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Effects of Ineffective Wastewater Drainage System on Quantity of Wastewater Reaching Rivers and Treatment Plants in Addis Ababa

The Case of Urban Densification and Expansion

A Thesis Submitted and Presented to
The School of Graduate Studies of Addis Ababa University in
Partial Fulfillment of the Degree of Masters of Science in
Civil Engineering (Major in Water Supply and Environmental Engineering)

By

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Declaration

I *declare that this thesis, which I submitted to the School of Graduate Studies of Addis Ababa University in partial fulfilment of the requirement of degree of Masters of Science in Civil Engineering, is my own personal effort. This thesis has not been submitted previously, in whole or in part, to qualify for any other academic award. Furthermore, I took reasonable care to ensure that the work is original, and, to the best of my knowledge, does not breach copyright law, and has not been taken from other sources except where such work has been cited and acknowledged within the text.*

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Acronyms and Abbreviations

AAWSA……………...Addis Ababa Water Supply and Sewerage Authority
AAEPA………………Addis Ababa Environmental Protection Authority
SSO………….........Sanitary Sewer Overflow
HQ……………………Head Quarter
AAU…………………..Addis Ababa University
AAiT…………………..Addis Ababa Institute of Technology
MUDC………………..Ministry of Urban Development and Construction
MOH………………….Ministry of Health
EBCS…………………Ethiopian Building Code Standard
HA…………………....Hectare
PF……………………..Peaking Factor
SSA…………............Steady State Analysis
EPS…………............Extended Period Simulation
BSF……………………Base Sanitary Flow
I & I……………………Inflow and Infiltration
CO…………………….Conduit / Pipe
12HD22……………….Manhole Name
CA……………………..Catchment
DWF…………………...Dry Weather Flow
WWF…………………..Wet Weather Flow
FDRE………………….Federal Democratic Republic of Ethiopia
MWIE………………….Ministry of Water, Irrigation and Energy
WHO…………………..World Health Organization
DO……………………..Dissolved Oxygen
BOD…………………...Biochemical Oxygen Demand
COD…………………...Chemical Oxygen Demand
PE……………………...Population Equivalent
WWTP…………………Wastewater Treatment Plant
VIP……………………..Ventilation Improved Pit Latrine
NRW…………………...Non-Revenue Water
US EPA………………..United States of America Environmental Protection Agency
SCADA………………...Supervisory Control and Data Acquisitions
MH……………………..Manhole
WEF……………………Water Environment Federation
L/S……………………...Liter per Second
L/D……………………...Liter per Day
CBE…………………....Commercial Bank of Ethiopia
ETC………………….....Ethio Telecom

Abstract

There have been rapid land use change both in the center and in the outskirts of Addis Ababa. However, the existing conventional wastewater drainage system has been in use in the central part for around 40 years while sewer system has not yet developed in the expanding residential areas. In view of that, this research was conducted to identify how ineffective existing sewer system and onsite wastewater management facilities are contributing for the discharge of untreated wastewater into rivers in addition to assessing inflow and infiltration quantity in the existing sewer. For these purposes, Senga Tera and Tulu Dimtu study areas were selected to represent urban densification and urban expansion respectively. The existing land use plans of both areas, and as-built data and sewer master plan for the existing sewer system were collected and reviewed. Flow rate were manually measured at selected manholes on field for model calibration in addition to analyzing six months of ArcGIS water use data's. Moreover, the number of stories and floor areas of high-rise buildings which are now under construction were surveyed in Senga Tera. Similarly, field research was conducted to identify the existing onsite wastewater management facilities inTulu Dimtu. Then, steady state analysis and modeling for the existing sewer system and for the proposed non-conventional sewer system in Tulu Dimtu were conducted using Sewer GEMS V8i. Accordingly, it was revealed that 87% and 53% of the existing manholes in in Senga Tera could be surcharged and overflowing due to rapid land use change during wet weather season respectively. It was also found that around 15.59 l/s of wastewater was cross connected into the nearby storm water drainage system. As a result, overflows and leakage through the walls of the existing cesspools in Tulu Dimtu and Sanitary Sewer Overflows (SSOs) from manholes and sewer cross connections in Senga Tera area have been found to be factors for the discharge of untreated wastewater first into the nearby storm water drainage system and then outfall into nearby rivers. Moreover, the quantity of average inflow and infiltration which was estimated in Senga Tera was around 71%. This in turn could contribute to induce SSOs on the existing sewer system in addition to become a factor for the hydraulic overloading of the existing Kality Wastewater Treatment Plant. Therefore, it is recommended to enhance the existing sewer system through master plan review and to use non-conventional sewer system instead of cesspools in the expansion areas.

Keywords*: Addis Ababa River, sanitary sewer overflows, non-conventional sewer, Inflow and Infiltration, cesspool*

Chapter One

1. Introduction

1.1. Background

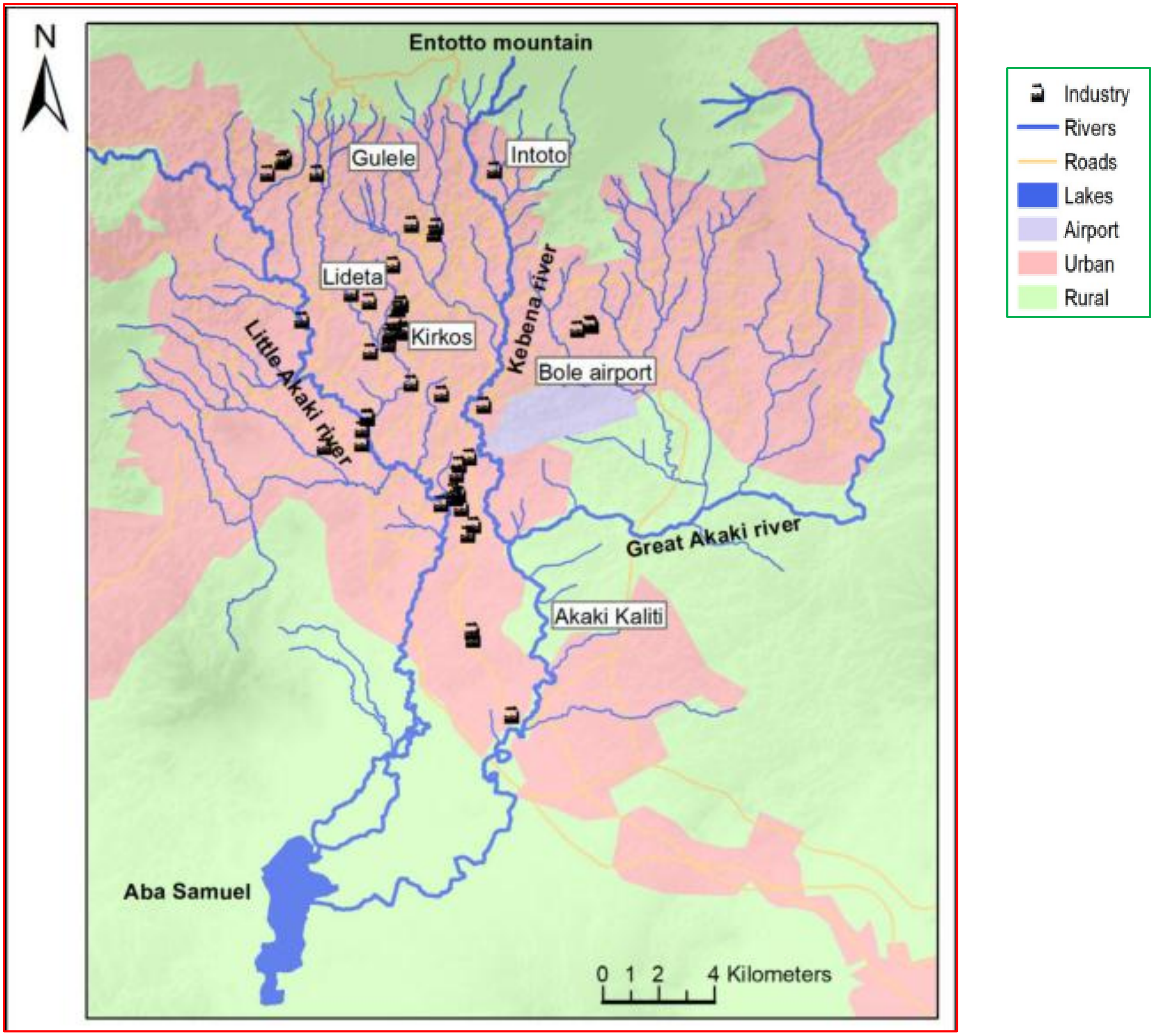
More than half of the population of less developed countries worldwide do not have access to sanitation and around 80% of the wastewater generated is directly (MWIE,32017) discharging into surface and ground water bodies. The origin of Addis Ababa rivers pollution (D. Adugna et.al, 2019) are from the discharge of untreated or partially treated domestic and industrial wastewater. The pollution of rivers have been noticed in both areas where there is an existing sewer system and in other areas where the municipal wastewater drainage system does not exist at all. Non-point source pollution from inefficient management of solid waste in the city is also contributing pollution. The practice of open defecation is also being practiced at the banks of rivers. The existing effluent standards (EEPA and UNIDO 2003) and other environmental laws (EPCP, 2002; EIAP, 2002) are not effectively enforced by the Addis Ababa Environmental Protection Authority.

The polluted water (Tadesse A., 2011) is being used for urban agriculture without much health consideration. Vegetables harvested by the river is being washed using polluted water by merchants before sending to local markets (Agaje M., 2007). When the piped water is cut off for a couple of days which is common in this city, low income people utilize river water for washing hands and cloth. In south sub urban part of the city, it has been consumed by both cattle's and by humans every so often. During every rainy season, there have been many reports from local newspapers that some city residents were hospitalized and a few even dead due to cholera outbreak.

Studies which have been conducted so far by several researchers revealed that chemical pollutants (D. Adugna et.al, 2019), the BOD and COD levels of Addis Ababa Rivers are very high compared with WHO and international standards. As a result, the DO concentration is depleted (Abdulshikur M., 2007) and life inside these rivers ceases existing. The extent of pollution is also increasing from time to time due to an increase in urbanization and industrial discharge from existing as well as new ones. The levels of existing law enforcement and awareness by stakeholders to protect sewage discharge into Addis Rivers are at low level.

The protection as well as cleaning up of Addis Ababa Rivers (Figure 1) pollution are not going to be achieved over night. In order to achieve that, several integrated approaches need to be implemented. Providing efficient wastewater drainage system and treatment is the most cost effective method (Meena Palaniappan et.al, 2010) to protect river pollution in an organize way. It is not also practical to install expensive wastewater treatment plants to treat polluted river water to clean up rivers.

The existing municipal wastewater drainage (Hendriks 2002 ; Morrison 2011) system (includes the older and recent sewer systems) is only yet available for Kality wastewater drainage catchment which is covering some part of northern and central Addis Ababa in addition to western part of the city. The rest of the city which includes the southern, eastern and a portion of northern and central Addis Ababa do not have a conventional sewer system yet.



Source: *Malin Eriksson and Jonathan Sigvant, 2019*

Figure 1: Map showing river networks in and around Addis Ababa

Therefore, there is a need for conducting research to identify the specific cause of complicated river pollution factors which are deep rooted. Based on the findings of the research, measures shall be recommended for the relevant city government agencies for actions in order to minimize as well as avoid the pollution of rivers in Addis Ababa.

1.2. Statement of the Problem

To ensure the development of Addis Ababa city as a modern city, there is a need for proper management of environmental pollution in general and river pollution in particular from the discharge of untreated and partially treated wastewater. Most studies (Agaje 2007; Benti Firdissa et.al, 2016) conducted so far on water quality revealed that, rivers flowing through this city have been polluted and acting as an open sewer. Accordingly, the under listed arguments are the statements of the problem to show the need for conducting specific research.

1.2.1. Wastewater Management Challenges

Wastewater management has been challenging in Addis Ababa both in densification and expansion parts of the city which are located relatively in the central and in the outskirts of the city respectively. Conventional wastewater drainage system is available in Kality wastewater drainage catchment. Nevertheless, it has not yet been developed in the remaining two catchments which are the Eastern and Akaki wastewater drainage catchments. As a result, on site wastewater management facilities have been in use both in the expansion as well as in the densification parts of the city where municipal sewer does not exist. However, the existing sewer system and onsite wastewater management facilities have been experiencing the following problems

1.2.1.1. Sewer Performance

There has been rapid land use change in the center of the city where high rise buildings are under construction for different uses. These areas have been redeveloping from the existing slum houses into somehow planned neighborhoods. As a result, the demand for connecting building sewer or lateral with the existing municipal sewer system has been increasing from time to time. However, the existing conventional older sewer capacity in these areas may be limited to handling the entire wastewater flow rates.

1.2.1.2. Onsite Wastewater Management Practice

In the absence of conventional sewer system, cesspool and septic tank have been widely used to manage wastewater from residential and commercial developments. However, it is common to see overflowed and leaked sewage around the existing septic tanks and cesspools. The nearby storm water drainage ditches in some places are carrying untreated wastewater. Moreover based on my transect walk along some rivers, I have observed that on site wastewater management facilities are not existing at all in some places where houses and buildings were built closer to left and right sides of Addis Ababa river banks.

1.2.2. River Pollution and its Impacts

Several researches which have been conducted on the quality of surface water in Addis Ababa revealed the pollution of rivers from physical, chemical and bacteriological constituents. The lower level of dissolved oxygen concentration is becoming a threat for the existence of life in the river ecosystem. The higher level of nutrients like nitrogen and phosphorous can be the cause for algal bloom due to eutrophication process with in the river, on urban agricultural land as well as on the downstream part of the river like in Aba Samuel Lake. There is health risks associated with the use of river water for irrigation which is polluted with heavy metals. There is also post-harvest contamination of vegetables where farmers use river water for washing vegetables to prepare for local markets.

Therefore, this research focuses on studying the effect of ineffective wastewater drainage and management on surface water and treatment plants due to rapid land use change in selected part of an older and new expansion city areas.

1.3. Research Questions

- How does rapid change of land use plan in a certain area in the city impacts the capacity of the city older exiting conventional wastewater drainage systems which was commissioned in 1982?

- Does sanitary sewer overflows (SSO) has been contributing to the discharge of untreated wastewater into the Addis Ababa Rivers?

- What is the extent of inflow and infiltration on the existing wastewater drainage system in the study area which may contribute to overload sanitary sewers and Waste Water Treatment Plants?

- Does a non-conventional sewer system be preferred over a separate inefficient septic tanks (without effluent treatment units) or cesspools for single or multi-family houses for a certain community or housing cooperatives in Addis Ababa city to manage their wastewater in a communal way?

1.4. Objective of the Study

The objectives of this research have been divided into general and specific objectives as follows.

1.4.1. General Objectives

- To identify specific factors which are contributing to the pollution of rivers in Addis Ababa by considering rapid land use change in densification and expansion parts of urban areas followed by recommending technical and policy measures.

1.4.2. Specific Objectives

- To study and identify the impacts of the ever-changing land use plan on the capacity or size of the older existing municipal sewer system in Kality sewer shed area for a selected subdivision which are developing high rise buildings .

- To analyze and model a typical non-conventional wastewater drainage system for a certain selected community or new housing associations in order to show its advantage over using individual onsite wastewater management facilities like cesspools.

- To recommend measures which need to be taken action by the city administration in order to protect the pollution of rivers in Addis Ababa.

1.5. Significance of the Study

This study exemplifies the need for conducting prior proper study, analysis and modeling before connecting building sewer or lateral with the nearby existing sanitary sewer for a certain neighborhood which is undergoing rapid land use change in Addis Ababa.

This study process is also beneficial for academicians and researchers who will conduct similar researches on model calibration and capacity evaluation of the existing sanitary sewer system in Addis Ababa.

Above all, this research depicts the necessity of implementing efficient wastewater drainage system throughout Addis Ababa supported by master plan review and updates of the older or existing sewer systems before the end of the planned design periods.

And if this sewer system is followed up by proper operation and maintenance management measures, it will have paramount importance on protecting Addis Ababa Rivers from pollution.

1.6. Limitation of the Study

There are no available recorded wastewater flow rate data through manholes in the study area in Senga Tera in particular and in Addis Ababa in general. So, flow data were measured manually for this study.

The existing manholes in Senga Tera area are placed on asphalt roads at a distance of around 1.5m from the edge of pavement. During manual flow measurement, distraction of vehicle movements in the area was occurring. Authorization from AAWSA and from the traffic polices were also needed. Manual flow measurement during wet weather period and the disruption on the ground were challenging on field. As a result, these process may affect the accuracy of flow rates.

Flow recorded using flow measuring devises would enable to get diurnal and seasonal flows. This could help to get better study results. Moreover, metered flow rates in this way from mid night through 6AM helps to separate base sanitary flow (Dry Weather Flow) from infiltration induced by ground water. Practically, it is unlikely to conduct manual flow measurement after mid night.

1.7. Thesis Organization

This thesis is organized into six chapters starting from introduction and goes through conclusion and recommendation. The first chapter is introduction which describes the background, statement of the problem, research questions and objectives, significances and limitations of the study.

The second and the third chapter articulates about the literature review and the study methodologies respectively. The material and methods section encompasses description of the study area, existing wastewater drainage situations of the study areas, data collections, description of model calibration process, surveys conducted on field and other related.

The fourth chapters describes data analyses and shows data summaries for both the case of urban densification and expansion for Senga Tera and Tulu Dimtu respectively.

Chapter five of the study report explains the results and discussions of the research process followed by chapter six which contains concluding remarks and recommendations.

Chapter Two

2. Literature Review

2.1. Land Use Change

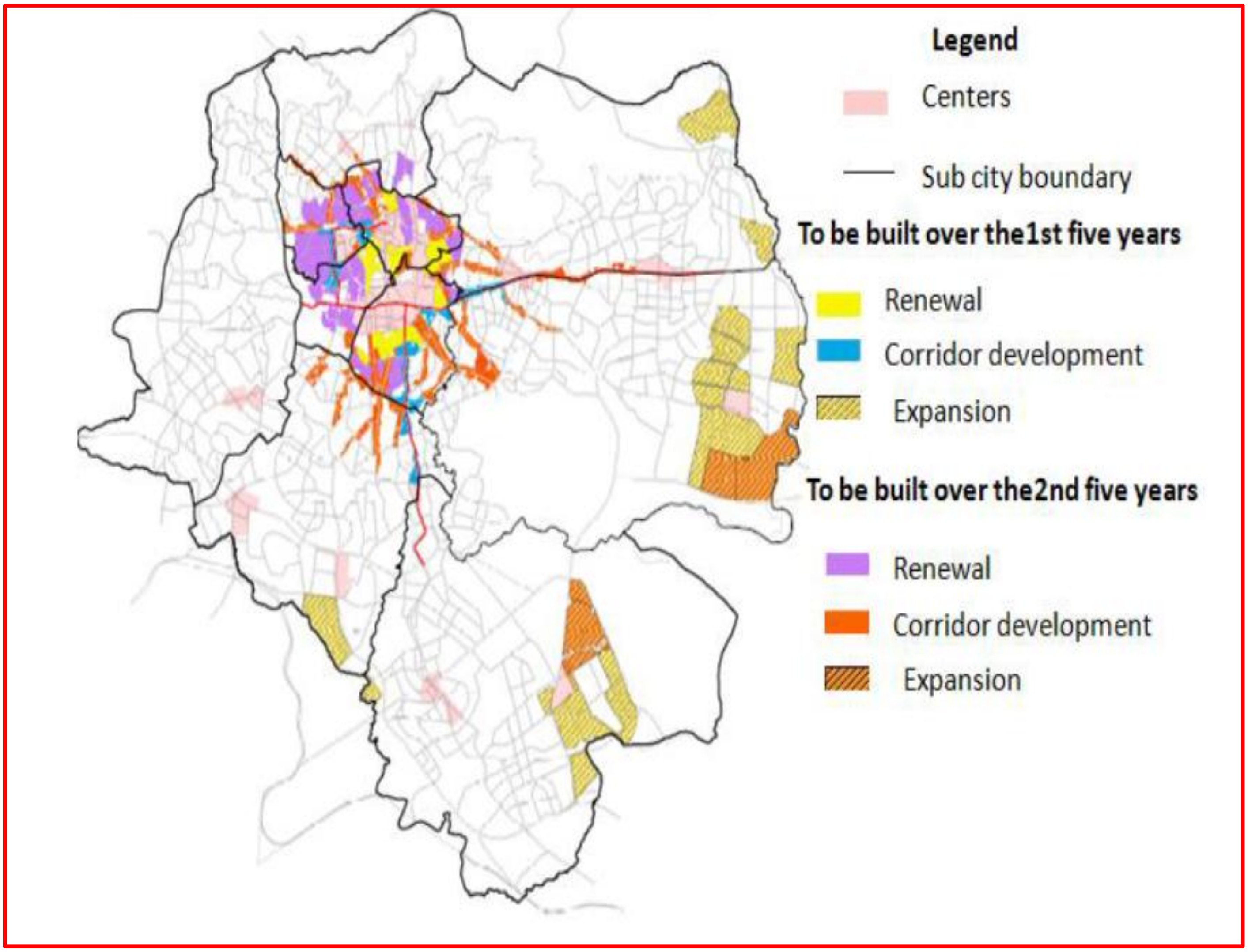
The city land use has been changing rapidly. The city structural plan (AACSP, 2017) indicated that the total built up area has increased by at least 25% for a decade before 2017. Recent research was (Larissa Larsen et.al, 2019) conducted in 2019 to see the impact of rapid urbanization and public housing development on urban form and density for a period of between 2006 and 2016 in central and surrounding Addis Ababa. This city wide study was based on around 13 land use types. Accordingly, the land use change occurred considering different scenarios has been summarized as shown under (Table 1) below.

Table 1: land use change in Addis Ababa for a period of ten years (2006 - 2016)

	Central Addis Ababa			Surrounding Addis Ababa			Citywide		
	Area (ha) in 2006	Area (ha) in 2016	% Change By Land Use	Area (ha) in 2006	Area (ha) in 2016	% Change By Land Use	Area (ha) in 2006	Area (ha) in 2016	% Change by Land Use
1. Agriculture	6	2	−61.6%	1,9786	1,1424	−42.3%	1,9791	1,1426	−42.27%
2. Vegetation	106	116	9.5%	7161	5408	−24.5%	7267	5524	−23.98%
3. Minerals	0	0	0.0%	418	1993	377.0%	418	1993	376.97%
4. Recreation and Conservation	33	48	46.4%	95	868	812.4%	128	916	617.19%
5. Transport	421	364	−13.6%	1332	1879	41.1%	1754	2243	27.92%
6. Utilities and Infrastructure	6	4	−27.8%	281	355	26.1%	287	359	24.99%
7. Residential	2647	2242	−15.3%	1,4361	1,7880	24.5%	1,7008	2,0122	18.31%
8. Community Services	223	187	−15.9%	631	755	19.6%	854	942	10.30%
9. Retail/Businesses	201	554	174.8%	89	243	173.2%	291	797	174.31%
10. Manufacturing and Storage	40	187	368.3%	211	1995	847.0%	251	2182	770.64%
11. Administration	330	313	−5.2%	701	1029	46.7%	1031	1342	30.12%
12. Bare Land	61	81	33.2%	2669	2941	10.2%	2729	3022	10.72%
13. Special Use	124	101	−18.6%	22	46	105.1%	146	146	0.28%

Source: *Larisa Larsen et.al, 2019*

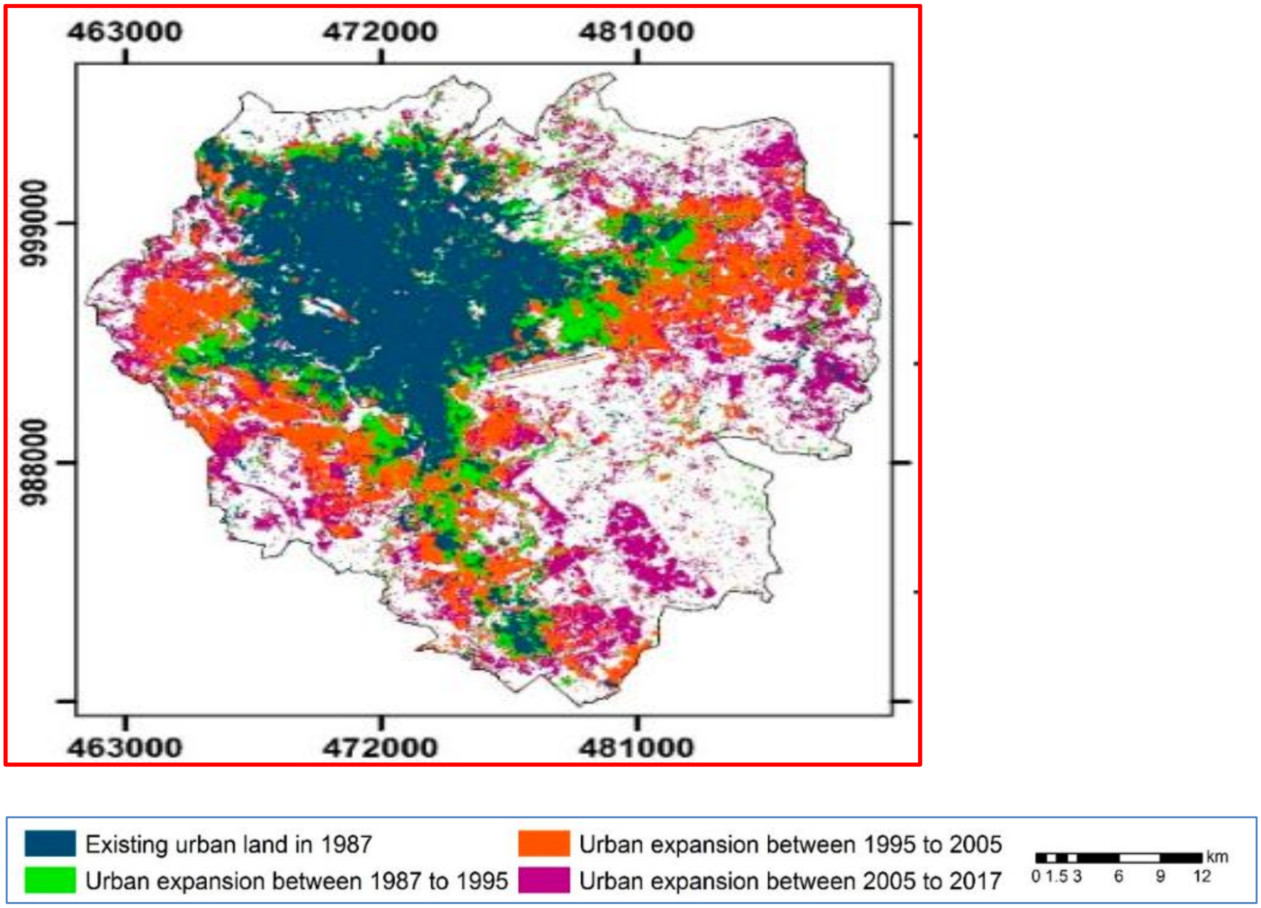
In order to change the land use plan of the city towards a modern city, the structural plan (Figure 2) of the city (AACSP, 2017) proposed to renew the center of the city which is predominate with slum houses while expanding new areas which are located in the outskirt of the city.



Source: *Addis Ababa City Structure Plan, 2017*

Figure 2: The first and second five-year housing development proposed land use

Furthermore another study (Berhanu K. Terfa et. al, 2019) was conducted to see the trend of urbanization in Addis Ababa from 1987 to 2017 using remote sensing and GIS technologies. Accordingly the study revealed that urban expansion focused largely towards western, eastern and southern direction from 1987 through 1995 and from 1995 through 2005 respectively. In addition, urban expansion intensified more towards eastern and southern Addis Ababa between 2005 through 2017 (Figure 3).



Source: *Berhanu Keno Terfa et.al. 2019*
Figure 3: Urban expansion in Addis Ababa

2.2. Land Use Change and River Pollution

Human pressure on rivers flowing through or crossing a certain city is increasing all over the world, threatening the water quality (Zaharias L.et, al. 2016), and the aquatic ecosystem health. The problem is particularly more pronounced in urbanized regions because of the cities rapid land use change, due to their specific features, are a major factor influencing the water cycle in general and the river systems in particular.

The impacts of land use change on rivers flowing through a certain city are complex. When water is flowing through the surface, it can be exposed to various pollutants in addition to direct flow of wastewater into rivers which can determine the quality of rivers. River pollution is the most common challenges in urban areas of developing countries. Kumasi River which is the source of water supply in Ghana like other rivers flowing through the city is highly polluted (Eduful M. Kofi, 2014) due to major influence of land use change among others. This study moreover revealed that urban land use can increase the nutrients contents of river water which can becomes threat for water quality.

Land use change in urban area is impacting the wastewater management system first and then it impacts on lowering the water quality of nearby rivers (Figure 4). In the absence of a conventional wastewater drainage system it is common to use onsite waste water treatment facilities. A Case Study (Dennis Abuya et.al, 2019) conducted on Ruaka Town, Kiambu County, Kenya disclosed that this facilities becomes the cause for nearby river water pollution.

Leakage from the walls of septic tanks and overflows results in the discharge of untreated sewage onto nearby roads in addition to direct discharge to rivers. In the absence of conventional sewer systems it is common to use inefficient onsite wastewater management facilities. This is because cities in developing countries plans to provide conventional sewer system later after the housing development have been taken place due to rapid land use change. Therefore, this study (Dennis Abuya et.al, 2019) recommends to provide conventional wastewater drainage system in addition to conducting regular operation and maintenance on the existing onsite wastewater facilities for the selected study area in Kenya in order to minimize the pollution of the nearby rivers.

Figure 4: Raw sewage flowing through a river by Ghion Hotel in Addis Ababa

In a related review of rivers located in Europe, the water quality of rivers is affected due to land use change and others in Bucharest region which is the largest urbanized area in Romania. This study was carried out focusing on four streams crossing the Bucharest region, namely the Dâmbovita, Colentina, Arges, and Sabar rivers. It is important to establish the water quality standards of a certain river. Water quality in Romania is established based on the ecological state of the watercourse, according to the provisions of the European Water Framework Directive taking into account biological, physicochemical and microbiological elements. Accordingly, there are five quality classes in Romania which includes very good quality, good quality, moderate quality, poor quality and bad quality.

Therefore this study revealed that in urbanized areas water quality and consequently aquatic ecosystem health are considerably influenced by the wastewaters released by the urban sewage system which are only partially treated (Zaharias L.et, al. 2016).

2.3. Urban Densification

When many people have tended to move from rural to urban areas, those areas have become more densely occupied with buildings expanding upwards and downward, and homes becoming more compact and closer together. The densification in Senga Tera area has been rapid for the last two decades (Figure 5).

Figure 5: Historical Imagery of Senga Tera area transforming from slum to tall buildings

Designing Buildings Wiki (DBW, 2021) is an online tool and based on that, the followings are methods by which urban density can be measured and it includes

- Floor area ratio: Total building floor area divided by the area of the land buildings are built on.
- Residential density: Number of dwelling units in a given area.
- Population density: Number of people in a given area.
- Employment density: Number of jobs in a given area.

There are many cities in the world which represent city densification. Home to over 13 million people, Tokyo is often used as an example of positive densification with a small proportion of high rise construction. This becomes an answer to some critics who believe that densification (DBW, 2021) necessarily leads to an increase in the number of tower blocks.

Densification of a city has its own advantages and disadvantages. Unplanned urban expansion and increased densification may cause (Wang L. et.al, 2019) a series of environmental and socioeconomic issues such as environmental degradation, loss of agricultural and natural land resources, and shortage or unequal distribution of water resources and associated infrastructure like roads, wastewater drainage systems and others. An increase of urban population has brought about a growing demand for more residential and commercial building spaces which then resulting in various negative impacts such as accelerated urbanization. In order to deal with these growth dynamics, city authorities are urged to consider alternative planning strategies aiming at mitigating the negative implications of densification (Wolfgang Loibl et.al, 2019) through rapid land use change.

The development of wastewater drainage system is challenged by rapid densification of a city though little attention is paid to the urban shape (Urban forms) and topography and its effects on these systems. The existing wastewater drainage sewer capacity may not handle sewage generated due to densification of an urban area. This study (Ning Jia et. al, 2019) revealed that it is difficult for a city to make its drainage systems simultaneously cost effective, efficient, and adaptable based on the computer-generated cities where the study was based. As a result, this study could inspire the urban planning of both built-up and to-be-built areas to become more sustainable with their wastewater drainage infrastructure by recognizing the pros and cons of different macro scale urban forms.

Densification is characterized by the development of European cities in the recent decades since it became a solution for excessive land consumption. Though compact cities are becoming a preferred option in this regard over dispersed cities, not all local condition are favorable to build high density urban areas. Densification (Stefano Fatone et.al, 2016) operations must consider specific conditions like the state of the environmental and urban context and assess threats and opportunities. These environmental parameters which may be affected by the densification of a certain city includes water, wastewater drainage , energy, seismic, public facilities, solid waste, mobility (Transportation), noise, and air quality are among others.

2.4. Urban Expansion

The city of Addis Ababa has been undergoing urban expansion towards the outskirt of the city in all directions. Urban expansion (also known as suburban sprawl or urban encroachment) is the unrestricted growth in many urban areas of housing, commercial development and roads over large expanses of land with little concern for urban planning. The term urban sprawl is highly politicized and almost always has negative connotations in similar cities in other countries too like in Addis Ababa. This expansion (Leulseged K., et.al, 2015) was contributed by the conversion of croplands, forest and grasslands. This indicates that the city's built-up area expansion is characterized by horizontal growth leaving the peri-urban environment and livelihoods at risk.

In an effort to address urban poverty and increase homeownership opportunities for low and middle-income residents, the Addis Ababa City Administration initiated a large-scale housing development project in 2005.The project has resulted in the completion of 175,000 units within the city with 132,000 more under construction.

In order to understand the impacts of both rapid growth and the housing program's impact on the city's urban form a study (Larissa Larsen et.al, 2019) was conducted considering developments which have taken place between 2006 through 2016.

The study method used hand-digitized, Ortho-rectified satellite images in Geographic Information Systems (GISs). Accordingly, this study revealed that residential housing increased from 33% to 39% and the proportion of informal housing decreased from 57% to 38%. The study further depicted that the majority of the new, higher density residential expansions are located near the eastern edges of the city and this outlying location has significant implications for residents, infrastructure construction, and future development.

Moreover, a related study was conducted for two selected time periods to analyze the extent of Addis Ababa city expansion. Accordingly it was revealed (Leulseged K., et.al, 2015) that in the first analysis period (between 1986 and 2000), the built-up area expansion was contributed by 35.8 km2 (55%), 27.05 km2 (42%), and 1.91 km2 (3%) for conversion of croplands, forest, and grasslands, respectively. Furthermore in the second analysis period (between 2000 and 2010), the built-up area expansion was contributed by 59.28 km2 (80%), 10.65 km2 (15%), and 4.29km2 (5%) conversion of croplands, forest, and grasslands, respectively.

However analysis of the current urban development and expansion of Addis Ababa could not be full-fledged (Asfaw Mohamed et.al, 2020) unless it comprises the surrounding districts and their respective towns, as they are repeating the city core problems.

Integrating the Addis Ababa and the surrounding Oromia urban system in the development planning and management is indispensable. Counties have applied various governance approaches to track their cities and hinterlands development and foster prosperity, equality, and inclusiveness among the residents.

The expansion of a city in Addis Ababa has been conducted without prior planning of wastewater management systems. On-site disposal of septic tank effluent (Thomas J. Bicki et.al, 1984) is the most common means of domestic waste treatment in rural and unincorporated areas without sewer systems. However, it essential to analyze the suitability of the soil for efficient infiltration of treated effluent so as to avoid ground water and surface water pollution. The biological and chemical characteristics of wastewater from individual households can have a profound impact on the performance of onsite sewage disposal systems.

2.5. Sewer Capacity Assessment

The capacity assessment objective is to identify the potential sanitary sewer overflow locations in the existing wastewater drainage system. The sanitary sewer system wet-weather flow management plan requires a sophisticated hydraulic capacity analysis. The flow monitoring data is used for understanding of the system behavior at the point of measurement during the monitoring time period and for calibration of the sewer system hydraulic model. The calibrated model is then applied for different conditions to assess the system performance (US EPA, 2005). In other words, it is the process of determining baseline hydraulic performance under the existing situation and using that for future projected land use change conditions.

2.5.1. Manning Equation

The manning equation is the most widely used equation for uniform open channel flow calculations.

$$\mathbf{Q = (1/n)\ A\ (R_h)^{2/3}(S)^{1/2}}$$

Where,

- **Q** is the volumetric flow rate passing through the channel reach in m^3/s
- **A** is the cross-sectional area of flow normal to the flow direction in m^2
- **S** is the bottom slope of the channel in m/m (dimensionless)
- **n** is a dimensionless empirical constant called the Manning Roughness coefficient
- $\mathbf{R_h}$ is the hydraulic radius = **A/P**
- **P** is the wetted perimeter of the cross-sectional area of flow in m

Moreover, the followings are additional design parameters for the modeling of the proposed wastewater drainage system and evaluation parameters for the existing wastewater drainage system.

These includes but not limited to:

- Manning's roughness (Harlan H. Bengtson) coefficient, n = 0.01 for PVC pipes
- In a partially full pipes for measured flows on field, the following sets of equations used to calculate n/n_{full} as a function of y/D over the range from $0 \le y/D \le 1$

Table 2: Manning roughness coefficient for varying depth of flow

$0 \le y/D \le 0.03$:	$n/n_{full} = 1 + (y/D)/(0.3)$
$0.03 \le y/D \le 0.1$:	$n/n_{full} = 1.1 + (y/D - 0.03)(12/7)$
$0.1 \le y/D \le 0.2$:	$n/n_{full} = 1.22 + (y/D - 0.1)(0.6)$
$0.2 \le y/D \le 0.3$:	$n/n_{full} = 1.29$
$0.3 \le y/D \le 0.5$:	$n/n_{full} = 1.29 - (y/D - 0.3)(0.2)$
$0.5 \le y/D \le 1$:	$n/n_{full} = 1.25 - (y/D - 0.5)(0.5)$

Source: *Harlan H. Bengtson, PhD, P.E.*

- Minimum self-cleansing velocity of 0.6 m/s is set at the average flow
- Maximum velocity at the peak design flow is set to not exceed 3.0 m/s to minimize turbulence and erosion, and
- Minimum slope of 0.3% can be used for this design purpose although smaller slopes can be used for larger diameter sewer lines. All gravity sewers between manholes should be laid with uniform slopes equal to or greater than the minimum slopes outlined as below.

Table 3: Minimum recommended design slopes for sanitary sewer

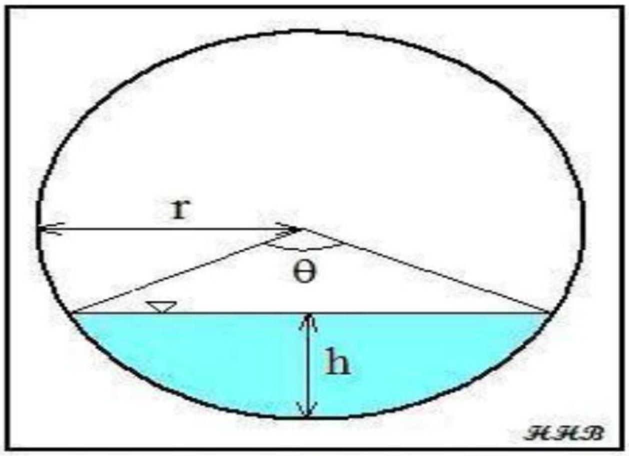
Sewer Diameter (mm)	Minimum Design Slope (m/100 m)
200	0.40
250	0.28
300	0.22
375	0.15
450	0.12

Source: *Great Lakes-Upper Mississippi River State Board, 2014*

2.5.1.1. Hydraulic Radius

The hydraulic radius is one of the parameters needed for manning equation calculations. Common hydraulic equations area available to calculate the hydraulic radius with known pipe diameter and depth of flow. However during manual flow measurement on field, the measured data are depth of flow In addition to the existing diameter pipe.

Case I: When the pipe is less than half full flow



$$r = \frac{D}{2} \qquad h = y$$

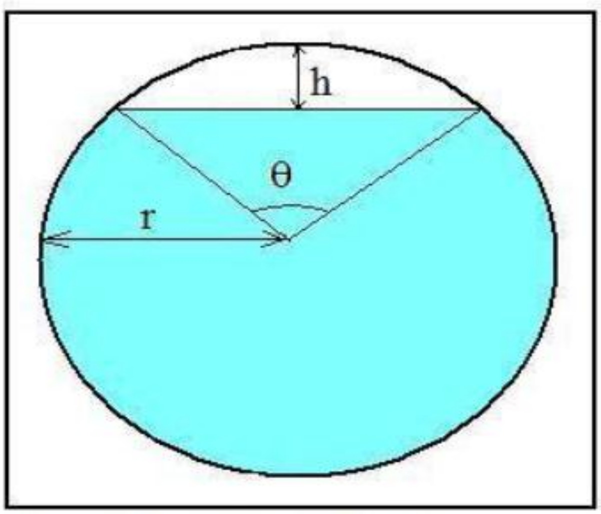
$$\theta = 2 \arccos\left(\frac{r-h}{r}\right)$$

$$A = \frac{r^2(\theta - \sin\theta)}{2}$$

$$P = r\theta$$

$$R_h = A/P$$

Case II: When the pipe is more than half full flow



$$r = D/2 \qquad h = 2r - y$$

$$\theta = 2 \arccos\left(\frac{r-h}{r}\right)$$

$$A = \pi r^2 - \frac{r^2(\theta - \sin\theta)}{2}$$

$$P = 2\pi r - r\theta$$

$$R_h = A/P$$

Source: *Harlan H. Bengtson, PhD, P.E.*

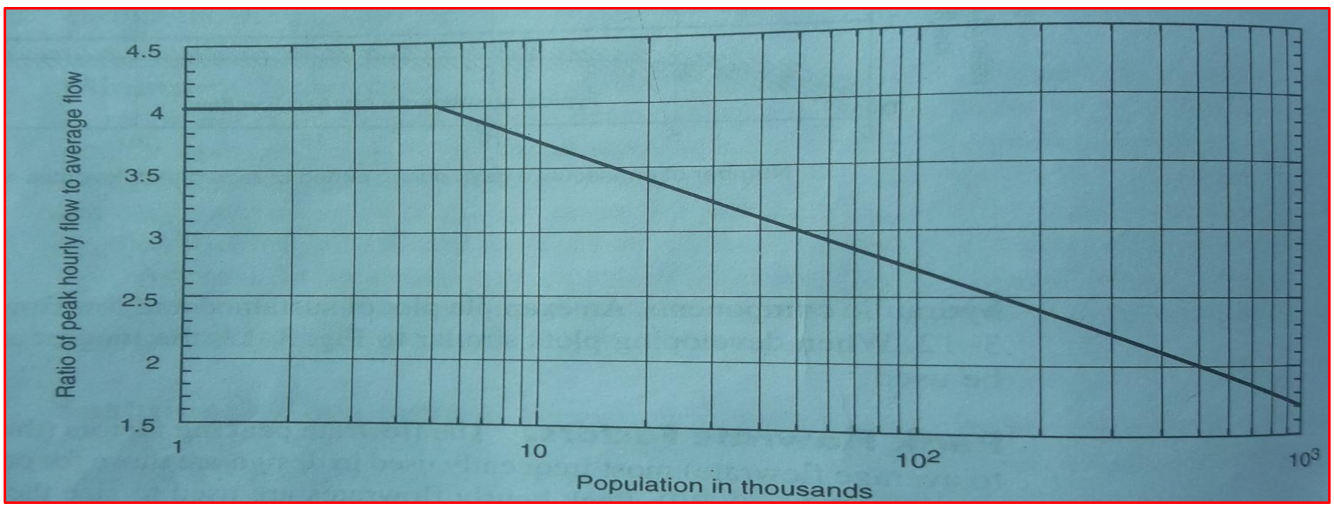
Figure 6: Equations used to convert depth of flow into hydraulic radius

Therefore, there is a need for converting the depth of flow into volumetric flow rate in m^3/s. In order to do that the wetted perimeter (P) and the cross-sectional flow area (A) can be be calculated.

2.5.2. Peaking Factor Determination

The peaking factor is the ratio of the maximum flow to the average daily flow in order to estimate the peak flow rate.

The main hydraulic parameter required for evaluating the capacity of the existing sewer systems and sizing new wastewater collection system is estimating the quantity of wastewater to be transported among others. In order to estimate peak flow rate, it is necessary to decide the peaking factor. The peaking factor in general can be determined using the following two approaches.



Source: *Metcalf and Eddy, 2003*

Figure 7: Peaking factor curve developed from flow records throughout the USA

2.5.2.1. Flow Rate Records

Peaking factor may be developed from flow rate records (Metcalf and Eddy, 2003) when data's available or based on published curves or data from similar communities.

Where flow rates records are available at least for 2 years, the data's can be analysed to develop the peak to average flow rate factors. Based on this fact, some countries or cities have developed or adopted their own peaking factors.

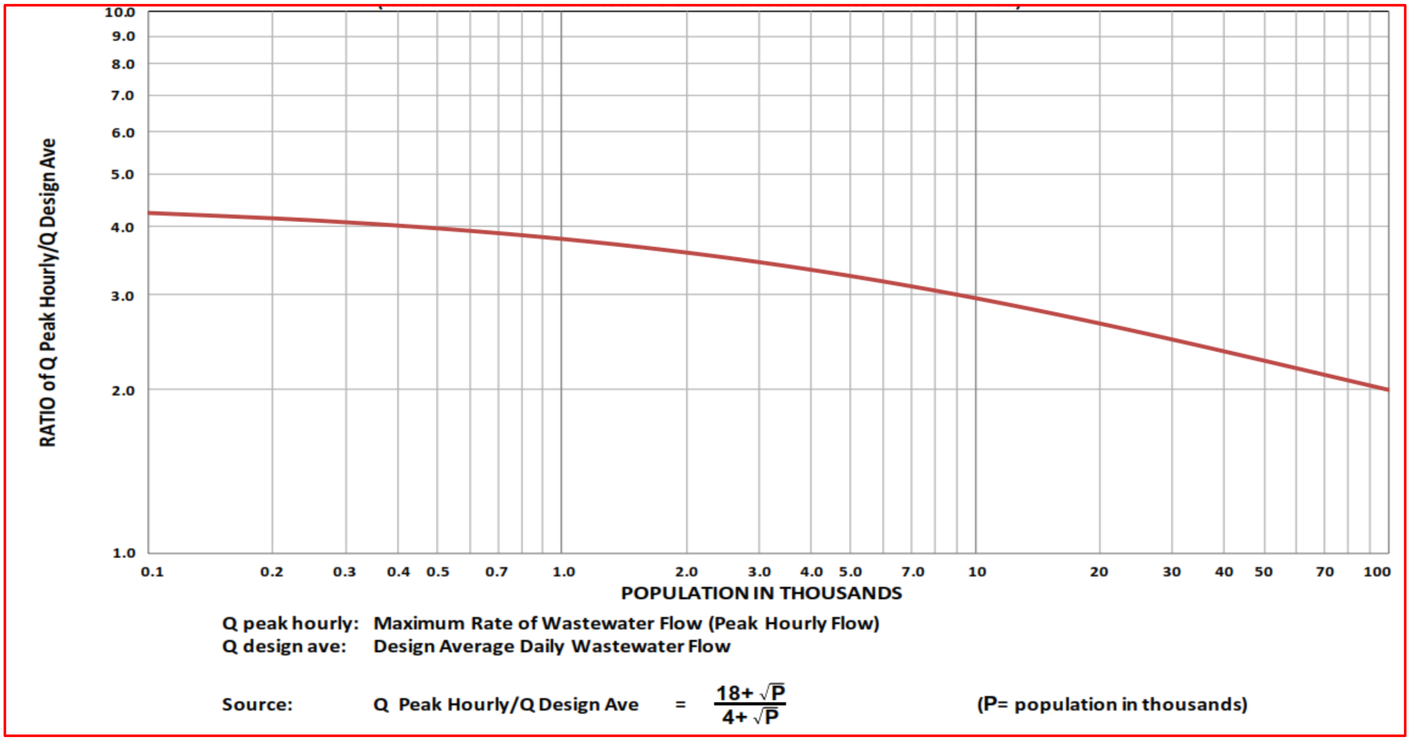
2.5.2.2. Empirical Formula

Empirical formulae can also be used to determine the approximate peaking factor for the analysis and design of the existing and propose sewer systems in the study areas respectively. Accordingly, the Harmon and Babbit equations are the commonly used equations.

Babbit Peaking Factor Equation **= $5/P^{0.2}$**

Harmon Peaking Factor Equation **= $1 + 14/P^{0.5} + 4$**

Where, P= Contributing Population in thousands and is upstream of the sewer under consideration

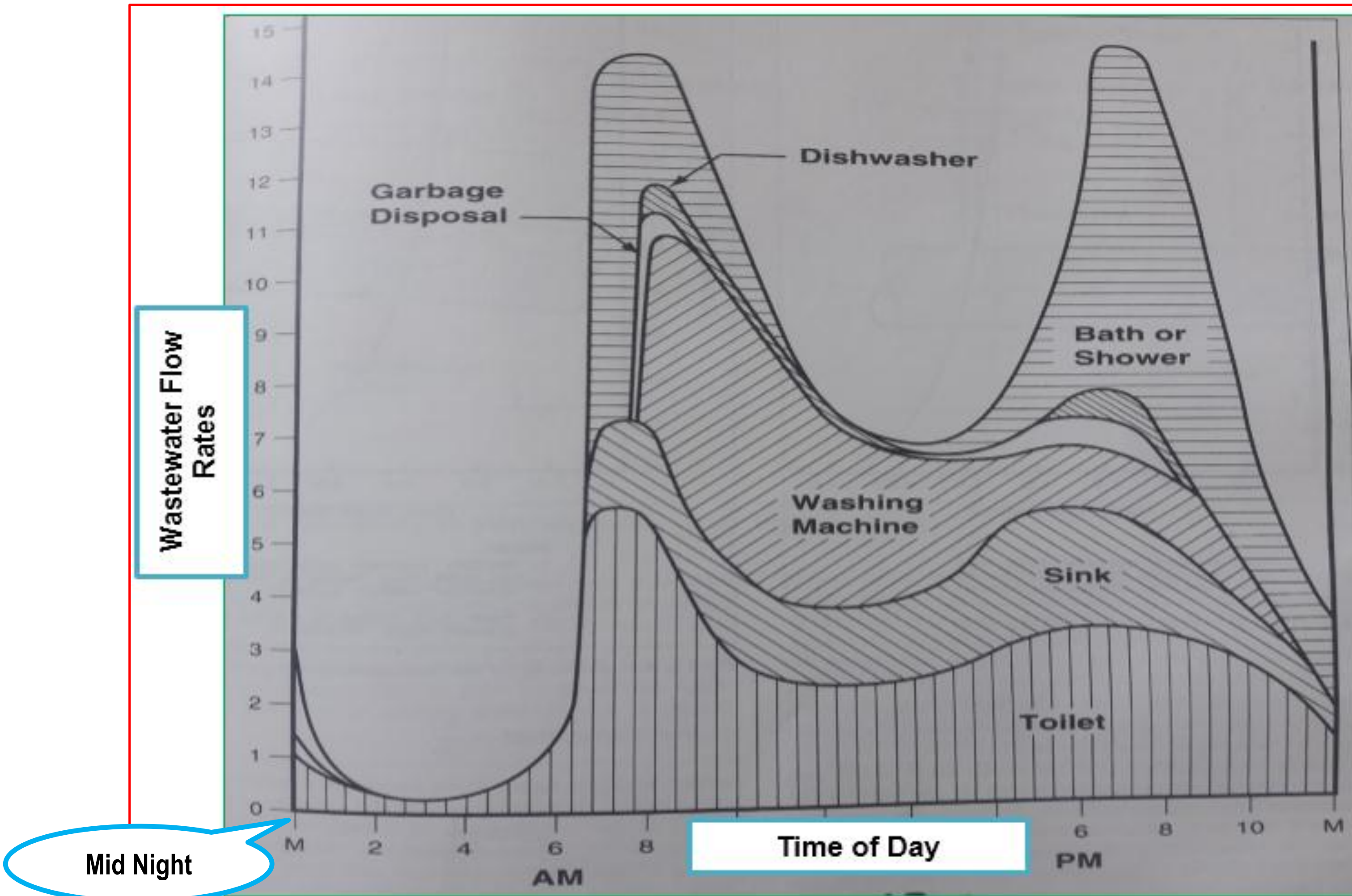


Source: *Fair, G.M and Greyer, J.C.,"Water Supply and Wastewater Disposal" 1st Edition*

Figure 8: Ratio of peak hourly flow to design average flow

The Harmon equation (Great Lakes, 2004) is a recommended formula by the Great Lakes-Upper Mississippi Board of State and Provincial Public Health and Environmental Engineers represented from ten states in America.

The common variable which is used to estimate the peaking factors are the number of population. This indicating that Empirical equations are limited to conditions for their applications. Related literatures in the form of books also dictates that, the peaking factor should be limited to a maximum value of 5 and the minimum value of 2.5 (Sidney O. Dewberry, 2002).



Source: *Sidney O. Dewberry, 2002*

Figure 9: Hourly variation of sewage flow during 24 hours for typical homes

Based on Figure 8 and using Harmon Equation, it can be seen that the minimum number of population is 100 and the maximum number of population is 100,000 where the peaking factor ranges from 4.2 to 2 respectively.

Similarly, the Babbit formula application is limited to the number of population ranging from 1000 to 100000 for a peaking factor ranging from 5 to 2 respectively.

Moreover, the Central Public Health and Environmental Engineering Organization of the Indian Ministry of Urban Development recommends (CPHEEO, 1993) peaking factors without endorsing the use of specific empirical formula.

Table 4: Peak factor based on contributing population

Contributory Population	Peak Factor
Up to 20,000	3.00
Above 20,001 to 50,000	2.50
Above 50,001 to 750,000	2.25
Above 750,001	2.00

Source: *CPHEEO, 1993*

From the above analyses it can be seen that the peaking factor decreases when the user population increases. The sewer system layout classification starts from laterals and continues the transition as branch, main (trunk) and then to interceptors before joining a wastewater treatment plant. The use of peaking factor also decreases along the way.

2.6. Model Calibration and Validation

Calibration is the process of adjusting model parameters to make a model fit with measured conditions (usually measured flows). The model parameters are adjusted until hydraulic model flow values reasonably represent actual recorded wastewater flows. During model calibration, it is necessary to achieve a reasonable match between observed and modeled peak flow (US EPA, 2007). However, in order to do model calibration accordingly, the existing wastewater drainage system flow rate need to be monitored daily, monthly and yearly using flow measuring devises in addition to using billed water consumption data's.

Once the model is calibrated, it can be used to analyze the hydraulic response of the system under different conditions including the following among others:

- Performance of the sewer system for a variety of future design years;
- Identifying hydraulic problems within the sewer system such as surcharged pipes, hydraulic bottlenecks, and reverse flows;
- To assess the impact of proposed developments;
- To identify the need for possible hydraulic upgrading schemes and to carry out initial scheme appraisals.

In evaluating the results of hydraulic model simulations, it is necessary to consider whether a model prediction is reasonable and/or can be supported by historical knowledge and experience of the system's operation. Errors in inventory data can substantially affect the output results of a hydraulic simulation.

However, present day hydraulic modeling software incorporates many built-in data checking and validation routines to help the hydraulic engineer identify potential errors.

2.6.1. Hydraulic Modelling

Inventory for hydraulic modeling can be obtained from record drawings, maps, databases, and Geographic Information Systems. Data must be checked for accuracy and completeness. Dynamic models require elevation data based on one datum to properly route flows through the modeled network. The pipe data needed to build a model is as follows:

- Details of the sewer network and connectivity;
- Pipe sizes;
- Ground levels;
- Pipe invert levels;
- Pipe roughness

The building of the sewer network inventory results in an input file to be used by the hydraulic model. The file contains inventory and flow data to be used for modeling. The flow data should be applied at the appropriate nodes.

2.6.2. Flow Monitoring Meters

Flow monitoring is required to quantify base wastewater production and infiltration and inflow in the collection system. The data collected can be used for hydraulic evaluation of the sewer system, calibration of hydraulic models, assessment of I & I, and assessment of effectiveness of rehabilitation measures in eliminating I & I.

Flow monitors are installed at strategic locations in the sewer system and the flow is measured at frequent intervals, typically 15 minutes. Flow meters may be installed as "permanent" or "temporary." Permanent open channel flow meters include (Philip M. Hanna et.al, 2004).

- Flumes such as Par shall flumes and Palmer-Bowlus flumes,
- Weirs, such as V-notch, rectangular, and trapezoidal,
- Velocity measuring devices, both Doppler and ultrasonic, and
- Depth measuring devices, including ultrasonic, bubbler, static pressure devices, and transducers,
- Various combinations of all of the above

2.6.3. Dry Weather Flow

Dry weather flow includes the sanitary flow plus infiltration, which can be separated into its individual components. It is all flow in a sewer (includes sanitary flow and infiltration) except that caused directly by rainfall. Measured during a period of extended dry weather (7 to 14 days) and seasonally high groundwater. This infiltration induced by ground water can be measured the average of the low nighttime flows (midnight to 6 am) per day for the same time period, minus significant industrial or commercial nighttime flows.

2.6.3.1. Base Sanitary Flow Estimation

The portion of wastewater which includes domestic, commercial, institutional, and industrial sewage and specifically excludes infiltration and inflow. The sanitary portion of the wastewater flow can be estimated through two methods, which can be used to 'check' each other and these includes;

- Flow meter data and
- Water consumption if all sewer customers are on metered water

The first method is to analyze the wastewater flow data at the treatment facility during a dry Weather period of 7 to 14 days. It is useful to choose the dry weather period during seasonal high water as you will be able to determine the peak infiltration rate at the same time. From the flow data, calculate the average daily flow for the dry weather period. The base sanitary flow can be estimated by subtracting the groundwater infiltration flow from the average daily dry weather wastewater flow.

In the second method, water usage records can be used to estimate the base sanitary flow for the sewered population. The best time to estimate flow using this method would be when outdoor water uses (swimming pool, landscaping) are low and wastewater from a residential area can be assumed to be the same as the billed water use (US EPA Water Infrastructure Outreach, 2014).

Moreover, in related literature (Philip M. Hanna et.al, 2004) the estimation of base sanitary flow has been explained in similar way as above. Base Sanitary Flow is the wastewater without infiltration and inflow. The daily wastewater production flow rate can be approximated using;

- Either direct measurement of average daily dry weather flow during dry weather/low groundwater conditions or
- Water consumption data.

2.6.4. Wet Weather Flow

The highest daily flow during and immediately after a significant storm event and these Includes sanitary flow, infiltration and inflow.

2.6.4.1. Inflow and Infiltration Estimation in Existing Sewer

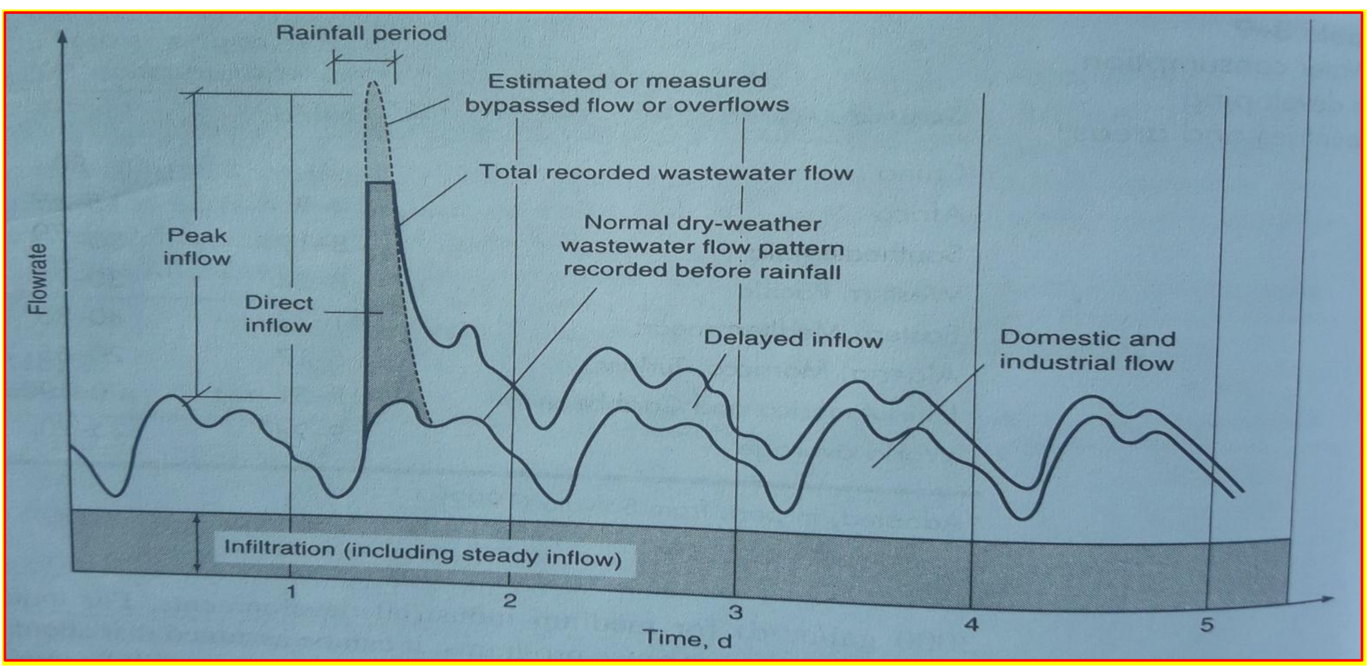
Inflow represents the influence of wet weather on the sewer system and can be estimated by subtracting out the sanitary wastewater and infiltration (from run off) flow during a time that the system has been influence by rain.

However, the type of inflow that causes a "steady flow" cannot be identified separately and so it may be included in the measured infiltration.

Ground water infiltration can be estimated as the difference between the monitored or measured wastewater flow rate and base sanitary flow rate estimated from the billed water use data (US EPA Water Infrastructure Outreach, 2014).

2.6.5. Sources of Inflow and Infiltration

Infiltration is water entering a collection system from a variety of entry points including service connections and from the ground through such means as defective pipes, pipe joints, connections, or walls of manholes.



Source: *Metcalf and Eddy, 2003*

Figure 10: Graphical identification of Infiltration and inflow

Inflow is a direct storm water runoff connection to the sanitary connection system and cause an almost immediate increase in wastewater flow rates. Possible sources of inflow are roof leaders, yard and areaway drains, manhole covers, cross connection from storm drains and catch basins (Adrien Comeau et,al, 2019).

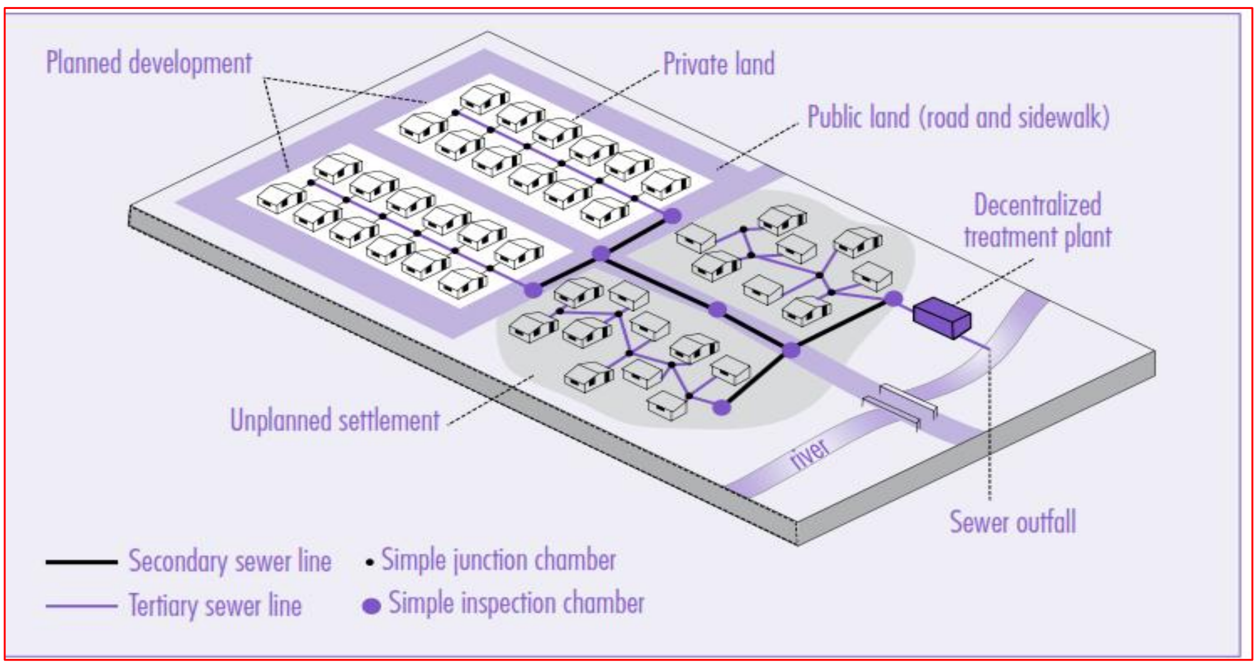
2.6.6. Inflow and Infiltration in New Sewer

(Metcalf and Eddy,2003) is suggesting that infiltration may range from 0.4 l/h.mm-Km to 40 l/h.mm-Km. Infiltration/ Inflow depends on the quality of sewer material, workmanship in constructing the collection system, availability of building connections, maintenance practice, and elevation of ground water table (compared with elevation of the sewer) are among others.

High rate of inflow and infiltration are parameters which must be discouraged through different measures which includes proper design, construction, operation and maintenances. Ten States Standards limits an infiltration *allowance not to exceed 0.4 l/h.mm-Km* (Great Lakes, 2004).

2.7. Non-Conventional Sewer System

In the absence of both conventional sewer system and efficient on site wastewater management system, it has been a common practice to develop a non-conventional sewer system by a certain community.



Source: *Jean-Marie Ily et.al, 2014*

Figure 11: Typical layout of non-conventional sewer system

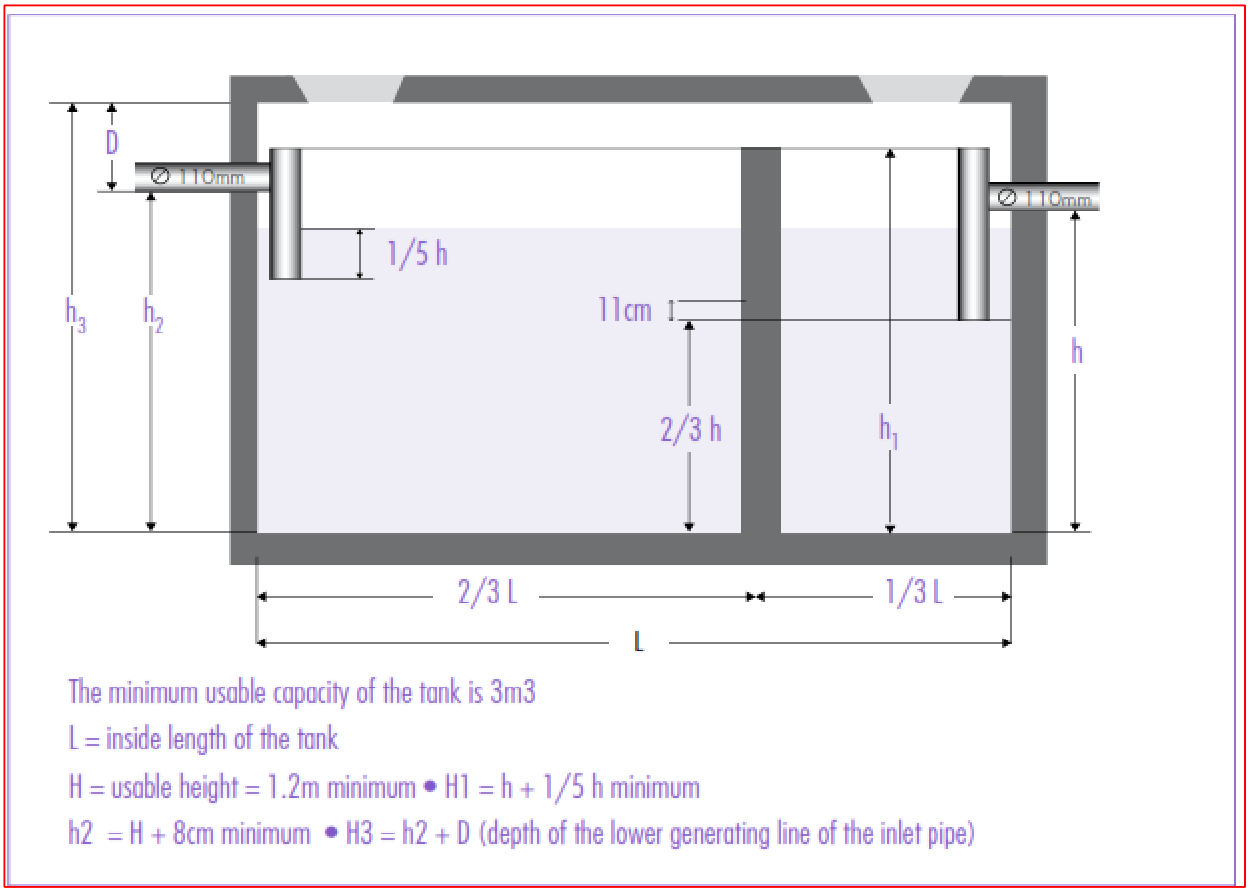
In some cases, even if a conventional sewer system exists for a certain city or urban areas, there have been low sewer connections (Ruth Kennedy-Walker, et.al, 2020) rates due to technical and non-technical reasons. As result, the wastewater treatment plants to which the sewers should discharge can be underutilized and this in turn may affect the performance of treatment facilities.

Non-conventional sewers are vulnerable to blockages from solid waste and sediment, storm water intrusion and breakages. Because of these, it is suited to urban areas which have solid waste collection services and storm water drainage systems. The following schematic shows an overview of a non-conventional sewer system for planned and unplanned areas.

The two main types of non-conventional sewers (Jean-Marie Ily, pS-Eau et.al, 2014) are *simplified sewer system* and *settled sewer system* which can serve for the collection of waste water and grey water respectively. Non-conventional sewer system has the following features over the conventional sewer system.

- Uses smaller diameter pipes and simplified connection methods and pipes are laid at shallower depth;
- Pipes can be laid under sidewalks rather than under roads and hence pipes can be laid at shallow depth to minimize excavation costs;
- Differs by virtue of their scale as they cover a residential area rather than the whole town hence it can be managed by the community;
- The length of the pipework can be reduced by crossing private land;
- Manholes can be replaced with a simple junction chamber and fewer inspection chambers
- It is economical and more reliable

Best practice in Senegal, Africa is showing that non-convention sewer system can also be used in conjunction with an individual household settling tank as shown below. In that case, the communal wastewater treatment plant shall be planned to treat grey water only.



Source: *Jean-Marie Ily et.al, 2014*

Figure 12: Individual household settling tank

2.8. River Polluting Factors Review

The extent of Addis Ababa River pollution have been a challenge for the city residents through impacting their health and quality of life. Several studies have been conducted by various scholars in order to assess the extent of this pollution. All of these researches have concluded that the level pollution is immense. Unfortunately, it is also worsening from time to time due to discharge of untreated or partially treated domestic and industrial wastewater among others.

Urban agriculture has been in practice stretched along several rivers in Addis Ababa. For irrigation purpose it has been a common practice to use river water (Tadesse A., 2011; Sisay D. 2017; Hamere Y., et.al, 2017) to grow mostly vegetables. Though municipal wastewater could be applicable to use for irrigation purpose as long as it satisfies the WHO standard, research conducted in this regard on selected rivers proved (Benti Firdissa et.al, 2016) that the river water constitutes heavy metals from the discharge of industrial wastewater.

The associated health risks of eating uncooked vegetables are even more. It was also revealed (Agaje, 2007) that it is difficult to assess immediate health impacts of eating vegetables grown using polluted river water as those associated diseases have long latency periods hence needs long period research works.

There is also current research conducted to study the impact of storm water quality in selected three rivers inside the Little Akaki catchment in Addis Ababa. The selected contributing factors for the river water quality were point sources and urbanization. Rivers flowing through the city are an outfall point for storm water drainage discharges. Accordingly, the study concluded that those rivers water quality does not satisfy international water quality standards. Moreover, this study revealed that the source of pollution in those rivers are direct discharge of untreated domestic and industrial wastewater in addition to non-point pollution sources (D. Adugna et.al, 2019).

In addition, there are other researches (Sisay D., 2017; Benti Firdissa et.al, 2016) which were conducted to see the extent of pollution on Addis Ababa focusing on little and big Akaki Rivers. During these studies, river water samples were taken for biological and physiochemical analyses. Accordingly, it was disclosed that those rivers are highly polluted from domestic and industrial wastewater discharges among others. Moreover, the concentration of dissolved oxygen was depleted (Abdulshikur M., 2007) to the extent that life does not exist inside those rivers.

Looking at international experiences, rivers flowing through a certain city are under high pressure due to the discharge of untreated wastewater produced in that city. The issue is even more significant when this water is used as a source of water supply. In this regard Yamuna River (Ani Kumar Misra, 2010) in India is a typical example. A research conducted in 2010 disclosed that this river was about to die at all. That means the concentration of dissolved oxygen was much less than the in stream water quality standards.

In addition to point source pollution which is direct discharge of untreated wastewater from domestic and industrial establishments, non-point source pollution (Meena Palaniappan et.al, 2010) for example leachate from solid waste is also among factor for river pollution.

Though there is 50m river buffer standard based on the city structural plan (AACSP, 2017) which was aimed to filter non-point pollution sources before joining rivers, for urban agriculture, parks, foot path etc., urban agriculture practice has been conducted mostly starting immediately from left and/or right side of river banks regardless of the slope of the land.

Table 5: River buffer development standard based on the city structural plan

	Permitted Function	Remark
Urban agriculture zone	• Crop and vegetable farming, livestock production and poultry, dairy farming, and other related agricultural activities • Permanent fruit tree farming • Fuel wood production	
Urban agriculture in river buffer zone	• Permanent fruit tree plating • Bee keeping	
Urban agriculture in multifunctional forest	• Permanent fruit tree planting • Bee keeping	
Urban agriculture inside water protection zone, including in river buffers and multifunctional zones		• Chemicals and fertilizer are not allowed • Cattle fattening, dairy farming, poultry etc. not allowed

Source: *Addis Ababa City Structure Plan, 2017*

From the city structural plan, it was also suggested that activities like using chemicals and fertilizers for urban agriculture inside the river buffer are prohibited.

Cleaning polluted river or giving appropriate treatment to satisfy acceptable standards are more expensive. The less expensive option is to protect (UNEP and WHO, 1997) rivers from pollution.

2.8.1. Inefficient Utilization of Existing Sewer System

According to related studies (WSP,2017) conducted by the World Bank Water and Sanitation brief research program in South East Asia and the Pacific Region, the basic reason for less number of household connection to drainage systems are technical reason in addition to failing to give timely information's to residents. The two countries which were focused for this kind of urban sanitation review were Indonesia and Vietnam.

This study also suggested to provide financial support and a comprehensive community support to realize effective household connection. There may be also situations where gravity flow cannot be achieved to drain wastewater into the municipal sewer systems. In that case, pumping would be needed but that will be costly to operate and maintain and this in turn can discourage connections.

It may be also necessary to rearrange the internal plumbing system and other arrangements on septic tank and cesspool areas so that one lateral can extends from a certain house in order to connect with the municipal sewer. In order to do this dwellers need technical assistance, finance and willingness. Other factors which may contribute for lower number of house sewer connection could be losing confidence on the efficient performance of the city wastewater drainage system.

This research brief on water and sanitation program (WSP, 2017) by the World Bank also concluded that approximately 85% to 90% of urban citizens in Indonesia and Vietnam rely on septic tanks and pit latrine for human waste disposal, and this is similar to the Philippines and other countries in the region due to low sewerage connection. However, less than 10% of generated wastewater is collected and conveyed to centralized treatment plants and the volume of sludge from septic tanks collected and disposed safely is very low.

Inefficient onsite wastewater management systems in Addis Ababa may be contributing to the pollution of Addis Ababa Rivers similar to situations in (Marion R. Scalf et.al, 1997; Will McDowell et.al, 2005) Indonesia and Vietnam in Southeast Asia.

2.8.2. Direct Wastewater Discharges to Rivers

Several commercial buildings and houses have been built by the Addis Ababa Rivers in addition to small to medium manufacturing units (AACSP, 2017). This has been giving the opportunity for some developers to directly discharge untreated or partially treated effluent directly to rivers. This illegal actions have been existing due to that fact that there has not been effective environmental law enforcement measures based on the existing effluent (EEPA and UNIDO,2003) standards (Table 6) Environmental Pollution Proclamation (EPCP,2002) and Environmental Impact Assessment Proclamation (EIAP,2002).

The Addis Ababa structural plan (2017 – 2027) study stated that Addis Ababa river banks are occupied by unplanned or informal settlements which in turn facilitates the pollution of rivers. There are both kind of houses which are slum houses and commercial buildings which have been built by river and creek. Based on the survey conducted by the Addis Ababa Environmental Protection Authority during the preparation of the Addis Ababa City Structural Plan (AACSP, 2017), it was indicated that around 90% of industries in Addis Ababa are discharging untreated effluents directly to the nearby rivers and creeks and into wastewater drainage systems.

When Septic tanks are not being cleaned or desludge periodically (Marion R. Scalf et.al, 1997; Will McDowell et.al, 2005) overflowing of sewage occurs. A research conducted by the World Bank water and sanitation program again revealed that the majority of the toilets discharge into septic tanks or latrine pits, of which 66% in Indonesia and 75% in Vietnam have never been emptied. Other systems such as unsealed pits or sub-standard 'septic tanks' (without an effluent outlet) leach wastewater into the ground. As over 77% of on-site sanitation systems in Indonesia are less than 10 meters from domestic water wells, this presents a considerable water pollution (J.M Galbraith et.al, 2015) risk.

Table 6: Ethiopian standards for Effluent quality into rivers

Constituent Group or Parameter	Emission Limit Value (mg/l)
Basic Parameters	
pH	6 – 9 pH units
Temperature	40°C
Biochemical Oxygen Demand (BOD_5) at 20°C	80
Chemical Oxygen Demand (COD)	250
Suspended Solids (SS)	100
Total Dissolved Solids (TDS)	3000
Total Kjeldahl Nitrogen (as N)	80
Total Ammonia (as N)	30
Ammonia (as free ammonia)	5
Nitrate (as N)	20
Dissolved Phosphorus (as P)	5
Total Phosphate (as P)	10
Fats, Oils and Grease	20
Microbiological	
Total Coliforms (numbers per 100 ml)	400

Source: EEPA and UNIDO, 2003

For 60% of on-site systems surveyed in Vietnam, the tank or pit effluent overflows into a drain or river and 17% do the same in Indonesia. The inadequate on-site storage only provides partial treatment and thus highly pathogenic waste enters open drains and water bodies. There must be proper operation and maintenance in place for onsite wastewater management systems in addition to fecal sludge management (Linda Strandle et.al, 2014) so that environmental pollution can be minimized.

2.8.3. Storm Water Discharges Quality

In addition to non-point pollution sources, the Addis Ababa Rivers have been polluted by the discharge of untreated or partially treated domestic (Abdulshikr, M., 2007) and industrial effluent (Benti Firdissa et.al, 2016) which are point pollution sources. This discharges have two forms. The first type is a direct outfall into rivers from slum houses and buildings which were built closer to river banks. The second type is from the existing storm water drainage system in the city. This is because, the final outfall points are rivers and creeks for storm water flow collected from road pavements, roofs and green areas.

Several studies have been going on for the last two decades in this regard to see the extent of pollution in selected rivers in Addis Ababa. A study which was conducted recently (D. Adugna et.al, 2019) on Shegole, Little Akaki and Jemo rivers to examine year round storm water impact on water quality which are exposed to point water pollution sources in addition to non-point pollution sources. For these study purposes different samples were taken to see the permissible limits of nutrients and heavy metals against national and international standards. Accordingly, this research revealed among other things that there was poor water quality in those rivers both in dry and wet seasons due to the fact that the dissolved oxygen (DO), NO_2-N, NH_4-N, PO_4-P, (Cr (VI) and Cu) concentration exceeds applicable standards.

Moreover, the study concluded that the source of water pollution in those rivers have been due to the discharge of untreated industrial effluents stretched along the river banks in addition to discharge of leachates from poor solid waste management in the city. Moreover, the year round river water quality issues were assumed to be from households which discharge domestic wastewater directly into rivers. This research (D. Adugna et.al, 2019) also mentioned that 56% of households in Addis Ababa assumed to be discharging partially treated or untreated wastewater into various rivers and creeks flowing through the city.

2.9. Modeling Equations

Hydraulic models are tools in order to understand the hydraulic behavior of wastewater flow both through the existing sewer and proposed sewer. For this purpose several public and commercial software's have been developed. There are several equations which were developed and it ranges from the full Saint equation to the conceptual reservoir models equations (Linear reservoir model, multi linear reservoir model and nonlinear reservoir model) (Ramesh Saagi, 2014).

Saint-Venant Equation: This sewer equation used to model sewer hydrodynamics based on open channel flow (Ramesh Saagi, 2014) concepts and it consists of both continuity and momentum equations as follows.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$gA(S_0 - S_f) = \frac{\partial y}{\partial x} + \frac{\partial}{\partial x}.\left\{\frac{Q^2}{A}\right\} + \frac{\partial Q}{\partial t}$$

Where,

A = Cross sectional area of the channel (m^2), Q= Flow rate (m^3/s), x=Distance in the x-axis (m), S_0 =Botttom slope, S_f=Friction Slope, y=Channel depth (m) and g= Acceleration due to gravity (m^2/s).

This equations require special numerical procedure to solve them since it is a partial differential equation which depends on time and space.

Moreover, the following are equations based on conceptual reservoir model based on:

Linear reservoir model: In this model the sewer system is represented as a series of varying volume storage tank (s) with outlet.

$$\frac{dV}{dt} = Q_{in} - Q_{out}$$

$$V = \frac{1}{K} Q_{out}$$

Where,

V = Volume of reservoir (m^3), Q_{in}= is the inflow of the reservoir (m^3/s), Q_{out}= is the outflow from the reservoir (m^3/s), 1/K is the residence time constant (s).

This model is based on the concept of Nash cascades (Viessman W. et.al, 1989) which was used for hydrological routing models in catchments.

Multi linear reservoir model: This model is based on a combination of different linear relationship between various components of sewer flow (Ramesh Saagi, 2014).

$$\frac{dV}{dt} = Q_{in} - Q_{out}$$

$$V = K(xQ_{in} + (1 - x)Q_{out})$$

Where, V = 1/K is the residence time constant (s) and x is a dimensionless factor

The Muskingum method is a multi-linear model where storage (V) is a function of both inflow and outflow (Achleinter S. et.al, 2007). The difference in rising and falling limb of the hyetograph which is obtained during a rain even can be represented by this equation. Simplified sewer models adopted this method.

Nonlinear reservoir model: This model can be used to replace the series of linera reservoirs with a single nonlinear reservoir model.

$$\frac{dV}{dt} = Q_{in} - Q_{out}$$

$$Q_{out} = cV^{1.5}$$

2.10. Modeling Software's

Based on the various modeling equations concepts, various available software's were developed which includes, Sewer GEMS, Sewer CAD, and SMMM among others. Out of this modeling software's Sewer CAD and Sewer GEMS have been used by AAWSA for analysis and modeling of sewer systems. Sewer GEMS can be used to design and analyze both wastewater and storm water drainage system in four interfaces (Standalone, Micro station, AutoCAD and ArcGIS). Sewer CAD is applicable for design and analysis of wastewater drainage system in standalone, Micro station and AutoCAD interfaces.

For the capacity analysis and planning of sanitary sewer systems (US EPA, 2007) software's are essential tools for modeling. Sanitary sewer system master plan update is necessary to do in order to solve issues related to land use change for a city. This can be achieved effectively through efficient use of modeling software's assisted by calibrated monitored flow data's (Adrien Comeau et.al, 2019). Modeling software's helps to conduct condition assessment (US EPA, 2009) of the existing wastewater drainage systems so that it helps to decide what kind of technical measured can be done to cope up the existing challenges.

2.10.1. Sewer GEMS

Sewer GEMS V8i by Bentley Systems Inc., is a program for the design, analysis and planning of gravity flow and pressure flow through pipe networks. The operational behavior of various gravity and pressure network elements (manholes, outlets, junction chambers, pressure junctions, wet wells and pumping stations) can be simulated. The sources of flow in the sewer system are called loads, and are classified as sanitary (dry Weather) loads, wet weather loads and known loads.

The gravity network is calculated using a built-in numerical model, which utilizes the gradually varied flow equations. Flow calculations are valid for both surcharged and varied flow situations, including backwater effects and drawdown curves. Pressure elements are simulated by the mass and momentum conservation equations; gravity and pressure components can be mixed freely.

Sewer GEMS V8i can run both Steady State Analyses (modeling a single instant in time) and Extended Period Simulation (modeling a network over a specified duration of time). Moreover, the program allows to automatically design gravity piping and structures, specifying the elements to be designed, from a single pipe size to the entire system, or anything in between, intending the program's design only as a preliminary step.

Sewer GEMS V8i can be run utilizing its own graphical interface (stand-alone mode) or utilizing an AutoCAD interface (AutoCAD mode), which represents an additional feature of the model. It also use ArcGIS and micro station interfaces. The graphical editor allows to create, move, edit, and delete network elements. An automated scenario management using inheritance allows for comparing input and result data associated with different set of calculations, eliminating any need to input or maintain redundant data.

Chapter Three

3. Materials and Methods

3.1. Description of the Study Areas

Two areas were selected (Figure 13) for this study. The first one is Senga Tera and the second one is Tulu Dimtu which are representing rapid land use change on the existing part of the city and new residential developments in the expansion areas in the outskirt of the city respectively.

3.1.1. **Senga Tera**

The Land use pattern of Senga Tera has been changing rapidly. Construction of head quarter buildings for major banking and insurance companies have been taking place. Most of these buildings are high rise buildings around thirty stories. There are also open spaces left for future similar developments in this area.

Table 7: Partial lists of tall buildings under construction in Senga Tera

Name of Buildings	Number of Story	Remarks
United Bank HQ	G+32	
Senga Tera Traders Union S.C	G+22	
Yobek Commercial Center	G+11	
Nib Bank HQ	G+33	
Nile Insurance HQ	G+25	
Zemen Bank HQ	G+32	
Enat Bank HQ		Under Planning Stage
Amhara Credit and Saving Institution HQ	4B+G+M+25	
Dashen Bank HQ	G+16	Construction Completed
Oromia International Bank HQ		

Source: *The Author, 2020*

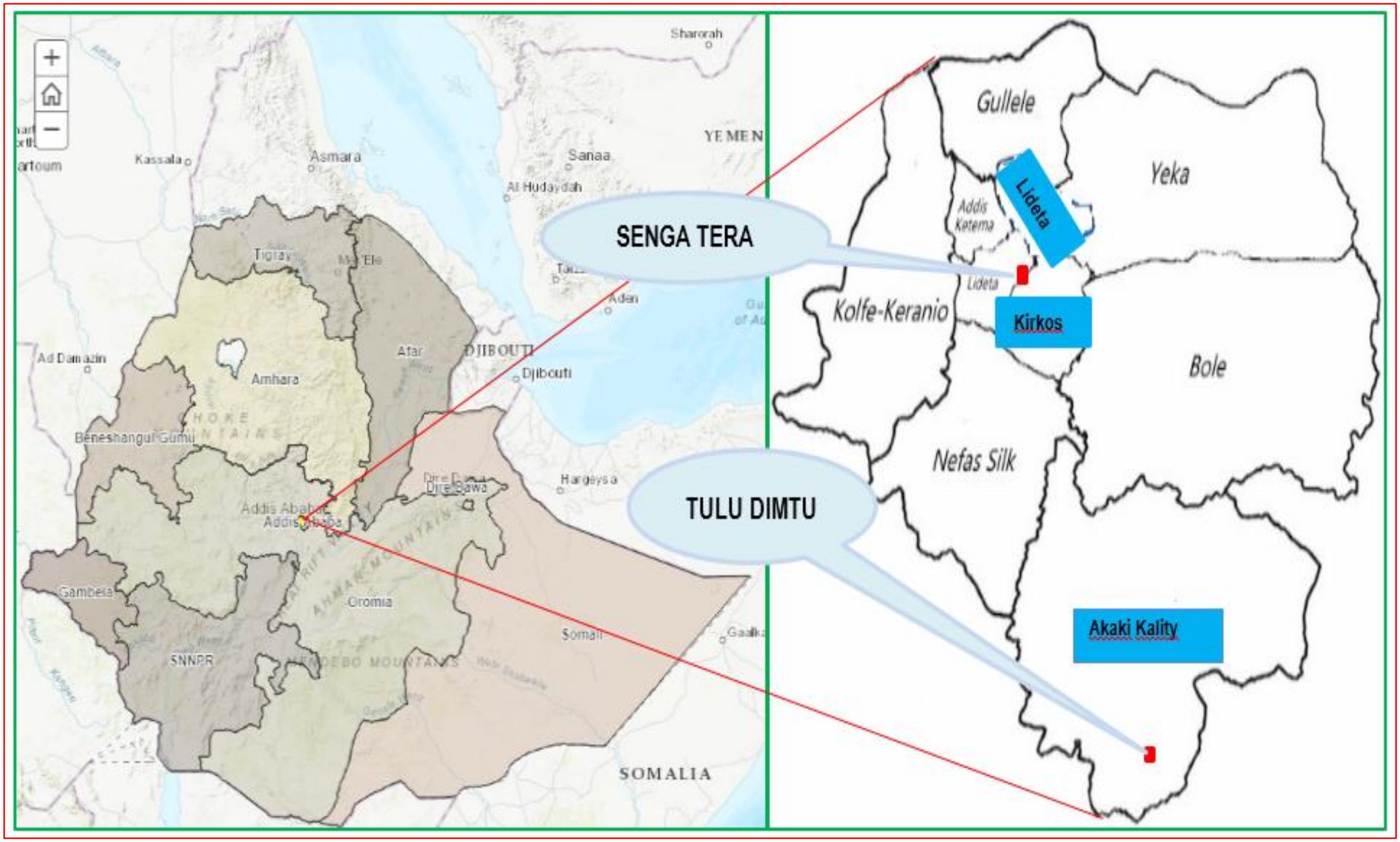


Figure 13: Map showing the location of the study areas in Addis Ababa

The construction of new residential and commercial buildings are either completed or now under construction. Most of this study area is located in Lideta sub-city where as the rest of development which are relatively older are located in Kirkos sub city.

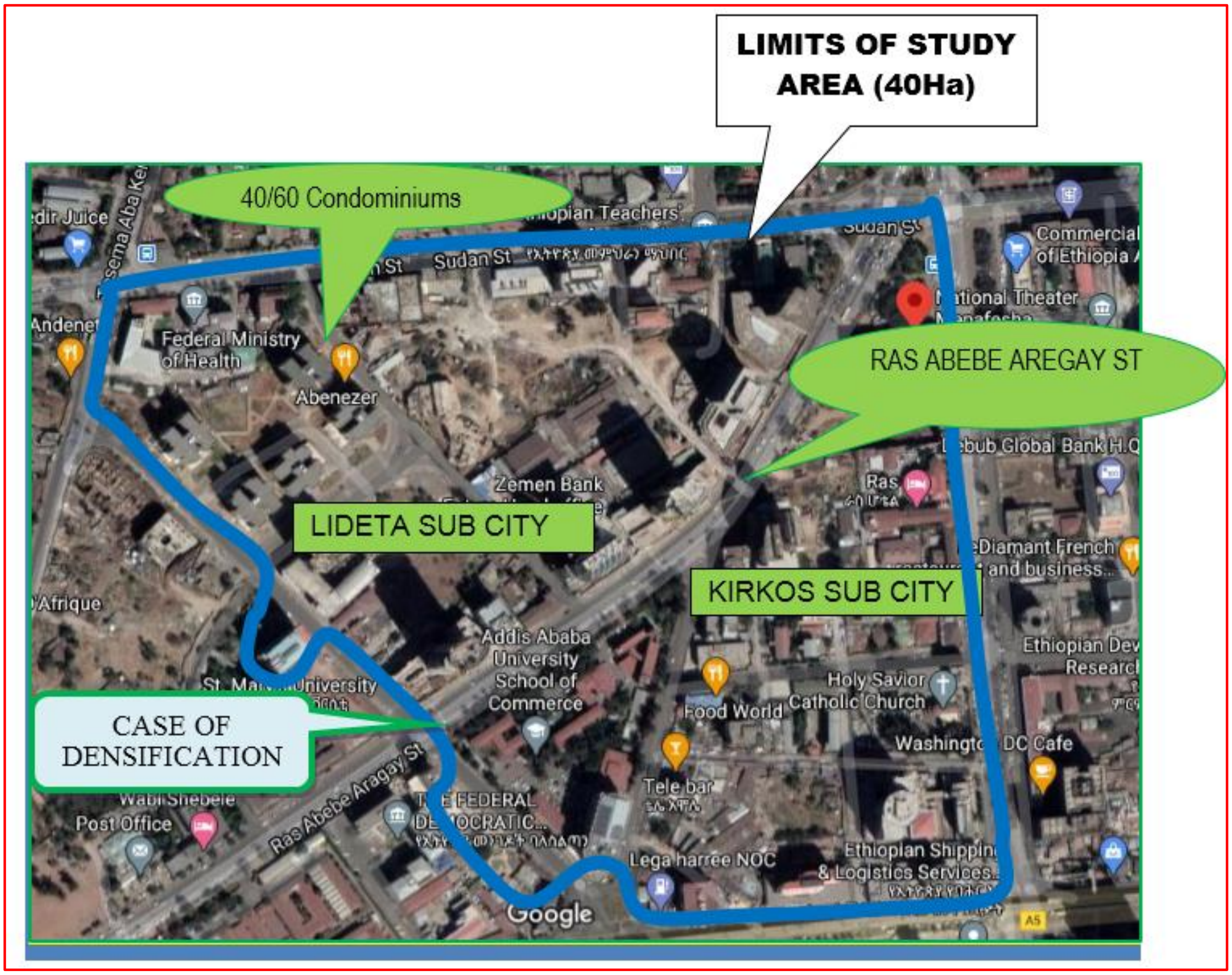
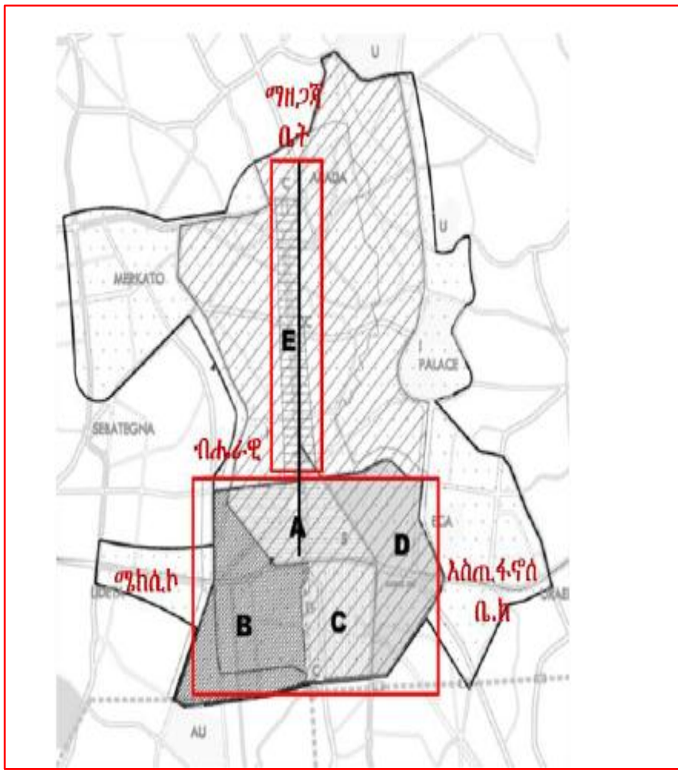


Figure 14: Limits of study area in Senga Tera

The study area is bounded by Sudan Street from North, Ras Mekonnen Street from South, Churchill Avenue from East and Senga Tera road (Street from Commercial College to the Ministry of Health) from East. Moreover, Ras Abebe Aregay Street stretches from around East to West in the middle which divides the study area in to North and South. The total study area estimated to be around 40 Ha.

Moreover, there are major government institutions in the area namely the Ministry of Health (MOH) and the Ministry of Urban Development and Construction (MUDC) in addition to the Commercial College of Addis Ababa University (AAU). There are also five blocks of each eleven stories 40/60 condominiums in the selected area which was developed by the Addis Ababa City Administration.

This area is among part of the city with rapid urbanization and categorized as a “The main city center” based on the structural plan of the city (AACSP, 2017). This area is also known as an emerging financial district. The complete list of new buildings are shown under (Table 18).



A - The National Theater District
B - The Cherkos District
C - The La Gare District
D - The Filweha-Meskel District
E - The Churchill Axis District

Note: Senga Tera financial district is located in The National Theater District

Source: *Addis Ababa city structural plan, 2017*

Figure 15: The National Theater district in Addis Ababa Main Center district

Based on the city structural plan it was proposed to develop a central business district in a 350ha (Figure 15) of land. Accordingly, the development of many high rise buildings are part of this planning. The minimum regulated building height in this area is 70m.

3.1.2. Tulu Dimtu

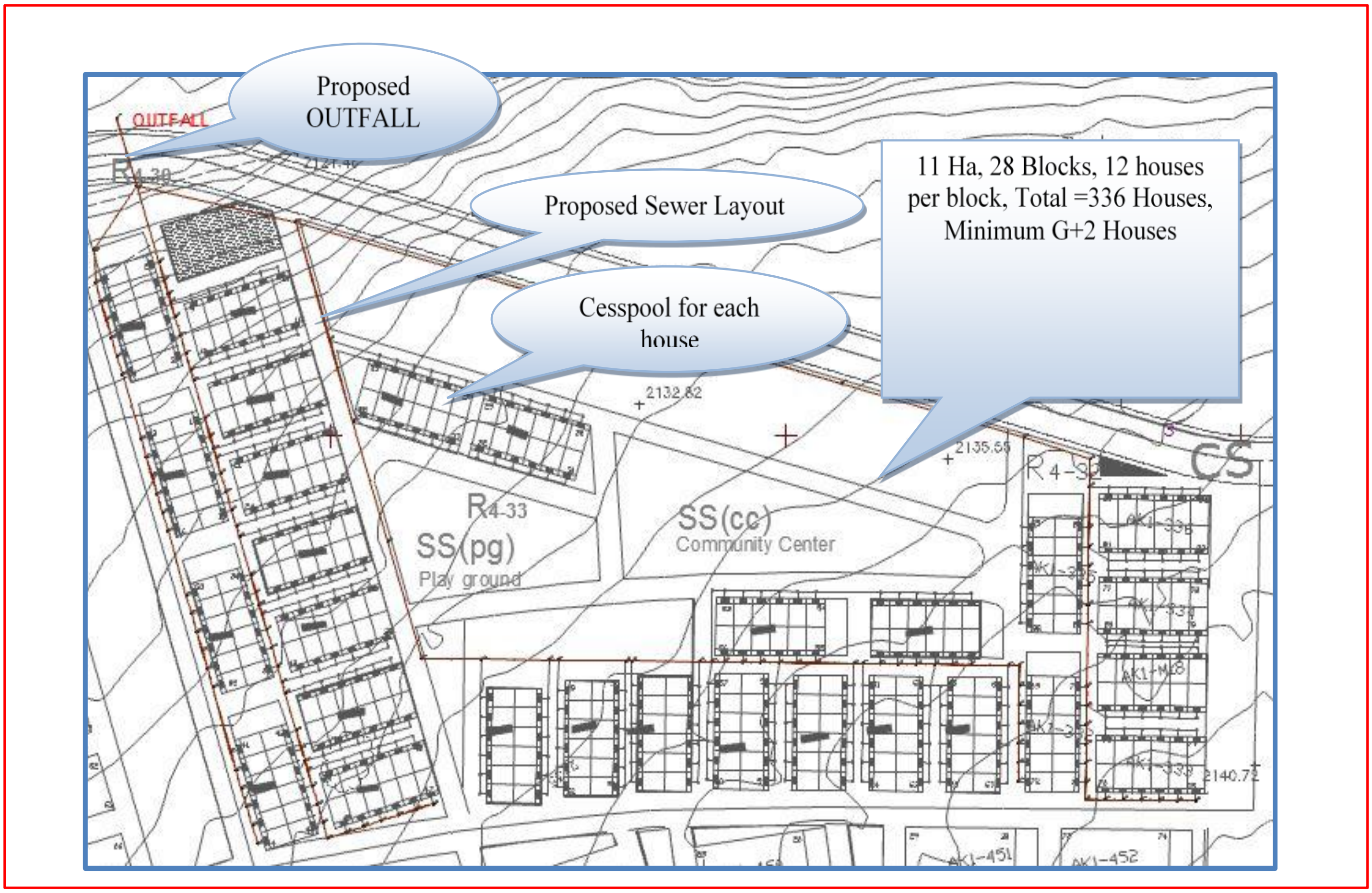
The second selected study area is located in Tulu Dimtu new residential area which is in Akaki Kality sub city. This selected area or community is located on the right side of the new high way along from Goro to Tulu Dimtu Condominiums and across a stream from the Addis Ababa Science and Technology University.

Massive single and multi-family houses are under construction which covers Woreda 1 and Woreda 13 administrations. These houses have been built by housing development cooperatives which are around 700.

There are 28 blocks in the study area where each block has 12 houses. The number of floors for a typical house in the area are raging from two floors to three floors. For this study purposes, an area covering around 10.41ha was selected inside Woreda 1 administration.

Figure 16: Limits of study area in Tulu Dimtu

In addition to the main city center which is the central business district like in Senga Tera area, Addis Ababa Structural Plan (AACSP, 2017) has been subdivided based sub-centers which includes secondary centers, Tertiary and local centers. The study area in Tulu Dimtu is located in Tertiary center. The development of this new housing expansion area was started back in 2002. The land use for this area used to be agricultural.



Source: *Akaki Kality Sub-city*

Figure 17: Land use plan of the selected study area in Tulu Dimtu

The housing development in expansion area was aimed to solve housing problem in the city. Based on the structural plan of the city, the housing need which was estimated for 2013 through 2023 is shown below.

Table 8: Estimated housing need in Addis Ababa (2013 - 2023)

Population in 2023	Address new family formation	Replace dilapidation	Address Backlog	Contingency (20%)	Total needed
4,408,656	207,015	269,814	500,000	195,366	1,172,195 rounded off to 1.2million

Source: *Addis Ababa city structural plan, 2017*

The land use plan of Tulu Dimtu new residential area can be considered as mixed residence land use. This is because, the construction of the houses which are completed now are serving as single and multi family residence in addition to other uses like shop, bar and restaurants, wood work, metal work, etc. Moreover, the proposed land use proportion in this area is based on 40%, 30% and 30% for built up areas, green areas, and road network respectively.

3.2. Existing Wastewater Drainage Situation and Others

Land use change for a certain city is directly related to planning to conduct infrastructure improvement. In order to develop a modern city, it is necessary to build all kinds of infrastructures in general and a wastewater drainage system in particular. The city wastewater drainage master plan need to be updated based on land use changes and in line with the current structural plan of the city in order to bring sustainable and economic development for the city.

Based on document reviews collected from the Addis Ababa Water Supply and Sewerage Authority, the 2001 Kality wastewater catchment master plan was updated in 2011 (Morrison, 2011). The study area in Senga Tera is located in Kality wastewater drainage catchment while the study area in Tulu Dimtu is located in Akaki wastewater drainage (not yet developed) catchment. Accordingly, the review of existing wastewater drainage system is summarized as follows.

3.2.1. Older Sewer System

The first wastewater drainage system covering a portion of the center of the city was built in 1982 and used to be out falling into the centralized oxidation pond wastewater treatment plant. This wastewater drainage system was located in Kality catchment. The length of the trunk sewer was approximately 30km and the secondary and later sewers were around 90km.The sewer system was proposed to serve for around 13,000 connections or households for domestic wastewater discharge and 27,000 PE (Its population equivalent was around 65,000 for a BOD load of 3500 kg/d which was proposed for the treatment plant)

The existing wastewater drainage system was covering only 10% of the city with a treatment plant having a capacity of 7600m3 up until the completion of another project in August 2018 entitled *“Kaliti Wastewater Treatment Plant Expansion and Rehabilitation and Expansion of Sewer Lines in the Kaliti Sewage Catchment*”.

This older sewer system were covering parts of Bole, Kirkos, Nefas Silk Lafto and Akaki Kality sub cities and which is otherwise known as older part of the city. The followings are some of designed data’s for the treatment works and the drainage systems (Hendriks, 2002).

Table 9: Some design data for the 1982 Kality wastewater drainage systems

Proposals During Design	Quantities	Remark
Planned number of sewer connection (domestic use)	13,000	
Population equivalent for institutional and commercial use	27,000 p.e	
Capacity of WWTP	7,600m3	
Approximate length of trunk sewer	30km	
Approximate length of secondary sewer and laterals	90km	
BOD5 load	3,500 kg/d	Population equivalent 65,000

***Source**: AWSSA*

3.2.2. Recent Sewer System

Since the existing wastewater drainage system was not satisfying the ongoing development of the city in Kality catchment, a new wastewater drainage system was commissioned in August 2018 to serve for around 1.5 million people. During this period some segment of the existing sewer has also been rehabilitated. The new sewer system was also integrated or connected with the 1982 older sewer system to outfall into the new Kality wastewater treatment plant. In addition to the trunk sewer, secondary and tertiary sewer were also built then focusing on houses which have flushed toilets.

The existing Kality oxidation pond wastewater treatment plant was redesigned in 2011 and the construction of Up flow Anaerobic Sludge Blanket (UASB) reactors followed by biological trickling filter treatment process as a secondary treatment process among other stages of treatment process were built. The capacity of this treatment plant is 100,000 m3 (Morrison, 2011).

The proposed sewage treatment plan also serve as a co-treatment for fecal sludge management. Septage generated from residential and commercial developments are being collected using vacuum trucks and disposed into seeptage receiving tank before it enters into anaerobic sludge digester.

3.2.3. Onsite Wastewater Situation

Most of domestic sewage generated from residential areas in Addis Ababa is being managed by inefficient onsite wastewater management facilities. These onsite sewage collection or storage facilities includes septic tanks, VIP latrine, pit latrine and cesspool which have been improperly managed and have not been providing the level of treatment necessary to adequately protect public health, surface and ground water quality

Table 10: Sanitation coverage at different levels of the sanitation ladder in Addis Ababa

Sanitation coverage	Sanitation ladder	Addis Ababa (% population)		National (% population)		
		Urban Slum*	Urban **	Urban ***	Rural***	National ** (***)
Improved sanitation	Pour/flush toilet	1.0	20.2	5.3	0.1	1.2 (0.8)
	IPL private	5.2	10.4	0.6	0.1	1.6 (0.2)
	Pit latrine private	5.2	10.6	11.6	2.3	45.1 (3.5)
	Total	11.4	41.2	17.5	2.5	47.9 (4.5)
Unimproved sanitation	Shared latrine	58.1	53.0	28.0	1.0	16.5 (4.5)
	UST	22.3	NR	45.8	58.6	NR (56.9)
	Open defecation	8.2	5.8	8.7	37.9	35.6 (34.1)
	Total	88.6	58.8	82.5	97.5	52.1 (95.5)

Note: IPL = improved pit latrine; NR = not reported; UST = unsanitary toilet; * = sample survey; ** = national inventory; *** = CSA (2014).

Source: *Beyene et.al 2015*

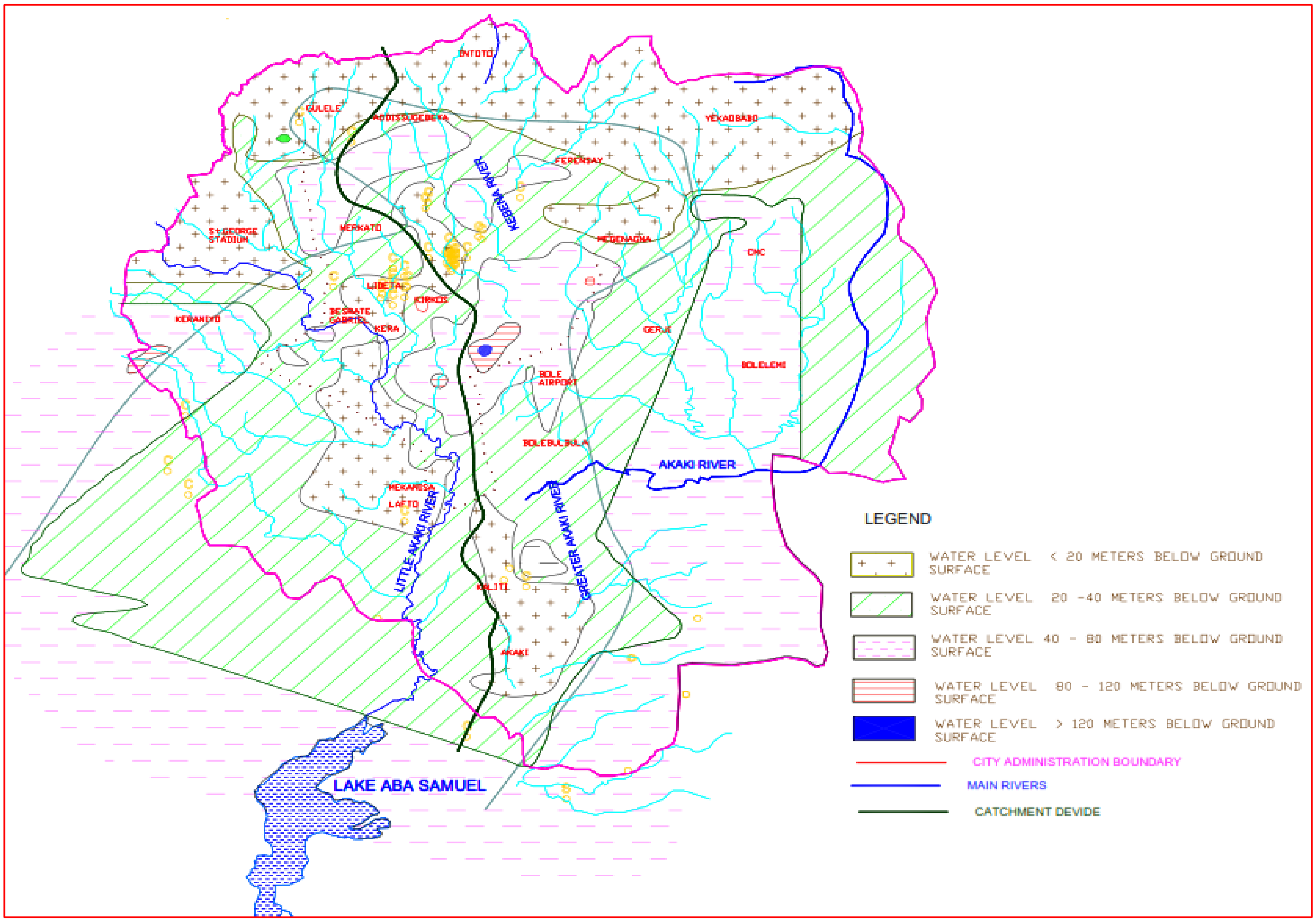
Table 10 is based Ethiopia Mini Demographic and Health survey [50] by the CSA in 2014.

3.2.4. Depth of Water Table

A study was conducted to categorize the estimated depth of water table in Addis Ababa based on borehole inventories carried out by AWSSA from April to May 2000 and through reviewing of previous studies (AAWSA, 2001).

Accordingly, the study map below is showing that the depth of water level in Lideta area is around 20m while the depth of water table in Kirkos area is around 20-40m.

Moreover, another study was reviewed to see the water table depth in Senga Tera. This was based on a borehole data drilled for raft foundation on the sites of Zemen and United Bank Headquarter buildings.



Source: *AAWSA, 2001*

Figure 18: Ground Water Depth of Addis Ababa

Based on these data's, minimum water tables depths were indicated though one cannot understand whether the ground water found was perched water or from unconfined aquifer.

The result hence indicated that the minimum water table depth was 7.6m and 6m from a drilling log report found for Zemen and United Bank sites respectively (Mahider M., 2018).

3.3. Model Calibration

3.3.1. Land Use and Sewer Master Plan

In order to conduct the capacity assessment of the existing sewer system and for proposing non-conventional sewer system, the land use plan for the study areas were collected. Accordingly, the land use plan which encompass the road layout, foot print of houses, buildings and institutions, contour map, open areas and other related were received from Kirkos, Lideta and Akaki Kality sub cities.

In addition, as-built information of the existing sewer system for Senga Tera were found from the 2011 Kality wastewater drainage master plan which includes but not limited to ; sewer layouts in AutoCAD format which have both the existing diameter and length of sewer. The proposed and invert elevations of manholes and other related information were available from the study documents.

3.3.2. ArcGIS Water Use Data

Base flow rate which represents the existing conditions in Senga Tera area was estimated based on water consumption data. Accordingly ArcGIS bill data record from Mekenisa and Arada AWSSA branch offices were collected. The water consumption data was from February 2020 through August 2020 for each catchments delineated through site visit investigation. From this data, water consumption for six months have been extracted from domestic, non-domestic and institutional existing developments. The following is ArcGIS shape file.

Source: *Arada and Mekenisa AAWSA Branch Offices Bill Data, 2020*

Figure 19: ArcGIS shape file delineated to collect water use data for Senga Tera area

3.3.3. Flow Rate Data

Wastewater drainage systems are initially designed based on theoretical engineering principles. The flow rate estimation which is an important parameter for design is usually derived based on the land use plan. The land use planning could be for residential, commercial, Institutional, industrial or mixed uses. Up to date census data sometimes may not be available. For example, the latest Population and Housing Census of Ethiopia was conducted in 2007. When a reliable census data's are available, the population estimation could be more realistic.

After estimating the flow rate based on population, per capita water use from codes, peaking factor etc. analysis and modeling can be conducted based on steady state condition. This kind of assumption does not take diurnal flow in to account. It is just based on maximum daily flow rate.

In order to calibrate models, measured flow rates are necessary. There has not been existing recorded wastewater flow rates in selected manholes of the city existing wastewater drainage system. In order to get reliable measured flow during dry weather and wet weather periods, there is a need for installing flow measuring devices like parshall flume, weir, Venturi and orifice type meters.

3.3.3.1. Manual Flow Measurement

In order to measure wastewater flowing through selected manholes, manual flow measurement was the last option available. For this purpose I have conducted prior studies and field investigations among others before starting flow measurement on field and these are listed out below.

- Repeated site visits for spotting the location of existing manholes on field based on the AutoCAD plan

- Decided the number and location of manholes which must to be opened depending on their location and taking into account how the measured flow can be distributed proportionally to the upstream manholes based on Thiessen Polygon Method

- Requested AWSSA authorization to open manhole covers

- Prepared a format (Annex 2) for recording the depth of flow at inlets and outlets of pipes

- Materials which are hand tools used for manual measurement were prepared and it includes the following among others:

  Measuring tape, Eucalyptus (Diameter 5cm and 4m long), Shovel, Hammer, Chisel, Wooden Mallet, Sledgehammer, Wrench, Screwdriver, Safety measures from Covid-19 (Mask, Glove and Sanitizer) and Umbrella.

Source: *WEF Sanitary Flow Monitoring, 2019*

Figure 20: Typical Area-Velocity flow monitoring setup using par shall flume

Accordingly, flow was measured on three (3) different days (August 5-2020 at 12AM, August 8-2020 at 6AM, August 10-2020 at 6PM) within a week and at different hours of the day during wet weather time at eight (8) selected (Figure 23) existing manholes.

List of manholes where flow measurements were taken includes 12HD14, 12HD24, 12HD22, 12HD11, 12HD07, 12HD23, 12HD28 and 12HD28A.

Moreover, it is worth mentioning typical challenges when conducting manual flow measurements during the study process. The major ones are:

- It was not allowed to open sanitary manhole covers without AAWSA staffs presence on field

Figure 21: Spotting Manhole 12HD14 by the crew **Figure 22:** Surcharged Manhole at 6PM

- It was also necessary to open manhole covers after getting traffic police authorization as the existing manholes were placed on pavement.
- As flow measurement was taken place after opening manhole cover, it was stinky as well as the measurement was taken during amidst corona virus when some research about coronavirus indicating that Covid-19 may be found on sewage.
- It was raining when the measurement was taken. If it was heavy rain, measurement cannot even be taken.

3.4. Field Research

In order to fully understand the existing wastewater drainage system in the absence of complete information which was not found in an AutoCAD plan, available modeling results, land use plan and other available documents, I found it necessary to make additional field research. The Kality older wastewater drainage system in the selected study area is around 40 years old. Even if there are as built data's and related information, it was important to double check in order to make sure the study is sounding.

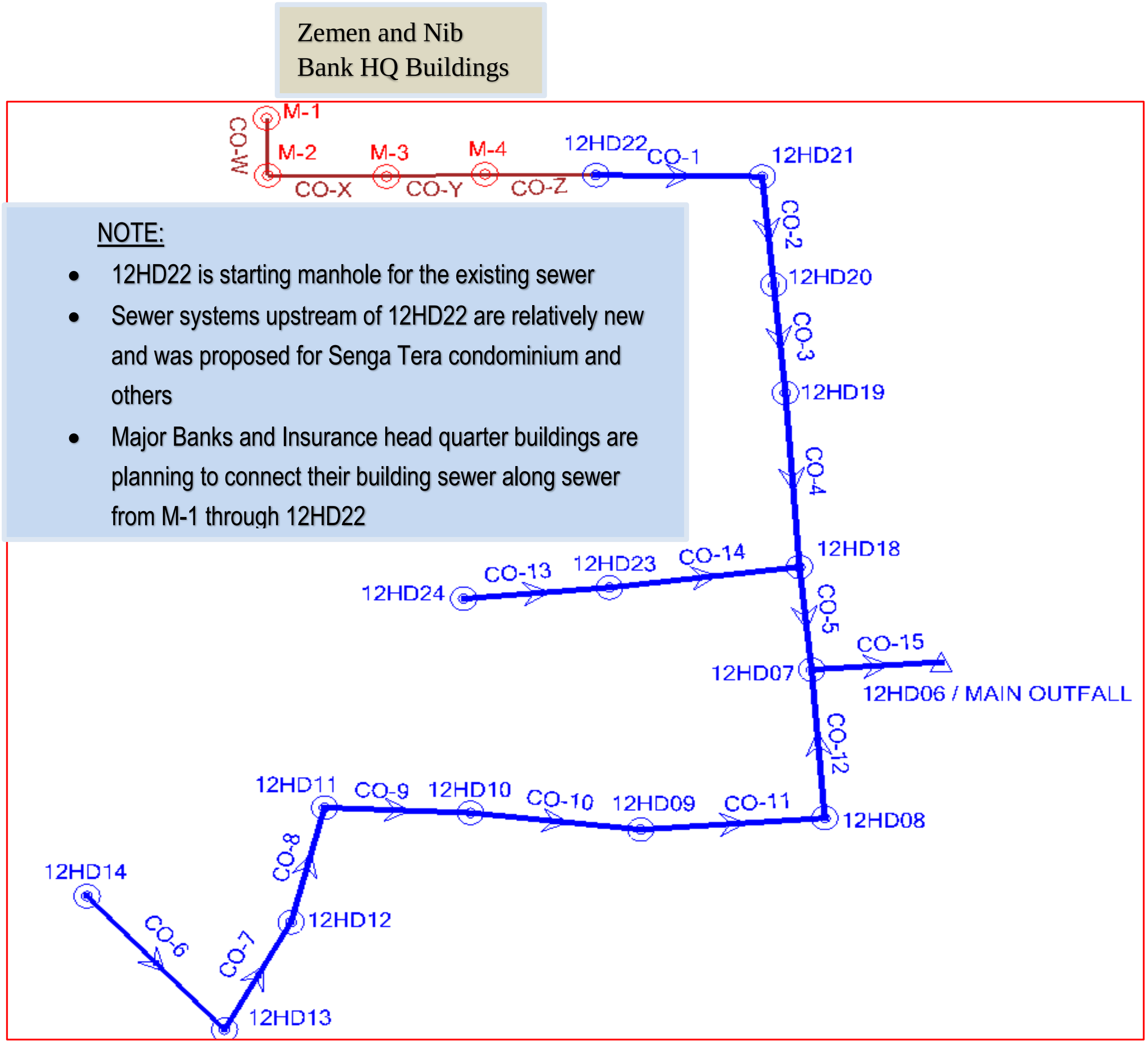


Figure 23: The existing sewer system schematic layout in the study area

For example a sewer alignment from 12HD28 through 12HD07 (this pipe extends from Lagare Hotel through Woreda 7 administration and finally joins manhole 12HD07) was missed in the AutoCAD as built plan.

Likewise, the following points were also taken into consideration when making field research. These includes but not limited to:

- Existing sanitary sewer overflows locations in the study area (if any)

Name of Catchment	Area, Ha
CA-1	2.77
CA-2	16.72
CA-3A	1.82
CA-3B	1.17
CA-3C	1.04
CA-4	4.4
CA-5	2.12
CA-6	0.51
CA-7A	0.39
CA-7	1.47
CA-8	3.77
TOTAL STUDY AREA	36.18

Table 11: Estimated area of sub catchment in the study area

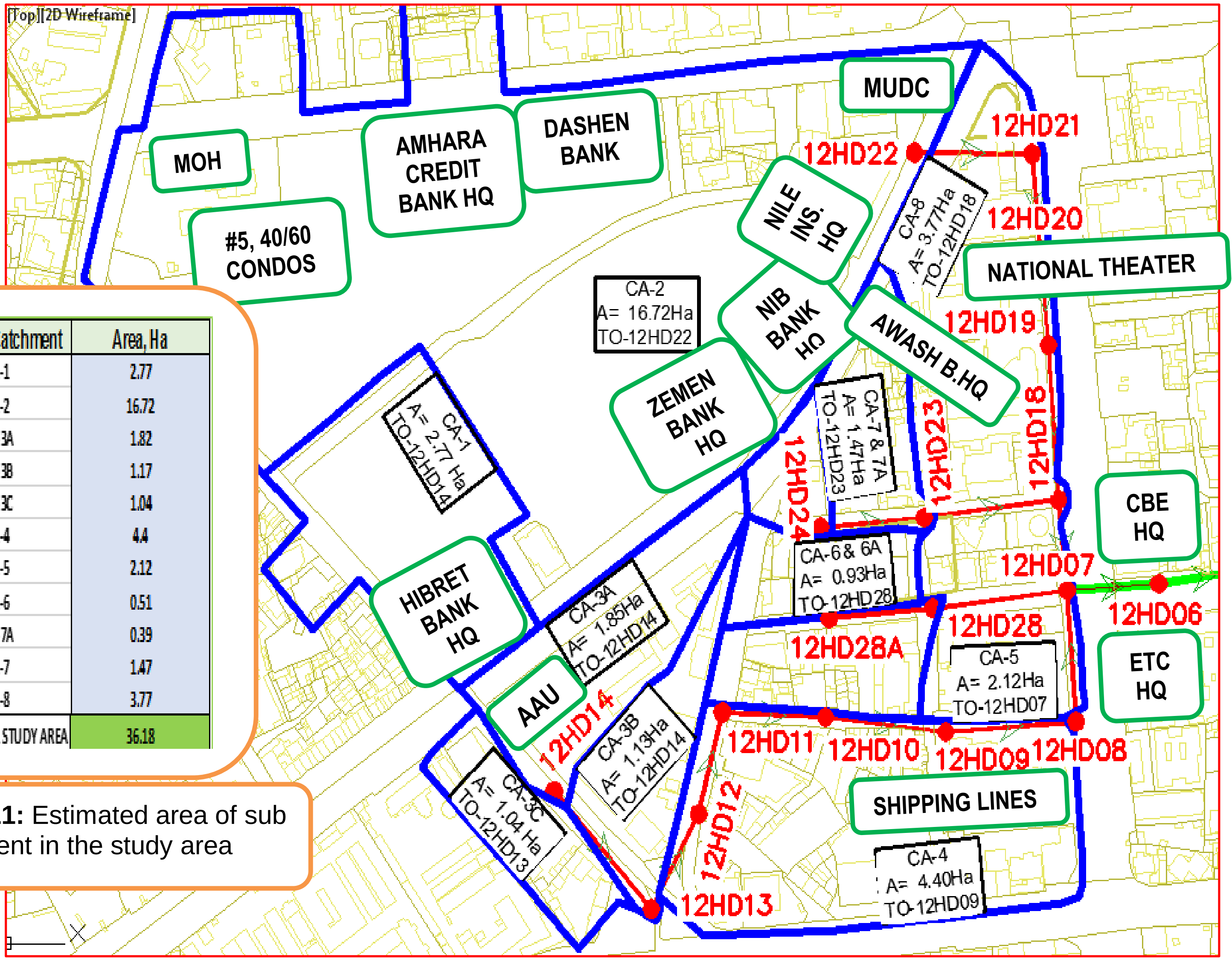


Figure 24: Existing Sewer layout and catchment delineation for the study area

Note: *The complete list of all existing buildings can be found under Annex 4*
The complete list of planned/future buildings can be found under Table 18
The red line in the above plan shows the older existing sewer layout
The blue line shows sewer shed delineation draining into the respective manholes

- To compare the ongoing development plan with the previous land use plan in the study area

- To see the practice of wastewater management system in the study area. This was to make sure whether or not some buildings still use onsite waste water management facilties instead of using the available municipal sewer systems in the area.

- To delineate wastewater flowing catchment areas.

- To identify outstanding issues in the area in order to supplement the available data's or documents for the research purpose

3.4.1. Sewer Shed Delineation

A certain area which is draining in to the nearby manhole was identified after opening several manholes and the sewer shed area has been estimated accordingly (Figure 24). This process helped me to distribute measured flows into other upstream manholes (where flow is not measured) proportionally based on their sewer shed areas.

3.4.2. Counting Buildings and User Population Estimation

The number of buildings, floor areas and number of stories, type of building occupancy and other related information were surveyed on field. It was almost like conducing housing census for the study area to estimate user population.

Moreover, literature review of previous studies (Estube K. 2019) on several banks head quarter buildings in that area were conducted. Then the number of users in the near future in the area were estimated based on relevant codes.

There are around eighteen buildings which are under construction in the selected study area in Senga Tera. This process helped to estimate the number of users in those buildings. All these buildings are planning to connect their building sewer or lateral with the existing wastewater drainage systems.

A separate study for each building cannot give full picture of the associated impacts on the capacity (US EPA, 2009) of the existing sewer system unless a sub division or a community is taken together. The limits of the study area was decided based on this fact.

3.4.2.1. Building Spatial Design Code

This code (EBCS-G, 2013) is part of the Ethiopian Building Code and Standards which is referred for design by Architects and Engineers. For this specific study, I used this code to relate building floor areas with the number of user people depending on the type of occupancy.

The proposed type of occupancy for high rise buildings in Senga Tera is Business occupancy. The purpose of Business Occupancy are offices for Banking and other professional services in addition to commercial shops. Accordingly, the following is a standard how net building area is related with number of persons (EBCS-G, 2013).

"The new width and area of rooms occupied by persons for an average duration of 2 (two) hours per day shall not be less than 2000mm and 5m^2 respectively".

However during a field survey, the gross estimated area of each buildings were collected. Therefore, it was necessary to estimate the net building areas. Accordingly, the following table shows the relation of net usable area as percentage of Gross Area (Walter T.)

Table 12: Office building efficiency

Building Height	**Net Usable Area as Percentage of Gross Area**
0-10 floors	Approximately 80%
0-20 floors	Floors 1-10 approximately 75%
	11-20 approximately 80%
0-30 floors	Floors 1-10 approximately 70%
	11-20 approximately 75%
	21-30 approximately 80%
0-40 floors	Floors 1-10 approximately 70%
	11-20 approximately 75%
	21-30 approximately 80%
	31-40 approximately 85%

***Source:** Walter T. Grandsir, Seventh Edition*

3.4.2.2. Plumbing Services of Buildings Code

After estimating the number of users based on the above process, the average water demand was estimated based on per capita water demand requirement set on plumbing code.

Table 13: Water requirements for residential and commercial use

Type of building occupancy	Water consumption per head per day (liter)
Dwellings with house connection	
i) Low consumption	80-120
ii) Medium consumption	120-200
iii) High consumption	200-300
Offices	35

***Source:** EBCS-2013*

This code (EBCS, 2013) relates building occupancy with water consumption per head per day in liter as follows.

3.4.3. Onsite Wastewater Survey in Tulu Dimtu

A field survey were conducted in Tulu Dimtu selected study area to see existing situation of wastewater drainage and onsite wastewater management facilities. Moreover, it was also to understand whether the existing practice in new expanding residential area is strictly following basic engineering principle and local codes (EBCS-2013) or not.

Based on a field research conducted in the study area where 28 blocks are located, all of the houses intended to manage wastewater in a cesspool which is otherwise known as septic tank traditionally.

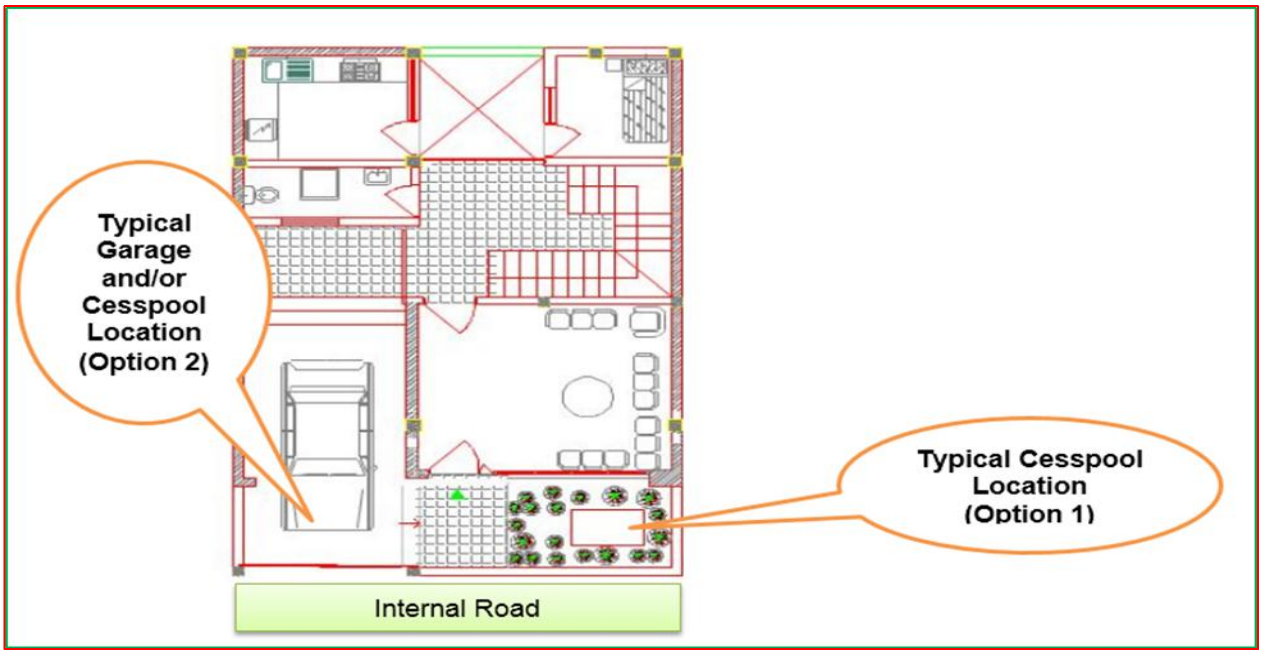


Figure 25: Typical ground floor plan of single family house in Tulu Dimtu area

The total site area of a typical house in the expansion area is around 96m2. There is no additional plot of land allocated for the construction of conventional septic tank with an effluent treatment unit which is the most common on site treatment method.

The front yard (Figure 25) in between the walls of the house and the fence is around 2m. That is where most cesspools for wastewater management were already built. Moreover, few cesspools are also built under the garage.

The following layout shows the locations of the proposed cesspools in one block. There are twelve (12) houses in one block which have interconnected or same foundation. The heights of the houses are ranging from G+2 to G+3.

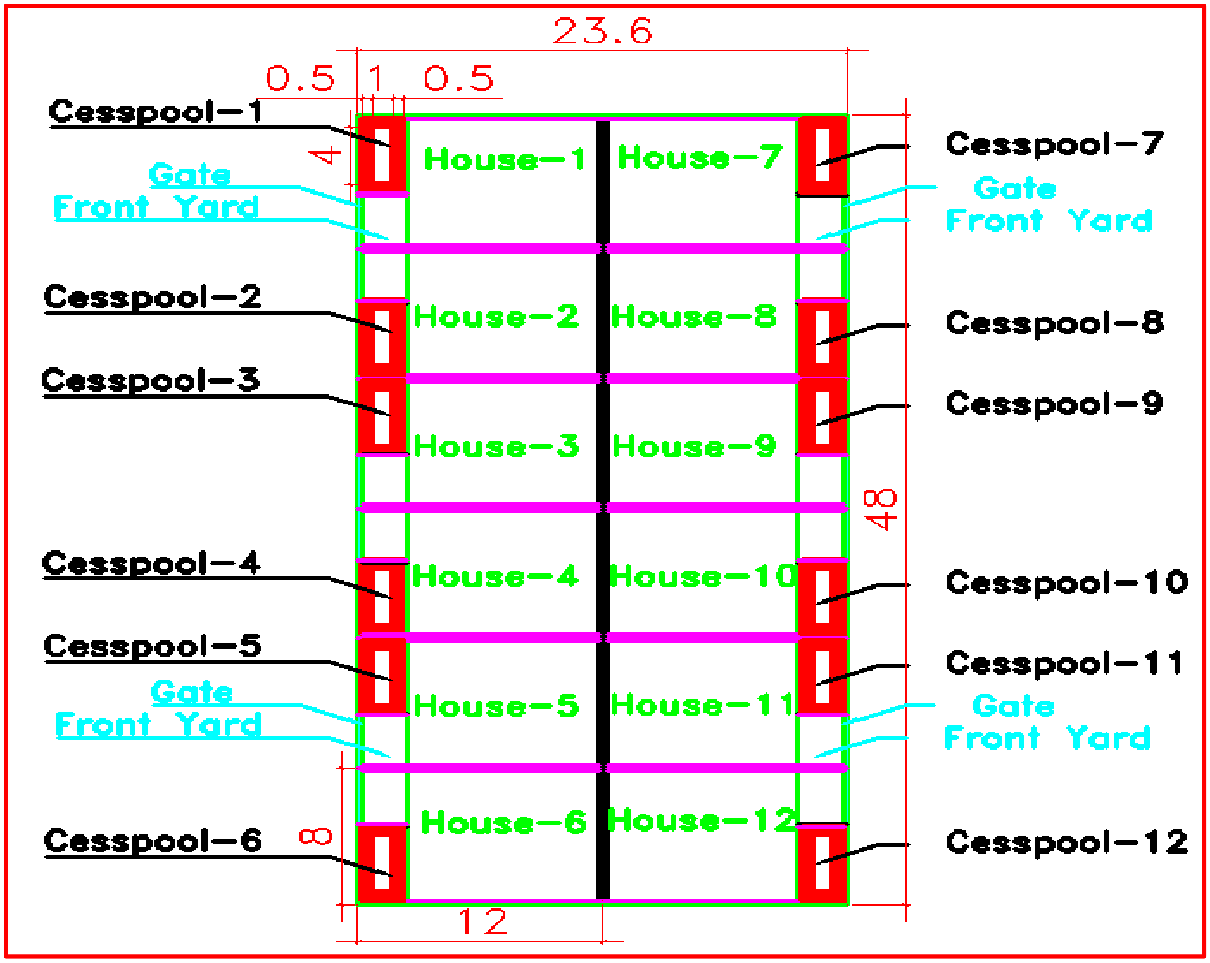


Figure 26: Layouts of cesspools in series and in parallel within one block

Note: 1. The approximate area of each front yard is 15m2

2. Cesspools are located in the respective front yards of each houses

The section view of a typical cesspool in the area is as shown below. As the walls of the masonry is only mortar jointed, it is not water tight. Most of the walls of the cesspools have been built side by side. There are also some homeowners, they chose to stack three concrete pipes having a diameter of 100cm instead of using rectangular masonry walls.

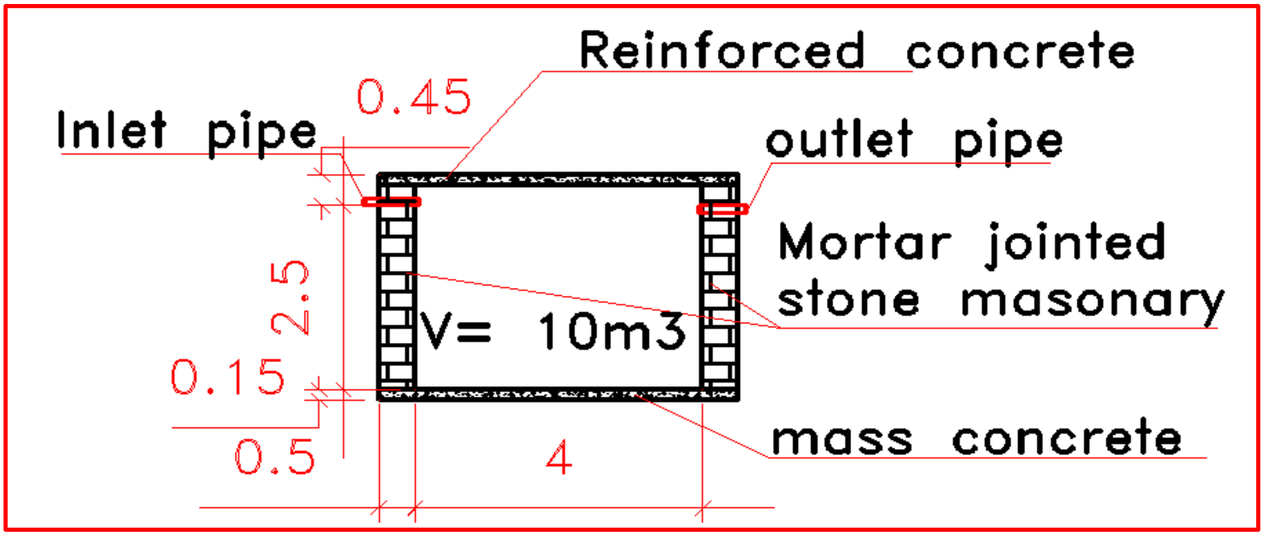


Figure 27: Typical section of a cesspool built in the study area

Photo: By Author, December 2021

Figure 28: Open ditch located at lower elevation from houses in Tulu Dimtu

Chapter Four

4. Data Analysis

This section summarizes results of analysis of collected data's. Based on these data's, modelings have be done and the results have been presented on the next chapter.

4.1. Case of Urban Densification

4.1.1. Measured Flow Rate

The depth of flow (Annex 2) measured at selected manholes were converted in to flow rate based excel spreadsheet (Annex 3). The slope of the sewer was found from the as-built data collected from AAWSA (Morrison, 2011). I set up two spreadsheets to calculate flow rate when the depth of flow inside the pipe is less than half full and more than half full.

Accordingly, Table 14 shows a summary of flow rate measured on field which was taken on three different days in a week. This flow rates are representing wet weather flows.

Table 14: Summary of flow rates measured on field at eight different manholes

No	Name of Manhole (Flow measurment were taken)	Measured Flow Rate (m^3/s), Less Than Half Full			Measured Flow Rate (m^3/s), More Than Half Full			Total Measured Flow (Average of flows)	
		9AM	12AM	6PM	9AM	12AM	6PM	m3/s	l/s
1	12HD14	0.022007	0.017298	0.009144				0.016150	16.15
2	12HD28	0.004770	0.007408	0.000294				0.004157	4.16
3	12HD22			0.034157	0.048803	0.043342		0.042101	42.10
4	12HD11			0.031875	0.036104	0.03989		0.035956	35.96
5	12HD23	0.023429	0.022734	0.006219				0.017461	17.46
6	12HD07 (Outlet Pipe)			0.102172	0.182027			0.142100	**142.10**
7	12HD07 , Inlet pipe from Sewer along Lagar Hotel Area (From 12HD28 to 12HD07)			0.017969	0.050546			0.034258	34.26
8	12HD07, Inlet pipe from Sewer along National Theater Area (From 12HD22 to 12HD07)			0.041542	0.050546			0.046044	46.04
9	12HD07, Inlet pipe from Sewer along Telebar/Ethiopian Insurance Enterprise Area (From 12HD11 to 12HD07)			0.042661	0.080935			0.061798	61.80
							Sum (7 to 9)	0.142100	**142.10**
10	Flow from the five condominiums (Measured at a new /recent manhole built upstream of 12HD22)			0.015590				0.015590	15.59

The measured flow rates were distributed to the rest of manholes which are located upstream of the respective manholes where flow was not measured, proportionally according to their sewer shed area contributions and the results are summarized below.

Table 15: Flow rate distribution to upstream manholes

Flow Measured at Manhole	Name of Upstream Manhole	Name of Upstream Catchment	Area, Ha	Proportion of Ditributed Flow Rate to Upstream Manhole(s), %	Total Measured Flow (Average flows)		Remark
					(m3/s)	(l/s)	
12HD14	None	CA-1	2.77	100	0.016150	16.15	12HD14 is Cosidered as a starting manhole for this capacity evaluation
		CA-3A	1.82				
		TOTAL	4.59				
12HD28	None	CA-6	0.51	100	0.004157	4.16	12HD28 is starting manhole
		TOTAL	0.51				
12HD22	None	CA-2	16.72	100	0.042101	42.10	12HD22 is Cosidered as a starting manhole for this capacity evaluation.
		TOTAL	16.72				
12HD11	12HD11	CA-3B	1.17	52.94	0.010486	10.49	
	12HD13	CA-3C	1.04	47.06	0.009321	9.32	
	12HD14	(CA-1) + (CA-3A)	_	_	0.016150	16.15	Actual measured flow rate at 12HD14
		TOTAL	2.21	100	0.035956	35.96	
12HD23	12HD23	CA-7	1.47	79.03	0.013800	13.80	12HD24 is starting manhole
	12HD24	CA-7A	0.39	21	0.003661	3.66	
		TOTAL	1.86	100	0.017461	17.46	
12HD07, (from 12HD22 to 12HD07)	12HD18	CA-8	3.77	66.96	0.002640	2.64	Deduct flow rate (m3/s) of 12HD 22 from 12HD07 to proportionate, (0.046044 - 0.042101) =
							0.003943
	12HD24	CA-7 A	0.39	6.93	0.000273	0.27	
	12HD23	CA-7	1.47	26.11	0.001030	1.03	
		TOTAL	5.63	100	0.003943	3.94	
12HD07, (from 12HD28 to 12HD07)	12HD28	CA-6	_	_	0.004157	4.16	Deduct flow rate (m3/s) of 12HD 28 from 12HD07 to proportionate, (0.034258 - 0.004157) =
	12HD28A	CA-6A	0.42	100.00	0.030101	30.10	**0.030101**
		TOTAL	0.42	100	0.034258	34.26	
12HD07, (from 12HD11 to 12HD07)	12HD09	CA-4	4.4	67.48	0.034628	34.63	Deduct flow rate (m3/s) of 12HD 11 from 12HD07 to proportionate, (0.061798 - 0.010486) =
	12HD08	CA-5	2.12	32.52	0.016684	16.68	**0.051312**
		TOTAL	6.52	100	0.051312	51.31	

4.1.2. Base Flow Rate

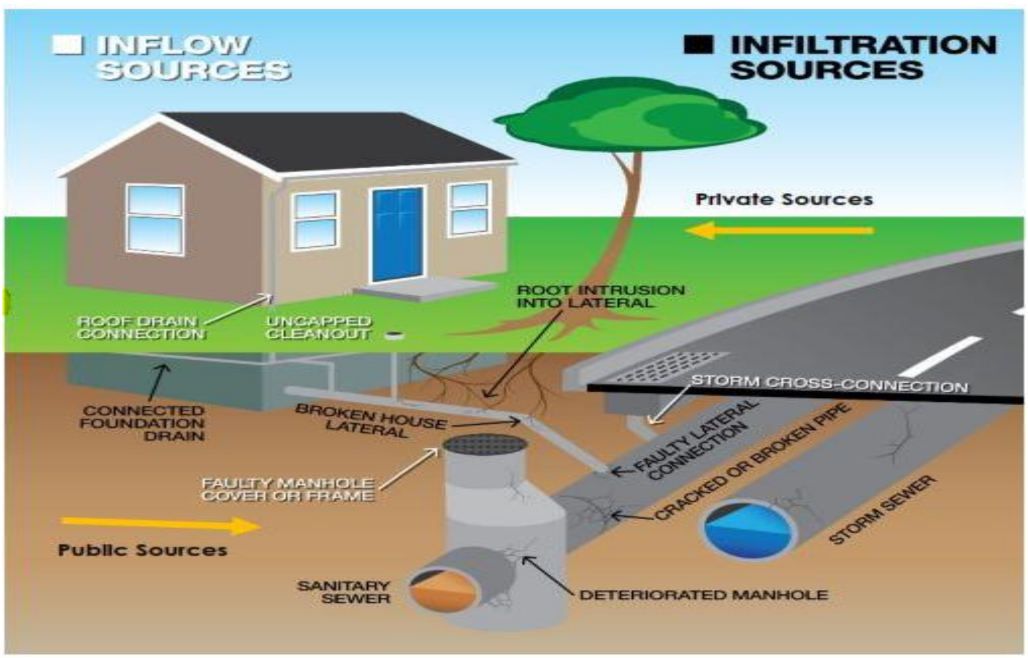
The base flow rate analysis which is shown on (Annex 4) were summarized based on Table 16.

Table 16: Summary of base flow rate based on six months water use ArcGIS data

Catchment Name	Area (Ha)	Flow Receiving Manhole Name	Average Base Sanitary Flow, (m3/s)	Average Base Sanitary Flow, (l/s)	Remark
CA-1	2.77	12HD14	0.000630	0.63	
CA-2	16.72	12HD22	0.004423	4.42	
(CA-3A) + (CA-3B)	2.99	12HD11	0.000433	0.43	
CA-3C	1.04	12HD13	0.000898	0.90	
CA-4	4.4	12HD09	0.032988	32.99	
CA-5	2.12	12HD07	0.002892	2.89	Load 2.89 +0.57 =3.46 at 12HD07
(CA-6A) + (CA-6)	0.93	12HD28	0.000570	0.57	
(CA-7A) + (CA-7)	1.43	12HD23	0.000624	0.47	
		12HD24		0.16	
CA-8	3.77	12HD18	0.001463	1.46	

4.1.3. Estimated Inflow and Infiltration

For the capacity evaluation of existing sewer systems in Senga Tera, inflow and infiltration was estimated (Table 17) based comparing base flow rate data with field measured flow rate data. The typical sources of inflow and infiltrations are shown under.



Source: *WEF, 2017*

Figure 29: Typical sources of I/I in sanitary sewer

Estimated Inflow and Infiltration (L/s) = Measured Wet Weather Flow Rate (l/s) – Average
(For Senga Tera) *Base Wastewater Flow (l/s) Rate*

Table 17: Estimation of Inflow / Infiltration in Senga Tera

Name of Manhole (Flow Measurment Take at)	Measured Average Wet Weather Flow (l/s), (1)	Average Base Sanitary Flow (From Water Use Data) (l/s), (2)	Estimated Inflow and Infiltration Quantity (l/s), (3)= (1) - (2)	Percentage (%) of Infiltration and Inflow against Wet Weather Flow	Remark
12HD14	16.15	0.63	15.52	96	
12HD22	42.10	4.42	37.68	89	Additional 15.59 l/s was mesured on a manhole upstream of 12HD22
12HD11	10.49	0.43	10.06	96	
12HD13	9.32	0.90	8.42	90	
12HD08 & 12HD09	51.31	32.99	18.32	36	Load this flow at 12HD09
12HD28 & 12HD28A	34.26	3.46	30.80	90	Load this flow at 12HD07
12HD23	1.03	0.47	0.56	55	
12HD24	0.27	0.16	0.11	42	
12HD18	2.64	1.46	1.18	45	

The water consumption data is monthly data. It does not show water consumption variation throughout the day. If diurnal water variation were known, a peaking factor could be introduced to calculate the peak base flow rate. In that case the rate of inflow and infiltration induced by surface water runoff could be less than from what is shown here. Therefore, for the analysis of existing sewer system in Senga Tera, estimated inflow and infiltration were used (Table 17). However, the analysis and modeling of non-conventional sewer in Tulu Dimtu an infiltration rate of 0.4 l/h.mm-Km were proposed since it is new and the material for construction is PVC.

4.1.4. Peak Design Flow Rate

Currently there are around eighteen (18) high rise buildings (Table 18) which are under construction in Senga Tera financial district area.

Peak Wet Weather Flow Rate (L/s) = Peak Dry Weather Flow Rate (l/s) + Estimated Inflow
(For Senga Tera)) *and Infiltration*

Design flow rate (Table 19) is based on base sanitary flow for the existing buildings and an additional flow rate contribution due to new land use.

Note: 1. *Base flow rate was estimated taking 80% of the average of six months domestic and non-domestic water Consumption data in Senga Tera*

2. The peak design flow rates due to new land use pattern in Senga Tera was estimated based on of average daily water consumption which was estimated based on EBCS-2013 and other related field research data.

Table 18: Estimated flow rate due to new land use in the study area in Senga Tera

Name of Sub Catchment	Name of Building	Occupancy Classification	Number of Storey	Estimated Gross Building Area, m2	Net Usable Area as Percentage of Gross Area, (m2), Take 70%	Area Occupied by One Person (m2). As per EBCS-G	Estimated Number of People	Water Consumption Per Head Per Day. As Per EBCS-9, (l/d)	Estimated Total Water Consumption, (l/s)	Estimated Flow Rate, (l/s). 80% of Water Consumption	Name of Flow Rate Receiving Manhole	Remark
Lideta Sub City												
CA-1 (2.77 Ha)												
	Commercial Development											
	1. United Bank Headquarters	Business	G+32,G+6	30000	21000	5	4200	35	5.10	4.08	12HD14	
	2. Sengatera Traders Union S.C.	Business	G+22,G+7	11160	7812	5	1562	35	1.90	1.52	12HD14	
	3. Yobek Commercial Center	Business	G+15,G+11	10640	7448	5	1490	35	1.81	1.45	12HD14	Considered already as base flow
	TOTAL						**5762**			**5.60**		
Lideta Sub City												
CA-2 (16.72 Ha)												
	Residential Development											
	1. Senga Tera 40/60 Condominiums (Block 1,2,3, 4 and 5)	Residential	2B+G+12	_	_	_	1720	120	3.58	2.87	12HD22	Considered already as base flow
	Commercial Development											
	2. Nib Bank Headquarters	Business	G+33	43249	30274	5	6055	35	7.36	5.89	12HD22	
	3. Nile Insurance Headquarters	Business	G+25, G+5	28747	20123	5	4025	35	4.89	3.91	12HD22	
	4. Zemen Bank Headquarters	Business	G+32	39900	27930	5	5586	35	6.79	5.43	12HD22	
	5. Enat Bank Headquarters	Business								5.66	12HD22	Average of flow rate from Nib and Zemen Bank HQ taken
	6. Amhara Credit and Saving Institutions Head Quarter	Business	G+6, 4B+6+M+25	19630	13741	5	2748	35	3.34	2.67	12HD22	
	7. Dashen Bank	Business	G+4,G+16	11200	7840	5	1568	35	1.91	1.52	12HD22	Considered already as base flow
	8. ODDA Building	Business	G+11	2340	1638	5	328	35	0.40	0.32	12HD22	Considered already as base flow
	9. KK Building	Business	G+22, G+5	9780	6846	5	1369	35	1.66	1.33	12HD22	
	10. Framed Structure Behind KK Building	Business	G+10	1980	1386	5	277	35	0.34	0.27	12HD22	
	11. Oromia International Bank Head Quarter									5.66	12HD22	Average of flow rate from Nib and Zemen Bank HQ taken
	12. Building Under Construction Behind Amahara Credit HQ	Business	G+2	2400	1680	5	336	35	0.41	0.33	12HD22	
	13. Open Space between Artistic Printing Press and Dashen Bank for Future									5.66	12HD22	Average of flow rate from Nib and Zemen Bank HQ taken
	TOTAL						**20396**			**36.81**		
Kirkos Sub City												
CA-4 (4.4 Ha)												
	1. Ethiopian Shipping Lines New Building	Business	G+16	4250	2975	5	595	35	0.72	0.58	12HD09	
	2. A Building Framed Structure Completed	Business	G+8	1944	1361	5	272	35	0.33	0.26	12HD09	
	TOTAL						**867**			**0.84**		
Kirkos Sub City												
CA-5 (2.12 Ha)												
	1. A New Building Under Construction infront of Mezid Plaza	Business	G+5	3600	2520	5	504	35	0.61	0.49	12HD07	
	TOTAL						**504**			**0.49**		
Kirkos Sub City												
CA-7 (1.04 Ha)	1. A Building Framed Structure Completed	Business	G+17	3240	2268	5	454	35	0.55	0.44	12HD23	
	TOTAL						**454**			**0.44**		
Kirkos Sub City												
CA-8 (3.77 Ha)	1. Oromia Cooperative Bank Head Quarter	Business								5.66		Average of flow rate from Nib and Zemen Bank HQ taken
	2. New National Theater Building (Under Construction)	Business	B+G+14	18000	12600	5	2520	35	3.06	2.45	12HD18	
	TOTAL						**2520**			**8.11**		
	Note : Total number of high rise buildings in Sengater area now and planned for near future are						**18**					

Source: *The number of stories and gross building area is based on field survey by the Author and Estube Ketema, 2019*

4.1.5. Peaking Factor

There is no locally developed or adopted peaking factors for the city of Addis Ababa. The result of the computed peaking factor based on Harmon's and Babbit formulae are shown on (Table 20) for Senga Tera and (Table 21) for Tulu Dimtu for comparison. As shown, these calculated values are much higher than CHPEEO except when the user population is more than 20, 0000.

Table 19: Estimated peak design flow rate for the capacity analysis of existing sewer system

Flow Receiving Manhole Name, (1)	Average Base Sanitary Flow, (l/s) (2)	Peaking Factor, (3)	Peak Base Sanitary Flow, (l/s) (4) = (2*3)	Additional Flow Due to Land Use Change		Peaking Factor, (6)	Peak Future Flow due to Land Use Change, (l/s) (7)=(5 * 6)	Peak Design Flow for Capacity Analysis, (l/s) (8) = (4 + 7)
				Name of Additional Flow Contributing Catchments	Estimated Average New Flows, (l/s) (5)			
12HD14	0.63	3	1.89	CA-1 (2.77 Ha)	5.6	3	16.8	18.69
12HD22	4.42	3	13.27	CA-2 (16.72 Ha)	36.8	2.6	97.30	110.57
12HD11	0.43	3	1.30	_	_	_	_	1.30
12HD13	0.90	3	2.69	_	_	_	_	2.69
12HD09	32.99	3	98.96	CA-4 (4.4 Ha)	0.84	3	2.52	101.48
12HD07/					_	_	_	
12HD28	3.46	3	10.38	CA-5 (2.12 Ha)	0.49	3	1.47	11.85
12HD23	0.47	3	1.40	CA-7 (1.04 Ha)	0.44	3	1.32	2.72
12HD24	0.16	3	0.47	_	_	_	_	0.47
12HD18	1.46	3	4.39	CA-8 (3.77 Ha)	8.11	3	24.33	28.72

Accordingly for these study purposes, peaking factor based on CPHEEO recommendation has been chosen. This is because, some literature (Metcalf Eddy, 2003) recommends to take peaking factors from similar community or country. In doing so, the results could be more realistic since it can avoid overestimation of the peak design flows.

Table 20: Peaking factor determination for Senga Tera study area

Description	Peaking Factor					
Type of Development	Senga Tera Financial District Buildings and Others					
Catchment Name	CA-1	CA-2	CA-4	CA-5	CA-7	CA-8
Average Number of Population per Catchment	5,762	20,396	867	504	454	2520
Chosen Peak Hourly Factor (Based on CPHEEO)	3	3	3	3	3	3
CPHEEO, 1993 Recommended Value	3	3	3	3	3	3
Babbit	9.7	2.7	5.1	5.7	5.9	4.2
Harmon	3.2	2.6	3.8	4.0	4.0	3.5
(P/1000)^0.5)+4	6.4	8.5	4.9	4.7	4.7	5.6
14/((P/1000)^0.2)+4)	2.2	1.6	2.8	3.0	3.0	2.5
		Babbit, PF = 5/P$^{0.2}$				
		Harmon, PF = 1 + 14/P$^{0.5}$ +4				
		P= Population in Thousands				

Table 21: Estimated design flow rate analysis for the design of the proposed communal sewer in Tulu Dimtu

Description	Wastewater Flow Analysis																												
Type of Development	**Single Family Residential**																												
Block Name	298	299	302	303	61	M14	300	M13	301	67	68	M12	304	226	326	M20	327	M21	330	331	328	M17	332	333	M18	334	335	336	28
Number of Houses Per Block	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1. Domestic Water Demand																													
Average Number of People Per Ho	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Average Number of People Per Blo	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Average Per Capita Water Demand (l/person/day) as per EBCS-9, 2013	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Total Average Domestic Water Demand (m^3/day) per Block	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
2. Domestic Watewater Flow Rate																													
Average Daily Wastewater Flow (m3/d), 80% of Daily Average	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20	7.20
Average Hourly Wastewater Flow (m3/h) during 24 Hours	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Peak Hourly Factor (Minimum of Babbit and Harmon Formula, and CPHEEO)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Peak Hourly Wastewater Flow (m^3/h) for sewer design per block	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Peak Hourly Wastewater Flow (m3/h) for sewer design for one House	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
CPHEEO, 1993 Recommended Value (See Section 3.5.3)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Babbit	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Harmon	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
(P/1000)^0.5)+4	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
14/((P/1000)^0.2)+4)	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Babbit, PF = $5/P^{0.2}$																													
Harmon, PF = $1 + 14/P^{0.5} +4$																													
P= Population in Thousands																													

4.2. Case of Urban Expansion

In Tulu Dimtu expansion areas, there have been residential housing developments almost for the last fifteen years though most of it is now under finishing stages apart from some houses which have already been in service. The study area is part of the Akaki wastewater drainage catchment. These massive new development in the expansion areas do not have existing conventional wastewater drainage system. So, the following flow rate is to propose non-conventional sewer systems.

The purpose of proposing a non-conventional sewer system (Jean-Marie Ilyet.al, 2014) for the study area is to show the preferred option over using individual existing cesspools. This is because wastewater generated from this selected area can be managed preferably by community managed decentralized wastewater treatment system (WSP, 2013) so that the associated pollution of using cesspool can be avoided.

4.2.1. Average Flow Rate

Average flow rate due to new residential developments was estimated based on taking 80% of average daily water consumption which was estimated based on EBCS-2013 as follows

Average Water Consumption (L/d) = [Per Capita Water Use (L/person/d)] x [Number of Users]

4.2.2. Peak Design Flow Rate

The peak design flow rate was estimated (Table 21) in order to do conduct analysis and modeling for the proposed non-conventional sewer network based on the site plan.

Peak Dry Weather Flow Rate (L/s) = Average Dry Weather Flow Rate (l/s) x Peak Factor

Peak Wet Weather Flow Rate (L/s) = Peak Dry Weather Flow Rate (l/s) + Extraneous Flow

Chapter Five

5. Results and Discussions

5.1. Results

Modeling has been taken place using the estimated wastewater flow rates for different situations, following the data collection process and flow rate analyses. The followings section summarizes what was found during the research process. Accordingly, the first four modeling results are for the capacity evaluation of the existing sewer system in Senga Tera and the fifth modeling result is for non-conventional sewer for Tulu Dimtu.

5.1.1. Results Based on Water Use Data’s

The existing sewer system is modeled using ArcGIS water use data’s for the current land use. There are residential, commercial and institutional establishments in the area. The wastewater flow rate was derived from metered water consumption data which represents base sanitary flow without inflow and infiltration (Philip M. Hanna et.al, 2004; US EPA Water Infrastructure Outreach, 2014) .

Table 22: Analysis and modeling results summary of base flow rate

Type of Simulation	List of All Manholes	Surcharged and Overflowing Manhole	Flow / Capacity Design of Pipes (%)
Steady State	12HD22, 12HD21, 12HD21, 12HD19, 12HD18, 12HD14, 12HD13, 12HD12, 12HD11, 12HD10, 12HD09, 12HD08, 12HD24, 12HD23 and 12HD07	None	Varies (0.3 – 57.1)

This base flow rate was estimated using six months of water consumption data’s. The water use data record were from February 2020 to August 2020 grouped based on their respective sewer sheds (Annex 4).

Therefore, in order to assess the capacity of the existing sewer system using base sanitary flow rate, steady state simulation was run. Accordingly, the complete results of analysis and modeling has been presented under (Annex 5) in addition to summarize results which is shown above.

Moreover, the following is typical profile for the existing sewer from manhole 12HD22 through the main outfall where the result is showing that the hydraulic and energy grade lines are in the pipes.

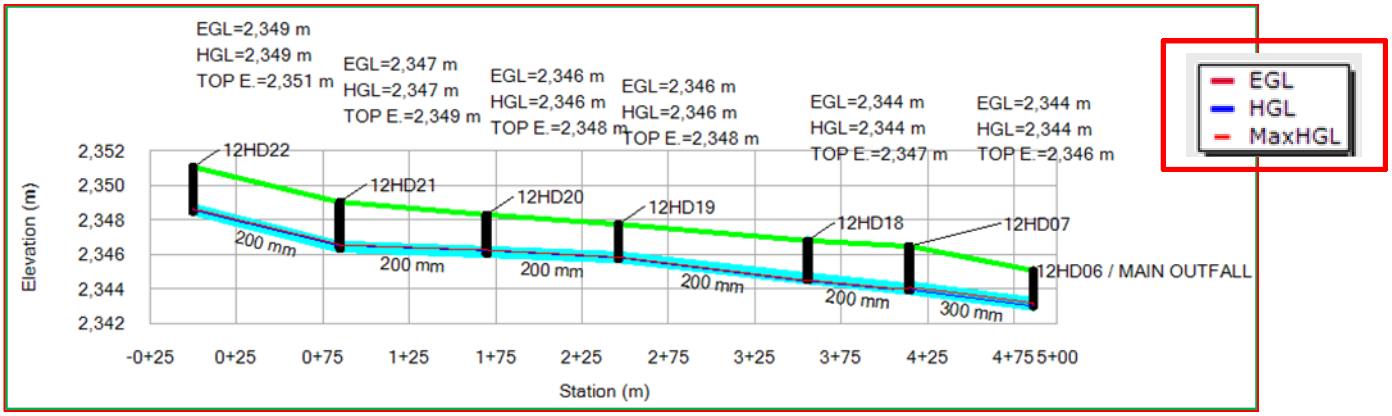


Figure 30: Typical sewer profile based on water use data's

5.1.2. Results Based on Measured Flow Rates Data's

5.1.2.1. **Scenario 1:** With Flow Diversion

This model is representing the existing older sewer system (Figure 32). The estimated quantity of this flow rate measured at upstream of Manhole 12HD22 was 15.59 l/s. This flow rate was by-passed before flowing into Manhole 12HD22. Existing sewers and manholes upstream of 12HD22 are relatively new and were laid out for the purpose of collecting wastewater generated from the 40/60 condominiums .

Accordingly this scenario is simulated by introducing an Outfall-2 as shown in the layout below. This means that the diverted flow (15.59l/s) is not flowing through the existing pipes in order to outfall into Manhole 12HD06 (Main outfall).

Scenario 1: Measured flow at Manhole 12HD22, Q = 42.10 l/s which is draining towards the main outfall which represents the actual flow condition in the study area.

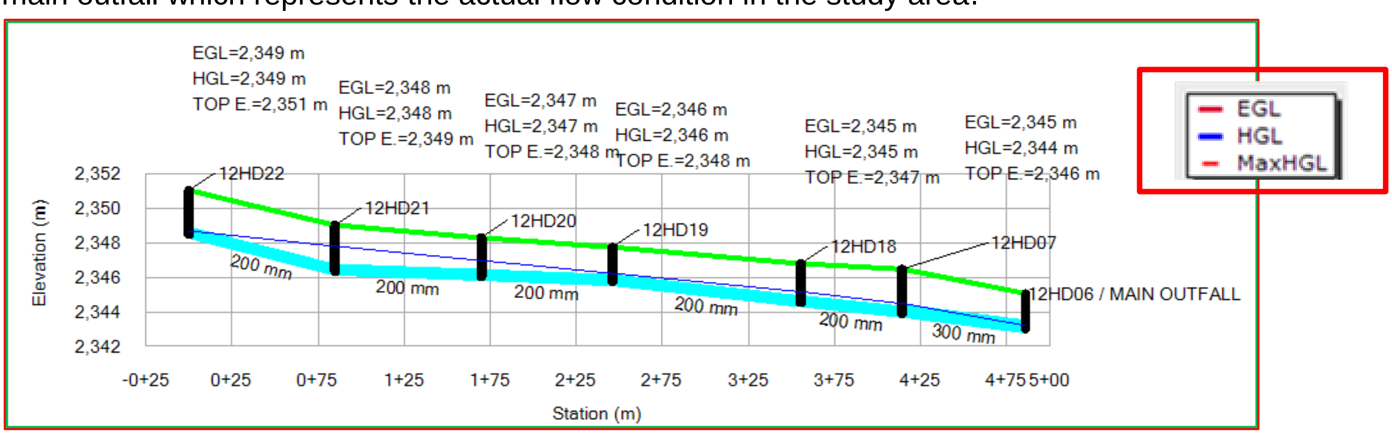


Figure 31: Typical sewer profile based on measured flow with flow diversion

The measured average quantity of wastewater at manhole 12HD22 was 42.10 l/s. This flow rate was collected from other buildings in the same catchment inside CA-1 which includes the MUDC, MOH and other commercial existing developments in the area.

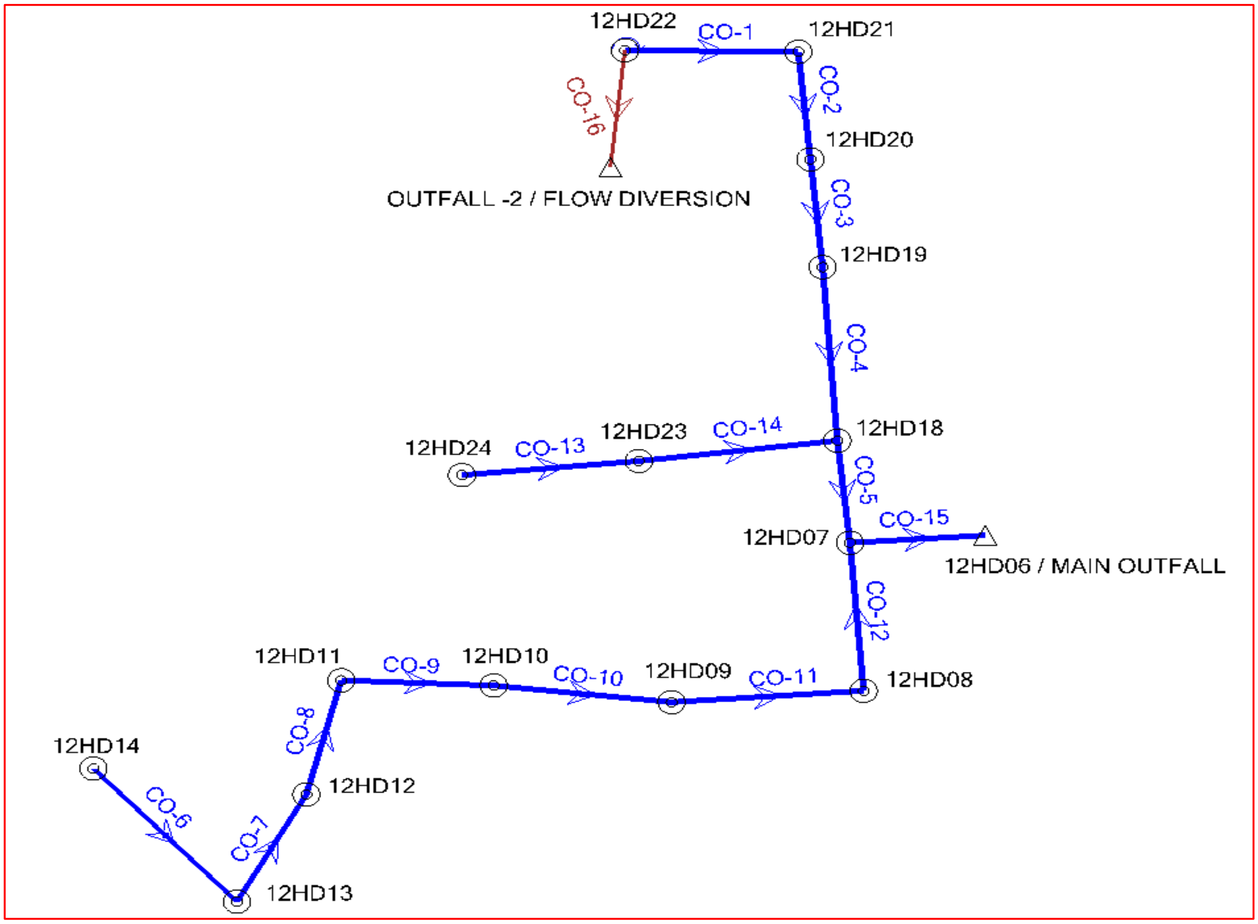


Figure 32: The existing sewer system schematic layout diverting flow through outfall-2

It is important here to note that, with in the measured flow rates there are sanitary flows, inflow and infiltrations as this measurement was conducted during wet weather period. In addition, this situation is representing the current condition which is without additional buildings which are now under construction.

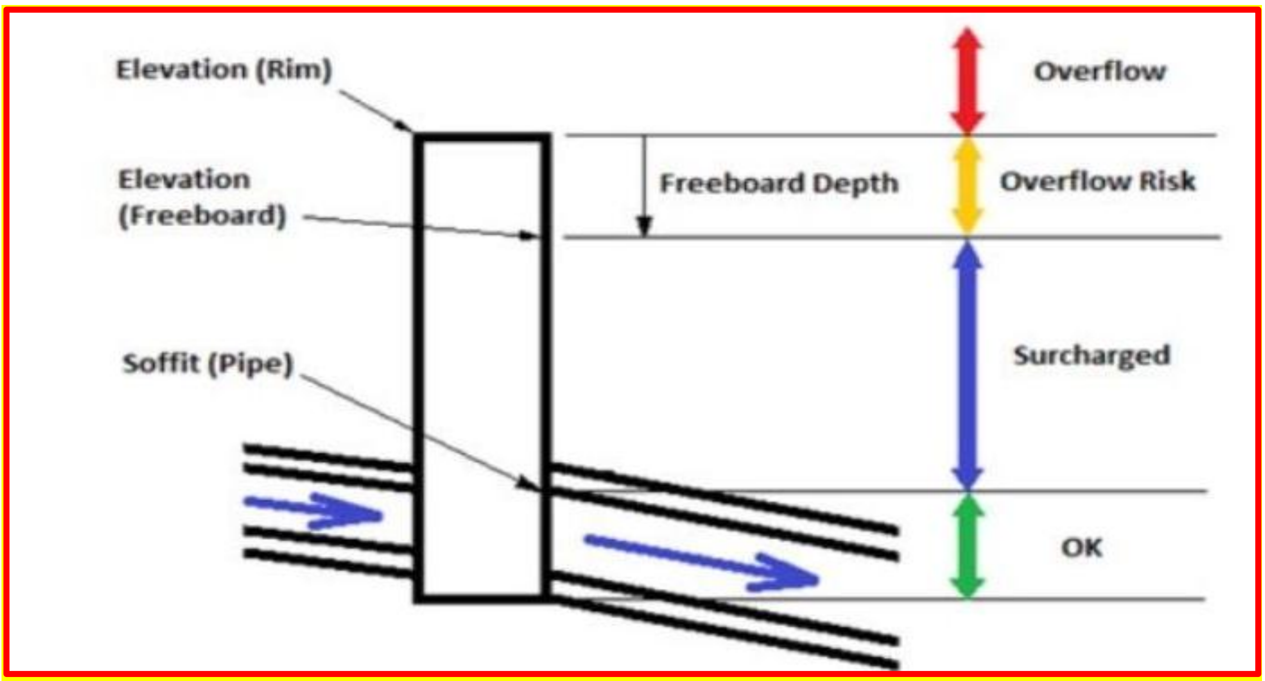
Therefore, based on Scenario 1, the followings are summaries of manholes which are surcharging and overflowing, and pipes which are above design discharges during wet weather flow.

Moreover, the complete results of analysis and modeling is shown under (Annex: 6).

Table 23: Analysis and modeling results summary of measured flows with diversion

Type of Simulation	List of Surcharged Manholes	List of Overflowing Manholes	Flow / Capacity Design of Pipes (%), (Pipes greater than 100%)
Steady State for Scenario-1	12HD21, 12HD20, 12HD19, 12HD18, 12HD09, 12HD08, and 12HD07	None	CO-2, CO-3, CO-4, CO-5, CO-11, CO-12 and CO-15

When pipes are flowing above their capacity, the manholes connecting the pipe could either be surcharging or overflowing. The following figure describes the difference between the two.



Source: *https://communities.bentley.com*

Figure 33: Figure showing the difference between surcharged and overflowing node

5.1.2.2. **Scenario 2:** Without Flow Diversion

The existing sewer system (Figure 34) is modeled considering as if wastewater collected from condominiums and others in the area is draining through the existing system though this assumption does not represent the reality in the ground.

Scenario 2: Measured flow at Manhole 12HD22 plus flow measured at upstream of Manhole 12HD22 (42.10 l/s plus Q=15.59 l/s = 57.69 l/s) which is draining towards Manhole 12HD06 (Main Outfall). This is a "what if" situation.

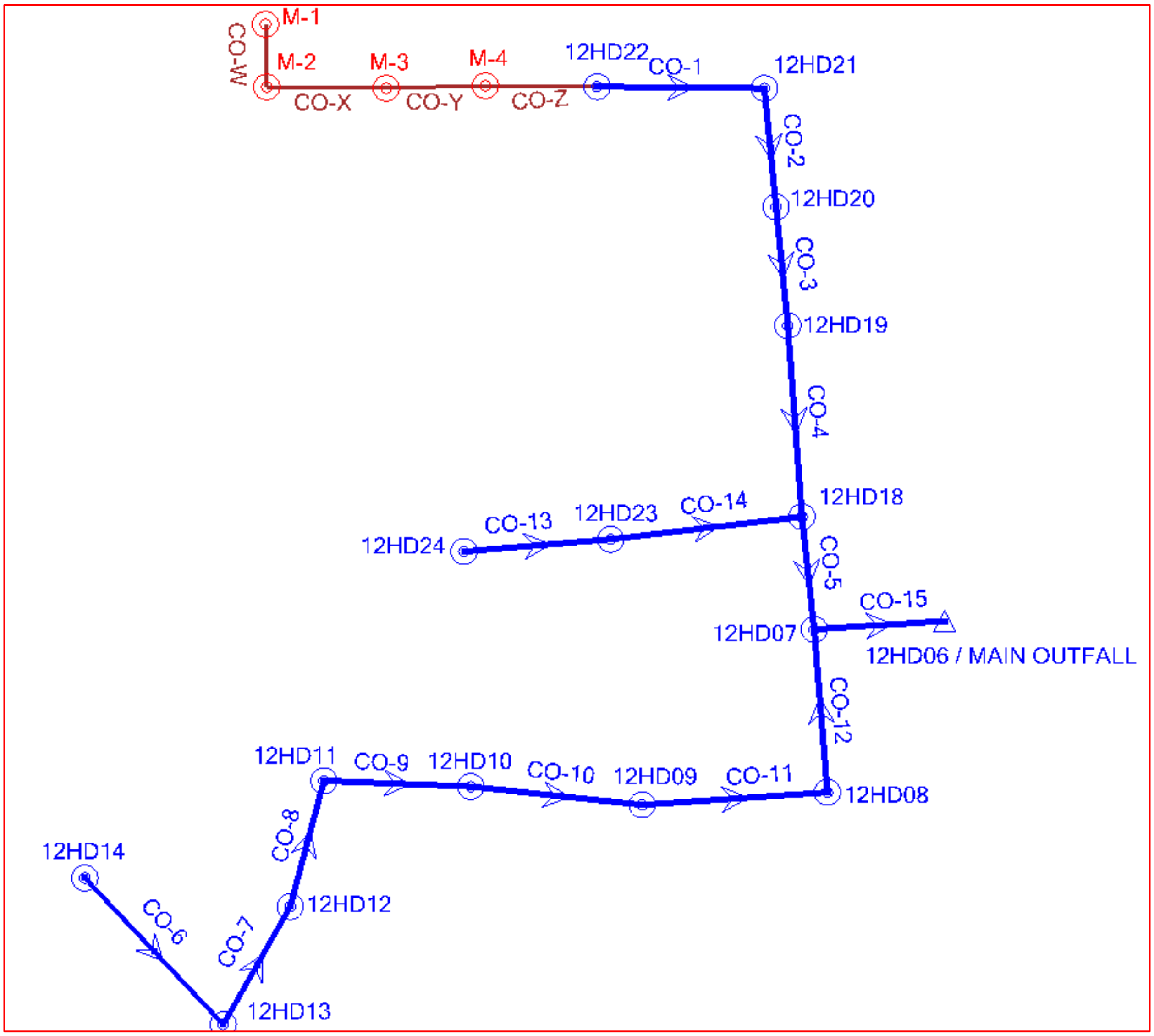


Figure 34: The existing sewer system schematic layout with Main Outfall

Accordingly, the results of analysis and modeling is showing that there are still pipes which are above design discharges in addition to surcharged and overflowing manholes.

The complete analysis and modeling result is also shown under (Annex: 7).

Table 24: Analysis and modeling results summary of measured flows without diversion

Type of Simulation	List of Surcharged Manholes	List of Overflowing Manholes	Flow / Capacity Design of Pipes (%), (Pipes greater than 100%)
Steady State for Scenario-2	12HD22, 12HD21, 12HD20, 12HD19, 12HD18, 12HD09, 12HD08 and 12HD07	12HD21, 12HD20 and 12HD19	CO-2, CO-3, CO-4, CO-5, CO-11, CO-12 and CO-15

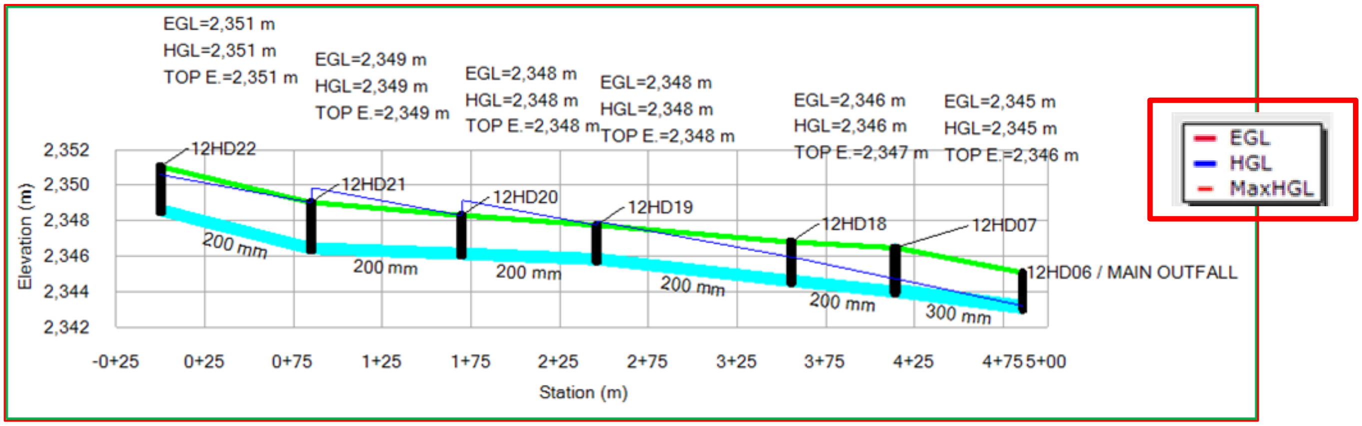


Figure 35: Typical sewer profile based on measured flow without flow diversion

5.1.3. Results Based on Rapid Land Use Change

The ultimate analysis and modeling due to rapid land use change has been simulated accordingly. This is the most critical situation which can predict the future situation of wastewater discharge in the study area.

Total Peak Flow Rate = *Base Flow Rate (Current Situation) + Flow Rate Due to New Land Use (Future Situation) + Estimated I and I*

Table 25: Analysis and modeling results summary for the ultimate flow rate

Type of Simulation	List of Surcharged Manholes	List of Overflowing Manholes	Flow / Capacity Design of Pipes (%), (Pipes greater than 100%)
Steady State	12HD22, 12HD21, 12HD20, 12HD19, 12HD18, 12HD13, 12HD12, 12HD11, 12HD10, 12HD09, 12HD08, 12HD23 and 12HD07	12HD22, 12HD21, 12HD20, 12HD19, 12HD18, 12HD09, 12HD08 and 12HD07	CO-1, CO-2, CO-3, CO-4, CO-5, CO-7,CO-11, CO-12 and CO-15

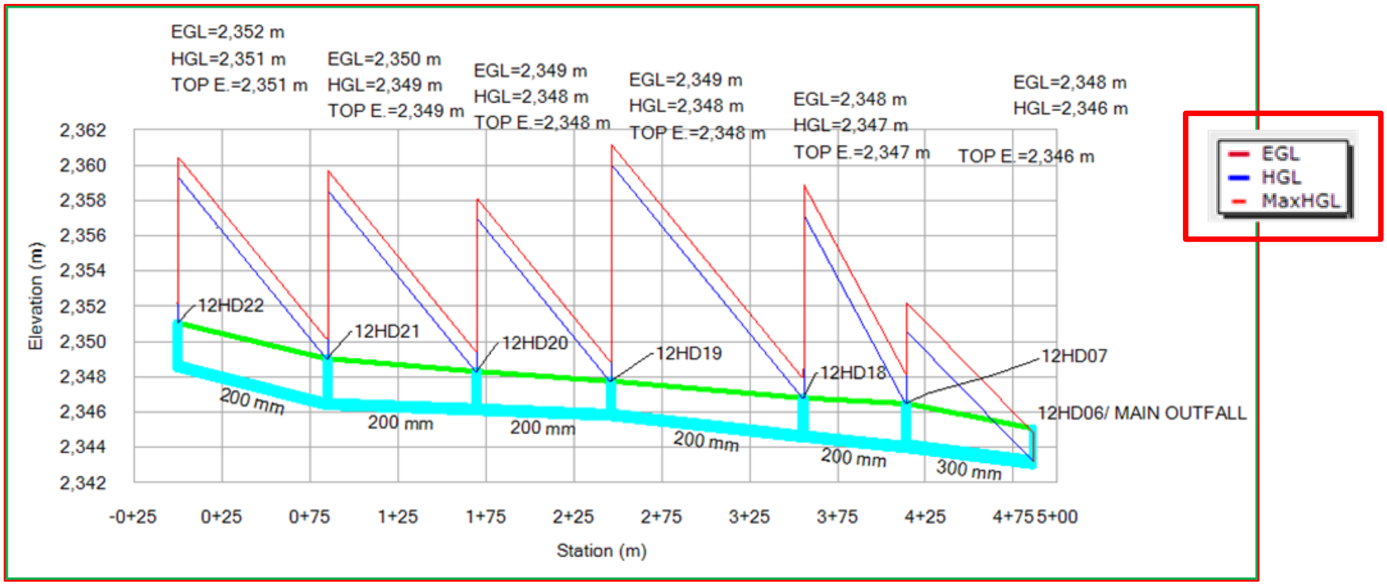


Figure 36: Typical sewer profile based on ultimate design flow due to rapid land use

Accordingly, complete modeling and analysis results of the study for the ultimate condition has been shown under (Annex 8) and summary results and typical profile are shown above.

5.1.3.1. Model Calibration Parameters

Measured flow rates using flow measuring devices (Weir, Par shall flume, orifice) are not available for the existing sewer system. These measuring devices can take the daily, monthly and yearly flow variations into account and make this type of study easier. In the absence of such data's, my study was based on manual flow measurement for the steady state analysis.

Since there was no existing model to start with, I built and run my model first using estimated sanitary base flow rate which is based on water metered data collected for the current land use conditions. This is because, metered water consumption data's are more reliable than data's based on manual flow measurements. In addition, base flow rate estimated in this manner can exclude inflow and infiltration.

The second parameter was adjusting the inflow and infiltrations. So, I measured wet weather flow rates manually in eight selected manholes. Then these flow rates were distributed to the rest of manholes (which were not measured in the study area) using Thiessen polygon method. Accordingly, Inflow and Infiltration was estimated and is equal to Measured Wet Weather flow minus Base sanitary flow.

Therefore, it is based on this flow calibration process that the impacts of proposed development (Rapid Land use change in Senga Tera) were assessed which includes among others:

- Identifying hydraulic problems with the existing sewer system like surcharged pipes and manholes, and overflowing manholes.
- Identifying hydraulic bottle necks due to flat slopes

5.1.4. Results Based on non-Conventional Sewer over Cesspools

A non-conventional wastewater drainage system which replaces cesspools in the study area has been proposed. For this purpose, wastewater estimation conducted and the results of analysis and modeling presented under (Annex 9).

Table 26: Analysis and modeling results summary for the peak flow rate in Tulu Dimtu

Type of Simulation	List of Surcharged Manholes	List of Overflowing Manholes	Flow / Capacity Design of Pipes (%), (Pipes greater than 100%)
Steady State	None	None	None

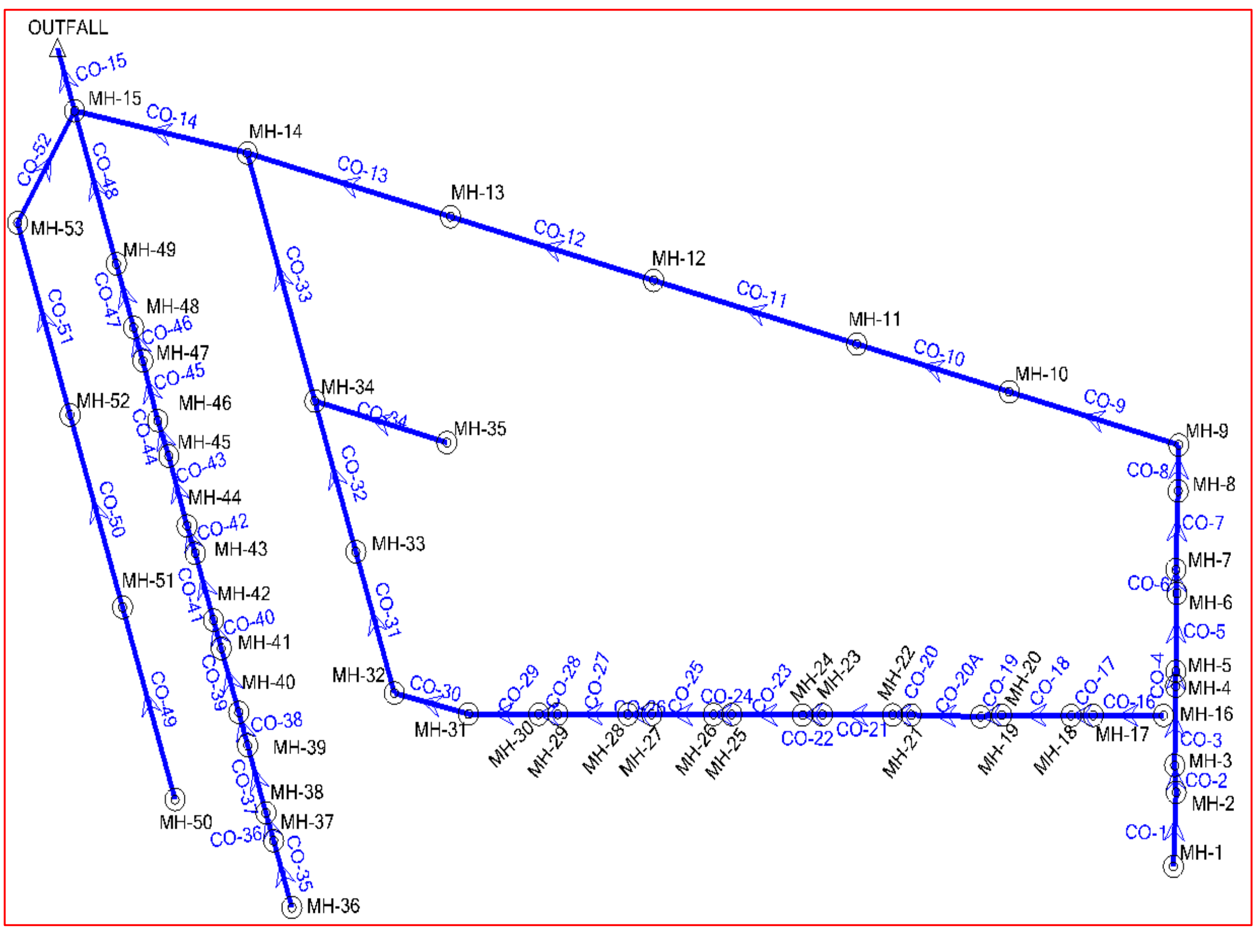


Figure 37: The proposed sewer system schematic layout in the study area in Tulu Dimtu

The implication of this study result is to show a non-conventional sewer system for the study area which can help to protect the nearby storm water drainage systems and nearby rivers from the discharge of untreated wastewater from the leaking and overflowing cesspools.

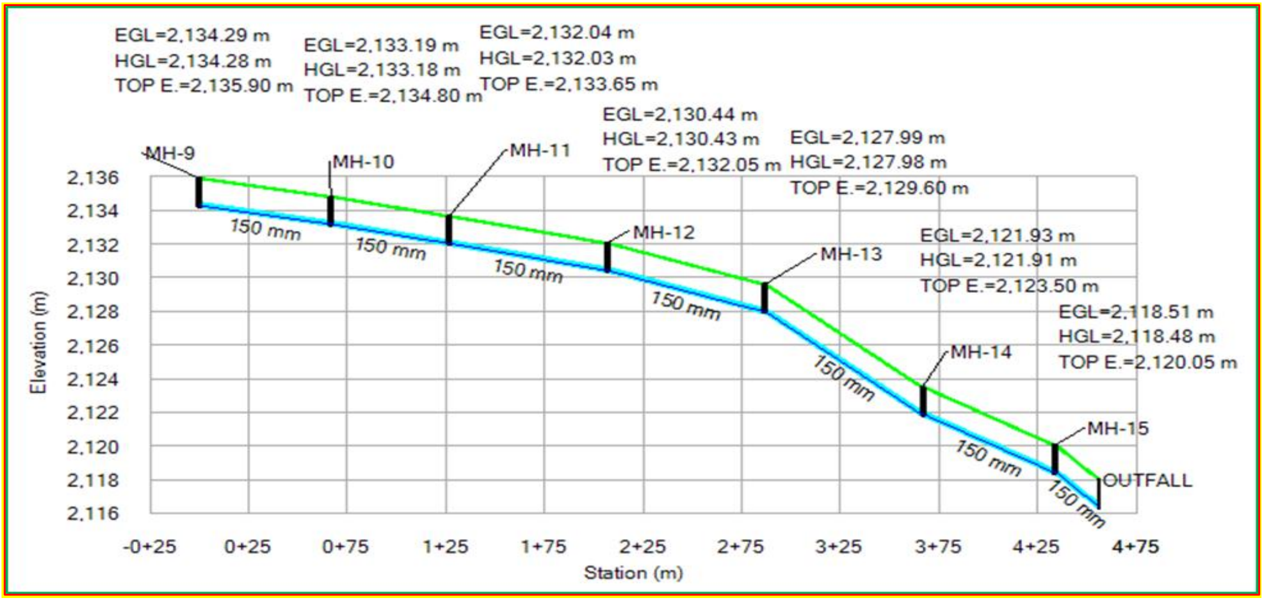


Figure 38: Typical sewer profile for non-conventional sewer system

5.2. Discussions

5.2.1. Urban Densification Contribution for Untreated Wastewater Discharge

Rapid land use change is contributing factor for the discharge of untreated wastewater into rivers in Addis Ababa when ineffective existing sewer systems are in place. Based on the study results in the study area in Senga Tera, 87% and 53% of the existing manholes could be surcharged and overflowing respectively if the current ongoing rapid land use change drains their wastewater into the existing older wastewater drainage system without enhancement.

Table 27: Summarized results of surcharged and overflowing manholes

Type of Simulation	Total Number of Manholes	Number of Surcharged Manholes	Number of Overflowing Manholes	Surcharged Manholes (%)	Overflowing Manholes (%)
Steady State	15	13	8	87	53

Similarly, 60% of the pipes do not have sufficient capacity to carry flow rate generated due to the proposed land use. The higher flow also cause the pipes to flow above the maximum permissible velocity of 3 m/s and these pipes are covering around 53%.

Table 28: Summarized results of pipes with over capacity and excess velocity

Type of Simulation	Total Number of Pipes	Number of Pipes (Flow/Capacity greater than 100%	Number of Pipes (Velocity greater than 3m/s)	Over Capacity Pipes (%)	Pipes greater than 3m/s (%)
Steady State	15	9	8	60	53

Alternatively, a sewer profile (Figure 36) was shown along a selected sewer alignment where the model is indicating that manholes are overflowing. This is the most critical sewer alignment where most of head quarter buildings of banks and insurances will be draining into. The internal diameter of the existing sewer along this alignment is 150mm. This is the minimum pipe size recommended for a sewer system by most municipalities.

Wastewater discharge into river is occurring due to Sanitary Sewer Overflows. When this occurs especially during wet weather periods, untreated overflowed wastewater can mix with run off. Storm inlets and ditches in the area collects wastewater and directs into the storm water drainage system. Addis Ababa Rivers are an outfall point for storm water discharges. There is no also efficient storm water management practice to improve the quality of storm water before discharging nearby rivers.

Figure 39: Raw sewage flow through Kurtume River by Ambassador Park in Addis Ababa

A research was conducted (D. Adugna et.al, 2019) recently to see the impact of storm water discharge in the quality of selected rivers in Addis Ababa. Accordingly, wastewater samples were taken and physiochemical analysis were conducted for dry and wet weather periods. In doing so, it was revealed that the quality of river water in general was poor. This is because the quality of storm water discharge into river is affecting the quality of Addis Ababa Rivers among other factors.

5.2.2. Impact of Excess Inflow and Infiltration

5.2.2.1. Sanitary Sewer Overflows

The impacts of inflow and infiltration is pronounced in separate sewer system that we have in Addis Ababa. Even though some residents are thinking that the existing sewer systems are used for the collection of both wastewater and storm water, the fact is that it was not planned and designed to serve as a combined sewer system.

This estimation was based on manual flow measurement during wet weather period on August 2020. This flow rate was compared with base flow rate which was estimated based on six months of water consumption data's. Accordingly, the results have been summarized in the following Table.

Table 29: Summarized results of estimated inflow and infiltration from current land use

Name of Manhole Where Flow Measurements Were Taken on Field	12HD14	12HD22	12HD11	12HD13	12HD09	12HD07	12HD23	12HD24	12HD18
Inflow and Infiltration (%)	96	89	96	90	36	90	55	42	45

Number of Manholes	Average Estimated Inflow and Infiltration (%)
9	71

Accordingly the above results indicated that, higher rate of inflow and infiltration was recorded and this was found to be the common cause for inducing sanitary sewer overflows (Philip M. Hanna et.al 2004) among other technical reasons. The rate of inflow and infiltration ranges from 36% to 96% where the average is 71%.

However, the higher rate of inflow and infiltration record in the study area can also be contributed by the followings.

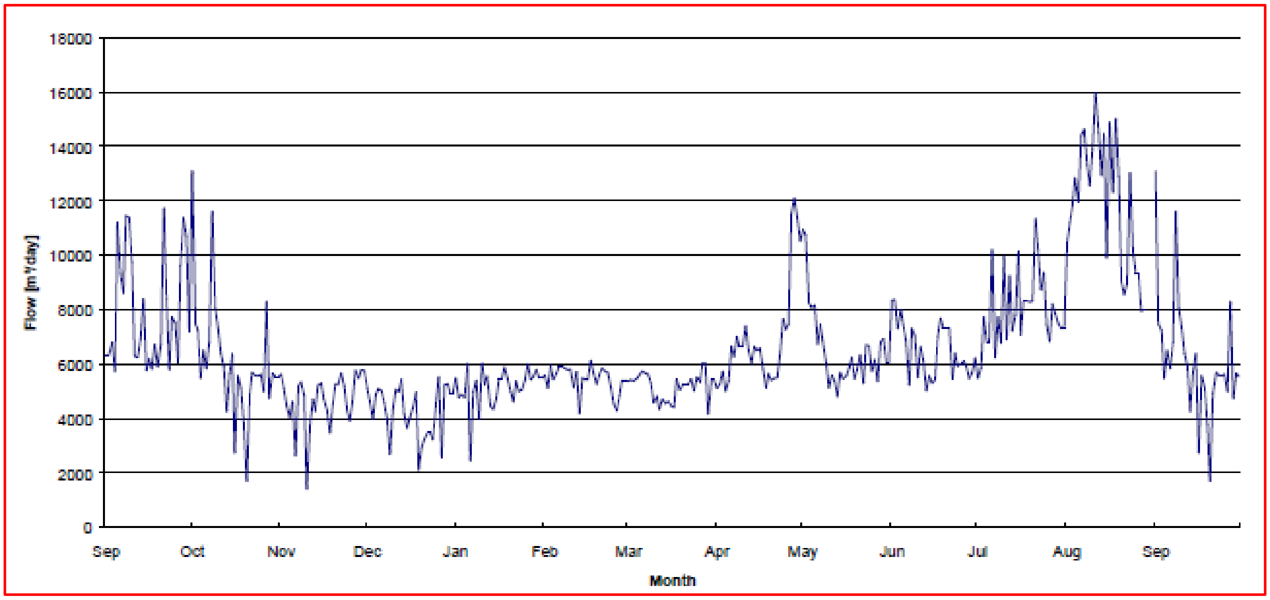
- Lack of efficient storm water drainage system in the area can encourage run off ponding in the area and this can results in more inflow and infiltration quantity;
- The existing sewer system in the study area may be deteriorated due to aging;
- There has been poor operation and maintenance management practice in the city;
- Flow measurement was taken while it was raining and when the ground was wet;
- Poor design, installation and supervision practice can result in higher inflow due to the possibility of cross connecting down pipes and foundation drains with the nearby wastewater manholes

5.2.2.2. Wastewater Treatment Plant

The higher rate of inflow and infiltration is not only inducing SSOs to discharge untreated wastewater into the Addis Ababa Rivers but also it may result in the hydraulic loading the Kality Wastewater Treatment Plant.

Higher inflow and infiltration has a great impact on the removal rates at the WWTPs and on the effluent loadings. Based on wastewater flow recorded from the older oxidation pond Wastewater treatment plant from September 1999 through September 2000 (Figure 40), it was observed that the total wastewater flow entering into this treatment plant during wet weather season was closer to 16 000 m3/d against the designed capacity which was around 7600m3/d (Hendriks, 2002). This was due to higher inflow and infiltration discharges.

Moreover, it makes more sense to interrelate the study area of older sewer system in Senga Tera with the older oxidation pond treatment plant than with the new wastewater treatment plant which was commissioned recently in August 2018.



Source: *AAWSA, 2002*

Figure 40: Average daily inflow record in the Kality older WWTP

The new Sewage Treatment Plant was planned to serve the whole Kality wastewater drainage catchment in addition to the city center like Senga Tera areas with a proposed capacity of 100,000m3/d.

However, the new Waste Water Treatment Plant in Kality is not operating at full designed capacity yet. Six months (From February 2020 through July 2020) of flow record data which was taken daily is shown under (Annex: 1).

Based on that data, the flowing tables show summary of monthly minimum, maximum and average wastewater inflow records followed by summary of six months of inflow records.

Table 30: Summary of monthly inflow records at Kality Wastewater Treatment Plant

Type of Monthly Flow (m3/d)	February 2020 through July 2020					
	February	March	April	May	June	July
Minimum	41,129	41,836	41,931	41,217	41,316	41,217
Maximum	51,885	51,122	51,611	51,163	73,584	51,163
Average	46,579	46,685	46,790	45,453	48,793	45,609

Table 31: Summary of six months of inflow records at Kality Wastewater Treatment Plant

Six Months of Flow Summary	Flow (m3/d)
Minimum	41,129
Maximum	73,584
Average	46,640

Infiltration and inflow is an issue recognized around the world to cause negative impacts on the operation of existing wastewater treatment plants. The following table shows summaries of extensive literature review conducted in Sweden taking modern cities around the world (Gerly Hey, et.al. 2016).

Table 32: Estimated average contribution of inflow and infiltration to sewer system reported in literature

Country	% I/I share	Reference
Germany (Baden-Württemberg)	35	Weiss et al, 2002
Netherlands	38	Schilperoort, 2004
Norway (14 different cities)	67	Ødegaard, 2016
Austria (32 WWTPs)	25-50	Ertl et al., 2008
Sweden	50	Svensson and Gustavsson, 1996; Gustavsson and Svensson, 1996
UK	45	White et al., 1997; Ainger et al., 1998
Scotland (Edinburgh)	60	GDSDS, 2005
Ireland (Dublin)	10-75	GDSDS, 2005
Switzerland	35-65	Kracht and Gujer, 2005
Canada	8	Holeton et al., 2011; Environment Canada, 2010
Czech Republic	45	Bares et al., 2008
USA	55-65	Pearlman, 2007

Source: Gerly Hey, et.al. 2016

5.2.3. Impact of Cross Connection with Storm Water Drainage

During field investigation process, around eight (8) manholes were selected for manual flow measurements. Each manholes were opened and flow were measured at three (3) different days to take into account wastewater flow variations throughout the day.

The field survey was a joint activity with four staffs of AWSSA who were assigned to assist me in the measurement process as this government agency does not allow to open manhole covers by others without their presence.

Manhole 12HD22 which is located in front of MUDC were investigated jointly as well. And it was concluded that no wastewater was entering into this manhole from a new sewer alignment coming from west direction. The reasons could be;

- Due to hydraulic bottlenecks. This means that may be it was not possible to achieve positive drainage in order to connect the new/recent sewer with an invert elevation of outlet pipe at oldest existing manhole (12HD22) which is located relatively at higher elevation;

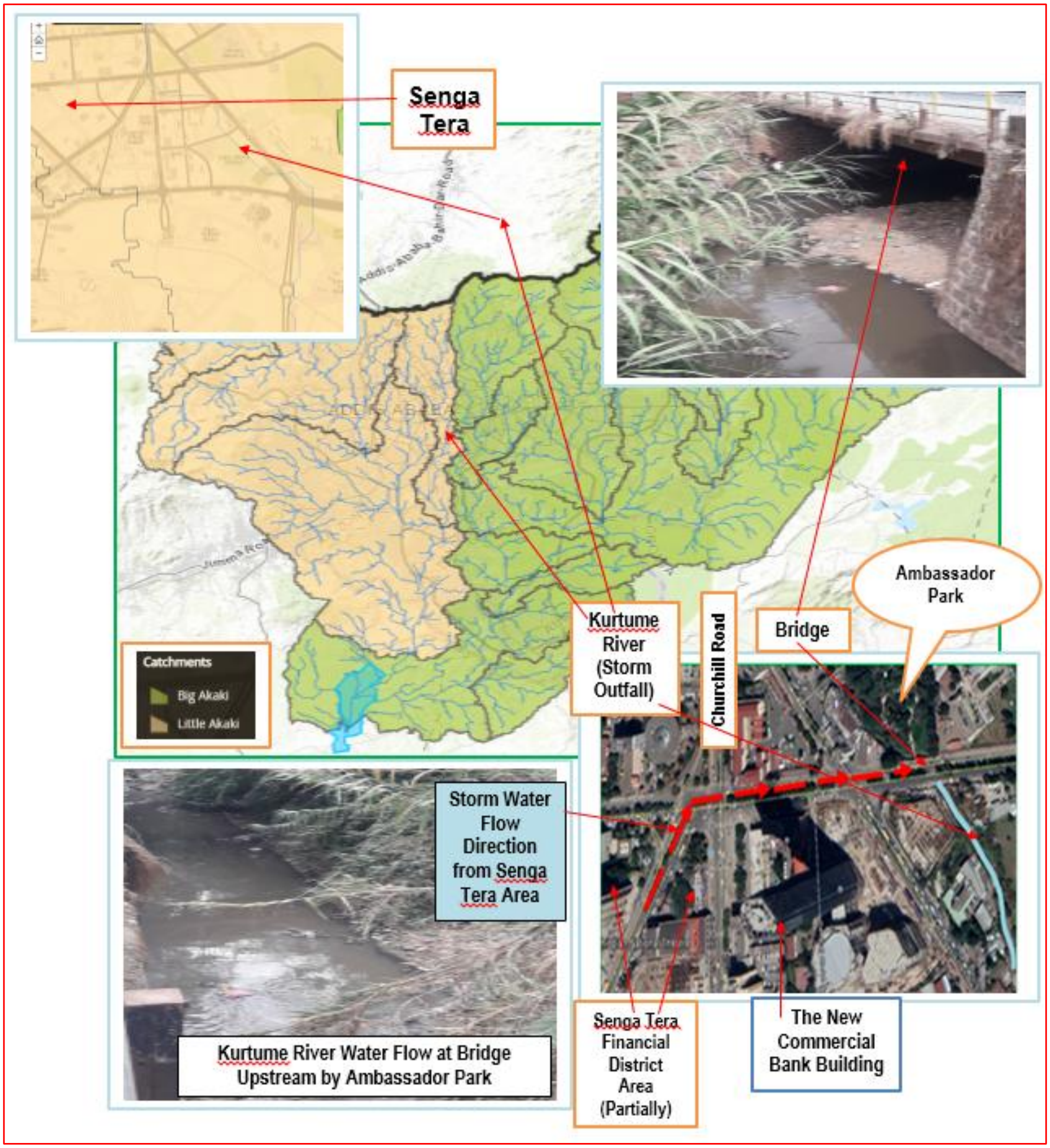
- May be no proper prior study was conducted before trying to connect

Therefore, this kind of actions can results in the discharge of untreated wastewater into the nearby storm water drainage system through cross connection.

However, it needs further field investigations to assess the cause, condition assessments and rehabilitation of the existing sewer system in the area to resolve SSOs and cross connections which is supported by different methods and instruments like CCTV monitoring and others (Philip M. Hanna et.al, 2004).

The extent of direct discharge of industrial wastewater into storm water drainage system and rivers without undergoing through the necessary effluent treatment has been immense. In this regard a survey (AACSP, 2017) undertaken by the AAEPA, indicated that 90% of manufacturing's in the city discharges industrial wastewater into rivers.

Additional study which were conducted by the AAEPA in 2007 and other studies (Benti Firdissa et.al, 2016; Worku Y. et.al, 2018) on selected tanneries, textiles, paint, food and beverage manufacturing's about the quality of effluents which are being discharged into rivers revealed that the BOD, COD and other constituent's quality levels are above the Ethiopian National Standards (Table 6).



Source: By Author

Figure 41: Map relating Senga Tera area with the nearby existing storm sewer and river

5.2.4. Urban Expansion Contribution for Untreated Wastewater Discharge

Housing developments in Tulu Dimtu have been carried out without efficient wastewater management system. The available option for the home owners to manage their wastewater have been to build an individual cesspool by or inside the house. However, based on the Ethiopian plumbing code (EBCS-2013), here is the definition of Cesspool

*“**Cesspool** is covered watertight tank used for receiving and storing sewage from premises which cannot be connected to a public sewer and where ground conditions prevent the use of on-site treatment works including a septic tank”*

Moreover again based on the code, the following is additional requirement for the use of cesspool among others and reads as,

“The site selected for a cesspool should not be so near to any inhabited building as to be liable to become a source of nuisance or a danger to health (a minimum of 15.0m is desirable) and it is essential that not well, stream, river, spring or aquifer likely to be used for drinking or domestic purposes is liable to be polluted”

However, contrary to these and other requirements, cesspools in the selected study areas are not built as a water tight structure. Based on field investigation, it was found that the walls of some of the cesspools are dry masonry wall aiming that the wastewater would infiltrate into the soil and then to drain into storm water drains located at lowest locations. The cesspool layout on site was around 50cm from the walls of the house which is against 15m setback requirement recommended by EBCS-13.

Best practices in developed world is showing that infrastructures like wastewater drainage systems are developed prior to (Sidney O. Dewberry, 2002) the housing construction. This helps developers to rearrange their plumbing systems in order to connect their building sewer or lateral through gravity flow and without any additional manhole at connection point.

In the absence of conventional sewer system it is preferable to plan a non-conventional sewer (Jean –Marie Ily, 2014) system simultaneously when planning housing development.
Moreover, studies conducted (WSP, 2015) to improve on-site sanitation and connections to sewers in South East Asia by the World Bank indicated that some residents in the community may not be even willing to connect their building sewer with a municipal sewer when this sewer system is developed later in the existing housing areas.

Therefore, developing a non- conventional sewer system can be used either to collect wastewater or grey water in order to be treated in decentralized wastewater treatment plant. If the latter is chosen, homeowners can manage the sludge part inside their individual water tight settling tank.

The cost of wastewater treatment process in communal way could also be lower. This practice can minimize or avoid the discharge and recharge of untreated wastewater into surface and ground water respectively (Jean-Marie et.al, 2014).

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Photo: By Author, December 2021

Figure 42: Open storm water ditch by new houses in Tulu Dimtu

Chapter Six

6. Conclusion and Recommendation

6.1. Conclusion

This study was conducted to assess the effects of ineffective wastewater drainage system on quantity of wastewater reaching rivers and treatment plant in Addis Ababa. Two study areas were selected in this regard to see the impacts of rapid land use change in Senga Tera and new housing expansion in Tulu Dimtu. It was found that both types of ongoing activities are contributing the discharge of untreated or partially treated wastewater into the nearby existing storm water drainage systems.

As a result, rivers and creeks which are storm water outfall points in the city have been acting as an open sanitary sewer. Therefore, it is possible to conclude the followings.

1. The existing aged wastewater drainage system in Senga Tera area do not have adequate capacity to carry ultimate wastewater flow rate from the anticipated rapid land use change. On account of that, sanitary sewer overflows can occur through manholes in addition to sewage backups.

2. In addition to sanitary sewer overflows, diverting of wastewater from the existing conventional sewer system into the nearby storm water drainage system in Senga Tera found to be a factor for the discharge of wastewater into rivers.

3. The rate of inflow and infiltration induced by surface run off in the existing sewer system in Senga Tera found to be higher. This higher rate can also contribute the occurrences of more sanitary sewer overflow during wet weather flow. Moreover, it can result in a hydraulic overload of the Kality Wastewater Treatment Plant.

4. It was also revealed that leakage through the walls of cesspools and sewage overflows from cesspools outlets in the expansion areas can also contribute the discharge of wastewater into nearby storm water ditches.

5. The Ethiopian Building Code Standard (EBCS-2013) has not not been efficiently enforced in relation to proper study and design of onsite wastewater treatments facilities. Cesspools are the most common wastewater management facilities in the expansion areas which are being built closer to houses and are not mostly water tight.

6. Grey water can be collected and drained using non-conventional sewer system which comprises of smaller diameter pipes, simplified connection methods and pipes laid at shallow depth from new expansion areas in order to protect the discharge of untreated or

partially treated wastewater into surface and ground water after making sure the walls and floors of all cesspools water tight so that it can act as settling thank for an anaerobic treatment.

6.2. Recommendation

1. Capacity enhancement of the existing sewer in Senga Tera is required in order to safely convey the existing as well future wastewater flow due to rapid land use change in the area. These may include installing parallel relief lines, replacing existing lines with larger ones, and /or using flow equalization basins.

2. The impact of densification in the capacity of existing sewer system in Senga Tera area may go beyond the study area which was delineated for this purpose. There are also many more commercial and real estate developments in La Gare areas. Therefore, it is necessary to update the Kality catchment wastewater drainage master plan.

3. For better operational decisions and optimization of the existing wastewater drainage system, flow calibration and advanced level modeling are necessary. For this purposes, flow measurement devices like par shall flume, weir etc. need to be installed as appropriate at the selected manholes.

   Manual flow rate measurement like I did is not recommended. These measuring devices can give more realistic flow rates during wet and dry weather flows measuring for daily, monthly and yearly. This in turn helps to understand diurnal flow rate patterns for modelling the sewer system using extended period simulation.

4. As-built sewer data's for the existing wastewater drainage system in Senga Tera area are available but it was not complete. These data's includes but not limited to: pipe length and diameter, geographic locations of manholes, manhole top and bottom elevations in addition to AutoCAD layouts of the system.

   However it was found during field research that, there are some more sewer layouts which are either missed in the existing AutoCAD files but found on site or the sewer alignment which is shown on plan versus on field do not match. Therefore, it is recommended to conduct through field investigation and update the as-built data's.

5. The availability of nearby existing municipal sewer system may not guarantee to connect building sewer in to the nearby manhole. It may be necessary to conduct an analysis and modeling to determine whether the size of the existing sewer is adequate or not to receive the proposed flow rate due to rapid land use change.

6. For the efficient operational decision of the existing wastewater drainage system in the city, it is recommended to study and implement the SCADA system. This will enable integrating hydraulic modeling with operational data's so that live modeling or real time modeling can be conducted. This also helps to mitigate sanitary sewer overflows among others.

7. It is recommended to conduct city wide inventory of onsite wastewater treatment facilities (septic tank with and without effluent treatment units, cesspools and others).

   This action helps to identify users involving in a direct discharge of raw sewage into nearby rivers and storm water drainage systems in addition to helping to conduct timely operation and maintenances measures. It is also helps to enforce effluent quality standards discharging into rivers.

8. It is recommended to conduct research by others for the followings;

   - ✓ To determine wastewater peaking factor and, inflow and infiltration in Addis Ababa;
   - ✓ To evaluate the treatment performance of the Kality Wastewater Treatment Plant in relation to the adjusted rate of inflow and infiltration;

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8. Annex

Annex 1: Six months of flow record entered into Kality Wastewater Treatment Plant

Date	Flow (m3/day)	Day
01 February, 2020	47,685	Saturday
02 February, 2020	47,491	Sunday
03 February, 2020	43,376	Monday
04 February, 2020	42,146	Tuesday
05 February, 2020	49,689	Wednesday
06 February, 2020	44,669	Thursday
07 February, 2020	49,740	Friday
08 February, 2020	48,679	Saturday
09 February, 2020	46,816	Sunday
10 February, 2020	46,478	Monday
11 February, 2020	41,589	Tuesday
12 February, 2020	50,771	Wednesday
13 February, 2020	47,522	Thursday
14 February, 2020	41,129	Friday
15 February, 2020	41,271	Saturday
16 February, 2020	50,383	Sunday
17 February, 2020	49,651	Monday
18 February, 2020	46,550	Tuesday
19 February, 2020	42,417	Wednesday
20 February, 2020	43,280	Thursday
21 February, 2020	47,282	Friday
22 February, 2020	49,356	Saturday
23 February, 2020	45,952	Sunday
24 February, 2020	49,417	Monday
25 February, 2020	51,885	Tuesday
26 February, 2020	47,442	Wednesday
27 February, 2020	43,174	Thursday
28 February, 2020	48,530	Friday
29 February, 2020	46,434	Saturday

Date	Flow (m3/day)	Day
01 March, 2020	41,953	Sunday
02 March, 2020	49,131	Monday
03 March, 2020	42,464	Tuesday
04 March, 2020	51,122	Wednesday
05 March, 2020	41,986	Thursday
06 March, 2020	43,810	Friday
07 March, 2020	49,994	Saturday
08 March, 2020	46,309	Sunday
09 March, 2020	46,912	Monday
10 March, 2020	42,014	Tuesday
11 March, 2020	46,063	Wednesday
12 March, 2020	48,627	Thursday
13 March, 2020	48,936	Friday
14 March, 2020	47,925	Saturday
15 March, 2020	41,876	Sunday
16 March, 2020	48,674	Monday
17 March, 2020	49,296	Tuesday
18 March, 2020	41,836	Wednesday
19 March, 2020	47,862	Thursday
20 March, 2020	48,379	Friday
21 March, 2020	46,810	Saturday
22 March, 2020	46,230	Sunday
23 March, 2020	48,329	Monday
24 March, 2020	47,217	Tuesday
25 March, 2020	46,049	Wednesday
26 March, 2020	49,350	Thursday
27 March, 2020	50,619	Friday
28 March, 2020	46,396	Saturday
29 March, 2020	50,120	Sunday
30 March, 2020	43,397	Monday
31 March, 2020	47,544	Tuesday

Date	Flow (m3/day)	Day
01 April, 2020	50,658	Wednesday
02 April, 2020	45,213	Thursday
03 April, 2020	41,931	Friday
04 April, 2020	46,237	Saturday
05 April, 2020	45,169	Sunday
06 April, 2020	50,358	Monday
07 April, 2020	49,384	Tuesday
08 April, 2020	47,281	Wednesday
09 April, 2020	45,360	Thursday
10 April, 2020	44,078	Friday
11 April, 2020	48,405	Saturday
12 April, 2020	48,152	Sunday
13 April, 2020	43,100	Monday
14 April, 2020	51,611	Tuesday
15 April, 2020	42,401	Wednesday
16 April, 2020	49,056	Thursday
17 April, 2020	51,526	Friday
18 April, 2020	42,727	Saturday
19 April, 2020	47,026	Sunday
20 April, 2020	45,719	Monday
21 April, 2020	46,169	Tuesday
22 April, 2020	44,640	Wednesday
23 April, 2020	47,983	Thursday
24 April, 2020	46,337	Friday
25 April, 2020	47,922	Saturday
26 April, 2020	43,338	Sunday
27 April, 2020	50,752	Monday
28 April, 2020	50,923	Tuesday
29 April, 2020	44,573	Wednesday
30 April, 2020	45,680	Thursday

Date	Flow (m3/day)	Day
01 May, 2020	41,249	Friday
02 May, 2020	50,203	Saturday
03 May, 2020	41,217	Sunday
04 May, 2020	50,131	Monday
05 May, 2020	42,568	Tuesday
06 May, 2020	45,658	Wednesday
07 May, 2020	43,694	Thursday
08 May, 2020	44,198	Friday
09 May, 2020	47,793	Saturday
10 May, 2020	50,385	Sunday
11 May, 2020	49,343	Monday
12 May, 2020	44,129	Tuesday
13 May, 2020	50,107	Wednesday
14 May, 2020	46,336	Thursday
15 May, 2020	46,526	Friday
16 May, 2020	50,433	Saturday
17 May, 2020	47,423	Sunday
18 May, 2020	45,560	Monday
19 May, 2020	43,840	Tuesday
20 May, 2020	44,319	Wednesday
21 May, 2020	44,903	Thursday
22 May, 2020	43,776	Friday
23 May, 2020	43,615	Saturday
24 May, 2020	51,163	Sunday
25 May, 2020	41,273	Monday
26 May, 2020	42,126	Tuesday
27 May, 2020	42,103	Wednesday
28 May, 2020	42,193	Thursday
29 May, 2020	43,179	Friday
30 May, 2020	45,397	Saturday
31 May, 2020	44,202	Sunday

Date	Flow (m3/day)	Day
01 June, 2020	50,570	Monday
02 June, 2020	45,106	Tuesday
03 June, 2020	45,796	Wednesday
04 June, 2020	42,431	Thursday
05 June, 2020	43,222	Friday
06 June, 2020	47,697	Saturday
07 June, 2020	50,856	Sunday
08 June, 2020	48,304	Monday
09 June, 2020	44,621	Tuesday
10 June, 2020	73,584	Wednesday
11 June, 2020	47,583	Thursday
12 June, 2020	43,818	Friday
13 June, 2020	41,774	Saturday
14 June, 2020	42,134	Sunday
15 June, 2020	70,008	Monday
16 June, 2020	66,336	Tuesday
17 June, 2020	63,960	Wednesday
18 June, 2020	43,946	Thursday
19 June, 2020	46,242	Friday
20 June, 2020	47,500	Saturday
21 June, 2020	48,847	Sunday
22 June, 2020	45,602	Monday
23 June, 2020	51,697	Tuesday
24 June, 2020	43,102	Wednesday
25 June, 2020	49,201	Thursday
26 June, 2020	41,650	Friday
27 June, 2020	44,115	Saturday
28 June, 2020	50,625	Sunday
29 June, 2020	42,147	Monday
30 June, 2020	41,316	Tuesday

Date	Flow (m3/day)	Day
01 July, 2020	41,249	Wednesday
02 July, 2020	50,203	Thursday
03 July, 2020	41,217	Friday
04 July, 2020	50,131	Saturday
05 July, 2020	42,568	Sunday
06 July, 2020	45,658	Monday
07 July, 2020	43,694	Tuesday
08 July, 2020	44,198	Wednesday
09 July, 2020	47,793	Thursday
10 July, 2020	50,385	Friday
11 July, 2020	49,343	Saturday
12 July, 2020	44,129	Sunday
13 July, 2020	50,107	Monday
14 July, 2020	46,336	Tuesday
15 July, 2020	46,526	Wednesday
16 July, 2020	50,433	Thursday
17 July, 2020	47,423	Friday
18 July, 2020	45,560	Saturday
19 July, 2020	43,840	Sunday
20 July, 2020	44,319	Monday
21 July, 2020	44,903	Tuesday
22 July, 2020	43,776	Wednesday
23 July, 2020	43,615	Thursday
24 July, 2020	51,163	Friday
25 July, 2020	41,273	Saturday
26 July, 2020	42,126	Sunday
27 July, 2020	42,103	Monday
28 July, 2020	42,193	Tuesday
29 July, 2020	43,179	Wednesday
30 July, 2020	45,397	Thursday
31 July, 2020	49,050	Friday

Annex 2: List of measured flow data on field on three different days in a week

	Field flow measurment taken on 5-8-20 at Manhole **12HD14, Internal Dia, = 200mm**																								Remark
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are inlets and outlet pipes
Depth of Flow (in),cm	**7**																								Located by Commercial College
Depth of Flow (Out),cm	**7**																								Receives flow from the 5 apartments too
Depth of Flow at Manhole,m																									This flow is not much as anticipated. Need additional measurment in this manhole

	Field flow measurment taken on 5-8-20 at Manhole **12HD22, Internal Dia, = 200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are three inlet pipes to this manhole
Depth of Flow (in),cm																									Located in front of MUDC
Depth of Flow (Out),cm	**14**																								Receives flow from the MUDC and Teachers Association
Depth of Flow at Manhole,m																									Not receiving flow yet fom the new financial district areas

	Field flow measurment taken on 5-8-20 at Manhole **12HD11, Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are one inlet and an outlet pipe
Depth of Flow (in),cm	**13**																								Located at road turn (around Tel Bar)
Depth of Flow (Out),cm	**13**																								
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 5-8-20 at Manhole **12HD23, Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are Three inlets (Awash Bank, Anti corruption and police station) and an outlet pipe
Depth of Flow (in),cm																									Located at road in between Awash Bank and Anti Corruption Buildings
Depth of Flow (Out),cm	**8**																								
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 5-8-20 space between **12HD10 and 12HD24, Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
Depth of Flow (in),cm																									
Depth of Flow (Out),cm	5																								This manhole is located at parallel road located in between road by Awash bank and road by Tel bar
Depth of Flow at Manhole,m																									This manhole doesn't exist on as-built plan

Note: These were measured on August 5-2020.There was light rain when measurements were taken

	Field flow measurment taken on 8-8-20 at Manhole **12HD14, Internal Dia, = 200mm**																								Remark
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are inlets and outlet pipes
Depth of Flow (in),cm																									Located by Commercial College
Depth of Flow (Out),cm																						8			Length towards next mahole =12m, Flow Time = 28 Sec
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 8-8-20 at Manhole **12HD22, Internal Dia, = 200mm**																								
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					Depth of flow at upper manhole (Before 12HD22) =11cm
																									There are three inlet pipes to this manhole
Depth of Flow (in),cm																									Located in front of MUDC
Depth of Flow (Out),cm																						16			Receives flow from the MUDC and Teachers Association
Depth of Flow at Manhole,m																									Not receiving flow yet fom the new financial district areas and Apartments

	Field flow measurment taken on 8-8-20 at Manhole **12HD11, Internal Dia, =200mm**																								
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are one inlet and an outlet pipe
Depth of Flow (in),cm																									Located at road turn (around Tel Bar)
Depth of Flow (Out),cm																						12			No flow is coming from Commercial college (Now and on previous measurment)
Depth of Flow at Manhole,m																									Length towards next mahole =?m, Flow Time = 59 Sec

	Field flow measurment taken on 8-8-20 at Manhole **12HD23, Internal Dia, =200mm**																								
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									corruption and police station) and an outlet pipe
Depth of Flow (in),cm																									Located at road in between Awash Bank and Anti Corruption Buildings
Depth of Flow (Out),cm																						8			Oromia coopertive Bank is planning to start construction of HQ Buildings inside Police station .
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 8-8-20 at Manhole 12HD28 (space between **12HD10 and 12HD24), Internal Dia, =200mm**																								
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
Depth of Flow (in),cm																									
Depth of Flow (Out),cm																						4			This manhole is located at parallel road located in between road by Awash bank and road by Tel bar
Depth of Flow at Manhole,m																									This manhole doesn't on as-built plan

	Field flow measurment taken on 8-8-20 at Manhole 12HD07																								
	Afternoon						Evening									Night				Morning					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	This manhole is an OUTFALL POINT (D=250mm) for the planned study and
	0 /24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	located across the street from
Peak Flow Times	**12AM**							**6PM**												**6AM**					
Depth of Flow (in),cm																									There are three inlet pipes. Inlet 1(From 12HD28, D=200mm) = 17cm, Inlet 2 (From National Theater, D=200mm) = 17cm
Depth of Flow (Out),cm																						20			
Depth of Flow at Manhole,m																									

Note: These were measured on August 8-2020.There was no rain during measurement but it was wet

	Field flow measurment taken on 10-8-20 at Manhole **12HD14, Internal Dia, = 200mm**																								Remark
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are inlets and outlet pipes
Depth of Flow (in),cm							5																		Located by Commercial College
Depth of Flow (Out),cm							5																		Length towards next mahole =11m, Flow Time = 42 Sec
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 10-8-20 at Manhole **12HD22, Internal Dia, = 200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					Depth of flow at upper manhole (Before 12HD22) =9cm
																									There are three inlet pipes to this manhole
Depth of Flow (in),cm																									Located in front of MUDC
Depth of Flow (Out),cm							9																		Receives flow from the MUDC and Teachers Association
Depth of Flow at Manhole,m																									Not receiving flow yet fom the new financial district areas and Apartments

	Field flow measurment taken on 10-8-20 at Manhole **12HD11, Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are one inlet and an outlet pipe
Depth of Flow (in),cm																									Located at road turn (around Tel Bar)
Depth of Flow (Out),cm							9																		No flow is coming from Commercial college (Now and on previous measurment)
Depth of Flow at Manhole,m																									Length towards next mahole =91m, Flow Time = 1'-4"

	Field flow measurment taken on 10-8-20 at Manhole **12HD23, Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are Three inlets (Awash Bank, Anti corruption and police station) and an outlet pipe
Depth of Flow (in),cm																									Located at road in between Awash Bank and Anti Corruption Buildings
Depth of Flow (Out),cm							4																		Oromia coopertive Bank is planning to start construction of HQ Buildings inside Police station .
Depth of Flow at Manhole,m																									

	Field flow measurment taken on 10-8-20 at Manhole 12HD28 (space between **12HD10 and 12HD24), Internal Dia, =200mm**																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Peak Flow Times	**12AM**							**6PM**												**6AM**					
Depth of Flow (in),cm																									This Manhole is located by Bedelu Building (No flow from Bedelu Building during all meaurments)
Depth of Flow (Out),cm							1																		This manhole is located at parallel road located in between road by Awash bank and road by Tel bar
Depth of Flow at Manhole,m																									This manhole doesn't exist on as-built plan

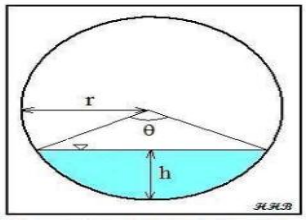
	Field flow measurment taken on 10-8-20 at Manhole 12HD07																								
	Afternoon							**Evening**								**Night**				**Morning**					
	12AM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM	12PM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	
	0/24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	This manhole is an OUTFALL POINT (D=250mm) for the planned study and located across the street from Commercial Bank head office
Peak Flow Times	**12AM**							**6PM**												**6AM**					
																									There are three inlet pipes. Inlet 1(From 12HD28, D=200mm) = 8cm, Inlet 2 (From National Theater, D=200mm) = 10cm
Depth of Flow (in),cm																									
Depth of Flow (Out),cm							12																		
Depth of Flow at Manhole,m																									

Note: These were measured on August 10-2020.There was no rain during measurement but it was wet

Annex 3: Sample calculation of volumetric flow rate from measured depth of flow on field

Less Than Half Full Flow

Manhole
12HD14
Dia =200mm



$$r = \frac{D}{2} \qquad h = y$$

$$\theta = 2 \arccos\left(\frac{r-h}{r}\right)$$

$$A = \frac{r^2(\theta - \sin\theta)}{2}$$

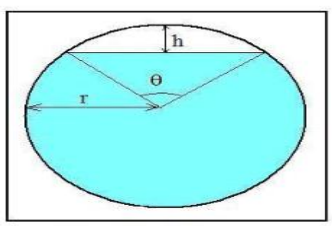
$$P = r\theta$$

$$R_h = A/P$$

Inputs			Calculations		
Pipe Diameter, D=	200	mm	Pipe Diameter, D=	0.2	m
Depth of Flow, y=	50	mm	Pipe Radius, r=D/2	0.1	m
(must have y ≤ D/2)					
			Circ. Segment Height, h=	0.05	m
Manning Roughness, n_{full}	0.009		Central Angle, θ=	2.09	
			(θ in radians)		
Pipe Slope	0.015	m/m	Cross-Sect. Area, A=	0.00614	m^2
			Wetted Perimeter, P=	0.2094	m
			Hydraulic Radius, R_h	**0.0293**	m
y/D	0.25		n/n_{full}= (See Equations)	1.28	
			$n_{partial}$	0.01152	
			Flow Rate, $Q = (1.49/n)A(R_h^{2/3})S^{1/2}$	**0.009144**	m3/s
			Velocity $_{average,}$ $V = Q/A$	**1.49**	m/s

More Than Half Full Flow

Manhole
12HD22
Dia =200mm



$$r = D/2 \qquad h = 2r - y$$

$$\theta = 2 \arccos\left(\frac{r-h}{r}\right)$$

$$A = \pi r^2 - \frac{r^2(\theta - \sin\theta)}{2}$$

$$P = 2\pi r - r\theta$$

$$R_h = A/P$$

Inputs			Calculations		
Pipe Diameter, D=	200	mm	Pipe Diameter, D=	0.2	m
Depth of Flow, y=	140	mm	Pipe Radius, r=D/2	0.1	m
(must have y ≥D/2)					
			Circ. Segment Height, h=	0.06	m
Manning Roughness, n_{full}	0.009		Central Angle, θ=	2.32	
			(θ in radians)		
Pipe Slope	0.024	m/m	Cross-Sect. Area, A=	0.02347	m^2
			Wetted Perimeter, P=	0.3961	m
			Hydraulic Radius, R_h	**0.0593**	m
y/D	0.70		n/n_{full}= (See Equation)	1.35	
			$n_{partial}$	0.01215	
			Flow Rate, $Q = (1.49/n)A(R_h^{2/3})S^{1/2}$	**0.043342**	m3/s
			Velocity $_{average,}$ $V = Q/A$	**1.85**	m/s

Annex 4: Base flow rate estimation for each sub catchment based on ArcGIS water use data

Lideta Sub City

Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA- 1 (2.77 Ha)	**Commercial Development**												
	1. Yobek Commercial Center(Berhane Gidey)	Non-Domestic	1022	892	926	790	1293	556	1293	43.10	0.000499	0.000399	
	2. Sengatera Traders Union S.C.	Non-Domestic	660	710	763	614	638	660	763	25.43	0.000294	0.000235	
											TOTAL	0.00063	**12HD14**

Lideta Sub City

Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA-2 (16.72 Ha)	**Residential Development**												
	40/60 Condominiums (Five Blocks)												
	1. Total for Blocks 1+ 2+ 3+ 4 +5	Domestic (With Shops)	4139	3666	3697	4404	3702	3813	**4404**	146.80	0.001699	0.001359	
											TOTAL	0.001359	**12HD22**
	Commercial Development												
	1. Dashen Bank	Non-Domestic	626	0	217	2661	1087	1246	**2661**	88.70	0.001027	0.000821	
	2. Biftu Adugna / ODDA Building	Non-Domestic	1091	818	849	728	782	1384	**1384**	46.13	0.000534	0.000427	
	3. Zemen Bank Head Quarter	Non-Domestic	400	310	591	428	271	569	**591**	19.70	0.000228	0.000182	
	4. Nib International Bank Head Quarter	Non-Domestic	304	262	300	433	569	632	**632**	21.07	0.000244	0.000195	
	5. Nile Insurance Head Quarter	Non-Domestic	196	200	165	105	112	51	**200**	6.67	0.000077	0.000062	
	6. KK Building	Non-Domestic	16	18	6	15	47	21	**47**	1.57	0.000018	0.000015	
	7. Addis Fana Share Company	Non-Domestic	3	5	5	4	7	9	**9**	0.30	0.000003	0.000003	
	8. Amara Credit and Savings Institutions Head (	Non-Domestic	225	267	259	259	97	1132	**1132**	37.73	0.000437	0.000349	
											TOTAL	0.002054	**12HD22**
	Institutional Development												
	1. Minstry of Health/Blood Bank	Non-Domestic	859	742	678	674	796	1125	**1125**	37.50	0.000434	0.000347	
	2. Minstry of Urban Development and Construction	Non-Domestic	569	99	92	85	638	902	**902**	30.07	0.000348	0.000278	
	3. Federal Urban Land & Land Related Property Registration and Information Agency	Non-Domestic	23	117	519	332	186	427	**519**	17.30	0.000200	0.000160	
	4. Ethiopian Teachers Assosiation(With Cafeteria)	Non-Domestic	61	67	42	34	47	35	**67**	2.23	0.000026	0.000021	
	5. Artistic Printing Press	Non-Domestic	99	88	81	90	98	116	**116**	3.87	0.000045	0.000036	
	6. Minstry of Health(MOH)	Non-Domestic	304	142	198	227	507	271	**507**	16.90	0.000196	0.000156	
	7. OPDO	Non-Domestic	19	27	26	21	21	34	**34**	1.13	0.000013	0.000010	
											TOTAL	0.001009	**12HD22**
											GRAND TOTAL	0.004423	

Kirkos Sub City

Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
(CA- 3A) + (CA-3B) (2.99 Ha)	**Institutional Development**												
	1. Addis Ababa University, School Of Commerce	Non-Domestic	1226	1402	1077	921	945	967	1402	46.73	0.000541	0.000433	
											TOTAL	0.000433	**12HD14**

Kirkos Sub City

Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA- 3C (1.04Ha)	**Institutional Development**												
	1. Mortgage Bank (Construction Bank)	Non-Domestic	173	251	291	164	120	228	**291**	9.70	0.001123	0.000898	
											TOTAL	0.000898	**12HD13**

Kirkos Sub City													
Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA- 4 (4.4 Ha)	**Commercial Development**												
	1. Ethiopian Shipping Lines & Logistics	Non-Domestic	377	402	394	478	574	443	574	19.13	0.002215	0.001772	
	2. Ethiopian Insurance Enterprise(Medin)	Non-Domestic	408	110	69	114	91	95	408	13.60	0.001574	0.001259	
	3. Woizerit Feben Towelde(Building of Abyssinya Bank, Loyal Snack,Maruf Book Store II.)	Non-Domestic	622	722	437	554	511	500	722	24.07	0.002785	0.002228	
	4. Lega Harree NOC	Non-Domestic	116	116	86	84	104	104	116	3.87	0.000448	0.000358	
	5. Ghion Travel & Tour(GTT)	Non-Domestic	96	83	63	60	37	71	96	3.20	0.000370	0.000296	
	6.Maritime & Transit	Non-Domestic	134	204	93	163	204	196	204	6.80	0.000787	0.000630	
	7.Woreda -7 Administration	Non-Domestic	111	183	160	155	182	182	183	6.10	0.000706	0.000565	
	8. Agency For Government Houses	Non-Domestic	261	225	159	239	188	273	273	9.10	0.001053	0.000843	
	9. Kirkos K.K.	Non-Domestic	254	236	209	191	132	234	254	8.47	0.000980	0.000784	
	10. Federal Housing Corporation	Non-Domestic	0	0	0	0	7858	1300	7858	261.93	0.030316	0.024253	
											TOTAL	0.032988	**12HD09**

Kirkos Sub City													
Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Us		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA- 5 (2.12Ha)	**Commercial Development**												
	1. Mezid Plaza Realstate PLC	Non-Domestic	300	277	223	193	212	251	300	10.00	0.001157	0.000926	
	2.Tadesse Mekuria	Non-Domestic	194	183	138	129	124	117	194	6.47	0.000748	0.000599	
	3.Beyene Mered School	Non-Domestic	179	258	85	95	112	109	258	8.60	0.000995	0.000796	
	4.Mohamode Mehayoube	Non-Domestic	132	130	90	86	75	84	132	4.40	0.000509	0.000407	
	5. Housing Adminstration	Non-Domestic	53	46	34	28	18	0	53	1.77	0.000204	0.000164	
											TOTAL	0.002892	**12HD07**

Kirkos Sub City													
Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
(CA- 6A) + (CA-6) (0.93 Ha)	**Commercial Development**												
	1. Grand Legar Hotel (Teklay Haile)	Domestic	569	640	534	527	385	352	640	21.33	0.000247	0.000198	
	2. Bedelu Building (Aba Baye)	Domestic	1221	499	248	254	218	469	1221	40.70	0.000471	0.000377	
											TOTAL	0.00057	**12HD28 /12HD07**

Kirkos Sub City													
Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
(CA- 7A) + (CA-7) (1.43 Ha)	**Commercial Development**												
	1. Awash Bank Head Quarter	Non-Domestic	1344	1217	1065	1133	1286	1306	1344	44.80	0.000519	0.000415	
	2. Federal Ethics and Anti Corruption (EYZMEX General Trading Plc)	Non-Domestic	164	145	0	209	0	360	360	12.00	0.000139	0.000111	
	3. Beherawi Mehandis Construction	Non-Domestic	123	144	105	79	93	107	144	4.80	0.000056	0.000044	
	4. Mulugeta Ayele	Non-Domestic	73	81	0	175	90	100	175	5.83	0.000068	0.000054	
											TOTAL	0.000624	**12HD23**

Kirkos Sub City													
Sub Catchment	Name of Buildings/Institutions	Charge Group	Six Months Customer Water Use (m3/month), Year 2020							Customer Water Use		Sewage Quantity	Flow Receiving Manhole
			Feburary	March	April	May	June	July	Maximum of Six Months	(m3/d)	(m3/s)	(m3/s)	
CA- 8 (3.77Ha)	**Commercial Development**												
	1. National Theater	Non-Domestic	743	656	361	306	231	158	743	24.77	0.000287	0.000229	
	2. Ras Hotel	Domestic	0	1001	1497	611	491	705	1497	49.90	0.000578	0.000462	
	3. A.A.R.H (Located by Hiwot Café and Restaurant)	Domestic	539	361	120	90	96	115	539	17.97	0.000208	0.000166	
	4. Mekonen H/slassie (Located by Ras Hotel)	Non-Domestic	401	295	275	286	261	268	401	13.37	0.000155	0.000124	
	5. Shell Ethiopia	Non-Domestic	421	301	164	250	29	7	421	14.03	0.000162	0.000130	
	6. Housing Adminstration (Located by Shell Ethiopia)	Non-Domestic	115	127	102	107	107	118	127	4.23	0.000049	0.000039	
	7. Afrotsion Construction	Non-Domestic	0	0	0	1013	102	60	1013	33.77	0.000391	0.000313	
											TOTAL	0.001463	**12HD18**

Annex 5: Analysis and modeling results of base flow rate based on water use data

Pipe Table

Label	Start Node	Stop Node	Length (User Defined) (m)	Invert (Start) (m)	Invert (Stop) (m)	Slope (%)	Velocity (m/s)	Internal Diameter (mm)	Manning's n	Design Percent Full (%)	Flow (Calculated) (L/s)	Capacity (Design) (L/s)	Capacity (Full Flow) (L/s)	Flow / Capacity (Design) (%)	Infiltration Load Type
CO-1	12HD22	12HD21	84.9	2,348.52	2,346.48	2.4	1.2	200	0.01	80	4.42	64.6	66.09	6.8	None
CO-2	12HD21	12HD20	84.9	2,346.48	2,346.18	0.35	0.61	200	0.01	80	4.42	24.77	25.35	17.8	None
CO-3	12HD20	12HD19	76.2	2,346.18	2,345.77	0.54	0.7	200	0.01	80	4.42	30.57	31.28	14.5	None
CO-4	12HD19	12HD18	109.5	2,345.77	2,344.41	1.24	0.95	200	0.01	80	4.42	46.45	47.52	9.5	None
CO-5	12HD18	12HD07	58.6	2,344.41	2,343.85	0.96	0.97	200	0.01	80	6.51	40.74	41.68	16	None
CO-6	12HD14	12HD13	121.7	2,353.92	2,352.09	1.5	0.56	200	0.01	80	0.63	51.11	52.28	1.2	None
CO-7	12HD13	12HD12	76.4	2,352.09	2,351.20	1.16	0.68	200	0.01	80	1.53	44.98	46.02	3.4	None
CO-8	12HD12	12HD11	66.8	2,351.20	2,350.00	1.8	0.79	200	0.01	80	1.53	55.86	57.15	2.7	None
CO-9	12HD11	12HD10	81	2,350.00	2,348.31	2.09	0.89	200	0.01	80	1.96	60.2	61.59	3.3	None
CO-10	12HD10	12HD09	78.9	2,348.31	2,345.70	3.31	1.05	200	0.01	80	1.96	75.8	77.55	2.6	None
CO-11	12HD09	12HD08	117.6	2,345.70	2,344.48	1.04	1.56	250	0.01	80	34.95	76.97	78.74	45.4	None
CO-12	12HD08	12HD07	95.9	2,344.48	2,343.85	0.66	1.31	250	0.01	80	34.95	61.25	62.66	57.1	None
CO-13	12HD24	12HD23	77.2	2,348.10	2,346.34	2.28	0.43	200	0.01	80	0.16	62.93	64.38	0.3	None
CO-14	12HD23	12HD18	113.3	2,346.34	2,344.41	1.7	0.59	200	0.01	80	0.63	54.39	55.64	1.2	None
CO-15	12HD07	12HD06 / OUTFALL-1	72	2,343.85	2,342.91	1.31	1.8	300	0.01	80	44.92	140.4	143.64	32	None

Manhole Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Elevation (Invert in 1) (m)	Elevation (Invert in 2) (m)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Surcharged?	Is Ever Surcharged?	Flow (Total In) (L/s)	Flow (Total Out) (L/s)	Flow (System Sanitary) (L/s)	Flow (System Total Wet Weather)	Depth (Structure) (m)
12HD22	2,351.04	2,348.52			2,348.58	2,348.58	FALSE	FALSE	0	4.42	4.42	0	2.52
12HD21	2,349.03	2,346.48	2,346.48		2,346.54	2,346.54	FALSE	FALSE	4.42	4.42	4.42	0	2.55
12HD20	2,348.30	2,346.18	2,346.18		2,346.24	2,346.24	FALSE	FALSE	4.42	4.42	4.42	0	2.12
12HD19	2,347.75	2,345.77	2,345.77		2,345.83	2,345.83	FALSE	FALSE	4.42	4.42	4.42	0	1.98
12HD18	2,346.80	2,344.41	2,344.41	2,344.41	2,344.48	2,344.48	FALSE	FALSE	5.05	6.51	6.51	0	2.39
12HD14	2,356.47	2,353.92			2,353.94	2,353.94	FALSE	FALSE	0	0.63	0.63	0	2.55
12HD13	2,355.41	2,352.09	2,352.09		2,352.12	2,352.12	FALSE	FALSE	0.63	1.53	1.53	0	3.32
12HD12	2,353.67	2,351.20	2,351.20		2,351.23	2,351.23	FALSE	FALSE	1.53	1.53	1.53	0	2.47
12HD11	2,352.66	2,350.00	2,350.00		2,350.04	2,350.04	FALSE	FALSE	1.53	1.96	1.96	0	2.66
12HD10	2,350.25	2,348.31	2,348.31		2,348.35	2,348.35	FALSE	FALSE	1.96	1.96	1.96	0	1.94
12HD09	2,348.28	2,345.70	2,345.70		2,345.85	2,345.85	FALSE	FALSE	1.96	34.95	34.95	0	2.58
12HD08	2,347.02	2,344.48	2,344.48		2,344.63	2,344.63	FALSE	FALSE	34.95	34.95	34.95	0	2.54
12HD24	2,350.66	2,348.10			2,348.11	2,348.11	FALSE	FALSE	0	0.16	0.16	0	2.56
12HD23	2,348.77	2,346.34	2,346.34		2,346.36	2,346.36	FALSE	FALSE	0.16	0.63	0.63	0	2.43
12HD07	2,346.48	2,343.85	2,343.85	2,343.85	2,344.01	2,344.01	FALSE	FALSE	41.46	44.92	44.92	0	2.63

Outfall Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Hydraulic Grade (m)	Flow (Total Out) (L/s)	Boundary Condition Type	Elevation (Invert in 1) (m)	Flow (System Sanitary) (L/s)	Flow (System Total Wet Weather) (L/s)	Depth (Structure) (m)
12HD06 / OUTFALL-1	2,345.07	2,342.91	2,343.03	44.92	Free Outfall	2,342.91	44.92	0	2.16

Annex 6: Analysis and modeling results of measured flow rate with flow diversion

Pipe Table

Label	Start Node	Stop Node	Length (User Defined) (m)	Invert (Start) (m)	Invert (Stop) (m)	Slope (%)	Velocity (m/s)	Internal Diameter (mm)	Manning's n	Design Percent Full (%)	Flow (Calculated) (L/s)	Capacity (Design) (L/s)	Capacity (Full Flow) (L/s)	Flow / Capacity (Design) (%)	Diversion Type	Diversion rating curve	Diversion rating curve <Count>	Is Diversion Link?	Cutoff Flow (L/s)
CO-1	12HD22	12HD21	84.9	2,348.52	2,346.48	2.4	2.23	200	0.01	80	42.1	64.6	66.09	65.2	Cutoff	<Collection: 1 item>	1	TRUE	15.59
CO-2	12HD21	12HD20	84.9	2,346.48	2,346.18	0.35	1.34	200	0.01	80	42.1	24.77	25.35	169.9					
CO-3	12HD20	12HD19	76.2	2,346.18	2,345.77	0.54	1.34	200	0.01	80	42.1	30.57	31.28	137.7					
CO-4	12HD19	12HD18	109.5	2,345.77	2,344.41	1.24	1.34	200	0.01	80	42.1	46.45	47.52	90.6					
CO-5	12HD18	12HD07	58.6	2,344.41	2,343.85	0.96	1.47	200	0.01	80	46.04	40.74	41.68	113					
CO-6	12HD14	12HD13	121.7	2,353.92	2,352.09	1.5	1.47	200	0.01	80	16.15	51.11	52.28	31.6					
CO-7	12HD13	12HD12	76.4	2,352.09	2,351.20	1.16	1.5	200	0.01	80	25.47	44.98	46.02	56.6					
CO-8	12HD12	12HD11	66.8	2,351.20	2,350.00	1.8	1.77	200	0.01	80	25.47	55.86	57.15	45.6					
CO-9	12HD11	12HD10	81	2,350.00	2,348.31	2.09	2.04	200	0.01	80	35.96	60.2	61.59	59.7					
CO-10	12HD10	12HD09	78.9	2,348.31	2,345.70	3.31	2.42	200	0.01	80	35.96	75.8	77.55	47.4					
CO-11	12HD09	12HD08	117.6	2,345.70	2,344.48	1.04	1.78	250	0.01	80	87.27	76.97	78.74	113.4					
CO-12	12HD08	12HD07	95.9	2,344.48	2,343.85	0.66	1.78	250	0.01	80	87.27	61.25	62.66	142.5					
CO-13	12HD24	12HD23	77.2	2,348.10	2,346.34	2.28	0.51	200	0.01	80	0.27	62.93	64.38	0.4					
CO-14	12HD23	12HD18	113.3	2,346.34	2,344.41	1.7	0.73	200	0.01	80	1.3	54.39	55.64	2.4					
CO-15	12HD07	12HD06 / MAIN OUTFALL-1	72	2,343.85	2,342.91	1.31	2.37	300	0.01	80	167.57	140.4	143.64	119.4					
CO-16	12HD22	OUTFALL-2 _ FLOW DIVERSION	5	2,348.52	2,348.47	1	1.03	200	0.01	80	15.59	32.06	32.8	48.6					

Manhole Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Elevation (Invert in 1) (m)	Elevation (Invert in 2) (m)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Overflowing?	Is Ever Overflowing?	Is Surcharged?	Is Ever Surcharged?	Sanitary Loads <Count>	Flow (Total In) (L/s)	Flow (Total Out) (L/s)	Flow (System Sanitary) (L/s)	(System Total Wet Weather) (L/s)	Depth (Structure) (m)
12HD22	2,351.04	2,348.52	2,348.52		2,348.63	2,348.63	FALSE	FALSE	FALSE	FALSE	1	0	57.69	15.59	0	2.52
12HD21	2,349.03	2,346.48	2,346.48		2,347.80	2,347.80	FALSE	FALSE	TRUE	TRUE	0	42.1	42.1	42.1	0	2.55
12HD20	2,348.30	2,346.18	2,346.18		2,346.98	2,346.98	FALSE	FALSE	TRUE	TRUE	0	42.1	42.1	42.1	0	2.12
12HD19	2,347.75	2,345.77	2,345.77		2,346.23	2,346.23	FALSE	FALSE	TRUE	TRUE	0	42.1	42.1	42.1	0	1.98
12HD18	2,346.80	2,344.41	2,344.41	2,344.41	2,345.17	2,345.17	FALSE	FALSE	TRUE	TRUE	1	43.4	46.04	46.04	0	2.39
12HD14	2,356.47	2,353.92			2,354.03	2,354.03	FALSE	FALSE	FALSE	FALSE	1	0	16.15	16.15	0	2.55
12HD13	2,355.41	2,352.09	2,352.09		2,352.23	2,352.23	FALSE	FALSE	FALSE	FALSE	1	16.15	25.47	25.47	0	3.32
12HD12	2,353.67	2,351.20	2,351.20		2,351.34	2,351.34	FALSE	FALSE	FALSE	FALSE	0	25.47	25.47	25.47	0	2.47
12HD11	2,352.66	2,350.00	2,350.00		2,350.16	2,350.16	FALSE	FALSE	FALSE	FALSE	1	25.47	35.96	35.96	0	2.66
12HD10	2,350.25	2,348.31	2,348.31		2,348.47	2,348.47	FALSE	FALSE	FALSE	FALSE	0	35.96	35.96	35.96	0	1.94
12HD09	2,348.28	2,345.70	2,345.70		2,347.20	2,347.20	FALSE	FALSE	TRUE	TRUE	1	35.96	87.27	87.27	0	2.58
12HD08	2,347.02	2,344.48	2,344.48		2,345.71	2,345.71	FALSE	FALSE	TRUE	TRUE	0	87.27	87.27	87.27	0	2.54
12HD24	2,350.66	2,348.10			2,348.11	2,348.11	FALSE	FALSE	FALSE	FALSE	1	0	0.27	0.27	0	2.56
12HD23	2,348.77	2,346.34	2,346.34		2,346.37	2,346.37	FALSE	FALSE	FALSE	FALSE	1	0.27	1.3	1.3	0	2.43
12HD07	2,346.48	2,343.85	2,343.85	2,343.85	2,344.48	2,344.48	FALSE	FALSE	TRUE	TRUE	1	133.31	167.57	167.57	0	2.63

Outfall Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Hydraulic Grade (m)	Flow (Total Out) (L/s)	Boundary Condition Type	Elevation (Invert in 1) (m)	Depth (Structure) (m)	Flow (System Sanitary) (L/s)	Flow (System Total Wet Weather) (L/s)	Depth (Structure) (m)
12HD06 / MAIN OUTFALL-1	2,345.07	2,342.91	2,343.20	167.57	Free Outfall	2,342.91	2.16	167.57	0	2.16
OUTFALL-2 / FLOW DIVERSION	2,350.50	2,348.47	2,348.57	15.59	Free Outfall	2,348.47	2.03	15.59	0	2.03

Annex 7: Analysis and modeling results of measured flow rate without flow diversion

Pipe Table

Label	Start Node	Stop Node	Length (User Defined) (m)	Invert (Start) (m)	Invert (Stop) (m)	Slope (%)	Velocity (m/s)	Internal Diameter (mm)	Manning's n	Design Percent Full (%)	Flow (Calculated) (L/s)	Capacity (Design) (L/s)	Capacity (Full Flow) (L/s)	Flow / Capacity (Design) (%)	Is Diversion Link?
CO-1	12HD22	12HD21	84.9	2,348.52	2,346.48	2.4	1.84	200	0.01	80	57.69	64.6	66.09	89.3	FALSE
CO-2	12HD21	12HD20	84.9	2,346.48	2,346.18	0.35	1.84	200	0.01	80	57.69	24.77	25.35	232.9	FALSE
CO-3	12HD20	12HD19	76.2	2,346.18	2,345.77	0.54	1.84	200	0.01	80	57.69	30.57	31.28	188.7	FALSE
CO-4	12HD19	12HD18	109.5	2,345.77	2,344.41	1.24	1.84	200	0.01	80	57.69	46.45	47.52	124.2	FALSE
CO-5	12HD18	12HD07	58.6	2,344.41	2,343.85	0.96	1.96	200	0.01	80	61.63	40.74	41.68	151.3	FALSE
CO-6	12HD14	12HD13	121.7	2,353.92	2,352.09	1.5	1.47	200	0.01	80	16.15	51.11	52.28	31.6	FALSE
CO-7	12HD13	12HD12	76.4	2,352.09	2,351.20	1.16	1.5	200	0.01	80	25.47	44.98	46.02	56.6	FALSE
CO-8	12HD12	12HD11	66.8	2,351.20	2,350.00	1.8	1.77	200	0.01	80	25.47	55.86	57.15	45.6	FALSE
CO-9	12HD11	12HD10	81	2,350.00	2,348.31	2.09	2.04	200	0.01	80	35.96	60.2	61.59	59.7	FALSE
CO-10	12HD10	12HD09	78.9	2,348.31	2,345.70	3.31	2.42	200	0.01	80	35.96	75.8	77.55	47.4	FALSE
CO-11	12HD09	12HD08	117.6	2,345.70	2,344.48	1.04	1.78	250	0.01	80	87.27	76.97	78.74	113.4	FALSE
CO-12	12HD08	12HD07	95.9	2,344.48	2,343.85	0.66	1.78	250	0.01	80	87.27	61.25	62.66	142.5	FALSE
CO-13	12HD24	12HD23	77.2	2,348.10	2,346.34	2.28	0.51	200	0.01	80	0.27	62.93	64.38	0.4	FALSE
CO-14	12HD23	12HD18	113.3	2,346.34	2,344.41	1.7	0.73	200	0.01	80	1.3	54.39	55.64	2.4	FALSE
CO-15	12HD07	MAIN OUTFALL	72	2,343.85	2,342.91	1.31	2.59	300	0.01	80	183.16	140.4	143.64	130.5	FALSE

Manhole Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Elevation (Invert in 1) (m)	Elevation (Invert in 2) (m)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Overflowing?	Is Ever Overflowing?	Is Surcharged?	Is Ever Surcharged?	Sanitary Loads <Count>	Flow (Known) (L/s)	Flow (System Sanitary) (L/s)	Flow (Total In) (L/s)	Flow (Non-Diverted Out) (L/s)	Depth (Structure) (m)
12HD22	2,351.04	2,348.52			2,350.58	2,350.58	FALSE	FALSE	TRUE	TRUE	1	15.59	42.1	0	57.69	2.52
12HD21	2,349.03	2,346.48	2,346.48		2,349.03	2,349.03	TRUE	TRUE	TRUE	TRUE	0		42.1	57.69	57.69	2.55
12HD20	2,348.30	2,346.18	2,346.18		2,348.30	2,348.30	TRUE	TRUE	TRUE	TRUE	0		42.1	57.69	57.69	2.12
12HD19	2,347.75	2,345.77	2,345.77		2,347.75	2,347.75	TRUE	TRUE	TRUE	TRUE	0		42.1	57.69	57.69	1.98
12HD18	2,346.80	2,344.41	2,344.41	2,344.41	2,345.96	2,345.96	FALSE	FALSE	TRUE	TRUE	1		46.04	58.99	61.63	2.39
12HD14	2,356.47	2,353.92			2,354.03	2,354.03	FALSE	FALSE	FALSE	FALSE	1		16.15	0	16.15	2.55
12HD13	2,355.41	2,352.09	2,352.09		2,352.23	2,352.23	FALSE	FALSE	FALSE	FALSE	1		25.47	16.15	25.47	3.32
12HD12	2,353.67	2,351.20	2,351.20		2,351.34	2,351.34	FALSE	FALSE	FALSE	FALSE	0		25.47	25.47	25.47	2.47
12HD11	2,352.66	2,350.00	2,350.00		2,350.16	2,350.16	FALSE	FALSE	FALSE	FALSE	1		35.96	25.47	35.96	2.66
12HD10	2,350.25	2,348.31	2,348.31		2,348.47	2,348.47	FALSE	FALSE	FALSE	FALSE	0		35.96	35.96	35.96	1.94
12HD09	2,348.28	2,345.70	2,345.70		2,347.46	2,347.46	FALSE	FALSE	TRUE	TRUE	1		87.27	35.96	87.27	2.58
12HD08	2,347.02	2,344.48	2,344.48		2,345.96	2,345.96	FALSE	FALSE	TRUE	TRUE	0		87.27	87.27	87.27	2.54
12HD24	2,350.66	2,348.10			2,348.11	2,348.11	FALSE	FALSE	FALSE	FALSE	1		0.27	0	0.27	2.56
12HD23	2,348.77	2,346.34	2,346.34		2,346.37	2,346.37	FALSE	FALSE	FALSE	FALSE	1		1.3	0.27	1.3	2.43
12HD07	2,346.48	2,343.85	2,343.85	2,343.85	2,344.73	2,344.73	FALSE	FALSE	TRUE	TRUE	1		167.57	148.9	183.16	2.63

Outfall Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Hydraulic Grade (m)	Flow (Total Out) (L/s)	Boundary Condition Type	Elevation (Invert in 1) (m)	Depth (Structure) (m)	Flow (System Sanitary) (L/s)	Flow (System Total Wet Weather) (L/s)
12HD06 / OUTFALL-1	2,345.07	2,342.91	2,343.20	183.16	Free Outfall	2,342.91	2.16	167.57	0

Annex 8: Analysis and modeling results for the ultimate flow due to land use change

(Base flow rate + Future flow rate due to new land use + measured Inflow/Infiltration)

Pipe Table

Label	Start Node	Stop Node	Length (User Defined) (m)	Invert (Start) (m)	Invert (Stop) (m)	Slope (%)	Velocity (m/s)	Internal Diameter (mm)	Manning's n	Design Percent Full (%)	Flow (Calculated) (L/s)	Capacity (Design) (L/s)	Capacity (Full Flow) (L/s)	Flow / Capacity (Design) (%)	Infiltration Load Type
CO-1	12HD22	12HD21	84.9	2,348.52	2,346.48	2.4	4.72	200	0.01	80	148.25	64.6	66.09	229.5	None
CO-2	12HD21	12HD20	84.9	2,346.48	2,346.18	0.35	4.72	200	0.01	80	148.25	24.77	25.35	598.4	None
CO-3	12HD20	12HD19	76.2	2,346.18	2,345.77	0.54	4.72	200	0.01	80	148.25	30.57	31.28	484.9	None
CO-4	12HD19	12HD18	109.5	2,345.77	2,344.41	1.24	4.72	200	0.01	80	148.25	46.45	47.52	319.2	None
CO-5	12HD18	12HD07	58.6	2,344.41	2,343.85	0.96	5.79	200	0.01	80	182.01	40.74	41.68	446.7	None
CO-6	12HD14	12HD13	121.7	2,353.92	2,352.09	1.5	1.77	200	0.01	80	34.21	51.11	52.28	66.9	None
CO-7	12HD13	12HD12	76.4	2,352.09	2,351.20	1.16	1.44	200	0.01	80	45.32	44.98	46.02	100.7	None
CO-8	12HD12	12HD11	66.8	2,351.20	2,350.00	1.8	1.44	200	0.01	80	45.32	55.86	57.15	81.1	None
CO-9	12HD11	12HD10	81	2,350.00	2,348.31	2.09	1.8	200	0.01	80	56.68	60.2	61.59	94.2	None
CO-10	12HD10	12HD09	78.9	2,348.31	2,345.70	3.31	1.8	200	0.01	80	56.68	75.8	77.55	74.8	None
CO-11	12HD09	12HD08	117.6	2,345.70	2,344.48	1.04	3.6	250	0.01	80	176.48	76.97	78.74	229.3	None
CO-12	12HD08	12HD07	95.9	2,344.48	2,343.85	0.66	3.6	250	0.01	80	176.48	61.25	62.66	288.1	None
CO-13	12HD24	12HD23	77.2	2,348.10	2,346.34	2.28	0.63	200	0.01	80	0.58	62.93	64.38	0.9	None
CO-14	12HD23	12HD18	113.3	2,346.34	2,344.41	1.7	0.12	200	0.01	80	3.86	54.39	55.64	7.1	None
CO-15	12HD07	12HD06 / MAIN OUTFALL-1	72	2,343.85	2,342.91	1.31	5.67	300	0.01	80	401.14	140.4	143.64	285.7	None

Manhole Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Elevation (Invert in 1) (m)	Elevation (Invert in 2) (m)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Is Overflowing?	Is Ever Overflowing?	Is Surcharged?	Is Ever Surcharged?	Sanitary Loads <Count>	Flow (Total In) (L/s)	Flow (Total Out) (L/s)	Inflow (Wet) Collection <Count>	(System Total Wet Weather) (L/s)	Flow (System Sanitary) (L/s)	Depth (Structure) (m)
12HD22	2,351.04	2,348.52			2,351.04	2,351.04	TRUE	TRUE	TRUE	TRUE	1	0	148.25	1	37.68	110.57	2.52
12HD21	2,349.03	2,346.48	2,346.48		2,349.03	2,349.03	TRUE	TRUE	TRUE	TRUE	0	148.25	148.25	0	37.68	110.57	2.55
12HD20	2,348.30	2,346.18	2,346.18		2,348.30	2,348.30	TRUE	TRUE	TRUE	TRUE	0	148.25	148.25	0	37.68	110.57	2.12
12HD19	2,347.75	2,345.77	2,345.77		2,347.75	2,347.75	TRUE	TRUE	TRUE	TRUE	0	148.25	148.25	0	37.68	110.57	1.98
12HD18	2,346.80	2,344.41	2,344.41	2,344.41	2,346.80	2,346.80	TRUE	TRUE	TRUE	TRUE	1	152.11	182.01	1	39.53	142.48	2.39
12HD14	2,356.47	2,353.92			2,354.08	2,354.08	FALSE	FALSE	FALSE	FALSE	1	0	34.21	1	15.52	18.69	2.55
12HD13	2,355.41	2,352.09	2,352.09		2,352.72	2,352.72	FALSE	FALSE	TRUE	TRUE	1	34.21	45.32	1	23.94	21.38	3.32
12HD12	2,353.67	2,351.20	2,351.20		2,351.86	2,351.86	FALSE	FALSE	TRUE	TRUE	0	45.32	45.32	0	23.94	21.38	2.47
12HD11	2,352.66	2,350.00	2,350.00		2,351.11	2,351.11	FALSE	FALSE	TRUE	TRUE	1	45.32	56.68	1	34	22.68	2.66
12HD10	2,350.25	2,348.31	2,348.31		2,349.67	2,349.67	FALSE	FALSE	TRUE	TRUE	0	56.68	56.68	0	34	22.68	1.94
12HD09	2,348.28	2,345.70	2,345.70		2,348.28	2,348.28	TRUE	TRUE	TRUE	TRUE	1	56.68	176.48	1	52.32	124.16	2.58
12HD08	2,347.02	2,344.48	2,344.48		2,347.02	2,347.02	TRUE	TRUE	TRUE	TRUE	0	176.48	176.48	0	52.32	124.16	2.54
12HD24	2,350.66	2,348.10			2,348.12	2,348.12	FALSE	FALSE	FALSE	FALSE	1	0	0.58	1	0.11	0.47	2.56
12HD23	2,348.77	2,346.34	2,346.34		2,346.81	2,346.81	FALSE	FALSE	TRUE	TRUE	1	0.58	3.86	1	0.67	3.19	2.43
12HD07	2,346.48	2,343.85	2,343.85	2,343.85	2,346.48	2,346.48	TRUE	TRUE	TRUE	TRUE	1	358.49	401.14	1	122.65	278.49	2.63

Outfall Table

Label	Top Elevation (Existing) (m)	Elevation (Invert) (m)	Hydraulic Grade (m)	Flow (Total Out) (L/s)	Boundary Condition Type	Elevation (Invert in 1) (m)	Depth (Structure) (m)	Flow (System Sanitary) (L/s)	Flow (System Total Wet Weather) (L/s)
12HD06 / MAIN OUTFALL-1	2,345.07	2,342.91	2,343.21	401.14	Free Outfall	2,342.91	2.16	278.49	122.65

Annex 9: Analysis and modeling results of non-conventional sewer system in the study area in Tulu Dimtu

Pipe Table

Label	Start Node	Stop Node	Length (Scaled) (m)	Invert (Start) (m)	Invert (Stop) (m)	Slope (Calculated) (%)	Manning ,n	Design Percent Full	Material	Diameter (mm)	Velocity (m/s)	Flow (L/h)	Capacity (Design) (L/h)	Capacity (Full Flow) (L/h)	Flow / Capacity (Design) (%)	Infiltration Load Type	Infiltration Loading Unit	Infiltration Rate per Loading Unit (L/h)
CO-1	MH-1	MH-2	26.7	2,138.25	2,136.50	6.6	0.01	80	PVC	150	0.6	450	178,465.60	182,579.70	0.3	Link Length	km	0.4
CO-2	MH-2	MH-3	7.5	2,136.50	2,136.23	3.6	0.01	80	PVC	150	0.6	900	132,070.30	135,114.90	0.7	Link Length	km	0.4
CO-3	MH-3	MH-4	26.8	2,136.23	2,135.58	2.4	0.01	80	PVC	150	0.6	1,350.00	108,691.60	111,197.20	1.2	Link Length	km	0.4
CO-4	MH-4	MH-5	5	2,135.58	2,135.48	2	0.01	80	PVC	150	0.61	1,800.00	97,525.40	99,773.60	1.8	Link Length	km	0.4
CO-5	MH-5	MH-6	26.7	2,135.48	2,135.05	1.6	0.01	80	PVC	150	0.6	2,250.00	88,224.90	90,258.70	2.6	Link Length	km	0.4
CO-6	MH-6	MH-7	7	2,135.05	2,134.96	1.4	0.01	80	PVC	150	0.6	2,700.00	81,302.20	83,176.40	3.3	Link Length	km	0.4
CO-7	MH-7	MH-8	27.3	2,134.96	2,134.63	1.2	0.01	80	PVC	150	0.6	3,150.10	76,638.30	78,405.00	4.1	Link Length	km	0.4
CO-8	MH-8	MH-9	15.6	2,134.63	2,134.25	2.4	0.01	80	PVC	150	0.8	3,600.10	108,253.50	110,749.10	3.3	Link Length	km	0.4
CO-9	MH-9	MH-10	66.8	2,134.25	2,133.15	1.6	0.01	80	PVC	150	0.75	4,500.10	89,433.70	91,495.40	5	Link Length	km	0.4
CO-10	MH-10	MH-11	60	2,133.15	2,132.00	1.9	0.01	80	PVC	150	0.78	4,500.10	96,450.50	98,673.90	4.7	Link Length	km	0.4
CO-11	MH-11	MH-12	80	2,132.00	2,130.40	2	0.01	80	PVC	150	0.8	4,500.10	98,525.00	100,796.20	4.6	Link Length	km	0.4
CO-12	MH-12	MH-13	80	2,130.40	2,127.95	3.1	0.01	80	PVC	150	0.93	4,500.20	121,918.40	124,728.90	3.7	Link Length	km	0.4
CO-13	MH-13	MH-14	80	2,127.95	2,121.85	7.6	0.01	80	PVC	150	1.27	4,500.20	192,369.60	196,804.20	2.3	Link Length	km	0.4
CO-14	MH-14	MH-15	67	2,121.85	2,118.40	5.1	0.01	80	PVC	150	1.6	15,300.40	158,076.20	161,720.30	9.7	Link Length	km	0.4
CO-15	MH-15	OUTFALL	22.4	2,118.40	2,116.35	9.2	0.01	80	PVC	150	2.27	25,200.70	210,859.60	215,720.50	12	Link Length	km	0.4
CO-16	MH-16	MH-17	26.7	2,137.45	2,135.70	6.6	0.01	80	PVC	150	0.6	450	178,465.60	182,579.70	0.3	Link Length	km	0.4
CO-17	MH-17	MH-18	8	2,135.70	2,135.41	3.6	0.01	80	PVC	150	0.6	900	132,070.30	135,114.90	0.7	Link Length	km	0.4
CO-18	MH-18	MH-19	26.7	2,135.41	2,134.76	2.4	0.01	80	PVC	150	0.6	1,350.00	108,691.60	111,197.20	1.2	Link Length	km	0.4
CO-19	MH-19	MH-20	7.7	2,134.76	2,134.64	1.6	0.01	80	PVC	150	0.6	2,250.00	88,224.90	90,258.70	2.6	Link Length	km	0.4
CO-20	MH-21	MH-22	7	2,134.28	2,134.20	1.1	0.01	80	PVC	150	0.6	3,600.00	72,122.30	73,784.90	5	Link Length	km	0.4
CO-20A	MH-20	MH-21	26.7	2,134.64	2,134.28	1.4	0.01	80	PVC	150	0.6	2,700.00	81,302.20	83,176.40	3.3	Link Length	km	0.4
CO-21	MH-22	MH-23	26.7	2,134.20	2,133.94	1	0.01	80	PVC	150	0.6	4,050.10	68,628.00	70,210.00	5.9	Link Length	km	0.4
CO-22	MH-23	MH-24	7.7	2,133.94	2,133.88	0.8	0.01	80	PVC	150	0.6	4,950.10	63,267.90	64,726.40	7.8	Link Length	km	0.4
CO-23	MH-24	MH-25	26.7	2,133.88	2,133.68	0.8	0.01	80	PVC	150	0.6	5,400.10	60,896.80	62,300.60	8.9	Link Length	km	0.4
CO-24	MH-25	MH-26	6.9	2,133.68	2,133.63	0.7	0.01	80	PVC	150	0.6	6,300.10	57,099.80	58,416.10	11	Link Length	km	0.4
CO-25	MH-26	MH-27	26.7	2,133.63	2,133.35	1	0.01	80	PVC	150	0.72	6,750.10	71,355.90	73,000.80	9.5	Link Length	km	0.4
CO-26	MH-27	MH-28	5.8	2,133.35	2,133.25	1.7	0.01	80	PVC	150	0.87	7,200.10	91,657.60	93,770.50	7.9	Link Length	km	0.4
CO-27	MH-28	MH-29	26.7	2,133.25	2,132.85	1.5	0.01	80	PVC	150	0.84	7,650.10	85,334.10	87,301.30	9	Link Length	km	0.4
CO-28	MH-29	MH-30	7.2	2,132.85	2,132.75	1.4	0.01	80	PVC	150	0.84	8,100.10	82,277.50	84,174.20	9.8	Link Length	km	0.4
CO-29	MH-30	MH-31	26.7	2,132.75	2,132.25	1.9	0.01	80	PVC	150	0.94	8,550.10	95,406.50	97,605.80	9	Link Length	km	0.4
CO-30	MH-31	MH-32	29	2,132.25	2,131.45	2.8	0.01	80	PVC	150	1.1	9,000.10	115,761.10	118,429.70	7.8	Link Length	km	0.4
CO-31	MH-32	MH-33	50	2,131.45	2,129.45	4	0.01	80	PVC	150	1.25	9,000.10	139,335.30	142,547.40	6.5	Link Length	km	0.4
CO-32	MH-33	MH-34	53.3	2,129.45	2,128.05	2.6	0.01	80	PVC	150	1.08	9,000.20	112,920.90	115,524.00	8	Link Length	km	0.4
CO-33	MH-34	MH-14	87.7	2,126.68	2,121.85	5.5	0.01	80	PVC	150	1.48	10,800.20	163,520.50	167,290.00	6.6	Link Length	km	0.4
CO-34	MH-35	MH-34	52	2,128.55	2,126.68	3.6	0.01	80	PVC	150	0.6	900	132,070.30	135,114.90	0.7	Link Length	km	0.4
CO-35	MH-36	MH-37	23.7	2,131.45	2,129.90	6.6	0.01	80	PVC	150	0.6	450	178,466.60	182,580.80	0.3	Link Length	km	0.4
CO-36	MH-37	MH-38	10	2,129.90	2,129.54	3.6	0.01	80	PVC	150	0.6	900	132,070.30	135,114.90	0.7	Link Length	km	0.4
CO-37	MH-38	MH-39	23.7	2,129.54	2,128.96	2.4	0.01	80	PVC	150	0.6	1,350.00	108,691.60	111,197.20	1.2	Link Length	km	0.4
CO-38	MH-39	MH-40	10.7	2,128.96	2,128.75	2	0.01	80	PVC	150	0.61	1,800.00	97,525.40	99,773.60	1.8	Link Length	km	0.4
CO-39	MH-40	MH-41	23.7	2,128.75	2,128.37	1.6	0.01	80	PVC	150	0.6	2,250.00	88,224.90	90,258.70	2.6	Link Length	km	0.4
CO-40	MH-41	MH-42	10	2,128.37	2,128.24	1.4	0.01	80	PVC	150	0.6	2,700.00	81,302.20	83,176.40	3.3	Link Length	km	0.4
CO-41	MH-42	MH-43	23.7	2,128.24	2,127.95	1.2	0.01	80	PVC	150	0.6	3,150.10	76,741.00	78,510.10	4.1	Link Length	km	0.4
CO-42	MH-43	MH-44	10.7	2,127.95	2,127.60	3.3	0.01	80	PVC	150	0.89	3,600.10	126,107.60	129,014.70	2.9	Link Length	km	0.4
CO-43	MH-44	MH-45	23.7	2,127.60	2,126.85	3.2	0.01	80	PVC	150	0.91	4,050.10	124,037.60	126,897.00	3.3	Link Length	km	0.4
CO-44	MH-45	MH-46	10	2,126.85	2,126.65	2	0.01	80	PVC	150	0.8	4,500.10	98,524.70	100,795.90	4.6	Link Length	km	0.4
CO-45	MH-46	MH-47	23.7	2,126.65	2,125.80	3.6	0.01	80	PVC	150	1.01	4,950.10	132,048.10	135,092.10	3.7	Link Length	km	0.4
CO-46	MH-47	MH-48	10.7	2,125.80	2,125.25	5.1	0.01	80	PVC	150	1.18	5,400.10	158,097.80	161,742.30	3.4	Link Length	km	0.4
CO-47	MH-48	MH-49	23.7	2,125.25	2,123.45	7.6	0.01	80	PVC	150	1.38	5,850.10	192,158.20	196,587.90	3	Link Length	km	0.4
CO-48	MH-49	MH-15	54.1	2,123.45	2,118.40	9.3	0.01	80	PVC	150	1.51	6,300.10	212,854.20	217,761.00	3	Link Length	km	0.4
CO-49	MH-50	MH-51	68	2,129.55	2,127.11	3.6	0.01	80	PVC	150	0.6	900	132,070.30	135,114.90	0.7	Link Length	km	0.4
CO-50	MH-51	MH-52	68	2,127.11	2,125.50	2.4	0.01	80	PVC	150	0.64	1,800.10	107,074.00	109,542.30	1.7	Link Length	km	0.4
CO-51	MH-52	MH-53	68	2,125.50	2,121.35	6.1	0.01	80	PVC	150	1.01	2,700.10	172,107.50	176,075.10	1.6	Link Length	km	0.4
CO-52	MH-53	MH-15	43.6	2,121.35	2,118.40	6.8	0.01	80	PVC	150	1.14	3,600.10	181,193.20	185,370.20	2	Link Length	km	0.4

Manhole Table

Label	Elevation (Ground) (m)	Elevation (Manhole Bottom) (m)	Elevation (Invert in 1) (m)	Elevation (Invert in 2) (m)	Elevation (Invert in 3) (m)	Hydraulic Grade Line (In) (m)	Hydraulic Grade Line (Out) (m)	Sanitary Loads	Sanitary Loads <Count>	Flow (Total In) (L/h)	Flow (Total Out) (L/h)	Is Ever Surcharged?	Is Surcharged?	Depth (Structure) (m)
MH-1	2,139.90	2,138.25				2,138.26	2,138.26	<Collection: 1 item>	1	0	450	FALSE	FALSE	1.65
MH-2	2,139.50	2,136.50	2,136.50			2,136.51	2,136.51	<Collection: 1 item>	1	450	900	FALSE	FALSE	3
MH-3	2,139.50	2,136.23	2,136.23			2,136.25	2,136.25	<Collection: 1 item>	1	900	1,350.00	FALSE	FALSE	3.27
MH-4	2,138.85	2,135.58	2,135.58			2,135.60	2,135.60	<Collection: 1 item>	1	1,350.00	1,800.00	FALSE	FALSE	3.27
MH-5	2,138.80	2,135.48	2,135.48			2,135.50	2,135.50	<Collection: 1 item>	1	1,800.00	2,250.00	FALSE	FALSE	3.32
MH-6	2,137.75	2,135.05	2,135.05			2,135.08	2,135.08	<Collection: 1 item>	1	2,250.00	2,700.00	FALSE	FALSE	2.7
MH-7	2,137.60	2,134.96	2,134.96			2,134.98	2,134.98	<Collection: 1 item>	1	2,700.00	3,150.00	FALSE	FALSE	2.64
MH-8	2,136.45	2,134.63	2,134.63			2,134.65	2,134.65	<Collection: 1 item>	1	3,150.10	3,600.10	FALSE	FALSE	1.82
MH-9	2,135.90	2,134.25	2,134.25			2,134.28	2,134.28	<Collection: 1 item>	1	3,600.10	4,500.10	FALSE	FALSE	1.65
MH-10	2,134.80	2,133.15	2,133.15			2,133.18	2,133.18	<Collection: 0 items>	0	4,500.10	4,500.10	FALSE	FALSE	1.65
MH-11	2,133.65	2,132.00	2,132.00			2,132.03	2,132.03	<Collection: 0 items>	0	4,500.10	4,500.10	FALSE	FALSE	1.65
MH-12	2,132.05	2,130.40	2,130.40			2,130.43	2,130.43	<Collection: 0 items>	0	4,500.10	4,500.10	FALSE	FALSE	1.65
MH-13	2,129.60	2,127.95	2,127.95			2,127.98	2,127.98	<Collection: 0 items>	0	4,500.20	4,500.20	FALSE	FALSE	1.65
MH-14	2,123.50	2,121.85	2,121.85	2,121.85		2,121.91	2,121.91	<Collection: 0 items>	0	15,300.40	15,300.40	FALSE	FALSE	1.65
MH-15	2,120.05	2,118.40	2,118.40	2,118.40	2,118.40	2,118.48	2,118.48	<Collection: 0 items>	0	25,200.70	25,200.70	FALSE	FALSE	1.65
MH-16	2,139.10	2,137.45				2,137.46	2,137.46	<Collection: 1 item>	1	0	450	FALSE	FALSE	1.65
MH-17	2,137.65	2,135.70	2,135.70			2,135.71	2,135.71	<Collection: 1 item>	1	450	900	FALSE	FALSE	1.95
MH-18	2,137.45	2,135.41	2,135.41			2,135.43	2,135.43	<Collection: 1 item>	1	900	1,350.00	FALSE	FALSE	2.04
MH-19	2,137.80	2,134.76	2,134.76			2,134.79	2,134.79	<Collection: 1 item>	1	1,350.00	2,250.00	FALSE	FALSE	3.04
MH-20	2,137.70	2,134.64	2,134.64			2,134.66	2,134.66	<Collection: 1 item>	1	2,250.00	2,700.00	FALSE	FALSE	3.06
MH-21	2,137.30	2,134.28	2,134.28			2,134.31	2,134.31	<Collection: 1 item>	1	2,700.00	3,600.00	FALSE	FALSE	3.02
MH-22	2,137.40	2,134.20	2,134.20			2,134.23	2,134.23	<Collection: 1 item>	1	3,600.00	4,050.00	FALSE	FALSE	3.2
MH-23	2,136.90	2,133.94	2,133.94			2,133.98	2,133.98	<Collection: 1 item>	1	4,050.10	4,950.10	FALSE	FALSE	2.96
MH-24	2,136.70	2,133.88	2,133.88			2,133.91	2,133.91	<Collection: 1 item>	1	4,950.10	5,400.10	FALSE	FALSE	2.82
MH-25	2,135.90	2,133.68	2,133.68			2,133.71	2,133.71	<Collection: 1 item>	1	5,400.10	6,300.10	FALSE	FALSE	2.22
MH-26	2,135.70	2,133.63	2,133.63			2,133.67	2,133.67	<Collection: 1 item>	1	6,300.10	6,750.10	FALSE	FALSE	2.07
MH-27	2,135.00	2,133.35	2,133.35			2,133.39	2,133.39	<Collection: 1 item>	1	6,750.10	7,200.10	FALSE	FALSE	1.65
MH-28	2,134.90	2,133.25	2,133.25			2,133.29	2,133.29	<Collection: 1 item>	1	7,200.10	7,650.10	FALSE	FALSE	1.65
MH-29	2,134.50	2,132.85	2,132.85			2,132.89	2,132.89	<Collection: 1 item>	1	7,650.10	8,100.10	FALSE	FALSE	1.65
MH-30	2,134.40	2,132.75	2,132.75			2,132.79	2,132.79	<Collection: 1 item>	1	8,100.10	8,550.10	FALSE	FALSE	1.65
MH-31	2,133.90	2,132.25	2,132.25			2,132.29	2,132.29	<Collection: 1 item>	1	8,550.10	9,000.10	FALSE	FALSE	1.65
MH-32	2,133.10	2,131.45	2,131.45			2,131.49	2,131.49	<Collection: 0 items>	0	9,000.10	9,000.10	FALSE	FALSE	1.65
MH-33	2,131.10	2,129.45	2,129.45			2,129.49	2,129.49	<Collection: 0 items>	0	9,000.10	9,000.10	FALSE	FALSE	1.65
MH-34	2,129.70	2,126.68	2,128.05	2,126.68		2,126.73	2,126.73	<Collection: 1 item>	1	9,900.20	10,800.20	FALSE	FALSE	3.02
MH-35	2,130.20	2,128.55				2,128.56	2,128.56	<Collection: 1 item>	1	0	900	FALSE	FALSE	1.65
MH-36	2,133.10	2,131.45				2,131.46	2,131.46	<Collection: 1 item>	1	0	450	FALSE	FALSE	1.65
MH-37	2,132.55	2,129.90	2,129.90			2,129.91	2,129.91	<Collection: 1 item>	1	450	900	FALSE	FALSE	2.65
MH-38	2,132.15	2,129.54	2,129.54			2,129.55	2,129.55	<Collection: 1 item>	1	900	1,350.00	FALSE	FALSE	2.61
MH-39	2,131.30	2,128.96	2,128.96			2,128.98	2,128.98	<Collection: 1 item>	1	1,350.00	1,800.00	FALSE	FALSE	2.34
MH-40	2,131.15	2,128.75	2,128.75			2,128.77	2,128.77	<Collection: 1 item>	1	1,800.00	2,250.00	FALSE	FALSE	2.4
MH-41	2,130.70	2,128.37	2,128.37			2,128.40	2,128.40	<Collection: 1 item>	1	2,250.00	2,700.00	FALSE	FALSE	2.33
MH-42	2,130.15	2,128.24	2,128.24			2,128.26	2,128.26	<Collection: 1 item>	1	2,700.00	3,150.00	FALSE	FALSE	1.91
MH-43	2,129.60	2,127.95	2,127.95			2,127.98	2,127.98	<Collection: 1 item>	1	3,150.10	3,600.10	FALSE	FALSE	1.65
MH-44	2,129.25	2,127.60	2,127.60			2,127.63	2,127.63	<Collection: 1 item>	1	3,600.10	4,050.10	FALSE	FALSE	1.65
MH-45	2,128.50	2,126.85	2,126.85			2,126.88	2,126.88	<Collection: 1 item>	1	4,050.10	4,500.10	FALSE	FALSE	1.65
MH-46	2,128.30	2,126.65	2,126.65			2,126.68	2,126.68	<Collection: 1 item>	1	4,500.10	4,950.10	FALSE	FALSE	1.65
MH-47	2,127.45	2,125.80	2,125.80			2,125.83	2,125.83	<Collection: 1 item>	1	4,950.10	5,400.10	FALSE	FALSE	1.65
MH-48	2,126.90	2,125.25	2,125.25			2,125.29	2,125.29	<Collection: 1 item>	1	5,400.10	5,850.10	FALSE	FALSE	1.65
MH-49	2,125.10	2,123.45	2,123.45			2,123.49	2,123.49	<Collection: 1 item>	1	5,850.10	6,300.10	FALSE	FALSE	1.65
MH-50	2,131.20	2,129.55				2,129.56	2,129.56	<Collection: 1 item>	1	0	900	FALSE	FALSE	1.65
MH-51	2,129.20	2,127.11	2,127.11			2,127.13	2,127.13	<Collection: 1 item>	1	900	1,800.00	FALSE	FALSE	2.09
MH-52	2,127.15	2,125.50	2,125.50			2,125.52	2,125.52	<Collection: 1 item>	1	1,800.10	2,700.10	FALSE	FALSE	1.65
MH-53	2,123.00	2,121.35	2,121.35			2,121.38	2,121.38	<Collection: 1 item>	1	2,700.10	3,600.10	FALSE	FALSE	1.65

Outfall Table

Label	Elevation (Ground) (m)	Elevation (Invert) (m)	Elevation (Invert in 1) (m)	Boundary Condition Type	Hydraulic Grade (m)	Flow (System Sanitary) (m^3/h)	Flow (System Total Wet Weather) (L/h)	Flow (Total Out) (L/h)	Depth (Structure) (m)
OUTFALL	2,118.00	2,116.35	2,116.35	Free Outfall	2,116.35	25200	0.7	25,200.70	1.65