20 which are located within areas with high restaurant and hotel activities. At these discharge locations, it is therefore expected to find higher amounts of fats, oils, and grease contributing to high BOD levels. Additionally, Estep et al. [2017] highly suggests that these discharge locations are also potentially linked to eutrophication events caused by high nitrogen levels. These pollution characteristics are also expected to be found around Jan Thiel Area, which induces similar industrial wastewater, but where no documentation exists on where these fluxes are being discharged. Based upon arguments presented by U.M. Cordilia [1] and C. Profas [2] this area as a whole is not connected to any form of central sewage system and all forms of wastewater are directly discharged into the ocean at the south coast.

A fourth and major point of interest revolves around the modelled wastewater fluxes. In contrast to the high confidence level of the position of the discharge locations and the pump stations, the orientation and positioning of the hydraulic fluxes hold a more arbitrary character. Nevertheless, despite their potential geographical deviation from reality, they entirely satisfy their intended goal to visualize urban wastewater management within Willemstad. Consequently, the following consider-

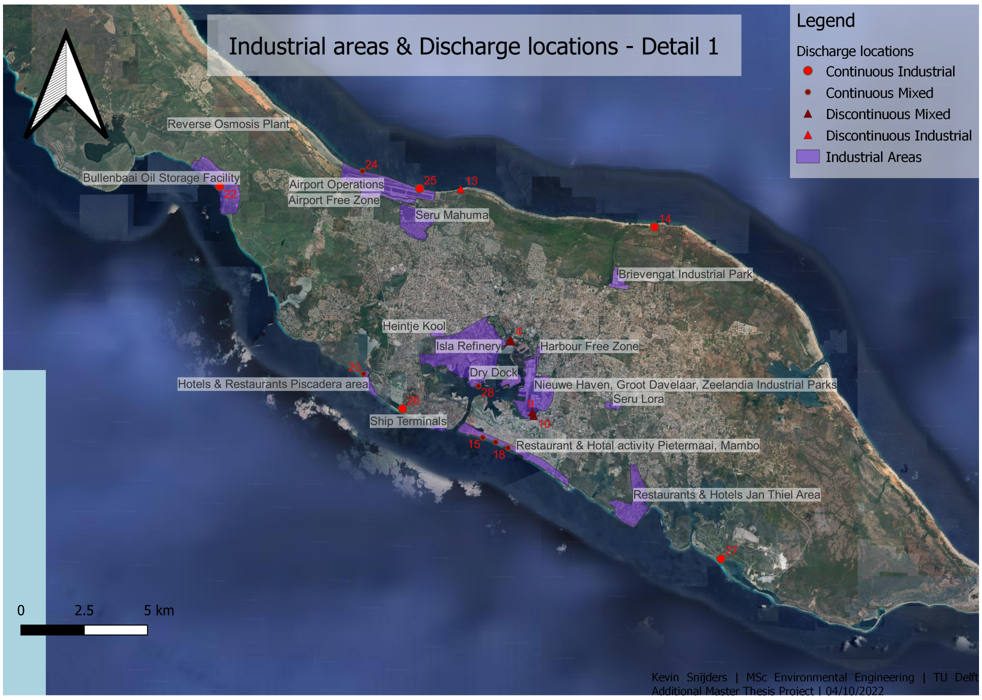


Figure 6.4: Industrial & Discharge - Detail 1/1. Constructed by author. October 2022

ations should be taken into account. First and foremost, most striking is that there is no documentation of any sewage system connecting to WWTP Klein Kwartier, Tera Cora, or Abattoir. As described earlier, this absence is in line with the documented dysfunctional state of Tera Cora as well as the specific functionality of Abattoir. In contrast, however, Klein Kwartier is designed for and operates as a domestic wastewater treatment plant for the East side of Curaçao. Despite this functionality, the government agencies were unable to provide any form of information on the situated sewage system. As to overcome this information deficiency the plotted pump stations, which remained undescribed with respect to their connection to other pump stations or treatment plants, are assumed to be included within this unknown sewage system. These potential fluxes are specified within the wastewater flux model and focused on in Figure 6.5 but should be interpreted as highly suggestive with respect to quality, quantity and orientation.

Contrasting, the wastewater fluxes directed towards WWTP Klein Hofje are far more accurately documented for and therefore assumed to be significantly better-reflecting reality. Complementary to the four identified main fluxes within the wastewater flux model, Figure 6.6 shows the dominant traces for urban wastewater fluxes directed towards Klein Hofje based on quality and quantity. These trajectories are revealed by filtering out and exposing the six most significant pump stations and the eleven biggest wastewater quality- and quantity- fluxes. Arising from these trajectories it is evident that the WWMS connected to the treatment plant Klein Hofje can be

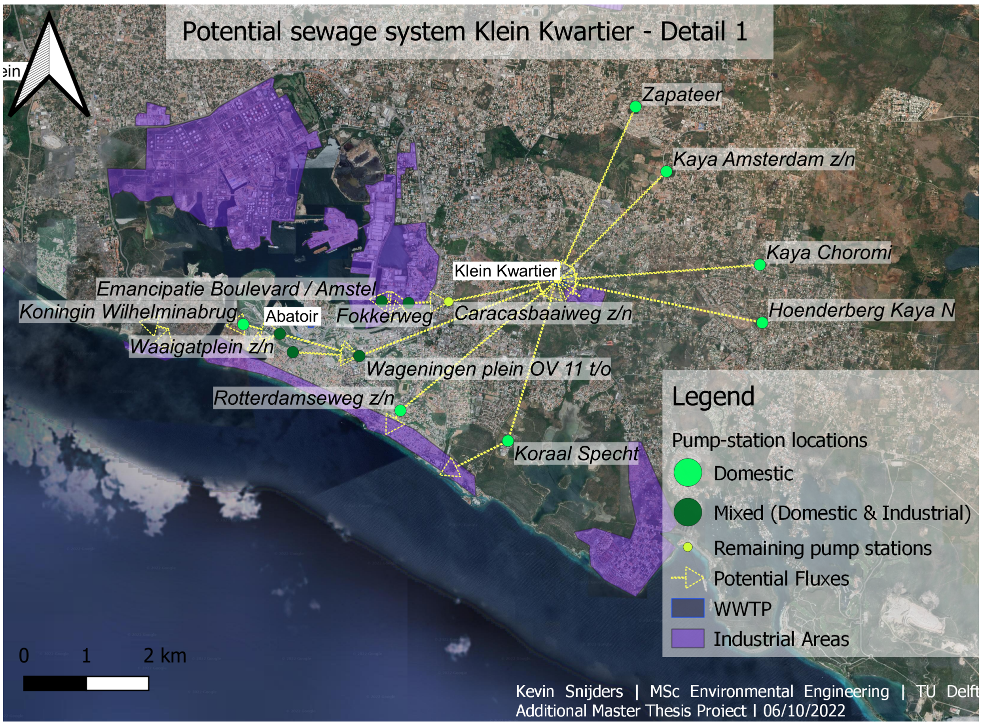


Figure 6.5: Potential sewage system Klein Kwartier - Detail 1/1. Constructed by author. October 2022

simplified and segmented into two major influent streams. Above all, the most significant quantity, as well as the level of contamination within the urban wastewater streams, is estimated to originate from the 'Northern' trace being Bonam - Suffisant F - Garipitoweg - Argentinaweg. This trace is expected to primarily contain domestic wastewater with industrial pollutants such as paint chemicals, pharmaceutical chemicals, minerals and detergent, induced by the Brievengat industrial area. This stream is expected to contain enhanced BOD due to this industrial influence, hence contributing to possibly declaring elevated BOD loading found within the influent and effluent of WWTP Klein Hofje. On the other side, both figuratively and literally, situates the second to most important wastewater flux. This flux originates from pump station SVB and is expected to solely transport domestic wastewater to Klein Hofje. Despite this trace being relatively short compared to the former, and therefore suggesting lesser connected area, the concentration of inhabitants, restaurants, and hotels is significantly higher. Therefore, it is in line with expectations that both fluxes contain comparable urban wastewater quantities. In contrast, despite the documented estimated water quality of this trace to be essentially domestic, it is highly assumable that this water is contaminated with industrial wastewater originating from the high concentration of hotels and restaurants situated along this wastewater sewage line. This statement is supported by the argued fact that restaurants and hotels often discharge their unfiltered wastewater onto the central system despite prohibiting laws as a result of insufficient means to perform controls and law enforcement by the government.

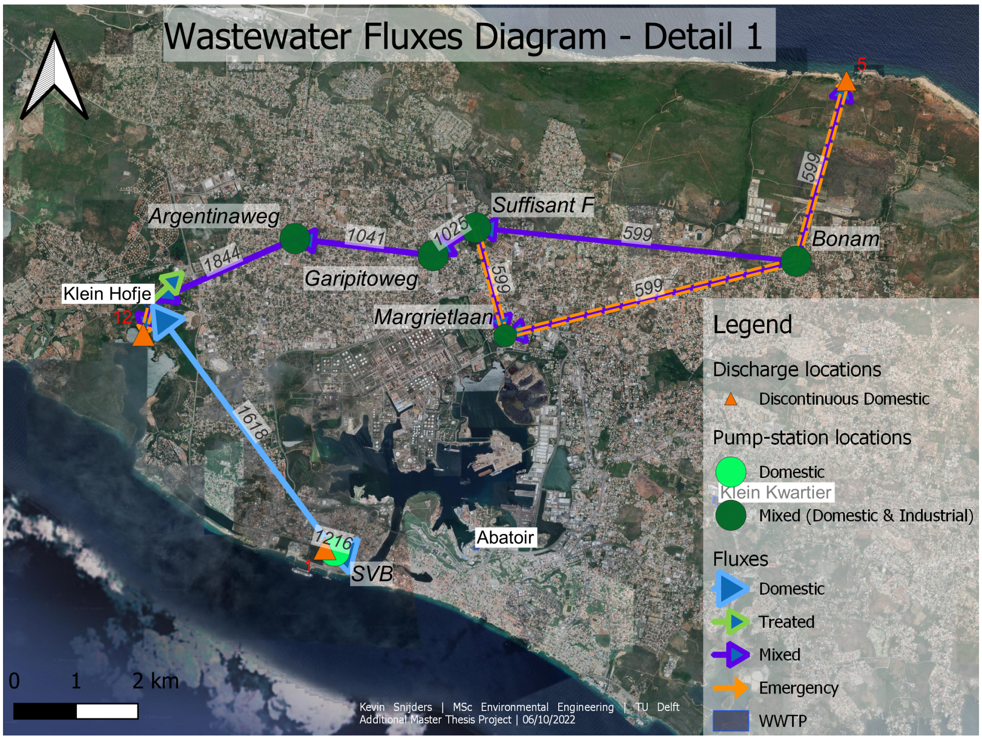


Figure 6.6: Wastewater Fluxes Diagram - Detail 1/1. Constructed by author. October 2022

Finally, the last remark with respect to these result interpretations concerns the identification of potential system bottlenecks. Evidently, arising from the formerly described points of discussion, bottlenecks are likely to occur within the main traces presented in Figure 6.6. Special attention should be paid to the pump station within the 'Northern' trace such as Bonam, Argentinaweg and Suffisant F due fact that these harvest wastewater fluxes from many other pump-station making them significantly more sensitive to system failures. Especially pump station Bonam is appointed by the MTTSP as a major bottleneck location often causing large discharge events at Playa Kanoa.

6.3 Limitation Acknowledgement

This research, and therefore its implementation, is limited due to the following set of factors. First and foremost, the discussed information gap limits the accuracy of the research results. As this research has raised the fact that detailed and up-to-date information regarding the WWMS is hardly available within open literature, one is dependent on government agencies to provide information. However, for external researchers, it remains difficult to come into contact with these entities let alone establish a mutual agreement on transparent and complete information transfer. On top of that, the relatively short set time frame for this specific project made this collecting of information the main challenge to overcome. As a result, this research is limited to the information that is gathered within the time frame, the goodwill of the mentioned ministries to provide information and ultimately the accuracy of the provided information. Another limiting aspect concerns the sensitivity of the information. Arising from the responsibility 'dilution' within the government with respect to waste(water) management, certain types of information, such as GIS models and detailed water quality reports, are classified and were not cleared for usage nor referencing to within this report. This limits both the accuracy of this research as well as the potential for further research.

Concerning the quality and quantity of the indicated fluxes, the identified significant traces, key discharge locations, and essential pump stations, the following limitations should be considered. First of all, the provided information lacks documentation of quality analysis of wastewater fluxes within the urban sewage system and therefore limits quality-related results to be suggestive solely based on their origin and connected areas. Worsening this, the effect of illegal discharging onto the central domestic sewage system remains unclear with respect to quality and quantity as a result of insufficient means to perform adequate control and law enforcement. Furthermore, another point of limitation concerns the operation of the sewage systems and their emergency discharge locations. Arising from the assumption that emergency discharge locations are either active, hence discharging all wastewater that is concentrated at the connected pump station, or inactive, hence not discharging any wastewater at all. This limits the accuracy of the results. In other words, the presented research results fail to recognize and account for the plausible partial operating of these discharge locations, i.e. potential overestimation of the volume of wastewater fluxes being discharged in the case of partial usage of the emergency pathway. Lastly, as previously mentioned, the scope of this research did not incorporate the effect of urban stormwater discharge. Doing so underestimates the volume of wastewater fluxes within the modelled system as well as undermines the potential effects of either inducing pollutants and/or diluting the wastewater streams.

7 Recommendation

To promote the implementation as well as to build upon the acquired research findings, this chapter proposes a set of five main aspects recommended for future research.

As discussed within the previous chapter, the prevailing knowledge gap existing both intergovernmental as well as towards external research is determined to be one of the most crucial limiting factors for development within the urban WWMS. To support the closing of this gap it is recommended to actively promote complete and transparent information transfer of this as well as future studies. Strengthening this recommendation is that openly sharing information enables interested parties to utilize collaborative knowledge, advocates model verification and improvement, and ultimately promotes implementation and development. Extending this recommendation, this research should be advanced through coupling its findings to results obtained in other related fields such as marine biology, land use and stormwater hydrology. Only through combining all studies related to marine environment implications the true significance of the urban wastewater management within this dilemma can be fully analysed and possibly concluded upon.

Secondly, as this research is limited due to excluding urban stormwater drainage pathways, it is highly recommended to investigate the effect on urban wastewater management. Moreover, since these domains are closely linked it is expected to be beneficial for the understanding of both domains. To promote this investigation this report suggests upon to contact the domain of stormwater discharge at Public Works (MTTSP) through contact person J. Sebastiana as indicated within the information network diagram.

The third recommendation indicated by this research is to set up a study program to investigate the following set of objectives. The modelled fluxes, in particular the discussed major urban wastewater flux traces, should be analysed both qualitatively and quantitatively to verify the modelled estimates. Quantitatively it is recommended to measure the indicated wastewater fluxes. Furthermore, it is recommended to consult the drinking water company Aqualectra to acquire information on the amount of delivered drinking water within the research area, in particular the consumers which are also connected to the central sewer system. This set of information is essential to estimate the total amount of produced wastewater introduced to the sewage system and with that validate the model as well as to contribute to the construction of an overall water balance. Qualitatively it is highly recommended to validate the presented influent characteristics of the treatment plants. Hence the fact that the presented values are a essential point of the raised discussion based on the credibility, their validation is of utmost importance for the estimated quality of the fluxes. Overall, the verification of the constructed model would give valuable insight and enables the comparison of the modelled theoretical urban wastewater fluxes and the actual fluxes. Moreover, performing this research would allow for model improvements and with that improve upon the estimation of environmental implications. Secondly, it is recommended to quantify water quality parameters at the indicated discharge locations. Especially continuous industrial discharge locations, which are identified as containing significant contamination effects, should be points of interest for further research. It is recommended to both consult U.M. Cordilia (DOW, MTTSP) as well as C. Profas (MHEN) to set up this research.

Lastly, it is recommended to investigate the activity of the plotted discharge locations. First of all, as mentioned within the discussion chapter, these research results are limited due to the fact that it remains undescribed how the discontinuous discharge locations are operated within the urban sewage system leading to a potential overestimation of the discharged volume. To this end, it is recommended to investigate pump stations identified to be of interest due to high volume, high contamination loading, and/or a large number of connected fluxes upon operation performance which would indicate which emergency discharge locations will be utilized and in what frequency. Additionally, it is expected that this operation performance report would conclude whether emergency discharge locations are operated for partial discharge as well. A recommended research strategy that could be executed for this purpose is a combination of neighbourhood surveys and fieldwork collaboration with the Public Works domain of MTTSP. To realise such a research program it is recommended to contact U.M. Cordilia (DOW, MTTSP).

8 Conclusion

This research was set out to estimate the quantity and quality of urban wastewater fluxes originating from Willemstad, Curaçao, to gain valuable insight into the management cycle of domestic and industrial waster fluxes. Additionally, it aimed to gain a better understanding of the environmental implication correlated to this domain. Answering the main research question *"How does the urban wastewater management of Willemstad, Curaçao, function with respect to the quantity and quality of wastewater fluxes directed towards the ocean?"* will be substantiated by the results obtained by answering the stated sub-questions. The following line of concluding arguments form this final answer.

The urban wastewater management cycle is organized as a central sewage system for the connected inhabitants (33%) and a combination of decentralized cesspits and septic tanks for the unconnected inhabitants (67%). Although the system is solely designed for the transportation and treatment of wastewater fluxes of a domestic character, obtained results are contradicting this and point out that also industrial wastewater fluxes find their way into the central sewage system, hence contaminating the water quality. These illegal contamination pathways, in combination with concluded insufficient treatment capacity of the two main treatment plants, are identified as the main factors causing effluent quality parameters to exceed the set requirements.

Furthermore, arising from the urban wastewater flux model, results conclude that the urban wastewater drainage area connected to WWTP Klein Hofje is transported via two major traces. The northern trace, consisting of pump stations Bonam, Sufficant F, Margrietlaan, Suffisant F, Garipitoweg and Argentinaweg, is identified to contain mixed wastewater fluxes of both domestic and industrial character. In contrast, the southern trace consisting network going from pump station SVB to Klein hofje, in theory only transports domestic wastewater. Both traces transport large amounts of volume and are therefore concluded as major points of interest for future research. In contrast to this, results concluding upon the wastewater flux network connected to WWTP Klein Kwartier, contains a more suggestive character and is in need for further research to be concluded upon.

Despite that, this research successfully identified and categorized 42 discharge locations on the estimated activity, water quality, water quantity, and water origin, it is limited to substantiate a sound conclusion upon the potential environmental implications of the individual discharge locations. Results conclude upon 14 discharge locations estimated to be of significant contamination loading, significant discharge volume, or both. However, further research is argued to be required to determine the exact water quality as well as to determine the precise operating conditions of these discharge locations.

Concerning the origin of pollutants, this research identified 18 industrial areas expected to be of major environmental implication. Due to the character of these wastewater fluxes, locations identified to discharge these fluxes are concluded to be of utmost contamination risk to the natural environment. Furthermore, despite active legislative frameworks preventing the incorrect handling of industrial wastewater, the government lacks sufficient means to enforce the law controlling these illegal activities. Additionally, this research concludes that initiatives aiming to improve overall wastewater management are in place but often lack sufficient financial and public support to be realized.

Overall, this research has successfully identified and visualized how the urban wastewater management of Willemstad functions with respect to the quantity and quality of wastewater fluxes directed towards the ocean. Despite its described research limitations, it has concluded upon the system characteristics, major flux traces, identified significant environment implication pathways, pinpointed pollution origins, and advises on recommendations for further research. Ultimately, it contributes to a better understanding of the urban wastewater fluxes and their effect on the marine ecosystems and with that initiated the momentum to eliminate the existing 'white spot' within the SEALINK Program.

Bibliography

Aqualectra (2021). Annual Report 2021 . Technical report, Willemstad.

Austen, M., Andersen, P., Armstrong, C., Döring, R., Hynes, S., Levrel, H., Oinonen, S., Ressurreição, A., Coopman, J., Heymans, J., Kellett, P., Muñiz Piniella, A., French, V., and Alexander, B. (2019). Valuing marine ecosystems, taking into account the value of ecosystem benefits in the blue economy. page 32. ISSN: 4920-43696, DOI: 10.5281/zenodo.2602732. Ostend, Belgium. Accessed July 2022.

Bellwood, D. R., Hughes, T. P., Folke, C., and Nyström, M. (2004). Confronting the coral reef crisis. *Nature*, 429(6994):827–833. Accessed July 2022.

Canon van Curaçao (2020). 39. Water.

Cinner, J., Huchery, C., Macneil, M. A., Graham, N. A., Mcclanahan, T. R., Maina, J., Maire, E., Kittinger, J. N., Hicks, C. C., Mora, C., and et al. (2016). Bright spots among the world's coral reefs. *Nature*, 535(7612):416–419. Accessed July 2022.

Civil Engineering Caribbean N.V. (1991). Afvalwaterstructuurplan samenvatting. Commissioned by Public Works Curaçao, Seru Loraweg 35, Willemstad, Curaçao. Accessed August 2022.

Coral Reef Alliance (2016). Biodiversity—what is it? shorturl.at/ikstZ. Posted in CORAL updates, Accessed June 2022.

Cordilia, U. (2017). Recent Development in Waste Management on Curaçao. Kick-off workshop, Presentation, Accessed June 2022.

Cordilia, U. (2018). Development of an improvement plan for reduction of surface water contamination in curaçao: optimal reduction of discharges of untreated wastewater into surface water. Master thesis, techno-mba, University of Curaçao, Willemstad. Privately shared document. Published December 2018; Obtained and Accessed August 2022.

De Paulo, H. (2016). Definitely not a waste of time. *Curaçao Business*, 1:32–33. https://blocks.mvmm.nl/images/pdf/8404.pdf, Wastewater, Accessed August 2022.

Diez, S., Patil, P., Morton, J., Rodriguez, D., Venzella, A., Rboin, D., Maes, T., and Corbin, C. (2019). Marine Pollution in the Caribbean: Not a Minute to Waste. Washington, D.C.: World Bank Group, Accessed August 2022.

DOW (1991a). Afdeling beheer afvalwater-district oost awzi klein kwartier. Privately shared document by U.M. Cordilia (DOW). Dienst Openbare Werken Eilandgebied Curaçao, Department Civil Health Engineering. Accessed August 2022.

DOW (1991b). Rioolwaterzuiveringsinrichting klein hofje. Privately shared document by U.M. Cordilia (DOW). Dienst Openbare Werken Eilandgebied Curaçao, Department Civil Health Engineering. Published August 1991, Accessed August 2022.

Eddy, T. D., Lam, V. W., Reygondeau, G., Cisneros-Montemayor, A. M., Greer, K., Palomares, M. L. D., Bruno, J. F., Ota, Y., and Cheung, W. W. (2021). Global decline in capacity of coral reefs to provide ecosystem services. *One Earth*, 4(9):1278–1285. Accessed July 2022.

Estep, A., Dr. Sandin, S., and Dr. Vermeij, M. (2017). Marine scientific assessment, the state of curaçao's coral reefs. Contributors: Senator Glenn Sulvaran (Governement of Curaçao), rosun (Ministry of Health, Environment and Nature), Jeremiah Peek (Chata Dive Task Force), Bryan Horne (Substation Curaçao), Gerdy Principaal (Public Works Curaçao) , Paul Hoetjes (National Office for the Caribbean Netherlands), Marlon LaRoche (Curaçao Ports Authority), Joe Lepore (Waitt Institute), and Michael Dessner (Waitt Institute). Accessed July 2022.

Fuldauer, L. I., Ives, M. C., Adshead, D., Thacker, S., and Hall, J. W. (2019). Participatory planning of the future of waste management in small island developing states to deliver on the sustainable development goals. *Journal of cleaner production*, 223:147–162. Accessed July 2022.

Girigori de Flores Martinez, P. (2020). The FUTURE of WATER in Curaçao. https://www.publicpolicycuracao.com/enquete-commissie-integraal-watermanagement-curacao/. Pages 25, Accessed June 2022.

Government of Curaçao (2017). Regeerprogramma 2017-2021: Ontplooien van Curaçao's Potentieel. Accessed August 2022.

Hughes, T. P., Barnes, M. L., Bellwood, D. R., Cinner, J. E., Cumming, G. S., Jackson, J. B. C., Kleypas, J., Van De Leemput, I. A., Lough, J. M., Morrison, T. H., and et al. (2017). Coral reefs in the anthropocene. *Nature*, 546(7656):82–90. Accessed July 2022.

Island Council of the Island of Curaçao (1994). Nuisance ordinance 1994.

Jager, C. (2021). *Curaçao Environmental Statistics 2020*. Central Bureau of Statistics Curaçao, Piscadera Bay. ISBN: 9789990451696, Accessed July 2022.

Luff, D., Baker, P., Apoteker, T., Watson, N., and Lancelot, M. (2013). Strategies for Sustainable Long Term Economic Development in Curaçao. Technical report. Framework of a project managed by TAC s.a.s., TAC Applied Economic and Financial Research, Accessed June 2022.

Metcalf Eddy, Inc., given i=G., given=George, f., given i=H., f., given i=R., given=Ryujiro, f., and given i=F., given=Franklin, f. (2013). *Wastewater Engineering: Treatment and Resource Recovery*. McGraw Hill, 5 edition.

Meteorological Department Curaçao (2021). Climate summary of the dutch leeward islands. shorturl.at/hWY05. Ministry of Traffic, Transport and Urban Planning, Accessed June 2021.

MIC N.V. (2016). Invitation to tender for the construction of the wastewater treatment plant at klein hofje and other works. Ministry of Traffic, Transport and Urban planning Curaçao. Privately shared document by U.M. Cordilia (DOW). Accessed August 2022.

Ministry of Health, Environment & Nature (2005). Draft wastewater ordinance, curaçao.

Ministry of Health, Environment and Nature (2014). National report of curaçao. shorturl.at/hWY05. United Nations Development Programme, Accessed June 2022.

Ministry of Traffic, Transport and Urban Planning, UNOPS, University of Oxford, and ITRC (2018). Evidence-Based Infrastructure: Curaçao. National Infrastructure Systems Modelling to Support Sustainable and Resilient Infrastructure Development. Technical report, Curaçao. Accessed July 2022.

Public Policy consultation Curaçao (2016). De toekomst van water, beleidsplan voor integraal waterbeheer. Technical Report 2016/0597, Curaçao. Government of Curaçao, Commission Integral Water Management Curaçao, Accessed July 2022.

Reid, W. V. (1998). Biodiversity hotspots. *Trends in Ecology & Evolution*, 13(7):275–280. Accessed July 2022.

Rhuggenaath, E., Koeiman, H., and Camelia-Römer, S. (2017). Realisando e maskimo potensial di korsou, akuerdo die gobernashon 2017-2021. Technical report, Pietermaai. Accessed July 2022.

Sensorex (2022). Biological Oxygen Demand (BOD) – How it Affects Wastewater Treatment Plants.

TU Delft (2018). Afvalwater-behandeling. Technical report.

UN Water (2022). Integrated Monitoring Guide for Sustainable Development Goal 6 on Water and Sanitation. Technical report. Targets and global indicators, part of the Sustainable Development Goals stated by the United Nations, Assessed Jule 2022.

UNOPS Curaçao (2018). Rapid Assessment to support the dicisionmaking process around the Shut disposal area. Privately shared document by C. Profas (GMN). Published June 2018. Accessed August 2022.

van der Molen, M. and Ruth, L. (2000). Afvalwaterbehandeling curaçao gericht op hygiëne, behoud kwaliteit oppervlaktewater en hergebruik effluent. Dienst Openbare Werken Curaçao. Accessed July 2022.

Vermeij, M. (2021). THE SEALINK PROJECT. https://www.sealinkcaribbean.net/. LAND, SEA, AND SOCIETY: Linking Terrestrial Pollutants and inputs to nearshore coral reef growth to identify novel conservation options for the Dutch Caribbean. Created with Wix.com, Accessed July 2022.

Waitt Institute, Blue Hallo Curacao, and Sustainable Fisheries Group UC Santa Barbara (2016). Economic Valuation of Curaçao's Marine Resources . Technical report. URL: https://www.waittinstitute.org/. Accessed July 2022.

Wilkinson, C. and Souter, D. (2008). Status of caribbean coral reefs after bleaching and hurricanes in 2005. *Global Coral Reef Monit. Network*.

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., Jackson, J. B. C., Lotze, H. K., Micheli, F., Palumbi, S. R., Sala, E., Selkoe, K. A., Stachowicz, J. J., and Watson, R. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314(5800):787–790. Accessed July 2022.

Zulaikha, S., Lau, W., Ismail, A., and Jaafar, J. (2014). Treatment of restaurant wastewater using ultrafiltration and nanofiltration membranes. *Journal of Water Process Engineering*, 2:58–62.

Appendix

1 Discharge locations table

Table 1: Location description where untreated wastewater is discharged by overflow to open water indicated on ??
Source: Cordilia [2018]

Nr	Discharge location	Wastewater characteristic	Cause of discharge	Source
1	The Rif Mangrove Area (South Coast)	Domestic	Breakdown of the pump station, pressure line rupture, clogging in the sewer system.	Pump-station SVB
2	St. Anna Bay (city)	Domestic	Breakdown of pump-station	Pump-Station Rouvilleweg
3	Shute area (North Coast)	Domestic	Breakdown of pump-station	Pump-station Serou Fortuna
4	St. Anna Bay (Isla Refinery Main Entrance)	Domestic	Breakdown of pump-station	Pump-station Margrietlaan
5	Playa Canoa (North Coast)	Domestic	Breakdown of pump-station	Pump-station Bonam
6	South Coast (South of Bolas Criollo)	Domestic	Breakdown of pump-station	Pump-Station Rotterdam
7	St. Anna Bay	Domestic	Breakdown of pump-station	Pump-station Wilhelminabrug
8	St. Anna Bay Waaigat Water (City)	Domestic	Breakdown of pump-station	Pump-station Waaigat
9	Inland water next to formal Amstel Brewery (Salinja)	Domestic	Breakdown of pump-station	Pump-station Amstel
10	Inland water net to KFC (Salinja)	Domestic	Breakdown of pump-station	Pump-station Fokkerweg
11	Swamp area east of WTC (Piscadera)	Domestic	Breakdown of pump-station	Pump-station WTC
12	Piscadera Bay	Domestic	Breakdown of pump-station	WWTP Klein Hofje

Continuation of Table 1

Nr	Discharge location	Wastewater characteristic	Cause of discharge	Source
13	Shute (North Coast)	Industrial / Domestic	Wastewater dumping activities	Vacuum Truck Companies
14	Playa Canoa (North Coast)	Industrial	Not routed to WWTP because no domestice waste water here	Sewage line form Industrial Park Brievengat and Wasserij Korsou sewage line
15	Former Camel Beach (South Coast)	Domestic	Not connected to sewer system to WWTP Klein Kwartier	Pump-station Waaigat pressure line
16	Noordkant (North Coast)	Domestic	WWTP Tera Cora not in operation	WWTP Tera Cora
17	Between Breezes and Cabana Beach (South Coast)	Domestic	Clogging of breakage in sewage system	Sewage system Koraal Specht
18	Boca Simon (South Coast)	Domestic	Not connected to sewer system	Houses and activities in the area of Boca Simon
19	Ala Conoa (South Coast)	Domestic	Not connected to sewer system	Houses and activities in the area of Ala Canoa
20	Near Pirate Bay (Piscadera)	Domestic	Not connected to sewer sytem	Activities near Pirate Bay
21	Inland water Spanish Water	Domestic	Not connected to sewer system	Houses and activities in the area of Spanish Water
22	Bullenbay Oil Terminal (South Coast)	Domestic	Not connected to sewer system	Operation Bullenbay Oil Terminal
23	St. Anna Bay (Parera)	Domestic	Not connected to sewer system	Houses and activities in the area of Baai Macola
24	Airport Free Zone (North Coast)	Domestic	Not connected to sewer system	Operation Airport Free Zone
25	Curaçao International Airport Hato (North Coast)	Industrial	Not connected to sewer system	Operation Curaçao International Airport Hato

Continuation of Table 1				
Nr	**Discharge location**	**Wastewater characteristic**	**Cause of discharge**	**Source**
26	Inland Water Corredor (South Coast)	Industrial	Not connected to sewer system	Operation Aqualectra Water Water plant Mundo Nobo
27	Inland water Jan Thiel	Industrial	Not connected to sewer system	Water plant Jan Thiel Operation
28	St. Anna Bay (City)	Industrial / Domestic	Not connected to sewer system	Operation of Isla Refinery Operation
29	Near Hilton Hotel	Domestic	Not connected to sewer system	Part of Hilton Hotel Rooms
30	Inland water East of Corendon Hotel	Domestic	Continuous clogging in sewer system	Pater Euwensweg Sewer system (Otrobanda)
31	St. Anna bay at Riffort	Domestic	Breakdown of pump-station	Pump-station Kodela
End of Table				

2 Wastewater Categories

Table 2: Categories of wastewater. Table information obtained from Cordilia [2018]

Category description	**Suitable for treatment by WWTP's of government**
Domestic wastewater from households and simple industrial activities, containing biodegradable components, including sludge from septic tanks.	Yes
High salinity water, from Reverse Osmosis (RO) water production plants (Aquaelectra), cruise ships, and others.	No
Water with high content of **organic fat**, oil and grease, originating from restaurants and others.	No.
Water containing **industrial oil** (mineral oils), from industrial activities (oil refinery), cruise ships, garages, and others.	No.
Chemical Wastewater containing solvents, color, or other toxic components, from hospitals, paint industry, industrial gases industry and others.	No.

3 Obtained information from Information Network

Table 3: Overview documents & information obtained during research

Name	Description	Source	Format
Curaçao Industrial Wastewater Rapid Assessment Report	UNOPS report conducted to support the decision-making process around the Shut disposal point in the North Coast of the Island - June 2018. On request of the Ministry of Traffic, Transport and Urban Planning (VVRP) and its Water Management Commitee.	GMN (Ciaretta Profas)	Report (PDF)
Road Map Proposal	Recommendation produce by UNOPS Rapid Assessment to support the dicision-making process around the Shute Disposal area - June 2018	GMN (Ciaretta Profas)	Report (PDF)
Afvalwater-structuurplan Samenvatting	Summary of Wastewater management plant 1991	GMN (Ciaretta Profas)	Report (PDF)
Beleidsplan Water	Management plan Water constructed by Government of Curaçao	GMN (Ciaretta Profas)	Report (PDF)
De Toekomst van Water op Curaçao	Presentation on the future plans on water management of Curaçao. Constructed by P. Girigori de Flores Martinez MSc - Secretary CIWC	GMN (Ciaretta Profas)	PowerPoint presentation
Recent Development in Wastewater Management on Curaçao	Presentation made by Ing. Ursel Cordilia MBA - Public Works Curaçao - Public Facilities, Section Wastewater Management	DOW (Ursel Cordilia & Franklin Gilbert)	PowerPoint presentation
Influent Collection Scheme	Figure giving an overview of the influent collection scheme constructed by U. Cordilia	DOW (Ursel Cordilia & Franklin Gilbert)	Figure (PDF)

Continuation of Table 3			
Name	**Description**	**Source**	**Format**
Influent Scheme	Overview colletion influent - Public Works, department Wastewater and Sanitation - Project: Wastewater	DOW (Ursel Cordilia & Franklin Gilbert)	Figure (PDF)
Pumping Station Pater Euwensweg	Detail schematic figure of general pump station utilized within sewer system	DOW (Ursel Cordilia & Franklin Gilbert)	Figure (PDF)
Klein Hofje Process Description	Complete description of WWTP Klein Hofje	DOW (Ursel Cordilia & Franklin Gilbert)	Report (PDF)
Klein Kwartier Process Description	Complete description of WWTP Klein Kwartier	DOW (Ursel Cordilia & Franklin Gilbert)	Report (PDF)
Development of an Improvement Plan for reduction of surface water contamination in Curaçao: optimal reduction of discharges of untreated wastewater into surface water	Master Thesis of Ing. Ursel M. Cordilia	DOW (Ursel Cordilia)	Report (PDF)
Wastewater Management	Department of Public Works - Island Territory of Curaçao - Wastewater management description	DOW (Ursel Cordilia & Franklin Gilbert)	Report (PDF)
GS Riool: Otrobanda deel 1 - 4	Detail figures of Sewage system improvements and projects in Otrobanda, Euwensweg	DOW (Ursel Cordilia & Franklin Gilbert)	Report (PDF)
Klein Hofje Effluent Distribution Design 1 - 7	Detailed scheme of Wastewater distribution system of WWTP Klein Hofje	Esin Erdogan	Figure (PDF)
AFZET EFFLUENT RWZI's Levering West en Oost	Overview of treated effluent consumers	Esin Erdogan	Word document

Continuation of Table 3			
Name	**Description**	**Source**	**Format**
0000Dammen_LVV.lyr	GIS map of all Dams	DOW (Gerdy Principaal)	LYR-file
FL18223_Curacao_10cm.exw.aus	GIS DEM model	DOW (Gerdy Principaal)	XML-file
FL18223_Curacao_10cm.exw	GIS DEM model	DOW (Gerdy Principaal)	XML-file
Gemaal	GIS Model of all pump-stations on the Curaçao	DOW (Gerdy Principaal)	Shape file
Leidingen_OV	GIS Model of some wastewater pipes	DOW (Gerdy Principaal)	Shape file
Pand_Lijn	GIS Model of outlines of buildings on Curaçao	DOW (Gerdy Principaal)	Shape file
Pand_vlak	GIS Model of all buildings (area) on Curaçao	DOW (Gerdy Principaal)	Shape file
PERS_LEIDING	GIS Model of some pressure lines on Curaçao	DOW (Gerdy Principaal)	Shape file
Rioolering_Snijders.mxd	GIS Model of part of sewage sytem	DOW (Gerdy Principaal)	MXD-file
Rooien	GIS Model of some gullies in Curaçao	DOW (Gerdy Principaal)	Shape file
Puten_OV	GIS Model of all wells on Curaçao	DOW (Gerdy Principaal)	Shape file
Weg_Lijn	GIS Model of all roads on Curaçao	DOW (Gerdy Principaal)	Shape file
End of Table			

4 Industrial Areas table

Table 4: Overview industrial wastewater production areas on Curaçao. Information obtained from sources: UNOPS Curaçao [2018]; Cordilia [2018]; Civil Engineering Caribbean N.V. [1991]

Name of area	**Contamination activities**
Isla Refinery and CRU	Within this industrial area oil is refined. In theory the wastewater streams are treated in dedicated wastewater treatment facilities within the refinery plant itself whereafter the cleaned water is discharged into Schottegat waters. However, based on the personal interview with both U.M. Cordilia [2] and C. Profas [1] these activities are not controlled by the government.

Continuation of Table 4	
Name of area	**Contamination activities**
Brievengat Industrial Park	The following industrial activities take place within this area: • **Global Paint Products**: Produces water-based paint (80%) and oil paints (20%) for the local and regional export. In total UNOPS Curaçao [2018] estimates its total industrial wastewater production to be 30.000 [$m3/year$] containing high levels of chemical and oil contaminants. These wastewater streams are collected and sent to Selikor, which is the designated waste processing company, to be processed in incineration ovens. Domestic wastewaters produces by this company are discharged into the central sewage system. • **Lovers Industrial Corporation**: Produces dairy and fruit products. Wastewater is expected to have high concentrations of organing pollutants and some oil and grease. Moreover, it is reported that these wastewater contain high BOD levels which are out of range for the central sewage system. Currently, these wastewater streams are being discharged into the central sewage system despite these contamination levels. • **Smith & Nephew**: Pharmaceutical products are produced in this area associated with high contamination wastewater levels with respect to pollutants and chemicals. In theory this company has its own treatment facility to treat the industrial wastewater which is thereafter discharged into the central sewage system. From reports it remains unclear what the quantity of these fluxes us nor if the discharge stream is combined or separated from the domestic sewage. • **Soap company**: The industrial wastewater orginating from this company is associated with high BOD levels. The volume of the wastewater produced by this company remains unknown and is assumed to be directly discharged onto the central domestic sewage system. • **Concrete Industry**: From this activity it is expected that the industrial wastewater contains high levels of minerals as well as settleable particles. Evidence provided by UNOPS Curaçao [2018] claims that these wastewater streams are directly discharged into open water bodies via the rain discharge gullies. • **Korsow Wasserij BV**: This company profides textile cleaning for hotels, healhtcare companies, restaurants, and garments. These wastewater streams are expected to have high levels of detergents, organic pollution, and chemical pollutants and are directly discharged into the central domestic sewage system.

Continuation of Table 4	
Name of area	**Contamination activities**
Harbour Free Zone	This area quantifies 23 hectares and facilitates over 100 individual merchants accumulatively occupying 91.000 [m^2]. Although this area does have the facilities to accommodate manufacturing activities, there are no records of any, therefore the produced wastewater is assumed to meet the standards of domestic sewage. The total produces volume is unknown, but certain to be collected within the central sewage system and transported towards WWTP Klein Hofje.
Airport Free Zone	This area mainly consists of business buildings and commercial stores. Therefore gross of the wastewater is assumed to be domestic which is stored in septic tanks, whereafter it is transported to the Curinde sewer network and withouth treatment discharged into open waters. Currently the only known industrial wastewater production in this area is that of the Gold refinery, which is associated with high mineral and heavy metal contamination.
Nieuwe Haven, Groot Davelaar, Zeelandia Industrial Parks	Witin this area the following activities area present: • **Antillean Paints**: The produced wastewater is likely to contain high levels of pollutants like white spirit. The discharge point of this water flux remains unknown. • **BOC Gases Curaçao NV**: Manufacturing and Distribution of Industrial Gases such as Oxygen. Wastewater is likely to contain high levels of chemical pollutants and is collected via vacuum trucks to be discharged at the Shut disposal area. • **Coca Cola**: Production of Coca Cola beverages. Wastewater often contains high BOD loading is in theory treated at the facility it self whereafter it is discharged to the central domestic sewage system. • **Hospital & several clinics**: These wastewater often contain high chloride levels, chemicals, and medical pollutants. It is argueded by U.M. Cordilia [2] to be collected by vacuum trucks and transported to be discharged at the Shute disposal area.

Continuation of Table 4	
Name of area	**Contamination activities**
Heintje Kool	The industrial activities within this area mainly consists of commercial store and warehouses. However, based on the GIS 'basiskaart' provided by Public Works there is also a concrete production company and a car painting company. Based on this information it can be assumed that the wastewater is mainly domestic but could have mineral and chemical contaminations which are discharged into the central domestic sewage system.
Seru Lora	Activities in this industrial park remain partially undescribed apart from a small company producing alcoholic beverages. The total wastewater of this area is discharged to the sewer network which is connected to either Klein Kwartier or Klein Hofje.
Seru Mahuma	Both wastewater production shemes, as well as, discharge points of this area are unknown.
Ship Terminals	In total Curaçao receives 200-220 cruise ships annually bringing large volumes of domestic wastewater, bilge water, sludge, scrubbers water, and reverse osmosis concentrate which are discharged onto the sewer system, collected and sent for recycling to the refinery, recycled in asphalt industry, transported by vacuum trucks and discharged at Shut and disposed at shut respectively.
Dry Dock	This area is approximately 1.600 [m^2] and contains ship cleaning and maintenance activities which leads to high quantities of industrial oil residue, paint particles, and metallurgical related contamination into the wastewater streams. Where these wastewater streams are discharged remains unknown.
Airport operations	Within this area the following contamination are produced: • **Blue waters from chemical toilets**: these waste streams, which argued by U.M. Cordilia [2] within a private interview, to have very high viscosity due to dissolved toilet paper. These streams are directly discharged into sea via a discharge system situated at the facility. • **Hydraulic oils and fuel residue**: There is no knowledge of management scheme for these contaminated fluxes but are deemed extremely toxic and hazardous for environmental entities. • **Aircraft washing**: These wastewater fluxes contain various pollutants such as minerals, chemicals and oils which currently unknown in volume and discharge location.

Continuation of Table 4	
Name of area	**Contamination activities**
Reverse Osmosis Plant	These activities are divided in the following aspects: • **Aqualectra Reverse Osmosis plants**: Production of drinking water producing a brine wastewater stream which is discharged into sea at Fuik or at Piscadera. • **Refinery**: This facility discharges direclty to sea. • **Commercal mall Sambil**: Wastewater is discharged into a rain pond which discharges again to Piscadera lagoon. • **Hotels**: Some hotels have an own Reverse Osmosis facility which in all cases discharges their brine wastewater directly to sea.
Restaurant related activities	Approximately 200 restaurants on Curaçao produce wastewater streams containing large concentrations of oils and grease. These streams are either separately collected via vacuum trucks and disposed at Shut or illegally discharged onto the domestic sewage system without the required pre-filtration causing blockage of the pipes.
Dry cleaning activities	The total amount of companies nor the total volume of wastewater produced by this sector remains unknown. Based on the activity it is assumed that the wastewater contains large amounts of organic pollutants, detergents, and potentially chemical pollutants which are most likely transported to and discharged at the Shut disposal area.
Car washing and car garage activities	A high number of non-regulated car washing and garage activities exist on Curaçao which are associated with effluents containing soaps, minerals, organic compounds, and industrial oil residues. The total volume nor the discharge locations remain unknown.
Curoil and Bullenbaai oil storage facilities	These wastewater streams are assumed to mainly domestic which are discharged directly to sea or into the central system. However, there could potentially be additional contaminated wastewater that is produced during the cleaning of the tanks. The total volume nor the discharge location of this contaminated water remains unknown.
Mijnmaatschappij Curaçao	For this activity it remains unknown if there are any industrial wastewater fluxed produced.

Continuation of Table 4	
Name of area	**Contamination activities**
Other activites	Other industrial activities that remain unknown in quantity and quality, but could pose significant contamination effects, are: • Blue water from portable toilets • Wastewater from beauty salons. • Wastewater from car battery recycling facilities.
End of Table	

5 Attribute tables from Wastewater Flux QGIS Model

Table 5: Attribute table QGIS Model layer 'Discharge locations'

Attribute	Description	Unit
ID	Numerical value to identify and label discharge point	Integer
Name	Name of location	Text
Waterclass	Water category; Domestic, Industrial, or Domestic & Industrial	Text
est.qualit	Textual explanation of water quality estimation	Text
activity	Activity category: Continuous or Discontinuous	Text
descript	Room for discripton of area	Text
Photo	Room to upload a photo of discharge point	JPEG
extra	Room for extra notes by researcher	Text
Area m2	Area estimation connected to discharge point expressed in [m^2]	Numerical value
Flow m3.d	Flow estimation connected to discharge point expressed in [m^3/d]	Numerical value
confidence	Level of confidence expressed in High, Medium, Low, Very low	Text
w.source	Water source, i.e. first upstream point the water originated from	Text
Inf.source	Source of information	Text

Table 6: Attribute table QGIS Model layer 'Pump-station locations'

Attribute	**Description**	**Unit**
Name	Name of pump-station	Text
ID	Numerical value to identify pump-station	Integer
Area m2	Area estimation connected to pump-station expressed in [m^2]	Numerical value
Flow m3.d	Flow estimation connected to pump-station expressed in [m^3/d]	Numerical value
water type	Water category; Domestic, Industrial, or Domestic & Industrial	Text
est.qual	Textual explanation of water quality estimation	Text
descript	Room for description of pump-station	Text
Photo	Room to upload a photo of pump-station	JPEG
extra	Room for extra notes by researcher	Text
confidence	Level of confidence expressed in High, Medium, Low, Very low	Text
Inf.source	Source of information	Text
Inhabitant	Estimation of amount of inhabitants connected to pump-station	Integer

6 Other

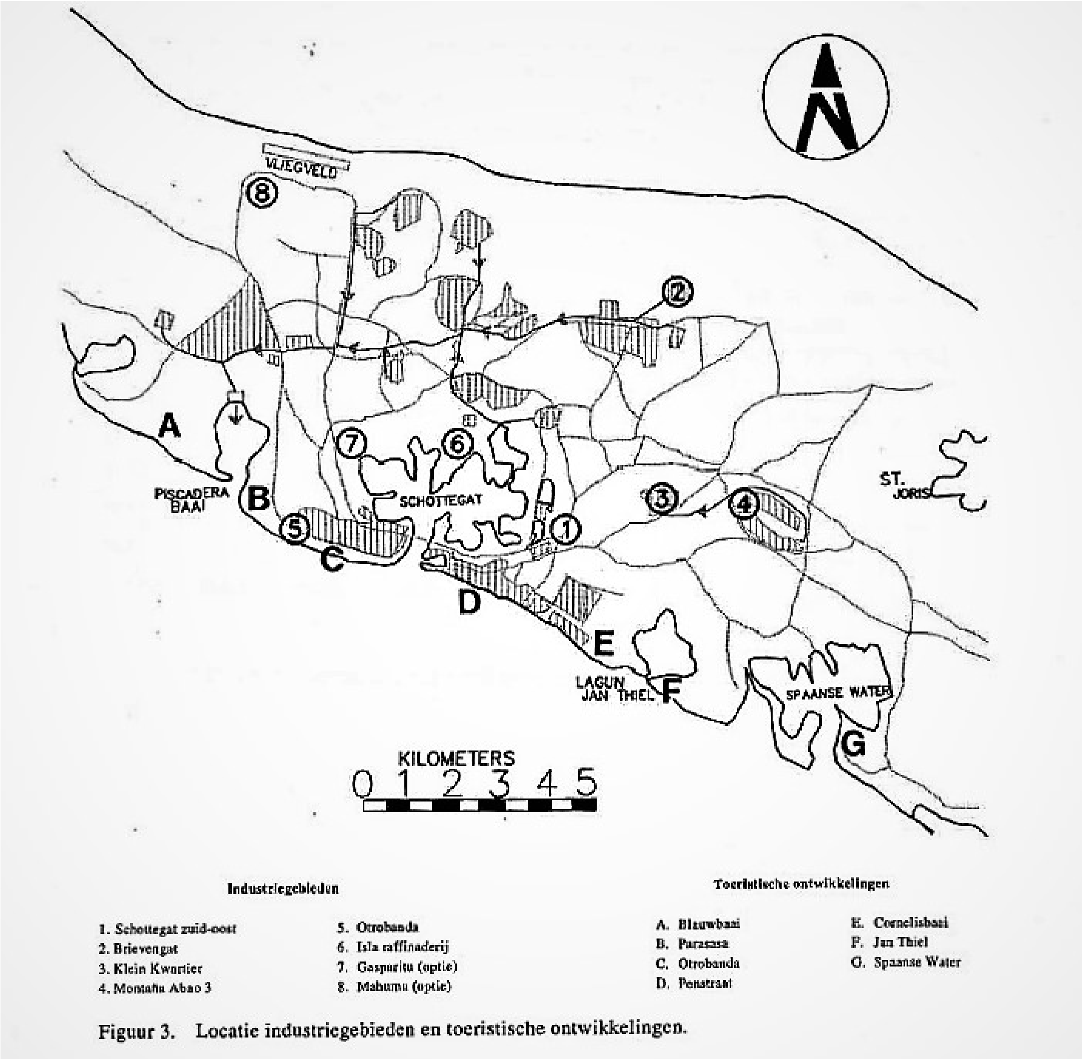


Figure 1: Location of all industry areas and tourism development areas. Source Civil Engineering Caribbean N.V. [1991]

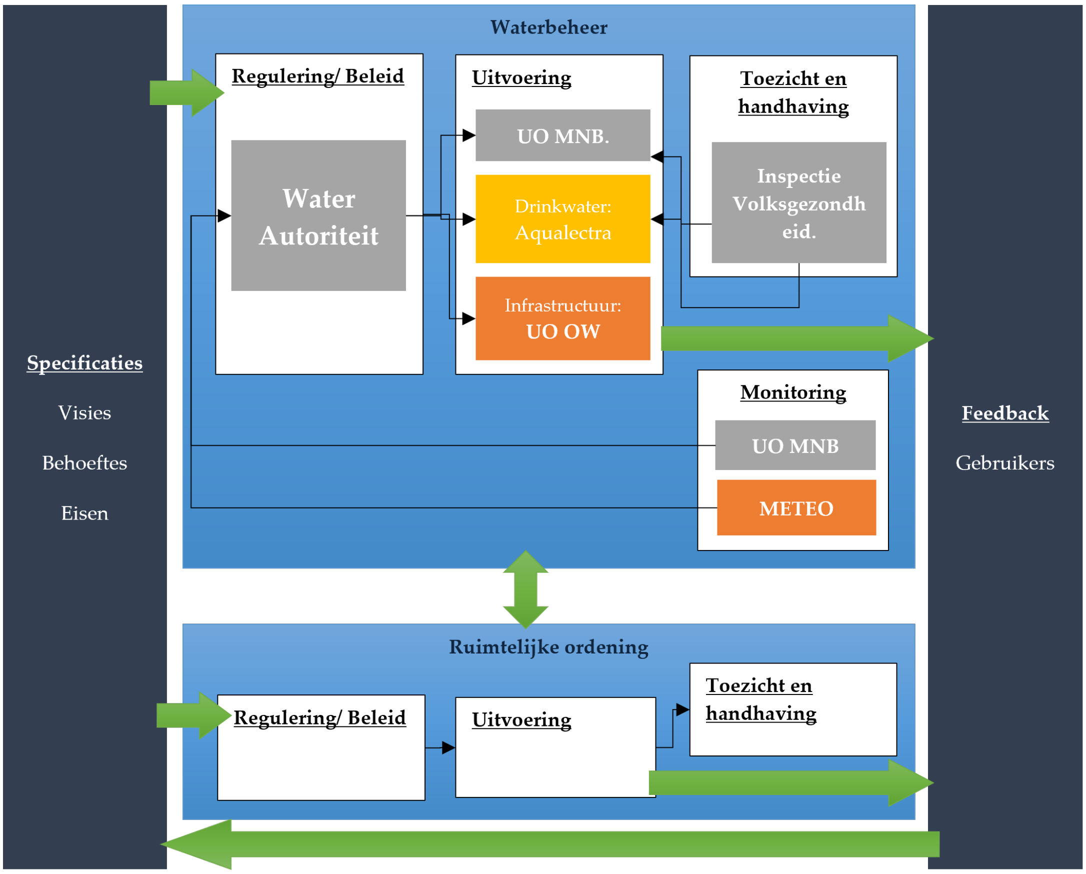


Figure 2: Institutional framework for wastewater future. Source Girigori de Flores Martinez [2020]

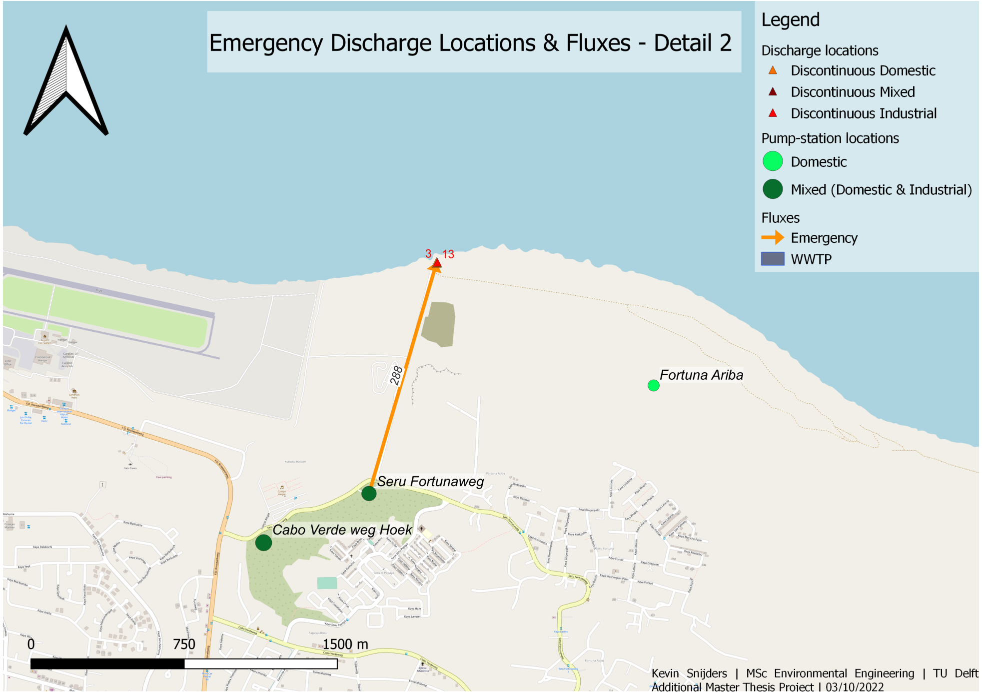


Figure 3: Emergency flux - Detail 2/5. Constructed October 2022 by author

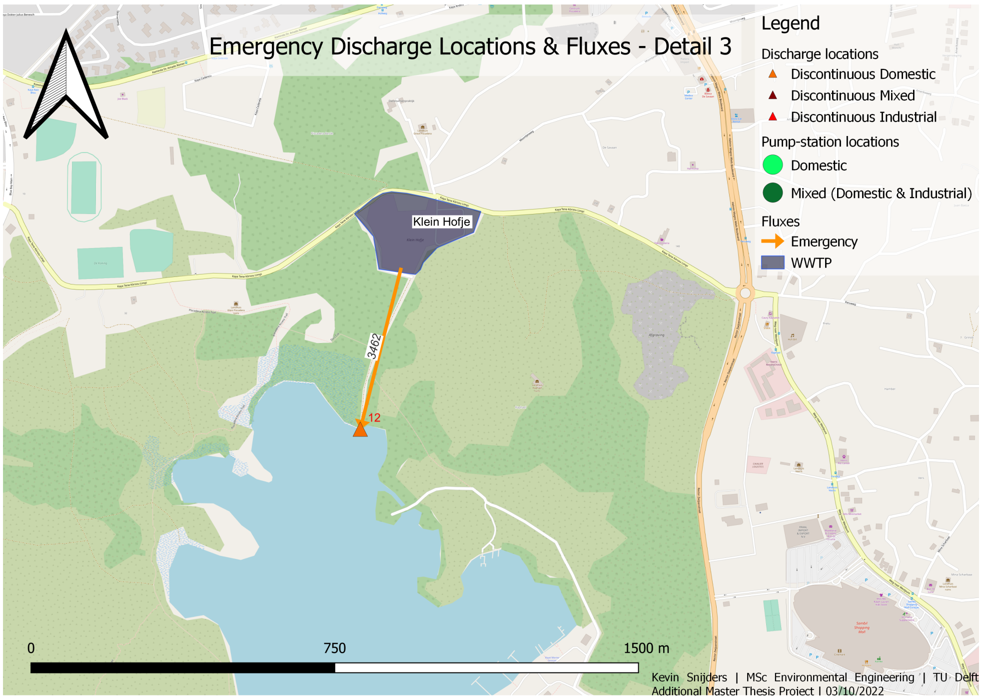


Figure 4: Emergency flux - Detail 3/5. Constructed October 2022 by author

Table 7: Attribute table QGIS Model layer 'Fluxes'

Attribute	Description	Unit
ID	Numerical value to identify flux	Integer
Flow m3.d	Flow estimation expressed in $[m^3/d]$	Numerical value
Area m2	Area estimation connected to flux expressed in $[m^2]$	Numerical value
water type	Water category; Domestic, Industrial, or Domestic & Industrial	Text
w.source	Water source, i.e. first upstream point the water originated from	Text
Inf.source	Source of information	Text
Conf.lvl	Level of confidence expressed in High, Medium, Low, Very low	Text
Line type	Type of line: pressure line or gravity line	Text
extra	Room for extra notes by researcher	Text
Photo	Room to upload a photo	JPEG
Disch.loc	Discharge location of flux	Integer
Inhabitant	Estimation of amount of inhabitants connected to Flux	Integer
Activity	Activity: Emergency or continuous	Text
est.qual	Textual explanation of water quality estimation	Text

Table 8: Attribute table QGIS Model layer 'Potential Fluxes'

Attribute	Description	Unit
ID	Numerical value to identify flux	Integer
Flow m3/d	Flow estimation expressed in $[m^3/d]$	Numerical value
Area m2	Area estimation connected to flux expressed in $[m^2]$	Numerical value
water type	Water category; Domestic, Industrial, or Domestic & Industrial	Text
w.source	Water source, i.e. first upstream point the water originated from	Text
Conf.lvl	Level of confidence expressed in High, Medium, Low, Very low	Text
extra	Room for extra notes by researcher	Text
Photo	Room to upload a photo	JPEG
Disch.loc	Discharge location of flux	Integer
Inhabitant	Estimation of amount of inhabitants connected to Flux	Integer
Line type	Type of line: pressure line or gravity line	Text
Inf.source	Source of information	Text
qual.est.	Textual explanation of water quality estimation	Text

Table 9: Attribute table QGIS Model layer 'WWTP'

Attribute	**Description**	**Unit**
ID	Numerical value to identify WWTP	Integer
Name	Name of WWTP	Text
flow m3/d	Estimated flow collected by WWTP	Numerical value
area m2	Estimated area connected to WWTP	Numerical value
inhab.eq	Inhabitant equivalent connected to WWTP	Integer
capa	Hydraulic capacity of WWTP expressed in $[m^3/d]$	Numerical value
Activity	Current state/activity of WWTP	Text

Table 10: Attribute table QGIS Model layer 'Industrial Areas'

Attribute	**Description**	**Unit**
ID	Numerical value to identify industrial area	Integer
Name	Name of WWTP	Text
flow m3/d	Estimated flow produced by industrial area	Numerical value
Water Type	Water category; Domestic, Industrial, or Domestic & Industrial	Text
Conf.lvl	Level of confidence expressed in High, Medium, Low, Very low	Text
qual.est.	Textual explanation of water quality estimation	Text
Discharge	Discharge location of industrial area	Integer
Photo	Room to upload a photo	JPEG
Extra	Room for extra notes by researcher	Text
Inf.source	Source of information	Text

Colophon

This document was typeset using $\LaTeX$, using the KOMA-Script class `scrbook`. The main font is Palatino.