THE STATUS AND EXTENT OF DE FACTO WATER REUSE IN SOUTH AFRICA

CD Swartz, C Lourens, J Robbertse and SJC Slabbert

WATER RESEARCH COMMISSION

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THE STATUS AND EXTENT OF DE FACTO WATER REUSE IN SOUTH AFRICA

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

SCOPE OF THE PROJECT

De facto reuse is occurring on a widespread basis throughout South Africa. The compounding effect of partially treated or untreated wastewater into many of the major rivers and dams in the country is resulting in these water sources being used as intake water to drinking water treatment plants, many of which are not able to remove the micro-pollutants before the treated water is distributed to the communities. This leads to an increasing risk of negative health impact and possible outbreak of diseases. As a first step to addressing this serious problem, it is imperative that the extent and impact of such unintended (de facto) reuse be quantified. This will allow further decision-making and policy development, in line with the Department of Water Affairs and Forestry (DWAF) (now the Department of Water and Sanitation (DWS)) National Strategy for Water Reuse (2011).

As a result of the health implications of the rapidly growing occurrence of de facto reuse, it had become a high priority to quantify the extent of de facto reuse in South Africa. This would allow a necessary knowledge base for remedial actions to be established. Such a study would also help water resource planners and public health agencies understand the extent and importance of de facto water reuse. The study would also allow the assessment of how available treatment technologies compare in terms of treatment performance, and what the limitations and challenges of current technologies are.

AIMS AND OBJECTIVES

The overall objective of the project was to quantify the national extent of de facto water reuse in the country. This was done by determining the percentage wastewater content of the raw water sources (rivers and dams) supplying the major cities and large towns, as well as the concentrations of micro-pollutants found in the wastewater discharges, in the rivers, and at water treatment plant abstraction points.

APPROACH AND METHODOLOGY

The approach that was followed to determine the status and extent of de facto reuse in South Africa consisted of identifying all wastewater treatment plants in the country as well as the rivers or streams they discharge to, and to represent it on a Geographical Information System (GIS) map. Ten rivers known or suspected to contain high percentages of wastewater were selected for further investigation in this project. These ten rivers are:

Berg River	Sundays River
Breede River	Crocodile River
Buffalo River	Olifants River
Modder River	Upper Vaal River
Umgeni/Duzi River	Middle Vaal River

Wastewater treatment plants discharging to these river systems, and water treatment plants abstracting water from the rivers for treatment to potable water standard, were identified, along with measuring stations in the rivers. These facilities were then represented on GIS maps.

Using the river flows at the measuring stations (as obtained from DWS) and wastewater treatment plant capacities, volumetric calculations were done to determine the percentage of wastewater at the measuring stations and at the water treatment plant abstraction points. Based on the calculated wastewater percentages, a classification of the river quality in terms of wastewater percentage was then developed, which will predict whether the downstream water treatment plants would be treating water containing 50% or more wastewater (which is considered to be the level implying that the water treatment plant will effectively constitute a reuse plant (reclamation plant)).

Samples were subsequently taken at these points in all ten of the rivers and analysed for a number of selected chemicals of emerging concern (CECs) (micro-pollutants). The CECs analysed for were selected to represent priority indicators and markers from pharmaceuticals, natural compounds, pesticides, recreational drugs, and industrial chemicals. The results of this sampling were used to determine impacted river hotspots and de facto reuse drinking water treatment plants, based on the concentrations of the identified indicator compounds.

All the results of the above characterisations of the ten rivers were then imported on an interactive GIS mapping system.

KEY FINDINGS

The results of the research answered a number of research questions regarding the status and extent of de facto reuse in South Africa, most notably:

- Insight on the extent of de facto reuse in the country.
- Knowledge on the impact of municipal wastewater to potable water supply.
- A methodology was established for future monitoring and management of de facto reuse.
- Information on the occurrence of CECs in South African wastewater effluents and surface waters.

As expected, it was also found that wastewater percentage contributions are highest during low flow seasons and in tributaries where the base flow is low. Therefore, wastewater percentage contributions are highly dependent on streamflow and size of the rivers.

Results of the occurrence of CECs in wastewater effluent and surface waters revealed that CEC concentrations are highest in wastewater effluents, and that concentrations are diluted when entering the surface waters. CEC concentrations have a higher impact on rivers where the urban population and wastewater infrastructure capacity increases. Water treatment plants show reduction but not complete removal of CECs.

CONCLUSIONS AND RECOMMENDATIONS

A number of recommendations can be made on the gaps and challenges regarding future regulation of de facto reuse in South Africa, namely:

- There is a need to model wastewater content and de facto reuse in South African rivers, taking all types of discharge into account (and very specifically from unsewered informal settlements) as well as withdrawals from the rivers.
- The model should consider mass loadings in determining the impact of wastewater discharge on rivers and drinking water supply.
- The model should include persistent and biodegradable CECs to facilitate the prediction and estimation of CECs prior to drinking water treatment plants.
- Additional future research should be directed at one case study to account for all point and non-point sources discharging to the river and capture all special and temporal variations resulting from these discharges.
- There is a need to adopt the methodology developed in this study as part of the national water resource monitoring programs.
- CECs should be incorporated in the Department of Water and Sanitation’s water quality database and data dissemination platforms.
- Further development of the GIS mapping system to assist in the development of national water quality monitoring programs and regulations on effluent and drinking water quality.

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CAPACITY BUILDING / COMPETENCE DEVELOPMENT

In striving towards of capacity building for the project theme and related engineering skills, a MEng (Process Engineering) student was given the opportunity to participate in the project. The project provided the student with a platform to obtain specialist knowledge in the field of river modelling, with an emphasis on river hydrology and pollution modelling within rivers. The student will be able to apply the knowledge and skills gained in his studies for future projects working toward quantifying wastewater pollutants in surface water source. The student studied the hydrological modelling of pollutants in rivers by determining the effect of major point and non-point sources, which included municipal wastewater treatment plants and diffuse pollution from informal settlements, on the quality of river water and downstream drinking water treatment plants.

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ACRONYMS AND ABBREVIATIONS

ARV	Antiretroviral
AS	Activated Sludge
Ave (or Avg)	Average
AWWA	American Water Works Association
BEH	Bridged Ethyl Hybrid
BOD	Biological Oxygen Demand
CDR	Crocodile West River
CEC	Chemical of Emerging Concern
CNS	Central Nervous System
COD	Chemical Oxygen Demand
CSIR	Council of Scientific and Industrial Research
DEET	N-N-diethyl-m-toluamide
DFR	De Facto Reuse
DWS	Department of Water and Sanitation
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DPR	Direct Potable Reuse
DRINCS	De Facto Reuse in our Nation's Consumable Supply (model)
DWTP	Drinking Water Treatment Plants
E. coli	*Escherichia coli*
EC	Electrical Conductivity
EDC	Endocrine-Disrupting Compound
EPA	Environmental Protection Agency
EU	European Union
GAC	Granular Activated Carbon
GC	Gas Chromatograph
GIS	Geographic Information System
GPS	Global Positioning System
HPLC	High Performance Liquid Chromatography
IQL	Indifference Quality Level
IRIS	Integrated Regulatory Information System
IS	Internal Standard
LC	Liquid chromatography
LSM	Living Standard Measure
MAD	Mean Annual Discharge
Max	Maximum
MBR	Membrane Biological Reactor
MDL	Method Detection Limit
MDMA	3,4-methylenedioxy-methamphetamine
Min	Minimum

MMAD	Mean Minimum Annual Discharge
MPAF	Mean Predictive Accuracy Factor
MRM	Multiple Reaction Monitoring
MS	Mass Spectroscopy
NF	Nanofiltration
NIWIS	National Integrated Water Information System
NOM	Natural Organic Matter
NSAID	Nonsteroidal Anti-Inflammatory Drug
PAC	Powder Activated Carbon
PET	Polyethylene Terephthalate
PhAC	Pharmaceutically Active Compound
PI	Proximity Index
PPCP	Pharmaceuticals and Personal Care Product
RO	Reverse Osmosis
RQIS	Resource Quality Information Service
SK	Relative Skewness
SU	Stellenbosch University
TCEP	Tris (2-carboxyethyl) phosphine
TCPP	Tri Chlor Propyl Phosphate
TDB	Treatability Database
TQ-MS	Triple Quadrupole Mass Spectrometer
UF	Ultrafiltration
UPLC	Ultra-Performance Liquid Chromatograph
USA	United States of America
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
UV	Ultraviolet
WHO	World Health Organisation
WQI	Water Quality Index
WRC	Water Research Commission
WRP	Water Reclamation Plant
WSA	Water Supply Authorities
WSP	Water Service Providers
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

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CHAPTER 1: INTRODUCTION

1.1 CONTEXTUALIZATION

The quality of drinking water sources is rapidly deteriorating on a global scale, largely due to overloaded wastewater treatment systems, industrial discharge and unsewered informal settlements. The situation is exacerbated during times of drought, when a large portion of river flow consist of wastewater (when the base flow is low). Studies in the USA have shown that in some prominent river systems the contribution of wastewater in the river flow can be as high as 100% (Rice, 2014). This situation is even worse in South Africa where drought conditions and increasing frequency of localised droughts have led to a drastic increase in deterioration of water quality in rivers and dams due to a high wastewater content.

A large number of water supply authorities (WSAs) and water service providers (WSPs) are dependent on these polluted water sources for drinking water supply to the communities and industry that they serve (e.g. Midvaal, Dusi River, Olifants River, Vaalkop Dam, etc.). The drinking treatment plants that were originally provided for drinking water production were not designed to treat poor quality water and consisted of conventional water treatment processes. As the raw water quality deteriorated, provision was made to add new or modify existing treatment processes, but this was only done on a project-by-project basis, and only at the larger water treatment plants, resulting in a high risk for pollutants (in particular micro-pollutants) to pass through the treatment plants and have a health impact on the communities. This problem already exists at present, and it is suspected that it may have a negative impact on the end-users (health impact as well as aesthetical impact, e.g. taste and odour problems associated with algal blooms). The most important is, however, the health impact.

These plants are now considered to be de facto reuse plants because they in fact reuse wastewater that is discharged to rivers and dams and then abstracted downstream for potable use. De facto reuse is defined as the unplanned or incidental presence of treated wastewater in a water supply source (see Section 2.1). This implies that the process configurations for treatment plants treating these waters should also include advanced treatment technologies to ensure removal of all unwanted pollutants from the incoming water.

1.2 AIMS AND OBJECTIVES

It has become a high priority to quantify the extent of de facto reuse in South Africa. The overall objective of the project was to study de facto reuse, which will ensure that the national extent, health impact and economic impact of this current situation be researched and documented. This would provide the necessary knowledge base for remedial actions to be undertaken. Such a study would help water resource planners and public health agencies understand the extent and importance of de facto water reuse. The study will also allow the assessment of how available treatment technologies compare in terms of treatment performance, and what the limitations and challenges of current technologies are.

The project therefore had three main aims, namely:

a. To quantify the extent and status of de facto reuse in the country
b. To develop a methodology for future monitoring and management of de facto reuse
c. To establish a baseline of public knowledge on water reuse in South Africa.

1.3 SCOPE

Several studies have suggested the use of anthropogenic organic compounds as chemical markers (indicators) of municipal wastewater due to their loading and persistent behaviour, *e.g.* caffeine, carbamazepine, sulfamethoxazole, and sucralose (Oppenheimer et al., 2011). The percentage wastewater in the raw water intake will be determined during the sampling campaigns using a suitable chemical marker that will be selected. The wastewater content in the inflow to the water treatment plant will be mapped on a GIS-system compatible with that of the Resource Quality Information System (RQIS).

The sampling campaigns will also be undertaken for raw water characterization and to determine the treatment plants' removal capability of the bulk organic parameters, nutrients, and trace organics (micro-pollutants), including 8 CECs that were detected from the priority list that was drawn up in WRC Project K5/2369 (Swartz et al., 2018).

A public acceptance and awareness study will be undertaken as part of the project aims in cities or towns served by de facto reuse in four case studies to determine what the perception of the general public is regarding acceptance and occurrence of using water containing wastewater (i.e. de facto reuse). An important output from this study is the extent to which higher public awareness of de facto reuse (knowledge) is correlated with higher acceptance. If, indeed, increased knowledge means increased acceptance, then the information on occurrence of de facto reuse can be used to improve the negative perceptions (by improving their knowledge of this aspect of water supply). For this purpose, the project team will develop multimedia educational materials on de facto reuse.

1.4 LIMITATIONS

There were a number of limitations in carrying out the research and reporting on the results:

a. GPS coordinates for all the water treatment plants in the country could not be obtained.
b. Only WWTP discharges (point sources) were considered in the wastewater percentage calculations.
c. Wastewater effluent contributions were estimated using the design capacity of the WWTP; however, WWTPs do not necessarily operate at design capacity and its final effluent flows may also fluctuate.
d. Only discharges to the raw water sources were considered in the calculations and not withdrawals as well.
e. The effect of dams located within the rivers were not considered in the calculations of the wastewater percentages.
f. Only one sampling campaign was undertaken, therefore spatial and temporal variations in the occurrence of CECs in wastewater effluent and surface waters was not taken into consideration.
g. Grab samples were used for the analysis; therefore, the presented data only provide some insight into the occurrence of CECs in wastewater effluents and surface water samples, and not a complete analysis of the variations in effluent discharges.

CHAPTER 2: LITERATURE REVIEW

2.1 DE FACTO WATER REUSE: TERMINOLOGY AND DEFINITIONS

Literally, de facto reuse is a term used to describe a situation where wastewater is unintentionally reused for some beneficial purpose. The term is used to distinguish between other situations where wastewater is intentionally reused for beneficial purposes, primarily for non-potable purposes. But generally, and in the case of this project report, the term de facto reuse refers to one or both of the following situations (National Rerearch Council, 2012).

- where secondary treated wastewater from one town or city enters an environment from where another town or city abstracts its raw water for treatment at a conventional water treatment works (WTP)
- where untreated wastewater from an informal settlement enters an environment from where another town or city abstracts its raw water for treatment at a conventional WTP

The most common environment associated with de facto reuse is river systems although it is not impossible for groundwater aquifers and surface lakes or dams to also be involved (MED-EUWI, 2007). De facto reuse is an inherent health risk, since in most cases the receiving WTP was not designed to remove the pollutants that will be present in the reuse water (National Rerearch Council, 2012)

Since de facto reuse is so undesirable, it is commonly assumed that it only occurs in rural areas and in countries where safe drinking water is not a high priority, but this is a faulty assumption. In fact, it is possible that urban areas and first world countries also experience de facto reuse. This is partly due to population growth (MED-EUWI, 2007)(Mediterranean Wastewater Reuse Working Group). Originally a source may have been considered pristine since the portion of wastewater in the sources was small (negligible), but as the population grew, the volume of wastewater discharged increased. The amount of clean (unpolluted) water in the source did not necessarily increase proportionately, hence a situation that used to be safe, could become unsafe over time. This is largely due to the growth in population and the associated increase in wastewater being discharged to the environment (treated or untreated).

In addition to population growth, the health risk of de facto reuse is also seasonal since catchment areas receive less water during low flow (dry) seasons. During these periods, the portion of wastewater in the river is higher and therefore pose a larger health risk (Swayne et al., 1980).

In Table 2.1 a summary is provided of the most important terminology and definitions relating to water reclamation and reuse (MED-EUWI, 2007).

Table 2.1: Abbreviated list of terms and definitions in water reclamation and reuse (from (MED-EUWI, 2007))

Name	Definition
De facto reuse	The unplanned or incidental reuse of treated wastewater discharged into a surface body which after dilution is abstracted downstream for beneficial reuse or treatment to potable quality
Direct reuse	The beneficial use of appropriate treated wastewater without interim storage in a surface water body or aquifer. The conversion of wastewater directly into recycled water, irrigation water, process water or cooling water without any interim storage
Direct potable reuse (Australian national guidelines)	The introduction of highly treated reclaimed water either directly into the potable water supply distribution system downstream of a water treatment plant, or into the raw water supply immediately upstream of a water treatment plant. Only justifiable when there is no choice such as in Windhoek Namibia or outer space
Environmental buffer	An environmental buffer may consist of a stretch of river, a water supply reservoir, or a soil aquifer system to which recycled water is added. The need for an environmental buffer is an important component of risk management.
Indirect reuse	The beneficial use of appropriate treated wastewater with interim storage in a surface water body or aquifer. The use of reclaimed water for irrigation or other non-potable applications after a period of storage in surface or a groundwater body.
Indirect potable reuse	The use of reclaimed water for potable supplies after a period of storage in surface or a groundwater. The discharge of recycled water directly into groundwater or surface water with the intent of augmenting drinking water supplies.
Raw water	Water in its natural state before any treatment or the water entering the first treatment process of a water treatment plant
Reclaimed water (Metcalf & Eddy 2007)	Municipal wastewater that has been treated to a specific water quality criterion so it can be beneficially reused. This is normally a higher quality than secondary treatment.
Recycled water (Australian national guidelines)	Water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use. (In industry recycled water can relate to cooling water recycling where there is minimum treatment)
Source water	Water in its natural state (but that may have received treated wastewater discharges upstream), before any treatment to make it suitable for drinking
Treated wastewater reuse	Reuse is the term used in the EU regulations to describe the beneficial use of appropriately treated wastewater. Treated wastewater (or water) reuse: the beneficial use of treated water
Water recycling (Australian National Guidelines)	A generic term for treated wastewater reclamation and reuse. It can also be used to describe a specific type of “reuse” where water is recycled and used again for the same purpose (e.g. recirculating systems for washing or cooling), with or without treatment in between.

2.2 OCCURRENCE OF WASTEWATER IN SURFACE WATER SUPPLIES

2.2.1 Wastewater pollution

The National Rerearch Council (2012) reported that although population density has increased substantially in parts of the country with limited water resources, a systematic analysis of the contribution of municipal wastewater effluent to potable water supplies had not been made in the United States for over 30 years. The lack of such data impedes efforts to identify the significance and potential health impacts of de facto water reuse. Because new water reuse projects could decrease the volume of wastewater discharged to water sources where de facto reuse is being practiced, the lack of understanding of the contribution of wastewater effluent to water supplies restricts our ability to assess the net impact of future water reuse on the nation's water resource portfolio.

Ideally, these efforts would take advantage of existing monitoring networks (e.g. U.S. Geological Survey [USGS] streamflow gauging stations), data on wastewater effluent discharges submitted by National Pollutant Discharge Elimination System permit holders, and hydrological models developed to study watersheds with historical concerns about the impact of effluent discharges on water quality. These efforts could be updated periodically (e.g. every 5 to 10 years) to provide decision makers with an understanding of the role of de facto reuse in the nation's potable water supply. This could spur the development and/or application of contaminant prediction tools or lead to enhanced monitoring programs that could increase public health protection.

2.2.2 Point and non-point sources of pollution

The pollution of natural water sources can come from many sources. These water sources then get abstracted for domestic, industrial, agricultural, recreational, and environmental use, and can indirectly be using polluted water. These pollution sources can be divided into two types, namely point and non-point sources (Wu, Zhang and Chen, 2012)

2.2.2.1 Point source water pollution

Point sources discharge large volumes and at specific and identifiable locations, usually through a pipeline, channel, or other conduit (Chapra, 2008). This type of pollution can contain various types of pollutants, which include nutrients, metals, biological material, bacteria, etc.(National Geographic Society, 2019). The main dischargers of point source pollution are wastewater treatment plants and industrial dischargers, but also include discharges from mining effluent and power plant discharges (Pegram and Görgens, 2001).

2.2.2.2 Non-point source water pollution

Non-point source locations are not as easily identified and are difficult to quantify, as they usually release in a wide area (Chapra, 2008). This type of pollution can include pollutants like pesticides, fertilisers, nutrients, oils, faeces, trash, etc.(National Geographic Society, 2019). These sources can include stormwater runoff, drainage agricultural land-use, diffuse pollution from informal areas, etc.(Pegram and Görgens, 2001). As this pollution is difficult to physically measure, researchers usually aim to model them. They either model a specific non-point source, or a group of them.

Therefore, this type of source pollution was not included in this project. As wastewater effluents are the most abundant and largest point source and overall contributors to surface water sources, this project focused only on wastewater treatment plants.

2.3 ESTIMATING WASTEWATER CONTENT BASED ON FLOWS

Swayne et al. (1980) undertook a study to determine the impact of upstream wastewater discharge on water supply utilities serving populations of more than 25,000, using data and information that was available from existing reports. The specific objectives were to:

- identify all utilities supplying drinking water from surface water to communities of 25,000 persons or more.
- identify all upstream municipal and industrial dischargers.
- determine municipal discharge effluent quality type (primary, secondary, tertiary), flow and organic loading (measured by BOD)
- determine annual average and minimum river flows at the water treatment plants' intake points.
- determine ratio of the sum of municipal effluent discharge flows to water supply source flow, *i.e.* flow in the river at the intake point (giving the percentage of wastewater in the inlet to the water treatment plants)
- estimate BOD loads in the intake water to selected water treatment plant sites.

The study identified from the EPA Inventory of Public Water Supplies a total of 1,246 water sources serving 540 utilities. Source water supply flow data was difficult to obtain. Gauging stations were often not close to the utility abstraction points, in which case flows were approximated through extrapolation, or otherwise left blank. It was further assumed that dischargers were concentrated at points midway between each adjacent upstream utility as a means of providing necessary data for organic loading models.

Although the above deficiencies in the availability of data were encountered, the results were significant because:

- identifiable links were established between wastewater dischargers and major drinking water treatment plants.
- drinking water treatment plants which may be impacted by potentially significant amounts of pollutants were identified and are likely candidates for further studies.
- a database with information on estimated amounts of wastewater in receiving water sources was developed, which can be easily updated as more data becomes available.

The accuracy of data and lack of completeness of data did not support detailed analysis at specific water intakes. For this reason, it was pointed out that the results should not be used for estimating the concentration of certain pollutants at the drinking water treatment plant intake. However, it was considered that the data did provide an excellent reference on national level useful for identifying those water treatment plants which have a high probability of being significantly impacted.

The database was a first step toward developing the capability to estimate the impact of wastewater dischargers quickly and efficiently on surface water supplies. The authors pointed out that further work is required on:

- water supply intake locations (coordinates and/or river miles)
- water supply intake flows on a seasonal basis.
- location of the wastewater discharge points (coordinates and/or river miles)
- discharger activities and flows by season.
- presence and concentrations of pollutants in discharges
- fate of pollutants in the receiving waters.

According to this way of calculating the percentage wastewater at the water treatment plant intake it is possible to have percentages higher than 100% (in this study by Swayne et al. (1980), a percentage as high as 350% was calculated during low river flow in the Saluda River). For this type of calculation, percentages greater than 100% may indicate:

- water being used more than once.
- loss of water in the river due to evaporation
- loss to ground or consumptive withdrawals
- inaccurate source data.

The results of the study further showed the following:

- of the persons utilising surface water (more than 62 million), most are served by supplies containing zero or low concentrations of wastewater during both average and low flow conditions.
- about 15 million people were shown to be served by surface water supplies containing at least 10% wastewater at low flow conditions.
- 4 million persons use municipal supplies that contain 100% wastewater during low flow conditions.
- it was unknown to what extent alternative water supplies were used during low flow conditions or to what extent supplies are combined. The data, therefore, reflected the maximum estimated impact rather than the actual estimated impact.
- For most regions, a high percentage of source waters contain zero or a small percentage of wastewater.

In the U.S., the Mississippi River, the Trinity River in Texas, and the Schuylkill River in Pennsylvania are examples of de facto reuse. The Mississippi River receives wastewater discharges from 10 different states at various locations along the river, and many of those states also designate the river as a domestic water supply (National Rerearch Council, 2012). Model estimates increased under low flow conditions (modelled by Q95), in several cases treated wastewater made up 100% of the water supply (cf. the work done by Swayne et al.). De facto reuse occurs at levels that is more than what is publicly perceived in the three cities of Atlanta, GA, Philadelphia, PA, and Phoenix, AZ. Respondents with knowledge of de facto reuse occurrence were 10 times more likely to have a high acceptance (greater than 75%) of treated wastewater at their home tap.

In a study that the Technical University of Munich (TUM) performed for the European Commission in 2017, several European countries were investigated in order to assess the degree to which wastewater is contained in surface water sources (Drewes et al., 2017). The motivation for the research came from the European Commission after concerns were raised regarding agricultural irrigation and ground water recharge qualities.

As was the approach in the US EPA study of the United States, the European Commission study also made use of flow data in order to quantify the ratio of wastewater to natural water in the rivers and streams. The study also only included wastewater from domestic wastewater treatment plants and therefore did not include industrial wastewater treatment plants or other sources of untreated wastewater.

The study primarily focused on the agricultural sectors of Spain, Italy, and France, although the research was done per water basin, and not per country. The findings of the research indicated that river basins in Spain contained wastewater varying between 3% and 82% (again taking dry and wet season into consideration). Basins in Italy contained wastewater varying between 14% and 68% and in France basins contained wastewater varying between 0.3% and 51% (Drewes et al., 2017).

Wang, Shao and Westerhoff (2017) aimed to predict percentages and trends of de facto reuse throughout the Yangtze River watershed in order to understand the relative contribution of wastewater discharges into the river and its tributaries towards averting water scarcity concerns. The Yangtze River is the third longest in the world and supports more than 1/15 of the world's population, yet the importance of wastewater on the river remains ill-defined. Municipal wastewater produced in the Yangtze River Basin increased by 41% between 1998 and 2014, from 2580 m^3/s to 3646 m^3/s. Under low flow conditions in the Yangtze River near Shanghai, treated wastewater contributions to river flows increased from 8% in 1998 to 14% in 2014. The highest levels of de facto reuse appeared along a major tributary (Han River) of the Yangtze River, where de facto reuse can exceed 20%. While this initial analysis of de facto reuse used water supply and wastewater data from 110 cities in the basin and 11 gauging stations with N50 years of historic streamflow data, the outcome was limited by the lack of gauging stations at more locations (i.e. data had to be predicted using digital elevation mapping) and lack of precise geospatial location of drinking water intakes or wastewater discharges. This limited the predictive capability of the model relative to larger datasets available in other countries (e.g. USA). This assessment is the first analysis of de facto wastewater reuse in the Yangtze River Basin (Wang, Shao and Westerhoff, 2017).

Table 2.2: De facto reuse under average streamflow conditions in the Yangtze River (adapted from Wang, Shao and Westerhoff (2017))

De facto reuse under average annual streamflow condition of 11 sites in 1998 and 2014 (names in parentheses indicate Yangtze River tributary river names).

Year	Yibin	Chongqing	Yichang	Shashi	Wuhan	Jiujiang	Nanjing	Shanghai	Huangzhuang (Han River)	Chenglingji (Dongting)	Hukou (Poyang)
1998	0.5%	0.7%	0.8%	0.9%	1.4%	1.3%	1.8%	1.7%	1.3%	0.9%	1.2%
2000	0.6%	0.8%	1.0%	1.2%	1.9%	1.7%	2.3%	2.4%	1.6%	1.2%	1.6%
2003	0.7%	0.9%	1.1%	1.3%	2.0%	1.8%	2.5%	2.7%	1.8%	1.2%	1.6%
2006	1.0%	1.5%	2.1%	2.2%	3.0%	2.7%	3.5%	4.0%	4.5%	1.6%	1.7%
2010	1.0%	1.2%	1.6%	1.8%	2.4%	2.2%	2.8%	3.0%	2.3%	1.1%	1.3%
2014	1.1%	1.3%	1.5%	1.7%	2.3%	2.3%	3.0%	3.5%	7.8%	1.3%	2.2%

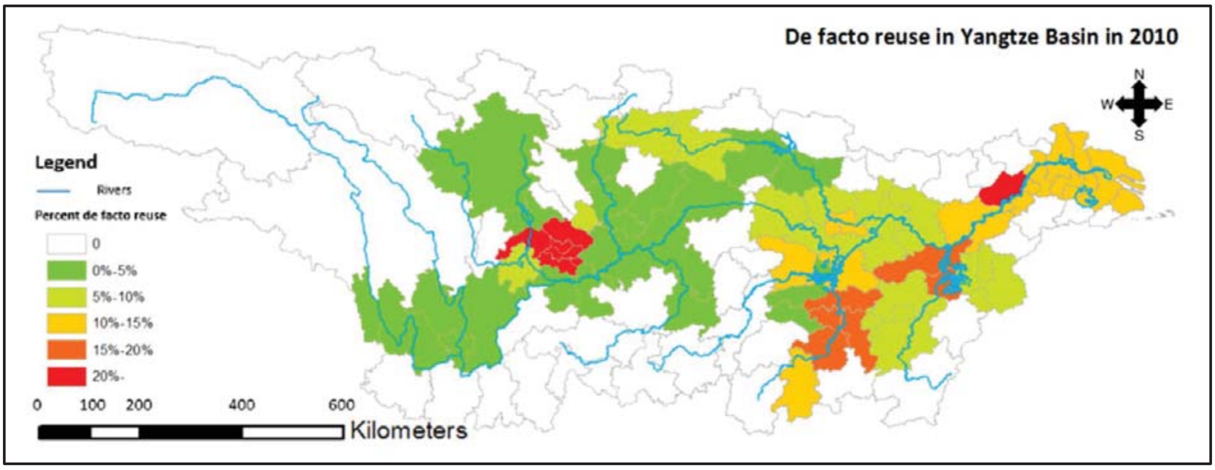


Figure 2.1: De facto reuse in the Yangtze River basin in 2010 (adapted from Wang, Shao and Westerhoff (2017))

Table 2.3: De facto reuse under annual low flow conditions in the Yangtze River (adapted from Wang, Shao and Westerhoff (2017))

De facto reuse under annual low flow condition (7Q10) at representative locations with long term historic streamflow data (names in parentheses indicate Yangtze River tributary river names). The location with the highest potential de facto reuse (Huangzhuang on the Han River tributary of the Yangtze River) is highlighted in bold text.

Year	Yibin	Chongqing	Yichang	Shashi	Wuhan	Jiujiang	Nanjing	Shanghai	Huangzhuang (Han River)	Chenglingji (Dongting)	Hukou (Poyang)
1998	1.5%	4.2%	5.0%	5.3%	6.8%	7.1%	7.7%	8.3%	**11%**	4.5%	4.8%
2000	1.5%	4.2%	5.1%	5.8%	7.2%	7.6%	8.1%	9.4%	**11%**	4.5%	4.9%
2003	1.6%	4.3%	5.6%	5.8%	7.2%	7.6%	8.2%	10%	**11%**	4.7%	4.9%
2006	1.6%	4.6%	6.3%	6.6%	7.8%	8.1%	8.3%	12%	**14%**	4.8%	5.0%
2010	1.8%	5.0%	7.4%	7.7%	8.8%	9.2%	9.5%	13%	**14%**	5.1%	5.5%
2014	1.9%	5.5%	7.5%	7.8%	8.9%	9.5%	9.8%	14%	**15%**	5.8%	6.8%

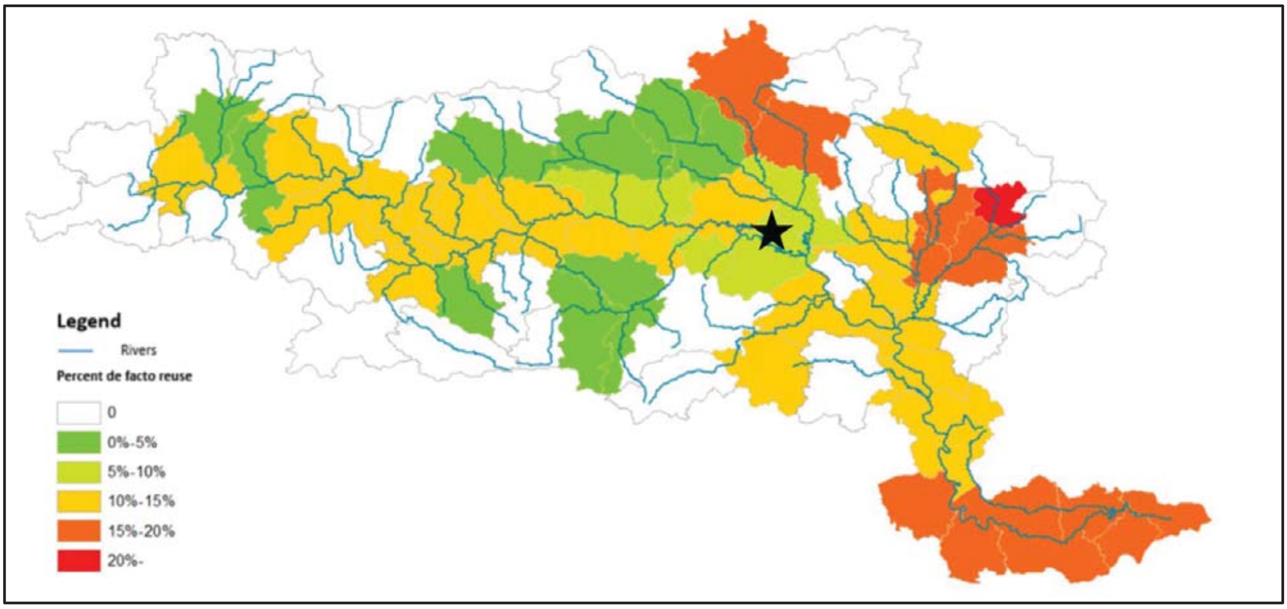


Figure 2.2: De facto reuse in the Yangtze River basin under low flow conditions (adapted from Wang, Shao and Westerhoff (2017))

The de facto reuse observed in the Yangtze River in this study were comparable with de facto reuse levels predicted in large river systems in USA (Rice, Wutich and Westerhoff, 2013; Rice and Westerhoff, 2015; Rice, Via and Westerhoff, 2015).For example, under average flow on the Mississippi River, which is the largest river in the USA, the levels of de facto reuse are lowest in its headwaters and increase to ~1% in the lower reaches. Like the Han River tributary of the Yangtze River, it is the smaller tributaries (i.e. lower Strahler order streams) of the Mississippi River that have higher potential for de facto reuse. Large river systems in the western and desert regions of the USA can have de facto reuse levels exceeding 15% (e.g. Rio Grande River) because there is extensive water consumption for agriculture that removes water from the river while wastewater flows continue along the length of the river before it enters the Gulf of Mexico. The lower portions of the Colorado River (USA) have 1 to 3% de facto reuse potential under average flow. For smaller streams, there is potential for the river to contain a majority of wastewater (i.e. de facto reuse N50%) during mild drought periods (e.g. 20th percentile stream flows) or low flow years (Rice and Westerhoff, 2015; Rice, Via and Westerhoff, 2015).Overall, the trends in the Yangtze River basin were similar to those in the USA.

In a study by Karakurt et al.(2019), an ArcGIS model using spatial and operational WWTP data (i.e. location of the WWTP, point and amount of discharge, capacity, and level of treatment) and stream gauging station runoff data was generated to perform automated assessments of relative contributions from treated wastewater effluents to rivers. The locations of WWTP discharge and gauging station (i.e. nodes) were spatially linked to hydrological data of the German river network at a scale of 1:250,000 (DLM250). Flow direction estimation and network analysis for the streams were performed using a geometric network. The wastewater effluents upstream of a river segment were cumulatively calculated and assigned to a specific gauging station. The percentage of wastewater effluent contributions ($WW_{effluent}$ [%]) at each individual gauging station was subsequently determined by calculating the ratio of the total discharge rate of upstream WWTPs ($\sum Q_{WW\ effluent}$) to the Mean Annual Discharge (MAD) and Mean Minimum Annual Discharge (MMAD) data at the respective gauging station ($Q_{gauging\ station}$) using Equation 1, which was coded into GIS using Python scripts. For rivers of stream order 1-5 (indicating level of branching in a river stream) with more than two gauging stations, the MAD or MMAD along a river were first determined by linear interpolation, and the relative wastewater effluent contributions were subsequently calculated for these fictitious gauging stations with varying discharge conditions in an automated assessment using Equation (1).

$$WW_{effluent}\ [\%] = \frac{\sum Q_{WW\ effluent}}{Q_{gauging\ station}} \times 100\% \qquad (1)$$

The relative wastewater effluent contributions of the ArcGIS model determined for a given gauging station were validated using water quality monitoring data of the wastewater-derived conservative indicator chemical for select sites at the river Main (Equation (2)). Where the $C_{river\ indicator}$ and the $C_{WW\ effluent\ indicator}$ are the indicator chemical concentrations at the gauging stations and the wastewater effluent, respectively. These sites, and the indicator chemical carbamazepine, were chosen for this assessment due to data availability provided by local water utilities and regulatory agencies. Only 24 WWTPs out of 7,550 facilities across Germany are currently employing advanced wastewater treatment processes.

$$WW_{effluent}\ [\%] = \frac{C_{river\ indicator}}{C_{WW\ effluent\ indicator}} \times 100\% \qquad (2)$$

The ArcGIS model deriving wastewater effluent contributions in the Main River was validated by concentrations of the wastewater indicator chemical carbamazepine, determined both in the wastewater effluent and along the river. Grab samples were taken at nine gauging stations along the Main River during March 2017. Wastewater effluent contributions calculated by carbamazepine concentrations more closely follow the distribution of MMAD conditions (average MMAD-CBZ = 4%±4%) than MAD conditions (average CBZ-MAD = 15 %±5%).

Given the prevalence of low discharge conditions, wastewater effluent contributions during MMAD conditions were determined and depicted for all rivers across Germany (Figure 2.3-a). Based on the results of this study, wastewater effluent contributions of more than 10-20% during MMAD conditions dominate in many river basins (Figure 2.3-b). For more than 40% of their gauging stations, the rivers Neckar, Ems, Main, and tributaries of the lower and middle Rhine exhibit wastewater effluent contributions of more than 20-30%. During MAD conditions, however, the contributions from wastewater effluents vary only between 0-5% for more than 50% of the gauging stations nationwide, except for the Neckar River basin (Figure 2.3-c).

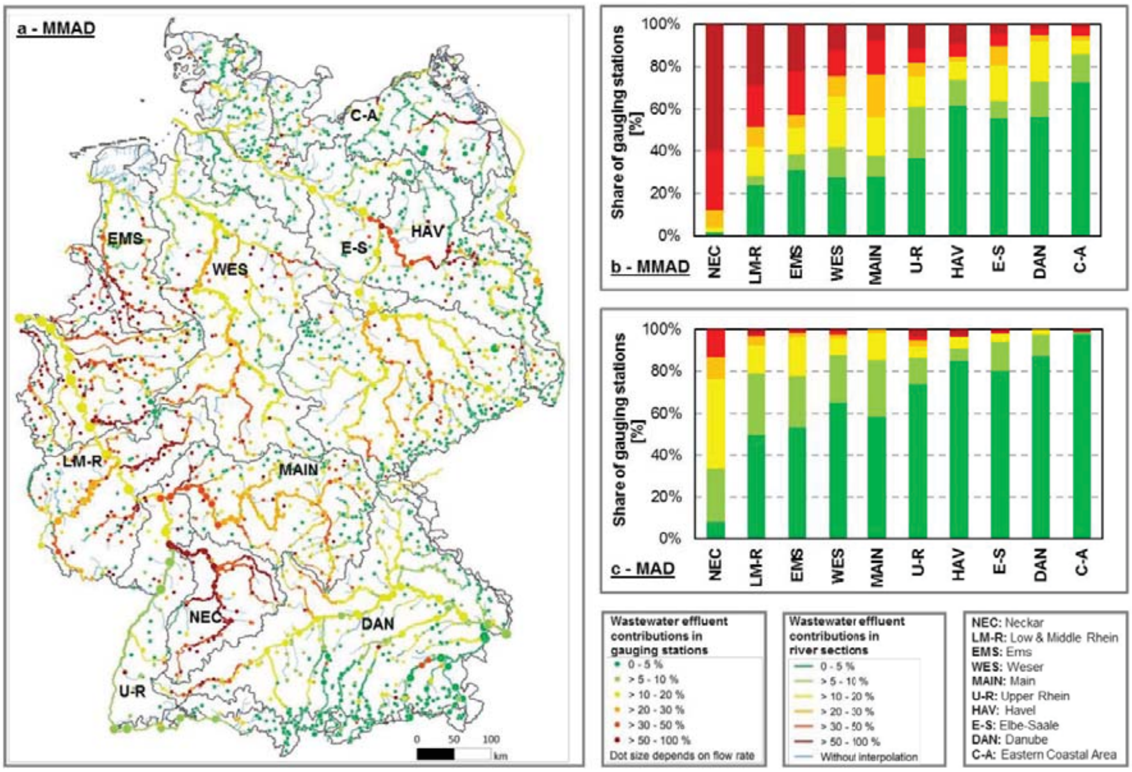


Figure 2.3: Map of the nationwide wastewater effluent contributions under MMAD conditions (a) and share of gauging stations with relative wastewater effluent contributions for river basins under MMAD (b) and MAD (c) conditions. (Karakurt et al., 2019).

The findings of this study reveal a high degree of wastewater impact on streams, which also serve as an important source water for drinking water abstraction, industrial usage, or irrigation purposes, particularly in many urbanized areas across Germany. Moreover, high wastewater effluent contributions can impair the ecological and chemical state of surface water due to oxygen consumption, discharge of hazardous substances, and elevated amounts of nutrients, which might pose a higher risk to aquatic life.

In an investigation on the conditions of rivers in Switzerland (Ort et al., 2009) , a model was developed to determine the impact of the effluents of WWTPs on the micropollutant loading in river basins. The following objectives were set up for the model:

1) To realistically predict micropollutant loading from WWTPs in rivers
2) To identify hotspot concentrations at a national scale
3) Using the minimum required input data

Inputs to the model included an existing digital river network, the locations of 742 WWTPs (which serves 97% of Switzerland's population), consumption data, human metabolism data and WWTP removal rates for each of the compounds that were investigated. These compounds were soluble and polar in nature and therefore, sorption of the compounds to the riverbank sediment was not accounted for. The model used Q95 (the flow reached in 95% of the time annually, over a ten-year period) as base flow conditions to account for minimum dilution. The daily load of the compounds in a river section was calculated using Equation (3) below.

$$L(S)_{river\ catchment\ WWTP_j} = \frac{1000}{365} \sum_i \left[\frac{C_{CH}}{P_{CH}} \times (p+m)\right] \cdot \bar{P}_{WWTP} \cdot (1-\bar{e}) \cdot T_{ij} \quad (3)$$

$$T_{ij} = (I - W)^{-1} \quad (4)$$

$L(S)$ is the average daily load of compound S, g/day; C_{CH} is the annual national consumption of compound S, kg/year; P_{CH} is the total population of Switzerland, 7.459 million; p is the fraction of parent compound excreted and discharged to sewers; m is the fraction of known metabolites; $\bar{P}_{WWTP}$ is the population connected to each WWTP; $\bar{e}$ is the fraction of compound S eliminated in WWTPs; T_{ij} is the topology-matrix, derived from Equation (4)

2.4 QUANTIFYING THE EXTENT OF DE FACTO WATER REUSE

2.4.1 Overview of modelling approaches

Rice (2014) carried out a research project to quantify the extent of de facto reuse by developing a model that estimated the amount of wastewater effluent that was present in drinking water treatment plants. The model was then used in conjunction with a survey to help assess public perceptions of de facto reuse. A four-step approach to accomplish this goal included the following:

1. Creating a GIS-based model coupled with Python programming.
2. Validating the model with field studies by analysing sucralose as a wastewater tracer
3. Estimating the percentage of wastewater in raw drinking water sources under varying streamflow conditions
4. Assessing through a social survey the perceptions of the general public relating to acceptance and occurrence of de facto reuse.

The resulting de facto reuse model estimated that treated municipal wastewater is present at nearly 50% of drinking water treatment plant intakes sites serving greater than 10,000 people (N=2,056). Contrary to the high frequency of occurrence, the magnitude of occurrence was relatively low with 50% if the impacted intakes yielding less than 1% de facto reuse under average streamflow conditions.

To better understand a drinking water utility's potential contribution to human or ecological exposure to organic chemicals of emerging concern (CECs) of wastewater origin under a range of streamflow conditions, a model (De Facto Reuse in our Nation's Consumable Supply [DRINCS]) has subsequently been developed to estimate the de facto reuse across the United States (Rice, Wutich and Westerhoff, 2013; Rice and Westerhoff, 2015; Rice, Via and Westerhoff, 2015). Assumptions used to develop the model include the following:

- The WWTP discharge flow is equal to its operational capacity.
- No in-stream losses to WWTP effluent.
- Complete mixing of all water bodies.
- The average river flows did not include municipal wastewater inputs.

Results from a specific sampling effort were compared by analysing surface water intakes from 22 surface water treatment plants for 192 organic CECs, with predictions of DFR from DRINCS. The relative location and distance of WWTP discharge points upstream of DWTP intakes are presented, along with the design capacity of the WWTPs, to aid in the comparison and interpretation of the model and chemical results. The objective is to increase the understanding of how the proximity of upstream WWTP discharges increases the vulnerability of downstream surface water DWTPs to contaminants of wastewater origin across the United States (Nguyen et al., 2018).

Impacts of varying streamflow (daily, seasonal, and annual) were considered two ways in the DRINCS model. Firstly, historical streamflow data was used to obtain fifth and 90th percentile streamflow datasets. This is because this influence the potential range of higher to lower DFR values, respectively, that could be expected to occur at a DWTP intake. Only 59 out of nearly 4,392 WWTPs considered in this study have design capacities >10 MGD. Thus, there are large numbers of small WWTPs in the studied watersheds.

Nguyen et al. (2018) used the DRINCS model developed by Rice (2014) to further compare it with field sampling efforts. Specifically, it was used to compare CEC concentrations at 22 WTPs with predicted de facto reuse percentages. What differed in this study, is that two more methods were used to compare the CEC concentrations with, namely the proximity index (PI) and the relative skewness (SK). These two factors will be used to compare the relationship between CEC concentration and the distance of the WWTP from the site (M_i). PI can be calculated as in Equation (5) and Equation (6). A large PI suggest that large WWTPs are located close to the sampled site, and therefore could indicate a large impact from wastewater on the site.

$$PI_i = \frac{Q_{WW,i}}{M_i} \tag{5}$$

$$PI = \frac{\sum PI_i}{Q_{WW,T} \times 1000} \tag{6}$$

Relative skewness would range between 0 and 1. It can be calculated using Equation (7). A large SK could mean that a large WWTP is close to the sampling site. It should be noted that there is no relationship between PI and SK, but they can both be used for the same reason, separately.

$$SK = \frac{M_{0.1}}{M_{0.5}} \qquad (7)$$

$M_{0.1}$ is the distance associated with $F_{0.1}$, where F is the dimensionless, normalised cumulative distribution when plotting cumulative WWTP wastewater flows with distance; $M_{0.5}$ is the distance associated with $F_{0.5}$

2.4.2 Qualitative comparison of CEC detection and DRINCS model DFR predictions:

The over 4,000 WWTPs present in the watersheds of the DWTPs studied herein include a wide range of treatment processes from aerated lagoons to advanced nutrient control. Biodegradation, biosorption, volatilization, hydrolysis, oxidation, and other biochemical or physical processes within different types of WWTPs can potentially influence the extent of CEC removal. DRINCS does not directly account for these differences in treatment process, and DFR simply represents a conservative estimate for potential risk of having surface DWTP supplies containing CECs of wastewater origin.

The CEC source water data set is comprehensive both in terms of the number of chemicals analysed and number of WTPs sampled (n = 25). However, grab samples are only representative of a single point in time, many of the CECs were below reporting or detection limits, and quantitative concentrations were not reported. Therefore, the researchers made a qualitative comparison of CEC occurrence and DRINCS model outputs rather than using a formal statistical analysis.

12 DWTPs were used for field studies to validate the DRINCS model's accuracy. Rice reported that the model proved to be a good estimate for average flow conditions. But for low flow conditions the standard error increased, especially at sites where de facto percentage levels were greater that 10%. Standard error and standard deviation for average flow conditions were calculated to be 0.002 and 0.016, respectively. For low flow conditions they were calculated to be 0.020 and 0.046, respectively.

Limitations to the DRINCS model, to mention a few, included accuracy of WTP and WWTP locations, incomplete datasets leading to some calculations only being based on average flow conditions, few field study sites, and the exclusion of non-point sources.

The study by Nguyen et al. (2018) showed that a higher de facto percentage had a direct relationship with larger amounts of CECs. The study also states a big limitation of the DRINCS model, which is that the model does not account for non-WWTP sources, which could have significant CEC contributions.

For the three indexes (de facto reuse, PI, and SK) the strongest trends were observed for de facto reuse compared to all organic CEC concentrations. PI showed strong relationships for WTPs that are especially impacted by nearby WWTPs. But SK showed no correlation with CECs at all. The study also concludes that composite sampling would increase the accuracy of sampling results, compared to grab samples. Therefore, the model works as an indicator of hotspots where further, more detailed monitoring is required.

The model by Ort et al. (2009) was validated with site-specific measurements. As Switzerland had no monitoring program in 2006, nine small creeks and medium sized rivers were selected for sampling to compare to model outputs. Data were also obtained from two recent studies. Samples were also taken at 14 WWTPs to determine per capita load variations in influents and effluents.

A Monte Carlo simulation was used to determine the effect of uncertainty on the model results. Uncertainty was used to assess the effect of geographic and temporal variation. For the loads at the 14 WWTPs an uncertainty values were assigned randomly according to a uniform range of $\pm$50%: uniform ($-$0.5, 0.5). For the discharge rates of the WWTPs a uniform range of $\pm$20% was used: uniform ($-$0.2, 0.2). The uncertainty of Q95, ranges of $\pm$70%, $\pm$50% and $\pm$30% were used for small creeks (Q95 < 60 L/s), medium-sized river (60 L/s < Q95 < 600 L/s) and large rivers (Q95 > 600 L/s), respectively.

The average daily mass fluxes were calculated for carbamazepine and diclofenac for all river sections. For the validation, the data was plotted with the model predicted loads ($C_{model,i}$) on the Y-axis and the measured loads ($C_{measured,i}$) on the X-axis. Two validation parameters were used, namely the mean predictive accuracy factor (MPAF, calculated using Equation (8)) and the R^2-value from linear regression forced through 0.

$$MPAF = \frac{1}{n}\sum \frac{C_{model,i}}{C_{measured,i}} \tag{8}$$

The MPAF for carbamazepine and diclofenac were 1.0 and 1.1, respectively (excluding one outlier for diclofenac), and the R^2-values were 0.78 and 0.94. The MPAFs showed that there was no bias in the predicted loads, and the R^2-values showed that the loads were proportional to population size and that error with increasing flow distances is not significant.

2.4.3 Summary

The variability in CEC detection at a particular DWTP intake depends on many factors including streamflow, type of treatment processes used at any upstream WWTP, WWTP discharge flow rates, travel distance, water quality within the receiving waters, and so on. As indicated in the prior study in which the CEC occurrence data were collected (Glassmeyer et al., 2005), the conclusion noted that samples collected at a single point in time make up a snapshot of occurrence, and future studies would benefit from more detailed and focused time series sample collection designs that better capture temporal variations. The general comparison of DRINCS and the “snapshot” of CEC occurrence data compared here advances the validity of using DRINCS as a tool to identify locations of DWTPs for future sampling and treatment technology testing. Before development and simulation of the DRINCS model (Rice and Westerhoff, 2015) the only other available nationwide documentation linking drinking water sources to wastewater percentage was several decades old (Swayne et al., 1980).

Levels of DFR from DRINCS were previously compared with the potential occurrence of Unregulated Contaminant Monitoring Rule CECs (Rice and Westerhoff, 2015), which included only a few wastewater indicator-compounds. However, this paper demonstrates, for the first time, the ability of DRINCS to be used for a much broader range of CECs of wastewater origin, especially since Nguyen et al. (2018) correlated a high DFR with a large number of CECs. Another ability is the model’s capability to be used on a much larger scale – national scale. Databases linked with DRINCS include populations served and type of unit processes at the WWTPs and DWTPs. In addition, DRINCS is able to calculate the number and size of WWTP discharges into surface waters upstream of the DWTP intakes.

Queries could be made that include some of the factors described herein that would affect CEC occurrence. Although the comparison of model and field results in this study indicates the general validity of the DRINCS model, the data also suggest that predictive capabilities could be enhanced by closer proximity of instream flow information, such as that provided by stream gages near DWTP intakes, to more accurately measure DFR. Ongoing improvements in chemical analytical capabilities and expansion of the range of CECs routinely determined will also serve to better anchor model predictions with observed ambient source water conditions. Another query, as pointed out by Nguyen et al. (2018), is that even though DFR was a better estimate compared to the two distance indexes (PI and SK) used in the study, it still does not account for proximity of WWTPs to a DWTP. It only considers which WWTPs are upstream of a DWTP and calculates their cumulative effect on the DWTP, with no distance parameter included in the calculation. Integration of such a proximity or distance variable would highly increase the value and accuracy of the output of the model.

2.5 CHEMICAL COMPOUNDS AS INDICATORS OF WASTEWATER CONTAMINATION

Traditionally, wastewater contamination is monitored and tracked using microbial and chemical analysis. Chemical analysis is usually focused on pH, alkalinity, nitrogen, sulphates, etc. These analysis do not, however, allow the identification of the origin of the pollution source (Sankararamakrishnan and Guo, 2005). The presence of bacterial indicators, such as *E. coli (Escherichia coli)*, have been investigated through microbiological analysis, but there are disadvantages and limitations to these methods. The analysis is time consuming; the markers lack source specificity (natural, animal, or human occurrences) and have relatively short survival times in natural waters. (Buerge et al., 2003; Glassmeyer et al., 2005).

Another, simpler, approach is to determine the cumulative volume of wastewater being discharged into the water sources upstream of the relevant abstraction point. In this case accurate information about the upstream dischargers is required as well as the natural flow rate of the rivers and streams during normal and low flow conditions (see 2.3 above). Unfortunately, it is possible that the flow volume approach can become unviable due to a lack of information, either of the flow figures for the streams and rivers, or of the wastewater being discharged into the water source. It is therefore necessary to have an alternative approach.

In the last two decades, there have been numerous extensive reports and studies related to the detection of wastewater contaminants in surface water. Numerous chemical indicators have been investigated and utilized to detect contamination of wastewater to surface water (Buerge et al., 2003, 2009; Glassmeyer et al., 2005; Bradley et al., 2007; Dickenson et al., 2011; James et al., 2016; Gonçalves et al., 2017; Tran et al., 2019). Glassmeyer et al. (2005) suggested that chemical indicators can fall into three categories: (1) those that are produced by humans, (2) those that passes through humans and (3) those that are associated with a sewage-contaminated waste system. The use of a chemical indicator as tracer of wastewater contamination has the advantages of being more source specific and stable compared to microbial indicators and can be detected more rapidly and reliably (Lim, Ong and Hu, 2017).

In this case it would be important to identify chemical compounds or microbiological species that are representative of wastewater. These indicators should be selected very carefully in order to ensure that they will not be affected by:

- The type of wastewater being discharged (treated or untreated)
- The performance of the WWTP from where the wastewater is discharged.
- The relative location of the wastewater source to the abstraction point
- The condition of the river system (oligotrophic, eutrophic, hypertrophic)
- Differences in human activities in or around the water source
- Differences in animal activities in or around the water source.

Despite the large number of water quality indicators that are typically used in environmental surveys and water treatment specialists, the indicators that are required for the current WRC project are somewhat unique since the goal is not simply to indicate the quality of the water, but specifically to indicate the contribution made by domestic wastewater. Typical indicators like *E. coli* will therefore not suffice, since the bacteria may come from animal waste (Wu, Zhang and Chen, 2012).

2.5.1 Estimating wastewater content using indicator compounds

Oppenheimer et al. (2011) used an array of anthropogenic compounds (including DEET, caffeine and sulfamethoxazole) to compare it to sucralose with regard to serving as wastewater indicators. Samples were taken of final effluents from WWTPs, raw water sources with known wastewater discharges as well as raw water sources without any wastewater discharges. Despite many of the anthropogenic compounds testing positive in the wastewater effluents, the only compound that consistently tested positive in both the wastewater effluent and raw water sources where wastewater was discharged but tested negative in the raw water sources where wastewater was not discharged, was sucralose. Sucralose is not degraded in the human body and travels through the digestive system being excreted through urine and faeces, making sewage its dominant source to the environment. Its high loading to WWTPs is coupled by no significant degradation during wastewater treatment processes. It is a highly stable compound, which undergoes negligible metabolism in mammals, and displays a low biodegradation potential in the environment.

A study by Mawhinney et al. (2011) took a different approach in determining the value of sucralose regarding predicting wastewater contamination. In their study, the intake water from 19 WTPs in the US were sampled and analysed. The study found that 15 out of 19 WTPs had sucralose in the source water used by the WTPs, and that 13 out of 17 samples of the final water produced by those WTPs still tested positive for sucralose. The significant finding was that sucralose was only found in the raw water sources where wastewater impacts were known to occur as well as recreational activities.

In a study by Wu, Zhang and Chen (2012) caffeine was tested in order to determine whether it can be used as a method for detecting sewage leaks near or in water bodies. For the study, several rivers and channels were sampled and analysed. The primary aim was to determine whether there is a significant increase in caffeine as well as human pharmaceuticals in areas where wastewater contamination takes place, as well as to quantify the correlation between caffeine and other wastewater related indicators.

The study found that there was a significant positive correlation between caffeine and faecal coliform in the samples that were analysed. There was however not a significant correlation between caffeine and chemical oxygen demand (COD) in the samples that were analysed, which is also beneficial since COD may have multiple pathways for entering a river, but caffeine does not. The study was also able to conclude that caffeine sampling can be used for identifying wastewater contamination in natural water bodies.

In a study by Archer et al. (2017) (a) to investigate the fate of various micropollutants, their metabolites and illicit drugs in wastewater treatment plants and in rivers, a total of 55 ECs was found in WWTP influent water, 41 ECs in WWTP effluent, and 40 ECs in environmental waters located upstream and downstream of the WWTP plant. Several emerging contaminants persisted through the WWTP process, with 28% of all detected emerging contaminants removed by less than 50%, and 18% of all CECs were removed by less than 25%. The researchers propose the potential of the pharmaceutical's carbamazepine, naproxen, diclofenac, and ibuprofen to be regarded as priority CECs for environmental monitoring due to their regular detection and persistence in environmental waters, and their possible contribution towards adverse health effects in humans and wildlife.

Table 2.4 compares the concentrations of priority CECs that were measured in several international and local studies.

Table 2.4: Comparison of indicator concentrations found in the local and international studies (all concentrations in ng/L)

Contaminant of Concern	Ternes et al. (2004)					
	WWTW influent	WWTW effluent	River/ Surface water	WWTW influent	WWTW effluent	River/ Surface water
	Germany			Austria		
Carbamazepine	2200	2100	250	912	960	75
Diclofenac	3500	810	150	3100	1500	20
	Poland			Spain		
Carbamazepine	1150	n.a.	n.a.	n.a.	n.a.	n.a.
Diclofenac	1750	n.a.	n.a.	<IDL	<IDL	<IDL
	France			Switzerland		
Carbamazepine	n.a.	1050	78	690	480	30-150

Contaminant of Concern	Ternes et al. (2004)			Archer et al. (2017) (b)	
	Finland				
	WWTW influent	WWTW effluent	River/ Surface water	Upstream of WWTP	Downstream of WWTP
Acetaminophen				20.8	63.7
Caffeine				812.2	2077.5
Carbamazepine	750	400	70	157.1	279.5
Diclofenac	350	250	15	467.4	1461.5
Sulfamethoxazole				757.4	1013.2

Contaminant of Concern	Snyder et al. (2006)					
	Raw Drinking Water			Finished Drinking Water		
	Min	Max	Ave	Min	Max	Ave
Acetaminophen	1.1	9.5	2.7			
Caffeine	9.1	87	34	2.6	83	25
Carbamazepine	1.2	39	6.2	1.1	5.7	2.8
Sulfamethoxazole	1.2	44	14	20	20	20

Contaminant of Concern	Petrie et al. (2016)			Agunbiade and Moodley (2014)		
	WWTW influent	WWTW effluent	River/ Surface water	WWTW influent	WWTW effluent	River/ Surface water
Acetaminophen	138164	1454	163			5800-58700
Caffeine	74813	5991	247			
Carbamazepine	650	316	75.8			
Diclofenac	549	436	21.5	222700	123700	1100-15600
Sulfamethoxazole	113	47.5	1.8			3680

Contaminant of Concern	Archer et al. (2017) (a)			Matongo et al. (2015)		
	WWTW influent	WWTW effluent	River/ Surface water	WWTW influent	WWTW effluent	River/ Surface water
Acetaminophen	136900-343600	40-200	20-200	5800		1000-1700
Caffeine	5100-1214400	500-3800	600-6600	4500	600	100-3300
Carbamazepine	300-600	400	200-300	2200	900	100-3200
Diclofenac	2700-5600	2200-2500	300-2200			
Sulfamethoxazole	600-2600	1200-1600	600-2400	34500		1200-5300

Contaminant of Concern	Hendricks and Pool (2012)			Patterton (2011)		
				Drinking Water		
	WWTW influent	WWTW effluent	River/ Surface water	1	2	3
Carbamazepine				20-300	10-20'	30-100
Sulfamethoxazole	100-200	80-100				

2.5.2 Selection of indicator compounds

Key considerations or criteria in the selection of ideal chemical indicator to evaluate wastewater contamination, include the indicator to be widely used and source specific. The indicator should be persistent and present in ubiquitously concentrations in the receiving waters and be detectable in contaminated water (but not in clean water) using available analytical methods. Finally, the prospective chemical indicator should not be significantly retained or degraded in WWTPs and should be resistant to environmental alterations. (Takada et al., 1997).

Furthermore, Kasprzyk-Hordern et al. (2009) emphasized that an ideal indicator should not undergo any significant bio- and photodegradation and absorption in water and wastewater. Therefore, the indicator should ideally have high water solubility, low hydrophobicity, expressed as the octanol/water partition coefficient (K_{ow}) and low volatility.

Figure 2.4 shows a matrix with sorption and transformation rates a number of potential indicators of CECs that take place during secondary treatment of wastewater.

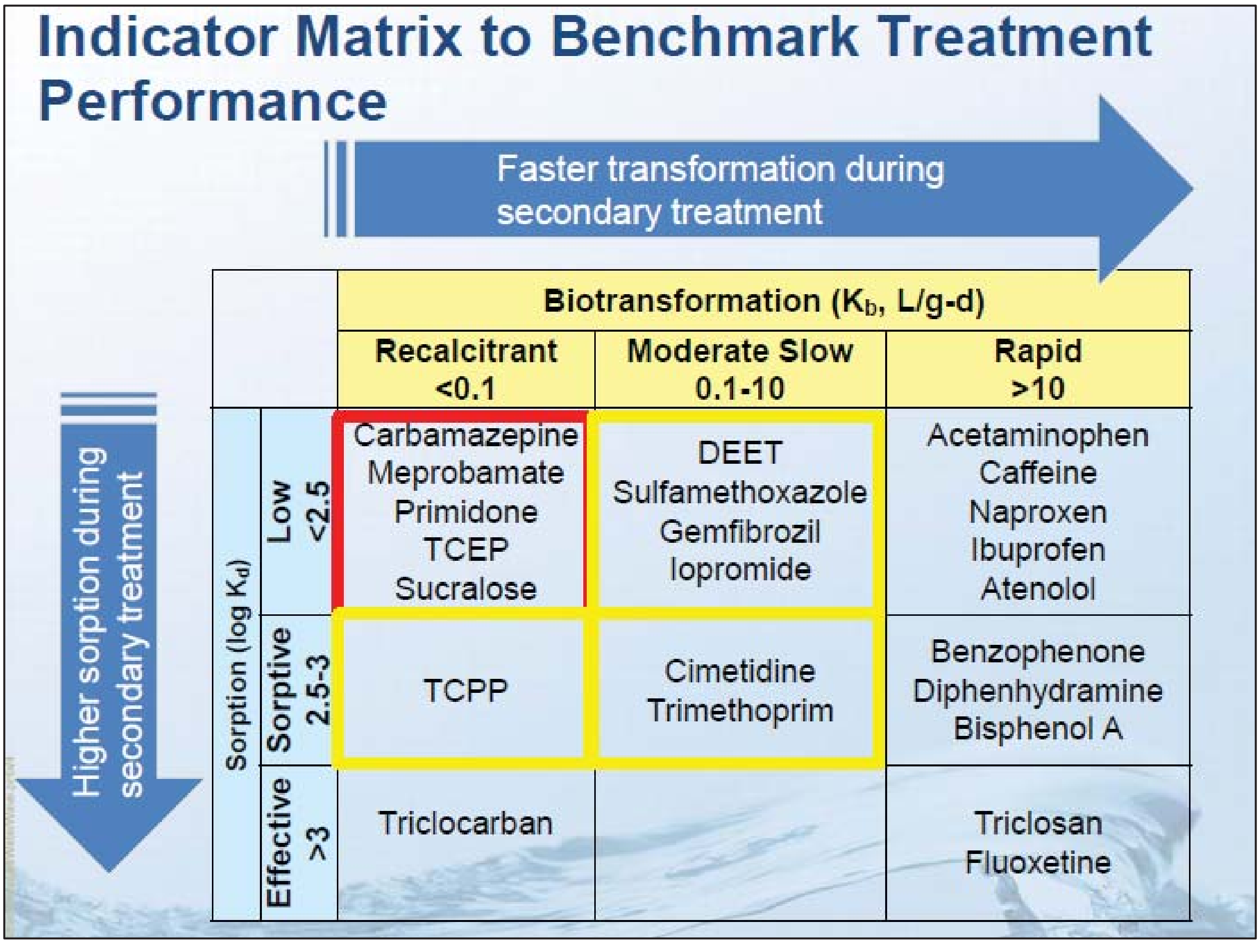


Figure 2.4: Matrix of indicators to benchmark treatment performance

CECs are an extensive class of compounds and are good candidates for indicators of wastewater contamination. CECs have a wide range of use patterns and varying physiochemical properties, increasing the potential chemicals to choose from. Therefore, a combination of CECs with different use patterns and different fate and transport properties can be used to assess wastewater contamination in receiving waters (James et al., 2016).

Table 2.5 provides a list of 21 CECs identified in the literature study as potential indicator compounds of wastewater contamination in surface water, for the purposes of this study. A full description of each CEC, including their trade name and potential health risks, can be found in Appendix G.

Sucralose was excluded from this list, as it is simply not as prevalent in South Africa as it is in the US and Western Europe, and the cost of analysing the samples would not result in any significant contributions to the task of the study.

Table 2.5: Potential indicator compounds investigated for suitability of indicating wastewater content.

Constituent	Class	Type
Caffeine	Stimulant	Central Nervous System (CNS)
Sulfamethoxazole	Pharmaceutical	Antibiotic
Carbamazepine	Pharmaceutical	Anticonvulsant
Diclofenac	Pharmaceutically Active Compound (PhAC)	Anti-Inflammatory
Efavirenz	Pharmaceutical	Antiretroviral (ARV)
Emtricitabine	Pharmaceutical	Antiretroviral (ARV)
Methaqualone	Recreational Drug	Sedative-hypnotic drug
Acetaminophen	Pharmaceutical	Paracetamol
10,11-dihydro-11-hydroxycarbamazepine	Pharmaceutical	Anticonvulsant/ Active metabolite of oxcarbazepine
Benzotriazole	Heterocyclic compound	Anticorrosive and ultraviolet stabilizer
Benzoylecgonine	Pharmaceutical	Cocaine metabolite
Carbamazepine-10,11-epoxide	Metabolite/Epoxide	Active metabolite of Carbamazepine
Cocaine	Recreational Drug	Psychoactive stimulant drug
Codeine	Pharmaceutical	Opioid Analgesic
MDMA (3,4-methylenedioxy-methamphetamine)	Recreational Drug	Psychoactive drug
Methamphetamine	Recreational Drug	Central Nervous System (CNS)
Naproxen	Pharmaceutical	Nonsteroidal anti-inflammatory drug (NSAID)
Atrazine	Herbicide	Chlorotriazine herbicide
Cetirizine	Pharmaceutical	Antihistamine
Tramadol	Pharmaceutical	Opioid Analgesic
Venlafaxine	Pharmaceutical	Antidepressant

2.6 WATER POLLUTION MANAGEMENT STRATEGIES

2.6.1 Managing chemicals of emerging concern in water resources

Chemicals of emerging concern have surfaced as one of the key environmental problems threatening environmental and public health. The South African water sector recognises the presence of CECs in water resources, and the need to monitor, regulate and manage these contaminants.

The Department of Human Settlement, Water and Sanitation (DHSWS) do not have a formalised strategy for dealing with CECs at this point in time. Existing policy documents addressing emerging contaminants, such as the 2017 Integrated Water Quality Management Strategy, only establishes the need for further research, financial support, capacity-building and inter-laboratory collaborations, and partnerships. These proposed actions are seen as a means for eventually filling knowledge gaps and in due course address CECs in South African water resources.

Geissen et al. (2015) provided the requirements for monitoring and management programs of CECs in aquatic environments and is illustrated in Figure 2.5.

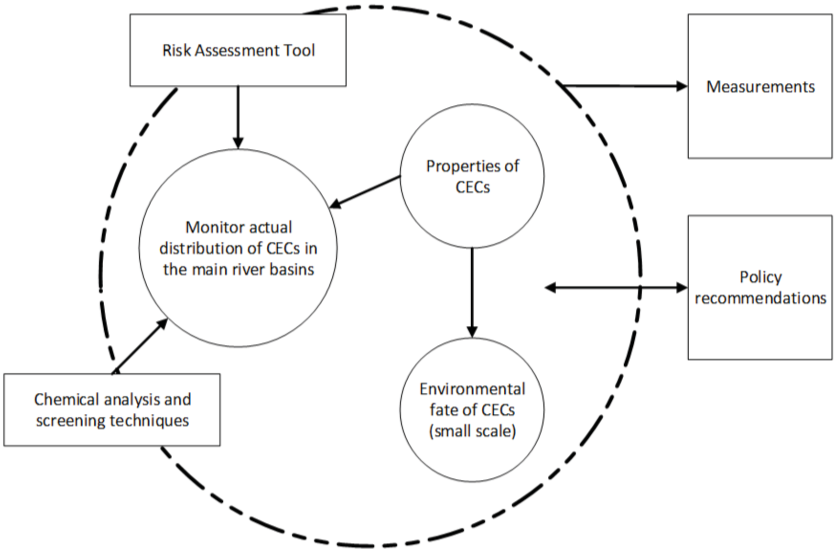


Figure 2.5: Concept for the monitoring and management of CECs in aquatic environments (adapted and redrawn from Geissen et al., 2015).

However, the monitoring of CECs poses several challenges. Due to the sheer number of CECs and their transformation products, it would be impossible to monitor each of the chemicals individually and will be extremely time-consuming and expensive. Another challenge is that the relevance of these chemicals changes a lot over time due to changes in production, use and disposal and the availability of new information about their occurrence, fate, and hazards.

Current methods for the identification and quantification of CECs are based on gas chromatograph (GC) and liquid chromatography (LC) coupled with mass spectroscopy (MS). These methods are hardly used for routine monitoring, as they are sophisticated, time-consuming, and very expensive. Furthermore, these analytical methods are typically dedicated to certain classes of CECs and do by far not cover the full range of CECs.

CEC pollution to surface water can occur from both point and non-point sources of pollution. However, the transport of these chemicals from these sources depends on the properties of these chemicals. These properties, which include volatilisation, biodegradation, polarity and adsorption properties, result in CECs having different reactions and interactions within the water matrix. Monitoring programs needs to take this into account when developing monitoring programs for CECs.

2.6.2 Water treatment process removal capabilities

Westerhoff (2003) aimed at addressing the question: If EDCs and PPCPs are present in raw drinking water supplies, will conventional water treatment processes remove the compounds, or are advanced treatment processes necessary? With funding from AWWA Research Foundation, Westerhoff and co-workers at the Arizona State University and the Southern Nevada Water Authority conducted bench-scale studies that simulate water treatment plant processes on model and natural waters spiked with 30 to 80 different EDC and PPCP compounds at environmentally relevant concentrations.

In these studies, they found that coagulation (alum or ferric) removed less than 20 percent of the compound concentrations. Slightly higher removal rates were observed in the presence of a hydrophobic dissolved organic carbon (DOC) material, indicating some partitioning of hydrophobic EDC and PPCP compounds with the DOC and concurrent removal. EDCs or PPCPs associated with particulate matter (i.e. that were adsorbed) were effectively removed during coagulation, sedimentation, and nonbiological filtration.

Coagulation with either alum or ferric chloride was not efficient at removing target analytes, with only few compounds exhibiting greater than 30% removal.

Westerhoff (2003) also found that powder activated carbon (PAC) added with a 4-hour contact time in a 5 milligram per litre (mg/L) dose achieved more than 90 percent removal of many of the EDC and PPCP compounds studied; some compounds were removed to below detection levels. Other compounds had lower removals (40 to 60 percent); this included ibuprofen, sulfamethoxazole, meprobamate, and iopromide. A trend in removal capability was observed, with hydrophobic compounds (octanol-water partition coefficient (logKOW)>5) having better removal than more polar compounds (deprotonated acids). Removal was dependent upon the PAC brand, PAC dose, and the presence of DOC in the water. The addition of PAC to conventional water treatment plants, similarly to what is currently used seasonally to control odour and taste, may be effective in removing more than 75 percent of EDCs and PPCPs.

Activated carbon, in both PAC and GAC forms, was very effective for the removal of selected contaminants. Adsorption increased with contact time and activated carbon dosage and was affected by the type of activated carbon and the NOM composition of the water.

Biofiltration was simulated using biological acclimated sand. Some compounds appeared to biodegrade; these included acetaminophen, caffeine, DEET, estrone, estradiol, naproxen, ibuprofen, and gemfibrozil. Other compounds were persistent, such as iopromide and meprobamate, and were not biodegraded.

Chlorination (1 to 6 mgCl2/L dose to achieve 1 mgCl2/L residual after 24 hours) either removed compounds by more than 90 percent or led to less than 20 percent removal.

Ozonation (1 to 8 mgO3/L for 3 to 5 minutes) oxidized similar compounds as chlorination but achieved slightly higher percentage removals.

Ultraviolet (UV) irradiation is capable of oxidizing aromatic EDCs and PPCPs but requires approximately 100 times higher UV dosages (greater than 5000 mJ/cm^2) than those required for microbial disinfection (5 to 50 mJ/cm^2). UV irradiation is unlikely to be used for EDC or PPCP removal in surface water treatment plants but may be appropriate for smaller well head treatment systems.

Conventional disinfection processes using free chlorine, chloramine, ozone and UV produced varying degrees of apparent contamination reduction. Advanced oxidation processes using ozone with the addition of H2O2 to enhance hydroxyl radical formation resulted in a marginal increase in removal by ozone alone.

Membrane treatment (ultrafiltration and nanofiltration) demonstrated a range of removal capability in bench-scale tests using dead-end cells. Ultrafiltration (1000 Dalton charged membrane) adsorbed many hydrophobic compounds (log Kow>4) and led to less than 30 percent of the initial compound concentration in the permeate. Nanofiltration also exhibited a high adsorption capacity for hydrophobic EDCs and PPCPs. In the bench-scale tests, hydrophobicity leading to adsorption, and polarity leading to charge repulsions appeared more important than molecular weight in overall EDC or PPCP removal.

Overall, Westerhoff (2003) concluded that, in general, in general, removal of an EDC or PPCP was dependent upon its intrinsic chemical properties, including molecular weight, octanol-water partition coefficient, aromatic carbon content, and functional group composition. Therefore, as additional compounds are identified in water, a fundamental approach should be utilized to evaluate their potential for removal.

The removal of pharmaceuticals and personal care products in wastewater and drinking water treatment plants in the context of water reuse was assessed by Ternes et al. (2004) and the following was reported:

- Diclofenac is a substance removed to a limited extent in WWTPs: low removal rates of about 14% are observed.
- Carbamazepine passes the WWTP without any significant change in concentration, since only up to 10% were the difference between inflow and effluent. Post treatment steps led to an additional 5% loss.

The researchers (Ternes et al., 2004) observed that after a flow time of 75 days in groundwater no additional removal for another 70 days was observed. Concentrations reached after 75 days remained stable for the rest of the flow time investigated. It could not be excluded that a situation with stable concentrations was reached before 75 days, because there was no sampling site between a flow time of 25 and 75 days, respectively.

Snyder et al. (2006) investigated EDC/PPCP occurrence before and after treatment at 20 drinking water utilities across the United States. Utilities treating source waters with known wastewater impact were selected for their increased potential to detect EDC/PPCP concentrations and to evaluate process removal efficiency.

Their study showed that some pharmaceuticals and personal care products could be frequently detectable at ng/L concentrations. They found that some compounds are not well removed by water treatment processes and will occur in finished drinking water. However, the concentrations of these contaminants are extremely low.

Conventional and advanced treatment processes were also evaluated by Snyder et al. (2006) to determine their efficacy to remove a diverse group of CECs. Bench-scale testing with synthetic and natural waters provided an initial screening of all treatment technologies. Atrazine, iopromide, lindane, meprobamate and TCEP proved to be the more difficult recalcitrant of the compounds evaluated.

In pilot-scale and full-scale evaluations using ambient compound concentrations, Snyder et al. (2006) found that full-scale removal was generally well-predicted by bench-scale and pilot-scale experiments. Results consistently showed that advanced treatment technologies such as ozone, UV/H_2O_2, reverse osmosis and activated carbon provided superior removal to conventional technologies such as coagulation, chlorination and chloramination. However, no single treatment process provided complete removal of all target compounds investigated.

In total, Snyder et al. (2006) found that activated carbon, RO/NF membranes, advanced oxidation and riverbank filtration showed superior efficiency for contaminant removal. PAC offers the advantage of removing contaminants when needed (i.e. during seasons of low surface water flows) and provides fresh material on a constant basis. Granular activated carbon is capable of removing all target compounds investigated.

RO and NF offer great promise for contaminant rejection; however, the concentrate waste streams produced during these processes must be considered.

Riverbank filtration has a high potential for contaminant removal and could provide a cost-effective barrier for utilities with suitable source water geography and topography (Snyder et al., 2006; Drewes et al., 2017).

Snyder et al. (2006) made the following recommendations regarding the optimisation of conventional treatment processes for CEC removal:

a. The efficiency of conventional disinfection processes for CEC removal is as follows:
   Ozone >> free chlorine >> chloramine > UV
b. For all these processes, the removal of recalcitrant target compounds increased with larger disinfectant dosage and longer contact time.
c. Lowering pH during chlorination increased the removal of target compounds due to the equilibrium shift from hypochlorite to hypochlorous acid.
d. Chloramine provided significantly less removal as compared to free chlorine. Longer contact times and higher dosages did not compensate for the inferior oxidative power of chloramine (as compared to free chlorine).
e. Ozone was the most powerful disinfectant for removal of target contaminants, with more than 50% of the selected compounds removed to below detection by typical disinfection dosages.
f. The addition of hydrogen peroxide in combination with ozone provided only a marginal increase in contaminant removal.
g. The fire retardant TCEP was not effectively removed by any of the oxidation processes. The structure of target compounds will define reactivity with disinfectants and subsequent removal/transformation.
h. Electron-rich functional groups on contaminants play a vital role in removal/transformation during oxidation processes.

Some EDCs and PPCPs can readily biodegrade, while others are quite resistant to biodegradation. In field and pilot studies, it was difficult to differentiate removal through biological degradation from removal through adsorption. Acetaminophen, caffeine, estradiol, gemfibrozil and ibuprofen all showed rapid degradation. During water reuse processes, biodegradation (i.e. MBRs and activated sludge) can play a major role in contaminant removal.

2.6.3 CEC removal databases and tools for prediction of treatment efficiency for removal of CECs

2.6.3.1 U.S. EPA (2008) Drinking Water Treatability Database (Database)

The drinking Water Treatability Database (TDB) will provide data taken from the literature on the control of contaminants in drinking water, and will be housed on an interactive, publicly available USEPA web site. It can be used for identifying effective treatment processes, recognizing research needs, completing literature reviews, and dealing with regulatory issues. The TDB will be of use to multiple stakeholders, including drinking water utilities, treatment process design engineers, first responders and emergency responders, USEPA researchers, other research organizations, academics, regulators (USEPA Office of Ground Water and Drinking Water, USEPA Office of Pesticides Programs, state regulators), and the public.

2.6.3.2 US EPA (2010) Treating Contaminants of Emerging Concern A Literature Review Database.

To house the data gathered in the literature review, EPA developed a relational database to store information about the reports reviewed, the technologies studied, and their performance. The database is intended as a tool for individuals interested in identifying information about the performance of particular treatment technologies. The report describes The CECs Removals Database, a Microsoft Access® database designed to store and manage information from published scientific studies of the removal of CECs from water and wastewater. The report does not present an analysis of the database information. For illustrative purposes, the report presents 16 of the over 200 CECs present in the database, and the average percent removals achieved by full-scale treatment systems that employ six of the greater than 20 reported treatment technologies. EPA makes no conclusions about these results but provides them only to illustrate how the database may be used.

The report presents:

- A description of the criteria EPA used to identify data for the database.
- A description of the organization of the information in the database.
- As an illustration of database output, a description of removal efficiencies for 16 CECs achieved by full-scale treatment systems that use six selected treatment technologies.

Report Appendices:

Appendix A: CEC Removals Database Output Tables.

Appendix B: Contaminants of Emerging Concern (CECs) Removals Database Version 3 User's Guide for the Non-Access®-Trained User.

Appendix C: CEC Removal Database Bibliography.

Appendix D: Detailed Abstracts of Key References.

2.6.4 Recommendation for further research

Although limited, the data produced indicate that computer modelling provides a useful tool in the evaluation of contaminant removal potential for key treatment processes. The ability to predict chemical properties and fate will provide rapid evaluation of the likelihood that a particular chemical will, or will not, be recalcitrant through a particular unit process.

Some target analytes are very persistent to current treatment processes, such as the flame retardant TCEP and the herbicide atrazine. These contaminants were commonly detected in drinking waters and posed the greatest challenges for removal. Future research should focus on key indicator compounds and establish relationships between these more challenging to remove compounds and other emerging contaminants.

CHAPTER 3: APPROACH AND METHODOLOGY

3.1 INTRODUCTION

In this chapter the methodology and results of the study are presented and discussed with reference to the main objective of the project, which was to investigate de facto reuse in South Africa. Two of the sub-aims of the project is addresses in this chapter: the first to develop a methodology for future monitoring and management of de facto reuse and the second to quantify the extent of de facto reuse in the country.

The methodology, which is presented first, was specifically developed to allow for then determination of the extent of de facto reuse as well as to assist with future monitoring and management of de facto reuse in the country. The results of the wastewater percentage calculations and analysis of indicator compounds, which are subsequently used to determine the extent of de facto reuse in the country are presented secondly.

3.2 APPROACH

This section gives an outline of the methodology that was developed to determine of the national occurrence of wastewater in surface water sources, and which then constitutes de facto reuse of wastewater for drinking water purposes at downstream water treatment plants. The methodology consisted of nine steps:

Step 1: Identifying all wastewater treatment plants in the country as well as the river it discharges to and represent it on a Geographical Information System (GIS) map.

Step 2: Selection of 10 representative rivers for the country using a selection criteria.

Step 3: Identification of relevant wastewater treatment plants, water treatment plants and measuring stations in the selected rivers and represent it on a GIS map.

Step 4: Estimation of the percentage wastewater content of the 10 rivers based on the flow volumes.

Step 5: Based on the calculated wastewater percentage, indicate the class of the receiving river on a GIS map.

Step 6: Sampling of water and wastewater effluent in selected rivers and analysis for indicator compounds

Step 7: Estimate of wastewater content at WTP raw water intake, based on the identified indicator compounds.

Step 8: Estimate the extent of de facto reuse in South Africa.

Step 9: Representation of results on interactive GIS mapping system.

3.3 MAPPING RECEIVING WATER RESOURCES AND WASTEWATER TREATMENT PLANT DISCHARGING POINTS (STEP 1)

The first step in determining the national occurrence of wastewater in surface water sources in South Africa was to identify all wastewater treatment plants in the country as well as the river it discharges to and represent that on a GIS-based mapping system. The mapping system that was used for this project was *Google Earth Pro*.

The mapping system was created by representing South Africa's primary drainage regions and primary river catchments on the mapping system. The names of the drainage regions and catchments were obtained from the National Integrated Water Information System (NIWIS) found on the Department of Human Settlements, Water and Sanitation's website. Google Earth supported files (.kmz) were obtained from the Resource Quality Information Service (RQIS) database. Figure 3.1 and Figure 3.2 shows the primary drainage and river catchments in South Africa, respectively.

Following the mapping of the primary river catchments was the identification of all the wastewater treatment plants (WWTPs) in South Africa, their respective design capacities, and the river their effluent is discharged to. This information was obtained from the Integrated Regulatory Information System (IRIS) and added to the Google Earth mapping system using placemarks. WWTPs are represented as with a green pin as shown in Figure 3.3. When hovering over any of the green pins, the name of the WWTP is displayed and when the user clicks on the icon, a dialog box (Figure 3.4) will appear revealing more information about the chosen WWTP.

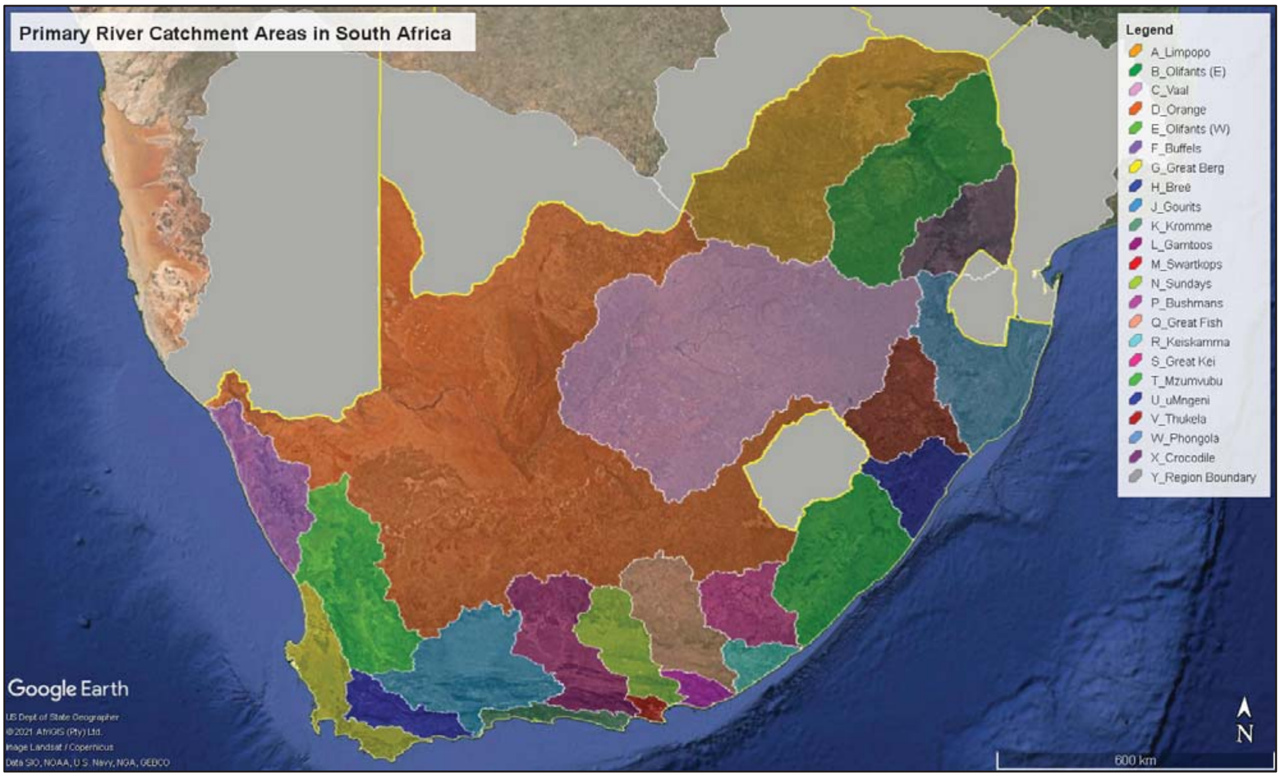


Figure 3.1: Primary drainage regions in South Africa

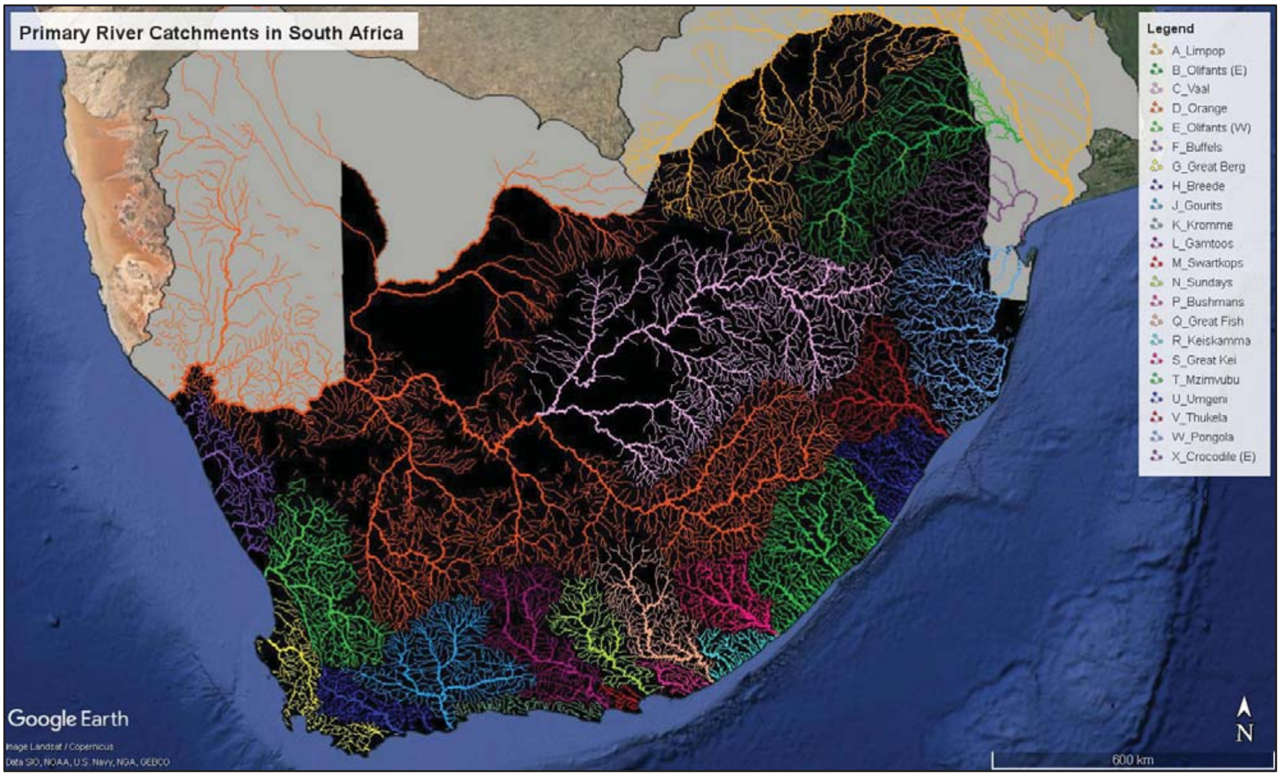


Figure 3.2: Primary River Catchments in South Africa

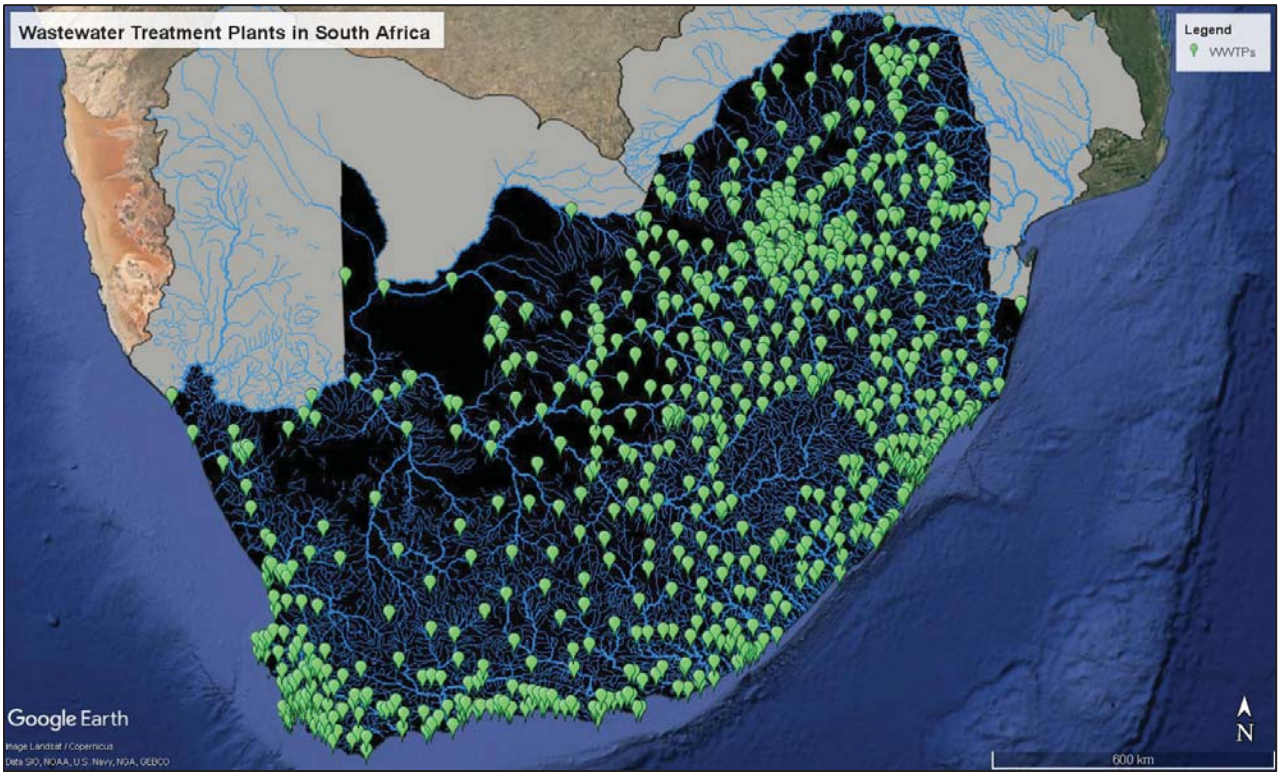


Figure 3.3: Wastewater treatment plants (WWTPs) in South Africa.

Paarl WWTP	
Drakenstein Local Municipality	
Latitude	-33.68929167
Longitude	18.98009722
Design Capacity (Ml/day)	35
Discharge	Berg River

Figure 3.4: Information displayed in WWTP dialog box on the Google Earth mapping system.

3.4 CASE STUDY APPROACH FOR ESTIMATING THE EXTENT OF DE FACTO REUSE IN SOUTH AFRICA

3.4.1 Case study selection (Step 2)

A sample of 10 of South Africa's most important rivers were chosen from the primary river catchments to represent the entire country for the purposes of this study. A selection criteria was followed in order to ensure that the whole of South Africa was represented. This criteria included the following:

- Rivers should geographically represent the entire country,
- The population served by the river should be significant, and
- The state of the river should be notorious for its polluted waters.

3.4.2 Description of selected case study rivers

Using the selection criteria and the GIS mapping system, showing the geographical locations of the selected rivers are shown in Figure 3.5. Table 3.1 provides a short description of each of the rivers, including information about the origin of the river, where the river debouches and its most likely sources of pollution.

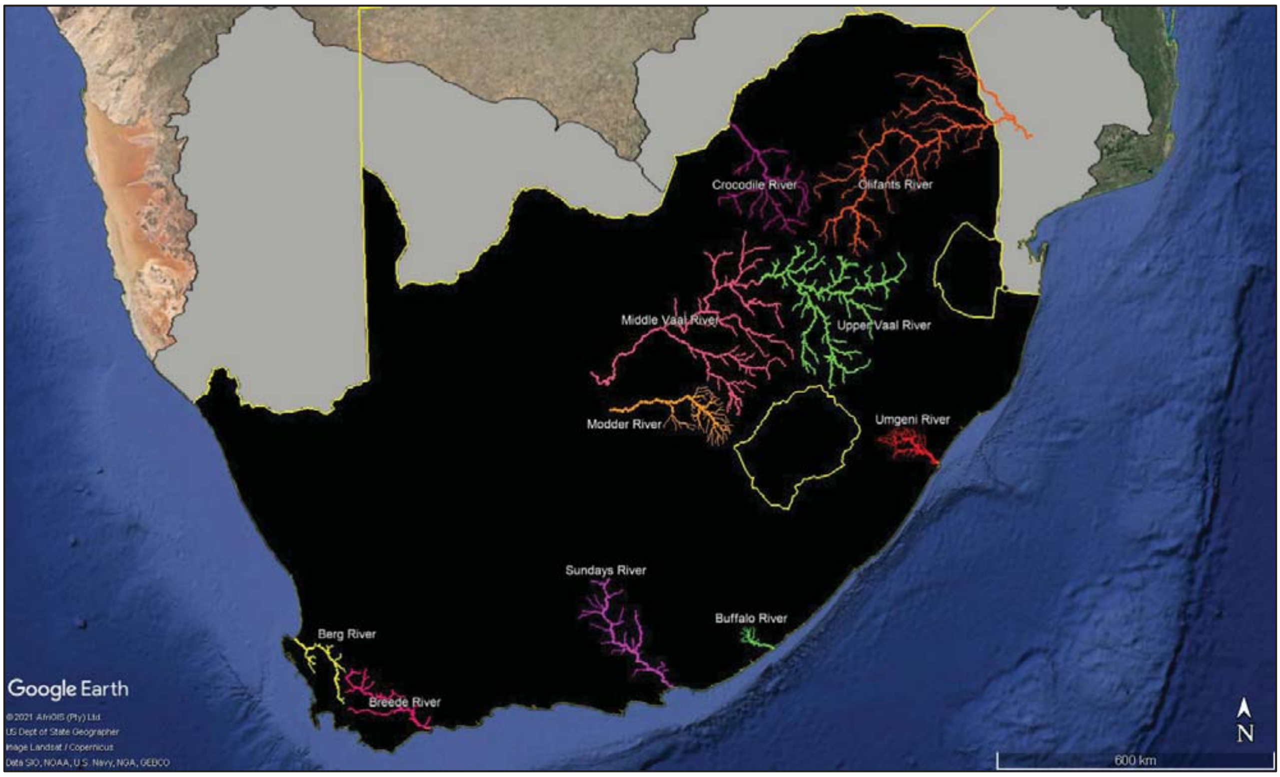


Figure 3.5: Geographical locations of the 10 selected rivers identified for investigation in this project.

Table 3.1: Ten selected rivers known to be highly impacted by wastewater pollution in South Africa.

River	Province	Primary Catchment	Description
Berg River	Western Cape	Berg	The Berg River rises in the Franschhoek and Drakenstein mountains in the Western Cape and flows northwards through Paarl and Wellington, past Porterville, Piketberg and Velddrif and drains into St. Helena Bay on the west coast of South Africa. The Berg River is essential for the local economy and ecology as it provides drinking water for the greater Cape Town region, supplies water to agriculture and industries and support rich aquatic ecosystems (Struyf et al., 2012). The Berg River is impacted by both diffuse pollution from agricultural run-off and point source pollution from urban and industrial wastewater.
Breede River	Western Cape	Breede	The Breede River is the largest river in the Western Cape and provides vital irrigation for the fruit and wine farms long the Breede River Valley. The Breede River originates in the Ceres Valley from where it snakes in a south-easterly direction pass Worcester, Robertson, Bonnievale and Swellendam and meets the Indian Ocean at Witsand. Major tributaries include the Hex River near the town of the De Doorns, the Riviersonderend River and the Buffeljagsrivier. The rapid development of agriculture, urban and particularly sub-urban areas in the Breede River catchment is of especial concern for the water quality of the river (Cullis et al., 2018).
Buffalo River	Eastern Cape	Keiskamma	The Buffalo River is located in the Eastern Cape and is important as the major source of raw water abstraction for irrigation and recreational purposes. The Buffalo River rises in the Amathola Mountains and flows southwards, pass King William's Town, Zwelitsha, and Mdantsane and meets the Indian ocean at the East London harbour. Major tributaries of the Buffalo River include the Cwengcwe, Izele, Mgqakwebe, Ngqokweni and Yellowwoods Rivers (Chigor, Sibanda and Okoh, 2013). The water quality of the Buffalo River is impacted by increased population growth in a small catchment area with inadequate water resources. Dysfunctional and overloaded wastewater systems and wastewater treatment plants with inadequate capacity and poor management.
Modder River	Free State	Vaal	The Modder River is a relatively small river in the central region of the Free State with a minor part in the Northern Cape. The Modder River is tributary of the Riet River and rises near Dewetsdorp and flows westwards pass Botshabelo and Bloemfontein to join the mainstream near Kimberly. The Modder River plays an important role in water supply for domestic, agricultural, and industrial use in the Bloemfontein, Botshabelo and Thaba N'chu areas. The Modder River is impacted diffuse pollution from agricultural run-off and surface water run-off from informal settlements on the banks of the river, as well as point source pollutions from urban and industrial wastewater.

River	Province	Primary Catchment	Description
Umgeni River	KwaZulu-Natal	Umgeni	The Umgeni River is located in KwaZulu-Natal and is the most reliable of the larger rivers in South Africa and is major source of raw water for agricultural, domestic, and recreational use. The Umgeni River rises in the wetlands near Howick and flows eastwards where it meets the Indian Ocean at the Durban harbour. The Umgeni River flows through four dams, namely the Midmar, Albert Falls, Nagle and Inanda dams. A noteworthy tributary of the Umgeni River is the Msunduzi (or Duzi) River which join the Umgeni between the Nagle and Inanda dams (Dikole, 2014). The Umgeni River water quality is impacted by the effects of industrialization, agricultural activities and increasing urban population in the catchment area.
Olifants River	Mpumalanga	Olifants (E)	The Olifants River is a river that goes through Mpumalanga and Limpopo Provinces in South Africa and in Mozambique and is a tributary of the Limpopo River. The Olifants River originates between Breyten and Bethal, in the Mpumalanga Province, and then flows towards the Limpopo Province through Witbank Dam, followed by the Loskop Dam. The river passes the Transvaal Drakensberg and flows across the Lowveld to join by the Letaba River. It then crosses over to the Gaza Province, in Mozambique and joins the Limpopo River that enters the Indian Ocean at Maputo. Pollution in the Olifants River is due to sewage, acid mine water, industrial refuse, weed killers and insecticides.
Crocodile River (W)	North West Province	Limpopo	The Crocodile River starts in the Witwatersrand Mountain range, near Constantia Kloof in Roodepoort of the Gauteng province. It flows through the Lake Heritage Dam west of the Lanseria Airport, before being joined by the Jukskei River. The river then crosses to the North West Province into the Hartbeespoort Dam, passes Brits and then flows into Roodekopjes Dam. After flowing through the Vaalkop Dam, the river is joined by the Elands River. The river then flows through the Klipvoor Dam before being joined by the Pienaars River joins its right bank, and then joins the Marica River in the Limpopo Province. Pollution in the river is mainly due to untreated industrial, mining, agricultural and household waste.
Sundays River	Eastern Cape	Sundays	The Sundays River is described as a life-giving river to the dry and barren Karoo landscape of the Eastern Cape province. The Sundays River rises in the Sneeuberg Mountain range near Graaff-Reinet, and flows south-eastward, around the town of Graaff-Reinet and continues through farming communities to Jansenville. From there the river meanders through the dry Karoo to the Darlington Dam. Outflows from Darlington dam continue to the Addo Elephant National Park, where a weir was built in the river to form a small impoundment, the Korhaansdrift Dam. Below this dam water is transported not only to the river itself but also in canals used for irrigation of citrus farms in the Kirkwood area.

River	Province	Primary Catchment	Description
Sundays River	Eastern Cape	Sundays	From Kirkwood the rive snakes past Colchester where it enters the Indian Ocean. The lower section of the Sundays River is modified by an inter-basin transfer scheme which transports water from the Orange River via the Great Fish River to the Sundays River at the Darlington Dam. The natural river flows are therefore artificially augmented (Janse van Vuuren and Taylor, 2015). The Sundays River is impacted by seasonal droughts, high return flow of irrigation schemes, diffuse and point source pollution form surface water run-off and urban wastewater treatment plants.
Vaal River	Northern Cape, North West Province and Gauteng	Vaal	The Vaal River is the largest tributary of the Orange River. The river has its source in the Drakensberg range near Breyten in the Mpumalanga province. This origin is east of Johannesburg, north of Ermelo and about 240 kilometres from the Indian Ocean. It then flows westwards, southwest of Kimberley in the Northern Cape and forms the border between the Free State and the Mpumalanga, Gauteng, and North West Provinces. Just after Breyten, the river is joined by the Rietspruit River, before flowing through Standerton and being joined by the Klip River. The river is then joined by the Waterval River, which flows by Greylingstad, flows past Villiers, and enters the Vaal Dam. Here the river is joined by the Wilge River and is then joined by the Suikerbosrant River at Vereeniging, before being joined by the Klip River. The river then flows past Sasolburg where it is joined by the Taaibosspruit River and then the Rietspruit River, where the combined river then flows past Parys. For this study, the river up until the town, Parys, is referred to the “Upper Vaal River”. Past Parys the river is referred to the “Middle Vaal River”. Then the river is joined by the Mooi River that flows past Potchefstroom, and thereafter is joined by the Renoster River. After flowing past Orkney, the Schoonspruit River flows past Klerksdorp and joins the Vaal River, before being joined by the Vals River near Bothaville. Then the river enters the Bloemhof Dam, joining with the Vet River that flows past Hoopstad, with the combined river continuing past Christiana, Warrenton and Windsorton. The river is then joined by the Harts River at Delportshoop, before being joined by the Riet River near Douglas, then entering the Orange River. The Orange River eventually enters the Atlantic Ocean at Alexander Bay. The deterioration in water quality in the Vaal River is majorly due to population growth, ageing infrastructure, vandalism, and lack of capacity, which leads to raw or partially treated sewage, as well as mine drainage effluent being pumped into the river.

3.4.3 Identification and representation of relevant WWTPs, WTPs and measuring stations on GIS mapping system (Step 3)

Once the rivers were identified for investigation, the relevant wastewater treatment plants that discharge into the river or its tributaries were identified and represented in the Google Earth mapping system. Following this, all the river flow measuring stations located within each selected river were identified and represented on the mapping system. This was necessary to obtain the river flow volumes for the wastewater percentage calculations. The names and locations for the measuring stations were obtained from NIWIS and the flow data were obtained from DHSWS's hydrology database. The final step was to identify and represent the water treatment plants that abstract from the river. The water treatment plant information was not readily available on any official departmental or municipal websites or documentation. Therefore, in order to obtain this information, the relevant water authorities, technical directors and/or managers were contacted to provide this information.

Figure 3.6 shows an image of the Breede River on the GIS map and the WWTPs, WTPs and measuring stations relevant to the Breede River for this project.

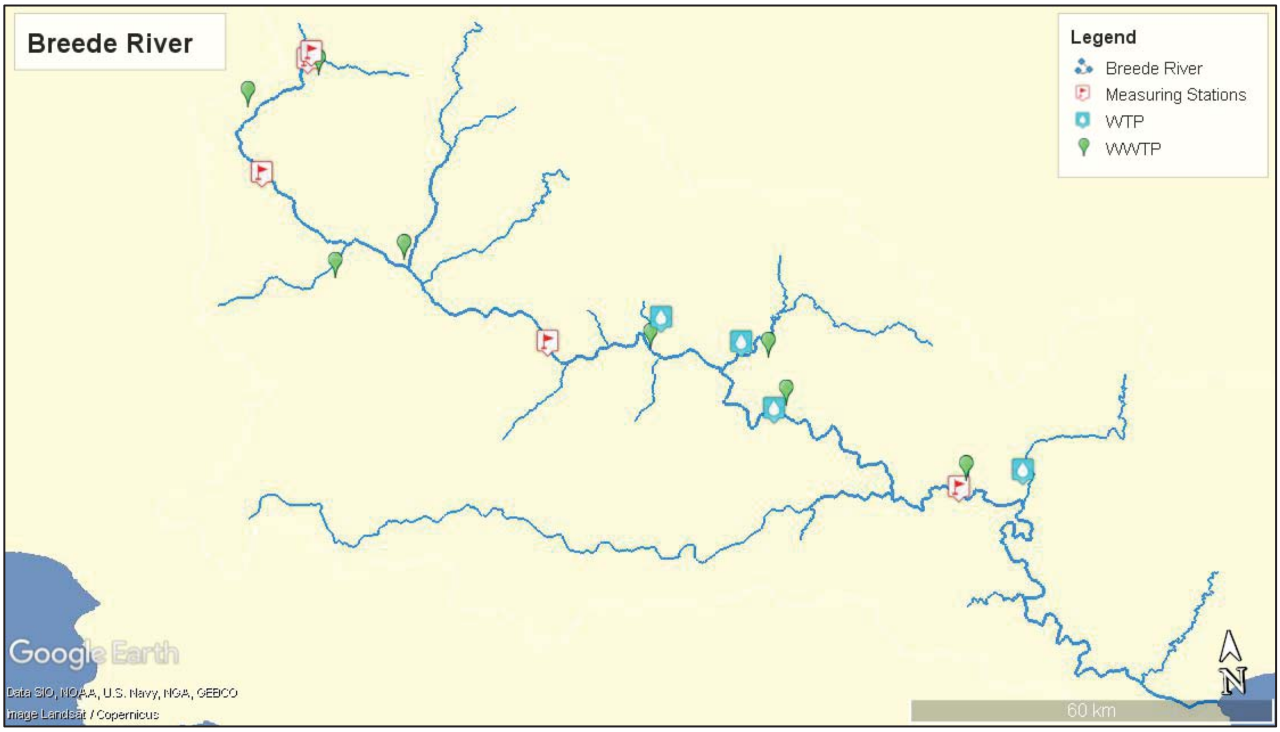


Figure 3.6: The Breede River and all its WWTPs, WTPs and measuring stations.

3.4.4 Estimation of wastewater percentages (Step 4)

The simplest methodology used to quantify the percentage wastewater that makes up the raw water source which serves as the intake to WTPs, is a flow-based methodology. This methodology is simply a flow-based estimation of the ratio of wastewater contained in a water sources, as a percentage. It is the simpler method to use since the alternative method requires the use of chemical constituents that ought to be indicative of human and industrial wastewater. However, finding such a constituent is much more complicated than it seems at first. The flow-based method is therefore the preferred method, despite having its own limitations.

In 1980, the US EPA published a document wherein they illustrate the power and simplicity of the flow-based methodology for quantifying de facto reuse throughout the United States (Swayne, 1980). In this document they outline the basic method used to provide an accurate estimation of the volumetric percentage of wastewater present in a water body that serves as a water source at the abstraction point of a water supply system (typically a municipal WTPs).

The method consists of finding the flow rate of the river at the abstraction point, or the flow rate of the river feeding the basin where the abstraction point of the WTPs is located. This flow rate is then used with the cumulative sum of any upstream WWTPs discharging into the river. The percentage wastewater in the source is the calculated by dividing the cumulated wastewater flow by the sum of the average river flow rate and the accumulated wastewater flow rate (Equation (9)) (Rice, 2014). This calculation assumes that average river flows do not include municipal wastewater inputs, due to the gauge adjustment being restricted by limitations in the number of stream gauges within a section of river.

$$\%_{wastewater\ in\ source} = \frac{cumulated\ wastewater\ flow}{\sum average\ river\ flow\ and\ accumulate\ wastewater\ flow} \quad (9)$$

The basic requirements for implementing this method are therefore:

- A database with river flow data at known GPS locations (flow weir, or gauge data)
- A database with the discharge volumes of WWTPs and the GPS locations where they discharge into rivers.

With this information, it is possible to calculate the percentage of wastewater contained in any surface water source where abstraction takes place for a WTPs. Unfortunately, there are also some difficulties with this method. Firstly, the information may not be readily available. Secondly, the information may change at any time. All WWTPs have variations in their performance and daily effluent discharge volumes. On the other hand, river systems are also subject to seasonal variation. Therefore, the following assumptions are typically made when performing these calculations:

- Assume that WWTP effluent is the sole contributor to wastewater in the river system.
- Assume that every WWTP discharges a volume equal to its design capacity.
- Assume all water bodies are completely mixed hydraulically.

With these assumptions, the data requirement for following this method is significantly reduced and the calculations are simplified. It may not be completely accurate, but for the purposes of this study, it is not truly required to be accurate within 5% since this is only to serve as an initial screen for identifying rivers that may require further investigation.

The wastewater percentages in the selected rivers were determined with the use of the identified WWTPs, WTPs and measuring station on the GIS mapping system as described in *Section 3.4.3*. The wastewater percentages were calculated at the measuring stations and WTPs downstream on the WWTPs by taking the cumulative wastewater flow and dividing it by the sum of either the minimum average or median river flow rate and the accumulated wastewater flow rate as shown in Equation (9).

To demonstrate this methodology, the Berg River will be used as example. Figure 3.7 shows an image of the Berg River on the GIS map and the WWTPs, WTPs and measuring stations relevant to the Berg River for this project.

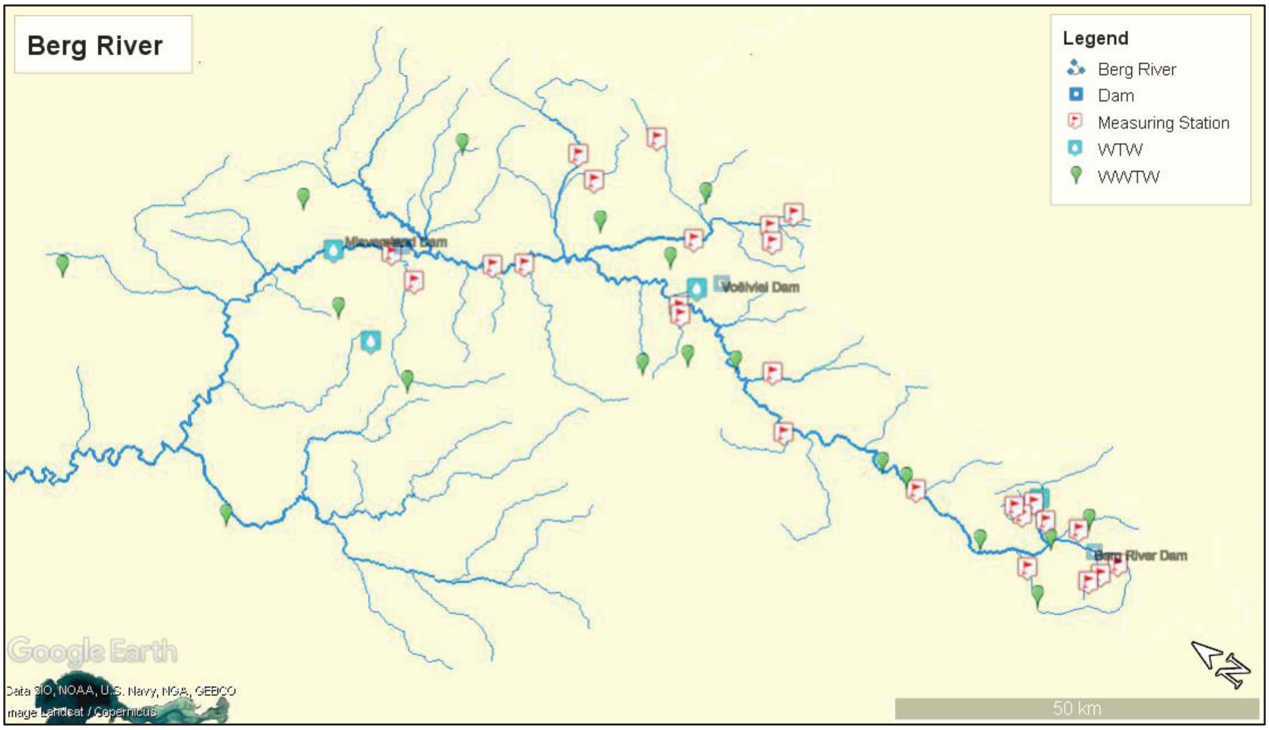


Figure 3.7: Berg River and all its WWTPs, WTPs and Measuring Stations.

A table of the wastewater treatment plants, and their design capacities were compiled, as indicated in Table 3.2. Following this, a table containing all the measuring stations and water treatment works downstream of the WWTPs in order of appearance relative to the WWTP was compiled (

Table 3.3). The minimum, average, and median flow rates of the river at the measuring station was also added to this table. The flow rate at the water treatment works was assumed to be the same as the upstream measuring station or the sum of the measuring station flow rates if there was a tributary flow into the river upstream of the WTP and downstream of the measuring station in the primary river. The wastewater percentages were subsequently calculated and shown in Table 3.4. The full calculation table and the calculations for all time periods for the Berg River can be found in Appendix B.

Table 3.2: Wastewater Treatment Plants discharging into the Berg River or a tributary

WWTP	Design Capacity (ML/day)
Pniel	1.35
Wemmershoek	0.85
Pearl Valley	2
Paarl	35
Wellington	16
Tulbagh	2.46
Porterville	1.2

Table 3.3: Measuring Stations and Water Treatment Works in the Berg River downstream of the WWTPs with their minimum, average, and median flows for 2015.

Measuring station/ Water Treatment Works	Coordinates		2015 River Flow Measurements (m^3/s)		
	Latitude	Longitude	Min	Avg.	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.1862	0.4684	0.3187
G1H020: Berg @ Daljosafat	-33.707554°	18.974283°	2.6634	5.3257	4.2276
G1H079: Berg @ Zonquasdrift	-33.341924°	18.979018°	1.4256	3.9966	3.2969
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	2.4618	5.8122	4.4205
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.3062	3.0166	1.2162
Withoogte WTW	-33.068256°	18.668064°	0.3062	3.0166	1.2162
Piketberg WTW	-32.965256°	18.741069°	0.3062	3.0166	1.2162

Table 3.4: Calculated Wastewater Percentages in the Berg River

Berg River							
Measuring station/ Water Treatment Works	2015 River Flow Measurements (m^3/s)			Cumulative flow of WWTPs	% wastewater in river (m^3/s) when river flow is at its minimum, average, and median flow		
	Min	Avg.	Median		Min	Avg.	Median
G1H078 Dwars River	0.1862	0.4684	0.3187	0.0156	8%	3%	5%
G1H020: Berg@ Daljosafat	2.6634	5.3257	4.2276	0.0486	2%	1%	1%
G1H079: Berg @ Zonquasdrift	1.4256	3.9966	3.2969	0.6389	31%	14%	16%
G1H013 Berg @Drieheuvels	2.4618	5.8122	4.4205	0.6674	21%	10%	13%
G1H031 Berg @ Misverstand	0.3062	3.0166	1.2162	0.6813	69%	18%	36%
Withoogte WTW	0.3062	3.0166	1.2162	0.6813	69%	18%	36%
Piketberg WTW	0.3062	3.0166	1.2162	0.6813	69%	18%	36%

3.4.5 River classification on the GIS map (Step 5)

Once the wastewater percentages have been calculated, it would be useful to display the results to the reader or user in a way that will give the reader/user an instant indication of the overall state of the rivers. This can be achieved through the implementation of a colour coding system. This will allow the reader/user to see which rivers are the most contaminated with wastewater based on the colour index.

In 2014, Umgeni Water decided to update their internal river and impoundment water quality indices (WQI's) used to classify the water resources in their area of operation (Hodgson et al., 2014). This colour coding system was used as the basis on which our colour coding system was developed.

The system was originally developed in 1990 and were sub-divided into three sections:

- **River WQI** – used as an indicator of catchment and river health and contamination.
- **Impoundment WQI** – used as an indicator of eutrophication risks and treatability of impounded water.
- **Raw water WQI** – used as an indicator of the treatability risk posed for potable water treatment.

For each of these sub-divisions, several indicator parameters where selected and provided with a weight based on relevance regarding health risks to humans and the environment. Apart from the weighted indicators, several other key parameters were also selected to act as "override parameters". These are parameters that will immediately change the status of a river to its worst condition should the parameter value fall within some critical limit.

An average weighted score is used to produce a single class value per sample point. In order to perform these calculations, each indicator parameter will be assigned several ranges of values wherein the tested sample can fall. For each of the ranges, a fixed score is assigned. This score is then multiplied by the weighting for that parameter in order to obtain a weighted score for the parameter. A class value for a sample point is then calculated by dividing the sum of all the weighted scores for all the parameters by the sum of the weighting factors themselves.

These class values can then also have some symbol and description assigned to them in order to provide some additional information when required. Table 3.5 illustrates the WQI Class Value descriptions.

Table 3.5: WQI Class Value descriptions (Hodgson et al., 2014)

Class Value	Class	Description
> 85	A	Excellent
75-85	B	Good
60-75	C	Satisfactory
45-60	D	Poor
30-45	E	Unsatisfactory

If a graphical information system (GIS) is available, or in place, it can easily be used to receive the class values for the different sampling points in order to add a colour filter to the GIS which can then be used to display the class value (or status) of each of the water bodies based on the information obtained from sampling those bodies as the designated sample points. A simple rule can be used to allocate a certain colour to a class value, and the class values can then be added to the database from which the GIS obtains its information.

A helpful addition to the GIS would then also consist of adding pop-up screens or text spaces where more information could be displayed. It should be noted, however, that the more information being displayed, the more work it will be to run, operate and maintain the databases, especially if the data being displayed requires frequent updating, for example adding environmental observations like odour and appearance of a water source where the odour and appearance of the water source may change on a daily basis.

An example of an operational GIS system where WQI's are used and text spaces for displaying additional information can be seen in the work done by Hodgson et al. (2014), which is shown in Figure 3.8.

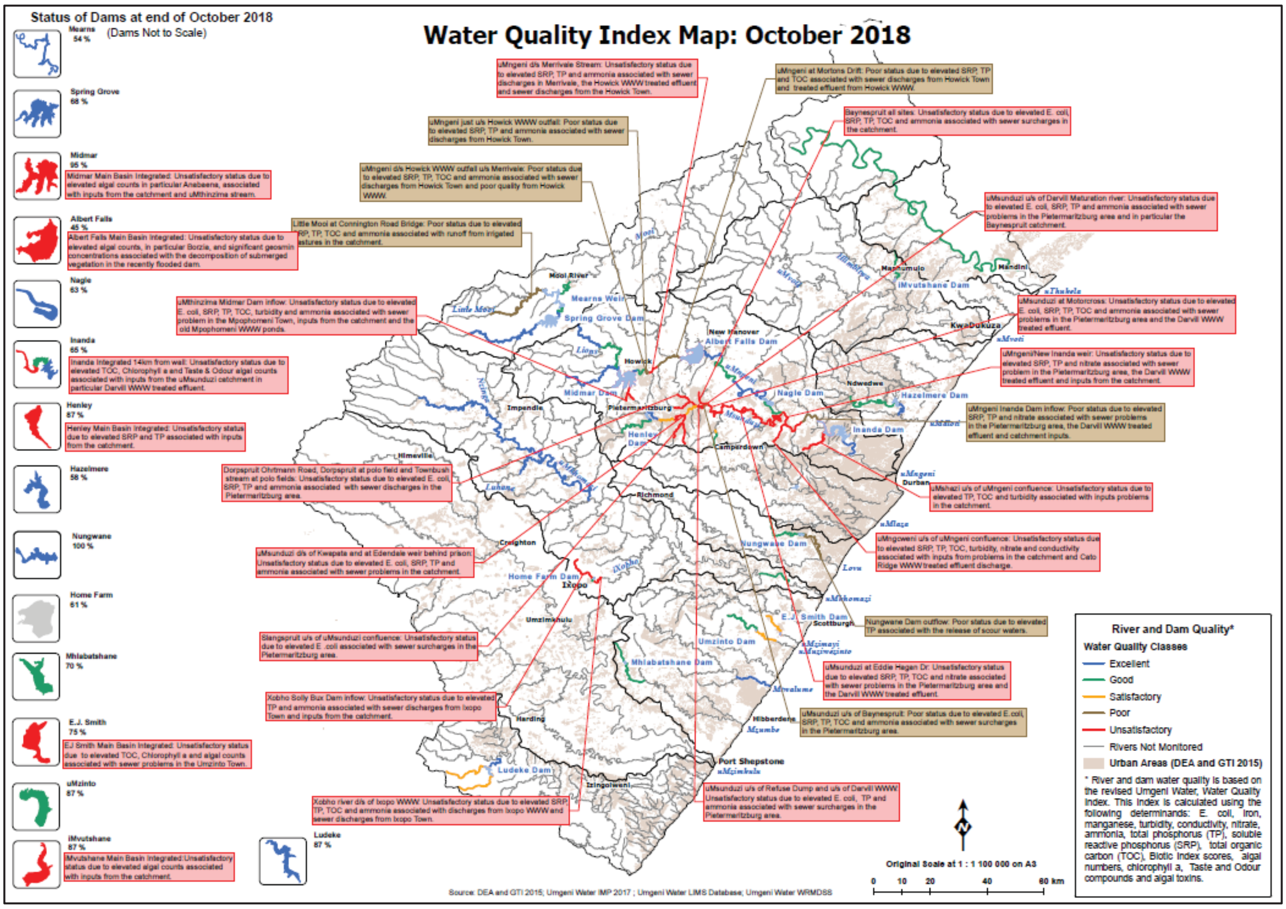


Figure 3.8: Water Quality Index Map of Umgeni Water (Hodgson et al., 2014)

The same concept was used to classify the wastewater contribution to the rivers in the De Facto study. The colour codes were however chosen not to indicate risk, but rather indicate the impact the percentage wastewater would have on the surface water. Table 3.6 shows the classification used to indicate the wastewater contributions to the river.

Table 3.6: Wastewater Contribution Classification

Class Value	Description
< 10%	Good river water quality; little effect on downstream WTP's
10-50%	Intermediate river water quality; increasing effect on downstream WTP's
> 50%	Poor river water quality; definite effect on downstream WTP's; classified as de facto reuse water source
	Part of river not included in current study

The colours were then applied to the wastewater percentage calculation tables, as shown in Table 3.7, to classify the river according to the contribution of wastewater to the river.

Table 3.7: Wastewater percentage contributions to the Berg River in 2015

Berg River							
	2015						
Measuring station/ Water Treatment Works	River Flow Measurements (m^3/s)			Cumulative flow of WWTPs	% wastewater in river (m^3/s) when river flow is at its minimum, average, and median flow		
	Min	Avg.	Median		Min	Avg.	Median
G1H078 Dwarf River	0.1862	0.4684	0.3187	0.0156	8%	3%	5%
G1H020: Berg @ Daljosafat	2.6634	5.3257	4.2276	0.0486	2%	1%	1%
G1H079: Berg @ Zonquasdrift	1.4256	3.9966	3.2969	0.6389	31%	14%	16%
G1H013 Berg @ Drieheuvels	2.4618	5.8122	4.4205	0.6674	21%	10%	13%
G1H031 Berg @ Misverstand	0.3062	3.0166	1.2162	0.6813	69%	18%	36%
Withoogte WTW	0.3062	3.0166	1.2162	0.6813	69%	18%	36%
Piketberg WTW	0.3062	3.0166	1.2162	0.6813	69%	18%	36%

These colour coded contributions were then used to draw a map of the river showing the river and the wastewater contributions to the different sections of the river, as illustrated in Figure 3.9 and Figure 3.10 for minimum and average river flow in 2015, respectively. The difference in the classification of the river between the two flow seasons can clearly be seen.

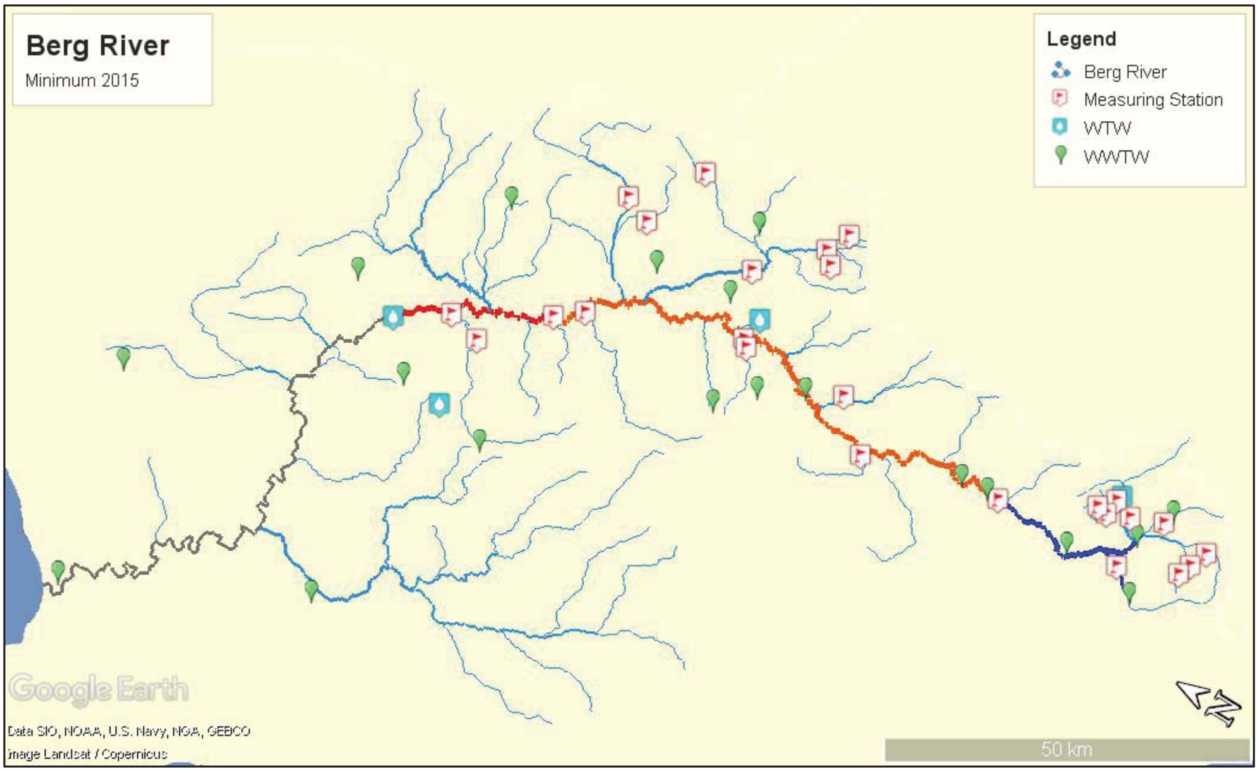


Figure 3.9: Wastewater effluent contributions to the Berg River in 2015 during minimum flow using the wastewater classification colour index.

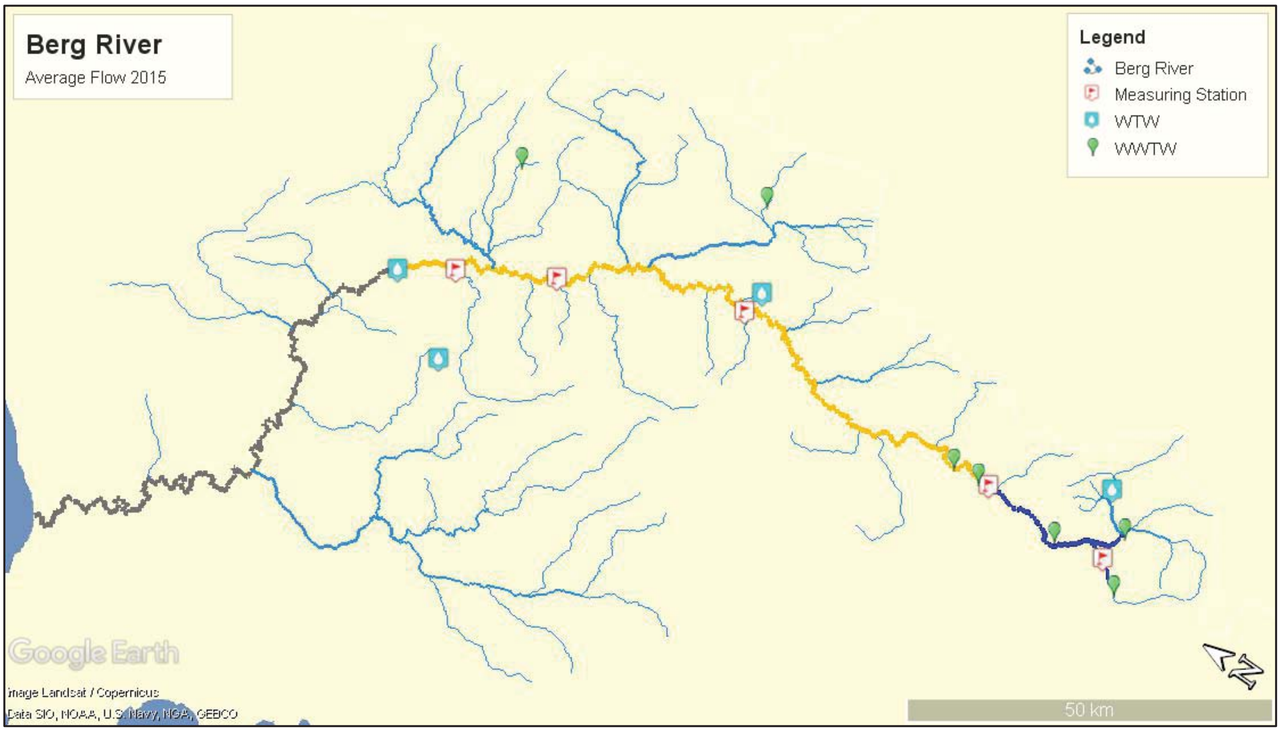


Figure 3.10: Wastewater effluent contributions to the Berg River in 2015 during average flow using the wastewater classification colour index.

3.4.6 Sampling and Analysis (Step 6)

An alternative approach to the flow-based estimation of wastewater in surface waters, is to make use of indicator compounds that are indicative of domestic wastewater. This method requires the sampling and analysis of the water in order to determine the presence and quantity of the selected indicator compounds, as listed in Section 2.5. The sampling and analysis procedures is described in this section.

3.4.6.1 Water quality parameters

The water quality parameters that were analyses for included the list of CECs as given in Table 2.5 in Section 2.5.2 as well as physico-chemical water quality parameters such as pH, electrical conductivity (EC), UV_{254} chemical oxygen demand (COD) and dissolved oxygen (DO).

3.4.6.2 Sampling locations

The location of the sampling sites was determined with the use of the locations of the relevant water and wastewater treatment plants and measuring stations on the GIS mapping system as described in Section 3.4.3. The sites were chosen so as to ensure that a complete picture of the river water quality is obtained. Maps showing the sampling locations in each of the selected rivers are shown in the results section.

3.4.6.3 Sample collection and preparation

Grab samples of 500 mL each in pre-rinsed PET bottles were taken of wastewater effluent at WWTP, raw intake water at WTP and river water at measuring stations during 10 sampling events between March 2019 March 2021. The samples were kept cold during sampling and transportation to the laboratory. Sample filtration and extraction occurred upon arrival at the laboratory. Duplicate samples (100 mL each) from each sampling site were filtered using a 0.7 µm glass microfibre filters (grade GF/F: Whatman®, Sigma-Aldrich) using a vacuum manifold. Each duplicate was then spiked with 50 µL of a 1 µg/mL internal standard (IS) stock mixture. The spiked aqueous samples were then extracted using Oasis HLB cartridges (3 cm^3, 60 mg). The cartridges were conditioned under gravity using 2 mL of HPLC-grade Methanol followed by 2 mL of ultrapure water and ±0.1% formic acid. The samples were then passed through the cartridges at a rate 5 mL/min, washed with 4 mL ultrapure water and allowed to run dry for at least 30 minutes. The dried cartridges were then frozen until the day of analysis for elution. On the day of analysis, the frozen cartridges were removed from the freezer and dried for 30 minutes. The cartridges were then eluted with 4 mL HPLC-grade Methanol into 5 mL sanitized glass tubes and dried under a gentle stream of nitrogen (5-10 psi, 25°C) in an evaporation cupboard. 500 µL of HPLC-grade methanol was then added to the dried samples and reconstituted in 100 mL LC-MS vials for the WWTP and 50 mL inserts for the WTP and river water.

3.4.6.4 CEC analysis

The analysis of these samples was done using the same method as reported by Archer, Wolfaardt and Tucker (2020).

Chromatography was acquired using an ultra-performance liquid chromatograph (UPLC; Waters AQUITY). Separation of the target analytes was achieved using de-ionised water (MilliQ) containing 0.1% formic acid (Mobile phase-A) and 100% HPLC-grade methanol (Mobile phase-B). Starting conditions were 100% mobile phase-A which were maintained for 0.2 mins and then reduced to 10% mobile phase-A over 6.8 mins and to 0% mobile phase-A over 0.1 mins. This was returned to 100% mobile phase-A over a period of 0.4 mins and maintained for 2.5 mins to allow for re-equilibration. The total run time was 10 mins.

This method used a reversed-phase BEH C18 column (Waters AQUITY, 1.7 µm pore size, 2.1 x 100 mm) equipped with a 0.2 µm in-line column filter. The column temperature was maintained at 50°C. The flow rate of the mobile phases was set at 0.4 ml/min and a sample injection volume of 2 µl. The UPLC was coupled with a triple quadrupole mass spectrometer (Xevo TQ-MS, Waters AQUITY) equipped with an electron spray ionisation source. All the analytes were determined using a positive ionisation mode (ESI+).

Nitrogen was used as both nebulising and desolvation gas, and argon as collision gas. The acquisition of the LC-MS data was achieved using a multiple reaction monitoring (MRM) mode using two fragment ions for each compound where possible. Linearity of a reference standard calibration curve for each target analyte was achieved using a 10-point concentration calibration curve (range 1 ng/mL to 750 ng/mL) during each sample analysis run in the same solvent as the re-constituted water samples (MeOH). The integration of the analyte standard curves and surface water sample concentrations were determined using the TargetLynx software (Version 4.1, Waters).

The quality and quantification of the analysis in the measured samples followed the criteria set by the European Commission Council Directive 2002/657/EC. Figure 3.11 illustrates a flow diagram of the analysis.

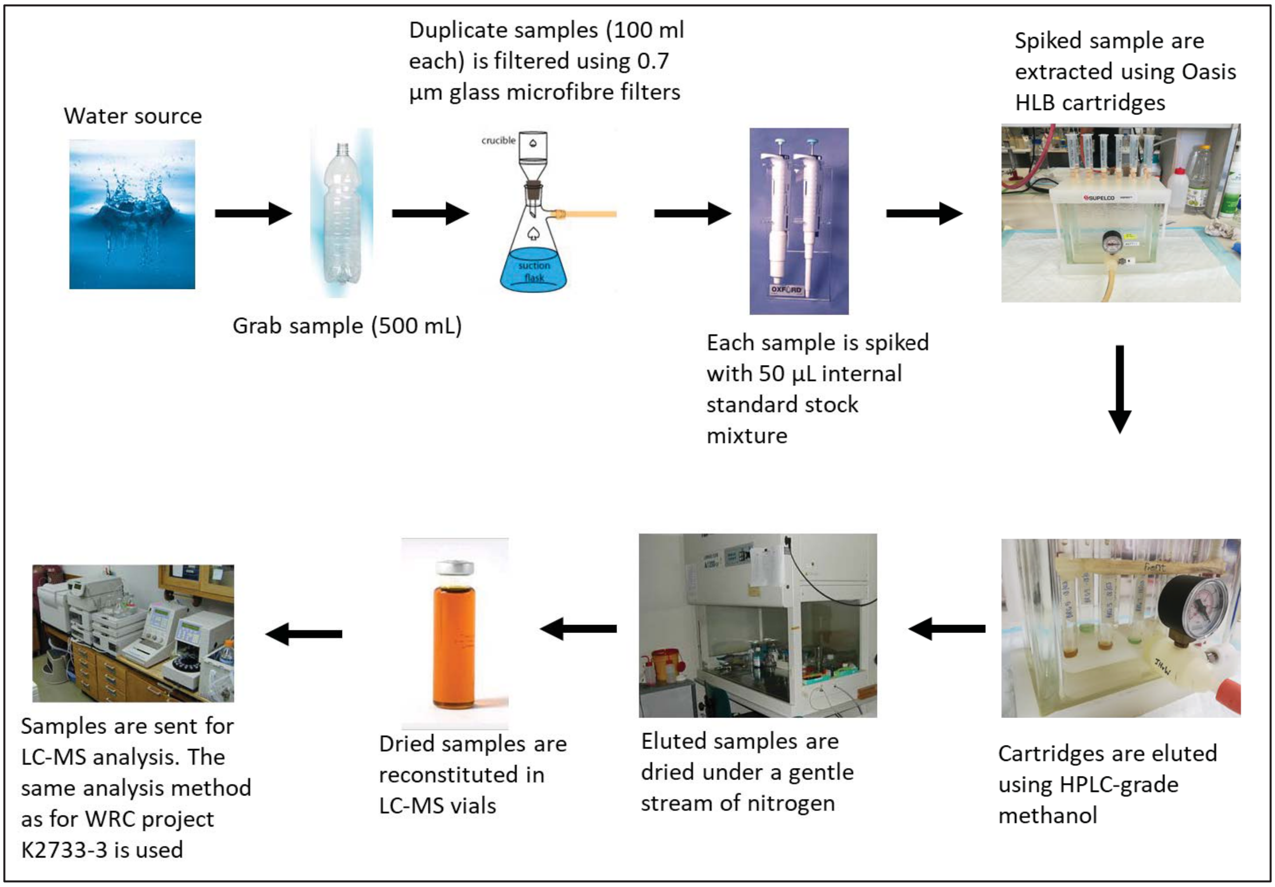


Figure 3.11: CEC sample analysis flow diagram

3.4.6.5 Physico-chemical analysis

Chemical oxygen demand (COD) was measured using the Spectroquant COD kit (CAT no. 1.14541.0001; Merck) according to the manufacturer’s instructions. Briefly, water samples were filtered using 0.7 µm glass fibre filters (CAT no. FT-3-1105-047; 47 mm, Sartorius) and a volume of 3 mL of the test sample filtrate added to the COD kit reaction cells. The reaction cells were digested for 2 hours at 148°C using a Spectroquant TR320 digester (Merck), allowed to cool down to room temperature and COD (in mg/L) measured using a spectrophotometer (Spectroquant Pharo300, Merck).

For the UV254 measurements, a volume of 4 mL unfiltered test water samples were added to a 5 mL quartz rectangular cuvete and absorbance/transmission measured at a wavelength of 254 nm on a spectrophotometer (Spectroquant Pharo300, Merck).

3.4.6.6 Data processing

The results obtained from the LC-MS analysis are processed using statistical analytical software. These results where then further processed using Microsoft Excel, configuring tables and graphs for visual representation in the report.

3.4.7 Estimation of wastewater content at WTP intakes based on indicator compounds (Step 7)

Wastewater content at drinking water treatment plant intakes were estimated based on the measured concentration of indicator compounds in wastewater effluents. In order to calculate this, a similar methodology as used by Rice, Via and Westerhoff (2015) were followed. They predicted the sum of CECs at downstream WTP intakes, by multiplying the De Facto Reuse (DFR) (which is the wastewater percentage in the case of this study) with the cumulative concentration of 13 common CECs found in treated wastewater based on literature.

CEC concentrations at WTP intakes in this study were estimated by multiplying the flow-based wastewater percentage calculated in Step 4 for the average flow over the five years, with the cumulative concentration of the sum of the measured indicator compounds at upstream wastewater treatment plants.

3.4.8 Estimation of the extent of de facto reuse in South Africa (Step 8)

Possible de facto reuse conditions can be identified with the assistance of this conceptual approach. A river is classified as having a wastewater content at such a level that a water treatment plant using this water to produce drinking water will be classified as a de facto reuse water treatment plant. Therefore, when a WTP abstracts water from a section of river that contains more than 50% wastewater, based on the flow-based calculations, that WTP can be classified as a potential de facto reuse plant. A WTP that abstracts water from a section of river that contains a higher measured concentration of CECs than estimated can be classified as a potential de facto reuse plant.

A combination of the calculated wastewater percentages and the results from the CEC data analysis were used to identify wastewater impacted hotspots in the selected rivers and de facto reuse water treatment plants. These results were then used to estimate the extent of de facto reuse in South Africa.

3.4.9 Representation of results on the interactive GIS mapping system (Step 9)

Finally, the results of the calculated wastewater percentages and the CEC analysis was added to the interactive mapping system. When the user clicks on a WWTP pin, WTP pin or measuring station pin on the GIS map, a dialog box opens to reveal the wastewater percentages calculated at that point, as well as the CEC and physico-chemical results if a sample was taken at that point. An example of the dialog boxes is shown in Figure 3.12. The interactive GIS mapping system is included with this report as Appendix A and is given as a separate .kmz file.

Paarl WWTP	
Drakenstein Local Municipality	
Latitude	-33.68929167
Longitude	18.98009722
Design Capacity (Ml/day)	35
Discharge	Berg River
Trace Organics	
CEC's*	**Concentration (ng/L)**
Caffeine	273.8
Sulfamethoxazole	625.7
Carbamazepine	2126
Dichlofenac	462.7
Efavirenz	10504
Emtricitabine	285.8
Methaqualone	129.8
Acetaminophen	<IQL
Atrazine	-
Wastewater Characteristics	
Parameter	**Result**
pH	7.76
EC (mS/m)	71
COD (mg/L)	314
UV254 (measured) (m^{-1})	0.285
DOC (calculated) (mg/L)	5.55
DO (mg/L)	-

CEC's = Chemicals of Emerging Concern

Figure 3.12: WWTP dialog box on the interactive GIS mapping system

CHAPTER 4: DETERMINING THE IMPACT OF WASTEWATER DISCHARGES ON RAW WATER QUALITY FOR DRINKING WATER PRODUCTION

4.1 INTRODUCTION

This section presents the results of the wastewater percentage calculations (as described in section 3.4.4) as well as the CEC data analysis of the samples taken in each of the selected rivers. The results are presented as case studies under each of the selected rivers and discussed with reference to the aims as mentioned. The results are presented as case studies under each of the selected rivers and discussed with reference to the aims as mentioned.

4.2 ESTIMATING THE CONTRIBUTION OF WASTEWATER DISCHARGES IN SELECTED CASE STUDIES

4.2.1 Wastewater content and chemicals of concern in the Berg River

4.2.1.1 Flow based wastewater percentage results for the Berg River.

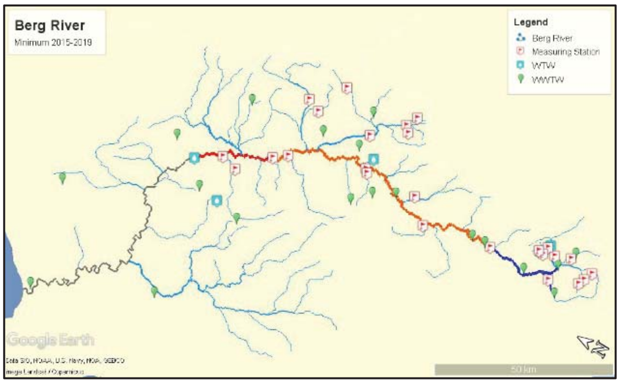
The flow-based wastewater contributions to the Berg River are shown in Table 4.1. The table shows the results obtained for years 2015 to 2019 as well as the average for the five years. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix B.

Table 4.1: Flow-based wastewater percentage results for the Berg River for the years 2015-2019

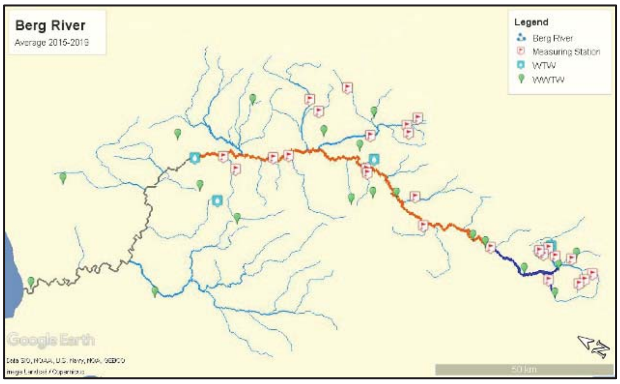
Berg River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
G1H078 Dwars River	8%	3%	5%	8%	3%	4%	11%	4%	5%
G1H020: Berg@Daljosafat	2%	1%	1%	2%	1%	1%	6%	2%	2%
G1H079: Berg@Zonquasdrift	31%	14%	16%	28%	11%	11%	73%	27%	33%
G1H013 Berg @ Drieheuvels	21%	10%	13%	20%	7%	10%	44%	23%	25%
G1H031 Berg @ Misverstand	69%	18%	36%	42%	6%	11%	92%	53%	64%
Withoogte WTW	69%	18%	36%	42%	6%	11%	92%	53%	64%
Piketberg WTW	69%	18%	36%	42%	6%	11%	92%	53%	64%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
G1H078 Dwars River	5%	2%	3%	27%	18%	20%	9%	3%	5%
G1H020: Berg@Daljosafat	3%	1%	2%	4%	2%	2%	3%	1%	1%
G1H079: Berg@Zonquasdrift	32%	11%	12%	97%	46%	47%	40%	16%	17%
G1H013 Berg @ Drieheuvels	25%	7%	11%	53%	27%	29%	28%	11%	15%
G1H031 Berg @ Misverstand	50%	4%	9%	93%	79%	83%	63%	10%	19%
Withoogte WTW	50%	4%	9%	93%	79%	83%	63%	10%	19%
Piketberg WTW	50%	4%	9%	93%	79%	83%	63%	10%	19%

The results from the wastewater percentage calculations indicate that the lower section of the Berg River, below measuring station G1H079 is more probable to contain higher percentages of wastewater than the upper section of the river, which is especially true during seasonal droughts when the river flow is at a minimum. These results show that, during minimum flow, the two downstream water treatment plants abstracting from the river can be considered as de facto reuse plants, based on the calculated flow-based wastewater percentages.

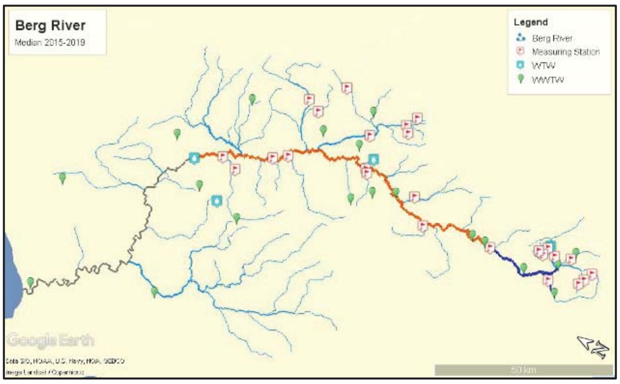
As described in Section 3.4.5, the river was also classified according to colour, based on the percentage calculated. Figure 4.1 (a), (b) and (c) shows the colour coded classification of the Berg River based on the average flows from 2015-2019. Larger maps, showing the minimum, average and median classifications for each year can be seen in Appendix B.



(a)



(b)



(c)

Figure 4.1: Wastewater contribution in the Berg River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.1.2 Chemicals of emerging concern in river and wastewater samples

Samples were taken at strategic points in the Berg River, hereafter the samples were analysed for chemicals of emerging concern. The samples consisted of river water and wastewater effluent.

Figure 4.2 shows a map of the Berg River with the marked sampling locations. The results of the CEC analysis are presented in terms of concentration as well as mass loading for the Berg River case study. Concentration is the mass of the pollutant in a defined volume of water and is useful to assess water quality when used for point-sources of pollution such as for wastewater effluent. Mass load is the amount of a pollutant that is discharged into a water body during a set period of time (e.g. in terms of grams per day), and is useful when evaluating the water quality of the entire watershed. Both concentration and mass loading can provide information of environmental significance.

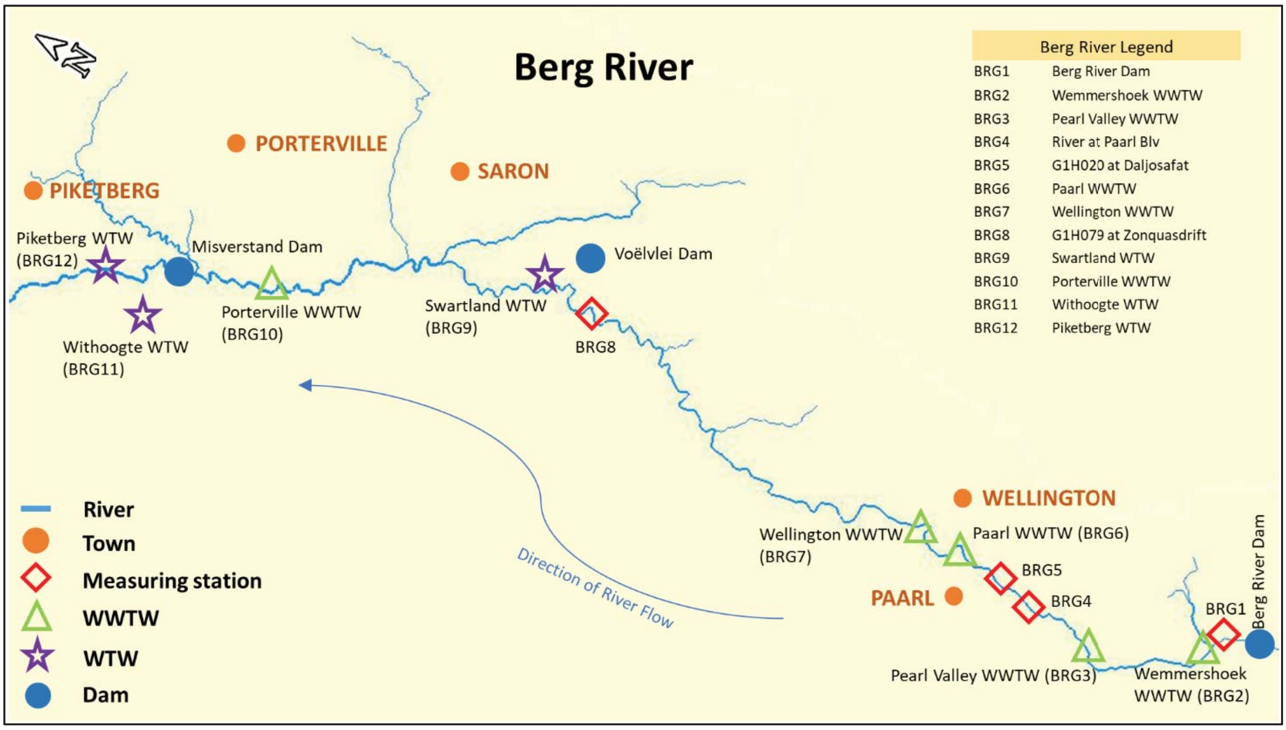


Figure 4.2: Map of the Berg River sampling locations for CEC analysis

Figure 4.3 show the results of eight indicator CECs found in the Berg River in terms of concentration. These eight contaminants were chosen to be presented graphically, as these contaminants are most commonly found at elevated levels in South African water sources.

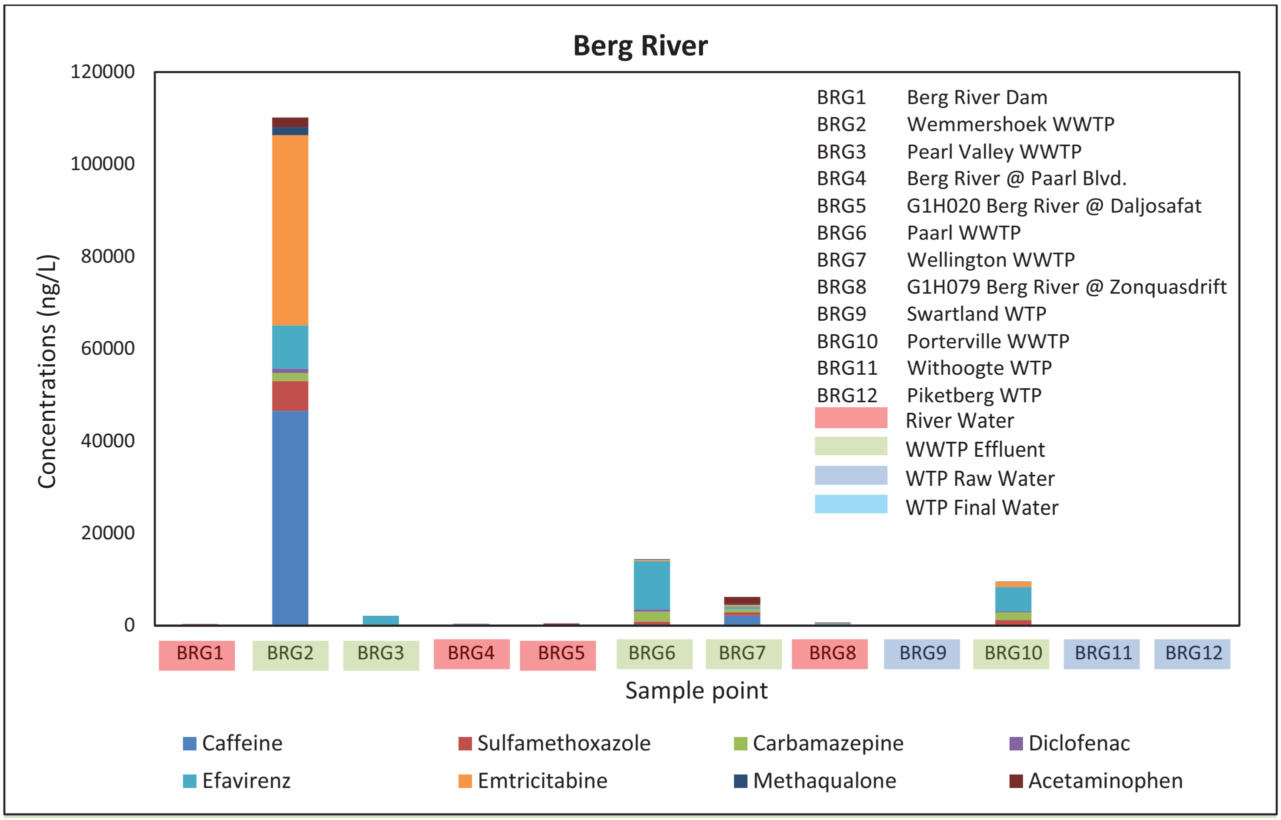


Figure 4.3: CEC concentrations at each of the sampling locations in the Berg River

From the figure it can be seen that the concentration levels of CECs found in effluent of the WWTPs are much more elevated than the concentrations of CECs in the river water samples, indicating that from a concentration perspective, wastewater treatment plants are indeed large contributors of wastewater to the river system. The results show that sample point BRG2 contributes large concentrations of CECs to the river system, compared to that of sample point BRG3, BRG6, BRG7 and BRG 10. This may be an indication of the performance of the plant, as the high caffeine and emtricitabine concentrations would not be expected at a plant that is well operated. Caffeine and emtricitabine are both wastewater markers that are easily degraded by wastewater processes, therefore the presence of these chemicals in such high concentrations in the final effluent of the plant may indicate that the plant was not working optimally at the time the sample was taken.

However, it is important to consider the mass loading of the CECs as well. Depending on the flow at the wastewater treatment plant, CEC concentrations may appear extremely high compared to the river samples, as the volume of water in the river may be much higher than that of the WWTP. Therefore, the concentration of CECs may become insignificant when diluted with the large volumes of water in the river. The results of the CEC analysis are shown as mass loadings in Figure 4.4 in order to normalise the occurrence of the CECs at the different sampling locations in the Berg River.

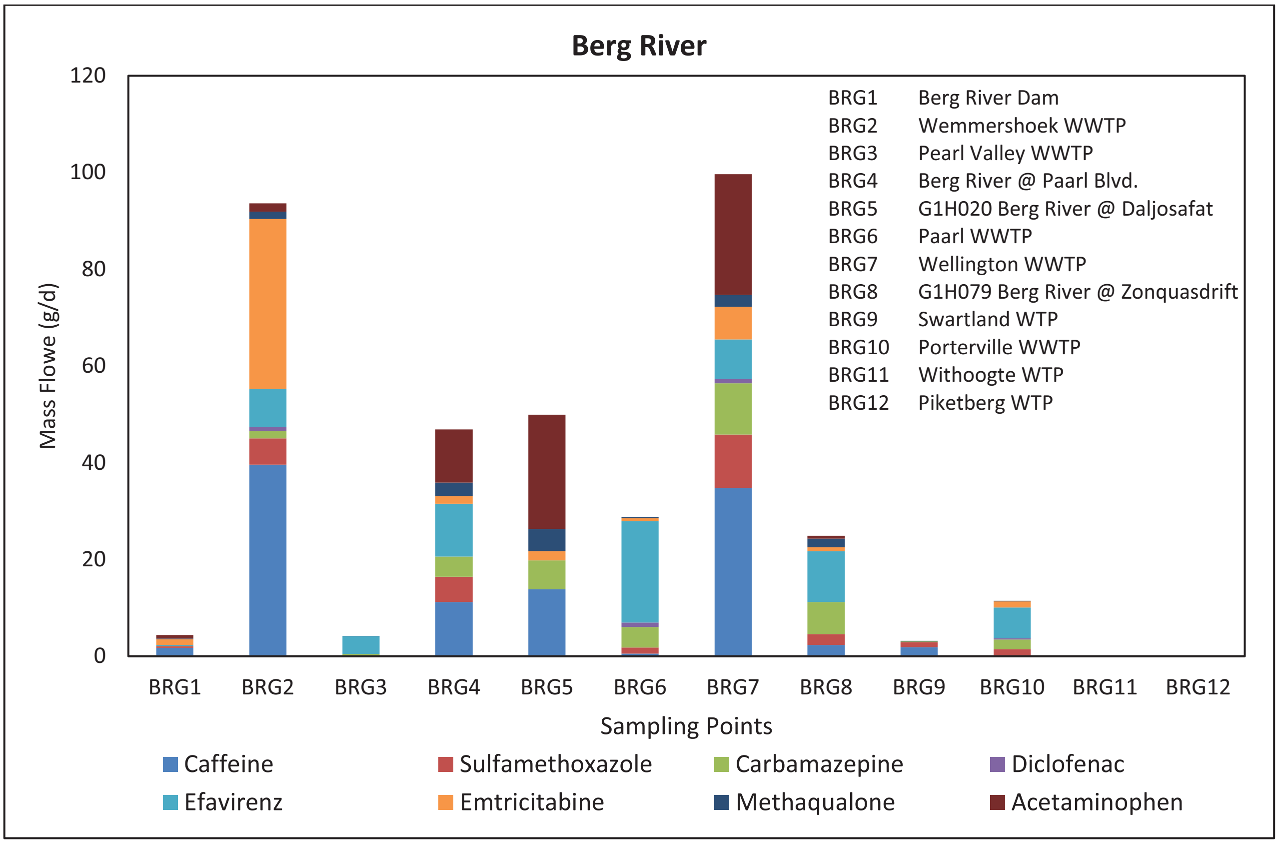


Figure 4.4: Estimated mass loadings of the CECs at each of the sampling locations in the Berg River

When viewing the mass loading of CECs at the different sampling points, it becomes clear that the WWTPs are still major contributors of CECs to the river system. However, the mass loadings allow the entire watershed to be evaluated as a whole. From the results in Figure 4.4 it can be seen that sampling point BRG2 is still a major contributor of CECs in terms of the amount of CECs that is discharged to the river system per day. However, from the results it can be seen that sample points BRG4 and BRG5 downstream of two WWTP discharge points has elevated levels of acetaminophen, which were not present in such high levels in the wastewater discharge samples. Therefore, this may indicate that there is some other form of wastewater pollution happening between the discharge point and the river sampling point. The results indicate that the mass loading of CECs in the river at sample points BRG4 and BRG5 is only 50% less than found in the effluent at BRG2 and contains almost 40% more CECs by mass as what is discharged into the river at sampling point BRG6. If a WTP were to abstract water at that one of those point, that WTP would have been classified as a de facto reuse plant. However, in the case of the WTPs abstracting water from the Berg River, none of the plants abstracts water with mass loading CECs comparable to that of a wastewater discharge sample. However, the abstracted water is also not completely free of CECs. These plants are therefore impacted by wastewater contaminated waters and can be seen as de facto reuse plants.

4.2.2 Wastewater content and chemicals of concern in the Breede River

4.2.2.1 Flow based wastewater percentage results for the Breede River.

Table 4.2 shows a summary of the flow-based wastewater percentage calculations for the Breede River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix C. Indented and grey coloured measuring stations and WTPs are located in a tributary of the Breede River.

Table 4.2: Flow-based wastewater percentage results for the Breede River for the years 2015-2019.

Breede River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	21%	10%	14%	15%	5%	9%	31%	16%	20%
H1H006 Bree @ Witbrug	11%	3%	5%	6%	1%	2%	12%	5%	6%
H2H006 Hex @ Glen Heatlie	5%	3%	3%	6%	3%	4%	9%	7%	7%
H4H017 Bree @ Le Chasseur	12%	4%	6%	9%	3%	5%	13%	7%	9%
Robertson WTW	13%	5%	7%	10%	3%	5%	14%	8%	9%
Ashton WTW	13%	7%	8%	22%	17%	18%	35%	28%	28%
H3H011 Kogmanskloof @ Gold	13%	7%	8%	22%	17%	18%	35%	28%	28%
H5H004 Bree @ Wolvendrift	26%	6%	11%	28%	5%	8%	64%	20%	33%
Bonnievale WTW	29%	7%	12%	30%	6%	9%	66%	22%	36%
H6H009 Reenen	1%	0%	1%	2%	1%	1%	13%	2%	2%
H7H006 Bree @ Swellendam	17%	4%	7%	18%	5%	7%	65%	20%	27%
H7H007 Grootkloof @ Sparken	3%	1%	2%	4%	1%	2%	4%	1%	2%
Buffeljagsrivier WTW	10%	2%	6%	13%	3%	6%	15%	4%	7%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	16%	5%	9%	30%	28%	28%	21%	9%	13%
H1H006 Bree @ Witbrug	5%	1%	3%	95%	17%	25%	9%	2%	4%
H2H006 Hex @ Glen Heatlie	7%	2%	3%	21%	17%	17%	7%	4%	4%
H4H017 Bree @ Le Chasseur	10%	2%	5%				11%	3%	6%
Robertson WTW	10%	2%	5%				12%	4%	6%
Ashton WTW	39%	31%	32%		N/A		23%	15%	17%
H3H011 Kogmanskloof @ Gold	39%	31%	32%				23%	15%	17%
H5H004 Bree @ Wolvendrift	27%	4%	8%				32%	6%	11%
Bonnievale WTW	30%	4%	9%				34%	7%	12%
H6H009 Reenen	8%	2%	3%	4%	0%	1%	3%	1%	1%
H7H006 Bree @ Swellendam	25%	5%	9%	79%	10%	21%	27%	6%	10%
H7H007 Grootkloof @ Sparken	5%	1%	3%	5%	1%	2%	4%	1%	2%
Buffeljagsrivier WTW	17%	4%	10%	16%	4%	8%	14%	3%	7%

The flow-based results indicates that during low-flow seasons, the river is at intermediate risk, with wastewater percentages between 10% and 50%. During minimum flow conditions, the percentage of wastewater contained in the Breede river averages at 21%, with 10% less wastewater under median flow conditions. Therefore, based on the flow-based wastewater percentage calculations, the water treatment plants abstracting from the Breede River cannot be classified as de facto reuse plants.

Figure 4.5 (a), (b) and (c) shows the maps of the Breede River for minimum, average, and median flow conditions, averaged for the years 2015-2019. Larger maps, showing the classifications for each year can be seen in Appendix C. The maps visually illustrate the contribution of wastewater to the river system and the impact thereof on the downstream WTPs.

Map (a) shows the river classification during low-flow conditions, indicating that the middle section of the river is impacted more by wastewater effluent discharge. This poses a significant risk to the downstream water treatment plants abstracting raw water from the river. During normal flow conditions (map (b)), the wastewater contributions will have no effect on the downstream WTPs, while the lower section of the river is impacted when considering the median flow values of the river (map (c)). Based on the estimated wastewater contribution percentages, the Bonnievale WTP can be considered a potential de facto reuse plant.

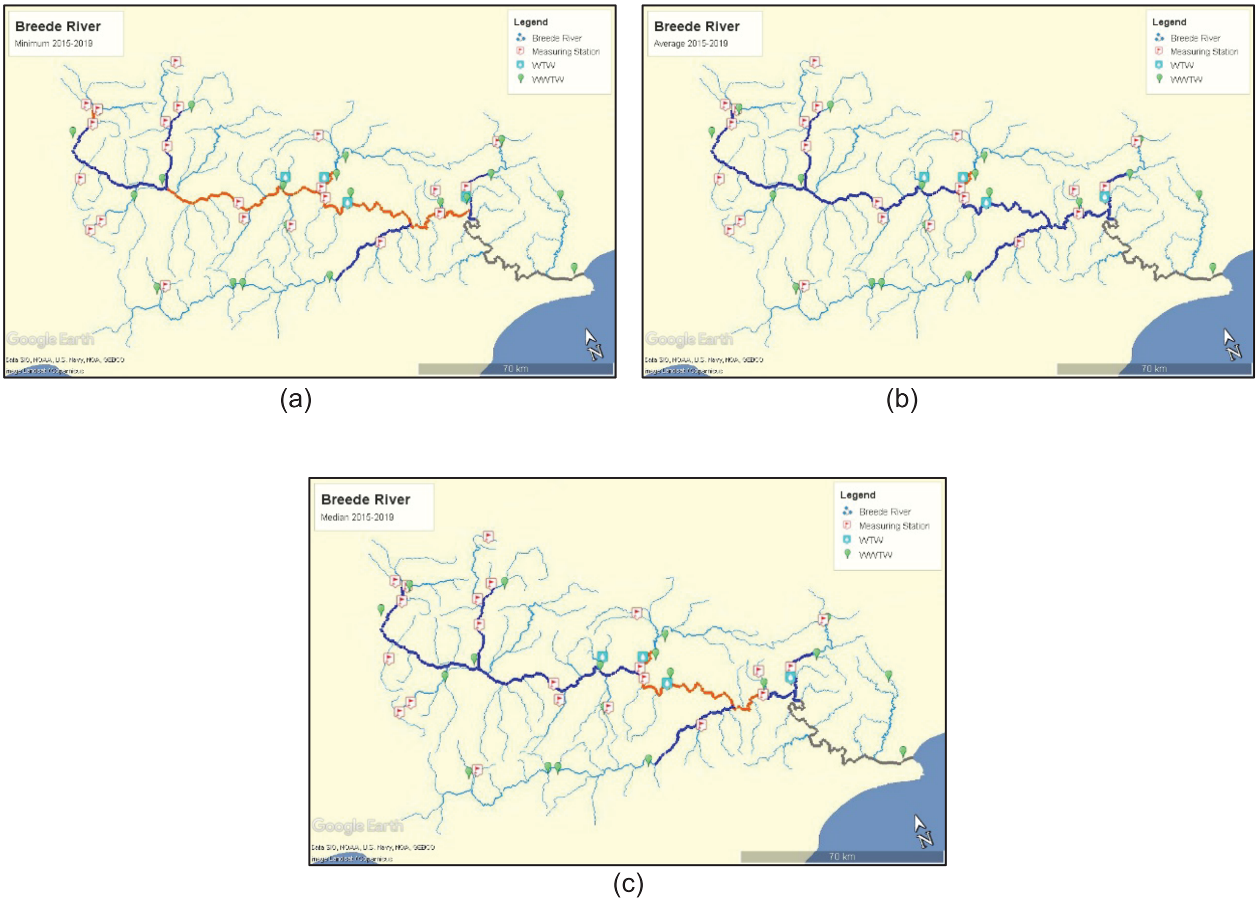


Figure 4.5: Wastewater contribution in the Breede River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.2.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.6 shows a map of the Breede River with marked sampling locations. The samples consisted of river water, wastewater effluent and final treated drinking water.

Figure 4.6: Map of the Breede River sampling locations for CEC analysis

Figure 4.7 shows the results of eight indicator CECs in the Breede River. The graph visually demonstrates the level of contaminants found in the Breede River at the different sampling points.

The results indicates that the concentrations of CECs in the wastewater effluent samples are much higher than what can be found in the river water samples. There is also a spike in CEC concentrations in sample BRD 10, which is the Robertson WWTP effluent. This is again an indication that, on the day the sample were taken, the treatment plant might not have been operating properly.

In order to obtain a clear perspective of the CEC concentrations in the Breede River, Figure 4.8 shows only the results for the CEC concentrations found at the measuring stations and the WTP abstraction points.

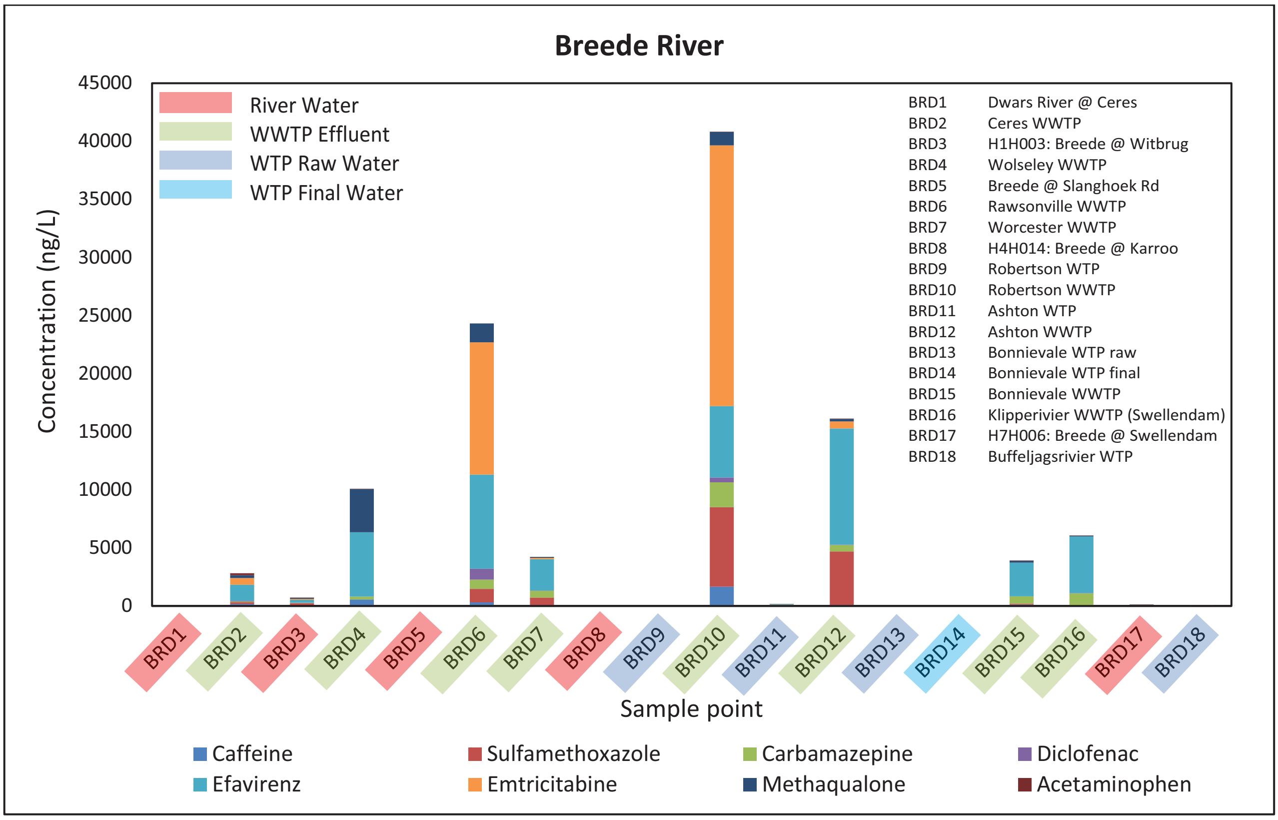


Figure 4.7: CEC results at each of the sampling locations in the Breede River

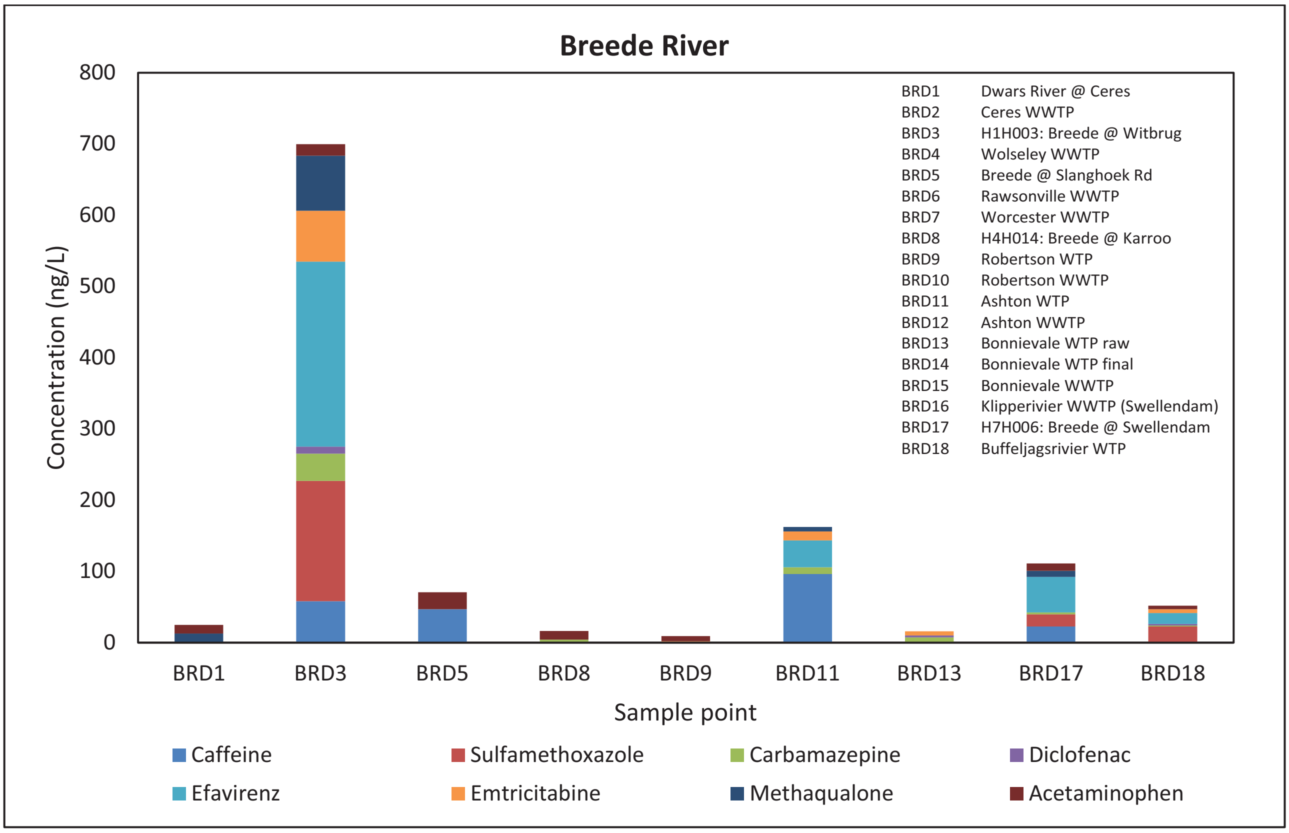


Figure 4.8: CEC results at the measuring stations and water treatment plants in the Breede River

Sample BRD 1 was taken in the Dwars River close to Ceres from where the Breede River originates from and is located within a residential area. Very low concentrations of acetaminophen and methaqualone was found at this point, which can be expected due to its location.

The river at BRD 3 have higher concentrations of CECs than the rest of the river, indicating that there is a wastewater source discharging to the river. As there is only one wastewater treatment plant upstream of this sampling location, it is possible that there might be other point and non-point sources contaminating the river. BRD 11 have elevated levels of caffeine, relative to the other river samples. Although the levels are not high enough to raise cause for concern, the spike should be taken note off.

4.2.3 Wastewater content and chemicals of concern in the Buffalo River

4.2.3.1 Flow based wastewater percentage results for the Buffalo River.

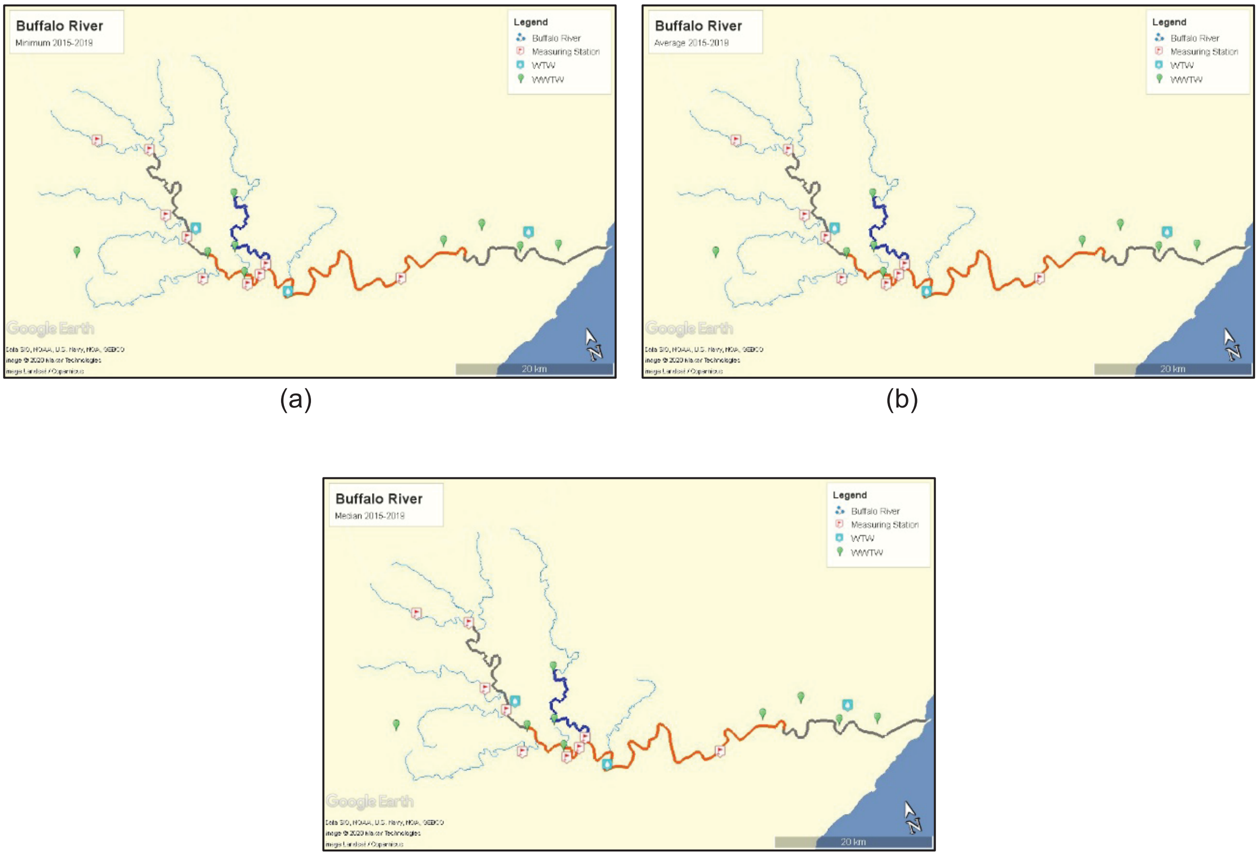
Table 4.3 shows a summary of the flow-based wastewater percentage calculations for the Buffalo River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix D. Indented and grey coloured measuring stations and WTPs are located in a tributary of the Buffalo River.

Table 4.3: Flow-based wastewater percentage results for the Buffalo River for the years 2015-2019.

Buffalo River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
R2H010 Macintyre Bridge	32%	13%	22%	48%	31%	36%	47%	21%	32%
R2H015 Yellowwoods @ Fort M	18%	4%	11%	34%	17%	22%	4%	2%	3%
Laing WTW	30%	10%	20%	46%	29%	34%	23%	11%	16%
R2H027 Buffalo @ Needs Camp	43%	9%	22%	88%	57%	67%	40%	11%	20%
Umzonyana WTW	43%	9%	22%	88%	57%	67%	40%	11%	20%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
R2H010 Macintyre Bridge	48%	22%	27%	61%	52%	55%	45%	22%	31%
R2H015 Yellowwoods @ Fort M	28%	10%	15%	2%	1%	1%	5%	3%	4%
Laing WTW	45%	20%	25%	13%	11%	11%	25%	14%	18%
R2H027 Buffalo @ Needs Camp	55%	21%	25%	20%	15%	16%	39%	15%	23%
Umzonyana WTW	55%	21%	25%	20%	15%	16%	39%	15%	23%

The flow-based results indicates that the Buffalo River is moderately impacted by the discharge of wastewater treatment plant effluent. The river is dominated by wastewater effluent contributions of more than 10-40% during low, average, and median flow conditions. In 2017, the effect of dilution can be seen when the Yellowwoods River confluence with the Buffalo River, diluting the wastewater percentages from 20-50% to 10-30%. The same effect is seen again in 2019, with a significant reduction in wastewater percentages from 50-60% to less than 20%. In 2016, there was a high potential for de facto reuse to occur near the bottom of the river catchment.

Figure 4.9 (a), (b) and (c) shows the maps of the Buffalo River for minimum, average, and median flow conditions, averaged for the years 2015-2019. Larger maps, showing the classifications for each year can be seen in Appendix D.



(a) (b)

(c)

Figure 4.9: Wastewater contribution in the Buffalo River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

These maps visually indicates that the classification of the river does not change with flow, and the river consistently have estimated wastewater contributions up to 50%. The Buffalo River is therefore moderately impacted by wastewater effluent contributions, putting the downstream WTPs at risk of becoming de facto reuse plants.

4.2.3.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.10 shows a map of the Buffalo River with marked sampling locations. The samples consisted of river water and wastewater effluent.

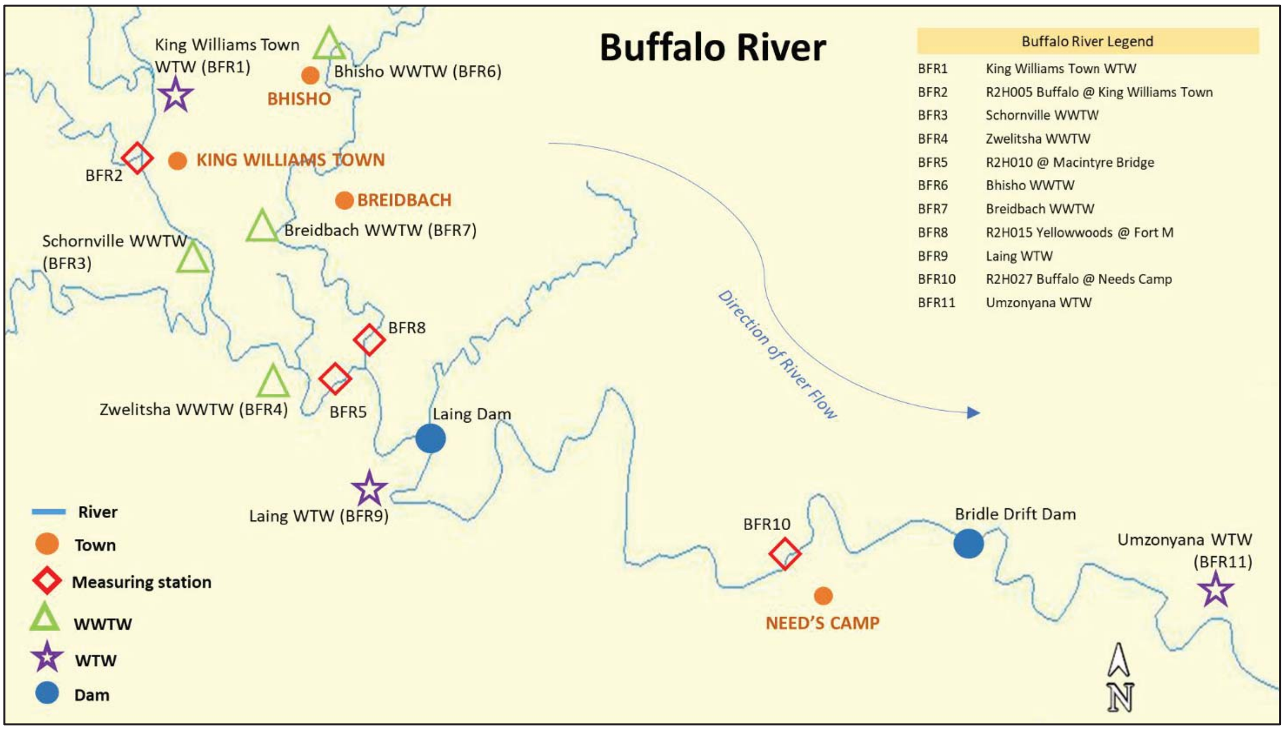


Figure 4.10: Map of the Buffalo River sampling locations for CEC analysis

Figure 4.11 shows the results of eight indicator CECs in the Breede River. The graph visually demonstrates the level of contaminants found in the Buffalo River at the different sampling points.

As with the Berg and Breede River, the results indicates that the high levels of CECs are found in the wastewater effluent discharged to the Buffalo River. Elevated levels of emtricitabine can be seen BFR 3, BFR6 and BFR7, which may be an indication of the operation of the wastewater treatment plants.

In order to view the concentration of CECs in the Buffalo River, the WWTP effluent sample results were removed from the graph and the results are shown in Figure 4.12.

BFR 5 draws immediate attention when viewing the results in Figure 4.12. The concentrations found at the point is extremely elevated relative to the rest of the river and compares better with wastewater effluent CEC concentrations. The location of this point in the river should be considered in order to make sense of the results. BFR 5 is a point in the Buffalo River that lies downstream of two wastewater treatment plants, which considering their CEC concentration results is not well operated and a large industrial area located in the town of Zwelitsha. There are also several informal settlements located within the surrounding area. All of these attributes combined might explain the high concentration of CECs at that point than any other point in the river.

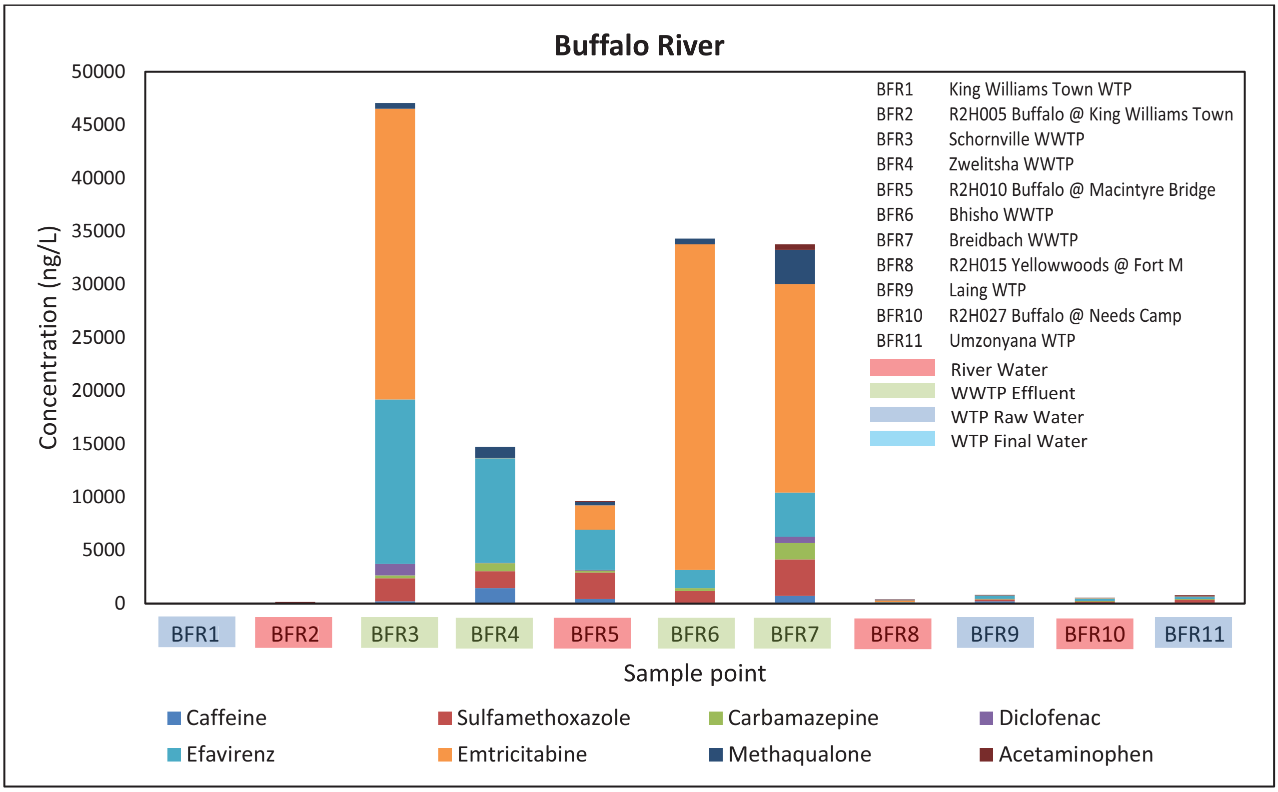


Figure 4.11: CEC results at each of the sampling locations in the Buffalo River

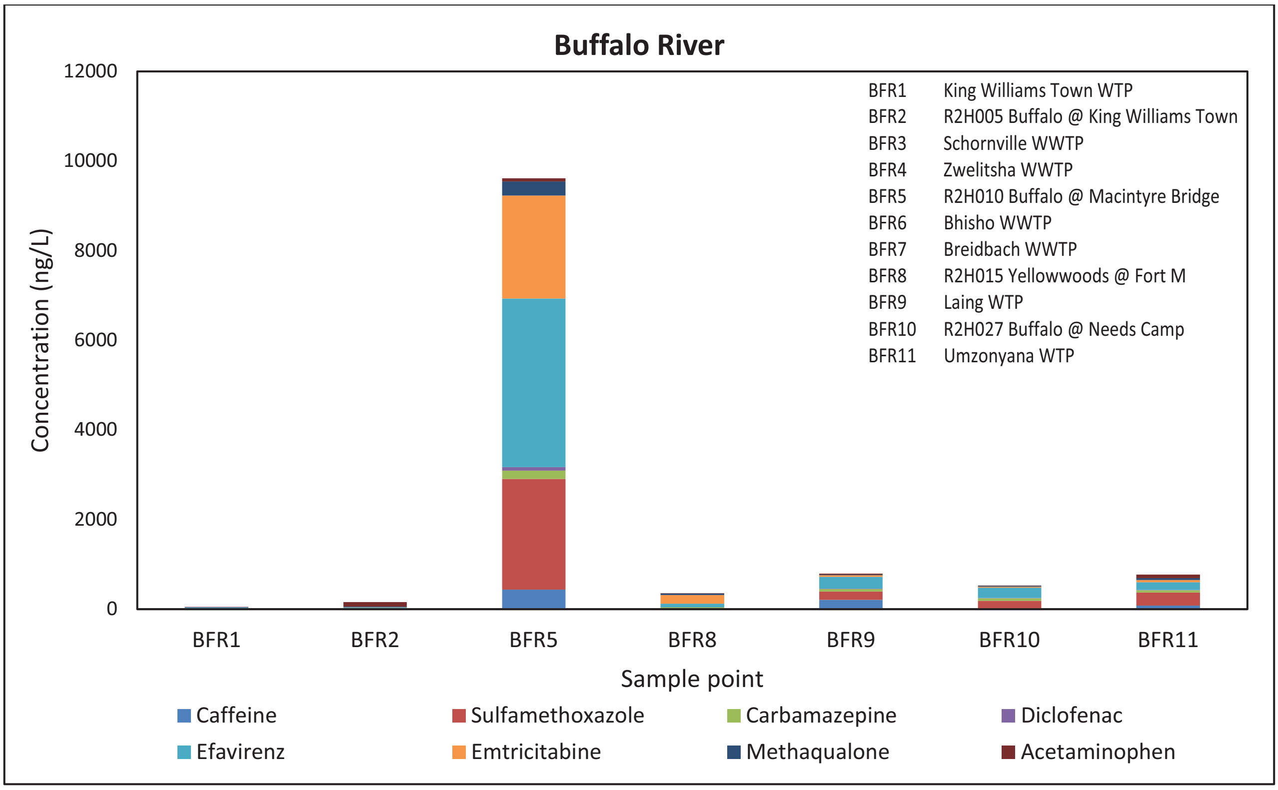


Figure 4.12: CEC results at the measuring stations and water treatment plants in the Buffalo River

4.2.4 Wastewater content and chemicals of concern in the Modder River

4.2.4.1 Flow based wastewater percentage results for the Modder River.

Table 4.4 shows a summary of the flow-based wastewater percentage calculations for the Modder River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix E. Indented and grey coloured measuring stations are located in the Renosterspruit, which is a tributary of the Modder River.

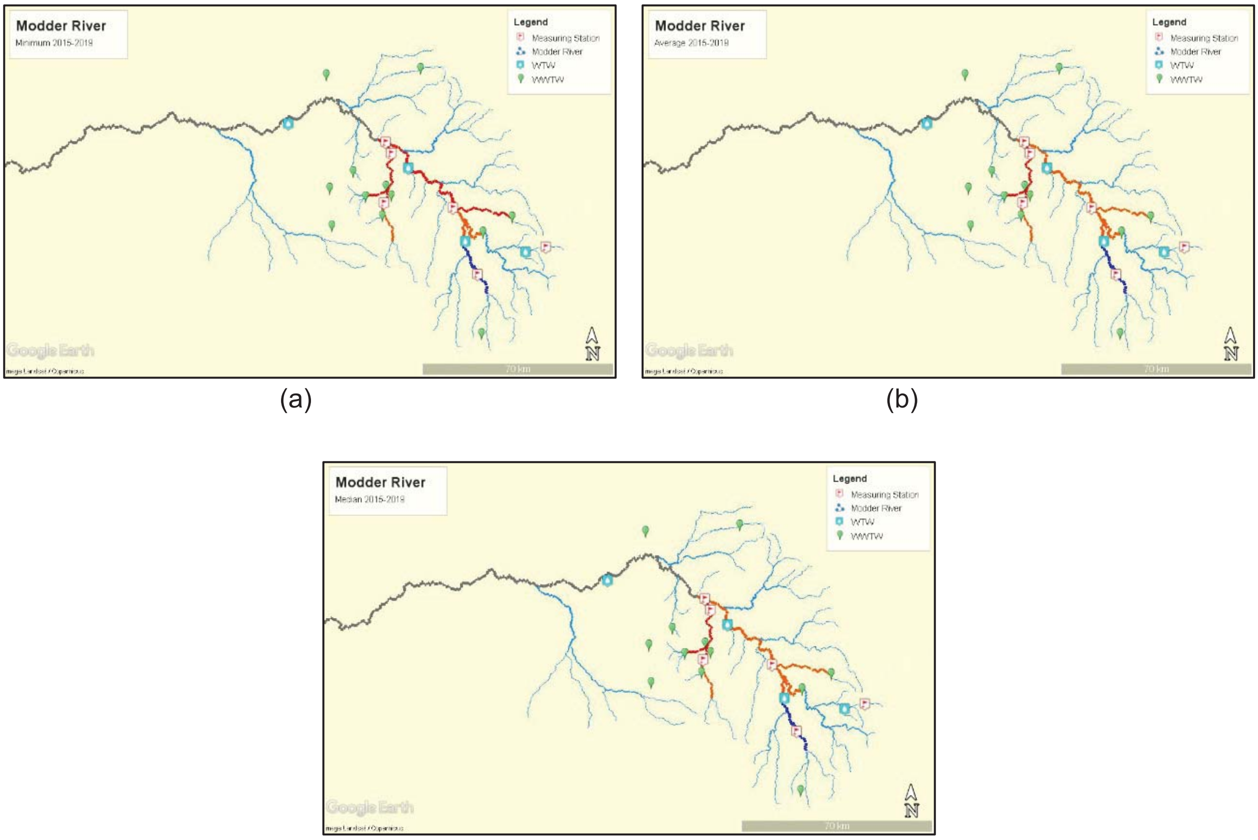
Table 4.4: Flow-based wastewater percentage results for the Modder River for the years 2015-2019.

Modder River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C5H056 Modder @ Diepwater	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rustfontein WTW	0%	0%	0%	0%	0%	0%	0%	0%	0%
C5H003 Modder @ Likatlong	57%	30%	49%	66%	19%	47%	48%	18%	27%
Maselspoort WTW	64%	36%	55%	72%	24%	53%	55%	22%	32%
C5H007 Renoster Sp @ Shanno	42%	19%	33%	51%	11%	32%	33%	11%	17%
C5H054 Renoster Sp @ Bishop	76%	60%	65%	85%	61%	72%	89%	55%	65%
C5H053 Modder @ Glen	77%	59%	63%	84%	33%	62%	87%	36%	43%
Measuring station/ Water Treatment Plant	2018			2019			2015 -2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C5H056 Modder @ Diepwater	1%	0%	0%	3%	0%	0%	0%	0%	0%
Rustfontein WTW	1%	0%	0%	3%	0%	0%	0%	0%	0%
C5H003 Modder @ Likatlong	39%	13%	24%	45%	17%	36%	50%	18%	34%
Maselspoort WTW	46%	16%	29%	52%	21%	42%	56%	22%	40%
C5H007 Renoster Sp @ Shanno	26%	7%	14%	31%	10%	23%	40%	22%	32%
C5H054 Renoster Sp @ Bishop	74%	52%	61%	80%	48%	62%	81%	55%	65%
C5H053 Modder @ Glen	82%	21%	38%	75%	16%	45%	78%	27%	48%

The flow-based results indicates that the Modder River is highly impacted by wastewater effluent discharge. The calculated wastewater percentages indicates that during low-flow seasons, various sections of the river is estimated to contain up to 100% of wastewater effluent. The Renosterspruit receives wastewater effluent from three wastewater treatment plants, which the impact on the river is evident in the wastewater percentages calculated in the Table 4.4. The flow in this tributary is not high enough to allow for dilution of the large amounts of wastewater effluent being discharged to the river daily.

Figure 4.13 (a), (b) and (c) shows maps of the Modder River for minimum, average, and median flow conditions, averaged for the years 2015-2019. Larger maps, showing the classifications for each year can be seen in Appendix E.

The contribution of wastewater to the river is highest during the dry periods, when the flow in the river is not very high. Map (a) illustrates this impact on the river clearly. During average and median flow, the risk it lower, however, the wastewater contributions will still have an increasing effect on the downstream water treatment plants.



(a) (b)

(c)

Figure 4.13: Wastewater contribution in the Modder River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.4.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.14 shows a map of the Modder River with marked sampling locations. The samples consisted of river water and wastewater effluent.

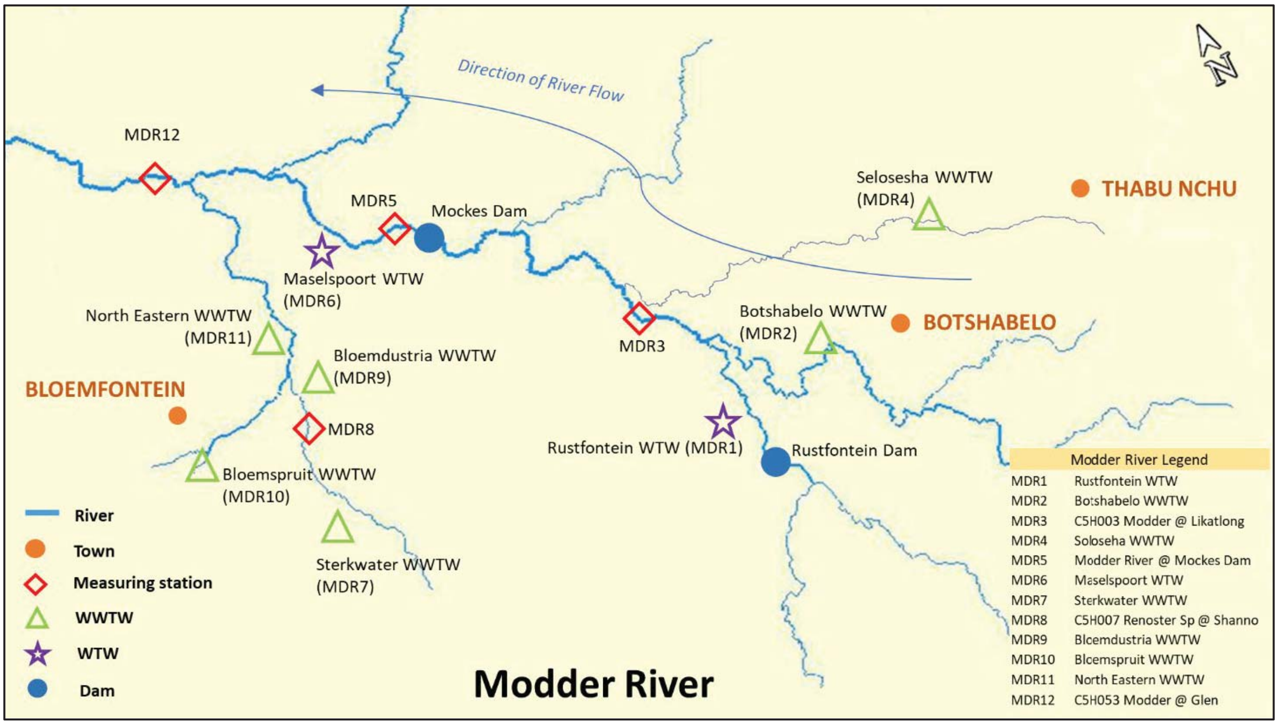


Figure 4.14: Map of the Modder River sampling locations for CEC analysis

Figure 4.15 shows the results of eight indicator CECs in the Modder River. The graph visually demonstrates the level of contaminants found in the Modder River at the different sampling points.

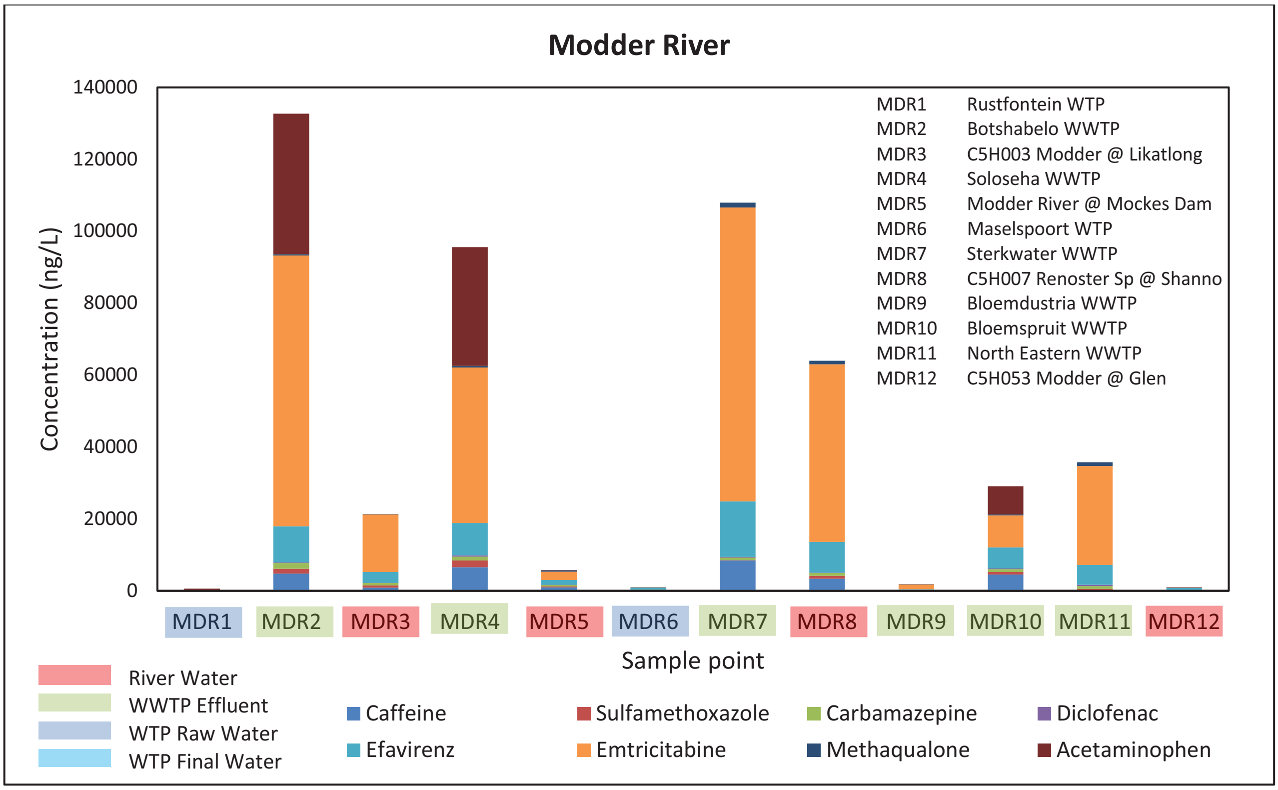


Figure 4.15: CEC results at each of the sampling locations in the Modder River

The results for Modder River show elevated levels of emtricitabine in the wastewater effluent samples. As mentioned in previous discussions, emtricitabine is a CEC than can easily be broken down in wastewater treatment processes if they work properly. Since no samples were taken of the raw wastewater entering the plant, one cannot definitively conclude that the treatment processes at the wastewater treatment plants is not operating well. Secondary to that, the results in the table below were obtained from a once-off grab sample. It is also possible that the plant may only have had problems in the days of weeks leading up to the sampling date. However, these levels are a cause for concern. Therefore, the wastewater treatment plants discharging into the Modder River can all be considered contamination hotspots.

Figure 4.16 shows the results of the CEC concentrations that were found in the Modder River itself.

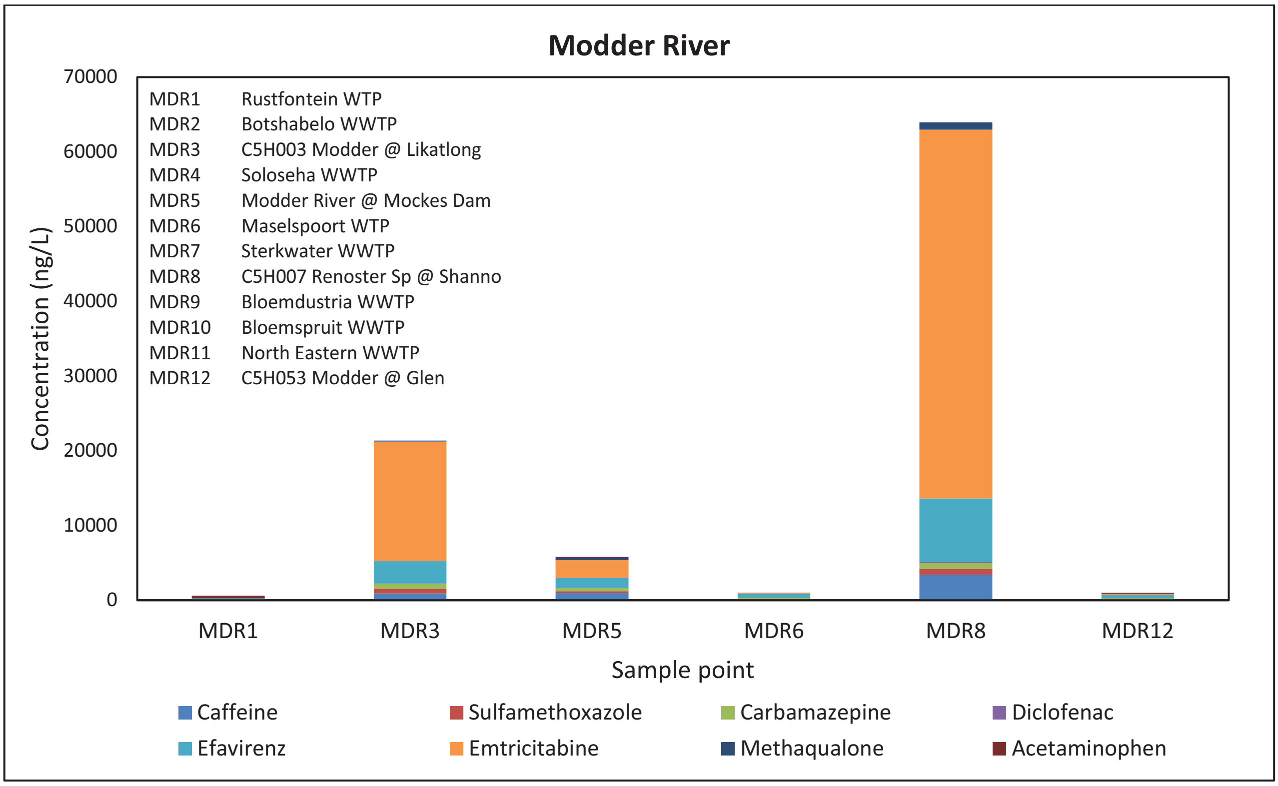


Figure 4.16: CEC results at the measuring stations and water treatment plants in the Modder River

MDR 3 is located downstream of the Botshabelo WWTP and various industrial activities. The effects of dilution, degradation and sorption can be seen in the results for MDR 5 and 6 which are located about 60 kilometres downstream of the wastewater treatment plants influencing these points. MDR 8 however, is only located about within a range of about 10-20 kilometres from three wastewater treatment plants discharging into the Renosterspruit River, a tributary of the Modder River. The effects of the discharges on the river becomes apparent in the concentrations found at site MDR 8.

4.2.5 Wastewater content and chemicals of concern for the Umgeni River

4.2.5.1 Flow based wastewater percentage results for the Umgeni River.

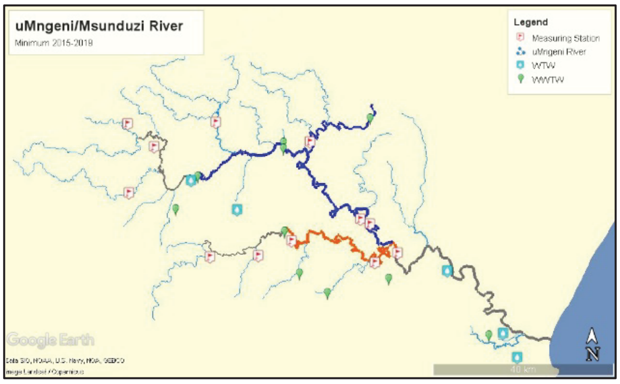
Table 4.5 shows a summary of the flow-based wastewater percentage calculations for the Umgeni/Duzi River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix F. Indented and grey coloured measuring stations are located in the Sterk and Duzi Rivers, which are both tributaries of the Umgeni River.

Table 4.5: Flow-based wastewater percentage results for the Umgeni/Duzi River for the years 2015-2019.

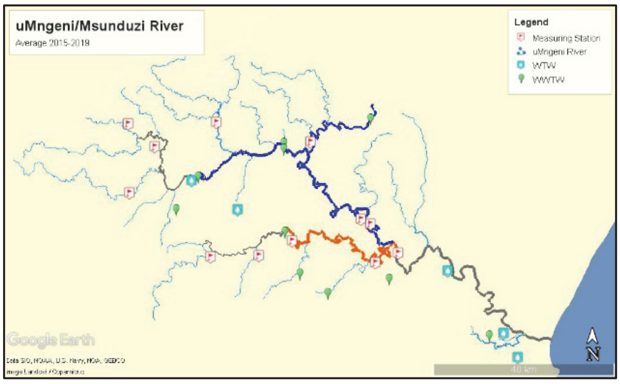
Umgeni/Duzi River									
Measuring station/ Water Treatment Plant	**% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow**								
	2015			**2016**			**2017**		
	Min	**Average**	**Median**	**Min**	**Average**	**Median**	**Min**	**Average**	**Median**
U2H012 Mpolweni @ Sterk River	9%	4%	5%	4%	3%	3%	5%	2%	2%
U2H005 Table Mountain	2%	2%	2%	3%	2%	3%	3%	2%	2%
U2H041 Motor Cross	32%	17%	19%	37%	14%	17%	38%	12%	16%
U2H022 Duzi Bridge	85%	24%	26%	37%	22%	25%	55%	26%	29%
U2H055 Mgeni @ Inanda Loc.	47%	22%	25%	57%	26%	28%	39%	24%	29%
Measuring station/ Water Treatment Plant	**2018**			**2019**			**2015 - 2019**		
	Min	**Average**	**Median**	**Min**	**Average**	**Median**	**Min**	**Average**	**Median**
U2H012 Mpolweni @ Sterk River	1%	1%	1%	1%	1%	1%	2%	1%	1%
U2H005 Table Mountain	4%	2%	3%	3%	2%	2%	3%	2%	2%
U2H041 Motor Cross	24%	6%	7%	36%	12%	12%	32%	11%	13%
U2H022 Duzi Bridge	28%	18%	20%	27%	5%	6%	38%	13%	15%
U2H055 Mgeni @ Inanda Loc.	31%	19%	22%	31%	19%	23%	39%	22%	25%

The results indicate that the Duzi River is consistently impacted by wastewater effluent contributions, especially during low-flow seasons. Even though there are no WTPs abstracting downstream of WWTPs in this river, the tributary flows into the Umgeni River and into the Inanda Dam, were the Wiggens WTP abstracts raw water for treatment.

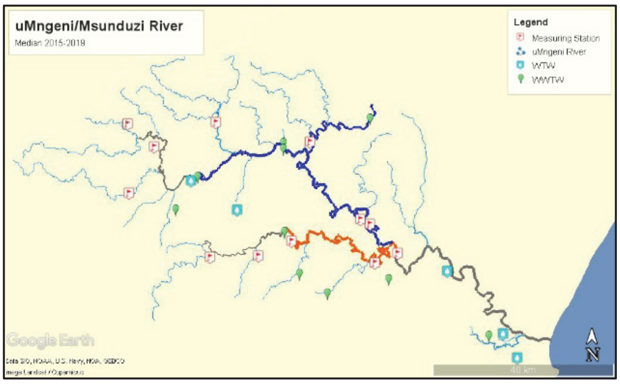
Figure 4.17 (a), (b) and (c) shows maps of the Umgeni and Duzi Rivers for minimum, average, and median flow conditions, averaged for the years 2015-2019. Larger maps, showing the classifications for each year can be seen in Appendix F.



(a)



(b)



(c)

Figure 4.17: Wastewater contribution in the Umgeni River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

The three maps clearly show that the upper section of the Umgeni River does not contain high contributions of wastewater, therefore the downstream WTPs poses a lower risk of being de facto reuse plants. However, the Duzi River can be classified as having an increasing effect on the downstream water treatment plant and have a greater potential for de facto reuse.

4.2.5.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.18 shows a map of the Umgeni/Duzi River with marked sampling locations. The samples consisted of river water and wastewater effluent.

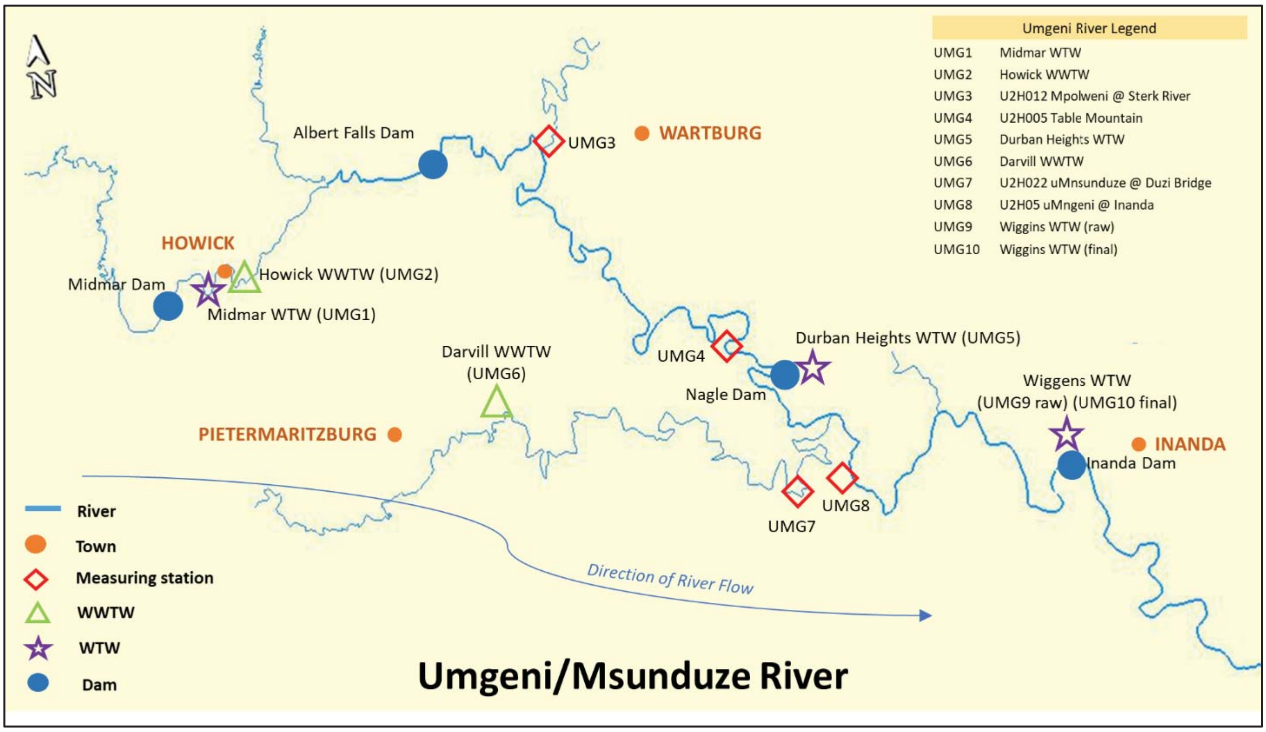


Figure 4.18: Map of the Umgeni/Duzi River sampling locations for CEC analysis

Figure 4.19 shows the results of eight indicator CECs in the Umgeni/Duzi River. The graph visually demonstrates the level of contaminants found in the Umgeni/Duzi River at the different sampling points.

The results indicate elevated levels of CECs at UMG 3. This sampling point is located within the Sterk River tributary, downstream of Dalton and within a large semi-informal settlement. Thus, introducing the potential for various sources of non-point sources of discharge to the tributary. Although the CEC levels are elevated at this site, the concentrations are reduced significantly towards UMG 4 and 5, due to the effects of dilution and sorption. Higher levels of CECs are then again introduced at sampling site UMG 6, which were a wastewater effluent sample.

It can be seen that there is some reduction of the CEC, however not very significant. It can also be seen that the ARV efavirenz is quite prominent in both the raw and final water. This is consistent with literature which has shown that efavirenz is extremely persistent, even in advanced treatment technologies.

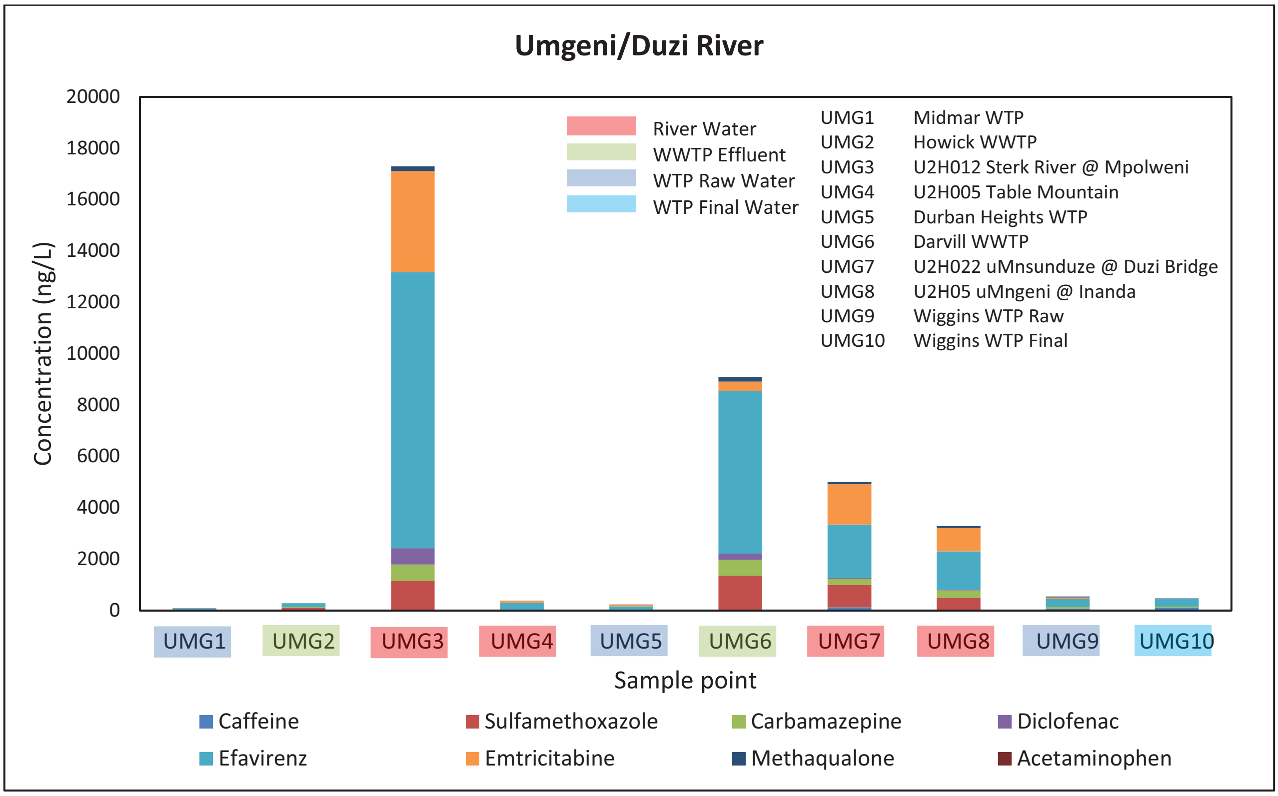


Figure 4.19: CEC results at each of the sampling locations in the Umgeni/Duzi River

Figure 4.20 show the results of CEC concentration found in the raw water abstracted from the Umgeni River for treatment and the final drinking water product of the water treatment plant.

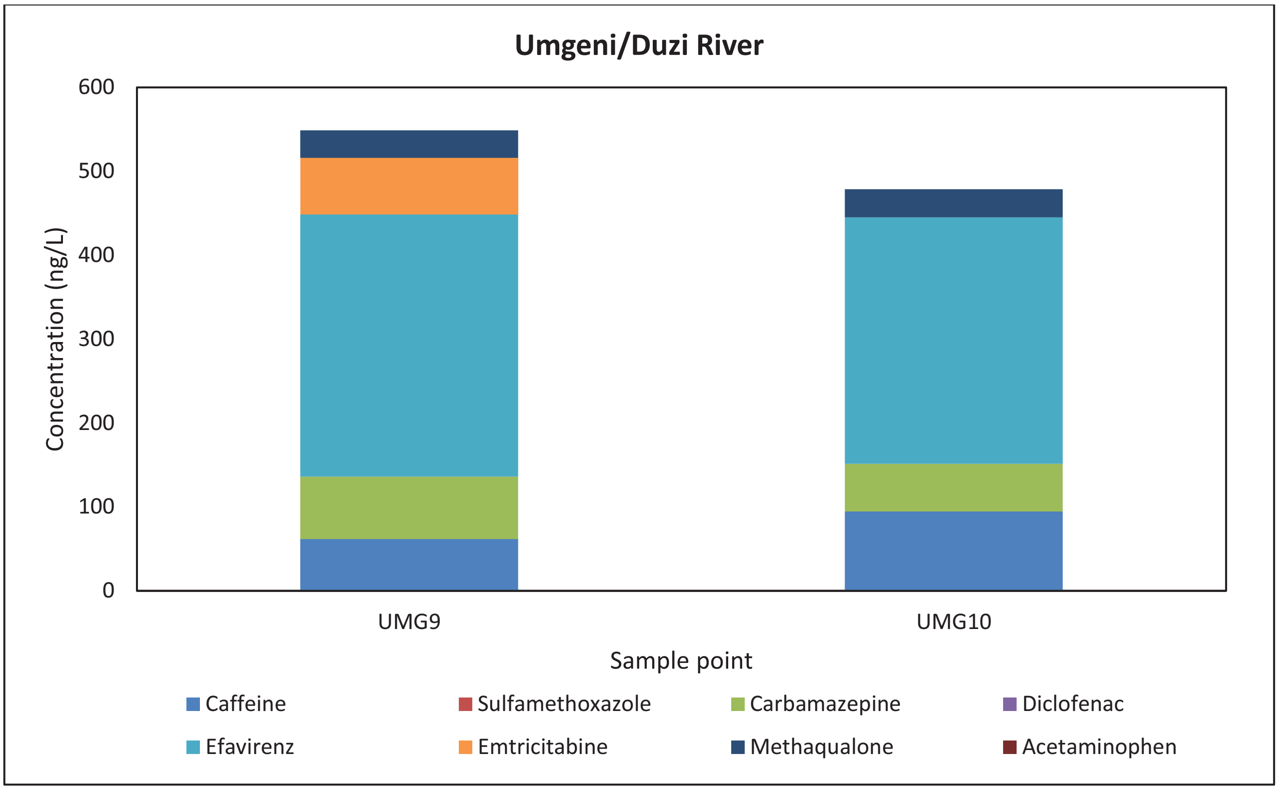


Figure 4.20: CEC results of samples taken of the raw water abstracted from the Umgeni River and the final drinking water after treatment.

4.2.6 Wastewater content and chemicals of concern for the Sundays River

4.2.6.1 Flow based wastewater percentage results for the Sundays River.

Table 4.6 shows a summary of the flow-based wastewater percentage calculations for the Sundays River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix G.

Table 4.6: Flow-based wastewater percentage results for the Sundays River for the years 2015-2019.

Sundays River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
Graaff-Reinet WTP	35%	0%	3%	63%	1%	87%	23%	0%	28%
N2H007 Sondags @ De Draay	99%	21%	82%	100%	52%	100%	98%	21%	98%
N4H001 Sondags @ Korhaanspo	36%	5%	6%	51%	8%	11%	59%	7%	11%
Kirkwood WTP	36%	5%	6%	51%	8%	11%	59%	7%	11%
Nooitgedacht WTP	44%	7%	8%	57%	10%	14%	65%	9%	13%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
Graaff-Reinet WTP	63%	1%	100%	50%	0%	100%	41%	0%	12%
N2H007 Sondags @ De Draay	100%	55%	100%	99%	41%	100%	99%	32%	96%
N4H001 Sondags @ Korhaanspo	33%	18%	47%	49%	18%	34%	43%	9%	13%
Kirkwood WTP	33%	18%	47%	49%	18%	34%	43%	9%	13%
Nooitgedacht WTP	38%	22%	54%	55%	22%	40%	50%	11%	16%

Based on the results of the wastewater percentage calculations for the Sundays River, wastewater effluent contributions in the upper course of the river (above the Darlington Dam) are consistently higher than in the lower course of the river. This may be due to the upper course of the river being highly dependent on thunderstorms, therefore certain sections of the river are frequently dry for long periods of time.

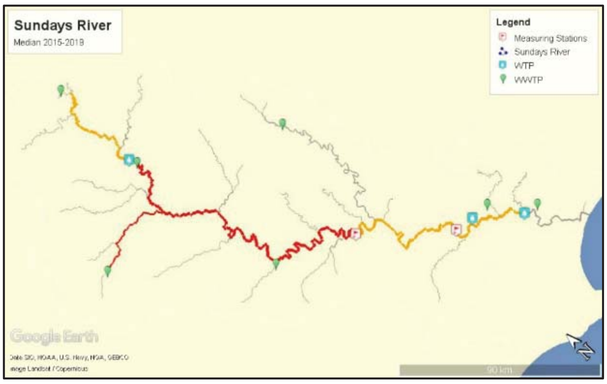
Figure 4.21 (a), (b) and (c) shows the river classification maps of the Sundays River for the average flow between 2015 and 2019. Larger maps showing the river classification for each year can be seen in Appendix G.

From the maps it can be seen that a large section of the upper course river is highly impacted by wastewater contributions, especially during low flow, or in the case of the Sundays River, dry periods. Fortunately, there are no WTPs abstracting from that section of the river, therefore there is not any potential for de facto reuse plants.

During average flow, the wastewater impact on the upper section of the river is considerably less, with wastewater contributions between 0-30%. The river is considered not to be impacted at wastewater percentages of less than 10% (blue sections) and only moderately impacted if wastewater percentages are between 10-50% (yellow sections).

(a)

(b)



(c)

Figure 4.21: Wastewater contribution in the Sundays River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.6.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.22 shows a map of the Sundays River with marked sampling locations. The samples consisted of river water, WTP final water, wastewater effluent and one sample of raw sewage taken at sampling location SNR 5. Due to a broken pump station at this sampling location, raw sewage was not pumped to the wastewater treatment plant and was flowing onto the Sundays River.

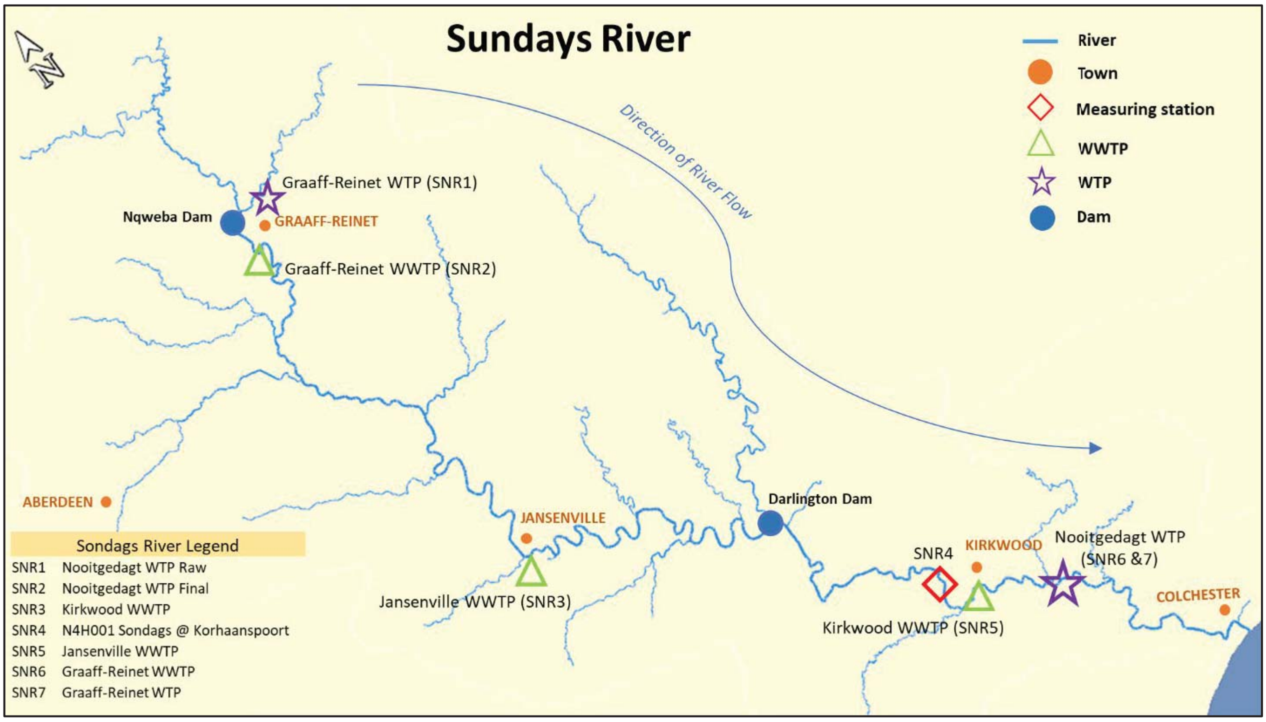


Figure 4.22: Map of the Sundays River sampling locations for CEC analysis

Figure 4.23 shows the results of eight indicator CECs in the Sundays River. The graph visually demonstrates the level of contaminants found in the Sundays River at the different sampling points.

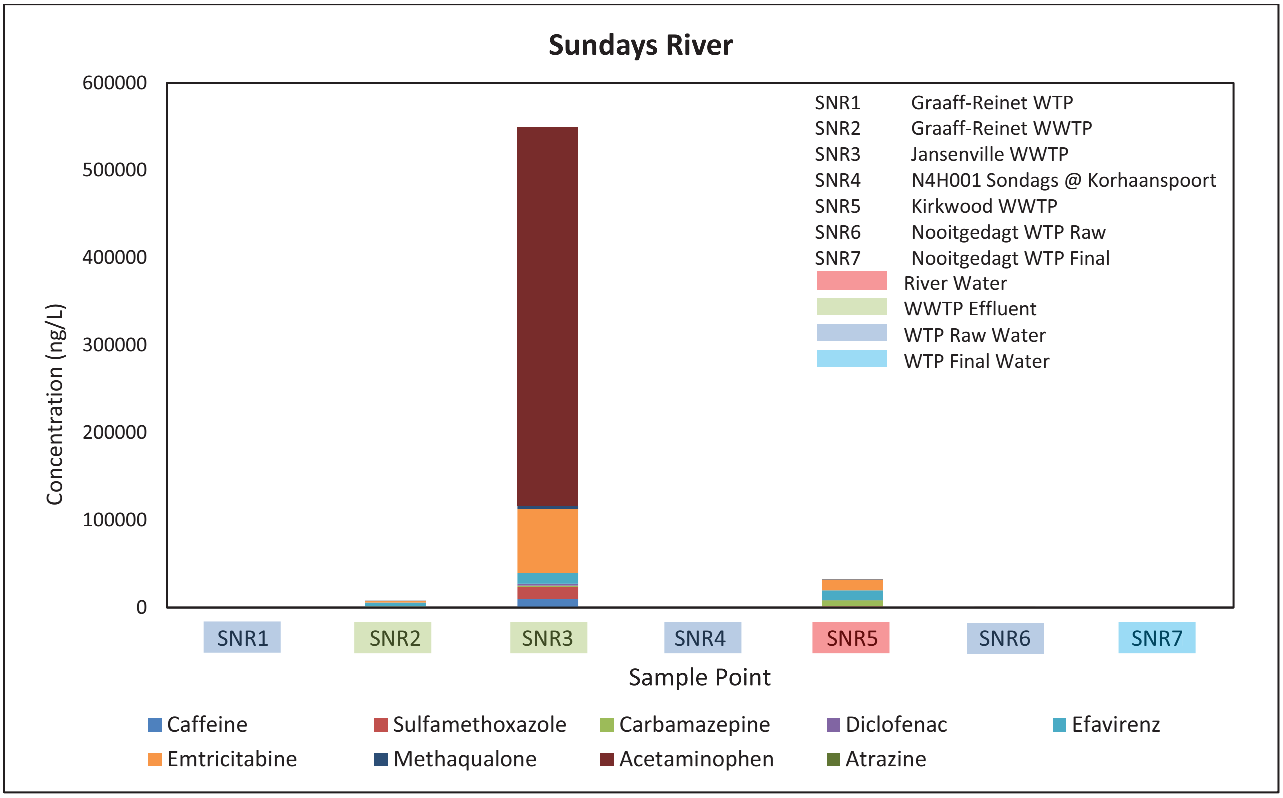


Figure 4.23: CEC results at each of the sampling locations in the Sundays River

From the results it can be seen that the CEC concentrations in the raw sewage sample taken at SNSR 5 are extremely high. The acetaminophen in the sample has an average concentration of more than 0.4 mg/L (433774.7 ng/L). The Sundays River was dry at the time the sample was taken; therefore, the raw sewage did not contaminate any surface water. However, should the sewage have entered a water stream concentrations of this magnitude would have been of great concern for any downstream water treatment plants.

Figure 4.24 shows the results of the CEC concentrations that were found in the Sundays River itself. Results indicate that the concentration of efavirenz in the raw water intake at SNR 6 are quite elevated with an average concentration of 665 ng/L. This is to be expected as this raw water abstraction point is located downstream of various wastewater treatment plant effluent discharges, agricultural activities, and other sources of non-point sources pollution. Trace levels of caffeine can be seen in sampling point SNR 1 and SNR 4, which could be an indication of non-point sources of pollution, as caffeine is readily broken down in wastewater treatment processes.

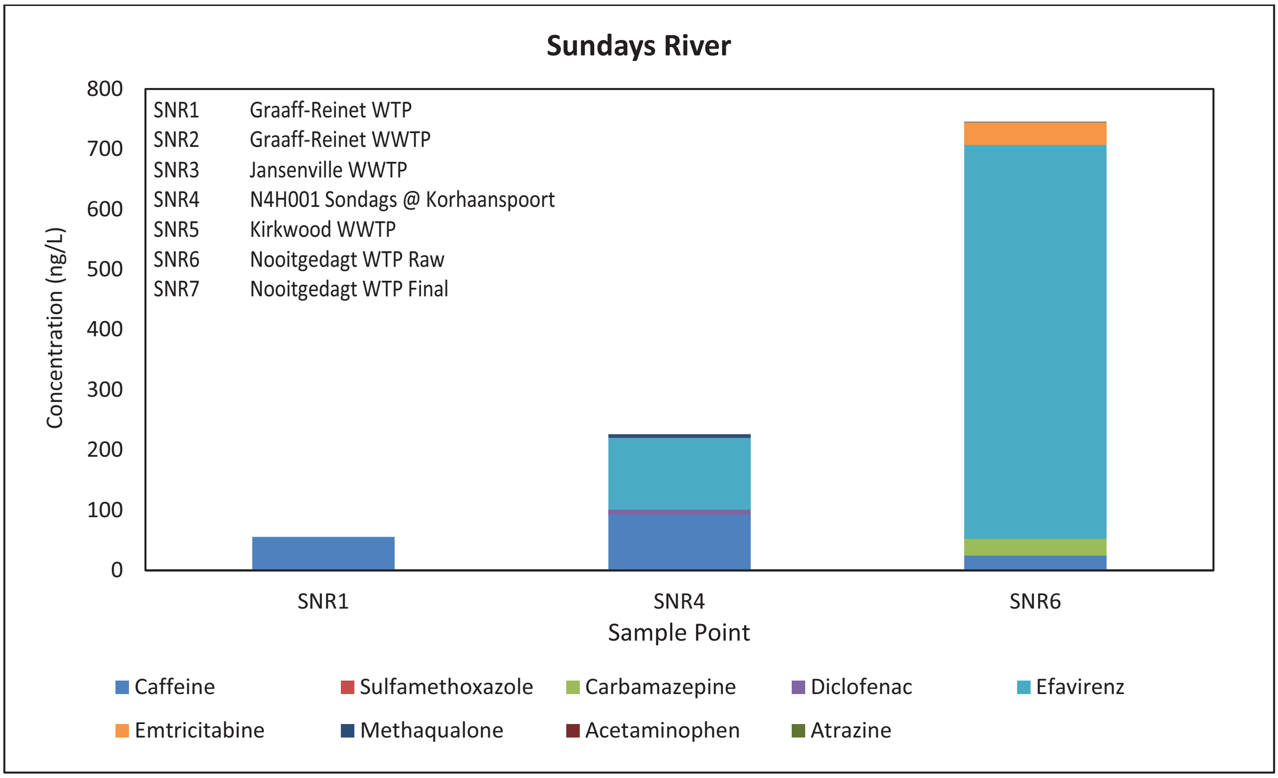


Figure 4.24: CEC results at the measuring station and water treatment plants in the Sundays River

Figure 4.25 shows the CEC results of the raw water intake and final water of the Nooitgedacht WTP. From the results it is observed that the processes used at this plant is very effective in removing the CECs contained in the raw water. The removal capabilities of the process units utilised at this plant will be discussed in more detail in Section Chapter 6: of this report. Elevated levels of efavirenz are found in the raw water intake, which can be an indication of either non-point source pollution of domestic wastewater.

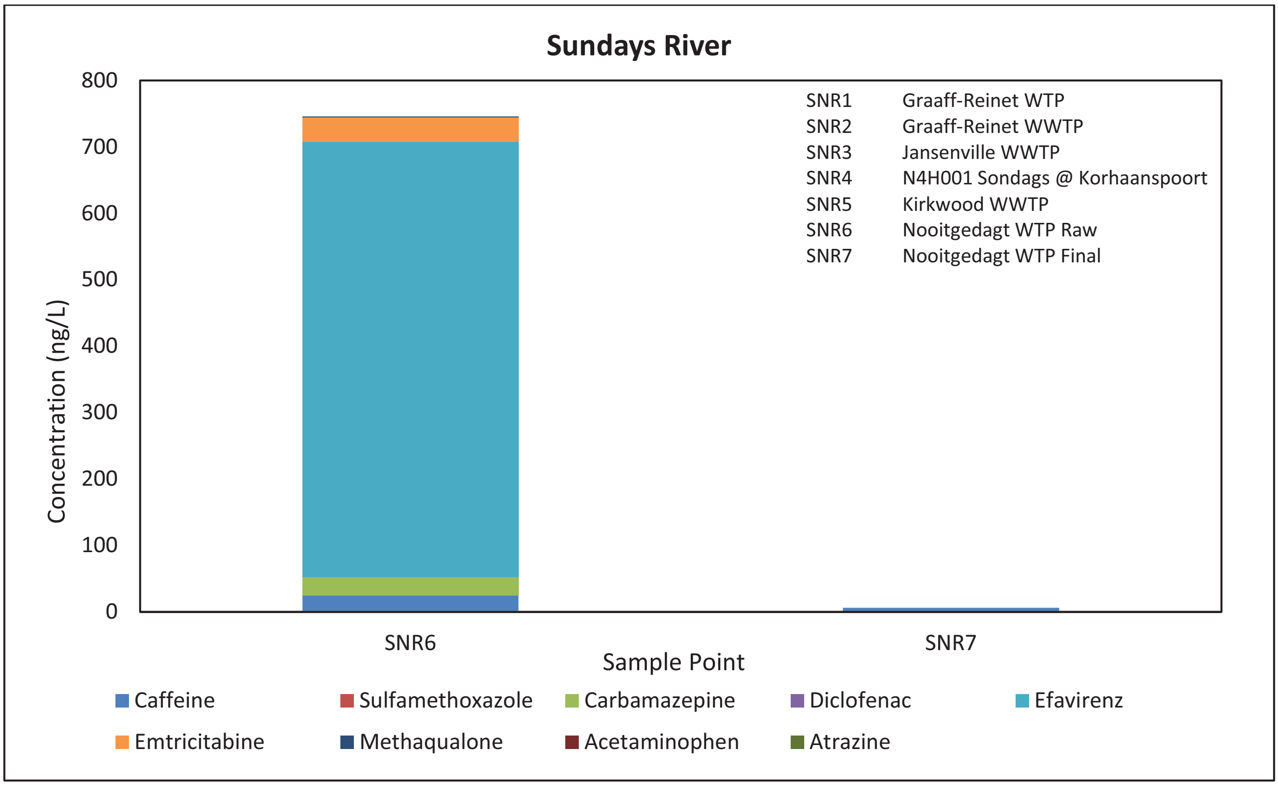


Figure 4.25: CEC results of the raw water intake and final water of a water treatment plant in the Sundays River.

4.2.7 Wastewater content and chemicals of concern of the Crocodile River

4.2.7.1 Flow based wastewater percentage results in the Crocodile River.

Table 4.7 shows a summary of the flow-based wastewater percentage calculations for the Crocodile River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix H. Indented and grey coloured measuring stations and water treatment plants are located in tributaries of the Crocodile River.

Table 4.7: Flow-based wastewater percentage results for the Crocodile (W) River for the years 2015-2019.

Crocodile (W) River

Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	38%	35%	36%	38%	33%	35%	34%	29%	31%
A2H050 Krokodil River @ Zwartkop	88%	82%	84%	92%	85%	89%	89%	82%	86%
A2H045 Krokodil River @ Vlakfontein	83%	79%	80%	84%	76%	79%	80%	71%	76%
A2H023 Jukskei River @ Nietgedacht	15%	10%	12%	15%	8%	11%	14%	7%	11%
A2H044 Jukskei River @ Vlakfontein	12%	9%	10%	14%	5%	7%	14%	7%	9%
Rietvlei WTP	23%	18%	21%	23%	16%	19%	25%	14%	20%
A2H014 Hennops River @ Skurweberg	52%	46%	49%	52%	42%	47%	55%	38%	49%
A2H012 Krokodil River @ Kalkheuwel	46%	40%	43%	48%	37%	42%	45%	34%	39%
A2H058 Swart Spruit @ Rietfontein	87%	78%	82%	93%	74%	80%	87%	57%	65%
A2H013 Magalies River @ Scheerpoort	6%	4%	4%	11%	6%	8%	7%	2%	4%
Brits WTP	82%	61%	64%	83%	54%	67%	76%	43%	53%
A2H048 Krokodil River @ Krokodilpoort	82%	61%	64%	83%	54%	67%	76%	44%	54%
Vaalkop WTP	18%	10%	10%	21%	9%	12%	21%	9%	8%
A2H059 Krokodil River @ Vaalkop	80%	67%	67%	83%	65%	72%	83%	65%	61%

Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	51%	30%	32%	61%	40%	42%	42%	33%	35%
A2H050 Krokodil River @ Zwartkop	96%	84%	87%	97%	92%	92%	92%	85%	87%
A2H045 Krokodil River @ Vlakfontein	88%	72%	78%	89%	57%	75%	85%	70%	78%
A2H023 Jukskei River @ Nietgedacht	23%	9%	13%	15%	7%	11%	16%	8%	11%
A2H044 Jukskei River @ Vlakfontein	20%	8%	10%	25%	6%	9%	16%	7%	9%
Rietvlei WTP	27%	16%	21%	24%	14%	17%	24%	16%	20%
A2H014 Hennops River @ Skurweberg	58%	42%	50%	54%	37%	43%	54%	41%	47%
A2H012 Krokodil River @ Kalkheuwel	44%	34%	39%	48%	29%	34%	46%	35%	39%
A2H058 Swart Spruit @ Rietfontein	91%	77%	82%	84%	43%	66%	88%	62%	74%
A2H013 Magalies River @ Scheerpoort	16%	3%	5%	32%	4%	6%	10%	4%	5%
Brits WTP	92%	36%	53%		N/A		86%	47%	59%
A2H048 Krokodil River @ Krokodilpoort	92%	36%	53%				86%	47%	59%
Vaalkop WTP	31%	5%	8%	23%	3%	6%	20%	4%	8%
A2H059 Krokodil River @ Vaalkop	89%	49%	61%	84%	38%	52%	82%	44%	60%

Based on the wastewater percentage results for the Crocodile River, it can be seen that the impact of wastewater is considerably lower in the tributaries. This suggest that that the natural flow of the tributaries is higher than that of the main river. It also suggests that WWTPs with larger design capacities discharge into the main river, having a larger impact, even when the flow is high. The results indicate that the Crocodile River, below the Hartbeespoort Dam can be considered a wastewater impacted water source. Subsequently, the Brits WTP can be considered a de facto reuse plant, as the plant abstract water from the wastewater impacted section of the river.

Figure 4.26 (a), (b) and (c) show the river classification maps for the Crocodile River for minimum, average and median flow, averaged for the years 2015-2019. Larger maps showing the classification for each year can be found in Appendix H. Map (a) clearly shows the impact of wastewater contributions to the river during low flow conditions. During this time, the entire river, including the tributaries may be considered impacted by wastewater.

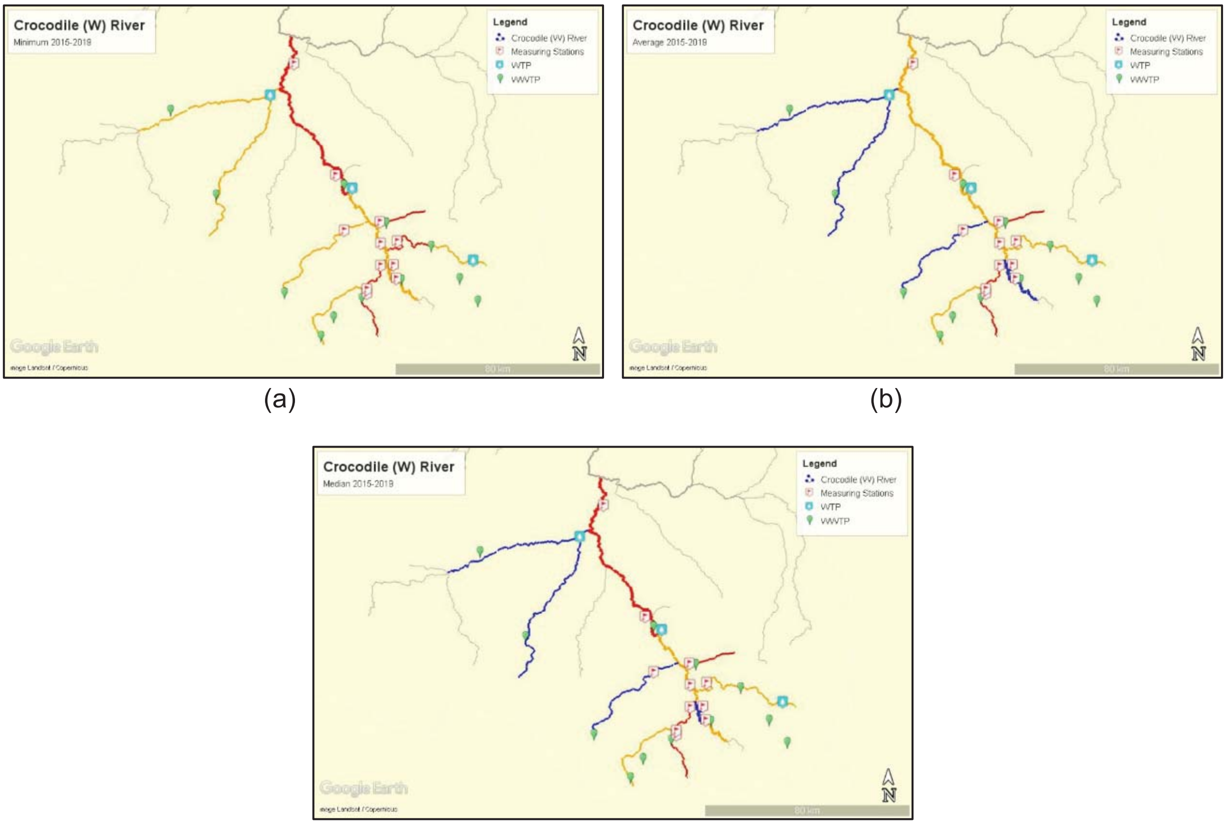


Figure 4.26: Wastewater contribution in the Crocodile River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.7.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.27 shows a map of the Crocodile River with marked sampling locations. The samples consisted of river water, WTP final water and wastewater effluent.

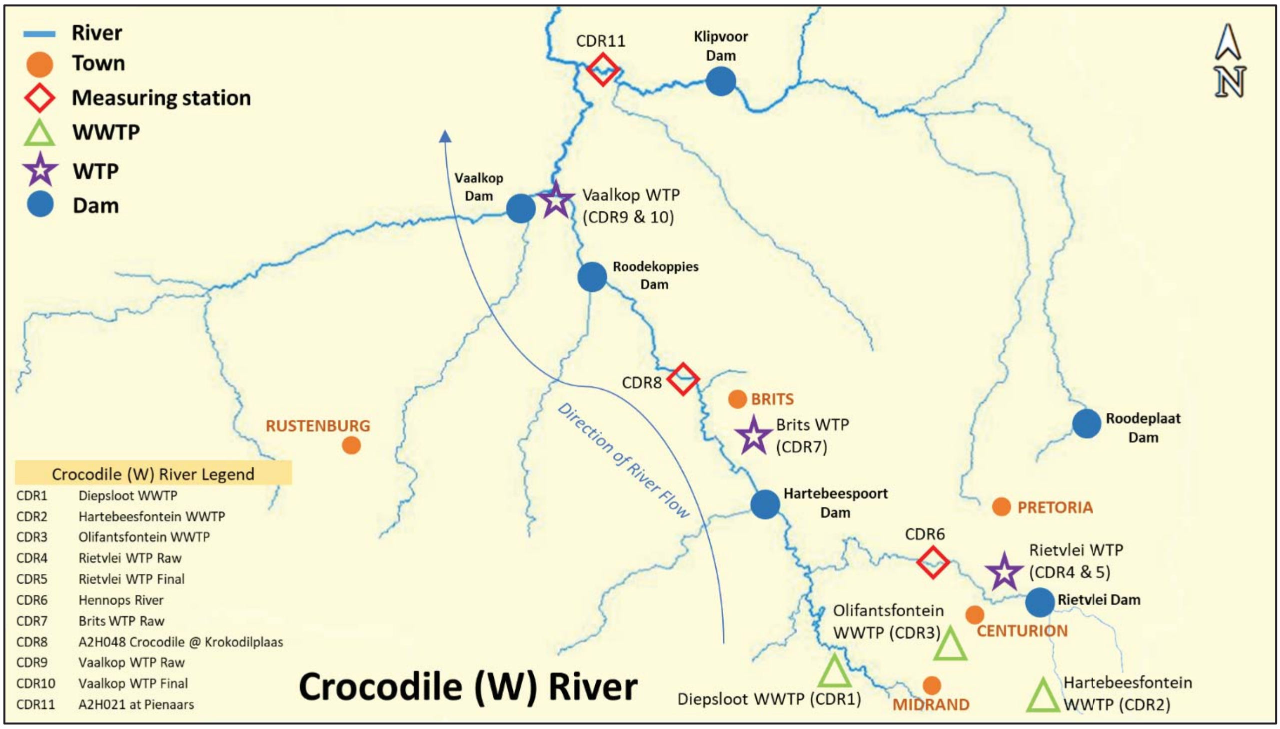


Figure 4.27: Map of the Crocodile River sampling locations for CEC analysis

Figure 4.28 shows the results of eight indicator CECs in the Crocodile River. The graph visually demonstrates the level of contaminants found in the Crocodile River at the different sampling points.

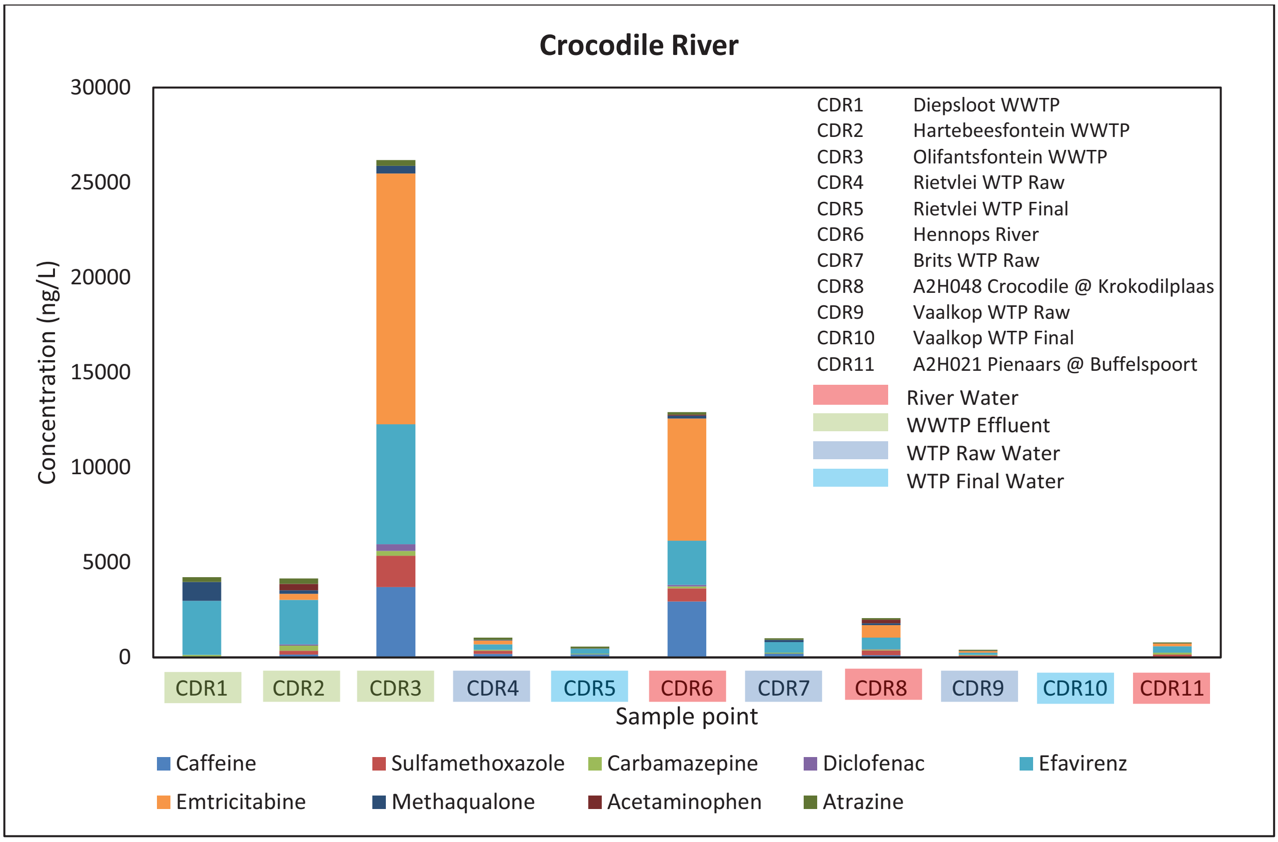


Figure 4.28: CEC results at each of the sampling locations in the Crocodile River

Results indicate that the CEC concentrations are highest in the wastewater treatment plant effluent, which is expected. However, the CEC concentrations at sampling point CDR 6 are highly elevated compared to concentrations in other river water samples. In Figure 4.29 it can be seen that there are high levels of caffeine, sulfamethoxazole, efavirenz and emtricitabine in the river. The combined concentration of the all the chemicals found at this point is 10 times higher compared to the combined concentrations at other sampling points in the river. Pollution in the Hennops River is an immensely complex problem due to extensive urbanisation, both formal and informal, as well as industrial pollution. Main sources of pollution in the Hennops are due to ill-managed and overflowing sewers, littering and illegal waste sites. The Hennops River can therefore be classified as a highly impacted river. Fortunately, there are no water treatment plants abstracting directly form the Hennops River. However, the river joins the Crocodile River and feeds the Hartbeespoort Dam.

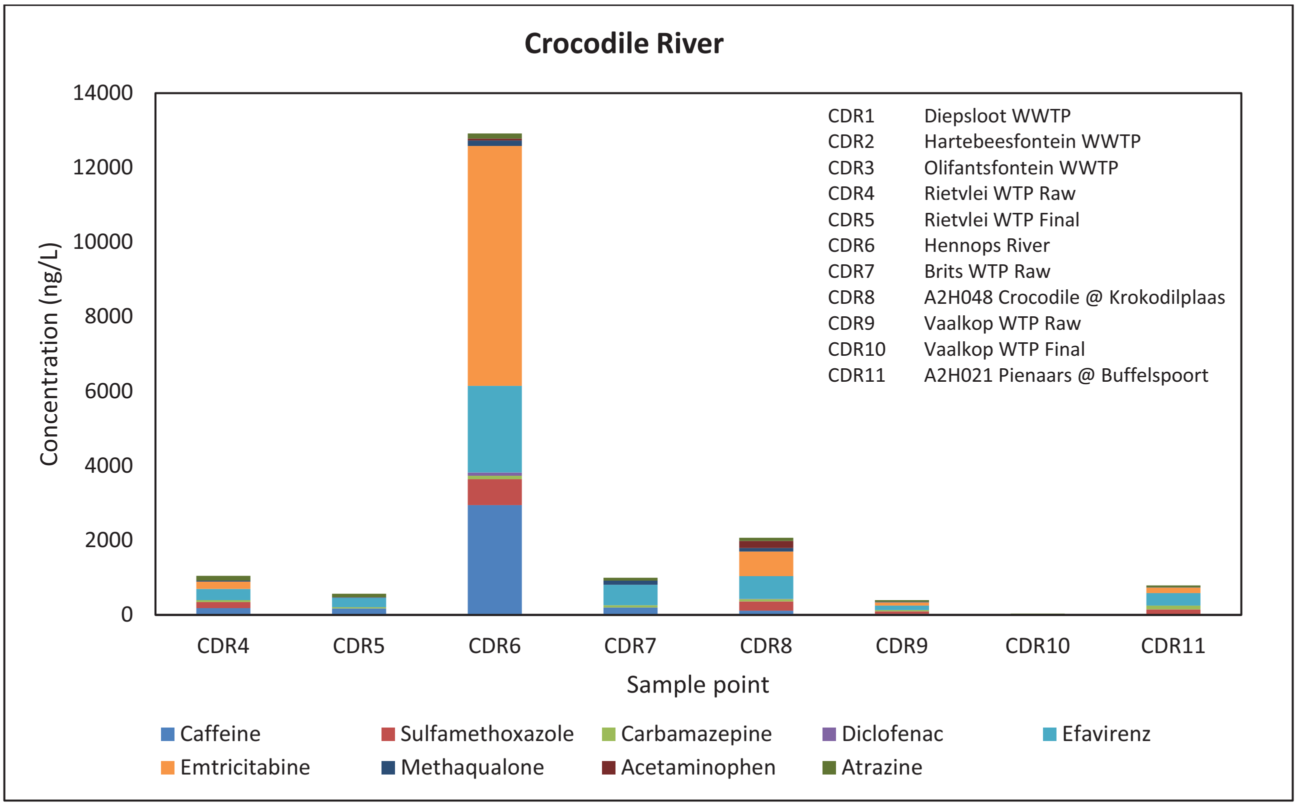


Figure 4.29: CEC results at the measuring stations and water treatment plants in the Crocodile River

4.2.8 Wastewater content and chemicals of concern of the Olifants River

4.2.8.1 Flow based wastewater percentage results for the Olifants River.

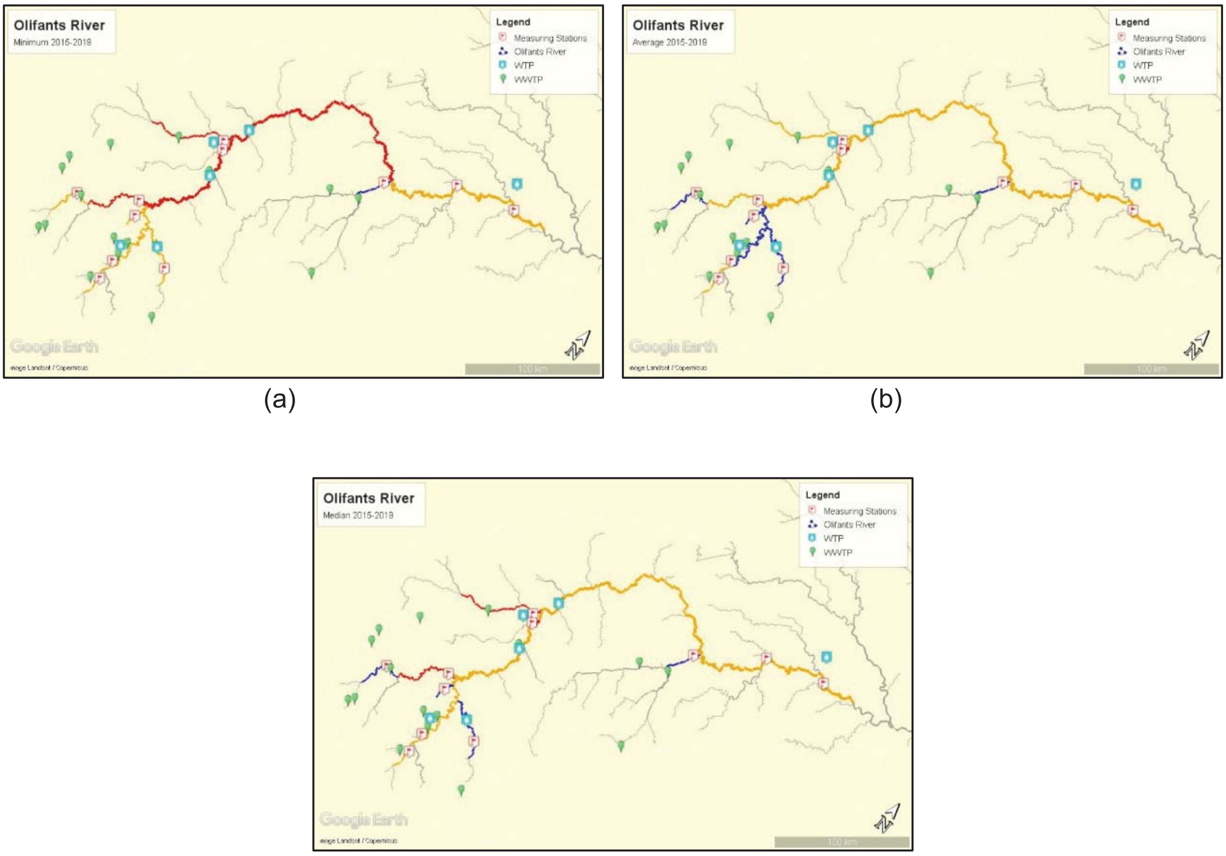
Table 4.8 shows a summary of the flow-based wastewater percentage calculations for the Olifants River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix I. Indented and grey coloured measuring stations and water treatment plants are located in tributaries of the Olifants River.

Table 4.8: Flow-based wastewater percentage results for the Olifants River for the years 2015-2019.

Olifants River									
Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	33%	13%	19%	32%	5%	8%	11%	2%	3%
B1H005 Olifants River @ Wolwekrans	27%	9%	12%	39%	3%	5%	7%	1%	2%
Witbank WTP	56%	26%	33%	70%	8%	15%	20%	4%	7%
B1H012 Little Olifants River @ Rondebosch	26%	10%	12%	33%	7%	9%	23%	5%	9%
Vaalbank WTP	26%	10%	12%	33%	7%	9%	23%	5%	9%
B1H004 Klipspruit @ Zaaihoek	38%	29%	31%	49%	8%	13%	13%	3%	6%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	85%	33%	38%	69%	8%	10%	12%	4%	6%
B2H016 Wilger River @ Waterval	25%	12%	15%	75%	11%	14%	91%	68%	76%
Groblersdal WTP	52%	29%	34%	68%	53%	59%	54%	34%	41%
B3H026 Eagle's Flight	39%	17%	22%	91%	75%	79%	93%	71%	78%
Marble Hall WTP	38%	17%	21%	83%	43%	53%	38%	17%	26%
B3H021 Elands River @ Skerp Arabie	90%	42%	60%	N/A			88%	59%	68%
Flag Boshielo WTP	48%	22%	28%	96%	47%	53%	56%	31%	38%
B4H025 Steelpoort River @ Taung	4%	1%	1%	1%	1%	1%	1%	1%	0%
B7H007 Olifants River @ Oxford	20%	11%	13%	39%	15%	22%	18%	10%	13%
Phalaborwa WTP	18%	8%	9%	42%	16%	21%	18%	8%	10%
B7H015 Olifants River @ Mamba KNP	18%	8%	9%	42%	16%	21%	18%	8%	10%
Measuring station/ Water Treatment Works	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	22%	4%	7%	17%	3%	4%	20%	4%	6%
B1H005 Olifants River @ Wolwekrans	10%	2%	4%	10%	4%	4%	12%	2%	4%
Witbank WTP	28%	7%	12%	29%	13%	13%	33%	8%	13%
B1H012 Little Olifants River @ Rondebosch	9%	3%	5%	18%	3%	4%	18%	4%	7%
Vaalbank WTP	9%	3%	5%	18%	3%	4%	18%	4%	7%
B1H004 Klipspruit @ Zaaihoek	15%	5%	8%	19%	4%	6%	20%	5%	8%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	14%	2%	4%	25%	1%	3%	15%	3%	5%
B2H016 Wilger River @ Waterval	95%	67%	78%	97%	25%	52%	95%	45%	67%
Groblersdal WTP	56%	43%	48%	61%	45%	50%	60%	44%	50%
B3H026 Eagle's Flight	97%	70%	86%	94%	43%	71%	94%	64%	79%
Marble Hall WTP	49%	25%	37%	54%	14%	21%	53%	23%	33%
B3H021 Elands River @ Skerp Arabie	93%	58%	70%	95%	18%	42%	93%	35%	57%
Flag Boshielo WTP	61%	15%	31%	76%	11%	24%	64%	20%	32%
B4H025 Steelpoort River @ Taung	1%	0%	0%	1%	0%	1%	1%	0%	1%
B7H007 Olifants River @ Oxford	29%	18%	19%	29%	15%	18%	25%	13%	16%
Phalaborwa WTP	32%	17%	19%	34%	11%	14%	25%	11%	13%
B7H015 Olifants River @ Mamba KNP	32%	17%	19%	34%	11%	14%	25%	11%	13%

The wastewater percentage calculations for the Olifants River indicate that the middle section of the Olifants River is more impacted by wastewater effluents. Tributaries are less impacted due to a lower presence of WWTPs that discharge into those rivers. River sections are especially dominated by wastewater contributions between 50-100% of wastewater during low-flow conditions. The Groblersdal and Marble Hall WTPs abstract their water from the Loskop Dam, which is situated in the Olifants River below the confluence of the Wilge and Klein-Olifants Rivers with the Olifants River. Therefore, that middle section of the river is impacted by the contribution of all the WWTPs that discharge into the tributaries. Therefore, water treatment plants abstracting from this impacted section of the river can be classified as de facto reuse plants.

Figure 4.30 (a), (b) and (c) shows the river classification maps for the Olifants River for the minimum, average, and median flow conditions, averaged for the years 2015-2019. Larger maps showing the river classification of the Olifants River for each year can be found in Appendix I.



(a) (b)

(c)

Figure 4.30: Wastewater contribution in the Olifants River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.8.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.31 shows a map of the Olifants River with marked sampling locations. The samples consisted of river water, WTP final water and wastewater effluent.

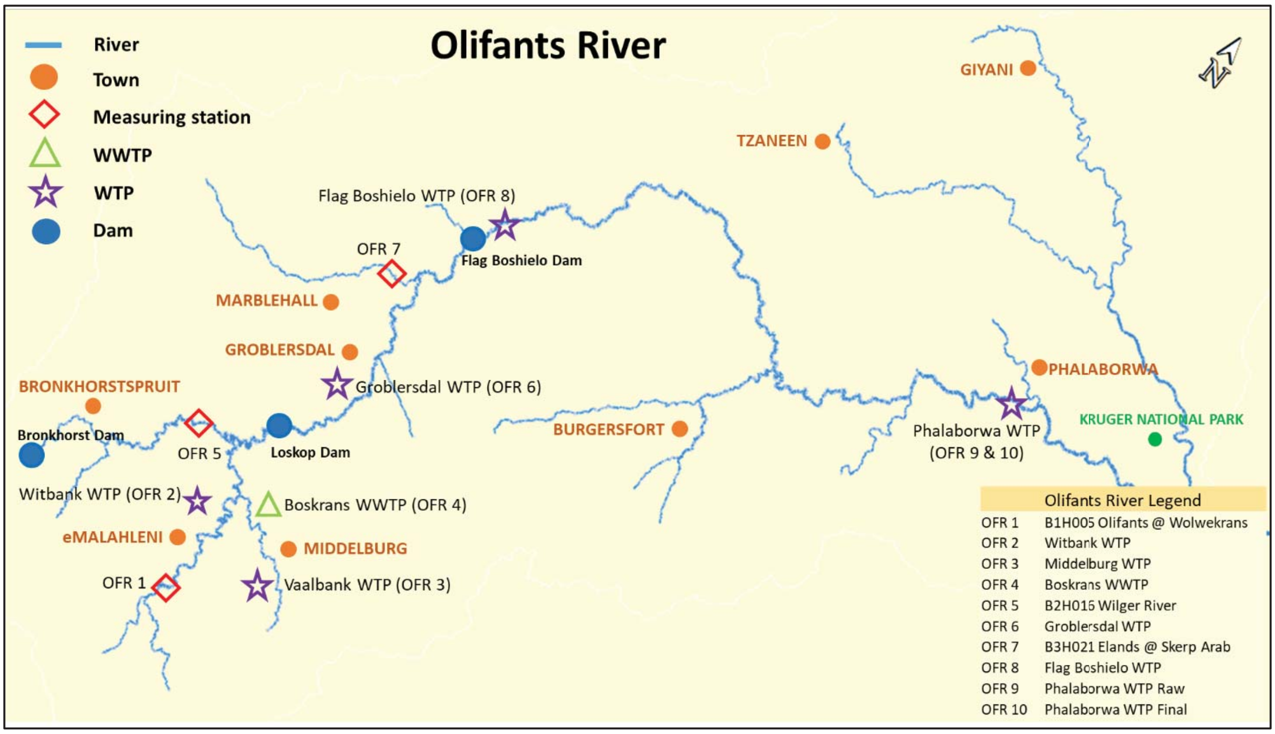


Figure 4.31: Map of the Olifants River sampling locations for CEC analysis

Figure 4.32 shows the results of eight indicator CECs in the Olifants River. The graph visually demonstrates the level of contaminants found in the Olifants River at the different sampling points.

Results indicate that the CEC concentrations are highest in the final effluent of the wastewater treatment plant. When removing the WWTP effluent concentrations in Figure 4.33, a clear perspective of the CEC concentrations in the Olifants River is observed. The combined concentration of CECs in each of these sampling points do not exceed 500 ng/L, which is about 75 to 300 times lower than the combined CEC concentrations found in the final effluent sample. The results in Figure 4.33 do however indicate that substantial amounts of the pesticide atrazine are now present in the river water samples. Atrazine is a herbicide most commonly used to control broadleaf and grassy weeds in important crops such as maize, sorghum and sugarcane and has been identified as an environmental endocrine disruptor and possible human carcinogen (Adams, 2014). These sampling points are situated within one of the major maize producing areas in the country. The Drinking Water Equivalent Level (DWEL)[1] for atrazine has been set as 3 µg/L (3000 ng/L) by the Water Research Foundation (Bruce and Pleus, 2015). The maximum concentration of atrazine was 440 ng/L at sampling point OLF 2 which is the raw water intake to the Witbank (eMalahleni) WTP.

[1] DWEL is the drinking water lifetime exposure level, assuming 100% exposure from that medium at which adverse noncarcinogenic health effects would not be expected to occur. Assuming a person consumes 2 litres of water per day (Bruce and Pleus, 2015).

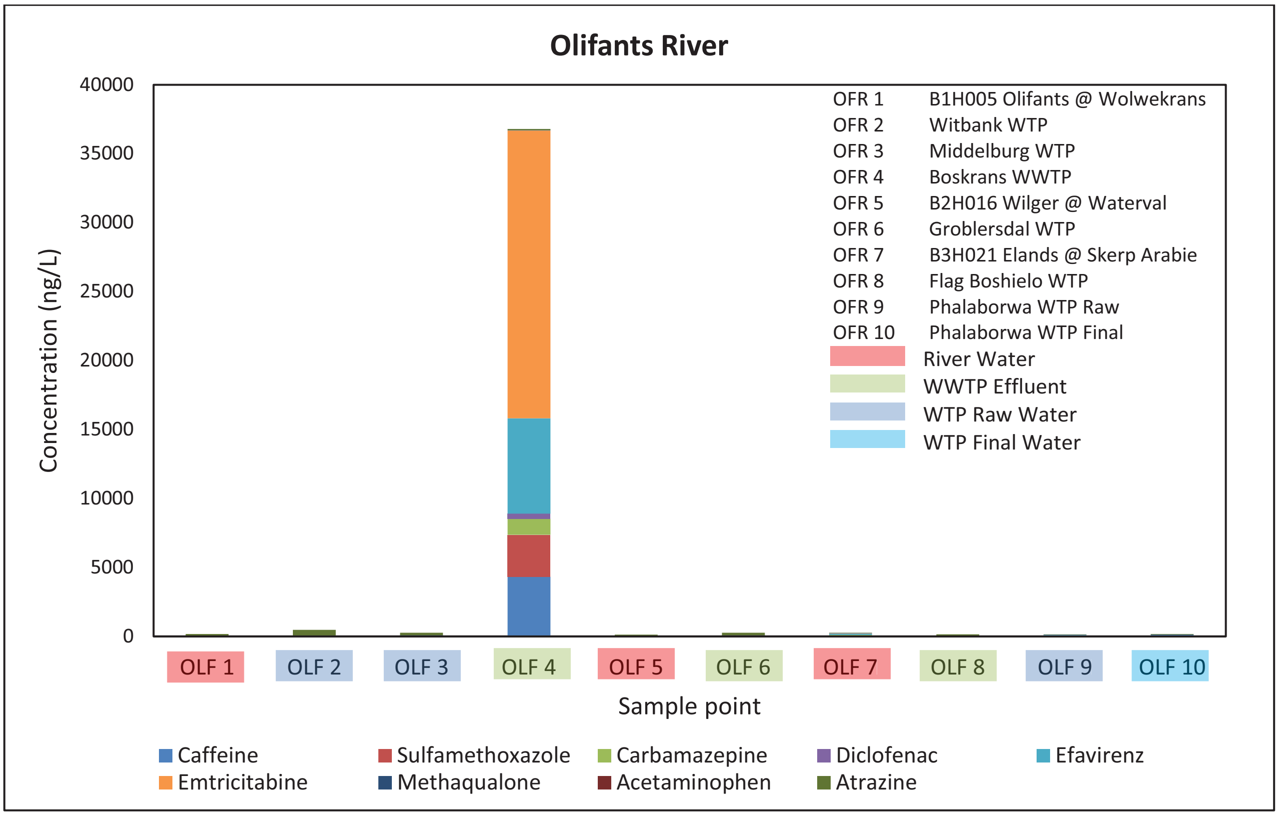


Figure 4.32: CEC results at each of the sampling locations in the Olifants River

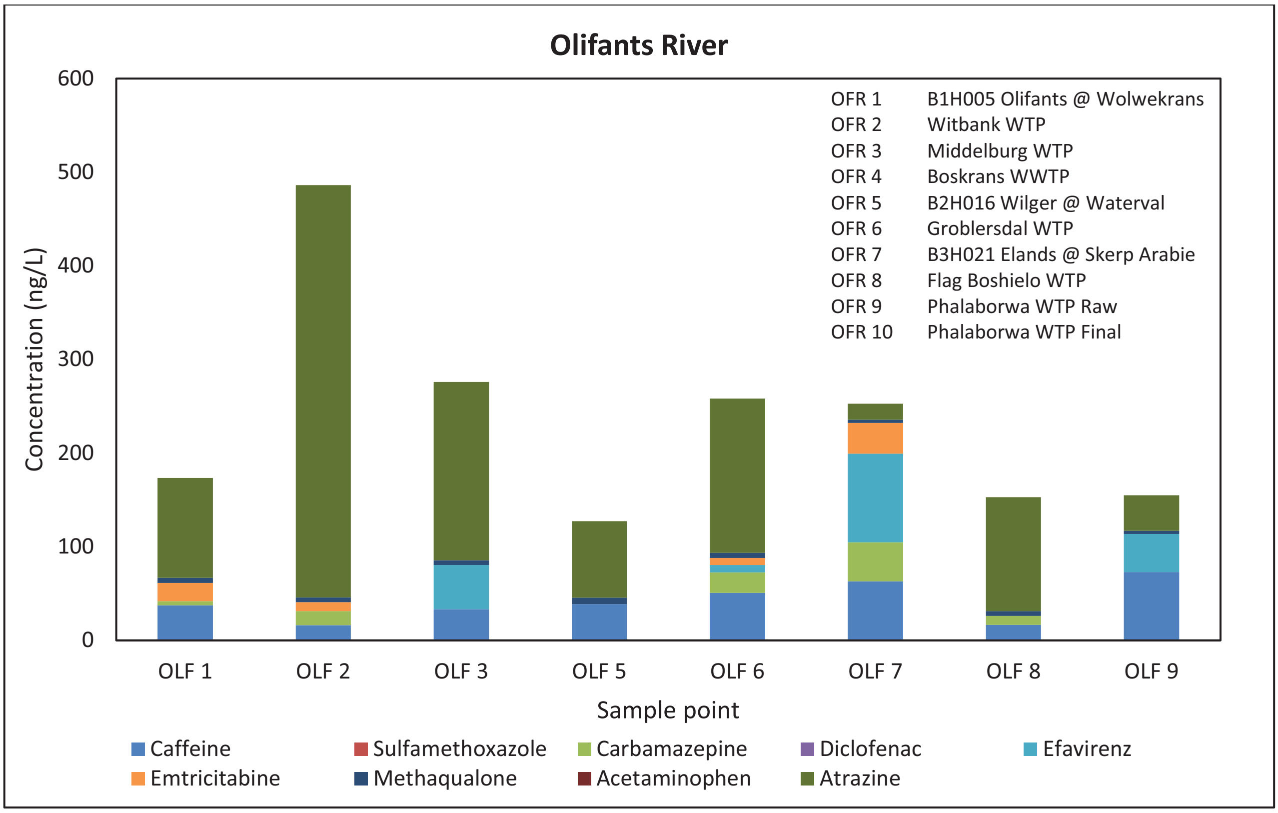


Figure 4.33: CEC results at the measuring stations and water treatment plants in the Olifants River

4.2.9 Wastewater content and chemicals of concern in the Upper Vaal River

4.2.9.1 Flow based wastewater percentage results in the Upper Vaal River

Table 4.9 shows a summary of the flow-based wastewater percentage calculations for the Upper Vaal River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix J. Indented and grey coloured measuring stations are located in tributaries of the Upper Vaal River.

Table 4.9: Flow-based wastewater percentage results for the Upper Vaal River for the years 2015-2019.

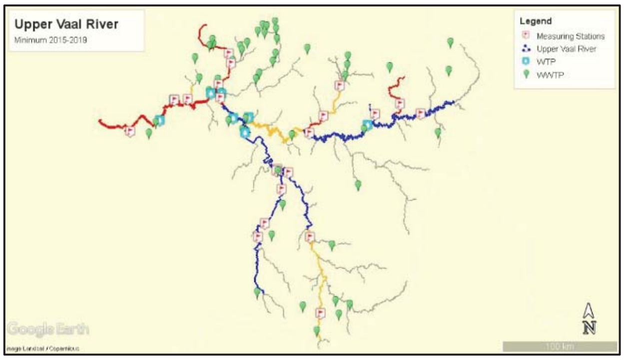
Upper Vaal River

Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C1H007 Vaal River @ Goedgeluk	5%	4%	4%	4%	1%	2%	4%	1%	2%
C1H006 Waterval River @ Elandslaagte	70%	21%	44%	64%	6%	22%	33%	4%	17%
C1H005 Leeu Sp @ Welbedacht	0%	0%	0%	0%	0%	0%	0%	0%	0%
Standerton WTP	8%	5%	6%	7%	2%	4%	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	6%	3%	3%	17%	3%	4%	5%	1%	2%
C1H004 Waterval River @ Branddrift	43%	30%	34%	30%	17%	25%	34%	7%	17%
C1H008 Waterval River @ Elandslaagte	76%	44%	56%	78%	12%	45%	77%	9%	36%
Vaal Marina WTP	26%	12%	15%	49%	10%	18%	23%	2%	8%
C8H005 Elands River @ Elands River Drift	24%	12%	14%	37%	12%	18%	19%	5%	9%
C8H028 Wilge River @ Bavaria	5%	2%	2%	16%	2%	2%	19%	3%	7%
C8H027 Wilge River @ Ballingtomp	6%	2%	3%	14%	3%	3%	11%	2%	4%
C8H037 Liebenbergsvlei @ Reward	1%	1%	1%	1%	1%	1%	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	2%	1%	1%	2%	1%	1%	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	2%	1%	1%	2%	1%	1%	2%	1%	1%
C8H030 Wilge River @ Slabberts	3%	2%	2%	3%	2%	2%	3%	1%	2%
C8H001 Wilge River @ Frankfort	3%	2%	2%	4%	2%	2%	4%	2%	2%
Oranjeville WTP	3%	2%	2%	4%	2%	2%	4%	2%	2%
Deneysville WTP	3%	6%	4%	3%	7%	4%	3%	7%	2%
C2H272 Vaal @ Bankfontein (Lethabo)	63%	38%	40%	91%	57%	62%	58%	18%	39%
Zuikerbossie WTP	82%	62%	64%	96%	78%	81%	78%	37%	63%
C2H137 Klip River @ Zwartkopjes	50%	45%	46%		N/A		53%	38%	41%
C2H136 Riet Spruit @ Waterval	77%	70%	72%	74%	62%	66%	79%	61%	65%
C2H071 Klip River @ Kookfontein	52%	47%	48%	49%	40%	40%	73%	43%	44%
Vereeniging WTP	58%	50%	52%	57%	46%	47%	74%	41%	48%
C2H005 Riet Spruit @ Kaalplaats	34%	31%	31%	33%	30%	30%	31%	27%	27%
Vaal Barrage WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%
C2H140 Vaal River @ Woodlands	49%	39%	41%	70%	33%	40%	61%	32%	35%
Parys WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%
C2H018 Vaal River @ De Vaal	52%	41%	43%	50%	35%	41%	51%	25%	35%

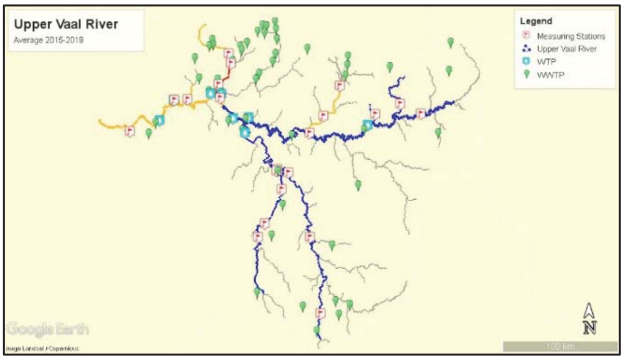
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C1H007 Vaal River @ Goedgeluk	4%	2%	3%	4%	2%	2%	4%	2%	3%
C1H006 Waterval River @ Elandslaagte	50%	9%	32%	62%	2%	27%	52%	5%	26%
C1H005 Leeu Sp @ Welbedacht	0%	0%	0%		N/A		0%	0%	0%
Standerton WTP	6%	2%	4%	6%	2%	4%	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	4%	1%	2%	22%	2%	3%	7%	1%	2%
C1H004 Waterval River @ Branddrift	43%	18%	33%	38%	11%	25%	37%	13%	25%
C1H008 Waterval River @ Elandslaagte	84%	16%	55%	90%	12%	52%	81%	14%	47%
Vaal Marina WTP	18%	4%	8%	58%	6%	14%	28%	5%	11%
C8H005 Elands River @ Elands River Drift	16%	5%	8%	35%	15%	20%	24%	8%	12%
C8H028 Wilge River @ Bavaria	10%	3%	4%	33%	9%	13%	11%	3%	3%
C8H027 Wilge River @ Ballingtomp	7%	2%	4%	25%	6%	8%	10%	3%	4%
C8H037 Liebenbergsvlei @ Reward	1%	1%	1%	2%	1%	1%	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H030 Wilge River @ Slabberts	2%	1%	2%	6%	1%	2%	3%	1%	2%
C8H001 Wilge River @ Frankfort	3%	2%	2%	5%	3%	3%	4%	2%	2%
Oranjeville WTP	3%	2%	2%	5%	3%	3%	4%	2%	2%
Deneysville WTP	3%	5%	3%	3%	9%	4%	3%	6%	3%
C2H272 Vaal @ Bankfontein (Lethabo)	78%	21%	20%	68%	42%	50%	70%	30%	36%
Zuikerbossie WTP	90%	41%	39%	85%	66%	72%	86%	52%	60%
C2H137 Klip River @ Zwartkopjes	52%	38%	39%	83%	44%	44%	63%	41%	42%
C2H136 Riet Spruit @ Waterval	72%	65%	66%	74%	62%	64%	75%	64%	67%
C2H071 Klip River @ Kookfontein		N/A			N/A		68%	43%	44%
Vereeniging WTP	97%	71%	69%	95%	87%	90%	72%	45%	47%
C2H005 Riet Spruit @ Kaalplaats	28%	26%	26%	35%	26%	26%	32%	28%	28%
Vaal Barrage WTP	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H140 Vaal River @ Woodlands	45%	32%	35%	42%	30%	33%	51%	33%	36%
Parys WTP	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H018 Vaal River @ De Vaal	55%	34%	37%	56%	31%	36%	53%	32%	38%

Wastewater percentage results of the Upper Vaal River indicate that the lower section of the river, which is the section below the Vaal Dam, is highly impacted by the contributions of wastewater effluent to the river. The upper section of the Upper Vaal River consists of average wastewater percentage contributions less than 10%, while the lower section has wastewater contributions of up to 100%. This suggests that water treatment plants such the Vaal Barrage WTP and Parys WTP can be considered as de facto reuse plants, as they abstract water from river sections that is highly impacted by the contribution of wastewater effluent.

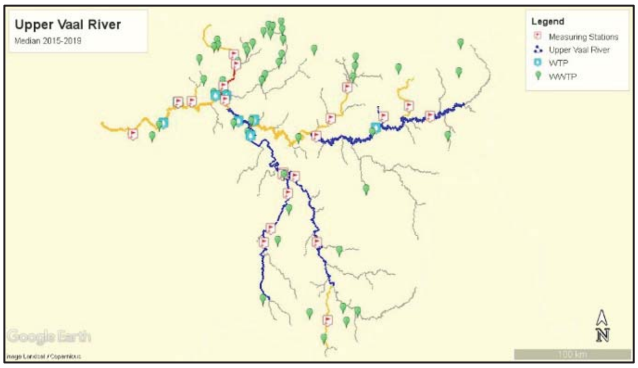
Figure 4.34 (a), (b) and (c) shows the river classification maps of the Upper Vaal River for minimum, average and median flow, averaged for the years 2015-2019. Larger river classification maps for each year for the Upper Vaal River can be found in Appendix J.



(a)



(b)



(c)

Figure 4.34: Wastewater contribution in the Upper Vaal River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.9.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.35 shows a map of the Upper River with marked sampling locations. The samples consisted of river water, WTP final water and wastewater effluent.

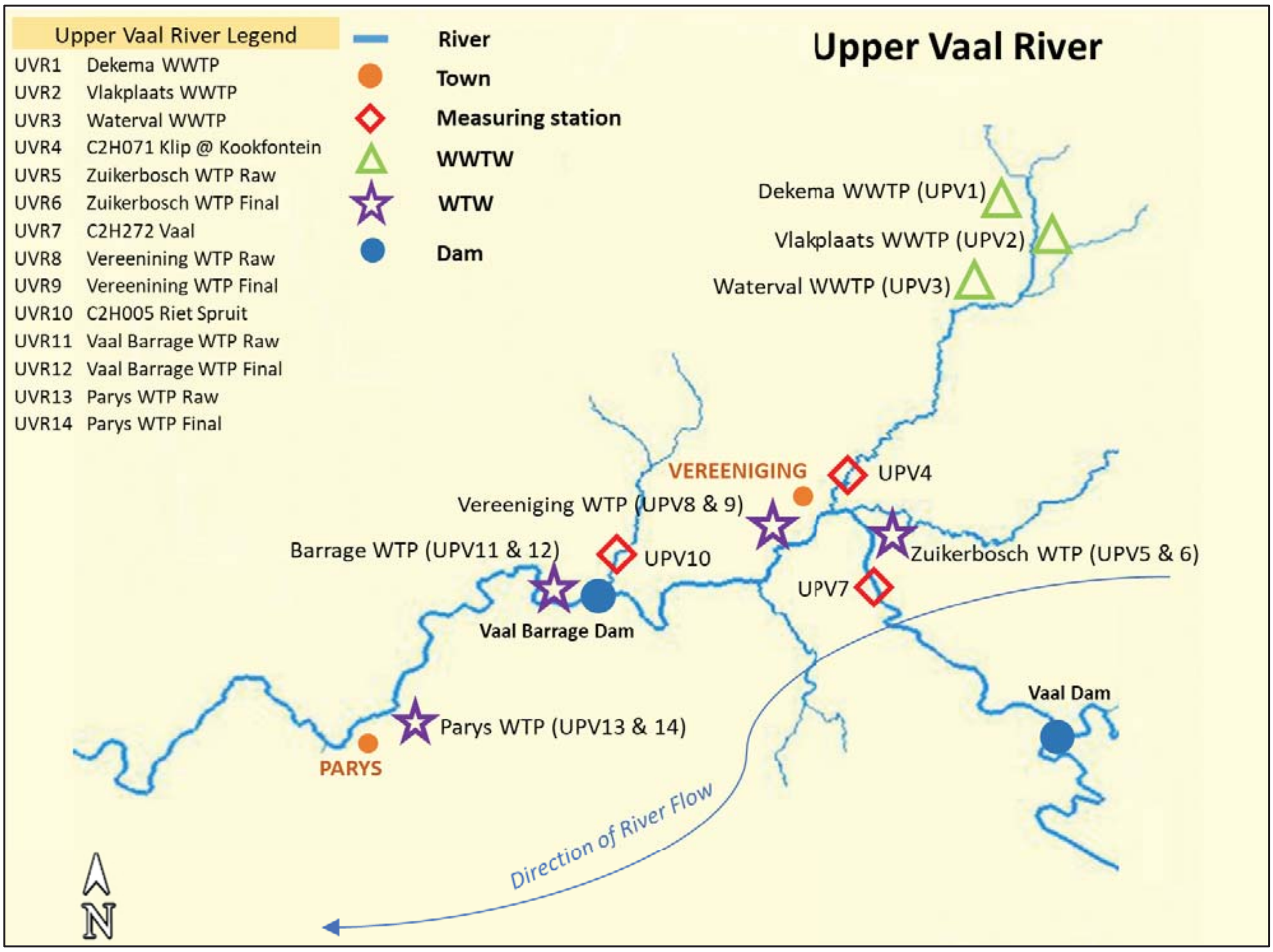


Figure 4.35: Map of the Upper Vaal River sampling locations for CEC analysis

Figure 4.36 shows the results of eight indicator CECs in the Upper Vaal River. The graph visually demonstrates the level of contaminants found in the Crocodile River at the different sampling points.

From the results it can be seen that the CEC concentrations are highly elevated in the final effluent of the three wastewater treatment plants that were sampled. Since all of the WWTPs discharge into the same river, it is no surprise that the CEC concentrations at UVR4 are highly elevated. From the results it can be seen that efavirenz and emtricitabine are persistently carried downstream with very little dilution, absorption, or degradation of the chemicals. This indicates that the Klip River is therefore highly impacted by wastewater effluent discharge.

UVR10 is a river sample taken in the Rietspruit River, which is a tributary of the Vaal River, and also has high levels of CECs. Pollution in the Rietspruit River has been a continuous problem and is mainly cause by poorly operated wastewater treatment plants and overflowing sewers. Figure 4.37 shows that UVR10 contains elevated levels of efavirenz and emtricitabine. The latter can readily be removed in conventional wastewater treatment processes, therefore indicating that the wastewater treatment plants upstream of this sampling point is poorly functioning.

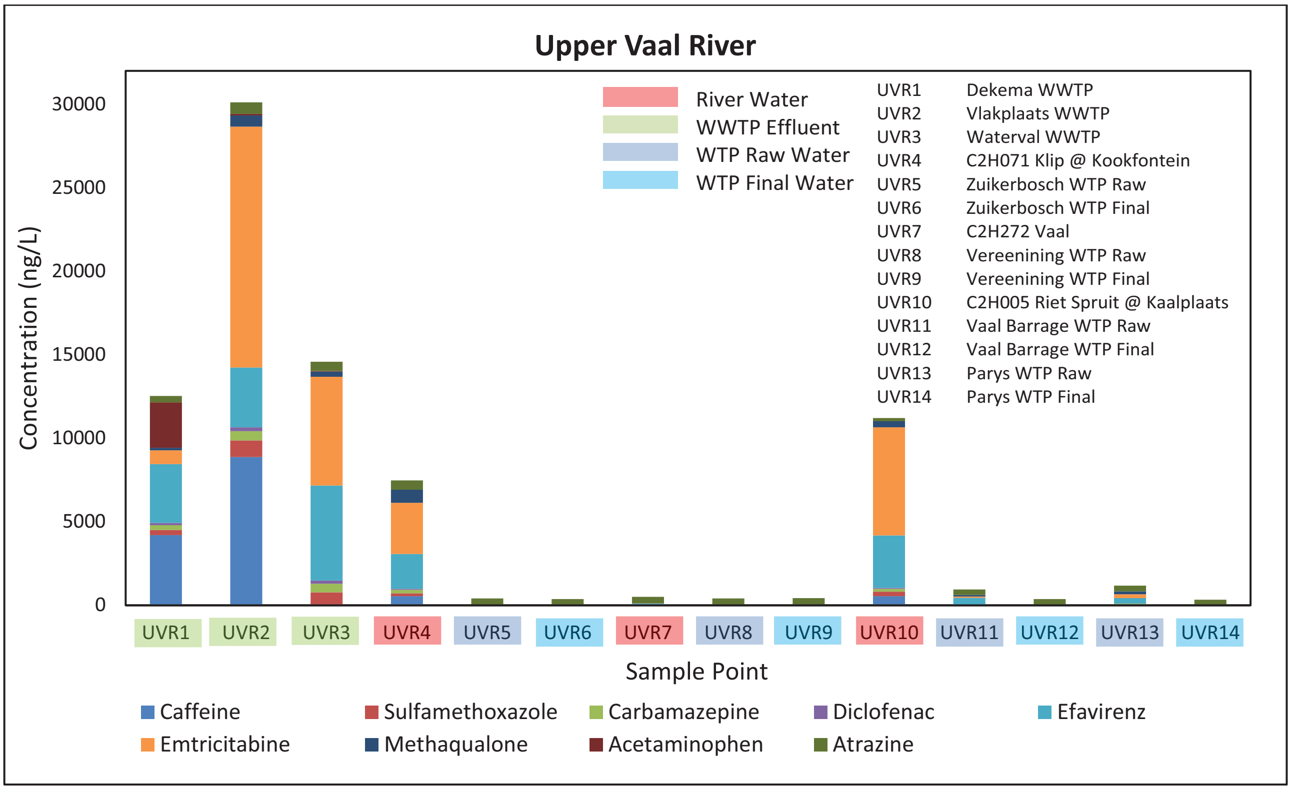


Figure 4.36: CEC results at each of the sampling locations in the Upper Vaal River

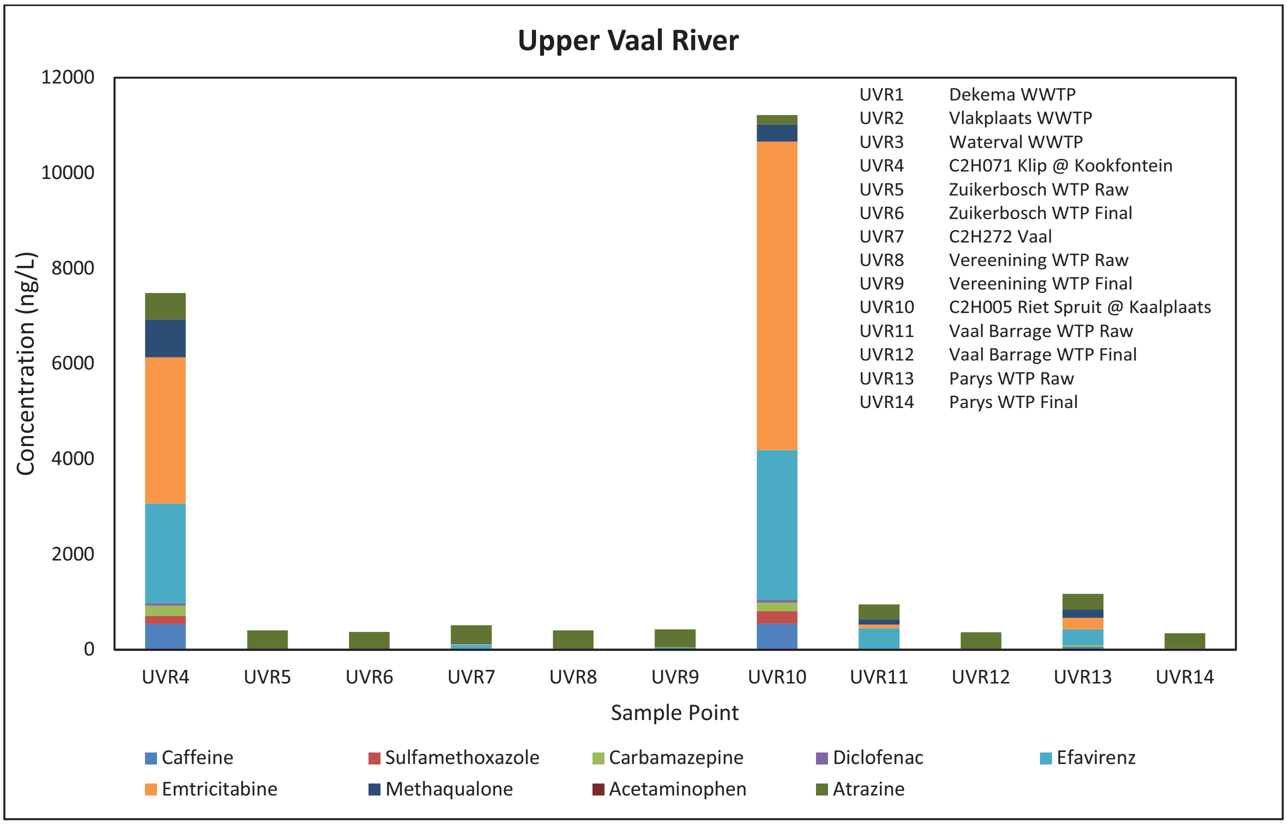


Figure 4.37: CEC results at the measuring stations and water treatment plants in the Upper Vaal River

4.2.10 Wastewater content and chemicals of concern in the Middle Vaal River

4.2.10.1 Flow based wastewater percentage results in the Middle Vaal River

Table 4.10 shows a summary of the flow-based wastewater percentage calculations for the Middle Vaal River. Tables showing more details on how the calculations were performed for this summary table can be found in Appendix K. Indented and grey coloured measuring stations are located in tributaries of the Middle Vaal River.

Table 4.10: Flow-based wastewater percentage results for the Middle Vaal River for the years 2015-2019.

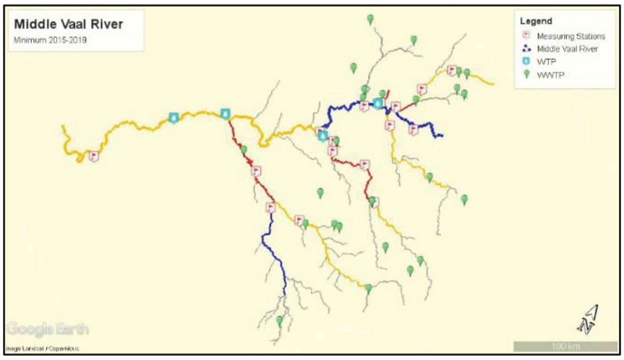
Middle Vaal River

Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C2H018 Vaal River @ De Vaal	0%	0%	0%	0%	0%	0%	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	33%	29%	30%	44%	25%	25%	35%	30%	31%
C2H001 Mooi River @ Witrand	18%	12%	12%	33%	20%	26%	22%	14%	15%
C2H085 Mooi River @ Hoogekraal	71%	62%	65%	72%	41%	64%	54%	18%	27%
C7H006 Renoster River @ Arriesrust	N/A			23%	2%	4%	12%	0%	1%
C2H139 Koekemoer Spruit @ Buffelsfontein	92%	87%	88%	88%	80%	83%	87%	70%	78%
Midvaal WTP	7%	4%	5%	6%	3%	4%	6%	1%	3%
C2H007 Vaal River @ Pilgrims Estate	8%	5%	5%	7%	4%	4%	5%	2%	3%
C6H007 Vals River @ Kroonstad	22%	1%	1%	45%	0%	0%	16%	0%	1%
C6H001 Vals River @ Roodewal	55%	35%	46%	74%	27%	54%	70%	5%	24%
C6H006 Vals River @ Tweefontein	91%	6%	6%	46%	5%	7%	58%	2%	4%
C6H002 Vals River @ Grootdraai	88%	77%	82%	92%	73%	82%	60%	47%	51%
Balkfontein WTP	15%	10%	11%	14%	8%	10%	10%	4%	6%
C2H061 Vaal River @ Klipplaatdrift	17%	11%	12%	16%	8%	10%	16%	8%	7%
C4H016 Sand River @ Bloudrif	55%	45%	48%	57%	26%	48%	37%	10%	16%
C4H015 Vet River @ Vaalkoppies	2%	2%	2%	2%	1%	2%	2%	1%	2%
C4H004 Vet River @ Fizantkraal	82%	49%	58%	87%	27%	62%	62%	13%	20%
Bloemhof WTP	20%	13%	14%	19%	9%	12%	18%	8%	9%
Christiana WTP	20%	13%	14%	19%	9%	12%	18%	8%	9%
C9H003 Vaal River @ Riverton	16%	13%	13%	16%	13%	13%	15%	9%	11%

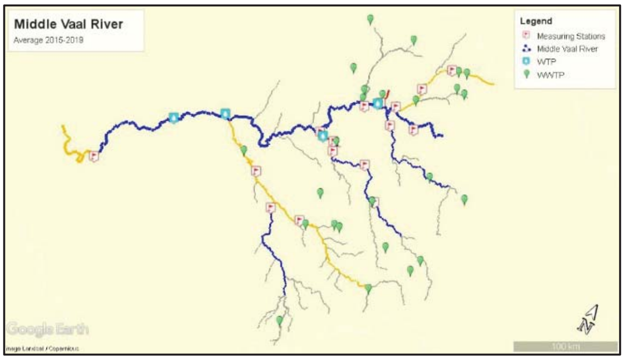
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C2H018 Vaal River @ De Vaal	0%	0%	0%	0%	0%	0%	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	42%	36%	37%	57%	40%	39%	41%	31%	31%
C2H001 Mooi River @ Witrand	37%	20%	20%	37%	27%	31%	27%	17%	18%
C2H085 Mooi River @ Hoogekraal	59%	31%	47%	66%	12%	49%	64%	24%	46%
C7H006 Renoster River @ Arriesrust	6%	2%	2%	79%	3%	56%	16%	1%	3%
C2H139 Koekemoer Spruit @ Buffelsfontein	96%	77%	83%	N/A			92%	78%	83%
Midvaal WTP	7%	3%	3%	7%	2%	3%	6%	2%	3%
C2H007 Vaal River @ Pilgrims Estate	5%	3%	3%	7%	3%	4%	6%	3%	4%
C6H007 Vals River @ Kroonstad	4%	0%	1%	11%	0%	0%	10%	0%	0%
C6H001 Vals River @ Roodewal	76%	9%	44%	71%	6%	40%	68%	9%	38%
C6H006 Vals River @ Tweefontein	89%	2%	3%	76%	1%	4%	67%	2%	4%
C6H002 Vals River @ Grootdraai	81%	51%	57%	74%	50%	57%	77%	57%	63%
Balkfontein WTP	10%	6%	7%	14%	6%	8%	12%	6%	8%
C2H061 Vaal River @ Klipplaatdrift	11%	6%	8%	14%	5%	8%	13%	6%	8%
C4H016 Sand River @ Bloudrif	42%	18%	31%	49%	7%	32%	47%	14%	30%
C4H015 Vet River @ Vaalkoppies	2%	1%	1%	2%	0%	1%	2%	1%	2%
C4H004 Vet River @ Fizantkraal	51%	19%	31%	47%	7%	20%	62%	15%	30%
Bloemhof WTP	13%	7%	9%	16%	6%	9%	15%	7%	10%
Christiana WTP	13%	7%	9%	16%	6%	9%	15%	7%	10%
C9H003 Vaal River @ Riverton	30%	12%	12%	35%	10%	12%	20%	11%	12%

The wastewater percentage results of the Middle Vaal River do not consider any wastewater treatment plant discharges from the Upper Vaal River and is considered as ‘n standalone river for the purposes of the wastewater percentage calculations. The results indicate that the tributaries of the Middle Vaal River, such as the Mooi, Koekemoer Spruit and the Vals Rivers, are most impacted by the presence of wastewater effluent, especially during low-flow conditions.

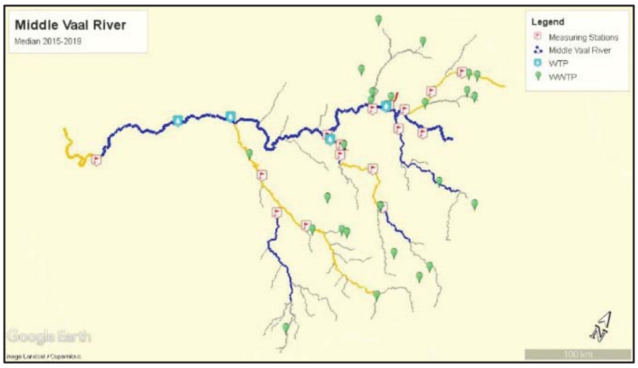
Figure 4.38 (a), (b) and (c) shows the river classification maps of the Middle Vaal River for minimum, average, and median flow, averaged for the years 2015-2019. Larger river classification maps for each year for the Middle Vaal River can be found in Appendix K.



(a)



(b)



(c)

Figure 4.38: Wastewater contribution in the Middle Vaal River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

4.2.10.2 Chemicals of emerging concern in river and wastewater samples

Figure 4.39 shows a map of the Middle Vaal River with marked sampling locations. The samples consisted of river water, WTP final water and wastewater effluent.

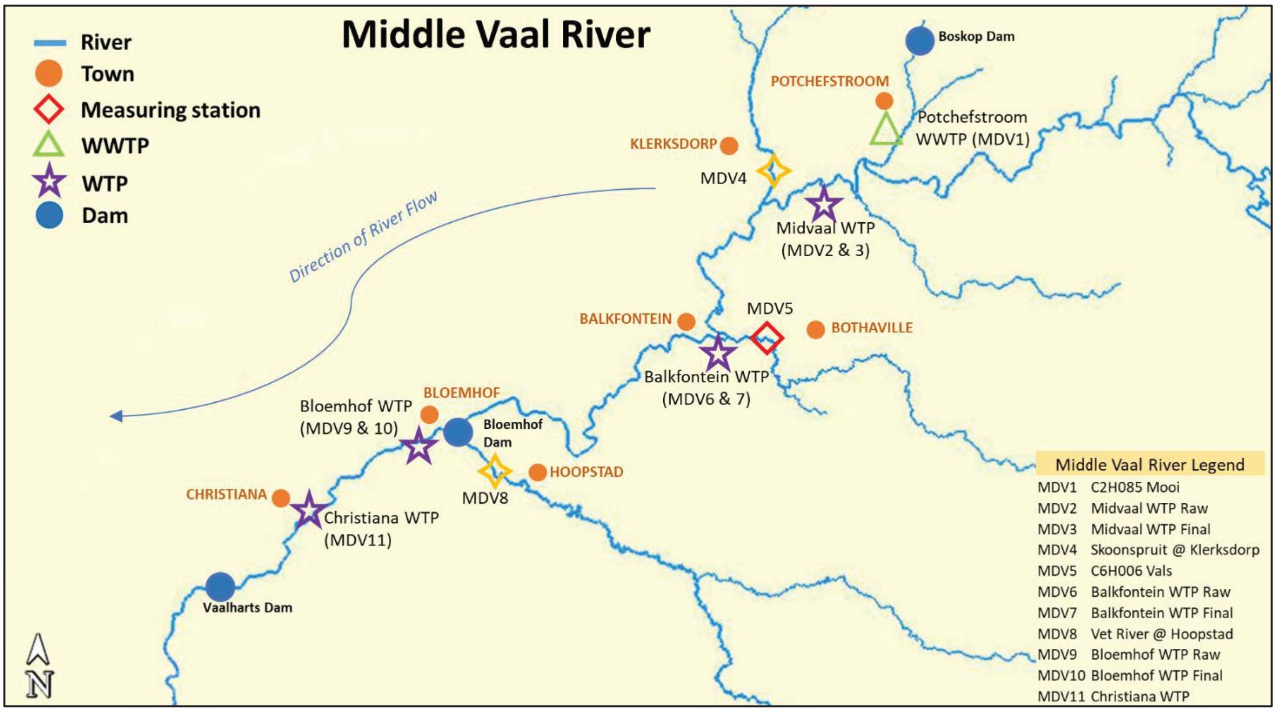


Figure 4.39: Map of the Middle Vaal River sampling locations for CEC analysis

Figure 4.40 shows the results of eight indicator CECs in the Middle Vaal River. The graph visually demonstrates the level of contaminants found in the Crocodile River at the different sampling points.

From the results it can be seen that the CEC concentrations in sample MDV1 is highly elevated, which can be expected from a wastewater effluent sample. However, the same cannot be said for the elevated CEC levels in sample MDV4, which is a river water sample taken in the Schoonspruit river. This is a clear indication that the Schoonpruit River is highly impacted by poorly treated wastewater effluent and other sources of point and non-point pollution.

In Figure 4.41 it can be seen that MDV4 contains elevated levels of caffeine, sulfamethoxazole, efavirenz and emtricitabine. Since caffeine degrades easily in wastewater treatment processes, the presence of this chemical in these concentrations could be due to two reasons: (1) the upstream wastewater treatment plants are functioning very poorly and/or (2) untreated wastewater is illegally dumped into the river.

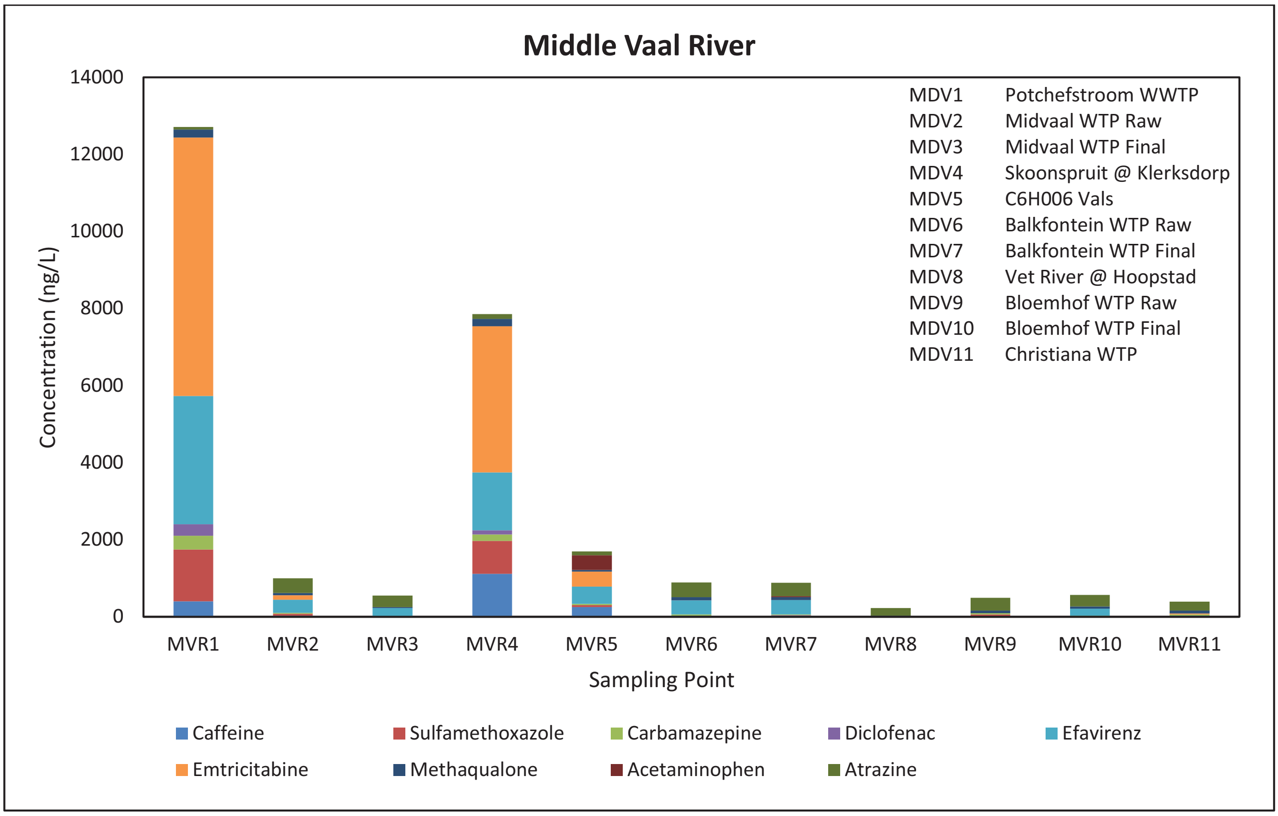


Figure 4.40: CEC results at each of the sampling locations in the Middle Vaal River

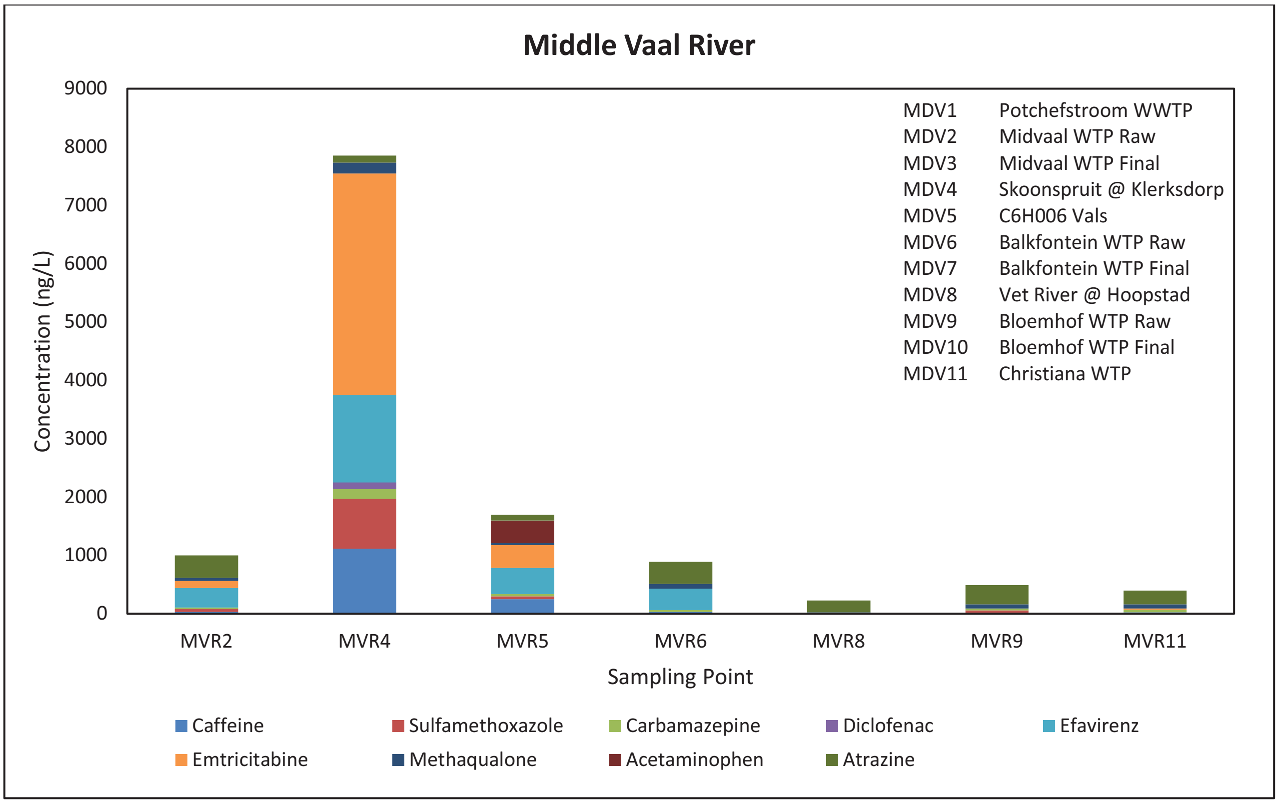


Figure 4.41: CEC results at the measuring stations and water treatment plants in the Middle Vaal River

4.3 SUMMARY

The following conclusions were made with regard to the wastewater percentage calculations and CEC sampling results.

4.3.1 Contributions of wastewater into water sources

Estimating the flow-based wastewater percentage contributions for the ten selected rivers in South Africa indicated the following:

- South African rivers shows a high degree of wastewater impacted streams.
- Estimates predict that the extent of de facto reuse to occur is quite high for the majority of these rivers.
- The wastewater percentage contribution is highly dependent on streamflow and stream size.
- The impact of wastewater effluent contributions can be considerably higher during dry periods when the base flow of the river is low.
- Tributaries with a higher base-flow can have a dilution effect on downstream wastewater effluent contributions.
- Limited density of measuring stations for flow data represents a critical limitation in assessing the wastewater percentage intake at WTP abstraction points.

4.3.2 Transfer of chemicals of emerging concern from wastewater into river water

The occurrence of 21 selected CECs, indicative of domestic wastewater, in the ten selected rivers in South Africa were examined to determine the impact of wastewater contributions to downstream water treatment plants. The findings of this study revealed the following:

- CEC concentrations are highest in wastewater effluents.
- Calculating the mass loading of CECs places the amount of CECs in surface water and wastewater effluents into perspective
- Tributaries with a lower base-flow contains higher concentrations of CECs.
- CEC contributions have a higher impact on rivers where the urban population and wastewater infrastructure capacity increases.
- The results reveal that not all CECs entering the river will be degraded, absorbed, or transformed through natural processes.
- Efavirenz and emtricitabine were consistently detected in all river water and wastewater effluent samples.
- Water treatment plants show reduction of CECs but not complete removal in treatment processes.

CHAPTER 5: ESTIMATING THE NATIONAL EXTENT OF DE FACTO REUSE IN SOUTH AFRICA

5.1 INTRODUCTION

Estimating the extent of de facto reuse in South Africa is achieved through the use of a combination of calculated wastewater percentages based on flow-volumes and the results from the chemicals of emerging concern (CEC) analysis.

5.2 APPROACH

There are approximately 690 drinking water treatment plants (WTPs) in South Africa. Of the 690 WTPs, approximately 100 of those abstracts from boreholes, aquifers, and other freshwater sources other than rivers, which are not impacted by the discharge of domestic wastewater effluent. Of the remaining 590 drinking water treatment plants that abstract feedwater from surface waters impacted by domestic wastewater effluent. To estimate the extent of de facto reuse in the country, this project considered 33 WTPs abstracting water from ten of the most important rivers in the country, providing a large part of the population with drinking water.

5.3 ESTIMATING THE NATIONAL EXTENT OF DE FACTO REUSE

Table 5.1 shows a list of all the water treatment plants investigated in this study, the river the plant abstracts from and whether the plant is considered to be a de facto reuse plant, based on the results of the flow-based wastewater calculations and the CECs results obtained from the sampling events of this project.

Table 5.1: Water treatment plants investigated as potential de facto reuse plants in this project

River	WTP	De Facto Reuse Plant	
		Flow-based calculations	CEC Results
Berg River	Piketberg	Yes	No
	Withoogte	Yes	No
	Swartland	Yes	No
Breede River	Robertson	No	No
	Ashton	No	No
	Bonnievale	No	No
	Buffeljagsrivier	No	No
Buffalo River	King Williams Town	No	No
	Laing	No	No
	Umzonyana	Yes	No
Modder River	Rustfontein	No	No
	Maselspoort	Yes	No
Umgeni/Duzi River	Midmar	No	No
	Durban Heights	Yes	Yes
	Wiggins	Yes	No

River	WTP	De Facto Reuse Plant	
		Flow-based calculations	CEC Results
Sundays River	Graaff-Reinet	Yes	No
	Nooitgedacht	Yes	No
Crocodile River	Rietvlei	No	Yes
	Brits	Yes	No
	Vaalkop	No	No
Olifants River	Witbank	No	No
	Vaalbank	No	No
	Groblersdal	Yes	No
	Flag Boshielo	Yes	No
	Phalaborwa	No	No
Upper Vaal River	Zuikerbosch	Yes	No
	Vereeniging	Yes	No
	Vaal Barrage	Yes	No
	Parys	Yes	No
Middle Vaal River	Midvaal	No	Yes
	Balkfontein	No	Yes
	Bloemhof	No	No
	Christiana	No	Yes

As a first approach, a flow-based methodology was used to assess the percentage of wastewater effluent to stream flow at particular locations or sections of the river. Based on the percentage calculations, a downstream WTP could be classified a potential de facto reuse plant, if the river from which the plant abstracts is classified as having a wastewater content of more than 50%. The results suggested that 48% of the WTPs (16 of the 33) could be classified as a de facto reuse plant using only the calculated wastewater percentages. The results also suggested that the degree of impact of wastewater on downstream WTPs is much more significant than during times of high flow. Figure 5.1 shows a map of the 10 case study rivers with the potential de facto reuse WTPs based on the flow calculations indicated with a red marker.

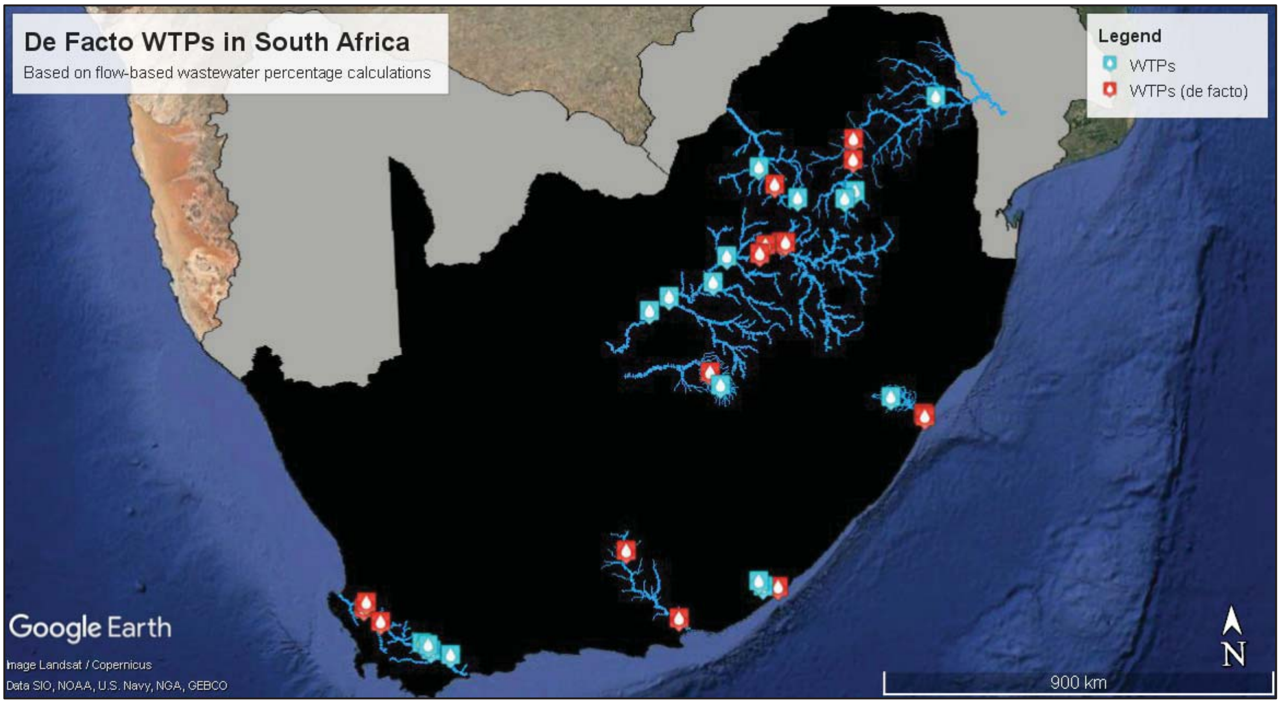


Figure 5.1: Potential de facto reuse water treatment plants in South Africa based on flow-based wastewater percentage calculations.

The second approach was to determine the extent of de facto reuse by estimating the wastewater content at drinking water treatment plant intakes based on the measured concentration of indicator compounds in wastewater effluents. This approach is more difficult since site conditions such as local degree of mixing and dilution, upstream load prior to discharge, and in-stream attenuation processes such as biodegradation or photolysis (Drewes et al., 2017) needs to be considered. Therefore, a WTP could be considered a potential de facto reuse plant if that plant abstracts water from a section of river that contains a higher measured concentration of CECs than estimated. The results indicated that only 12% of the WTPs (4 of the 33) abstracts water from a river section that contains a higher measured concentration of CECs than predicted. However, 100% of the WTPs abstracts water that contains some cumulative concentration of CECs indicative of treated domestic wastewater and therefore all WTPs can be considered as potential de facto reuse plants.

The four identified WTPs with higher measured concentrations is however considered a high risk and it is recommended that further studies be conducted at these sites or catchments. Figure 5.2 shows a map of the 10 case study rivers with the potential de facto reuse WTPs based on the CEC results indicated with a red marker.

Of the other WTPs which were not considered in this project, some of the plants may be impacted by feedwater containing domestic wastewaters, although to a lesser extent than those reported on in this project. A further number of drinking water treatment plants may not be affected by any wastewater pollution at all, or by a negligible degree.

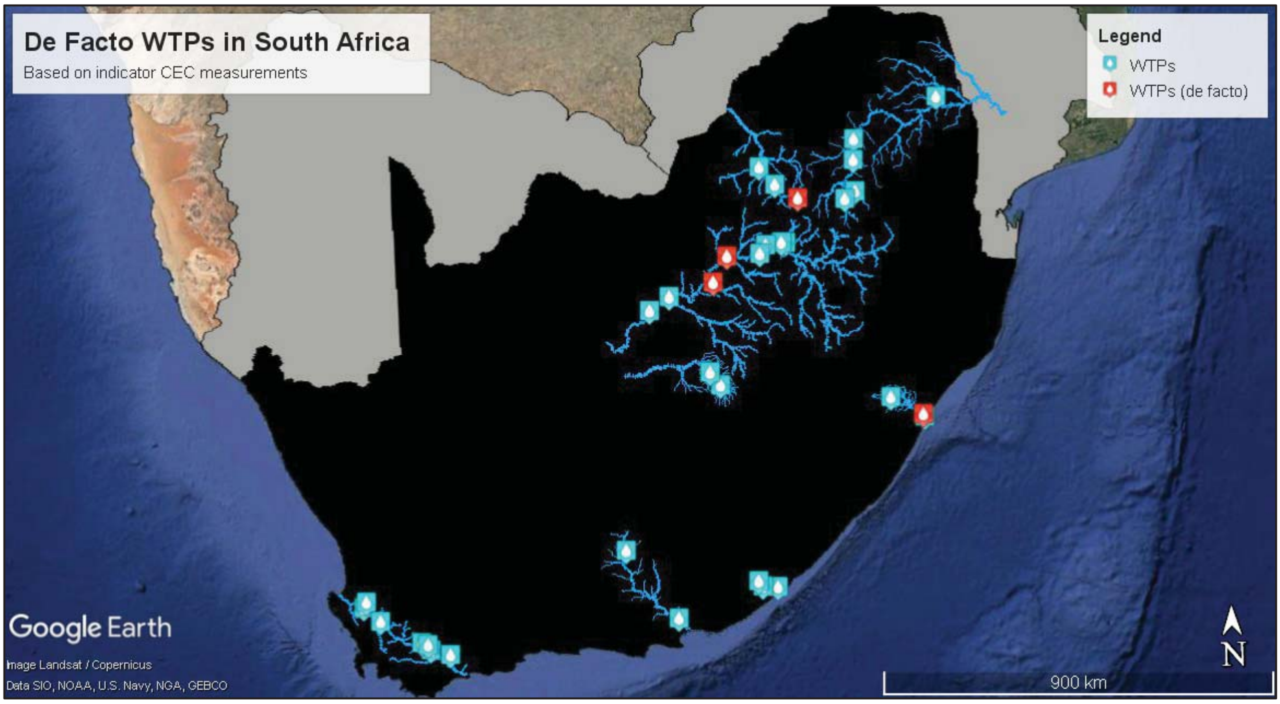


Figure 5.2: Potential de facto reuse water treatment plants in South Africa based on predicted and measured CEC results.

5.4 SUMMARY

In conclusion, the majority of drinking water treatment plants abstracting water from rivers will receive some level of wastewater in the feed water, so that all WTPs are potentially de facto reuse plants at some point or the other, often more prevalent during periods of drought and low or no river flow. In order to quantify the percentage of WTPs in the entire country that could be de facto reuse plants, calculations will be required at all the drinking water treatment plants in the country.

CHAPTER 6: ASSESSING WATER TREATMENT PLANT CAPABILITIES AS BARRIERS FOR DE FACTO REUSE

6.1 INTRODUCTION

The aim of this task in the project was to assess the typical removal capabilities of the technology trains used at the selected WTPs and compare this with the results that were obtained in the recently completed WRC project by Swartz et al. (2018) in which the pollutant removal potential were studies at two direct potable reuse (DPR) and three WWTPs in the country. Based on the information obtained in the two projects, it will be possible to obtain an indication of the technological requirements of de facto reuse plants to ensure effective removal of the pollutants, and in particular the CECs.

6.2 METHOD

6.2.1 Technology overview and removal efficiencies

Table 6.1 shows the removal capabilities of various unit treatment processes used in conventional water treatment plants as well as in advanced water treatment plants for the eight indicator chemicals that were used in this project.

No removal percentages could be found in literature for the two antiretrovirals (Efavirenz and Emtricitabine) as well as for the recreational drug (methaqualone).

Table 6.1: Removal capabilities of various unit treatment processes for the eight indicator chemicals

CEC removal capabilities by various unit treatment processes									
Chemical	Removal by treatment process (%)(average)								Reference
	Coagulation, Sedimentation, Filtration	Chlorine Disinfection	Ozone	GAC/PAC	UF	RO	UV disinfection	UV/H_2O_2	
Caffeine (Stimulant)		44	95	11		99	4.1		US EPA (2010)
	Low	Medium	High	Medium	Low		Low	Low	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Sulfamethoxazole (Antibiotic)		61	93	49		81	28		US EPA (2010)
	Low	High	High	Medium	Low		Medium	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Carbamazepine (Anti-epileptic)	65		88			98	2.3		US EPA (2010)
	Low	Low - Med	High	Med - High	Low		Low	Low	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Diclofenac (Anti-inflammatory)		61	100	59		98	34		US EPA (2010)
	Low	High	High	Medium	Low - Med		Medium	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Acetaminophen (Analgesic)		77		59		92	19		US EPA (2010)
	Low	High	High		Medium		Low	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Efavirenz (Antiretroviral)	No Data								
Emtricitabine (Antiretroviral)	No Data								
Methaqualone (Recreational drug)(Madrax)	No Data								
Atrazine (Pesticide)	Low	Low	Medium	Med - High	Low		Low	Med - High	Snyder et al. (2007)
			20-50	63			92		USBR (2009)

* v = variable

In Table 6.2, a comprehensive summary by the U.S. Department of the Interior Bureau of Reclamation (2009) (USBR) provides further removal percentage ranges for a number of CECs for conventional and advanced water treatment processes. The green shading shows processes that provides good removal (80-100%), the yellow shading represents moderate removal (50-80%), and the red (pink) shading shows poor removal (0-50%).

USBR (2009) reported that technologies that can remove CECs to a moderate extent (50-70%) included activated carbon absorption (GAC, PAC), UV Irradiation, conventional activated sludge systems, and MBR. Technologies that can remove CECs to a greater extent (>85%) include RO, ozone/AOP, UV/AOP, and BAC.

Table 6.2: Percentage removal ranges of conventional and advanced water treatment processes for a number of chemical compounds (CECs) (adapted from USBR, 2009)

Compound	Subcategory	Percentage Removal (%)									
		Activated Carbon Adsorption	Ozone	UV AOP	UV Irradiation	CAS	MBR	NF	RO	Biologically Active Sand	Biologically Active Carbon
1,4-Dioxane ($C_4H_8O_2$)[a]	Industrial	<20	<35	>95	<20	<20	<20	20-40	20-50	<20	<20
Acetaminophen ($C_8H_9NO_2$)	Analgesics	78	>95	>97	73	N/A[b]	>99	25-50	>90	79	95
Androstenedione ($C_{19}H_{26}O_2$)	Steroids	70	>80	96	89	N/A	>98	50-80	>61	96	97
Atrazine ($C_8H_{14}ClN_5$)	Pesticides	63	20-50	80	92	N/A	N/A	50-80	N/A	54	83
Benzon(a)pyrene ($C_{20}H_{12}$)	PAH	72	N/A	N/A	N/A	>85	N/A	>80	>90	N/A	89
Caffeine ($C_8HYN_4O_2$)	Stimulant	59	>80	89	44	>97	>85	50-80	>99	77	93
Carbamazepine ($C_{15}H_{12}N_2O$)	Analgesics, stimulant	72	>95	>88	60	N/A	20	50-80	>99	54	90
DDT ($C_{14}H_9Cl_5$)	Pesticides	70	N/A	N/A	N/A	N/A	N/A	>80	N/A	N/A	85
DEET ($C_{12}H_{17}NO$)	Pesticides	54	50-80	89	52	N/A	20	50-80	>95	37	80
Diazepam (Valium) ($C_{16}H_{13}ClN_2O$)	Anticonvulsant	67	50-80	93	52	<20	N/A	50-80	N/A	82	84
Diclofenac ($C_{14}H_{11}Cl_2NO_2$)	Analgesics	49	>95	>98	>98	N/A	>50	50-80	>97	67	75
Dilantin ($C_{15}H_{12}N_2O_2$)	Anticonvulsant	56	50-80	97	96	N/A	4	50-80	>99	77	80
Erythromycin ($C_{37}H_{67}NO_{13}$)	Antimicrobials	52	>95	50-80	39	N/A	96	>80	>98	79	78
Estradiol ($C_{18}H_{24}O_2$)	Steroids	55	>95	>98	93	60-80	N/A	50-80	N/A	85	94
Estriol ($C_{18}H_{24}O_3$)	Steroids	58	>95	>99	90	>85	>98	50-80	N/A	81	92
Estrone ($C_{18}H_{22}O_2$)	Steroids	77	>95	>99	94	80	82	50-80	>95	62	95
Ethinyl Estradiol ($C_{20}H_{24}O_2$)	Steroids	70	>95	>98	93	N/A	N/A	50-80	N/A	73	91
Fluorene ($C_{13}H_{10}$)	PAH	94	N/A	N/A	N/A	N/A	N/A	>80	N/A	N/A	>94
Fluoxetine (Prozac) ($C_{17}H_{18}F_3NO$)	Antidepressant	91	>95	>98	>98	N/A	40	>80	>96	98	>99
Galaxolide ($C_{18}H_{26}O$)	Fragrance	59	50-80	N/A	N/A	<20	N/A	50-80	>98	N/A	74
Gemfibrozil ($C_{15}H_{22}O_3$)	Heart Medication	38	>95	95	57	N/A	>86	50-80	>99	54	74
Hydrocodone ($C_{18}H_{21}NO_3$)	Analgesics	72	>95	>98	64	N/A	>94	50-80	>98	47	92
Ibuprofen (Advil) ($C_{13}H_{18}O_2$)	Analgesics	26	50-80	94	70	>80	95	50-80	>99	66	83
Iopromide ($C_{18}H_{24}I_3N_3O_8$)	X-Ray Contrast Media	31	20-50	91	99	N/A	20	>80	>99	28	42

Compound	Subcategory	Percentage Removal (%)									
		Activated Carbon Adsorption	Ozone	UV AOP	UV Irradiation	CAS	MBR	NF	RO	Biologically Active Sand	Biologically Active Carbon
Lindane (a-BHC) ($C_6H_6Cl_6$)	Pesticides	70	N/A	N/A	N/A	N/A	N/A	50-80	N/A	N/A	91
Meprobamate ($C_9H_{18}N_2O_4$)	Anticonvulsant	36	20-50	75	29	N/A	<1	50-80	>99	36	71
Metolachlor ($C_{15}H_{22}ClNO_2$)	Pesticides	50	N/A	N/A	N/A	N/A	N/A	50-80	N/A	N/A	79
Musk Ketone ($C_{14}H_{18}N_2O_5$)	Fragrance	69	N/A	N/A	N/A	<20	N/A	>80	N/A	N/A	83
Naproxen ($C_{14}H_{14}O_3$)	Anti-Inflammatory Agent, Analgesics	60	>95	>99	99	N/A	>86	20-50	>99	80	82
N-Nitrosodimethylamine (NDMA) ($C_2H_6N_2O$) [a]	DBPs	<20	40-70	>95	<20	<20	<20	20-50	30-70	<20	<20
Oxybenzone ($C_{14}H_{12}O_3$)	Sunscreen	92	>95	50-80	50	>85	95	>80	>93	83	98
Pentoxifylline ($C_{13}H_{18}N_4O_3$)	Heart Medication	71	>80	90	50	N/A	85	50-80	>96	91	90
Progesterone ($C_{21}H_{30}O_2$)	Steroids	84	>80	98	92	N/A	95	50-80	N/A	N/A	99
Sulfamethoxazole ($C_{10}H_{11}N_3O_3S$)	Antimicrobials	43	>95	>99	>99	N/A	20	50-80	>99	77	63
TCEP ($C_9H_{15}O_6P$)	Flame Retardant	60	<20	16	10	<20	20	50-80	>91	53	80
Testosterone ($C_{19}H_{28}O_2$)	Androgenic Steroids	71	>80	97	91	N/A	96	50-80	N/A	92	96
Triclosan ($C_{12}H_7Cl_3O_2$)	Antimicrobials	90	>95	>97	>97	70	70	>80	>97	97	97
Trimethoprim ($C_{14}H_{18}N_4O_3$)	Antimicrobials	69	>95	94	<5	N/A	>76	50-80	>99	24	94

6.2.2 Selected case studies for assessing CEC removal capabilities in water treatment plants

A sample of 28 drinking water treatment plants were selected as case studies to assess their capabilities as barriers for de facto reuse. The treatment plants were selected as part of Step 2: Case study selection in the project methodology (Section 3.4). The treatment plant was only required to abstract raw water from one of the case study rivers investigated in this study.

A list of the selected case study treatment plants can be found in Table 6.3, along with a description of the plant, including design capacity, treatment processes used, and the river from which the plant abstracts its raw water.

Table 6.3: Description of selected drinking water treatment plants

Drinking water treatment plant	Design capacity (ML/d)	Abstraction River	Description of treatment process
Piketberg WTP	2.4	Berg River	The Piketberg Water Treatment works is one of the old systems operated by Bergrivier Municipality (constructed in 1963). The plant treats about 2.4 ML/day, with an average production rate of 871 ML/annum and a peak production of 2.8 ML/day. The scheme provides a population of approximately 10 000 people. The treatment plant receives raw water from the adjacent Berg River. The raw water is dosed with alum for coagulation, after which the flocculated water flows to two settling tanks. From the settling tank the flow passes through five rapid sand filters. Water is then stabilised with lime and disinfected with chlorine gas prior to distribution. In addition to the treated water Piketberg area receives water from the Voëlvlei Spring directly into the network reservoir.
Withoogte WTP	72	Berg River	Raw water is pumped from the Berg River (Misverstand Weir) to the Raw Water Storage Reservoir at Withoogte, from where the water gravitates to the WTW. The water is stabilised by the addition of lime, which also causes the pH to increase for coagulation. The flocs formed after coagulation (with ferric sulphate) and flocculation subsequently settle out in the settling tanks. From the settling tanks the water gravitates through the sand filters to remove most of the remaining colloidal material (measured as turbidity). The last phase of the purification process is to disinfect the final water with chlorine. The final water gravitates to the storage reservoir before being pumped into the distribution network. The sludge, which is drawn off from the settling tanks, gravitates to sludge dams. The overflow water from the sludge dams is recovered by re-circulation back to the inlet works.
Bonnievale WTP	3.5	Breede River	Raw water is pumped to the Bonnievale Water Treatment Plant from the Breede River. The impurities and colour in the water is coagulated with Ultrafloc/poly aluminium chloride and then flocculated ahead of the settling tanks. The overflow from the settling tanks is treated in high-pressure sand filters, after which the final water is dosed with chlorine before being distributed in the town's reticulation network.
Laing WTP		Buffalo River	The Laing Water Treatment Plant abstracts water from the Laing Dam in the Buffalo River. After pre-treatment, the water undergoes coagulation and flocculation, where after the resultant flocs are removed in sedimentation tanks, followed by rapid sand filtration. The final water is disinfected with chlorine and then distributed to the consumers.
Umzonyana WTP	120	Buffalo River	The Umzonyana Water Treatment Plant receives its water from the Bridle Drift Dam in the Buffalo River. The raw water undergoes coagulation, before flowing to the clarification process. The overflow from the clarification tanks is treated with PAC in an adsorption conditioning process. From there the water is treated in a dissolved air flotation (DAF) and sand filtration process before dosing with chlorine and ammonia for chloramination disinfection treatment. The final water is distributed to consumers.
Rustfontein WTP	100	Modder River	Raw water is pumped to the Rustfontein Water Treatment Plant from the Rustfontein Dam in the Modder River. After undergoing pre-treatment, the water is subjected to a coagulation and flocculation process. The conditioned water then flows to a sedimentation process, and the overflowing water to sand filters. The final water is chlorinated and distributed to users via the reticulation networks.
Maselspoort WTP	130	Modder River	The Maselspoort Water Treatment Plant abstracts raw water from the Modder River. The water is dosed with lime to adjust the pH, as well as with AHC/Polyelectrolyte before undergoing coagulation and flocculation. The water is dosed with pre-chlorine before going through sedimentation tanks. The overflow from the tanks is further treated in rapid gravity filters, after which it is disinfected through dosing with chlorine gas. The final water is pumped to consumers.

Drinking water treatment plant	Design capacity (ML/d)	Abstraction River	Description of treatment process
Wiggens WTP	350	Umgeni/Duzi River	Wiggens Water Treatment Plant obtains raw water from the Inanda Dam in the Umgeni River. The water is treated with chlorine before undergoing ozonation. The water is subsequently dosed with lime as a stabiliser, and polyelectrolyte and bentonite are added to the stream as coagulant and coagulant aid. The coagulation step is followed by sedimentation (pulsators). The overflow is further treated in rapid gravity sand filters. The final water is treated with chlorine before being distributed to consumers.
Durban Heights WTP	690	Umgeni/Duzi River	Raw water is pumped form the Nagle Dam in the Umgeni River to the Durban Heights Water Treatment Plant. The water is dosed with lime, polyelectrolyte and bentonite for coagulation and flocculation. Sedimentation subsequently takes place in pulsators, and the overflow treated in rapid gravity sand filtration. Chlorine is dosed and the final water is distributed to consumers. The plant is currently operating at 615 ML/d.
Midmar WTP	250	Umgeni/Duzi River	The Midmar Water Treatment Plant receives its water from the Midmar Dam in the Umgeni River. The raw water is pre-chlorinated before the addition of a polymeric coagulant and bentonite for the coagulation treatment process. The water is subsequently dosed with lime before flowing to pulsators for sedimentation. The overflow is dosed with intermediate chlorine before undergoing rapid gravity sand filtration. The final water is dosed with chlorine and ammonia for chloramination disinfection before distribution to the public. The plant is currently operating at 220 ML/d.
Nooitgedacht WTP	160	Sundays River	The Nooitgedacht Water Treatment Plant is located to the north-east of Port Elizabeth and obtains its raw water from the Sundays River. The plant is currently under construction to increase the treatment capacity. It uses conventional water treatment unit processes, mainly for turbidity removal. It is one of the main water treatment works supplying the Nelson Mandela Bay Metro and surrounding areas with drinking water.
Graaff-Reinet WTP		Sundays River	The Graaff-Reinet Water Treatment Plant is located next to the dam wall of the Nqweba Dam on the perimeters of the town. The treatment plant employs conventional treatment processes (coagulation, flocculation, sedimentation, sand filtration and chlorination) to produce a final water which is distributed to the consumers in Graaff-Reinet.
Rietvlei WTP	40	Crocodile River	The Rietvlei Water Treatment Plant abstracts water from the Rietvlei Dam in the Hennops River, a tributary of the Crocodile River. The raw water is dosed with lime for stabilisation of the water and pH adjustment before aluminium sulphate or ferric chloride are dosed coagulants. The water is flash mixed and flows through baffled flocculation channels before entering a dissolved air flotation/sand filtration process combination (DAFF). The water is subsequently treated by ozonation followed by granular activated carbon adsorption. The final water is chlorinated before being distributed to consumers.
Brits WTP	80	Crocodile River	Raw water is pumped from the Crocodile River to the Brits Water Treatment Plant. The water flows through flocculation channels before going through dissolved air flotation. The water is then filtered in rapid gravity sand filters and the filtrate treated with ozone. Granular activated carbon adsorption takes place before dosing with lime. The final water is chlorinated and pumped to consumers.
Vaalkop WTP	270	Olifants River	The Vaalkop Water Treatment Plant receives raw water from the Vaalkop Dam in the Elands River, a tributary of the Crocodile River. The water first undergoes pre-chlorination using chlorine gas as a primary disinfectant and oxidant. Powdered activated carbon is dosed to the water> Lime is also dosed before the water flows to the coagulation and flocculation process. In addition to the floc growth, the baffled flocculation channels allow for adequate contact time of the powdered activated carbon. The water subsequently flows to the dissolved air flotation units followed by sedimentation in sedimentation tanks. Ozone is injected into the overflow, followed by filtration rapid gravity sand filters and granular activated carbon filtration. The final water is dosed with chlorine gas and ammonia. The final water is distributed for public consumption.

Drinking water treatment plant	Design capacity (ML/d)	Abstraction River	Description of treatment process
Witbank WTP		Olifants River	The Witbank Water Treatment Plants abstracts water from the Witbank Dam in the Olifants River to balancing tanks from where the water gravitates to the plant. The raw water is treated using a coagulation and flocculation process, which is followed by sedimentation using clarifiers. The overflow from the weirs from the clarifiers is subjected to filtration before the water is disinfected and pumped to consumers. The plant is currently operating at 105 ML/d.
Vaalbank WTP		Olifants River	The Vaalbank Water Treatment Plant is located in Middelburg and obtains its raw water from the Olifants River. It uses conventional drinking water treatment processes to provide a final water that is distributed to Middelburg and surrounding towns.
Groblersdal WTP	36	Olifants River	The Groblersdal Water Treatment Plant provides treated water to the town of Groblersdal and surrounding villages.
Flag Boshielo WTP	11.5	Olifants River	The Flag Boshielo Water Treatment Plants abstracts raw water from the adjacent Flag Boshielo Dam (formerly the Arabie Dam). The plant uses conventional treatment processes and is currently receiving major upgrading.
Phalaborwa WTP	150	Olifants River	The Phalaborwa Water Treatment Plant withdraws raw water from the Olifants River and supplies the town and surrounding mines with the final product water. The plant is owned and operated by Lepelle North Water.
Zuikerbosch WTP	1200	Upper Vaal River	Raw water is abstracted from the Vaal Dam and gravitates to the Zuikerbosch Water Treatment Plant via a pipeline feeding a canal. The water flows through a 500 ML buffer dam, with three 10 mm automatic screens preceding it. Lime is added to the water, as well as either polyectrolyte or silica as coagulant, before being mixed for coagulation, where PAC is also added to the flow for taste and odour removal. Flocculation takes place in spiral flocculators, where after the water enters the sedimentation tank. Stabilisation takes place via carbonation by bubbling carbon dioxide through the water, where the pH is reduced to acceptable levels. Rapid gravity sand filters further treat the water after carbonation. The water is disinfected by dosing with evaporated liquid chlorine and ammonia solution, and then distributed to users in the Gauteng area.
Vereeniging WTP	1600	Upper Vaal River	The Vereeniging Water Treatment Plant receives water from a barrage damming structure in the Vaal River, as well as from the Lethabo Weir that is located 20 km downstream of the Vaal Dam. The raw water goes through coagulation and flocculation before sedimentation takes place. The overflow from the sedimentation process is subjected to a filtration process before being disinfected and distributed for consumption.
Vaal Barrage WTP		Upper Vaal River	The Vaal Barrage Water Treatment Plant abstracts raw water from the Vaal Barrage Dam, located in the Vaal River. The raw water undergoes coagulation and flocculation before sedimentation occurs. The sedimentation process consists of primary and secondary sedimentation, which follow in series. The overflow from the secondary sedimentation process is subjected to pressurised sand filtration and then granular activated carbon adsorption. The plant also uses two disinfection processes, namely UV followed by chlorination. The final water is used for consumption by the public.
Parys WTP	25	Upper Vaal River	The Parys Water Treatment Plant receives its water from the Vaal River. The plant consists of three modules, namely the old plant, the expansion, and the package plant. Module 1 has a capacity of 5 ML/day and consists out of a flocculation process, which is followed by sedimentation. The overflow from the sedimentation process undergoes filtration via two sand filters. Module 2 has a capacity of 10 ML/day. It also consists out of a flocculation stage, followed by sedimentation. The sedimentation process uses two clarifiers, of which the overflow is subjected to filtration via six sand filters. Module 3 has a capacity of 10 ML/day. Two 5 ML/day Trident HS Package Plants work in parallel, each consisting of a high rate settling unit, an adsorption clarification process, mixed media filtration and UV disinfection. The final waters from each of the units go to three sumps, which are connected. Modules 1 and 2 feed these sumps and Module 3 feeds the third sump. The final water from the sumps gets pumped to the public. Module 3, the package plant, was the focus of the plant for the removal capabilities.

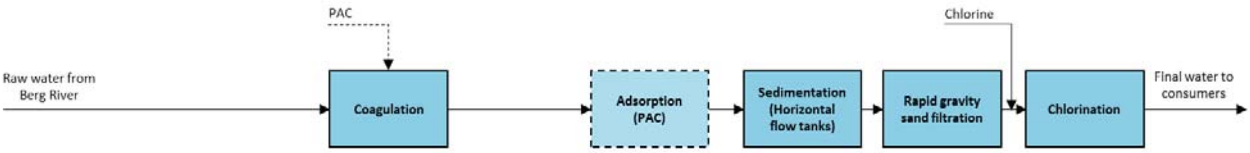
Drinking water treatment plant	Design capacity (ML/d)	Abstraction River	Description of treatment process
Midvaal WTP	320	Middle Vaal River	The Midvaal Water Treatment Plant receives raw water from the Vaal River. The water goes through a pre-ozonation step, before undergoing primary coagulation and flocculation. The flow from this process is then treated using dissolved air flotation, before going through an intermediate ozonation step. The water then undergoes secondary coagulation and flocculation, where PAC is dosed. The water then flows to the sedimentation process, where the overflow is subjected to sand filtration. The final water is chlorinated before it is delivered to consumers.
Balkfontein WTP	360	Middle Vaal River	Raw water is abstracted from the Vaal River and received by the Balkfontein Water Treatment Plant. The raw water undergoes a pre-chlorination step, before lime, FeCl3 and polyelectrolytes are added to the water for coagulation and flocculation to take place in the mixing canals and weirs. Then primary sedimentation occurs, followed by intermediate chlorination and carbonisation using carbon dioxide. Secondary sedimentation then occurs in secondary settling tanks, which is followed by rapid gravity sand filtration. Final chlorination of the water takes places before flowing through contact reservoirs, where after ammonia is dosed. The final water is then distributed.
Bloemhof WTP	14	Middle Vaal River	The Bloemhof Water Treatment Plant abstracts water from the Vaal River, directly upstream of the Bloemhof weir. The raw water undergoes pre-chlorination, where chlorine chips are added to the water, before flowing to a distribution chamber. The chamber splits the flow between a turbo clarifier, a Densadeg clarifier and a dissolved air flotation unit. The overflow from the weir of the turbo clarifier also goes to the Densadeg clarifier and the dissolved air flotation unit. The weir overflow from the Densadeg clarifier and the outflow from the dissolved air flotation unit undergoes sand filtration before final chlorination via chlorine gas. The water flows through a chlorine contact reservoir.
Christiana WTP	8	Middle Vaal River	Raw water is abstracted from the Vaal River by the Christiana Water Treatment Plant, just upstream of the Christiana Weir. The water undergoes sedimentation by pulsators, before the overflow goes to through rapid gravity sand filtration. The outflow from the filters is dosed using chlorine gas, before being distributed for public consumption.

6.2.3 Prediction of treatment efficiency and removal of selected CECs at selected case study water treatment plants

This section presents the removal capabilities of the selected case study drinking water treatment plants. The process configuration and unit treatment processes for each plant was established, where after the expected CEC removal by each process were calculated using the estimated removal capabilities of each process unit as found in literature (Table 6.1). The estimated overall removal percentage of the CECs at the plant were then calculated.

6.2.3.1 Prediction of treatment efficiency and removal of selected CECs at Piketberg WTP

Figure 6.1 shows the process configuration and unit treatment processes of the Piketberg WTP. Based on the literature, it is predicted that the Piketberg WTP will have high removal of sulfamethoxazole (86%) and diclofenac (89%) and moderate removal of carbamazepine (55%). The Piketberg WTP has the advantage of implementing an adsorption process to their configuration, which is a technology that has been proven to remove a variety of CECs. There are no results available for the final water produced by this plant, therefore the predicted and actual removal capability of the plant could not be compared.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed in PAC process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	<IQL	30	<IQL	11	<IQL	44	<IQL	-
Sulfamethoxazole	24.5	30	17.15	49	8.75	61	3.41	86
Carbamazepine	20	30	14	8.3	12.84	30	8.99	55
Diclofenac	2.2	30	1.54	59	0.63	61	0.25	89
Efavirenz	60.7	No information on removal capabilities available						
Emtricitabine	5.3							
Methaqualone	14.2							
Acetaminophen	<IQL	30	<IQL	59	<IQL	77	<IQL	-

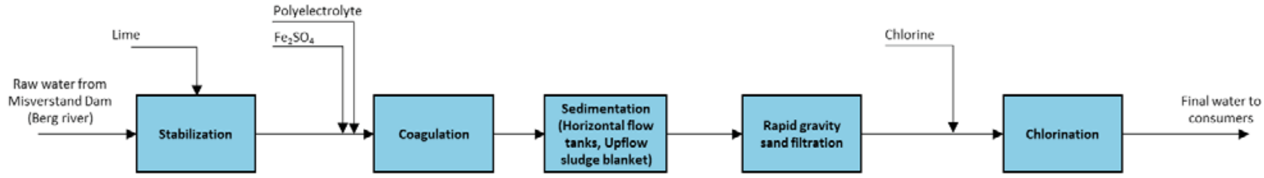
Figure 6.1: Process configuration and unit treatment processes of Piketberg WTP showing expected removal capabilities from international and local literature

Figure 6.2 shows an aerial view of the Piketberg Water Treatment Plant in the Western Cape.

Figure 6.2: Aerial view of the Piketberg WTP

6.2.3.2 Prediction of treatment efficiency and removal of selected CECs at Withoogte WTP

Figure 6.3 shows the process configuration and unit treatment processes of the Withoogte WTP. From the table it can be seen that the Withoogte WTP is predicted to have moderate removal of caffeine, sulfamethoxazole, and carbamazepine at 61%, 73% and 51% respectively. The Withoogte WTP only has conventional treatment processes, which generally have low CEC elimination rates. It is estimated that the plant has moderate removal capability. However, Kim and Zoh (2016) and Snyder et al. (2006) noted that the removal capabilities of different technologies differ, depending on the quality of the raw water. Withoogte WTP stabilizes the raw water with lime before entering the plant, which causes the pH to rise. This may impact the removal efficiency of the treatment processes.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	19.2	30	13.44	44	7.53	61
Sulfamethoxazole	14.4	30	10.08	61	3.93	73
Carbamazepine	20.3	30	14.21	30	9.95	51
Diclofenac	<IQL	30	<IQL	61	<IQL	-
Efavirenz	<IQL	No information on removal capabilities available				
Emtricitabine	<IQL					
Methaqualone	12.8					
Acetaminophen	<IQL	30	<IQL	77	<IQL	-

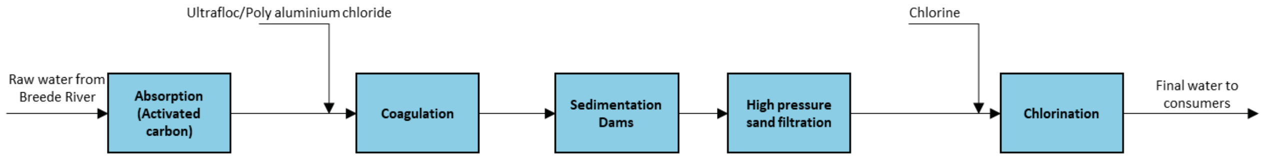
Figure 6.3: Process configuration and unit treatment processes of Withoogte WTP showing expected removal capabilities from international and local literature

Figure 6.4 shows and aerial view of the Withoogte Water Treatment Plant.

Figure 6.4: Aerial view of the Withoogte WTP

6.2.3.3 Prediction of treatment efficiency and removal of selected CECs at Bonnievale WTP

Figure 6.5 shows the process configuration and unit treatment processes of the Bonnievale WTP. The predicted removal capability of the plant indicates that moderate removal of selected CECs will be achieved, and good removal of acetaminophen at 84%. The measured concentrations of CECs in the final water indicates that good removal of CECs is achieved at the treatment plant. All of the CECs could not be detected in the final water, except for carbamazepine, which is only removed by 24%.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	<IQL	30	<IQL	44	<IQL	-	<IQL
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-	<IQL
Carbamazepine	7.3	30	5.11	30	3.58	51	5.5
Diclofenac	2.8	30	1.96	61	0.76	73	<IQL
Efavirenz	<IQL	No information on removal capabilities available					<IQL
Emtricitabine	5.7						<IQL
Methaqualone	<IQL						<IQL
Acetaminophen	38.7	30	27.09	77	6.23	84	<IQL

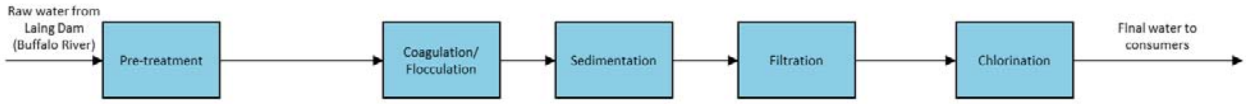
Figure 6.5: Process configuration and unit treatment processes of Bonnievale WTP showing expected removal capabilities from international and local literature

Figure 6.6 shows an aerial view of the Bonnievale Water Treatment Plant.

Figure 6.6: Aerial view of the Bonnievale WTP

6.2.3.4 Prediction of treatment efficiency and removal of selected CECs at Laing WTP

Figure 6.7 shows the process configuration and unit treatment processes of the Laing WTP. From the results, it can be seen that Laing WTP will have mostly moderate (50-75%) removal of CECs, with the exception of acetaminophen which will be removed very well (84%) by the existing treatment processes.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	207.3	30	145.1	44	81.28	61
Sulfamethoxazole	186.9	30	130.8	61	51.02	73
Carbamazepine	59.3	30	41.54	30	29.08	51
Diclofenac	6.7	30	4.68	61	1.82	73
Efavirenz	261.1	No information on removal capabilities available				
Emtricitabine	36.5					
Methaqualone	12.6					
Acetaminophen	20.1	30	14.08	77	3.24	84

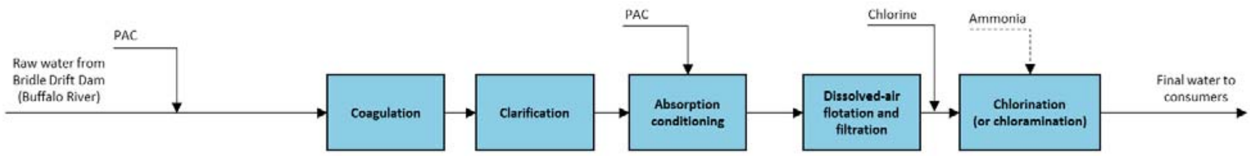
Figure 6.7: Process configuration and unit treatment processes of Laing WTP showing expected removal capabilities from international and local literature

Figure 6.8 shows and aerial view of the Laing Water Treatment Plant.

Figure 6.8: Aerial view of the Laing WTP

6.2.3.5 Prediction of treatment efficiency and removal of selected CECs at Umzonyana WTP

Figure 6.9 shows the process configuration and unit treatment processes of the Umzonyana WTP. From the calculations, is predicted that the Umzonyana WTP will have moderate removal of caffeine (65%) and carbamazepine (55%) and good removal of the remaining CECs (more than 80%). As noted previously, adsorption processes are known to remove a variety of CECs. However, Snyder et al. (2006) found that the efficiency of adsorption is a function of the carbon type, contact time, raw water quality and the structure of the contaminant.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed in Adsorption process		Expected CEC removed through chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	83.4	30	58.38	11	51.96	44	29.1	65
Sulfamethoxazole	288.4	30	201.88	49	102.96	61	40.15	86
Carbamazepine	50	30	35	8.3	32.1	30	22.47	55
Diclofenac	4.8	30	3.36	59	1.38	61	0.54	89
Efavirenz	176.6	No information on removal capabilities available						
Emtricitabine	45.7							
Methaqualone	42.6							
Acetaminophen	78.5	30	54.95	59	22.53	77	5.18	93

Figure 6.9: Process configuration and unit treatment processes of Umzonyana WTP showing expected removal capabilities from international and local literature

Figure 6.10 shows and aerial view of the Umzonyana Water Treatment Plant.

Figure 6.10: Aerial view of the Umzonyana WTP

6.2.3.6 Prediction of treatment efficiency and removal of selected CECs at Rustfontein WTP

Figure 6.11 shows the process configuration and unit treatment processes of the Rustfontein WTP. It is estimated that the Rustfontein WTP will have moderate removal of CECs, as the plant consists of conventional treatment processes with no advanced water treatment technology.

Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	61.01	30	42.70	44	23.91	61
Sulfamethoxazole	7.42	30	5.20	61	2.03	73
Carbamazepine	14.33	30	10.03	30	7.02	51
Diclofenac	<IQL	30	<IQL	61	<IQL	-
Efavirenz	186.9	No information on removal capabilities available				
Emtricitabine	0					
Methaqualone	3.65					
Acetaminophen	328.8	30	230.1	77	52.93	84

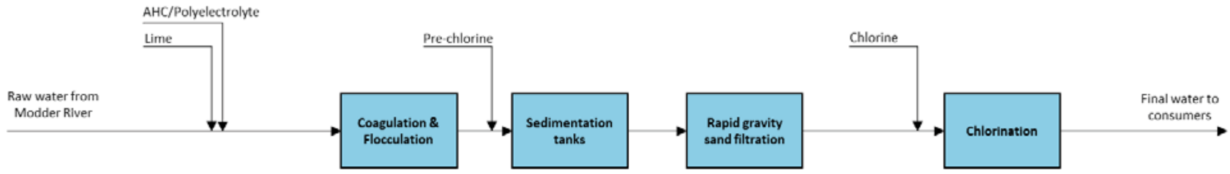
Figure 6.11: Process configuration and unit treatment processes of Rustfontein WTP showing expected removal capabilities from international and local literature

Figure 6.12 shows and aerial view of the Rustfontein Water Treatment Plant.

Figure 6.12: Aerial view of the Rustfontein WTP

6.2.3.7 Prediction of treatment efficiency and removal of selected CECs at Maselspoort WTP

Figure 6.13 shows the process configuration and unit treatment processes of the Maselspoort WTP. The plant consists of conventional water treatment processes, with no advance treatment technologies. It is predicted that the estimated removal capability of CECs in the plant will be moderate (50-75%).



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	102.5	30	71.75	44	40.18	61
Sulfamethoxazole	75.3	30	52.71	61	20.56	73
Carbamazepine	170.1	30	119.07	30	83.35	51
Diclofenac	20.4	30	14.28	61	5.57	73
Efavirenz	494.3	No information on removal capabilities available				
Emtricitabine	96.8					
Methaqualone	25.2					
Acetaminophen	<IQL	30	<IQL	77	<IQL	-

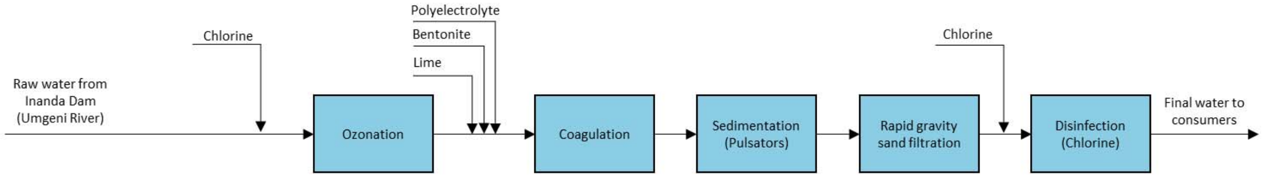
Figure 6.13: Process configuration and unit treatment processes of Maselspoort WTP showing expected removal capabilities from international and local literature

Figure 6.14 shows an aerial view of the Maselspoort Water Treatment Plant.

Figure 6.14: Aerial view of the Maselspoort WTP

6.2.3.8 Prediction of treatment efficiency and removal of selected CECs at Wiggens WTP

Figure 6.15 shows the process configuration and unit treatment processes of the Wiggens WTP. Based on the results, it is predicted that the Wiggens WTP will have very good removal of CECs. The plant has a ozonation unit process, which has proven to be very effective for the removal of CECs, as the contaminant reacts directly with the molecular ozone or through the formation of an HO* radical (USBR, 2009). The measured concentrations of CECs in the final water, however, does not indicate good removal. Instead, it reveals a higher concentration of caffeine in the final water than in the raw water.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed in Ozonation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	61.9	95	3.095	30	2.17	44	1.21	98	94.60
Sulfamethoxazole	<IQL	90	<IQL	30	<IQL	61	<IQL	-	<IQL
Carbamazepine	74.4	88	8.93	30	6.25	30	4.37	94	56.75
Diclofenac	<IQL	90	<IQL	30	<IQL	61	<IQL	-	<IQL
Efavirenz	312.1	No information on removal capabilities available							293.78
Emtricitabine	67.6								<IQL
Methaqualone	32.9								33.55
Acetaminophen	<IQL	90	<IQL	30	<IQL	77	<IQL	-	<IQL

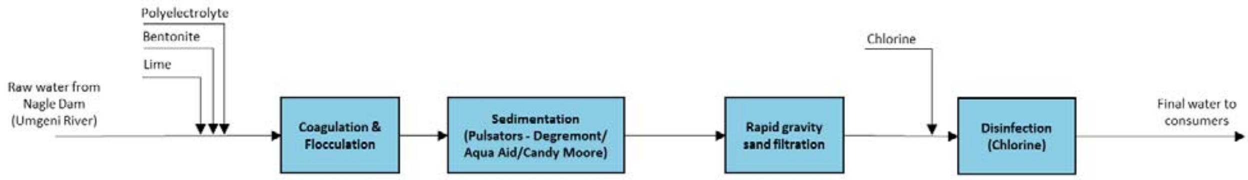
Figure 6.15: Process configuration and unit treatment processes of Wiggens WTP showing expected removal capabilities from international and local literature

Figure 6.16 shows an aerial view of the Wiggens Water Treatment Plant.

Figure 6.16: Aerial view of the Wiggens WTP

6.2.3.9 Prediction of treatment efficiency and removal of selected CECs at Durban Heights WTP

Figure 6.17 shows the process configuration and unit treatment processes of the Durban Heights WTP. It is predicted that the plant will have moderate removal of CECs, given the conventional treatment processes at the plant.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	9.8	30	6.86	44	3.84	61
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-
Carbamazepine	9.3	30	65.1	30	4.56	51
Diclofenac	19.5	30	13.65	61	5.32	73
Efavirenz	127.7	No information on removal capabilities available				
Emtricitabine	61.7					
Methaqualone	2.7					
Acetaminophen	<IQL	30	<IQL	77	<IQL	-

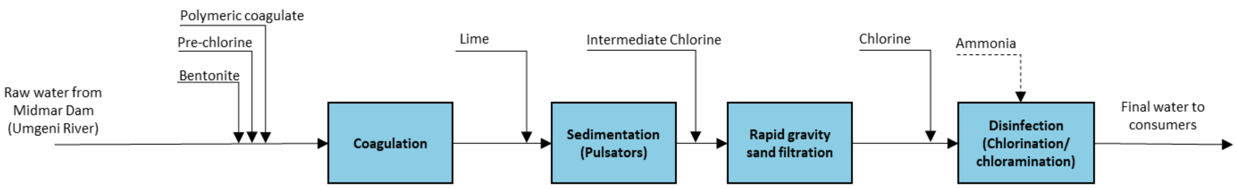
Figure 6.17: Process configuration and unit treatment processes of Durban Heights WTP showing expected removal capabilities from international and local literature

Figure 6.18 shows an aerial view of the Durban Heights Water Treatment Plant.

Figure 6.18: Aerial view of the Durban Heights WTP

6.2.3.10 Prediction of treatment efficiency and removal of selected CECs at Midmar WTP

Figure 6.19 shows the process configuration and unit treatment processes of the Midmar WTP. It is predicted that the plant will have moderate removal of selected CECs, given the conventional processes used at this plant.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	**Value (ng/L)**	**Removal % range from literature**	**Concentration remaining after this process (ng/L)**	**Removal % range from literature for chlorination**	**Estimated concentration in final water (ng/L)**	**Estimated overall removal (%)**
Caffeine	2.5	30	1.75	44	0.98	61
Sulfamethoxazole	8	30	5.6	61	2.18	73
Carbamazepine	<IQL	30	<IQL	30	<IQL	-
Diclofenac	<IQL	30	<IQL	61	<IQL	-
Efavirenz	67	No information on removal capabilities available				
Emtricitabine	<IQL					
Methaqualone	3.1					
Acetaminophen	<IQL	30	<IQL	77	<IQL	-

Figure 6.19: Process configuration and unit treatment processes of Midmar WTP showing expected removal capabilities from international and local literature

Figure 6.20 shows and aerial view of the Midmar Water Treatment Plant.

Figure 6.20: Aerial view of the Midmar WTP

6.2.3.11 Prediction of treatment efficiency and removal of selected CECs at Nooitgedacht WTP

The treatment configuration of the Nooitgedacht WTP was not known, therefore the predicted removal of CECs could not be calculated. However, the measured concentration of CECs in the raw and final water are shown in Figure 6.21. Based on the measured CEC results, it can be seen that very good removal of CECs is achieved at the plant, with complete removal of all CECs, except for caffeine where only 25% removal is achieved.

Raw water CEC concentrations		Measured final concentration
Chemical	**Value (ng/L)**	**Value (ng/L)**
Caffeine	25.1	6.2
Sulfamethoxazole	<IQL	<MDL
Carbamazepine	27.6	<MDL
Diclofenac	<IQL	<MDL
Efavirenz	655.0	<MDL
Emtricitabine	36.8	<IQL
Methaqualone	1.4	<MDL
Acetaminophen	<MDL	<MDL
Atrazine	<IQL	<IQL

Figure 6.21: CEC concentrations measured in raw and final water at the Nooitgedacht WTP

Figure 6.22 shows and aerial view of the Nooitgedacht Water Treatment Plant

Figure 6.22: Aerial view of the Nooitgedacht WTP

6.2.3.12 Prediction of treatment efficiency and removal of selected CECs at Graaff-Reinet WTP

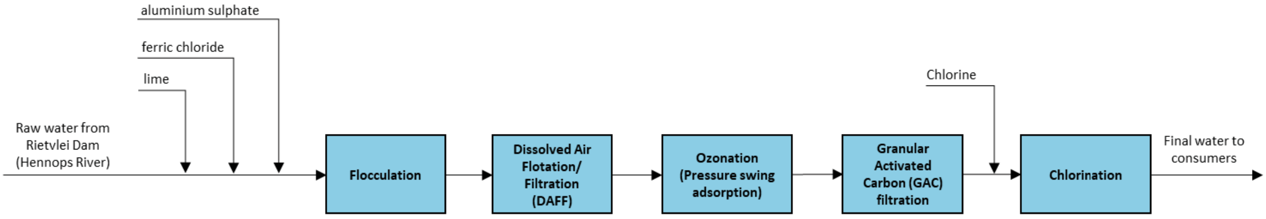
The treatment configuration of the Nooitgedacht WTP was not known, therefore the predicted removal of CECs could not be calculated. No measured CEC concentration results of the final water is available.

Figure 6.23 shows and aerial view of the Graaff-Reinet Water Treatment Plant

Figure 6.23: Aerial view of the Graaff-Reinet WTP

6.2.3.13 Prediction of treatment efficiency and removal of selected CECs at Rietvlei WTP

Figure 6.24 shows the process configuration and unit treatment processes of the Rietvlei WTP. The predicted removal capability of this plant is very good (more than 90%), as the treatment processes for this plant included absorption as well as ozonation. However, the measured concentrations of CECs in the final water does not indicate good removal. Based on the measured results (CEC concentration in raw water versus final water), the plant only removed about 9% of the caffeine in the raw water, and 35% and 24% of the carbamazepine and atrazine, respectively. It can also be seen from the results that sulfamethoxazole and diclofenac was less that the method detection limit (MDL) or the instrumentation quantification limit (IQL), indicating almost complete removal of these chemicals. The same is true for the antiretroviral, emtricitabine. As for the other ARV, efavirenz, only 14% removal was achieved in this process configuration and 32% removal was achieved for the recreational drug, methaqualone.



Raw water CEC concentrations		Expected CEC removed in Flocculation process		Expected CEC removed in Ozonation process		Expected CEC removed in GAC process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	186.10	30	130.27	95	6.51	11	5.80	44	3.25	98	169.45
Sulfamethoxazole	160.69	30	112.48	93	7.87	49	4.02	61	1.57	99	<MDL
Carbamazepine	53.57	30	37.50	88	4.50	8.3	4.13	30	2.89	95	35.06
Diclofenac	<IQL	30	<IQL	90	<IQL	59	<IQL	61	<IQL	-	<IQL
Efavirenz	295.02	No information on removal capabilities available									252.46
Emtricitabine	202.74										<IQL
Methaqualone	18.96										12.94
Acetaminophen	<IQL	30	<IQL	70	<IQL	59	<IQL	77	<IQL	-	<MDL
Atrazine	129.11	30	90.38	35	58.74	63	21.74	30	15.21	88	98.74

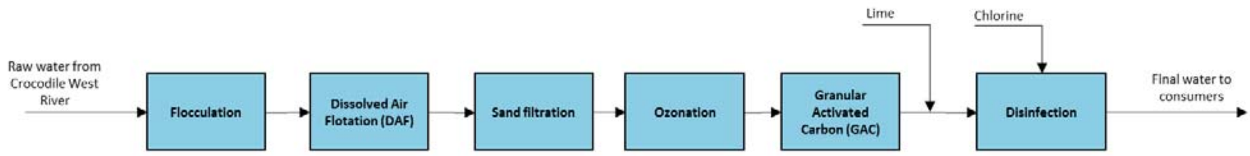
Figure 6.24: Process configuration and unit treatment processes of Rietvlei WTP showing expected removal capabilities from international and local literature

Figure 6.25 shows and aerial view of the Rietvlei Water Treatment Plant

Figure 6.25: Aerial view of the Rietvlei WTP

6.2.3.14 Prediction of treatment efficiency and removal of selected CECs at Brits WTP

Figure 6.26 shows the process configuration and unit treatment processes of the Brits WTP. It is predicted that the treatment plant will have very good removal of CECs, given the current process configuration. The plant uses both ozonation and absorption, which are very effective in removing CECs.



Raw water CEC concentrations		Expected CEC removed in Flocculation process		Expected CEC removed in Ozonation process		Expected CEC removed in GAC process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	197.24	30	138.07	95	6.90	11	6.14	44	3.44	98
Sulfamethoxazole	<MDL	30	<MDL	93	<MDL	49	<MDL	61	<MDL	99
Carbamazepine	62.04	30	43.43	88	5.21	8.3	4.78	30	3.34	95
Diclofenac	<MDL	30	<MDL	90	<MDL	59	<MDL	61	<MDL	99
Efavirenz	552.49	No information on removal capabilities available								
Emtricitabine	<IQL									
Methaqualone	111.24									
Acetaminophen	<IQL	30	<IQL	70	<IQL	59	<IQL	77	<IQL	98
Atrazine	77.79	30	54.46	35	35.40	63	13.10	30	9.17	88

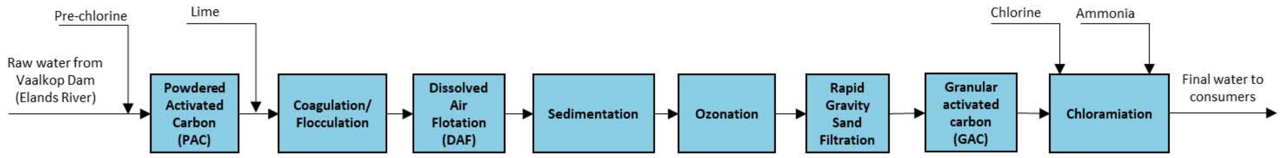
Figure 6.26: Process configuration and unit treatment processes of Brits WTP showing expected removal capabilities from international and local literature

Figure 6.27 shows an aerial view of the Brits Water Treatment Plant.

Figure 6.27: Aerial view of Brits WTP

6.2.3.15 Prediction of treatment efficiency and removal of selected CECs at Vaalkop WTP

Figure 6.28 shows the process configuration and unit treatment processes of the Vaalkop WTP. The Vaalkop WTP is predicted to have extremely good removal of CECs, as the process has two steps of absorption as well as ozonation. The measured concentrations of CECs in the final water are either less than the MDL or the IQL, indicating that the processes at the Vaalkop WTP has indeed the capability to remove more than 90% of CECs in the raw water as predicted the literature.



Raw water CEC concentrations		Expected CEC removed in PAC process		Expected CEC removed in Coagulation process		Expected CEC removed in Ozonation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	27.04	11	24.06	30	16.84	95	0.84	44	0.47	98	<IQL
Sulfamethoxazole	72.47	49	36.91	30	25.84	93	1.81	61	0.71	99	<MDL
Carbamazepine	31.98	8.3	29.32	30	20.52	88	2.46	30	1.72	95	<MDL
Diclofenac	<IQL	59	<IQL	30	<IQL	100	<IQL	61	<IQL	99	<IQL
Efavirenz	119.00	No information on removal capabilities available									<IQL
Emtricitabine	85.89										<MDL
Methaqualone	21.80										<MDL
Acetaminophen	<MDL	59	<MDL	30	<MDL	70	<MDL	77	<MDL	98	<MDL
Atrazine	40.86	60	15.12	30	10.58	35	6.88	30	4.82	88	32.18

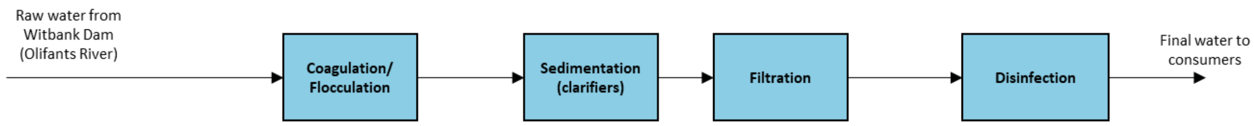
Figure 6.28: Process configuration and unit treatment processes of Vaalkop WTP showing expected removal capabilities from international and local literature

Figure 6.29 shows an aerial view of the Vaalkop Water Treatment Plant.

Figure 6.29: Aerial view of Vaalkop WTP

6.2.3.16 Prediction of treatment efficiency and removal of selected CECs at Witbank WTP

Figure 6.30 shows the process configuration and unit treatment processes of the Witbank WTP. It is predicted that the treatment plant will only moderately remove CECs from the raw water. Caffeine is removed by 61% while carbamazepine and atrazine are both removed by 51%. The treatment plant only has conventional treatment processes, with no advanced treatment technology.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	16.32	30	11.42	44	6.40	61
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-
Carbamazepine	14.82	30	10.38	30	7.26	51
Diclofenac	<IQL	30	<IQL	61	<IQL	-
Efavirenz	<IQL	No information on removal capabilities available				
Emtricitabine	9.61					
Methaqualone	5.12					
Acetaminophen	<MDL	30	<MDL	77	<MDL	-
Atrazine	440.34	30	308.24	30	215.77	51

Figure 6.30: Process configuration and unit treatment processes of Witbank WTP showing expected removal capabilities from international and local literature

Figure 6.31 shows and aerial view of the Witbank Water Treatment Plant.

Figure 6.31: Aerial view of Witbank WTP

6.2.3.17 Prediction of treatment efficiency and removal of selected CECs at Vaalbank WTP

The treatment configuration of the Vaalbank WTP was not known, therefore the predicted removal of CECs could not be calculated. No measured CEC concentration results of the final water is available.

Figure 6.32 shows an aerial view of the Vaalbank Water Treatment Plant.

Figure 6.32: Aerial view of Vaalbank WTP

6.2.3.18 Prediction of treatment efficiency and removal of selected CECs at Groblersdal WTP

The treatment configuration of the Groblersdal WTP was not known; therefore, the predicted removal of CECs could not be calculated. No measured CEC concentration results of the final water is available.

Figure 6.33 shows an aerial view of the Groblersdal Water Treatment Plant..

Figure 6.33: Aerial view of Groblersdal WTP

6.2.3.19 Prediction of treatment efficiency and removal of selected CECs at Flag Boshielo WTP

The treatment configuration of the Flag Boshielo WTP was not known, therefore the predicted removal of CECs could not be calculated. No measured CEC concentration results of the final water is available.

Figure 6.34 shows an aerial view of the Flag Boshielo Water Treatment Plant.

Figure 6.34: Aerial view of Flag Boshielo WTP

6.2.3.20 Prediction of treatment efficiency and removal of selected CECs at Phalaborwa WTP

The treatment configuration of the Phalaborwa WTP was not known; therefore, the predicted removal of CECs could not be calculated. However, the measured concentration of CECs in the raw and final water are shown in Figure 6.35. Based on the measured CEC results, it can be seen that very good removal of CECs is achieved at the plant, except for caffeine and atrazine, which showed an increase in concentration in the final water.

Raw water CEC concentrations		Measured final concentration
Chemical	**Value (ng/L)**	**Value (ng/L)**
Caffeine	72.9	128.4
Sulfamethoxazole	<IQL	<MDL
Carbamazepine	<IQL	<IQL
Diclofenac	<MDL	<IQL
Efavirenz	40.7	<MDL
Emtricitabine	<IQL	<IQL
Methaqualone	3.7	2.3
Acetaminophen	<IQL	<MDL
Atrazine	37.8	43.0

Figure 6.35: CEC concentrations measured in raw and final water at the Phalaborwa WTP

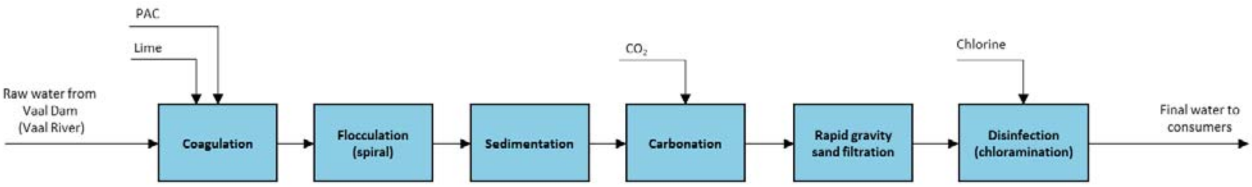
Figure 6.36 shows an aerial view of the Phalaborwa Water Treatment Plant.

Figure 6.36: Aerial view of Phalaborwa WTP

6.2.3.21 Prediction of treatment efficiency and removal of selected CECs at Zuikerbosch WTP

Figure 6.37 shows the process configuration and unit treatment processes of the Zuikerbosch WTP. From the results, it is predicted that the treatment plant will only have moderate removal of CECs. However, one of the treatment processes is carbonation, which to date, the removal capability of CECs using carbonation has not been evaluated. It is therefore unclear what the effect of having this process in the treatment plants configuration will have on the CEC removal capability of the plant.

The measured concentration of CECs in the final water produced by the Zuikerbosch WTP indicates poor removal of CECs. Caffeine is only removed by 39% and atrazine by a very low 7%. The results also indicates that the recreational drug, methaqualone, is removed by 28%. It can also be seen that sulfamethoxazole was not detected in the raw water but could be detected in the final water. This could be an indication that the chemical may be retained within the treatment process. It could also indicate that sulfamethoxazole might be a transformation product of some other chemical.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	**Value (ng/L)**	**Removal % range from literature**	**Concentration remaining after this process (ng/L)**	**Removal % range from literature for chlorination**	**Estimated concentration in final water (ng/L)**	**Estimated overall removal (%)**	**Measured final concentration (ng/L)**
Caffeine	20.24	30	14.17	44	39.20	61	12.27
Sulfamethoxazole	<MDL	30	<MDL	61	<MDL	-	4.25
Carbamazepine	<IQL	30	<IQL	L-M	<IQL	-	<IQL
Diclofenac	<MDL	30	<MDL	61	<MDL	-	<MDL
Efavirenz	<IQL	No information on removal capabilities available					<IQL
Emtricitabine	<IQL						<MDL
Methaqualone	5.43						3.89
Acetaminophen	<MDL	30	<MDL	77	<MDL	-	<MDL
Atrazine	381.62	30	267.13	30	186.99	51	353.54

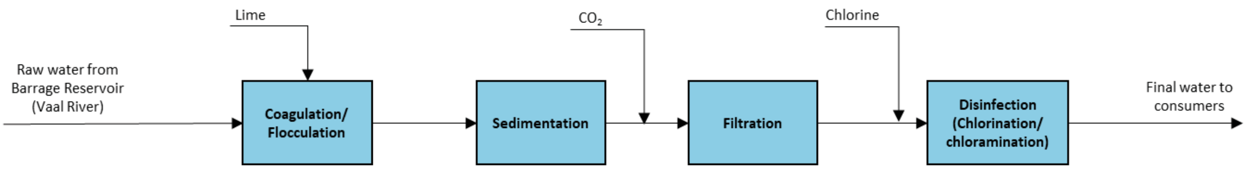
Figure 6.37: Process configuration and unit treatment processes of Zuikerbosch WTP showing expected removal capabilities from international and local literature

Figure 6.38 shows and aerial view of the Zuikerbosch Water Treatment Plant.

Figure 6.38: Aerial view of Zuikerbosch WTP

6.2.3.22 Prediction of treatment efficiency and removal of selected CECs at Vereeniging WTP

Figure 6.39 shows the process configuration and unit treatment processes of the Vereeniging WTP. The predicted removal capability of the plant indicates that only moderate removal of selected CECs will be achieved. The process consists of conventional treatment processes with no advanced treatment technology that is capable of good CEC removal. The measured CEC concentrations in the final water reveals that very poor removal of CECs is achieved at the treatment plant. Carbamazepine is only removed by 19% and atrazine by a mere 4%, while no removal is achieved for methaqualone.



Raw water CEC concentrations		Expected CEC removed in Sedimentation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	<IQL	30	<IQL	44	<IQL	-	39.07
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-	<MDL
Carbamazepine	10.52	30	7.36	30	5.16	51	8.50
Diclofenac	<MDL	30	<MDL	61	<MDL	-	<IQL
Efavirenz	<IQL	No information on removal capabilities available					<IQL
Emtricitabine	<IQL						<IQL
Methaqualone	6.91						6.92
Acetaminophen	<IQL	30	<IQL	77	<IQL	-	<IQL
Atrazine	387.93	30	271.55	30	190.09	51	370.83

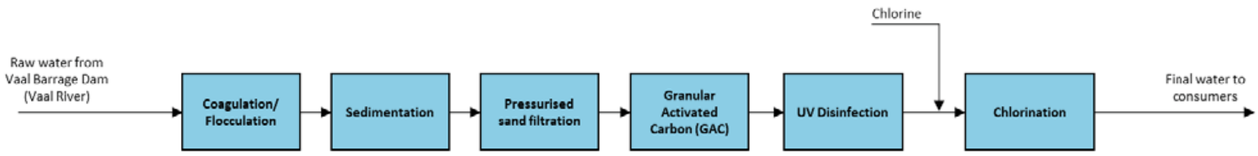
Figure 6.39: Process configuration and unit treatment processes of Vereeniging WTP showing expected removal capabilities from international and local literature

Figure 6.40 shows an aerial view of the Vereeniging Water Treatment Plant.

Figure 6.40: Aerial view of Vereeniging WTP

6.2.3.23 Prediction of treatment efficiency and removal of selected CECs at Vaal Barrage WTP

Figure 6.41 shows the process configuration and unit treatment processes of the Vaal Barrage WTP. The predicted removal capability of the plant indicates that the treatment plant will have moderate removal of caffeine (67%) and very good removal of atrazine (99%). The treatment process has an adsorption step as well as UV disinfection step, which is proven to remove various CECs. The measured concentrations of CECs in the final water indicates that excellent removal is achieved for methaqualone (96%). However, no removal was achieved for caffeine and atrazine.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed in GAC process		Expected CEC removed in UV process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	4.85	30	3.40	11	3.02	4.1	2.90	44	1.62	67	10.01
Sulfamethoxazole	<IQL	30	<IQL	49	<IQL	28	<IQL	61	<IQL	-	<IQL
Carbamazepine	<IQL	30	<IQL	8.3	<IQL	2.3	<IQL	30	<IQL	-	7.26
Diclofenac	<IQL	30	<IQL	59	<IQL	34	<IQL	61	<IQL	-	<IQL
Efavirenz	444.46	No information on removal capabilities available									<IQL
Emtricitabine	79.66										<IQL
Methaqualone	103.40										4.17
Acetaminophen	<MDL	30	<MDL	59	<MDL	19	<MDL	77	<MDL	-	<MDL
Atrazine	316.31	30	221.42	63	81.92	92	6.55	30	4.59	99	347.90

Figure 6.41: Process configuration and unit treatment processes of Vaal Barrage WTP showing expected removal capabilities from international and local literature

Figure 6.42 shows an aerial view of the Vereeniging Water Treatment Plant.

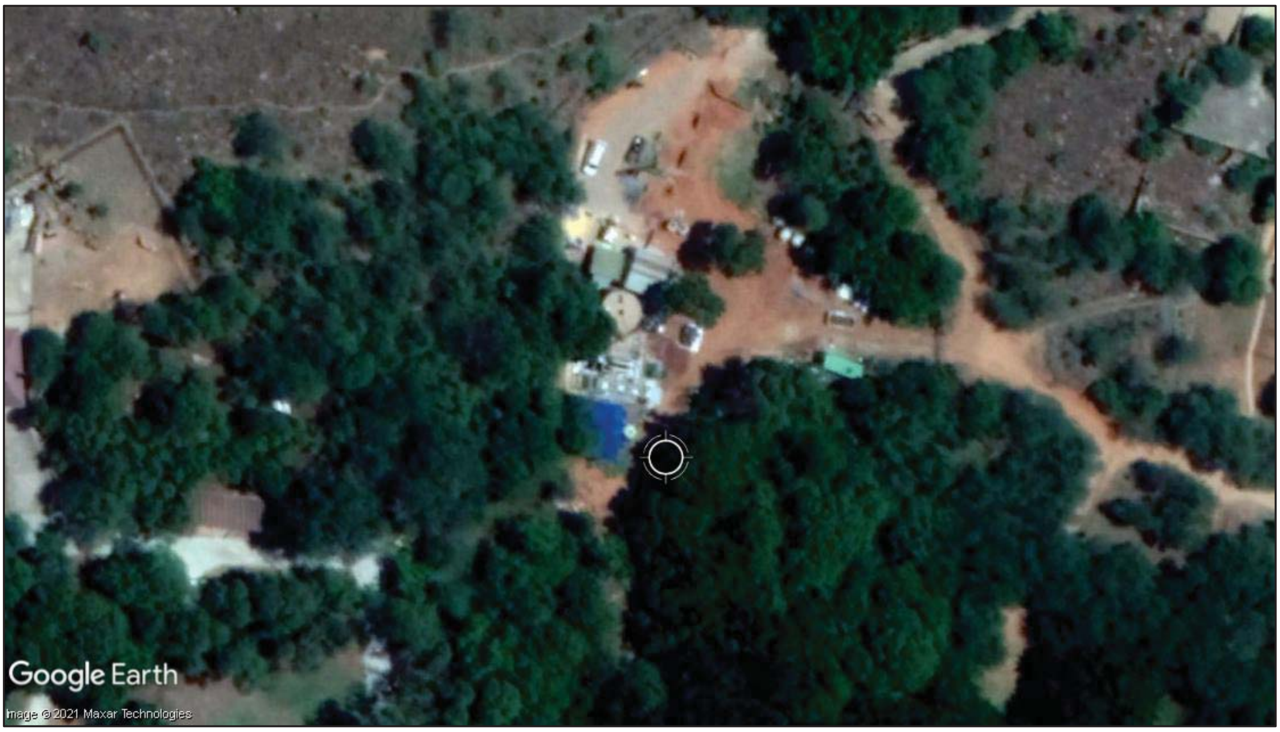
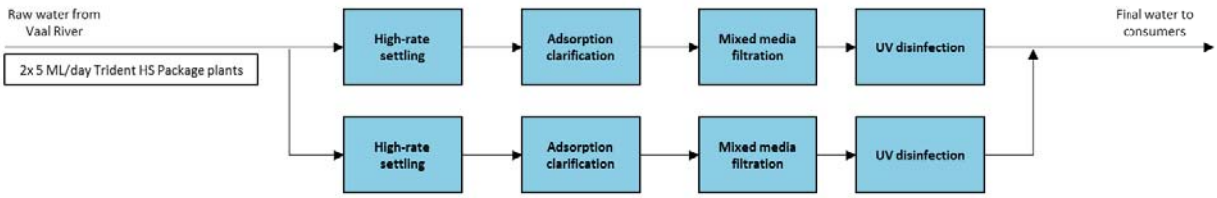


Figure 6.42: Aerial view of Vaal Barrage WTP

6.2.3.24 Prediction of treatment efficiency and removal of selected CECs at Parys WTP

Figure 6.43 shows the process configuration and unit treatment processes of the Parys WTP. The predicted removal capability indicates that the treatment plant will have poor removal of caffeine (33%) and carbamazepine (32%), however, very good removal of atrazine will be achieved due to UV disinfection that is proven to be effective in the removal of various CECs. Snyder et al. (2006) reported that UV doses of 600 to 700 mJ/cm^2 is required to obtain optimal removal.

The measured concentration of CECs in the final water reveals very good removal of CECs is achieved in the treatment plant. Sulfamethoxazole shows a higher concentration in the final water than measured in the raw water. This may be an indication of accumulation/ retention of the chemical in the treatment process. Good removal of methaqualone is achieved at 83% removal. However, contrary to the predicted removal of atrazine, the measured concentration reveals that only 6% removal of atrazine could be achieved in the plant.



Raw water CEC concentrations		Expected CEC removed in Sedimentation process of Package Plant		Expected CEC removed through Chlorination and expected final water concentration from Package Plant			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for UV Disinfection	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	62.67	30	43.87	4.1	42.07	33	<IQL
Sulfamethoxazole	<IQL	30	<IQL	28	<IQL	-	2.92
Carbamazepine	36.30	30	25.41	2.3	24.82	32	<IQL
Diclofenac	<IQL	30	<IQL	34	<IQL	-	<IQL
Efavirenz	328.55	No information on removal capabilities available					<IQL
Emtricitabine	241.28						<IQL
Methaqualone	172.56						30.11
Acetaminophen	<MDL	30	<MDL	19	<MDL	-	<MDL
Atrazine	332.12	30	232.48	92	18.60	94	311.49

Figure 6.43: Process configuration and unit treatment processes of Parys WTP showing expected removal capabilities from international and local literature

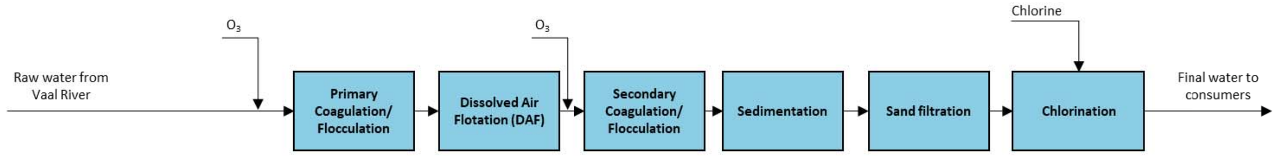
Figure 6.44 shows an aerial view of the Parys Water Treatment Plant.

Figure 6.44: Aerial view of Parys WTP

6.2.3.25 Prediction of treatment efficiency and removal of selected CECs at Midvaal WTP

Figure 6.45 shows the process configuration and unit treatment processes of the Midvaal WTP.

The predicted removal capability of the plant indicates that very good removal of CECs will be achieved at the treatment plant. The measured concentration of CECs indicates that various removal percentages will be achieved, depending on the chemical. Good removal is achieved for caffeine, carbamazepine and, emtricitabine as these concentrations are all below the MDL/IQL. Sulfamethoxazole is removed by 92% and methaqualone by 54%. Atrazine, however, is only removed by 25%.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed in Ozonation process		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	29.00	30	20.30	95	1.02	30	0.71	44	0.40	99	<MDL
Sulfamethoxazole	48.14	30	33.70	93	2.36	30	1.65	61	0.64	99	4.07
Carbamazepine	27.22	30	19.06	88	2.29	30	1.60	30	1.12	96	<MDL
Diclofenac	<IQL	30	<IQL	100	<IQL	30	<IQL	61	<IQL	-	<IQL
Efavirenz	338.28	No information on removal capabilities available									225.99
Emtricitabine	116.02										<MDL
Methaqualone	56.66										25.89
Acetaminophen	<MDL	30	<MDL	70	<MDL	30	<MDL	77	<MDL	-	<IQL
Atrazine	386.23	30	270.36	35	175.74	30	123.02	30	86.11	78	290.67

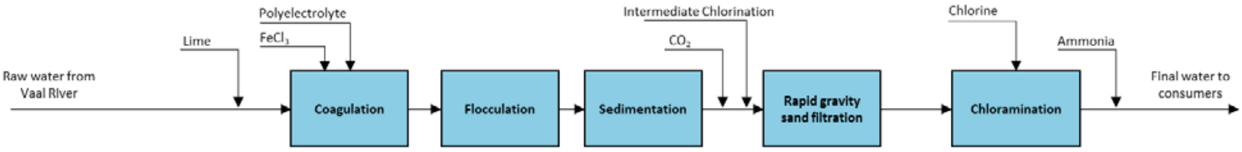
Figure 6.45: Process configuration and unit treatment processes of Midvaal WTP showing expected removal capabilities from international and local literature

Figure 6.46 shows an aerial view of the Midvaal Water Treatment Plant.

Figure 6.46: Aerial view of Midvaal WTP

6.2.3.26 Prediction of treatment efficiency and removal of selected CECs at Balkfontein WTP

Figure 6.47 shows the process configuration and unit treatment processes of the Balkfontein WTP. The predicted removal capability of the plant indicates that only moderate removal of CECs will be achieved at the plant. The measured concentrations of CECs in the final water reveals that very poor removal of CECs is achieved.



Raw water CEC concentrations		Expected CEC removed in Coagulation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	31.12	30	21.78	44	12.20	61	32.92
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-	12.21
Carbamazepine	30.49	30	21.34	30	14.94	51	19.88
Diclofenac	<IQL	30	<IQL	61	<IQL	-	<IQL
Efavirenz	365.46	No information on removal capabilities available					368.51
Emtricitabine	<IQL						<IQL
Methaqualone	83.06						77.14
Acetaminophen	<IQL	30	<IQL	77	<IQL	-	24.08
Atrazine	378.14	30	264.70	30	185.29	51	347.82

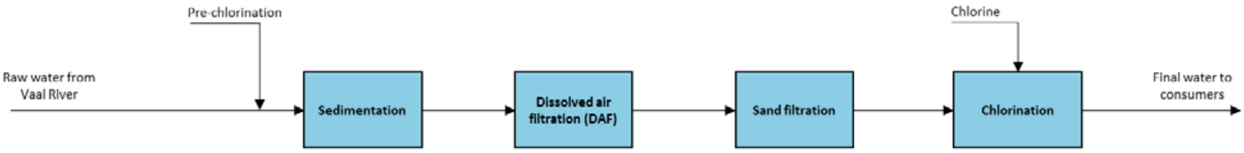
Figure 6.47: Process configuration and unit treatment processes of Balkfontein WTP showing expected removal capabilities from international and local literature

Figure 6.48 shows an aerial view of the Balkfontein Water Treatment Plant.

Figure 6.48: Aerial view of Balkfontein WTP

6.2.3.27 Prediction of treatment efficiency and removal of selected CECs at Bloemhof WTP

Figure 6.49shows the process configuration and unit treatment processes of the Bloemhof WTP. The results indicate that the treatment plant will have moderate removal of CECs (50-70%). The measured CEC concentrations in the final water indicates that the plant has very poor removal of CECs (less than 20% removal).



Raw water CEC concentrations		Expected CEC removed in Sedimentation process		Expected CEC removed through Chlorination and expected final water concentration			
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)	Measured final concentration (ng/L)
Caffeine	15.79	30	11.05	44	11.05	61	<IQL
Sulfamethoxazole	42.44	30	29.71	61	29.71	73	<MDL
Carbamazepine	33.92	30	23.75	30	23.75	51	29.03
Diclofenac	<IQL	30	<IQL	61	<IQL	-	<IQL
Efavirenz	<IQL	No information on removal capabilities available					180.18
Emtricitabine	<IQL						<MDL
Methaqualone	68.19						62.20
Acetaminophen	<IQL	30	<IQL	77	<IQL	-	<MDL
Atrazine	328.83	30	230.18	30	161.13	51	292.04

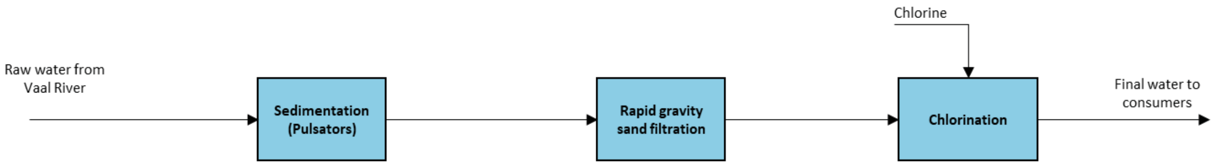
Figure 6.49: Process configuration and unit treatment processes of Bloemhof WTP showing expected removal capabilities from international and local literature

Figure 6.50 shows an aerial view of the Bloemhof Water Treatment Plant.

Figure 6.50: Aerial view of Bloemhof WTP

6.2.3.28 Prediction of treatment efficiency and removal of selected CECs at Christiana WTP

Figure 6.51 shows the process configuration and unit treatment processes of the Christiana WTP. The predicted removal capability of the plant indicates that only moderate removal of CECs will be achieved at the plant. The plant consists of conventional treatment processes with no advanced treatment technology.



Raw water CEC concentrations		Expected CEC removed in Sedimentation process		Expected CEC removed through Chlorination and expected final water concentration		
Chemical	Value (ng/L)	Removal % range from literature	Concentration remaining after this process (ng/L)	Removal % range from literature for chlorination	Estimated concentration in final water (ng/L)	Estimated overall removal (%)
Caffeine	25.58	30	17.90	44	10.03	61
Sulfamethoxazole	<IQL	30	<IQL	61	<IQL	-
Carbamazepine	39.58	30	27.70	30	19.39	51
Diclofenac	<IQL	30	<IQL	61	<IQL	-
Efavirenz	<IQL	No information on removal capabilities available				
Emtricitabine	24.88					
Methaqualone	73.33					
Acetaminophen	<MDL	30	<MDL	77	<MDL	-
Atrazine	232.50	30	162.75	30	113.93	51

Figure 6.51: Process configuration and unit treatment processes of Christiana WTP showing expected removal capabilities from international and local literature

Figure 6.52 shows an aerial view of the Christiana Water Treatment Plant.

Figure 6.52: Aerial view of Christiana WTP

6.3 SUMMARY

The removal capabilities of various unit treatment processes at selected case study water treatment plants in South Africa, for the removal of CECs, were evaluated in this section.

The results showed that conventional treatment processes such as coagulation, flocculation, sedimentation, and adsorption can remove moderate amounts of CECs (50 to 70%). However, the removal efficiency may vary depending on the physiochemical properties of the CECs as well as the quality of the water matrix. It was observed that the addition of an advanced oxidation process (AOP), such as ozonation, or a membrane process such as Reverse Osmosis (RO) to the treatment configuration of the plant drastically increased the removal capability to a high degree of CEC removal (> 85%). Therefore, a multi-barrier treatment configuration will be the most effective approach for the removal of CECs from surface waters for drinking water.

It was also observed that a direct correlation between the measures CEC concentrations in the raw and final water could not be made. This can be attributed to the fact that only one sample of the raw and final water was analysed in this project. The samples were taken on the same day, therefore, retention time of the raw water in the plant was not considered.

Therefore, it is recommended that a more comprehensive evaluation, directed to focussing on one case study, should be undertaken to collect more data on the removal of various CECs via conventional, as well as advanced, water treatment processes.

CHAPTER 7: HEALTH RISK ASSESSMENT OF PHARMACEUTICALS IN DRINKING WATER FROM DE FACTO REUSE IN SOUTH AFRICA

7.1 OVERVIEW

The Berg River was selected as a case study river for this assessment, as well as two drinking water treatment plants (DWTPs) along the Berg River. The human health risk assessment study was undertaken by the post-graduate students from the Chalmers University of Technology, in Sweden, under the supervision of Chris Swartz, the Project Leader on this WRC project. The aim of this study was to develop a model for the Quantitative Chemical Risk Assessment (QCRA) of human health risks due to long-term exposure to carbamazepine, diclofenac, and sulfamethoxazole in drinking water from the two DWTPs in the case study. The specific aims were to:

- Conduct a model for Quantitative Chemical Risk Assessment (QCRA),
- Characterize the human health risks of exposure to carbamazepine, diclofenac, and sulfamethoxazole in final drinking water,
- Perform a Monte Carlo uncertainty analysis for different potential scenarios of treatment efficiencies,
- Investigate public perception of the concept of de facto reuse,
- Find potential factors that influence the perception of the public.

The study consisted of three parts. Part 1 was the case study of the Berg River. Part 2 was creating the QCRA-model, including hazard identification, exposure assessment, dose-response, and risk characterisation. Part 3 was the interview study of public perception of using de facto water reuse.

7.2 PART 1: CASE STUDIES

The case study had two sections, the raw water quality in the Berg River, and the two DWTPs. The raw water quality section entailed the drinking water plants and the wastewater plants operating along Berg River that affect the raw water quality of the river. The DWTPs section focused on two drinking water treatment plants, namely Withoogte WTP and Piketberg WTP.

7.2.1 Berg River raw water quality

The Berg River is affected by five WWTPs that discharge to it and three DWTPs that abstract raw water. The summed design capacity of the WWTPs is 55 000 m^3/day (55 ML/day), relating to 55 000 m^3 of wastewater that enters the Berg River, per day (Current Project: Report No K5/2731 Progress Report). There are also two WWTPs with a design capacity of about 4 ML/day discharging into tributaries to Berg River, upstream of the DWTPs.

In 2017, a severe drought in South Africa caused a low flow in Berg River. At that time, Withoogte and Piketberg WTP abstracted raw water that contained up to 99% treated wastewater in certain sections of the river. For the period 2016 to 2018, the wastewater content in the Berg River was measured, and in 2016 and 2018 the highest wastewater content was 46% and 51%, respectively (Current Project: Report No K5/2731 Progress Report). Raw water abstracted by DWTPs from the Berg River is therefore unintendedly reusing wastewater (de facto reuse) due to the high volume-ratios of treated wastewater during dry periods. During the sampling period the effluents from WWTPs discharging to the Berg River contained the following concentrations of carbamazepine, diclofenac, and sulfamethoxazole, respectively: 0.2-2.1 µg/l, 0.06-0.5 µg/l and 0.02-6.4 µg/l.

7.2.2 Withoogte WTP

The Withoogte drinking water treatment plant is located approximately halfway down the length of the Berg River and has a design capacity is 72,000 m^3/day. The main raw water source from the Misverstand Dam in Berg River (Current Project: Report No K5/2731 Progress Report).

The first treatment process of the plant is stabilization. This first step aims to increase the pH by adding lime and to improve the coagulation process that follows. In this process raw water is mixed with flocculant to allow for flocs to form, where after the water goes to sedimentation tanks followed by rapid gravity sand filtration to remove the flocs. The last step of the treatment process is disinfection using chlorine, before the final water enters the distribution network (Swartz, 2011). The distribution network provides Langebaan, Hopefield, Vredenburg (Jacobs Bay & Paternoster), Saldanha, St Helena Bay, Moorreesburg, Koringberg, Velddrif and Dwarskersbos with municipal drinking water.

7.2.3 Piketberg WTP

The drinking water treatment plant Piketberg is the plant located furthest downstream in the Berg River and had a design capacity is 2 400 m^3/day (2.4 ML/day). The plant is designed to produce drinking water to a population of 10 000 people (Swartz, 2011).

The first treatment step is where coagulant is added to the raw water, with PAC also added for adsorption. PAC is used to reduce taste and odour of the water, but this process had not been operated the last couples of years (W. Burger, personal communication, April 06, 2021). Thereafter, the flocculated water flows into two setting tanks, followed by five rapid sand filters, where the treated water is stabilized using lime. Lastly, chlorine is dosed for disinfection (Swartz, 2011), before being stored in two reservoirs where it is pumped into the distribution network systems to reach the consumers living in Piketberg.

7.3 PART 2: DEVELOPMENT OF MODEL

The health risk assessment was divided into four steps: (1) hazard identification, (2) exposure assessment, (3) dose response determination and (4) risk characterization. The approach was developed by NRMMC (2008).

7.3.1 Sensitivity analysis

The method of the QCRA model was done using a sensitivity analysis with Monte Carlo simulations. For the Monte Carlo simulation, 10 000 simulations were performed using 10 000 random values of the input values. These values were used in calculating the results as a range of possible values. The sensitivity analysis addressed both variability and uncertainty. By including uncertainty, the risk assessment therefore considers gaps in knowledge, meanwhile variability accounts for heterogeneity across people, places, or time (EPA, 2011).

7.3.2 Hazard identification

Carbamazepine, diclofenac, and sulfamethoxazole were pharmaceutical compounds identified as hazards since they have been detected in the raw water of the Berg River. These three pharmaceuticals were chosen with the aim to reach a wide range of properties and usage, i.e. one anticonvulsant, one anti-inflammatory and one antibiotic.

7.3.3 Exposure assessment

The exposure assessment of pharmaceutical concentrations in the final drinking water was used to understand how exposed the population is to these pharmaceuticals via drinking water. This study used sample analyses from the raw water intakes of Withoogte and Piketberg DWTPs, as well as data from literature to validate the reliability of the results. These raw water concentration values were then reduced using pharmaceutical removal efficiencies for the DWTP treatment processes, found in literature.

The pharmaceutical concentrations in the Berg River were measured by taking samples over 5 weeks of the raw water intake entering the Withoogte DWTP and Piketberg DWTP. A mean and standard deviation was calculated from these sample concentrations and used as input for a log normal distribution in the Monte Carlo simulation. For comparison, another river case data for the Sesmylspruit River in Gauteng Province (Archer, Wolfaardt and Van Wyk, 2017), was used and tested in the QCRA model.

Scenarios for the exposure assessment in the QCRA

The exposure assessment in the QCRA was done using three scenarios for the raw water data of the three cases, namely Withoogte DWTP, Piketberg DWTP and Sesmylspruit River. The first scenario included treatment by coagulation, flocculation, sedimentation, sand filtration and chlorination. The second scenario assumed that technical/human failure led to no treatment. The third scenario was a future scenario where additional GAC filtration is applied.

Exposure concentration in the final drinking water

The final exposure concentration of carbamazepine, diclofenac and sulfamethoxazole in the final drinking water was calculated using Equation 10. $C_{final\ DW}$ is the final drinking water concentration (in µg/L), while $C_{raw\ water}$ is the raw water concentration (in µg/L), and TE_i is the treatment efficiency for each process (in %).

$$C_{final\ DW} = C_{raw\ water} \cdot \left(1 - \frac{TE_1}{100}\right) \cdot \left(1 - \frac{TE_2}{100}\right) \cdot \left(1 - \frac{TE_3}{100}\right) \qquad (10)$$

7.3.4 Dose-response function development

Firstly, an acceptable daily intake (ADI) (µg/kg body weight/day) for the studied pharmaceuticals was established. The ADI was then used to calculate the dose concentration where it can be said that no response or effect will occur in the human body, the Point of Departure (PoD). ADI values were obtained from literature, as well as calculated based on different PoDs. Calculated ADIs were based on different PoD levels mainly found in animal-related studies. The ADI values from literature ranged from 0.34 for carbamazepine to 510 for sulfamethoxazole.

To calculate the ADIs, the following was used: no observed adverse effect level (NOAEL), no observed effect level (NOEL), lowest observed adverse effect level, lowest observed effect level (LOEL), or the minimum therapeutic dose (MTD). Uncertainty factors (UF) applied to PoD levels were based on an approach by Schwab et al. (2005). When using MTD as the PoD value, the approach by NRMMC (2008) was used.

In the dose-response development, calculation of a provisional guideline value was made, denoted as a drinking water equivalent level (DWEL) representing the concentration where there is a reasonable certainty that there will not be an effect in humans during long-term exposure of the pharmaceutical residuals, which also is further explained below.

Calculating ADI from PoD

UFs of a value of 1 or 3 or 10 were applied to the PoD values according to the approach by Schwab et al. (2005). Five UFs represent five parameters of the PoD: (1) if the PoD was a NOAEL/NOEL or LOAEL/LOEL, (2) duration of exposure, (3) interspecies variation, (4) intra individual susceptibility and (5) data quality. The UF value for the data quality was always set to 1, because a conservative value was set for the other four UFs.

The ADI was calculated using to Equation 11 which is the same method as Schwab et al. (2005), NRMMC (2008) and WHO (2011) used. The calculated ADIs showed a range of 0.34 µg/kg/d (carbamazepine) to 54.2 µg/kg/d (carbamazepine).

$$ADI = \frac{PoD}{UF1 \cdot UF2 \cdot UF3 \cdot UF4 \cdot UF5} \qquad (11)$$

Calculating guideline value, denoted as drinking water equivalent level (DWEL)

The last step in the dose-response development was to calculate a guideline value, denoted as a drinking water equivalent level (DWEL) according to (WHO, 2011), as calculated using Equation 12. P is the fraction of ADI allocated to drinking water and IR is the ingestion, which was calculated using an average assumption of 2 L/day according to WHO (2011) for adults, with an average bodyweight (BW) is 60 kg. For children, an assumption of 1 L/day and a BW is 10 kg was assumed (WHO, 2011).

$$DWEL = \frac{ADI \ \cdot P}{IR \cdot 100} \tag{12}$$

DWEL= drinking water equivalent level (µg/L)
ADI = Acceptable daily intake (µg/kg/d)
P = Fraction of ADI allocated to drinking water (%)
IR= Ingestion rate (L/kg BW/day)

Four population groups were used in the QCRA-model, namely (1) infants that are breast fed, (2) infants that are formula fed, (3) children between the ages of 1 to 10 years old and (4) adults between the ages of 20 to 64 years old. The infants that are formula fed is the population group with the IR rate per BW.

Diclofenac and sulfamethoxazole are both used as veterinary drugs, which is an additional means by which people can be exposed to these substances, other than drinking water. Therefore, the fraction of exposure to diclofenac and sulfamethoxazole through drinking water alone (P), was assumed to be between 10-20%, each. For carbamazepine, people can be exposed to it through the ingestion of vegetables (via irrigation) (Schapira et al., 2020). Therefore, the fraction of exposure to carbamazepine through drinking water alone (P), was assumed to be between 10-20%. Therefore, P of 10-20% was assumed, to take into consideration the dietary variations for people. This excludes infants that was assumed to be between 40 and 50.

Two DWELs were calculated, both children and adults, respectively. For children, the IR was calculated as 0.1 L/kg/day and for adults it was 0.033 L/kg/day, and P was assumed to be 20%. The ADIs used were recommended by NRMMC (2008), and were 2.8 µg/kg/day, 0.5 µg/kg/day and 10 µg/kg/day, for carbamazepine, diclofenac, and sulfamethoxazole, respectively.

7.3.5 Risk characterisation

The risk characterization was used as a measure to compare the exposure dose and the DWEL. This was done by calculating a hazard quotient (HQ), as seen in Equation 13. A HQ value of above 1 indicates an exposure risk to the population, compared to the calculated DWEL. A HQ value of below 1 indicates no risk to the population.

$$HQ = \frac{Exposure\ dose\ [\frac{ug}{l}]}{DWEL\ [\frac{ug}{l}]} \tag{13}$$

7.4 PART 3: INTERVIEW STUDY

To get a wide range of views and a fair representation of people living along the Berg River, the interviews took place with people from different socio-economic and demographic backgrounds. The interview questions were mainly open-ended and covered a broad spectrum of concepts of de factor reuse. The questions had the following structures:

- Do you have any knowledge on where the water from your tap comes from?
- What do you use your tap water at home for?
- How do you feel about the water situation and scarcity in South Africa today?
- Are you familiar with the term “water reuse”? What does it mean to you?
- Do you trust water treatment technologies?
- Do you have trust in your authorities, such as municipalities, working with water in your region?
- Can you think of anything that could help increase your trust in water reuse for drinking water?

Two test interviews were followed by 11 anonymous interviews in total. The interviews were conducted telephonically and were about 20 to 30 minutes long. 10 out of the 11 interviews were performed successfully and were therefore used for the results of the interview study.

7.5 RESULTS AND DISCUSSION

7.5.1 Assessment of chemical health risks

Final drinking water concentration

When comparing the results from the three scenarios, the raw water intakes from Withoogte and Piketberg WTPs showed approximately equal exposure concentrations for the two DWTPs. For all scenarios, carbamazepine exposure concentrations were the lowest compared to diclofenac for both Withoogte and Piketberg. Sulfamethoxazole was not detected in the raw water intakes for either Withoogte or Piketberg, therefore no exposure concentrations were calculated.

The exposure concentration for scenario 1-3 of raw water intake from Sesmylspruit River was higher than that of Withoogte and Piketberg DWTP, for carbamazepine diclofenac and sulfamethoxazole. For carbamazepine, the exposure concentrations were about 30 times higher, and for diclofenac the exposure concentrations were about 80 times higher. Diclofenac was highest for both scenario 1 and scenario 2, followed by sulfamethoxazole and carbamazepine. For scenario 3 sulfamethoxazole had the highest concentrations, followed by diclofenac and carbamazepine.

Scenario 2 has the highest exposure concentrations for the pharmaceuticals, as expected as there was no treatment of the raw intake water. The carbamazepine concentrations for scenario 2 was about two times higher than that of scenario 1. For diclofenac and sulfamethoxazole, the concentrations from scenario 2 was about three times higher than that of scenario 1.

The conventional treatment and chlorination used in scenario 1 had the least impact on the reduction of carbamazepine, since it only reduced the exposure concentration with about 50% compared to scenario 2. For diclofenac and sulfamethoxazole, the reduction was about 70%. When GAC filters were used in scenario 3, the carbamazepine concentration was reduced with about 80% compared to scenario 1. For diclofenac and sulfamethoxazole, the reduction was about 70% and 50%, respectively. From this it was clear that GAC filters had the most impact on carbamazepine reduction, then followed by diclofenac and sulfamethoxazole.

See Table 7.1 below for the above-mentioned exposure concentrations for carbamazepine, diclofenac, and sulfamethoxazole for the three scenarios.

Table 7.1: Exposure concentrations for the three pharmaceuticals for the three scenarios

Exposure concentration [µg/l]	Scenario 1	Scenario 2	Scenario 3
Withoogte DWTP			
Carbamazepine (mean, SD)	0.005, 0,003	0.010, 0.004	0.001, 0.0008
Diclofenac (mean, SD)	0.006, 0.002	0.019, 0.001	0.002, 0.0005
Sulfamethoxazole (mean, SD)	ND	ND	ND
Piketberg DWTP			
Carbamazepine (mean, SD)	0.005, 0.002	0.010, 0.002	0.001, 0.0006
Diclofenac (mean, SD)	0.006, 0.002	0.019, 0.0007	0.002, 0.0005
Sulfamethoxazole (mean, SD)	ND	ND	ND
Sesmylspruit River			
Carbamazepine (mean, SD)	0.140, 0.048	0.280, 0.024	0.038, 0.015
Diclofenac (mean, SD)	0.460, 0.200	1.500, 0.510	0.150, 0.063
Sulfamethoxazole (mean, SD)	0.370, 0.200	1.010, 0.290	0.210, 0.120

**ND = not detected*

The health risk assessment showed that for the three scenarios, scenario 3 had the biggest impact on the mean of exposure concentration of diclofenac at Withoogte DWTP, followed by scenario 1 and then scenario 2. Therefore, GAC filtration addition > Conventional treatment > No treatment. For carbamazepine, the biggest impact on the exposure concentration was scenario 2, then scenario 3 followed by scenario 1. Therefore, No treatment > GAC filtration addition > Conventional treatment. This was due to the raw water at Withoogte having a larger standard deviation. For Piketberg DWTP, for both diclofenac and carbamazepine, the biggest effect on the exposure concentration was found to be for GAC filtration > No treatment > Conventional treatment.

Using Sesmylspruit River as comparison, the standard deviation for carbamazepine found in the raw water, was lower than for Withoogte and Piketberg. The concentration of diclofenac had a significantly larger standard deviation compared to that of the two DWTPs. Sulfamethoxazole was detected at Sesmylspruit River, compared to the two DWTPs, where no sulfamethoxazole was detected.

Drinking water equivalent level

Ranking the DWELs of the population groups in terms of lowers to highest level, the following was found: infants that are formula fed had the lowest values, followed by children, then adults, and infants that are breastfed had the highest value. For the pharmaceuticals, diclofenac had showed the lowest DWEL compared to the other pharmaceuticals, followed by carbamazepine, and then sulfamethoxazole had the highest DWEL for all population groups. This means that diclofenac had a much stricter DWEL value compared to carbamazepine and sulfamethoxazole, for the acceptable exposure concentration in final drinking water for it to be safe for human consumption.

In the health risk assessment, the effect the input parameters had on the mean of DWEL were compared. For most of the DWEL values, the input that effected the mean of DWEL the most was ADI. This excluded the sulfamethoxazole DWEL value for infants that are formula fed, where the IR had the biggest effect. For the DWEL values of infants that are breastfed and infants that are formula fed, the ADI and the IR had about the same effect. The fraction of ADI allocated to drinking water (P) had minimal effect on the DWEL values. See the Table 7.2 below for all DWEL values.

Table 7.2: DWEL values for each pharmaceutical per population group

DWEL (µg/L)		Infants, breast fed	Infants, formula fed	Children	Adults
Carbamazepine	mean, SD	2800, 4700	680, 8500	840, 1200	1300, 1700
	5th percentile	75	21	30	52
Diclofenac	mean, SD	320, 550	68, 270	94, 140	150, 200
	5th percentile	8.5	2.4	3.4	6.0
Sulfamethoxazole	mean, SD	4500, 8000	990, 6100	1300, 1800	2200, 2800
	5th percentile	120	33	44	85

Risk characterization and Hazard quotient

For most of the HQ values, the parameter that had the biggest effect on the mean HQ was the ADI, which was significant compared to the other parameters, namely raw water concentration, treatment efficiencies of conventional treatment, chlorination, GAC filtration, IR, and P. What is significant, is that even though the large variance in ADI resulted in high HQs, the HQ was never more than 1. That meant that even the most conservative ADI poses no risk to the HQ. See Table 7.3 below for all calculated HQ values, sorted by site, scenario, population group and pharmaceutical.

Table 7.3: HQ values for each pharmaceutical per population group per case study site

HQ		Infants, breast fed	Infants, formula fed	Children	Adults
Withoogte DWTP					
Scenario 1					
Carbamazepine	mean, SD	$4x10^{-5}$, 0.001	0.0001, 0.003	0.0001, 0.002	$6x10^{-5}$, 0.001
	95^{th} percentile	$7x10^{-5}$	0.0002	0.0002	0.0001
Diclofenac	mean, SD	0.0003, 0.002	0.001, 0.023	0.001, 0.020	0.0005, 0.007
	95^{th} percentile	0.0007	0.002	0.002	0.001
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95^{th} percentile	ND	ND	ND	ND
Scenario 2					
Carbamazepine	mean, SD	$9x10^{-5}$, 0.002	0.0003, 0.009	0.0002, 0.005	0.0001, 0.002
	95^{th} percentile	0.0001	0.0005	0.0004	0.0002
Diclofenac	mean, SD	0.001, 0.008	0.004, 0.084	0.004, 0.071	0.002, 0.027
	95^{th} percentile	0.002	0.008	0.006	0.003
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95^{th} percentile	ND	ND	ND	ND
Scenario 3					
Carbamazepine	mean, SD	$2x10^{-5}$, 0.0008	$6x10^{-5}$, 0.003	$4x10^{-5}$, 0.002	$2x10^{-5}$, 0.001
	95^{th} percentile	$2x10^{-5}$	$6x10^{-5}$	$5x10^{-5}$	$3x10^{-5}$
Diclofenac	mean, SD	$9x10^{-5}$, 0.008	0.0004, 0.007	0.0003, 0.007	0.0002, 0.002
	95^{th} percentile	0.0002	0.0008	0.0006	0.0003
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95^{th} percentile	ND	ND	ND	ND
Piketberg DWTP					
Scenario 1					
Carbamazepine	mean, SD	$4x10^{-5}$, 0.001	0.0001, 0.005	0.0001, 0.003	$5x10^{-5}$, 0.001
	95^{th} percentile	$7x10^{-5}$	0.0002	0.0002	0.0001
Diclofenac	mean, SD	0.0003, 0.003	0.001, 0.030	0.001, 0.021	0.0005, 0.009
	95^{th} percentile	0.0007	0.002	0.002	0.001
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95^{th} percentile	ND	ND	ND	ND
Scenario 2					
Carbamazepine	mean, SD	0.0001, 0.004	0.0003, 0.014	0.0002, 0.007	0.0001, 0.003
	95^{th} percentile	0.0001	0.0005	0.0004	0.0002
Diclofenac	mean, SD	0.001, 0.008	0.004, 0.08	0.004, 0.07	0.002, 0.026
	95^{th} percentile	0.002	0.008	0.006	0.003
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95^{th} percentile	ND	ND	ND	ND
Scenario 3					
Carbamazepine	mean, SD	$1x10^{-}5$, 0.0002	$3x10^{-5}$, 0.0008	$2x10^{-5}$, 0.0004	$1x10^{-5}$, 0.0002
	95^{th} percentile	$2x10^{-}5$	$6x10^{-}5$	$5x10^{-}5$	$3x10^{-}5$
Diclofenac	mean, SD	$9x10^{-}5$, 0.0008	0.0004, 0.009	0.0004, 0.008	0.0002, 0.003

HQ		Infants, breast fed	Infants, formula fed	Children	Adults
	95th percentile	0.0002	0.0008	0.0006	0.0003
Sulfamethoxazole	mean, SD	ND	ND	ND	ND
	95th percentile	ND	ND	ND	ND
Sesmylspruit River					
Scenario 1					
Carbamazepine	mean, SD	0.001, 0.036	0.004, 0.100	0.003, 0.063	0.002, 0.030
	95th percentile	0.002	0.006	0.005	0.003
Diclofenac	mean, SD	0.022, 0.160	0.090, 1.50	0.072, 1.40	0.036, 0.540
	95th percentile	0.055	0.19	0.14	0.08
Sulfamethoxazole	mean, SD	0.002, 0.080	0.006, 0.160	0.004, 0.070	0.003, 0.090
	95th percentile	0.003	0.01	0.007	0.004
Scenario 2					
Carbamazepine	mean, SD	0.003, 0.110	0.010, 0.400	0.006, 0.200	0.003, 0.0.085
	95th percentile	0.004	0.013	0.01	0.005
Diclofenac	mean, SD	0.070, 0.540	0.300, 5.000	0.240, 4.200	0.120, 1.700
	95th percentile	0.18	0.61	0.44	0.25
Sulfamethoxazole	mean, SD	0.007, 0.350	0.020, 0.710	0.012, 0.260	0.009, 0.400
	95th percentile	0.009	0.03	0.021	0.012
Scenario 3					
Carbamazepine	mean, SD	0.0004, 0.02	0.001, 0.070	0.0009, 0.034	0.0005, 0.014
	95th percentile	0.0005	0.002	0.0013	0.0008
Diclofenac	mean, SD	0.007, 0.057	0.030, 0.510	0.025, 0.430	0.012, 0.170
	95th percentile	0.017	0.06	0.044	0.025
Sulfamethoxazole	mean, SD	0.002, 0.130	0.005, 0.250	0.003, 0.080	0.002, 0.140
	95th percentile	0.0004, 0.02	0.001, 0.070	0.0009, 0.034	0.0005, 0.014

7.5.2 Empirical summary of interview study

Overall, the interviews showed that people had a positive feeling towards and showed support to the concept of water reuse, but 9 out of the 10 interviews said that more knowledge and education on the subject was needed. The interviews showed, that regardless of the level of knowledge on water reuse and the water cycle in general, the sharing of knowledge and spreading of information to the public is of importance. Most of the interviews expressed that they would like more involvement from politicians, municipalities, and water suppliers on the sharing of this knowledge and education on water reuse.

Majority of the interviewees expressed a concern for the potential health risks that are related to unsafe water quality. The interviews showed that are doubts concerning whether the water from their tap is safe to drink, and some even said that they would rather buy bottled water. One interview mentioned health related concerns regarding chemicals and pharmaceuticals found in the drinking water.

7.6 CONCLUSIONS

The results from the case study and QCRA show that, concerning the pharmaceutical concentrations detected in Berg River, there were no human health risks to any population group, due to exposure to any of the pharmaceutical investigated. Therefore, the drinking water supplied Withoogte and Piketberg DWTP pose to human health risks, even if events lead to no treatment of the raw intake water, as all HQ values were below one.

From the three pharmaceuticals investigated, diclofenac showed most risk to human health, compared to carbamazepine and sulfamethoxazole. The results showed that at higher raw water concentrations of diclofenac, due to a more polluted Berg River and no treatment occurring at the DWTPs, the pharmaceutical may pose a health risk to children. Therefore, compared to carbamazepine and sulfamethoxazole, diclofenac is of highest importance for future monitoring.

When comparing the results from the different scenarios, it was clear that the addition of GAC filtration to DWTPs reduced the risk to human health. It was recommended that if, in the future, the concentrations of carbamazepine, diclofenac or sulfamethoxazole increased in the raw water intake of the DWTPs, that an additional treatment step, like GAC filtration, was implemented to reduce the potential risk to human health.

The interview study showed that most people seemed to accept the concept of water reuse as an alternative source of water for drinking, but concern was expressed for the risks related to human health and whether the water would be safe to drink. The study also showed that knowledge on the topic is lacking, and that people want to be informed and educated on water reuse as an option. There was a correlation between the acceptance of the concept of water reuse and having knowledge about water reuse. The more people are educated on the topic, the more they would be likely to accept it as a valid option.

CHAPTER 8: PUBLIC ACCEPTANCE AND AWARENESS STUDY

8.1 RATIONALE

With a fast-growing population and recurring droughts, it has become critical for South Africa to plan for an increasing demand for freshwater. Water re-use is one of the strategies proposed in policy documents such as the National Water Resource Strategy and the National Water and Sanitation Master Plan.

The Water Research Commission (WRC) has done most of the research groundwork on the technical, financial and water quality aspects of water re-use. The WRC has also done several studies on social and cultural perceptions of water re-use, but the South African public's current awareness and understanding of aspects of water re-use and related aspects have not yet been tested.

Lack of understanding of the water cycle and treatment technology is cited in the literature to be correlated to negative perceptions on water re-use, and thus a major barrier to the implementation of water re-use, particularly direct potable re-use.

8.2 METHODOLOGY

The research team conducted a national survey in September 2019 as part of the OMNIBUS syndicated survey of Nielsen South Africa. The sample included 2 519 urban respondents (Metro and other urban) and 800 rural respondents. "Urban" is defined as areas of a community size of 8 000 and above. This includes cities and large and small towns.

The survey tested South Africans' knowledge of several aspects of water re-use and related aspects. The survey also determined which actions South Africans are likely to support in times of a severe drought.

The baseline study is a collaboration between two WRC projects: this project and WRC project K5/2805/3 (project leader: Dr Sarah Slabbert). The results of the survey informed the development of a communication strategy for a sustainable public education programme on water re-use (WRC Project K5/2805/3).

8.3 KEY FINDINGS

The survey found that South Africans across all demographic groups have poor knowledge and understanding of the basic terminology that is needed for a meaningful public discourse on water re-use. For example, only 35% of South Africans know that greywater is the term for wastewater from bathing, washing clothes and dishes. Only 28,3% know what 'potable water' means.

The pilots of the study found that knowledge of terms like 'wastewater' and 'treated wastewater' was so poor that these terms had to be explained upfront in a showcard before respondents could be asked any questions.

South African's knowledge of water re-use and related aspects was tested with 18 statements. The composite result was presented as an index score out of 20. On average, South Africans scored 12 out of 20. Since the questions tested very basic knowledge, one would expect at least an average score of 14 out of 20 from an educated public. This result therefore indicates that public knowledge of water re-use and related aspects must be improved.

Even for the highest LSM (Living Standard Measure) group, LSM 8-10 and for people with a post Grade 12 qualification the average scores were 13,05 and 12,65 respectively. This implies that a public education campaign on water re-use should target all demographic groups.

There were some demographic differences on the overall knowledge index, but not all were significant. Findings across provinces were inconsistent, indicating that province is not a good predictor when it comes to knowledge of water re-use and related aspects. LSM and education levels, on the other hand, were good predictors of knowledge of water re-use and related aspects.

Three sub-indices were calculated. On these sub-indices, South Africans scored as follows:

- 1,32 out of 3 for knowledge of the water cycle. This indicates that South African's knowledge of the water cycle is particularly poor.
- 1,81 out of 3 for knowledge of safety aspects of water re-use. On some aspects, knowledge was good (75% or more); on other, knowledge was poor.
- 4,58 out of 6 for knowledge of water and wastewater treatment. This knowledge result is quite remarkable as it shows that respondents have applied the explanation that they got in the showcard.

The statement about de facto water re-use got a large number of "Not sure'' responses (35,19%). South Africans seem to be unsure if there might be re-treated wastewater in their drinking water.

The survey indicated that South Africans would support water re-use in a severe drought situation, including direct potable re-use. 48,5% of the population mentioned direct potable re-use as an action that they will support. As expected, the support for direct potable re-use was lower than the support for industrial and greywater re-use, but the difference was less than 10%.

Although the correlation was weak, the survey confirmed that knowledge of water re-use and related aspects correlates positively with support for water re-use. The study also found that general education levels seem to be related to support for water re-use. Respondents with a post Grade 12 qualification (54,6%) support direct potable re-use in a drought significantly more than respondents with only primary education (39%).

One can therefore look forward to a positive outcome of improved public knowledge.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 SUMMARY OF KEY FINDINGS AND CONCLUSIONS

9.1.1 Impact of wastewater discharges on raw water sources for drinking water production

De facto reuse is increasing on a widespread basis in South Africa. The impact thereof is dependent on the concentration, volume, and consistency of wastewater in raw water sources in South Africa. It is the human health and environmental effects of exposure to the CECs in these waters that are of considerable concern.

The findings of estimating wastewater percentage contributions to raw water sources for the ten selected rivers revealed that South African rivers are highly impacted by municipal wastewater. These rivers serve as important resources for drinking water abstraction, industrial use, and irrigation purposes, therefore the extent of de facto reuse to occur in these rivers are quite high.

Under low base-flow conditions, the impact of wastewater effluent contributions increases dramatically, therefore the wastewater percentage contribution is highly dependent on streamflow and stream size. Wastewater percentage contributions under median flow conditions was also consistently higher when compared to average flow conditions. The difference was expected as the median statistic is a fit better for the river flow data since it takes temporal variations into consideration. In the case where the data is clustered to one end of the range and/or extreme values are present, the average is skewed (such will be the case where stream flows are very low or zero in extreme droughts or very high when flooding occurs). Under these circumstance the median is a better representation of the central tendency of the data. Based on the wastewater percentage estimation results, it was revealed that tributaries with a high base-flow can have a dilution effect on the downstream wastewater effluent contributions.

Limited density of measuring stations for flow data presented a critical limitation in assessing the wastewater percentage intake at water treatment plant abstraction sites. Other limitations in estimating the wastewater percentage contributions included the following:

a. Only WWTP discharge was considered in the calculations and did not consider the effect of industrial discharge and mining effluent, stormwater and surface water run-off, diffuse agricultural run-off, or other non-point sources of pollution such as diffuse surface water run-off from informal settlements on the banks of the river.
b. Wastewater effluent contributions was estimated using the design capacity of the WWTP, however, WWTPs do not operate at design capacity and its discharge flows may fluctuate.
c. Only discharges to the raw water sources were considered in the calculations and not withdrawals as well.

The occurrence of domestic wastewater indicator CECs was identified and quantified to determine the impact of wastewater effluent contributions on downstream water treatment plants. The findings of this study revealed that CEC concentrations are highest in wastewater effluents and that tributaries with lower base-flows, which receives these wastewater effluents, contain high concentrations of CECs. The results also showed that CEC concentrations have a higher impact on raw water sources in areas where the urban population and wastewater infrastructure capacity increases.

CECs present in wastewater effluent is not only diluted when they are discharged into surface waters, but will also undergo transformation, absorption, and degradation in the water matrix. However, results reveal that not all CECs will assimilate and can therefore be used as indicators of wastewater contributions. Efavirenz and emtricitabine, two antiretrovirals (ARVs) were persistently detected in all wastewater effluent and river water samples. The presence of ARVs in the water system is due to the high HIV/AIDs prevalence in South Africa. Subsequently, these chemicals can potentially be used as indicator CECs of wastewater effluent contributions.

The results also revealed that water treatment plants in most cases show a reduction of CEC concentrations, but not complete removal in the treatment processes. Therefore, this work corroborates the notion for further decision making and policy development on management of de facto reuse and monitoring of micro-pollutants in potable water supply.

Limitations observed for this study included the following:

a. Only one sampling campaign was undertaken, therefore special and temporal variations in the occurrence of CECs in wastewater effluent and surface waters was not taken into consideration.
b. Grab samples were used for the analysis; therefore, the presented data only provide some insight into the occurrence of CECs in wastewater effluents and surface water samples, and not a complete analysis of the variations in effluent discharges.

9.1.2 Estimating the extend of de facto reuse in South Africa

Therefore, as a first step, the extent and impact of de facto reuse has to be quantified. In this study, the national extent of de facto reuse in the country was determined by estimating the percentage wastewater content in raw water sources supplying to major cities and large towns, as well as the concentrations of CECs found in wastewater discharges, in rivers and at water treatment abstraction points.

The results of the research answered a number of research questions regarding the status and extent of de facto reuse in South Africa, most notably:

i. Insight on the extent of de facto reuse in the country
ii. Knowledge on the impact of municipal wastewater to potable water supply
iii. A methodology was established for future monitoring and management of de facto reuse
iv. Information on the occurrence of CECs in South African wastewater effluents and surface waters.

9.1.3 Need for a sustained programme for ensuring public water reuse literacy

Lack of understanding of the water cycle and treatment technology is cited in the literature to be correlated to negative perceptions on water re-use, and thus a major barrier to the implementation of water re-use, particularly direct potable re-use. The research team conducted a national survey to test South Africans' knowledge of several aspects of water re-use and related aspects.

The survey found that South Africans across all demographic groups have poor knowledge and understanding of the basic terminology that is needed for a meaningful public discourse on water re-use. For example, only 35% of South Africans know that greywater is the term for wastewater from bathing, washing clothes and dishes. Only 28,3% know what 'potable water' means.

The statement about de facto water re-use got a large number of "Not sure'' responses (35,19%). South Africans seem to be unsure if there might be re-treated wastewater in their drinking water.

The survey indicated that South Africans would support water re-use in a severe drought situation, including direct potable re-use. 48,5% of the population mentioned direct potable re-use as an action that they will support. As expected, the support for direct potable re-use was lower than the support for industrial and greywater re-use, but the difference was less than 10%.

One can therefore look forward to a positive outcome of improved public knowledge.

9.2 APPLICATION OF THE KNOWLEDGE GENERATED IN THIS STUDY

The knowledge generated in this project can lead to improved public understanding of the country's available water supplies, and the full costs and benefits associated with water reuse as water supply alternatives. This in turn could lead to more efficient processes for specific projects. The further understanding of de facto reuse can also result in the development and application of contaminant prediction tools on a national scale, which can in future lead to online monitoring systems that will strive towards improved public health protection.

Overall, the information and knowledge gained in this project will ensure remains on the scientific forefront in the field of water reclamation and reuse.

9.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This project is considered a first attempt to estimate the extent of de facto reuse in South Africa. However, a number of recommendations can be made on the gaps and challenges regarding future regulation of de facto reuse in South Africa.

To obtain a more thorough evaluation of the extent and potential od de facto reuse in the country, became apparent that there is a need to model wastewater content in South African rivers, taking all types of discharge into account (and very specifically from unsewered informal settlements) as well as withdrawals from the rivers. This model should also consider mass loadings in determining the impact of wastewater discharge on rivers and drinking water supply, as concentration may not accurately assess impact of individual polluters (such as WWTPs) on surface water quality impairments. Therefore, assessing the pollutant load would be a more accurate approach to evaluating contributions of individual wastewater polluters. Updating the model to incorporate persistent and biodegradable chemicals will not only facilitate its ability to estimate the presence of CECs prior to drinking water treatment but will also provide insight into the fate and behaviour of CECs in natural environments.

Additional future research should include water quality sampling that can capture the special and temporal variations in water quality. Future research may need to be directed at focussing on one case study to collect data to account for all point sources as well as non-point sources and capture all special and temporal variations resulting from these wastewater discharges.

There is also a need to adopt the methodology developed in this study as part of the national water resource monitoring programs, such as the Integrated Waster Quality Management Strategy (IWQMS), to better understand the level and impact of wastewater on surface water resources. It is also clear that CECs should be incorporated in the Department of Water and Sanitation's water quality databases and data dissemination platforms. Not only will this address various environmental and health challenges, but it will also assist in the evaluation of water and wastewater treatment operations and management.

Further development of the GIS mapping system will assist in performing a national assessment of de facto reuse and provide information to support the development of national water quality monitoring programs and regulations on effluent and drinking water quality.

CHAPTER 10: REFERENCES

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APPENDICES

Appendix A is the interactive GIS mapping system developed in this study and is included as a separate .kmz file.

Appendices B to K provides the results of the first five rivers studied to date. The results are presented under the following headings in each of the appendices:

1. Flow-based data and calculations
2. De facto wastewater percentage maps for the different time periods
3. Map of sampling points for CEC analysis
4. Results of the CEC analysis
5. CEC concentration results legend
6. Bar charts of indicator compound results
7. Results of other water quality parameters

APPENDIX B RESULTS FOR THE BERG RIVER

B1: Flow-based data and calculations for the Berg River

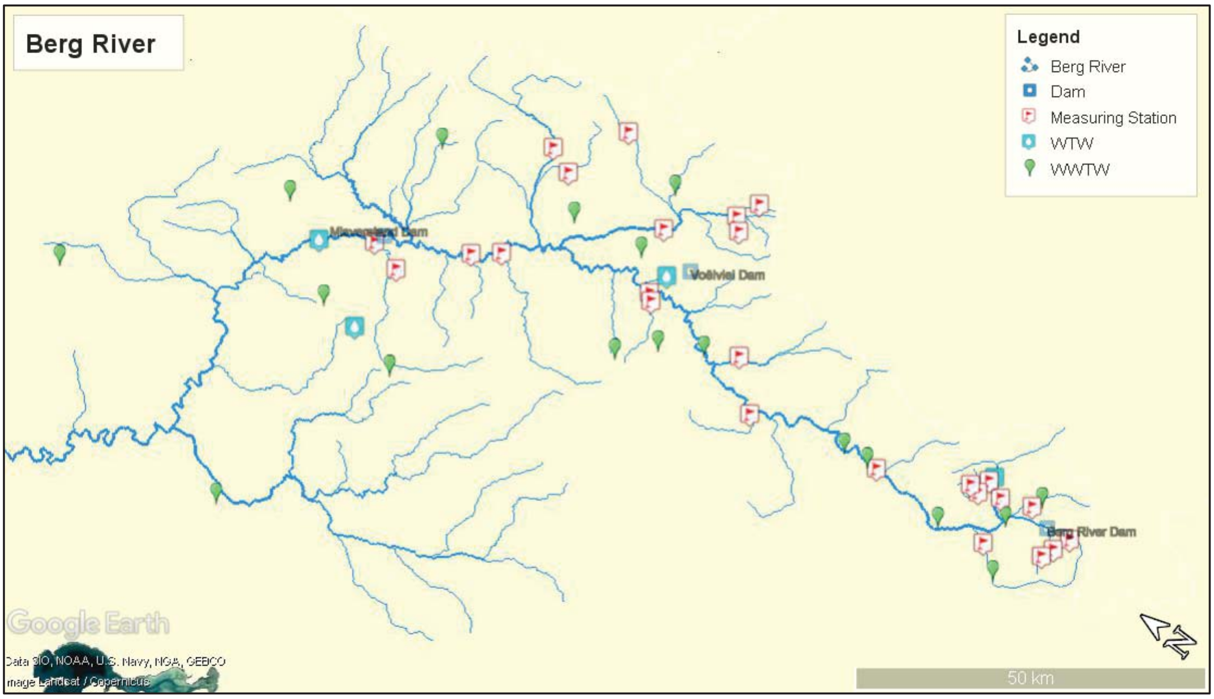


Figure B1.1 Berg River System, indicating all measuring stations, WWTP and WTP in this river

Table B1.1: Summary of wastewater percentages in the Berg River from 2015-2019

Berg River									
Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
G1H078 Dwars River	8%	3%	5%	8%	3%	4%	11%	4%	5%
G1H020: Berg@Daljosafat	2%	1%	1%	2%	1%	1%	6%	2%	2%
G1H079: Berg@Zonquasdrift	31%	14%	16%	28%	11%	11%	73%	27%	33%
G1H013 Berg @ Drieheuvels	21%	10%	13%	20%	7%	10%	44%	23%	25%
G1H031 Berg @ Misverstand	69%	18%	36%	42%	6%	11%	92%	53%	64%
Withoogte WTW	69%	18%	36%	42%	6%	11%	92%	53%	64%
Piketberg WTW	69%	18%	36%	42%	6%	11%	92%	53%	64%
Measuring station/ Water Treatment Works	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
G1H078 Dwars River	5%	2%	3%	27%	18%	20%	9%	3%	5%
G1H020: Berg@Daljosafat	3%	1%	2%	4%	2%	2%	3%	1%	1%
G1H079: Berg@Zonquasdrift	32%	11%	12%	97%	46%	47%	40%	16%	17%
G1H013 Berg @ Drieheuvels	25%	7%	11%	53%	27%	29%	28%	11%	15%
G1H031 Berg @ Misverstand	50%	4%	9%	93%	79%	83%	63%	10%	19%
Withoogte WTW	50%	4%	9%	93%	79%	83%	63%	10%	19%
Piketberg WTW	50%	4%	9%	93%	79%	83%	63%	10%	19%

Table B1.2: Wastewater percentage calculations for the Berg River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Berg River																
	2015															
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.1862	0.4684	0.3187	0.02							0.0156	8%	3%	5%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	2.6634	5.3257	4.2276	0.02	0.0098	0.0231					0.0486	2%	1%	1%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	1.4256	3.9966	3.2969	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	31%	14%	16%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	2.4618	5.8122	4.4205	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	21%	10%	13%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.3062	3.0166	1.2162	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	69%	18%	36%
Withoogte WTW	-33.068256°	18.668064°	0.3062	3.0166	1.2162	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	69%	18%	36%
Piketberg WTW	-32.965256°	18.741069°	0.3062	3.0166	1.2162	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	69%	18%	36%

(b)

Berg River																
	2016															
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.1848	0.5691	0.3913	0.02							0.0156	8%	3%	4%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	2.5649	5.3121	4.6991	0.02	0.0098	0.0231					0.0486	2%	1%	1%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	1.6717	4.9205	5.2732	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	28%	11%	11%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	2.6063	9.1729	6.2465	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	20%	7%	10%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.9461	10.0903	5.4093	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	42%	6%	11%
Withoogte WTW	-33.068256°	18.668064°	0.9461	10.0903	5.4093	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	42%	6%	11%
Piketberg WTW	-32.965256°	18.741069°	0.9461	10.0903	5.4093	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	42%	6%	11%

(c)

Berg River																
Measuring station/ Water Treatment Works	Coordinates		2017													
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.1228	0.3416	0.2717	0.02							0.0156	11%	4%	5%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	0.7922	2.3223	2.0131	0.02	0.0098	0.0231					0.0486	6%	2%	2%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	0.2333	1.7434	1.3005	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	73%	27%	33%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	0.8666	2.2707	2.0516	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	44%	23%	25%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.0598	0.6023	0.3774	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	92%	53%	64%
Withoogte WTW	-33.068256°	18.668064°	0.0598	0.6023	0.3774	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	92%	53%	64%
Piketberg WTW	-32.965256°	18.741069°	0.0598	0.6023	0.3774	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	92%	53%	64%

(d)

Berg River																
Measuring station/ Water Treatment Works	Coordinates		2018													
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.2981	0.7907	0.5721	0.02							0.0156	5%	2%	3%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	1.3635	4.2190	3.0225	0.02	0.0098	0.0231					0.0486	3%	1%	2%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	1.3810	5.2725	4.8356	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	32%	11%	12%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	2.0028	8.9657	5.2158	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	25%	7%	11%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.6756	15.6225	6.9689	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	50%	4%	9%
Withoogte WTW	-33.068256°	18.668064°	0.6756	15.6225	6.9689	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	50%	4%	9%
Piketberg WTW	-32.965256°	18.741069°	0.6756	15.6225	6.9689	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	50%	4%	9%

(e)

Berg River

Measuring station/ Water Treatment Works	Coordinates		2019											% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow			
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.0433	0.0715	0.0632	0.02							0.0156	27%	18%	20%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	1.2883	2.2889	2.2458	0.02	0.0098	0.0231					0.0486	4%	2%	2%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	0.0210	0.7423	0.7234	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	97%	46%	47%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	0.5908	1.7811	1.6499	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	53%	27%	29%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.0543	0.1824	0.1371	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	93%	79%	83%
Withoogte WTW	-33.068256°	18.668064°	0.0543	0.1824	0.1371	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	93%	79%	83%
Piketberg WTW	-32.965256°	18.741069°	0.0543	0.1824	0.1371	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	93%	79%	83%

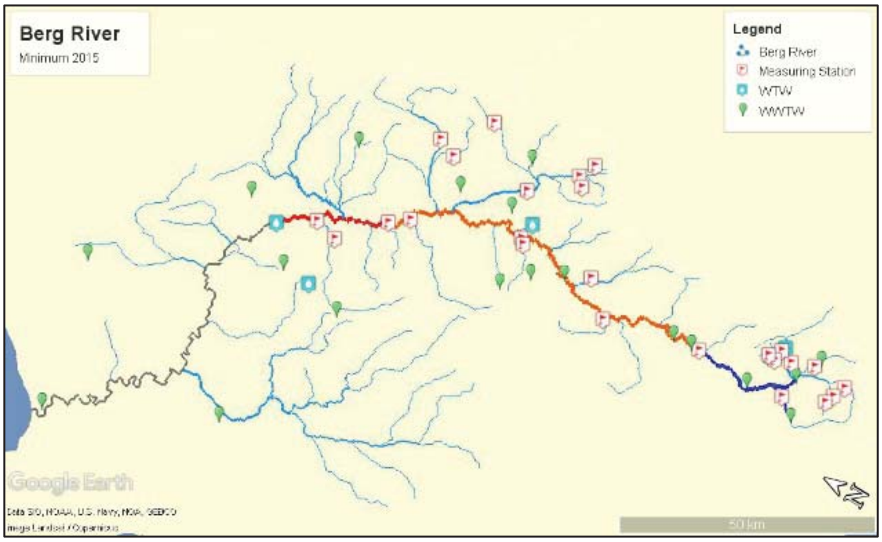
(f)

Berg River

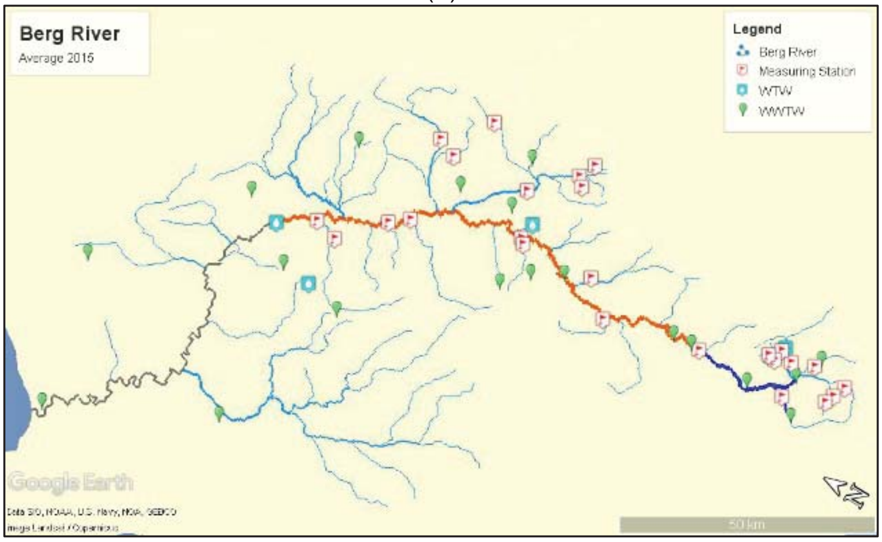
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019											% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow			
	Latitude	Longitude	Min	Average	Median	Pniel	Wemmershoek	Pearl Valley	Paarl	Wellington	Tulbagh	Porterville		Min	Average	Median
G1H078 Dwars River	-33.873595°	18.982287°	0.1670	0.4480	0.3230	0.02							0.0156	9%	3%	5%
G1H020: Berg@Daljosafat	-33.707554°	18.974283°	1.7340	3.8940	3.2420	0.02	0.0098	0.0231					0.0486	3%	1%	1%
G1H079: Berg@Zonquasdrift	-33.341924°	18.979018°	0.9470	3.3350	3.0860	0.02	0.0098	0.0231	0.4051	0.1852			0.6389	40%	16%	17%
G1H013 Berg @ Drieheuvels	-33.130897°	18.862822°	1.7060	5.6010	3.9170	0.02	0.0098	0.0231	0.4051	0.1852	0.0285		0.6674	28%	11%	15%
G1H031 Berg @ Misverstand	-33.023736°	18.788733°	0.4080	5.9030	2.8220	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	63%	10%	19%
Withoogte WTW	-33.068256°	18.668064°	0.4080	5.9030	2.8220	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	63%	10%	19%
Piketberg WTW	-32.965256°	18.741069°	0.4080	5.9030	2.8220	0.02	0.0098	0.0231	0.4051	0.1852	0.0285	0.01389	0.6813	63%	10%	19%

B2: De facto wastewater percentage maps for the different time periods in the Berg River

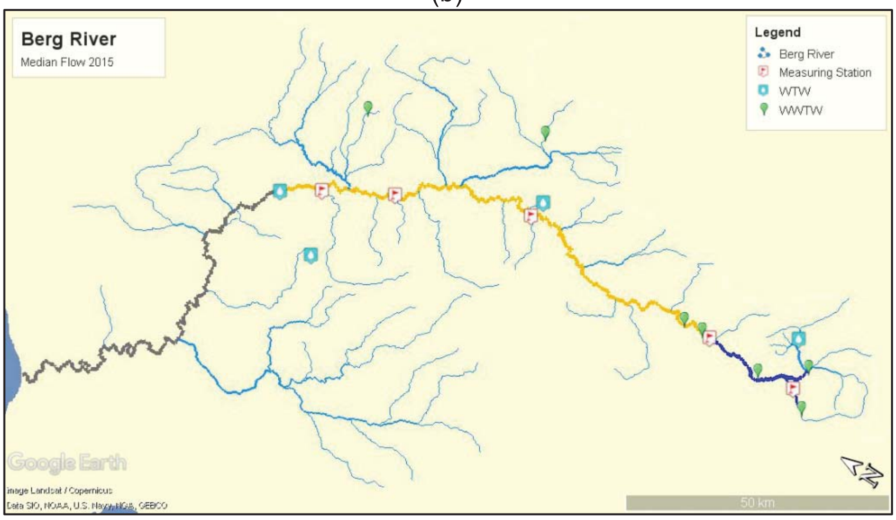
- **Wastewater Contributions in 2015**



(a)



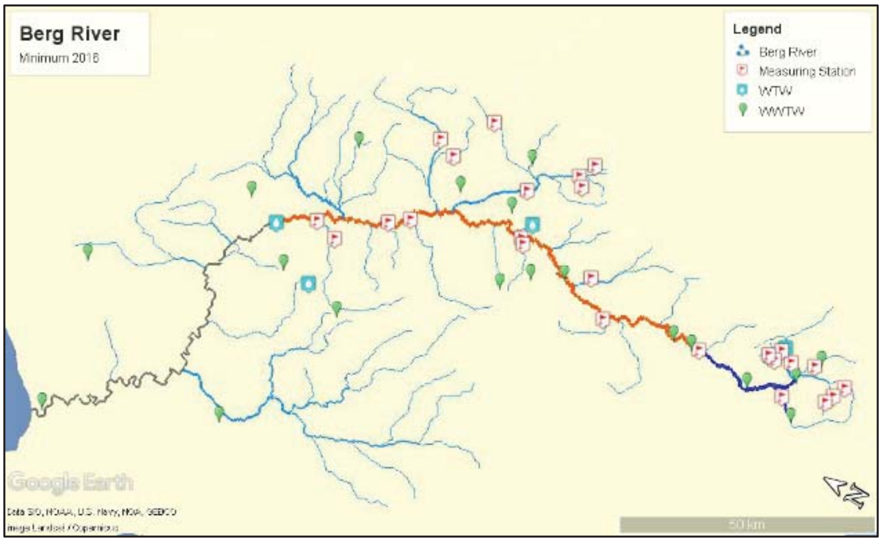
(b)



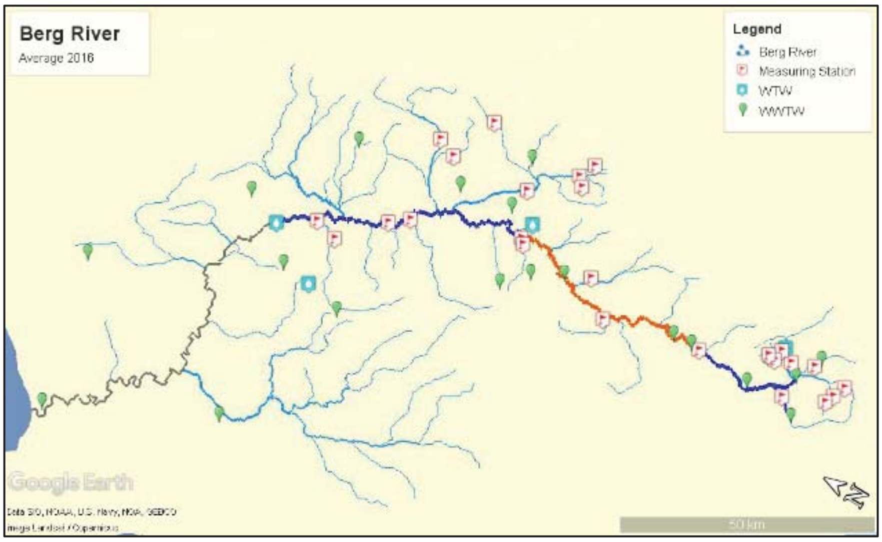
(c)

Figure B2.1: Wastewater contribution in the Berg River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

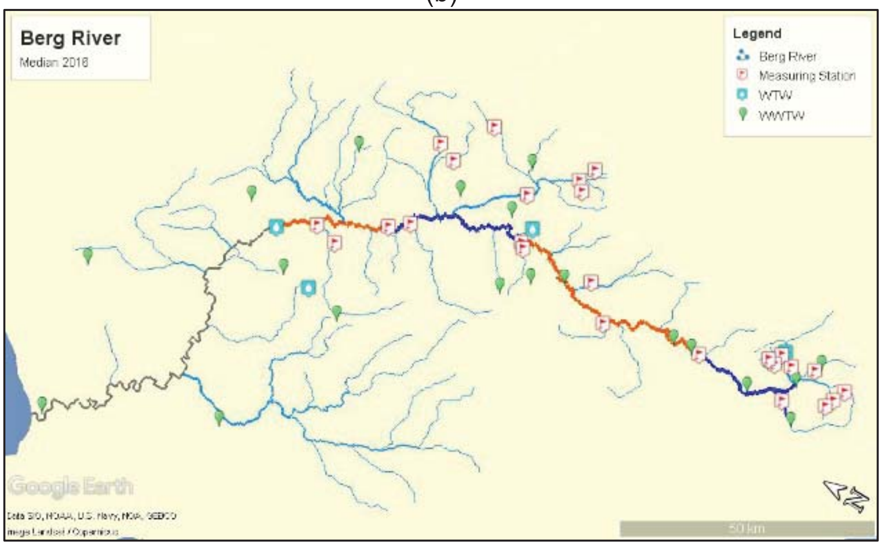
- **Wastewater Contributions in 2016**



(a)



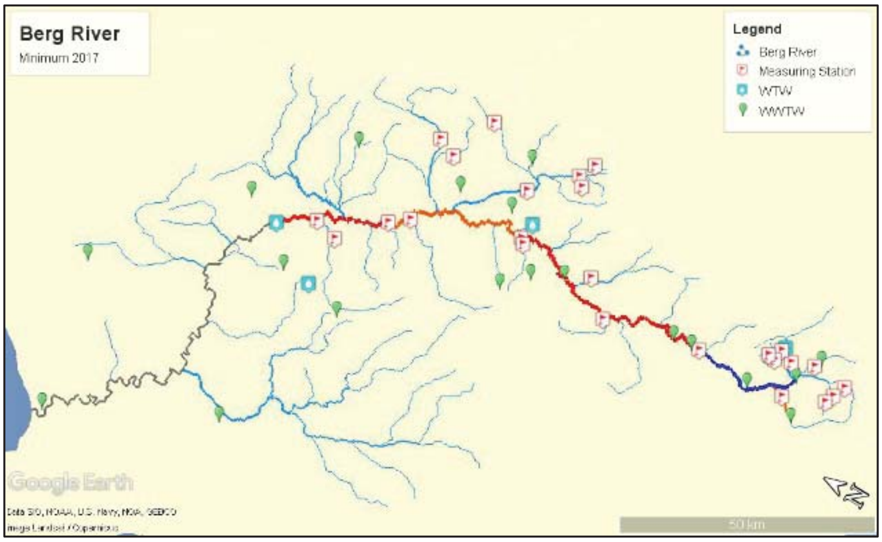
(b)



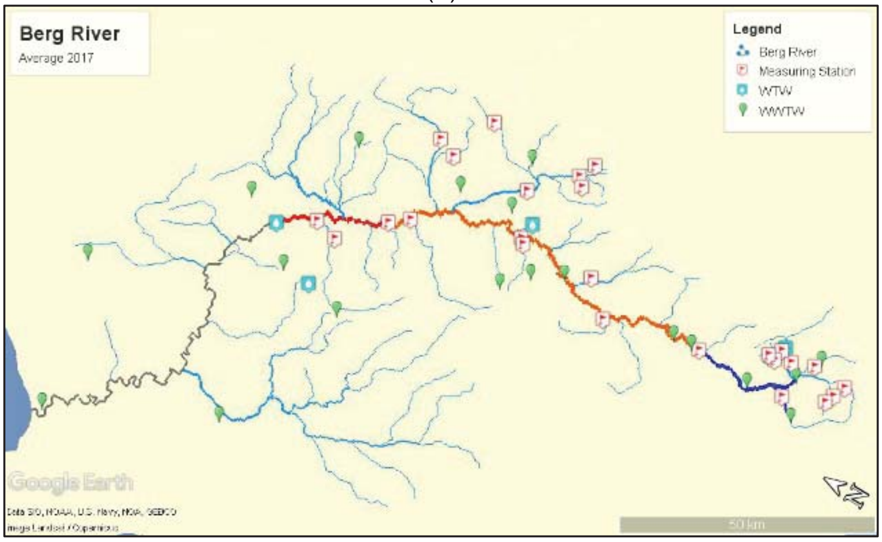
(c)

Figure B2.2: Wastewater contribution in the Berg River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

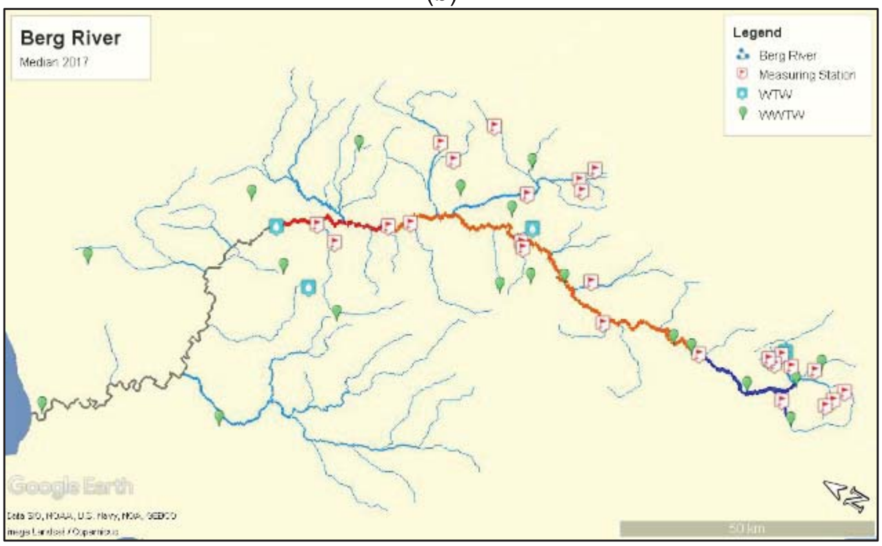
- **Wastewater Contributions in 2017**



(a)



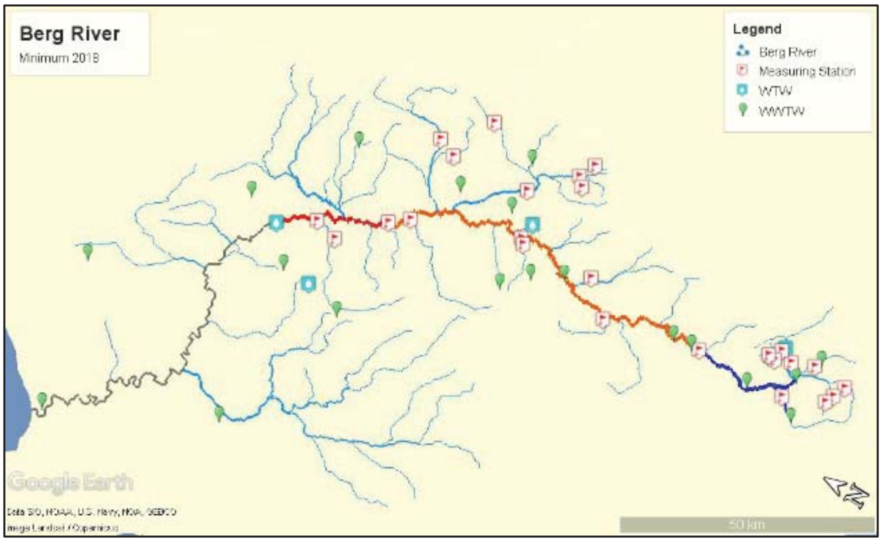
(b)



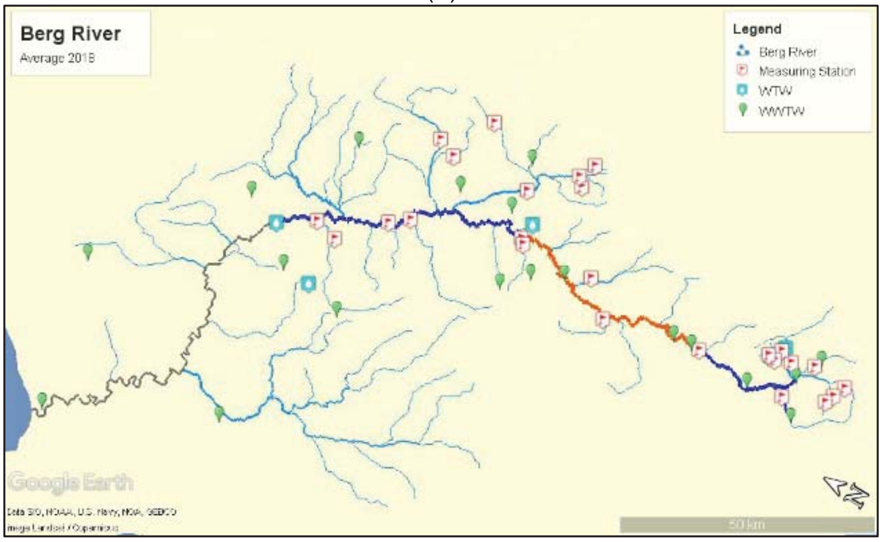
(c)

Figure B2.3: Wastewater contribution in the Berg River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

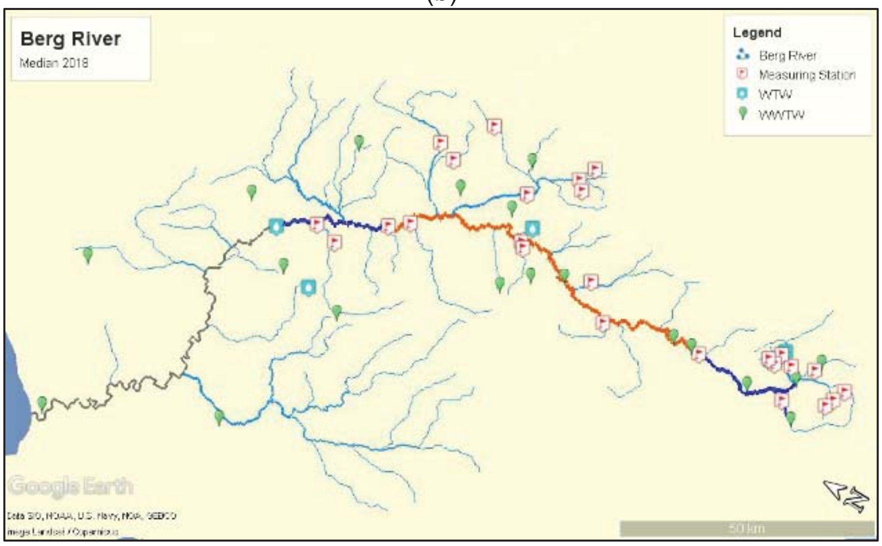
- **<u>Wastewater Contributions in 2018</u>**



(a)



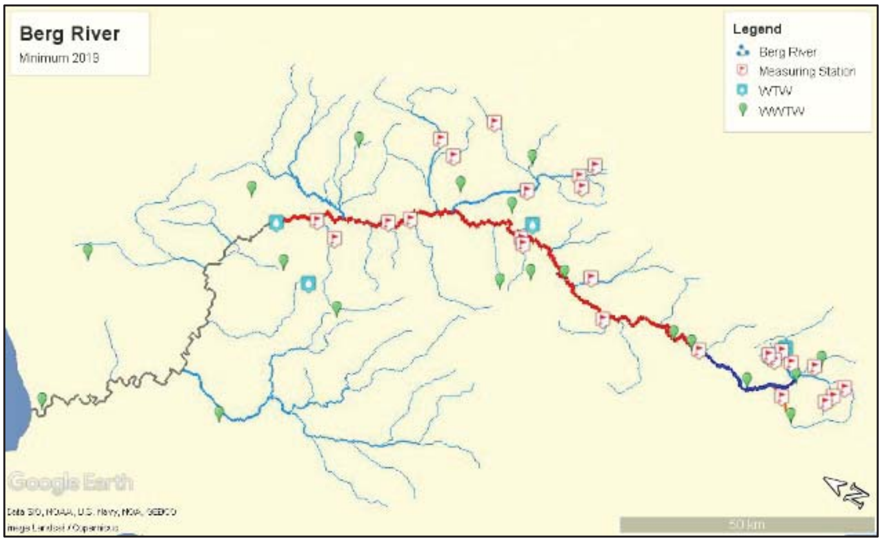
(b)



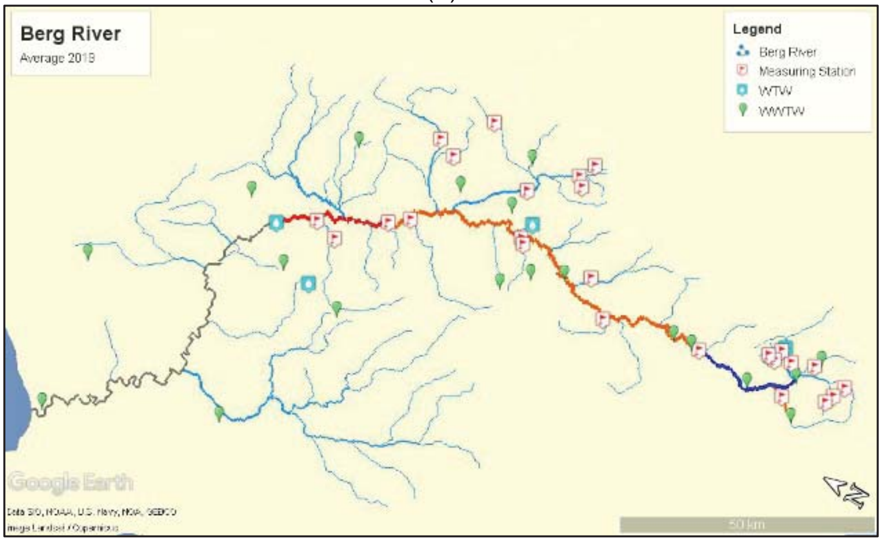
(c)

Figure B2.4: Wastewater contribution in the Berg River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

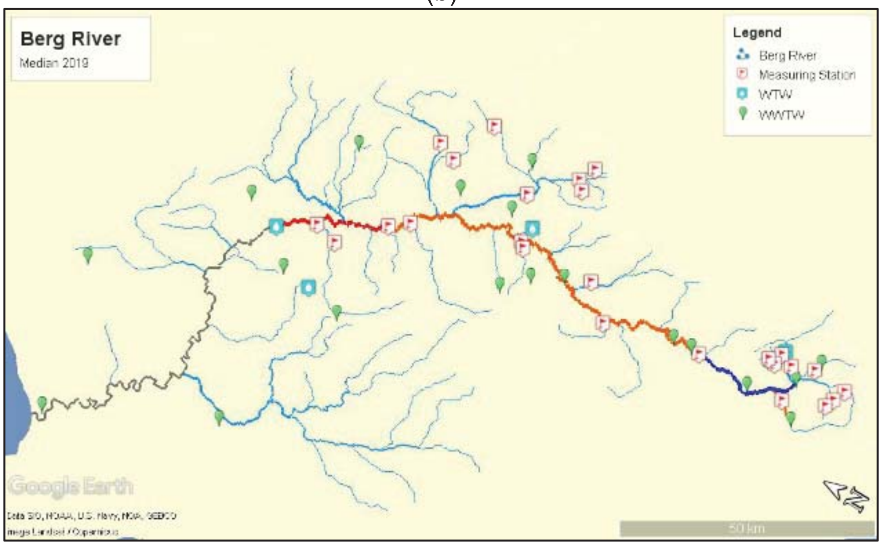
- **Wastewater Contributions in 2019**



(a)



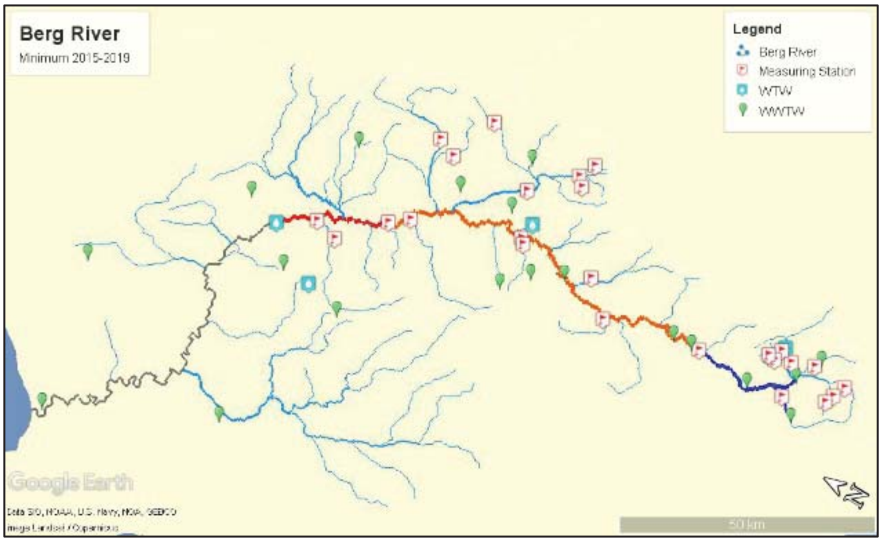
(b)



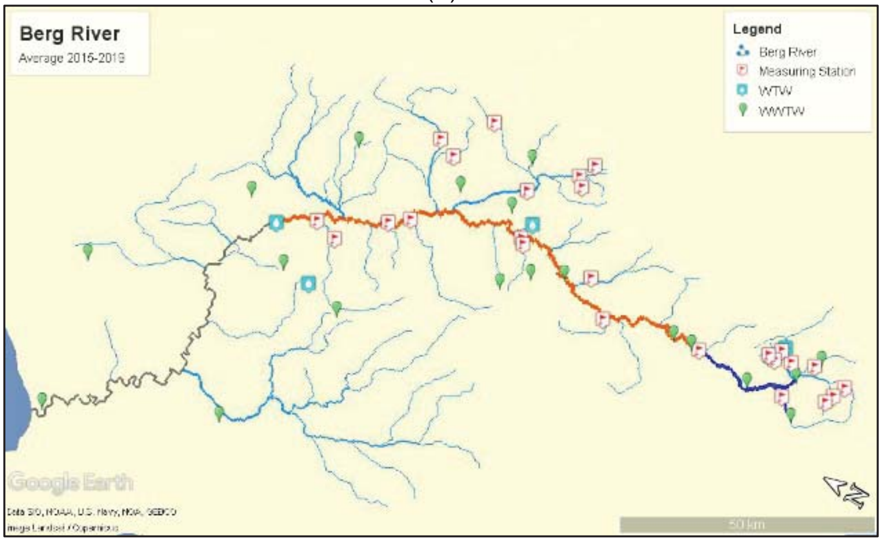
(c)

Figure B2.5: Wastewater contribution in the Berg River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

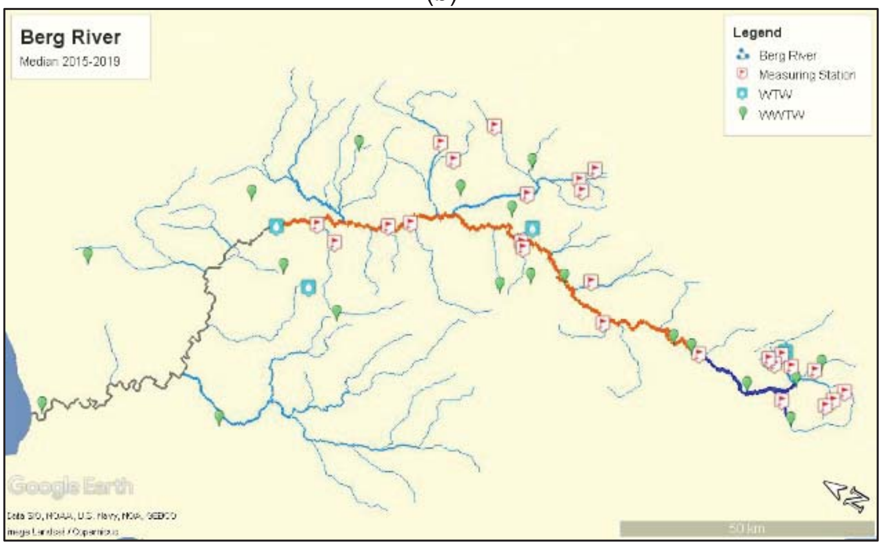
- **Wastewater Contributions in 2015-2019**



(a)



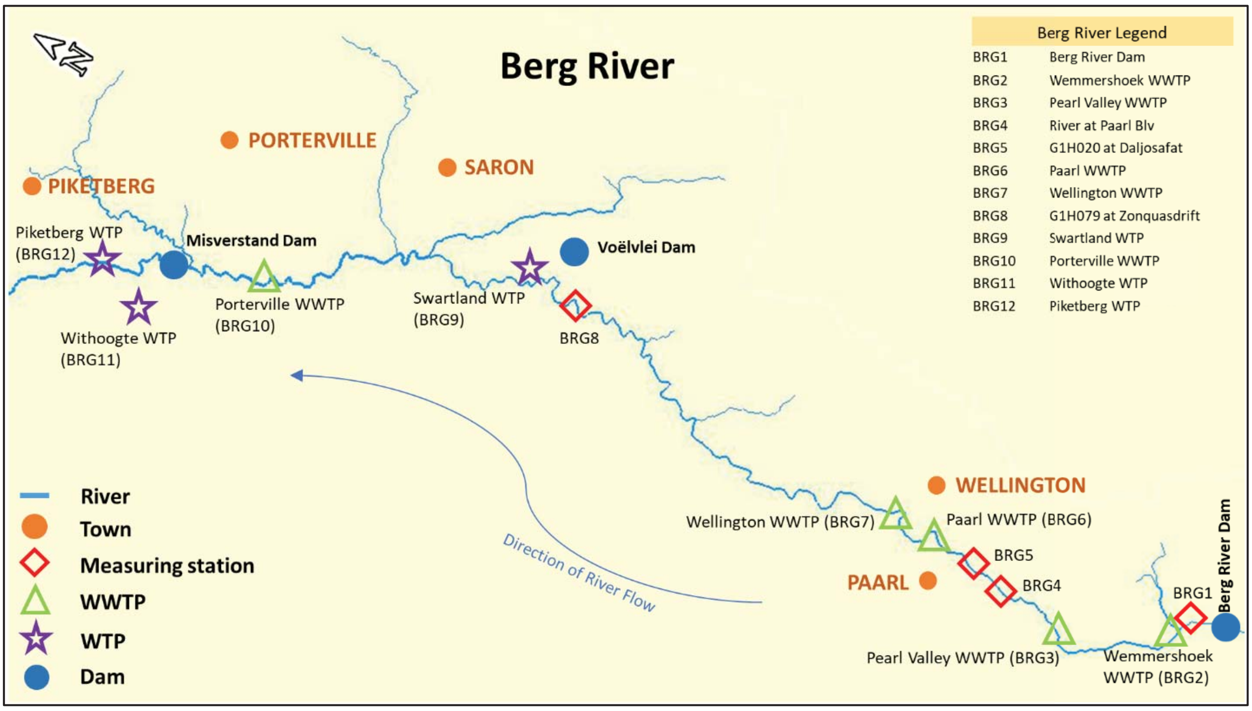
(b)



(c)

Figure B2.6: Wastewater contribution in the Berg River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

B3: Map of sampling points for CEC analysis in the Berg River



B4: Results of the CEC analysis for the Berg River

Table B4.1: Results of the CEC analysis for the Berg River

Constituent	Sample Points											
	Berg River Dam	Wemmershoek WWTW	Pearl Valley WWTW	River at Paarl Blv	G1H020 at Daljosafat	Paarl WWTW	Wellington WWTW	G1H079 at Zonquasdrift	Swartland WTW	Porterville WWTW	Withoogte WTW	Piketberg WTW
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
10,11-dihydro-11-hydroxycarbamazepine	<IQL	<IQL	29.49	<IQL	<IQL	137.5	40.22	<IQL	<IQL	21.9	<IQL	<IQL
Acetaminophen	51.13	2033	<IQL	97.42	208.4	<IQL	1560	16.96	<IQL	<IQL	<IQL	<IQL
Benzotriazole	<IQL	154.5	228.1	9.711	<IQL	1182	79.04	117.1	<IQL	48.65	19.87	19.15
Benzoylecgonine	<IQL	601.7	7.373	3.467	3.03	48.71	23.06	<IQL	<IQL	<IQL	<IQL	<IQL
Caffeine	110.9	46577	71.23	99.05	122.6	273.8	2175	60.44	48.49	40.95	19.15	<IQL
Carbamazepine	3.28	1749	167.9	36.47	52.3	2126	663.7	171.7	2.702	1691	20.3	19.99
Carbamazepine-10,11-epoxide	<IQL	41.74	80.66	<IQL	<IQL	111.9	53.35	9.878	<IQL	186.3	<IQL	<IQL
Cocaine	<IQL	57.14	<IQL	<IQL	2.717	6.074	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Codeine	<IQL	1995	<IQL	<IQL	<IQL	64.09	50.94	<IQL	<IQL	10.2	<IQL	<IQL
Diclofenac	<IQL	<IQL	<IQL	<IQL	<IQL	462.7	58.35	<IQL	<IQL	185.8	<IQL	2.211
Efavirenz	12.4	9375	1818	96.69	<IQL	10504	507	274.6	<IQL	5303	<IQL	60.73
Emtricitabine	79.45	41222	<IQL	14.06	17.29	285.8	422.5	19.28	<IQL	1077	<IQL	5.328
MDMA	<IQL	4.203	7.223	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Methamphetamine	<IQL	2585	<IQL	<IQL	8.112	56.25	231.6	<IQL	<IQL	41.47	<IQL	<IQL
Methaqualone	5.378	1786	34.43	24.3	40.18	129.8	150.5	46.39	3.824	88.94	12.83	14.16
Naproxen	<IQL	961.8	12.05	<IQL	<IQL	91.43	79.49	<IQL	<IQL	103.6	<IQL	<IQL
Sulfamethoxazole	23.48	6439	19.83	46.18	<IQL	625.7	689.4	59.4	28.68	1181	14.41	24.47

* <IQL = Less than Instrument Quantification Limits

B5: CEC Concentration Results Legend for the Berg River

Berg River Legend	
BRG1	Berg River Dam
BRG2	Wemmershoek WWTP
BRG3	Pearl Valley WWTP
BRG4	River at Paarl Blv
BRG5	G1H020 at Daljosafat
BRG6	Paarl WWTP
BRG7	Wellington WWTP
BRG8	G1H079 at Zonquasdrift
BRG9	Swartland WTP
BRG10	Porterville WWTP
BRG11	Withoogte WTP
BRG12	Piketberg WTP

B6: Bar charts of indicator compound results in the Berg River

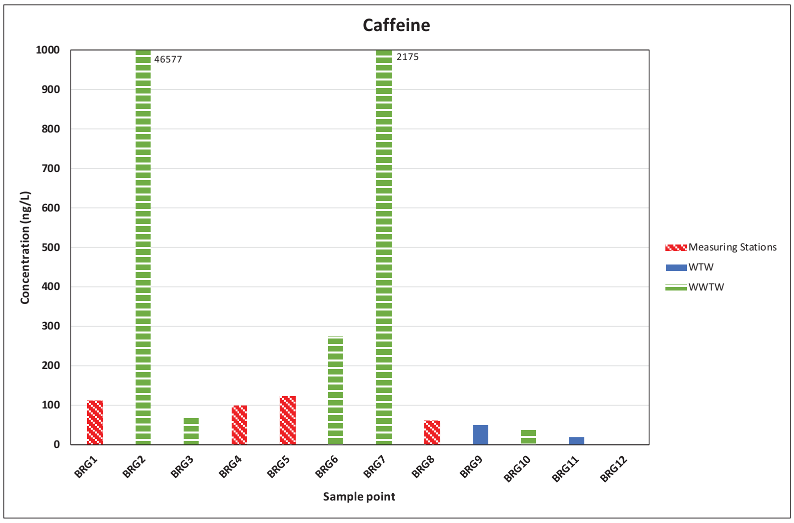


Figure B6.1: Concentrations of Caffeine in the Berg River

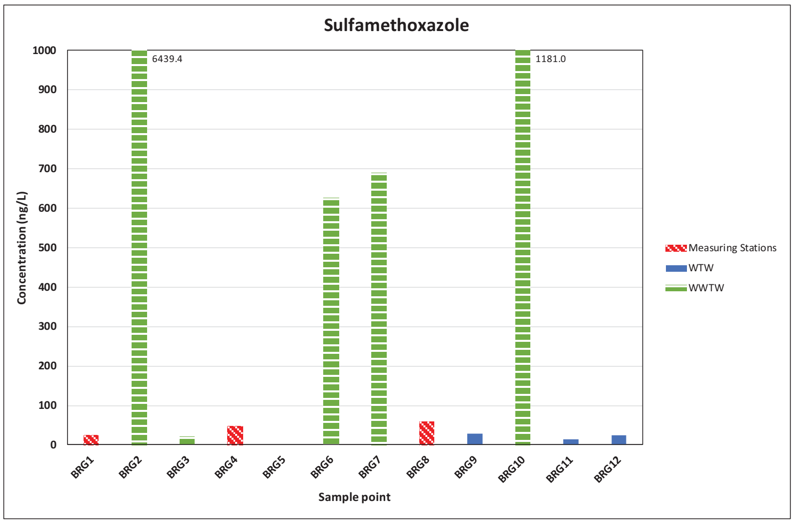


Figure B6.2: Concentrations of Sulfamethoxazole in the Berg River

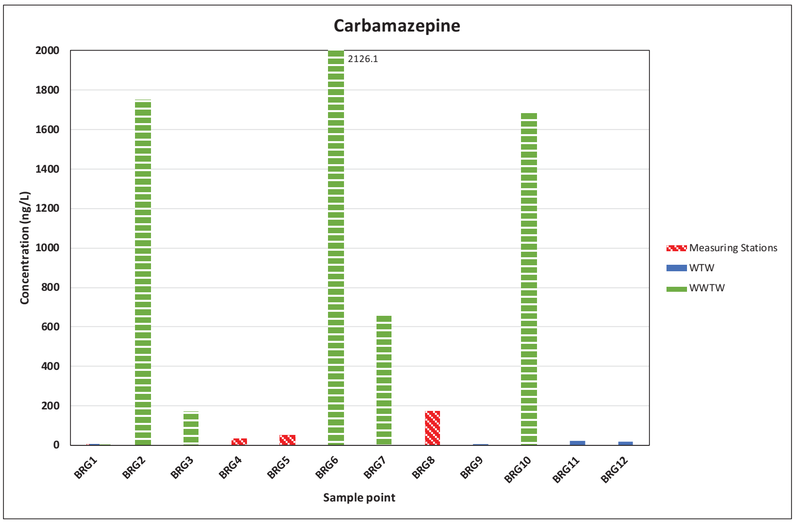


Figure B6.3: Concentrations of Carbamazepine in the Berg River

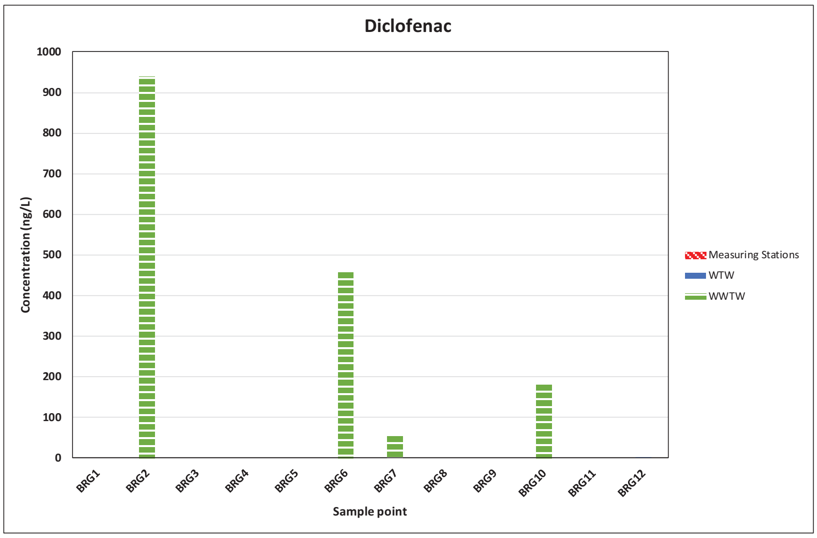


Figure B6.4: Concentrations of Diclofenac in the Berg River

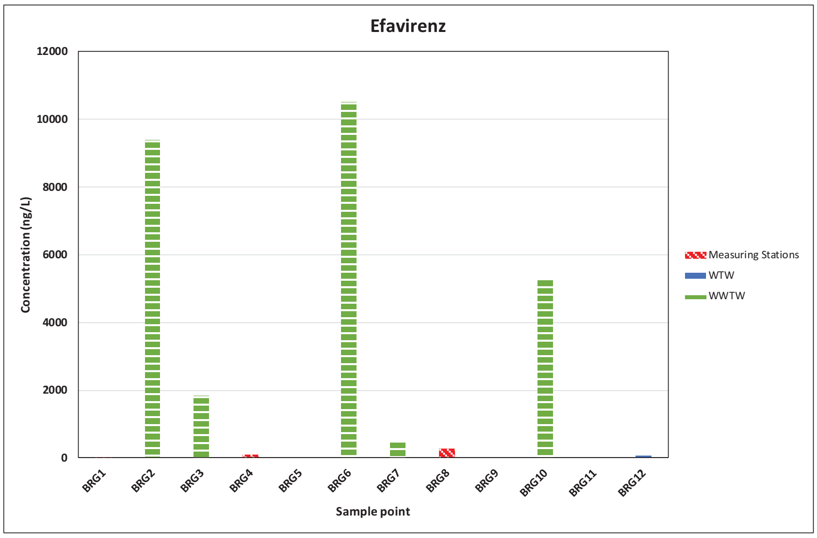


Figure B6.5: Concentrations of Efavirenz in the Berg River

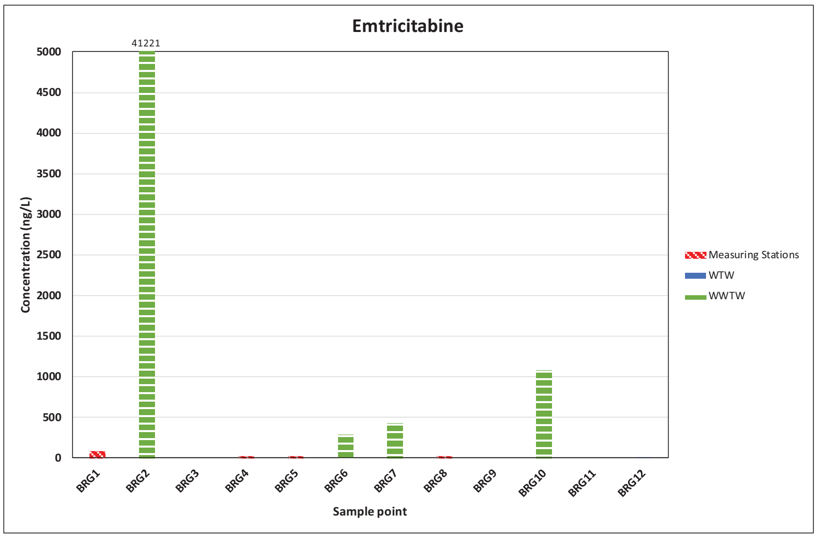


Figure B6.6: Concentrations of Emtricitabine in the Berg River

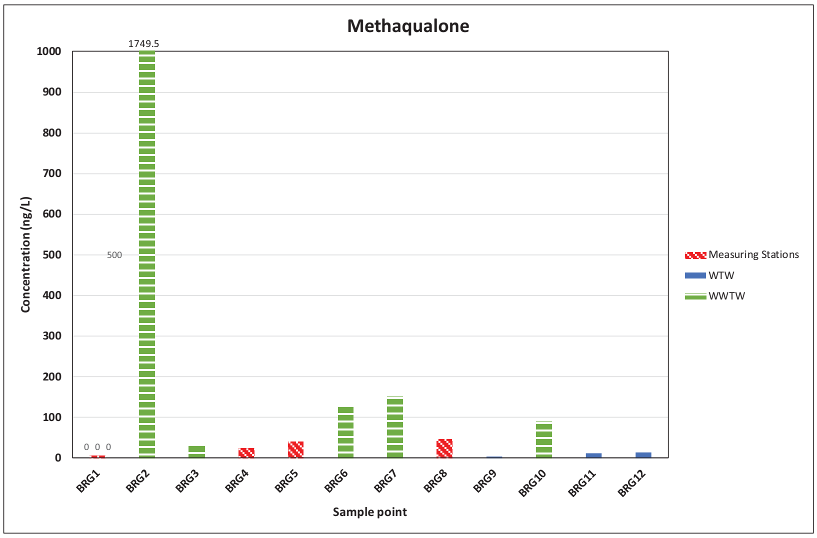


Figure B6.7: Concentrations of Methaqualone in the Berg River

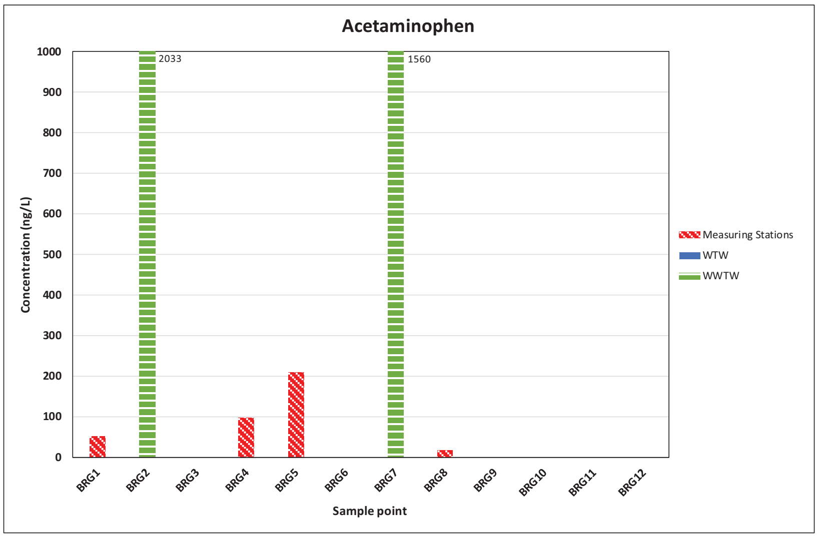


Figure B6.8: Concentrations of Acetaminophen in the Berg River

B7: Results of Other Water Quality Parameters in the Berg River

Sample Points	pH	EC	COD	UV 254	DOC
	-	mS/m	mg/L	m^{-1}	mg/L
Berg@Berg River Dam	9.33	4.29	59	0.06	2.39
Wemmershoek WWTP	7.57	89.89	244	0.52	8.89
Pearl Valley WWTP	7.85	87.63	33	0.14	3.54
Berg River Blv at Paarl	8.80	5.37	95	0.07	2.53
G1H020: Berg @ Daljosafat	8.52	5.45	80	0.07	2.47
Paarl WWTP	7.76	70.93	314	0.29	5.55
Wellington WWTP	7.74	111.6	312	0.42	7.48
G1H079: Berg @Zonquasdrift	8.00	22.77	1494	0.11	3.03
Swartland WTP	7.92	9.74	92	0.09	2.79
Porterville WWTP	7.62	80.30	184	0.28	5.50
Withoogte WTP	7.75	23.05	124	0.12	3.16
Piketberg WTP	7.69	27.53	154	0.10	2.94

APPENDIX C RESULTS FOR THE BREEDE RIVER

C1: Flow-based data and calculations for the Breede River

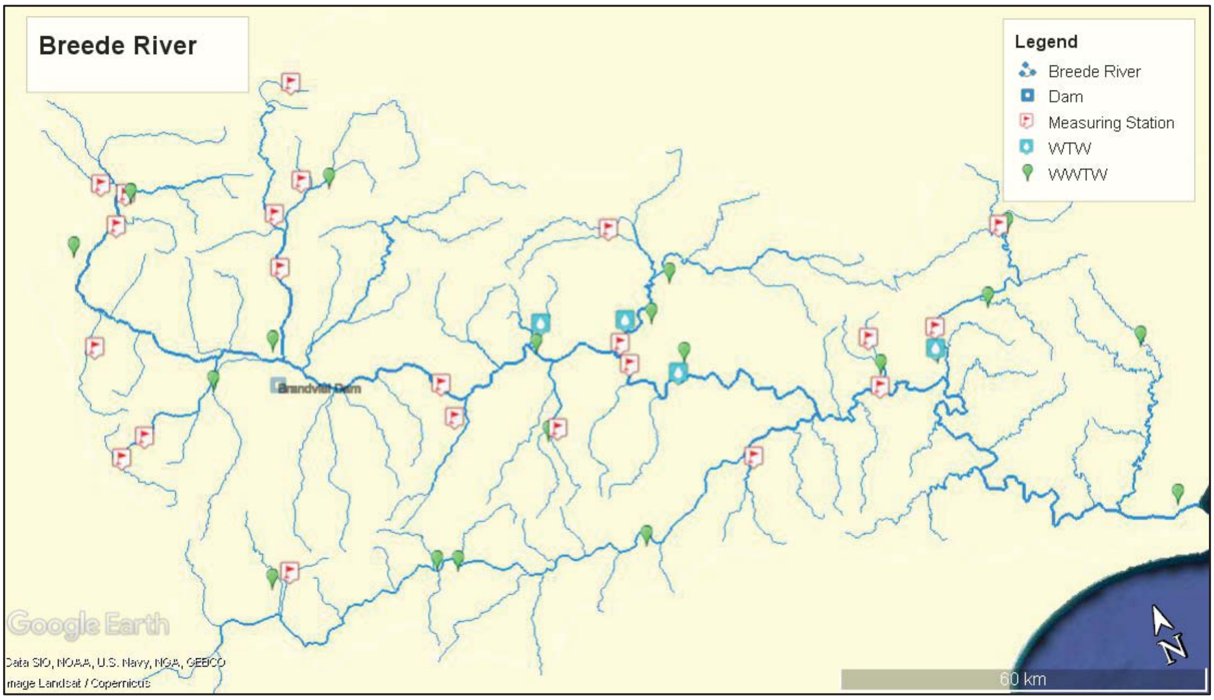


Figure C1.1: Breede River System, indicating all measuring stations, WWTP and WTP in this river.

Table C1.1: Summary of Wastewater Percentages in the Breede River from 2015-2019

Breede River

Measuring station/ Water Treatment Works	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	21%	10%	14%	15%	5%	9%	31%	16%	20%
H1H006 Bree @ Witbrug	11%	3%	5%	6%	1%	2%	12%	5%	6%
H2H006 Hex @ Glen Heatlie	5%	3%	3%	6%	3%	4%	9%	7%	7%
H4H017 Bree @ Le Chasseur	12%	4%	6%	9%	3%	5%	13%	7%	9%
Robertson WTW	13%	5%	7%	10%	3%	5%	14%	8%	9%
Ashton WTW	13%	7%	8%	22%	17%	18%	35%	28%	28%
H3H011 Kogmanskloof @ Gold	13%	7%	8%	22%	17%	18%	35%	28%	28%
H5H004 Bree @ Wolvendrift	26%	6%	11%	28%	5%	8%	64%	20%	33%
Bonnievale WTW	29%	7%	12%	30%	6%	9%	66%	22%	36%
H6H009 Reenen	1%	0%	1%	2%	1%	1%	13%	2%	2%
H7H006 Bree @ Swellendam	17%	4%	7%	18%	5%	7%	65%	20%	27%
H7H007 Grootkloof @ Sparken	3%	1%	2%	4%	1%	2%	4%	1%	2%
Buffeljagsrivier WTW	10%	2%	6%	13%	3%	6%	15%	4%	7%

leasuring station/ Water Treatment Wor	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	16%	5%	9%	30%	28%	28%	21%	9%	13%
H1H006 Bree @ Witbrug	5%	1%	3%	95%	17%	25%	9%	2%	4%
H2H006 Hex @ Glen Heatlie	7%	2%	3%	21%	17%	17%	7%	4%	4%
H4H017 Bree @ Le Chasseur	10%	2%	5%				11%	3%	6%
Robertson WTW	10%	2%	5%				12%	4%	6%
Ashton WTW	39%	31%	32%		N/A		23%	15%	17%
H3H011 Kogmanskloof @ Gold	39%	31%	32%				23%	15%	17%
H5H004 Bree @ Wolvendrift	27%	4%	8%				32%	6%	11%
Bonnievale WTW	30%	4%	9%				34%	7%	12%
H6H009 Reenen	8%	2%	3%	4%	0%	1%	3%	1%	1%
H7H006 Bree @ Swellendam	25%	5%	9%	79%	10%	21%	27%	6%	10%
H7H007 Grootkloof @ Sparken	5%	1%	3%	5%	1%	2%	4%	1%	2%
Buffeljagsrivier WTW	17%	4%	10%	16%	4%	8%	14%	3%	7%

Table C1.2: Wastewater percentage calculations for the Breede River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Breede River — 2015

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.3737	0.8670	0.5931	0.0984															0.0984	21%	10%	14%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	0.8223	3.3024	1.7691	0.0984															0.0984	11%	3%	5%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.5608	0.9668	0.8736					0.0278											0.0278	5%	3%	3%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	3.6951	10.9790	7.3739	0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	12%	4%	6%
Robertson WTW	-33.793328°	19.895817°	3.6951	10.9790	7.3739	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433	13%	5%	7%
Ashton WTW	-33.836108°	20.034861°	0.5732	1.1164	0.9407							0.0463	0.0405								0.0868	13%	7%	8%
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°	0.5732	1.1164	0.9407							0.0463	0.0405								0.0868	13%	7%	8%
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°	1.7801	9.8564	5.0500	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301	26%	6%	11%
Bonnievale WTW	-33.936544°	20.085933°	1.7801	9.8564	5.0500	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096	29%	7%	12%
H6H009 Reenen	-34.091340°	20.151670°	1.7324	6.7424	3.6402										0.0035	0.0081	0.0081				0.0197	1%	0%	1%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	3.4590	17.6072	9.3408	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	17%	4%	7%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.1068	0.4621	0.1883															0.0030	0.0030	3%	1%	2%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.1068	0.4621	0.1883														0.0087	0.0030	0.0117	10%	2%	6%

(b)

Breede River — 2016

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.5370	1.7154	1.0105	0.0984															0.0984	15%	5%	9%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	1.4705	8.4867	4.5898	0.0984															0.0984	6%	1%	2%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.4450	0.7820	0.7446					0.0278											0.0278	6%	3%	4%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	4.9458	16.5096	10.2915	0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	9%	3%	5%
Robertson WTW	-33.793328°	19.895817°	4.9458	16.5096	10.2915	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433	10%	3%	5%
Ashton WTW	-33.836108°	20.034861°	0.3118	0.4111	0.3965							0.0463	0.0405								0.0868	22%	17%	18%
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°	0.3118	0.4111	0.3965							0.0463	0.0405								0.0868	22%	17%	18%
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°	1.6243	11.6197	6.8651	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301	28%	5%	8%
Bonnievale WTW	-33.936544°	20.085933°	1.6243	11.6197	6.8651	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096	30%	6%	9%
H6H009 Reenen	-34.091340°	20.151670°	0.9309	3.0190	2.0473										0.0035	0.0081	0.0081				0.0197	2%	1%	1%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	3.1757	14.4364	9.1621	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	18%	5%	7%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.0754	0.3637	0.1793															0.0030	0.0030	4%	1%	2%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.0754	0.3637	0.1793														0.0087	0.0030	0.0117	13%	3%	6%

(c)

Breede River																								
Measuring station/ Water Treatment Works	Coordinates		2017																					
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.2221	0.5032	0.3945	0.0984															0.0984	31%	16%	20%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	0.7030	1.9666	1.4505	0.0984															0.0984	12%	5%	6%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.2732	0.3676	0.3622					0.0278											0.0278	9%	7%	7%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	3.2392	6.5514	5.2217	0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	13%	7%	9%
Robertson WTW	-33.793328°	19.895817°	3.2392	6.5514	5.2217	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433	14%	8%	9%
Ashton WTW	-33.836108°	20.034861°	0.1628	0.2249	0.2261							0.0463	0.0405								0.0868	35%	28%	28%
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°	0.1628	0.2249	0.2261							0.0463	0.0405								0.0868	35%	28%	28%
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°	0.3589	2.5084	1.2608	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301	64%	20%	33%
Bonnievale WTW	-33.936544°	20.085933°	0.3589	2.5084	1.2608	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096	66%	22%	36%
H6H009 Reenen	-34.091340°	20.151670°	0.1329	1.1965	0.8530										0.0035	0.0081	0.0081				0.0197	13%	2%	2%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	0.3682	2.8789	1.8988	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	65%	20%	27%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.0648	0.3029	0.1443															0.0030	0.0030	4%	1%	2%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.0648	0.3029	0.1443														0.0087	0.0030	0.0117	15%	4%	7%

(d)

Breede River																								
Measuring station/ Water Treatment Works	Coordinates		2018																					
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.5061	1.9407	0.9996	0.0984															0.0984	16%	5%	9%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	1.7260	7.6593	3.6962	0.0984															0.0984	5%	1%	3%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.3817	1.3390	0.9875					0.0278											0.0278	7%	2%	3%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	4.6915	21.3436	10.3795	0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	10%	2%	5%
Robertson WTW	-33.793328°	19.895817°	4.6915	21.3436	10.3795	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433	10%	2%	5%
Ashton WTW	-33.836108°	20.034861°	0.1349	0.1970	0.1875							0.0463	0.0405								0.0868	39%	31%	32%
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°	0.1349	0.1970	0.1875							0.0463	0.0405								0.0868	39%	31%	32%
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°	1.6934	15.3167	6.9582	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301	27%	4%	8%
Bonnievale WTW	-33.936544°	20.085933°	1.6934	15.3167	6.9582	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096	30%	4%	9%
H6H009 Reenen	-34.091340°	20.151670°	0.2160	1.1131	0.7359										0.0035	0.0081	0.0081				0.0197	8%	2%	3%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	2.1347	14.6534	7.4335	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	25%	5%	9%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.0578	0.2531	0.1068															0.0030	0.0030	5%	1%	3%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.0578	0.2531	0.1068														0.0087	0.0030	0.0117	17%	4%	10%

(e)

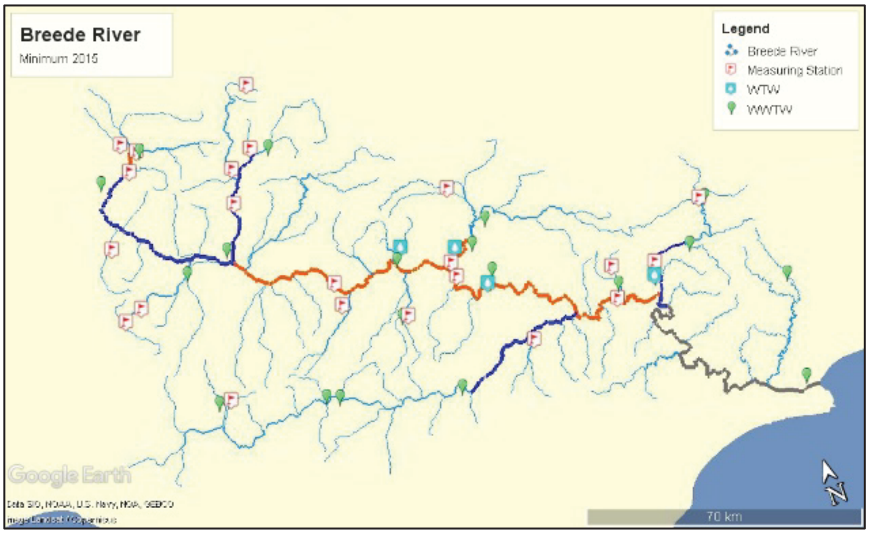
Breede River																								
Measuring station/ Water Treatment Works	Coordinates		2019																					
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.2250	0.2587	0.2540	0.0984															0.0984	30%	28%	28%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	0.0053	0.4804	0.2925	0.0984															0.0984	95%	17%	25%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.1045	0.1364	0.1339					0.0278											0.0278	21%	17%	17%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	NO DATA AVAILABLE			0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	N/A		
Robertson WTW	-33.793328°	19.895817°				0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433			
Ashton WTW	-33.836108°	20.034861°										0.0463	0.0405								0.0868			
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°										0.0463	0.0405								0.0868			
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°				0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301			
Bonnievale WTW	-33.936544°	20.085933°				0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096			
H6H009 Reenen	-34.091340°	20.151670°	0.5267	5.2583	2.0178										0.0035	0.0081	0.0081				0.0197	4%	0%	1%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	0.1893	6.3350	2.5657	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	79%	10%	21%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.0597	0.2861	0.1298															0.0030	0.0030	5%	1%	2%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.0597	0.2861	0.1298														0.0087	0.0030	0.0117	16%	4%	8%

(f)

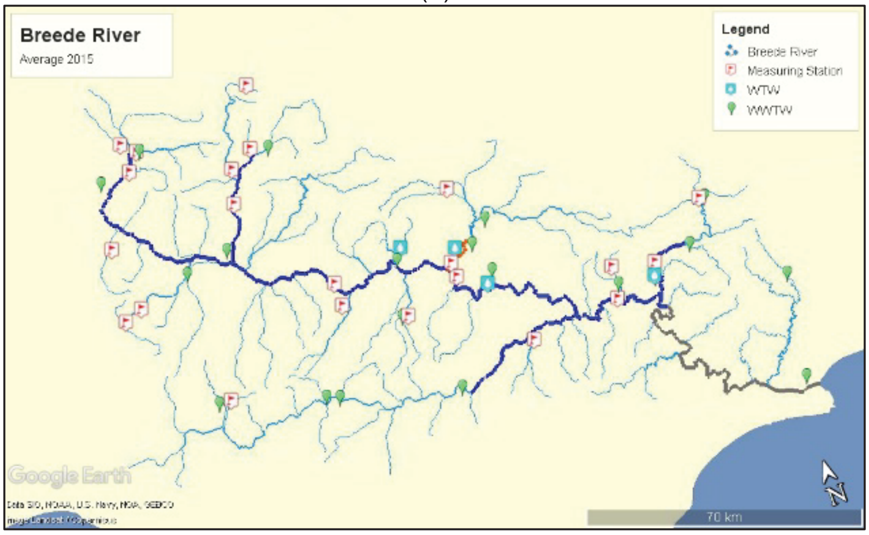
Breede River																								
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019																					
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity															Cumulative flow	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Ceres	Wolseley	Rawsonville	Worcester	De Doorns	Robertson	Ashton	Montagu	Bonnievale	Greyton	Genadendal	Riviersonderend	Klipperivier	Buffeljagsrivier	Suurbraak		Min	Average	Median
H1H003 Bree @ Ceres Golfbaan	-33.382828°	19.312181°	0.3730	1.0570	0.6500	0.0984															0.0984	21%	9%	13%
H1H006 Bree @ Witbrug	-33.419980°	19.275510°	0.9450	4.3790	2.3600	0.0984															0.0984	9%	2%	4%
H2H006 Hex @ Glen Heatlie	-33.571150°	19.511720°	0.3530	0.7180	0.6200					0.0278											0.0278	7%	4%	4%
H4H017 Bree @ Le Chasseur	-33.817867°	19.693703°	4.1430	13.8460	8.3170	0.0984	0.0417	0.0028	0.3241	0.0278											0.4947	11%	3%	6%
Robertson WTW	-33.793328°	19.895817°	4.1430	13.8460	8.3170	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486										0.5433	12%	4%	6%
Ashton WTW	-33.836108°	20.034861°	0.2960	0.4870	0.4380							0.0463	0.0405								0.0868	23%	15%	17%
H3H011 Kogmanskloof @ Gold	-33.863992°	20.011206°	0.2960	0.4870	0.4380							0.0463	0.0405								0.0868	23%	15%	17%
H5H004 Bree @ Wolvendrift	-33.897800°	20.012208°	1.3640	9.8250	5.0330	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405								0.6301	32%	6%	11%
Bonnievale WTW	-33.936544°	20.085933°	1.3640	9.8250	5.0330	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019	0.0087	0.0030	0.7096	34%	7%	12%
H6H009 Reenen	-34.091340°	20.151670°	0.7080	3.4660	1.8590										0.0035	0.0081	0.0081				0.0197	3%	1%	1%
H7H006 Bree @ Swellendam	-34.067533°	20.404728°	1.8650	11.1820	6.0800	0.0984	0.0417	0.0028	0.3241	0.0278	0.0486	0.0463	0.0405	0.0463	0.0035	0.0081	0.0081	0.0019			0.6979	27%	6%	10%
H7H007 Grootkloof @ Sparken	-34.025350°	20.54443	0.0730	0.3340	0.1500															0.0030	0.0030	4%	1%	2%
Buffeljagsrivier WTW	-34.047661°	20.520858°	0.0730	0.3340	0.1500														0.0087	0.0030	0.0117	14%	3%	7%

C2: De facto wastewater percentage maps for the different time periods for the Breede River

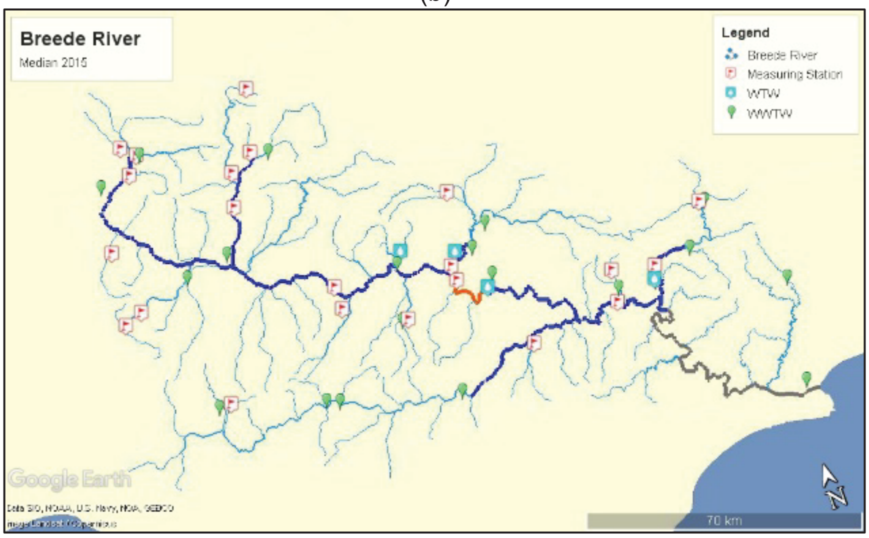
- **Wastewater Contributions in 2015**



(a)



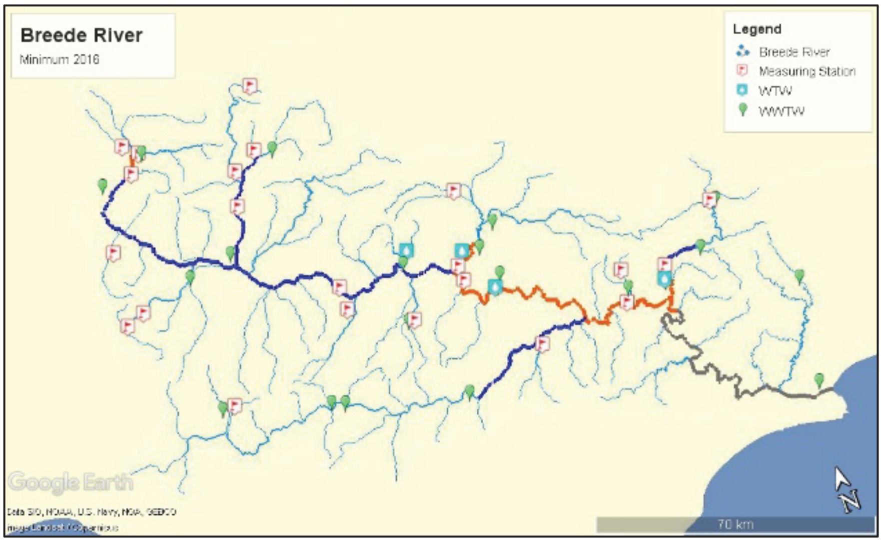
(b)



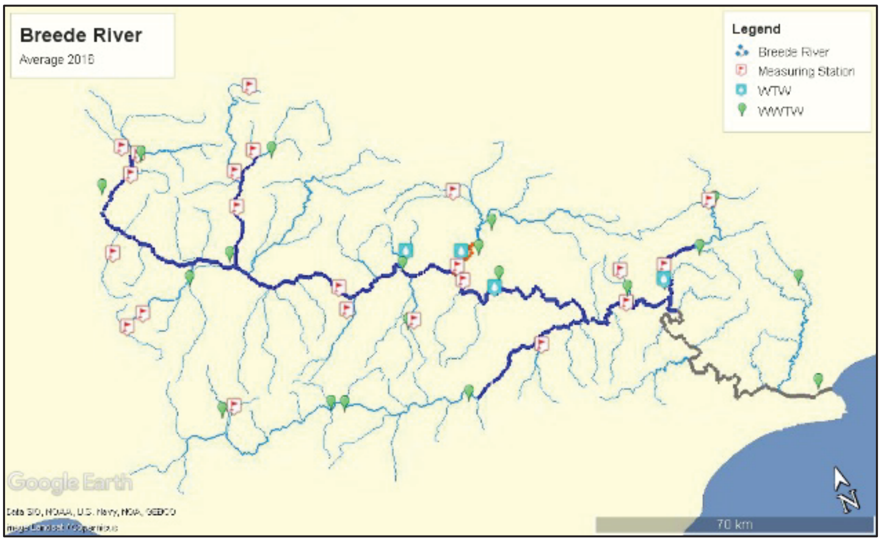
(c)

Figure C2.1: Wastewater contribution in the Breede River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

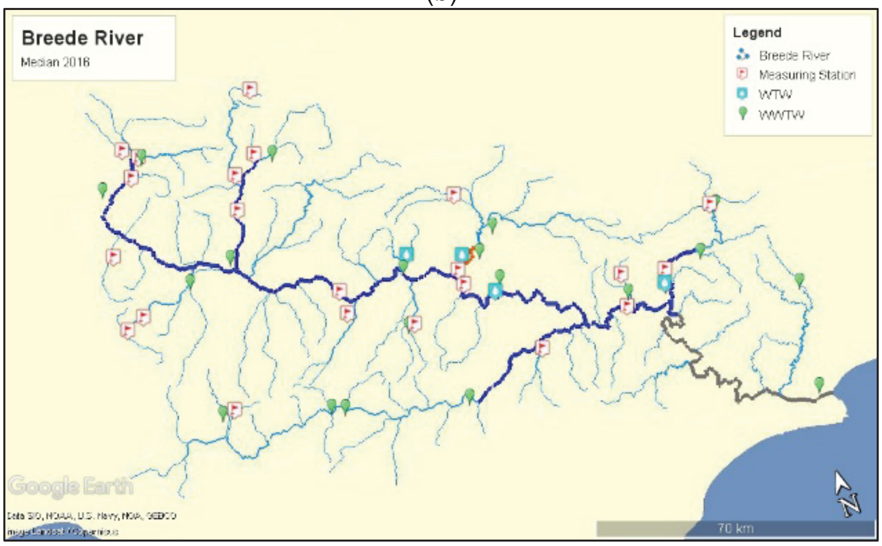
- **Wastewater Contributions in 2016**



(a)



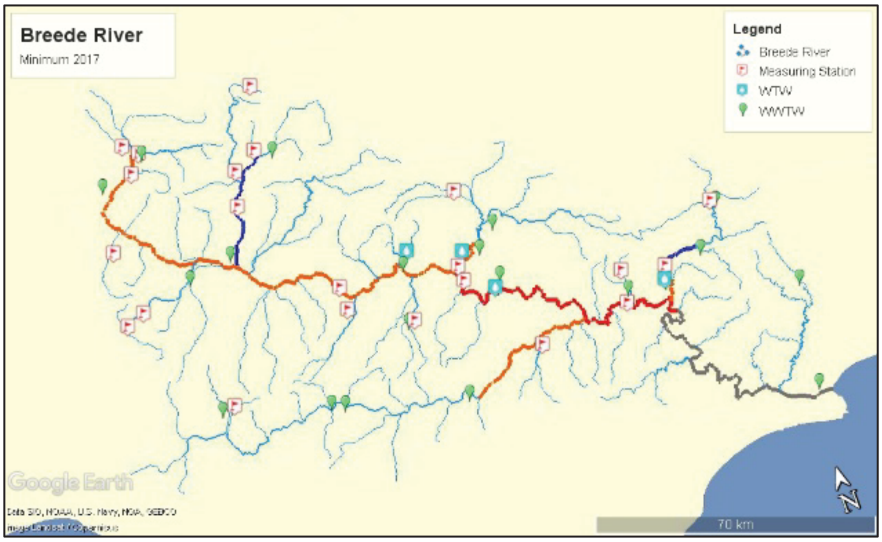
(b)



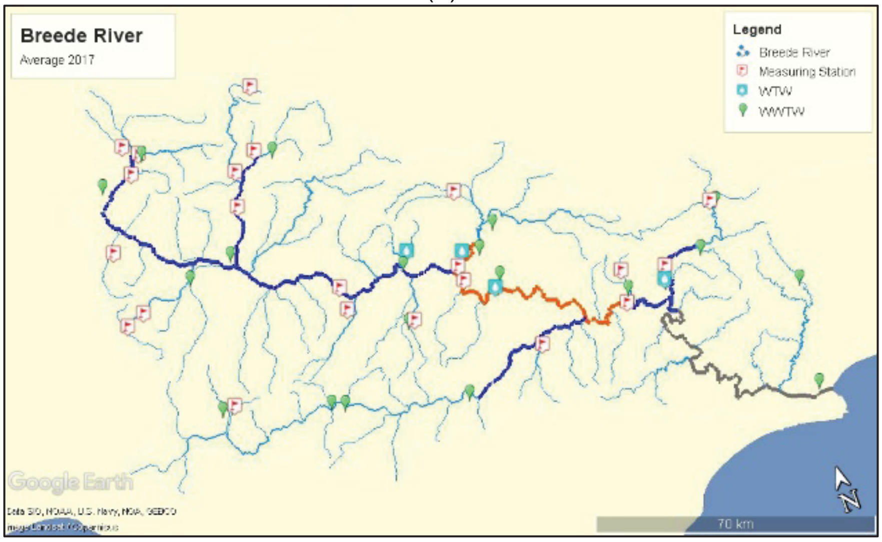
(c)

Figure C2.2: Wastewater contribution in the Breede River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

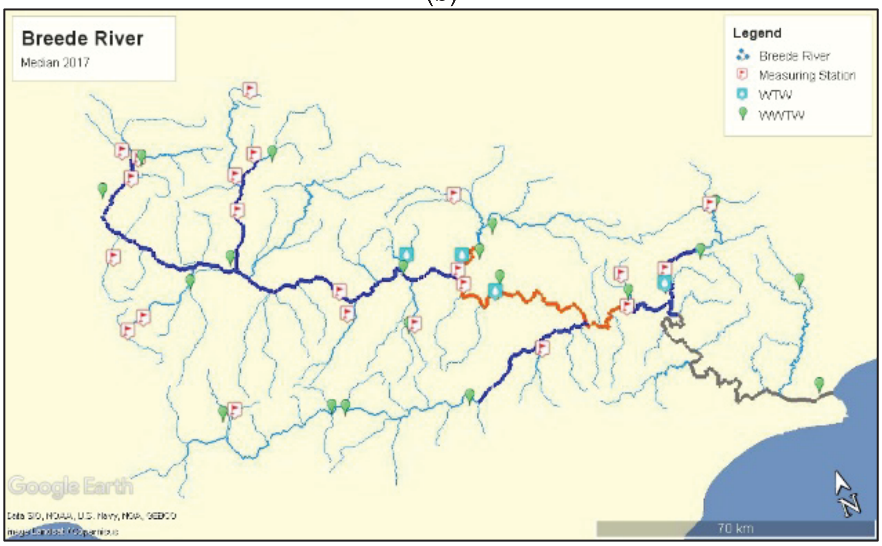
- **<u>Wastewater Contributions in 2017</u>**



(a)



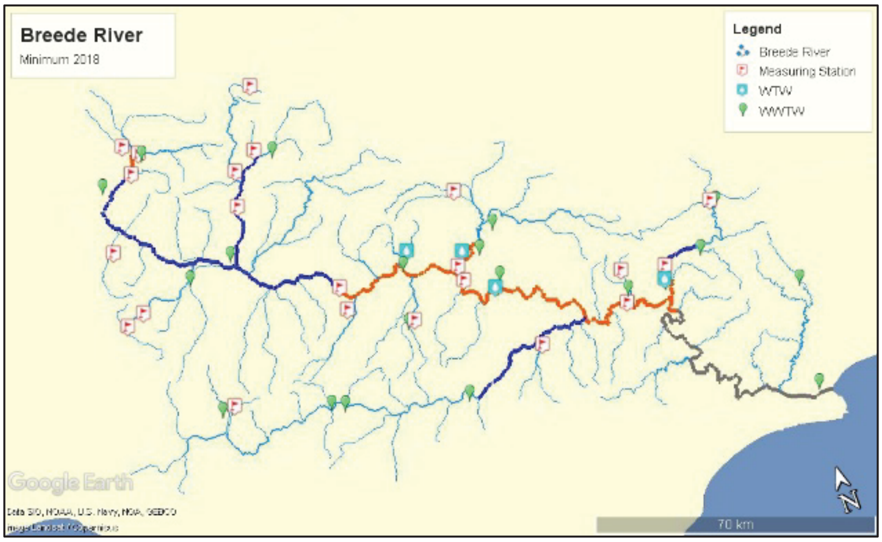
(b)



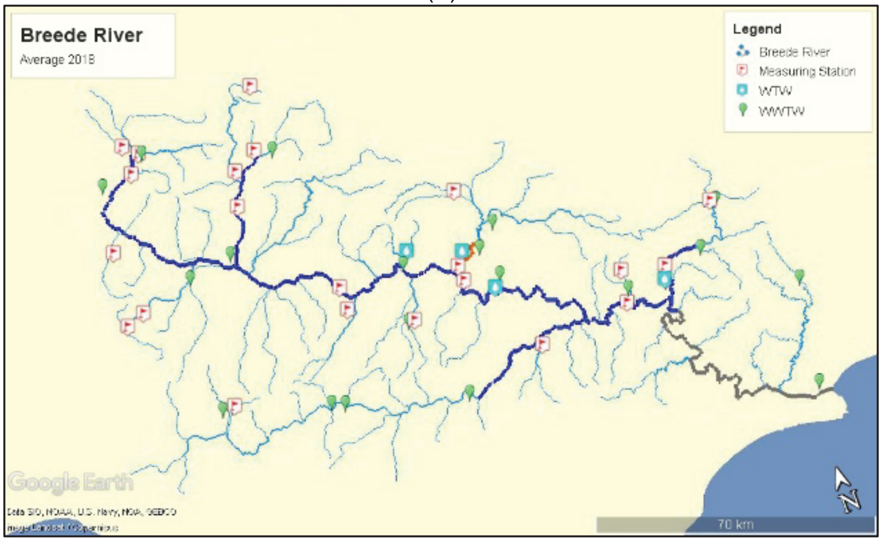
(c)

Figure C2.3: Wastewater contribution in the Breede River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

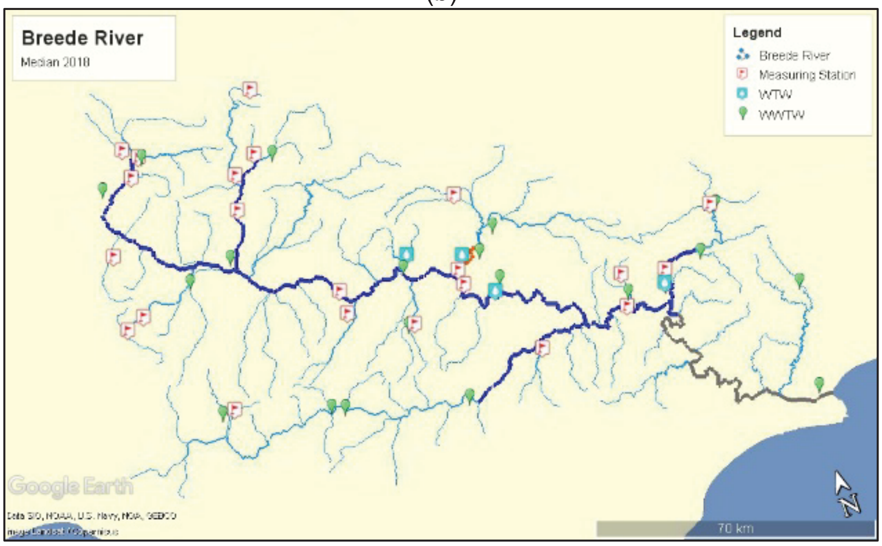
- **<u>Wastewater Contributions in 2018</u>**



(a)



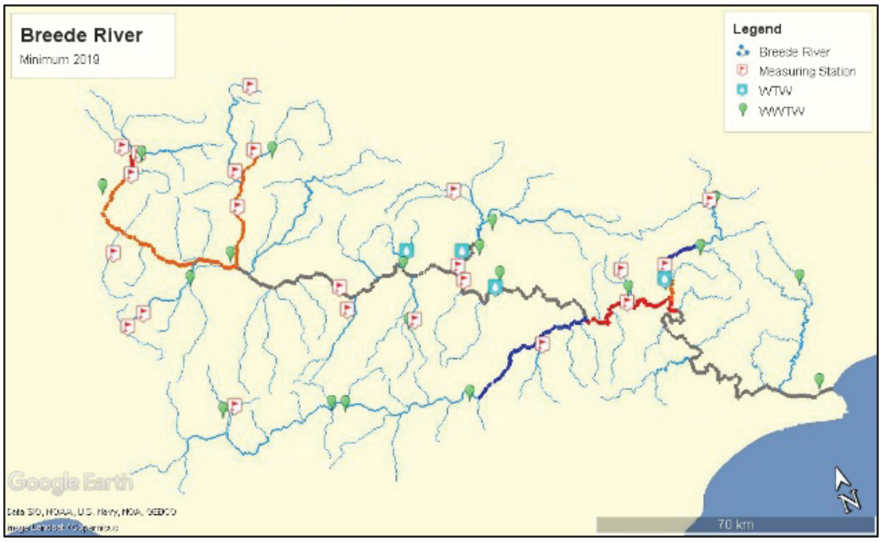
(b)



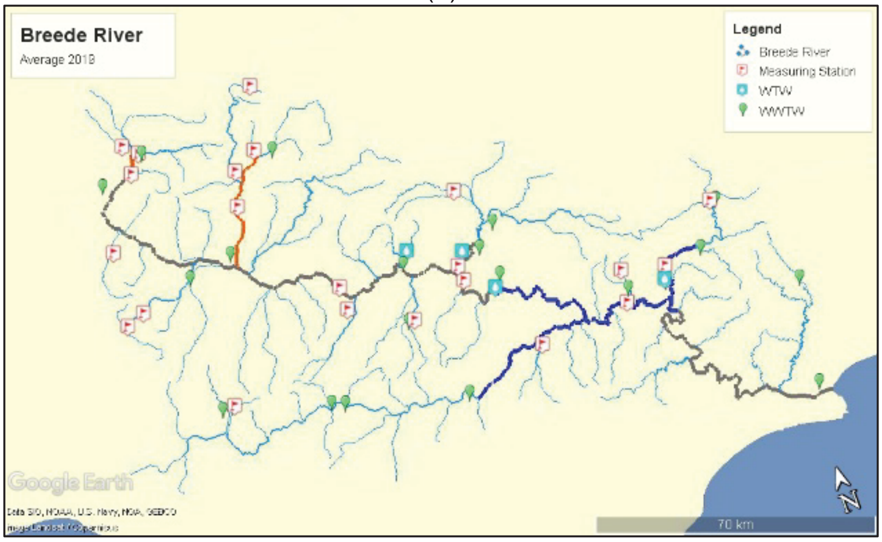
(c)

Figure C2.4: Wastewater contribution in the Breede River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

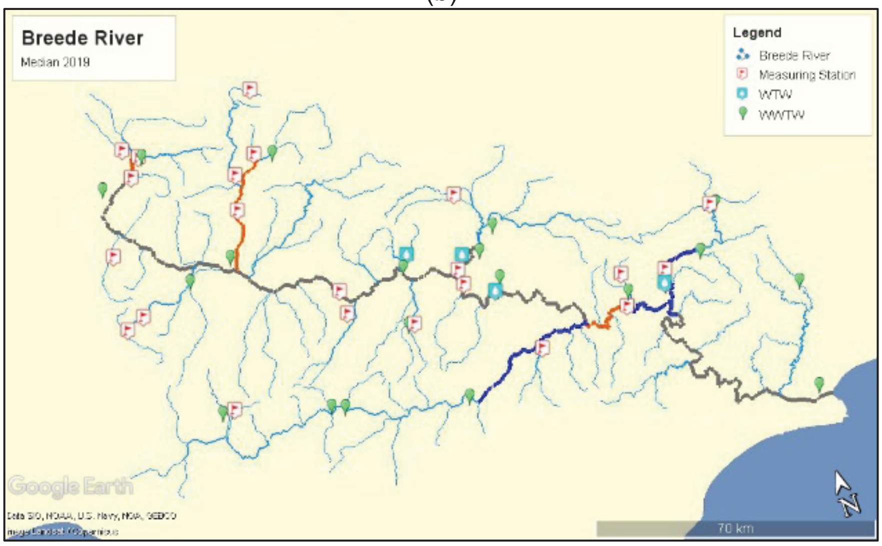
- **Wastewater Contributions in 2019**



(a)



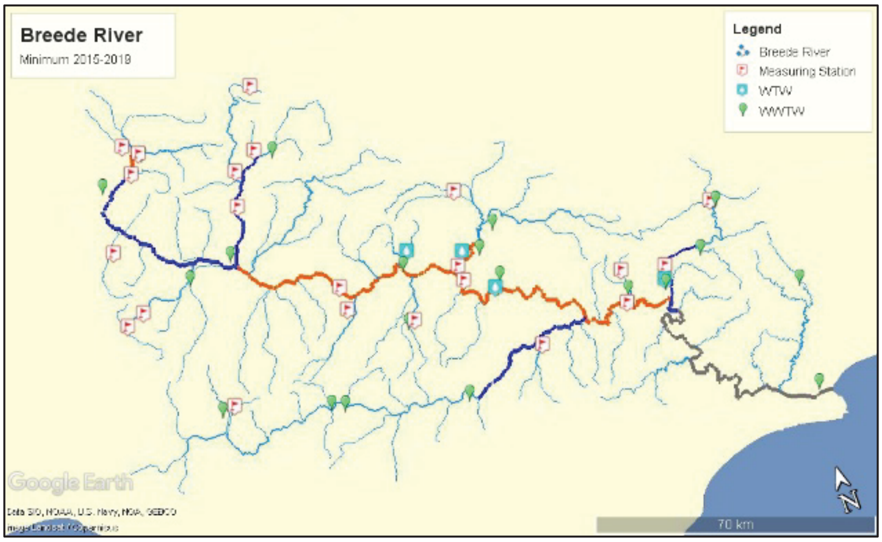
(b)



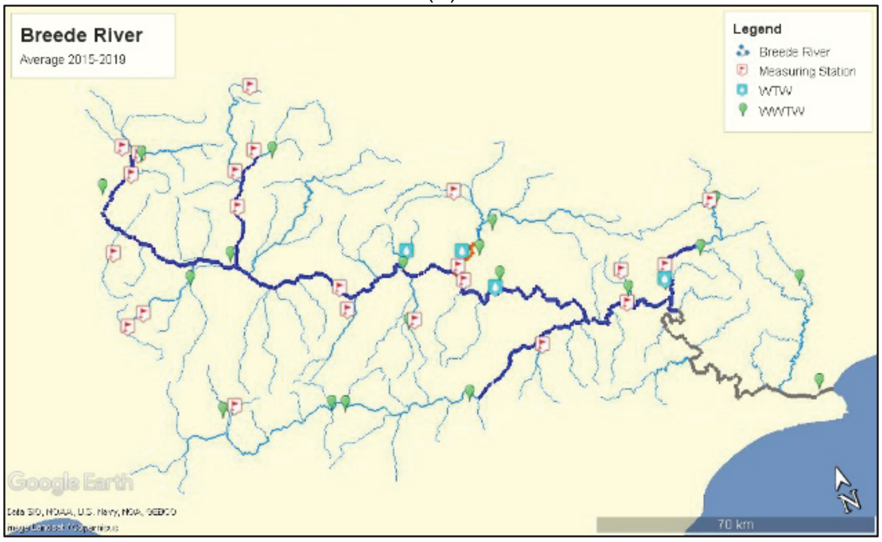
(c)

Figure C2.5: Wastewater contribution in the Breede River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

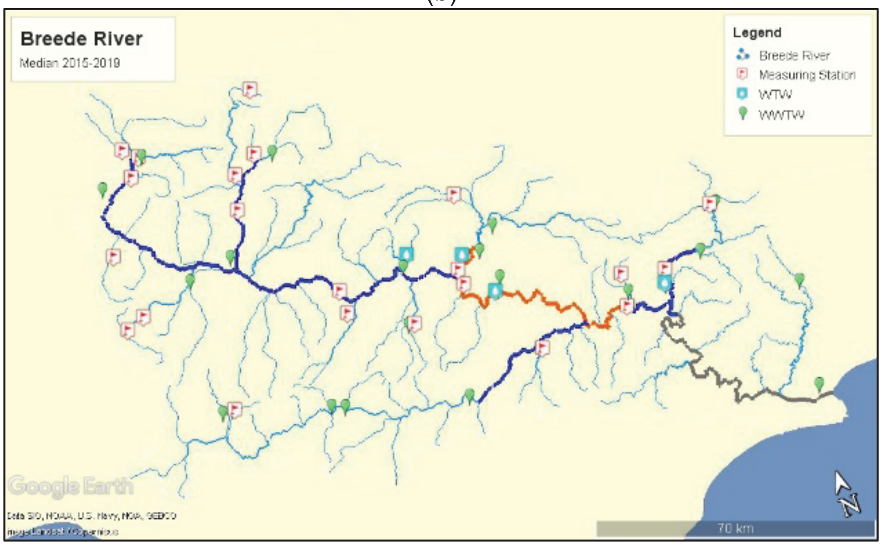
- **Wastewater Contributions in 2015-2019**



(a)



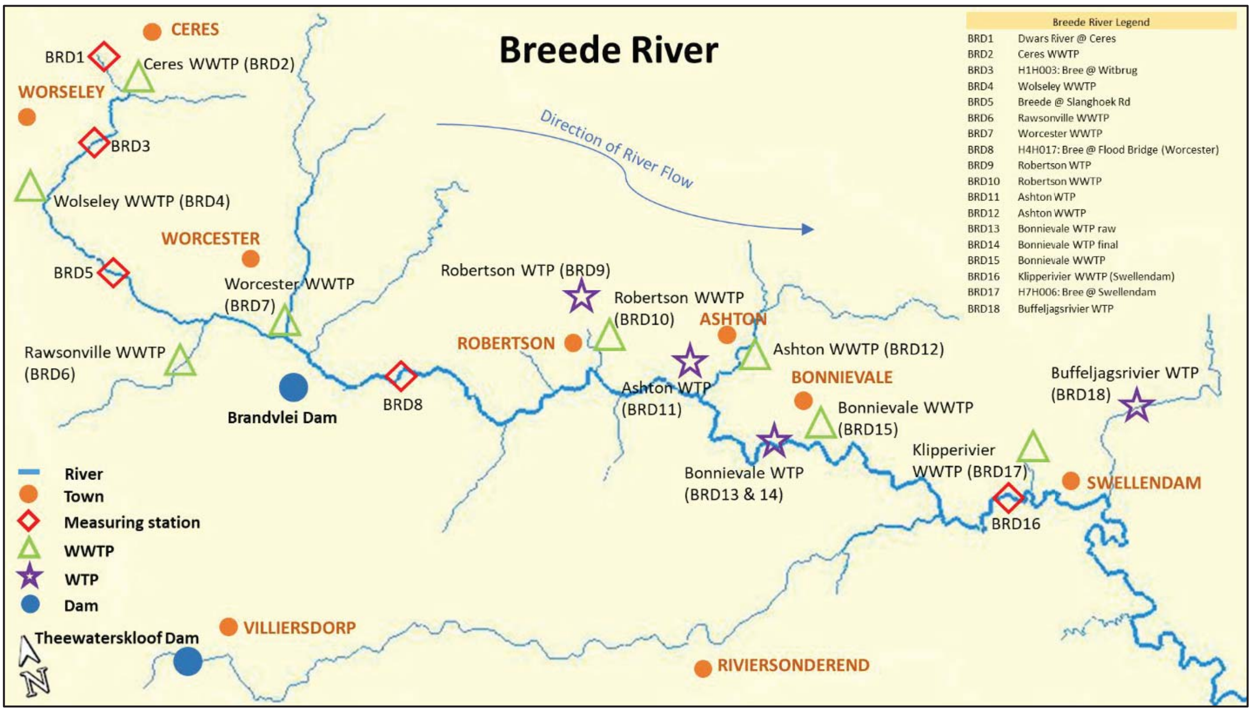
(b)



(c)

Figure C2.6: Wastewater contribution in the Breede River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

C3: Map of sampling points for CEC analysis in the Breede River



C4: Results of the CEC analysis for the Breede River

Table C4.1: Results of the CEC analysis for the Breede River

Constituent	Sample Points																	
	Dwars River @ Ceres	Ceres WWTW	H1H003: Bree @ Witbrug	Wolseley WWTW	Breede @ Slanghoek Rd	Rawsonville WWTW	Worcester WWTW	H4H017: Bree @ Flood Bridge (Worcester)	Robertson WTW	Robertson WWTW	Ashton WTW	Ashton WWTW	Bonnievale WTW raw	Bonnievale WTW final	Bonnievale WWTW	Klipperivier WWTW (Swellendam)	H7H006: Bree @ Swellendam	Buffeljagsrivier WTW
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
10,11-dihydro-11-hydroxycarbamazepine	<IQL	7.219	2.053	94.99	<IQL	25.4	3.947	0.414	<IQL	12.37	<IQL	2.489	<IQL	<IQL	<IQL	5.715	0.798	<IQL
Acetaminophen	12.33	165.8	16.28	5.161	24.09	<IQL	<IQL	12.37	7.178	39.41	<IQL	18.93	38.72	<IQL	15.82	11.98	10.37	5
Benzotriazole	3.705	82.75	13.93	39.02	<IQL	<IQL	54.59	<IQL	<IQL	334.4	<IQL	20.34	<IQL	<IQL	31.41	15.66	5.303	10.41
Benzoylecgonine	<IQL	<IQL	<IQL	<IQL	<IQL	21.81	<IQL	<IQL	<IQL	31.21	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	5.859	<IQL
Caffeine	<IQL	178.4	58.4	564	46.8	315	33.21	<IQL	<IQL	1654	96.37	93.13	<IQL	<IQL	114.7	<IQL	22.68	<IQL
Carbamazepine	<IQL	76.23	38.51	251.6	<IQL	807.4	594.6	4.114	<IQL	2139	9.325	538.1	7.295	5.538	641.5	1088	2.623	1.157
Carbamazepine-10,11-epoxide	<IQL	<IQL	4.465	38.48	<IQL	104.2	57.58	<IQL	<IQL	39.53	<IQL	51.51	<IQL	<IQL	58.77	57.92	<IQL	<IQL
Cocaine	<IQL	<IQL	<IQL	<IQL	<IQL	5.812	<IQL	<IQL	1.923	1.927	1.99	1.913	<IQL	2.055	<IQL	<IQL	<IQL	<IQL
Codeine	<IQL	<IQL	<IQL	43.07	<IQL	771.9	<IQL	<IQL	<IQL	251.6	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Diclofenac	<IQL	29.67	9.766	<IQL	<IQL	938.4	35.91	<IQL	<IQL	417.4	<IQL	52.54	2.776	<IQL	<IQL	18.78	<IQL	2.456
Efavirenz	<IQL	1377	259.6	5522	<IQL	8093	2693	<IQL	<IQL	6158	37.88	9991	<IQL	<IQL	2888	4889	49.76	15.05
Emtricitabine	<IQL	602.1	71.64	<IQL	<IQL	11381	110.1	<IQL	1.884	22431	12.48	621.2	5.741	<IQL	<IQL	<IQL	<IQL	5.685
MDMA	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	4.499	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Methamphetamine	<IQL	<IQL	<IQL	217.1	<IQL	131.2	194.3	<IQL	<IQL	215.2	<IQL	32.93	<IQL	<IQL	<IQL	24.36	<IQL	<IQL
Methaqualone	12.81	228.7	77.09	3731	<IQL	1631	87.15	<IQL	<IQL	1163	6.383	207.2	<IQL	<IQL	163.3	55.43	8.531	<IQL
Naproxen	7.222	<IQL	<IQL	<IQL	11.01	142.5	11.55	<IQL	<IQL	129.3	<IQL	17.19	<IQL	<IQL	<IQL	<IQL	20.96	<IQL
Sulfamethoxazole	<IQL	150.6	168.5	<IQL	<IQL	1155	677.6	<IQL	<IQL	6845	<IQL	4601	<IQL	<IQL	82.57	<IQL	17.23	22.69

<IQL = Less than Instrument Quantification Limit

C5: CEC Concentration Results Legend for the Breede River

Breede River Legend	
BRD1	Dwars River @ Ceres
BRD2	Ceres WWTP
BRD3	H1H003: Bree @ Witbrug
BRD4	Wolseley WWTP
BRD5	Breede @ Slanghoek Rd
BRD6	Rawsonville WWTP
BRD7	Worcester WWTP
BRD8	H4H017: Bree @ Flood Bridge (Worcester)
BRD9	Robertson WTP
BRD10	Robertson WWTP
BRD11	Ashton WTP
BRD12	Ashton WWTP
BRD3	Bonnievale WTP raw
BRD14	Bonnievale WTP final
BRD15	Bonnievale WWTP
BRD16	Klipperivier WWTP (Swellendam)
BRD17	H7H006: Bree @ Swellendam
BRD18	Buffeljagsrivier WTP

C6: Bar charts of indicator compound results in the Breede River

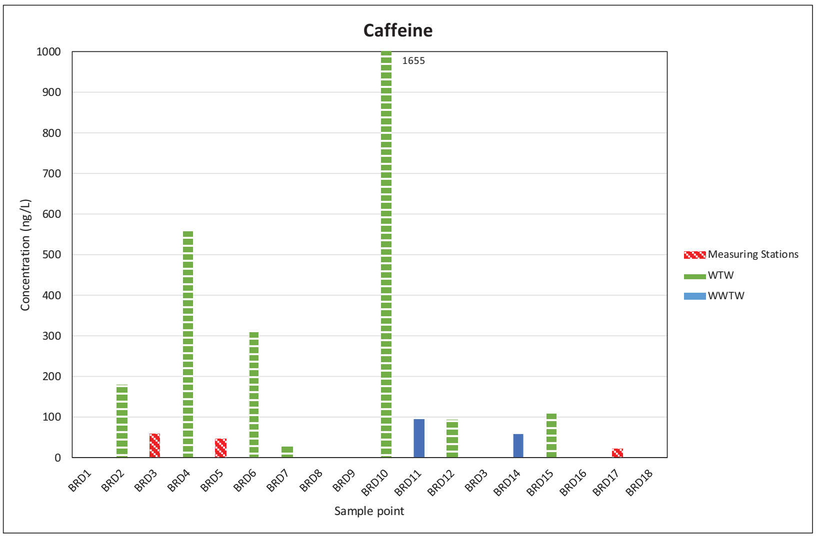


Figure C6.1: Concentrations of Caffeine in the Breede River

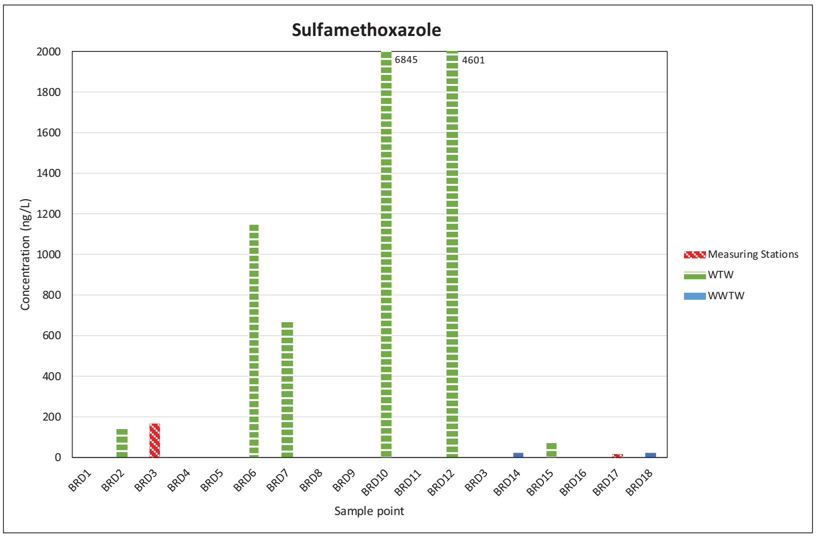


Figure C6.2: Concentrations of Sulfamethoxazole in the Breede River

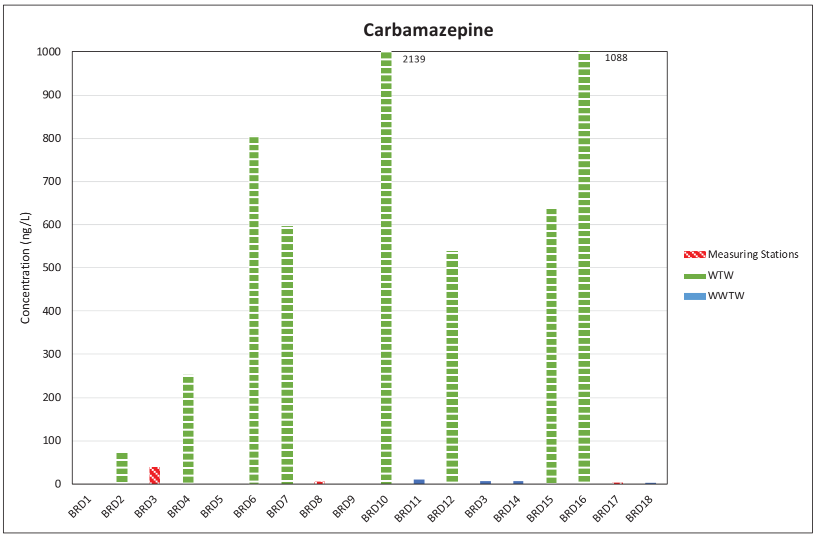


Figure C6.3: Concentrations of Carbamazepine in the Breede River

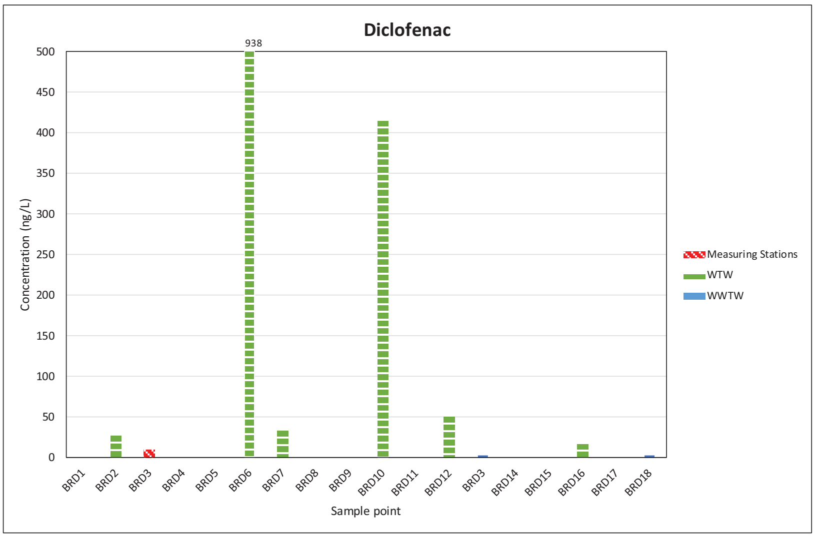


Figure C6.4: Concentrations of Diclofenac in the Breede River

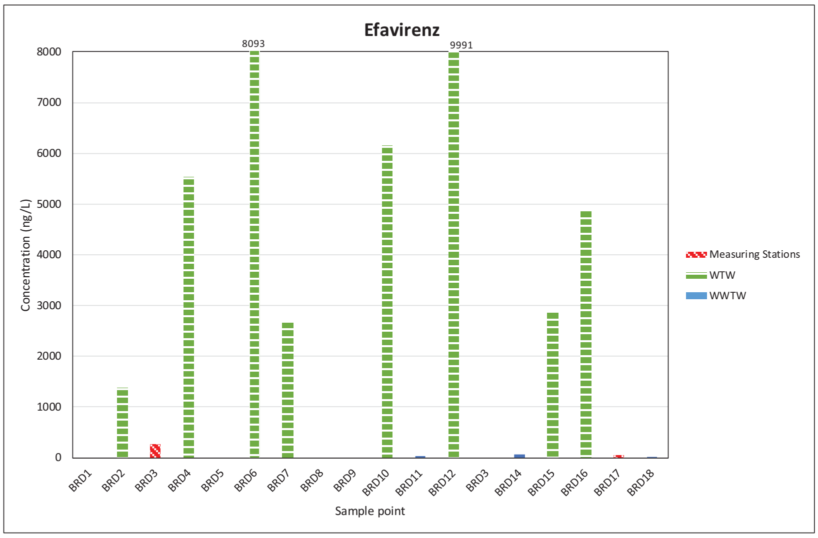


Figure C6.5: Concentrations of Efavirenz in the Breede River

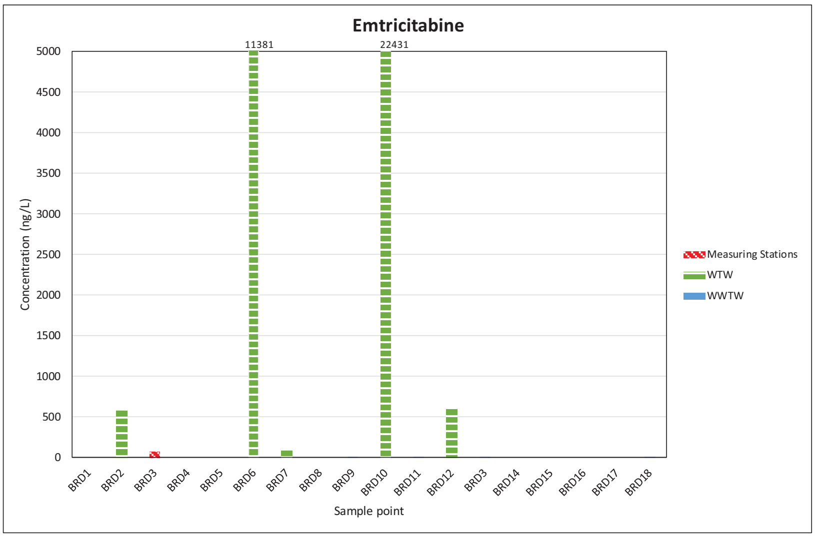


Figure C6.6: Concentrations of Emtricitabine in the Breede River

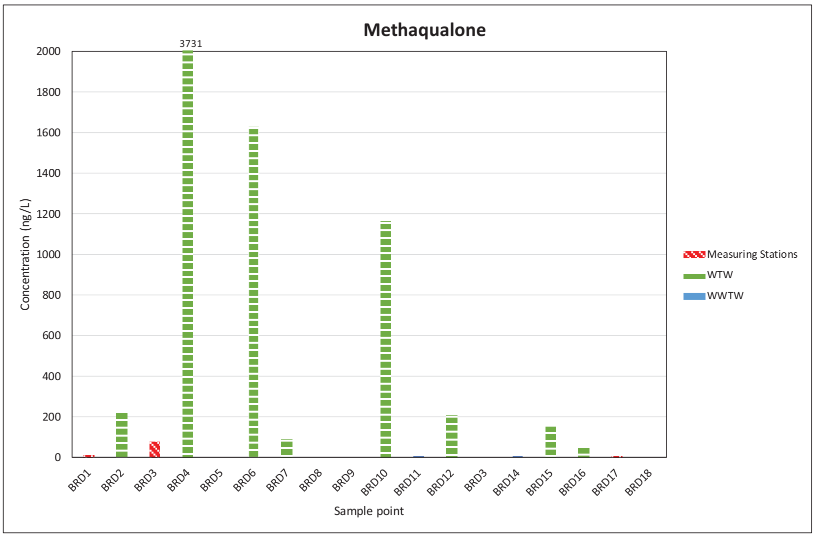


Figure C6.7: Concentrations of Methaqualone in the Breede River

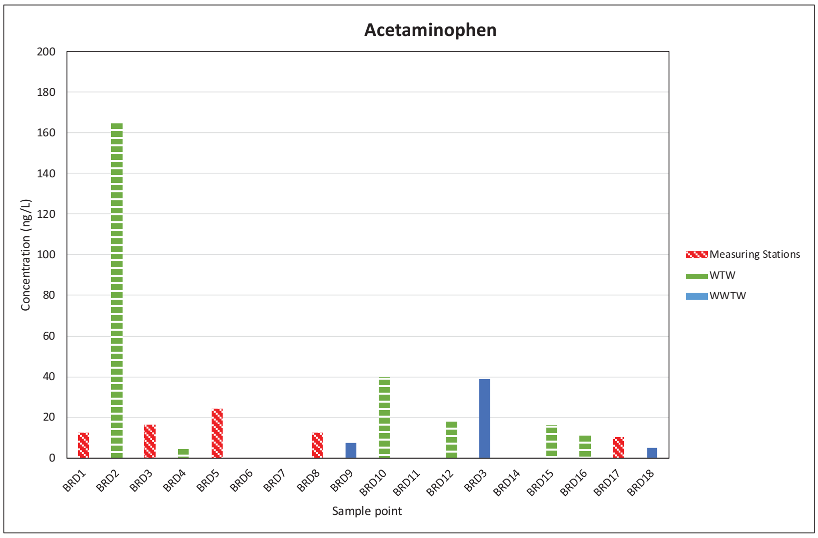


Figure C6.8: Concentrations of Acetaminophen in the Breede River

C7: Results of Other Water Quality Parameters for the Breede River

Sample Points	pH	EC	COD	UV 254	DOC
	-	mS/m	mg/L	m^{-1}	mg/L
Breede Origin: Dwars @ Ceres	7.83	5.97	<25	0.04	2.01
Ceres WWTP	7.90	53.17	32	0.25	5.10
H1H003: Bree @ Witbrug	7.85	11.01	<25	0.05	2.28
Wolseley WWTP	7.66	93.53	38	0.36	6.59
Berg @ Slanghoek Rd	8.08	5.02	<25	0.07	2.55
Rawsonville WWTP	7.48	74.11	45	0.32	6.11
Worcester WWTP	7.75	98.98	42	0.31	5.88
H4H017: Bree @ Flood Bridge (Worcester)	7.76	11.02	<25	0.08	2.67
Robertson WTP	8.86	5.64	<25	0.30	5.80
Robertson WWTP	8.14	173.90	118	0.62	10.34
Ashton WTP	8.04	66.92	<25	0.12	3.16
Ashton WWTP	7.79	104.60	41	0.31	5.84
Bonnievale WTP (raw)	8.20	62.05	<25	0.13	3.35
Bonnievale WTP (final)	7.85	94.36	<25	0.06	2.29
Bonnievale WWTP	7.89	141.40	26	0.23	4.83
Klipperivier WWTP (Swellendam)	7.78	101.50	32	0.24	4.96
H7H006: Bree @ Swellendam	7.55	112.30	46	0.59	9.84
Buffeljagsrivier WTP	7.61	5.97	55	1.21	18.65

APPENDIX D RESULTS FOR THE BUFFALO RIVER

D1: Flow-based data and calculations for the Buffalo River

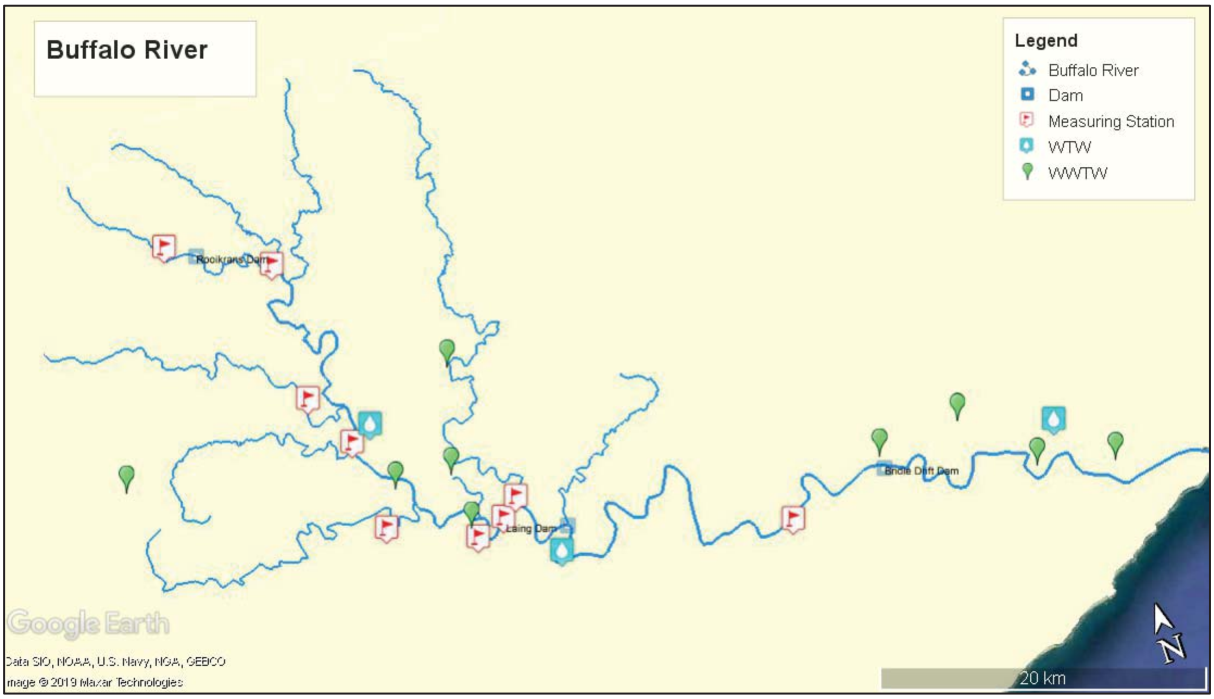


Figure D1.1: Buffalo River System, indicating all measuring stations, WWTP and WTP in this river.

Table D1.1: Summary of the Wastewater Percentages for the Buffalo River for 2015-2019

Buffalo River									
Measuring station/ Water Treatment Works	% wastewater in river (m3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
R2H010 Macintyre Bridge	32%	13%	22%	48%	31%	36%	47%	21%	32%
R2H015 Yellowwoods @ Fort M	18%	4%	11%	34%	17%	22%	4%	2%	3%
Laing WTW	30%	10%	20%	46%	29%	34%	23%	11%	16%
R2H027 Buffalo @ Needs Camp	43%	9%	22%	88%	57%	67%	40%	11%	20%
Umzonyana WTW	43%	9%	22%	88%	57%	67%	40%	11%	20%
Measuring station/ Water Treatment Works	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
R2H010 Macintyre Bridge	48%	22%	27%	61%	52%	55%	45%	22%	31%
R2H015 Yellowwoods @ Fort M	28%	10%	15%	2%	1%	1%	5%	3%	4%
Laing WTW	45%	20%	25%	13%	11%	11%	25%	14%	18%
R2H027 Buffalo @ Needs Camp	55%	21%	25%	20%	15%	16%	39%	15%	23%
Umzonyana WTW	55%	21%	25%	20%	15%	16%	39%	15%	23%

Table D1.2: Wastewater percentage calculations for the Buffalo River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Buffalo River													
			2015										
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.3468	1.1395	0.5755	0.0579	0.1076			0.1655	32%	13%	22%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	0.0848	0.4602	0.1562			0.0093	0.0093	0.0185	18%	4%	11%
Laing WTW	-32.968003°	27.490197°	0.4317	1.5998	0.7317	0.0579	0.1076	0.0093	0.0093	0.1840	30%	10%	20%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.2415	1.9274	0.6363	0.0579	0.1076	0.0093	0.0093	0.1840	43%	9%	22%
Umzonyana WTW	-32.984856°	27.822411°	0.2415	1.9274	0.6363	0.0579	0.1076	0.0093	0.0093	0.1840	43%	9%	22%

(b)

Buffalo River													
			2016										
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.1815	0.3688	0.2950	0.0579	0.1076			0.1655	48%	31%	36%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	0.0363	0.0880	0.0672			0.0093	0.0093	0.0185	34%	17%	22%
Laing WTW	-32.968003°	27.490197°	0.2178	0.4568	0.3623	0.0579	0.1076	0.0093	0.0093	0.1840	46%	29%	34%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.0247	0.1375	0.0918	0.0579	0.1076	0.0093	0.0093	0.1840	88%	57%	67%
Umzonyana WTW	-32.984856°	27.822411°	0.0247	0.1375	0.0918	0.0579	0.1076	0.0093	0.0093	0.1840	88%	57%	67%

(c)

Buffalo River													
Measuring station/ Water Treatment Works	Coordinates		2017										
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.1867	0.6244	0.3483	0.0579	0.1076			0.1655	47%	21%	32%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	0.4178	0.8960	0.6205			0.0093	0.0093	0.0185	4%	2%	3%
Laing WTW	-32.968003°	27.490197°	0.6045	1.5205	0.9687	0.0579	0.1076	0.0093	0.0093	0.1840	23%	11%	16%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.2788	1.5079	0.7398	0.0579	0.1076	0.0093	0.0093	0.1840	40%	11%	20%
Umzonyana WTW	-32.984856°	27.822411°	0.2788	1.5079	0.7398	0.0579	0.1076	0.0093	0.0093	0.1840	40%	11%	20%

(d)

Buffalo River													
Measuring station/ Water Treatment Works	Coordinates		2018										
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.1802	0.5811	0.4550	0.0579	0.1076			0.1655	48%	22%	27%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	0.0478	0.1601	0.1013			0.0093	0.0093	0.0185	28%	10%	15%
Laing WTW	-32.968003°	27.490197°	0.2280	0.7412	0.5562	0.0579	0.1076	0.0093	0.0093	0.1840	45%	20%	25%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.1510	0.6851	0.5607	0.0579	0.1076	0.0093	0.0093	0.1840	55%	21%	25%
Umzonyana WTW	-32.984856°	27.822411°	0.1510	0.6851	0.5607	0.0579	0.1076	0.0093	0.0093	0.1840	55%	21%	25%

(e)

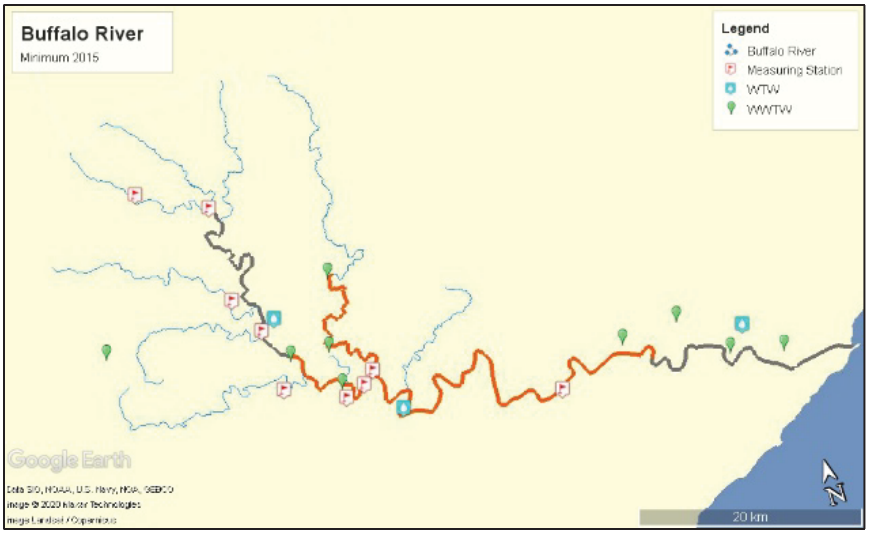
Buffalo River															
Measuring station/ Water Treatment Works	Coordinates		2019												
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.1055	0.1539	0.1361	0.0579	0.1076			0.1655	61%	52%	55%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	1.1130	1.3188	1.3329			0.0093	0.0093	0.0185	2%	1%	1%
Laing WTW	-32.968003°	27.490197°	1.2185	1.4727	1.4691	0.0579	0.1076	0.0093	0.0093	0.1840	13%	11%	11%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.7331	1.0403	0.9818	0.0579	0.1076	0.0093	0.0093	0.1840	20%	15%	16%
Umzonyana WTW	-32.984856°	27.822411°	0.7331	1.0403	0.9818	0.0579	0.1076	0.0093	0.0093	0.1840	20%	15%	16%

(f)

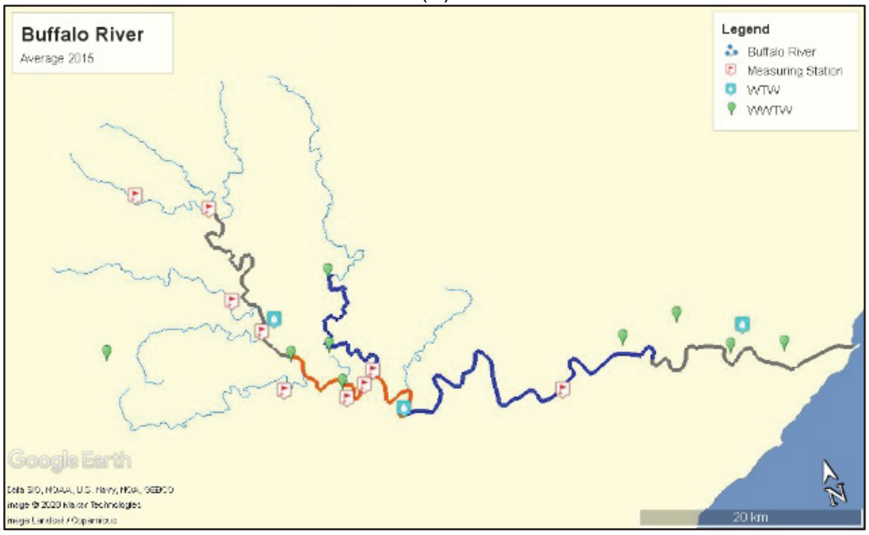
Buffalo River													
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019										
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity				Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Schornville	Zwelitcha	Bhisho	Breidbach		Min	Average	Median
R2H010 Macintyre Bridge	-32.940533°	27.460800°	0.2000	0.5740	0.3620	0.0579	0.1076			0.1655	45%	22%	31%
R2H015 Yellowwoods @ Fort M	-32.931686°	27.472719°	0.3400	0.5850	0.4560			0.0093	0.0093	0.0185	5%	3%	4%
Laing WTW	-32.968003°	27.490197°	0.5400	1.1590	0.8180	0.0579	0.1076	0.0093	0.0093	0.1840	25%	14%	18%
R2H027 Buffalo @ Needs Camp	-32.991606°	27.640103°	0.2860	1.0600	0.6020	0.0579	0.1076	0.0093	0.0093	0.1840	39%	15%	23%
Umzonyana WTW	-32.984856°	27.822411°	0.2860	1.0600	0.6020	0.0579	0.1076	0.0093	0.0093	0.1840	39%	15%	23%

D2: De facto wastewater percentage maps for the different time periods for the Buffalo River

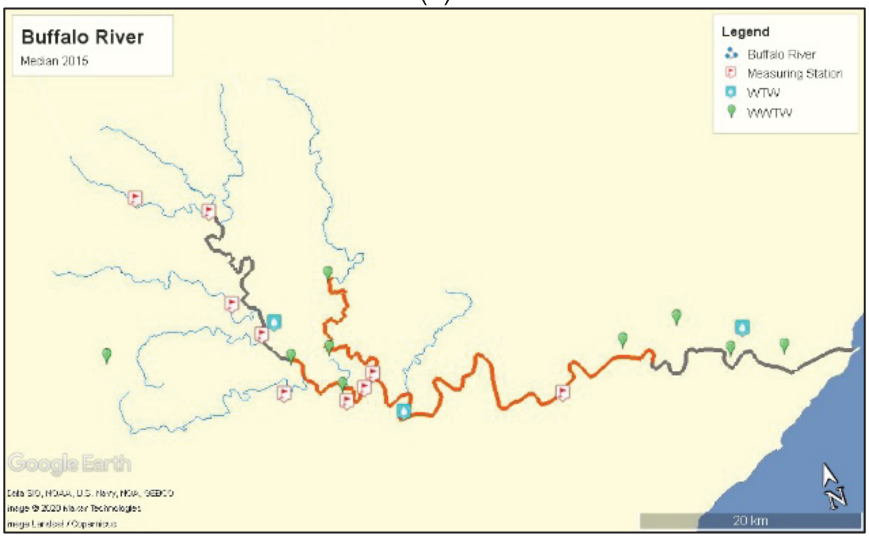
- **Wastewater Contributions in 2015**



(a)



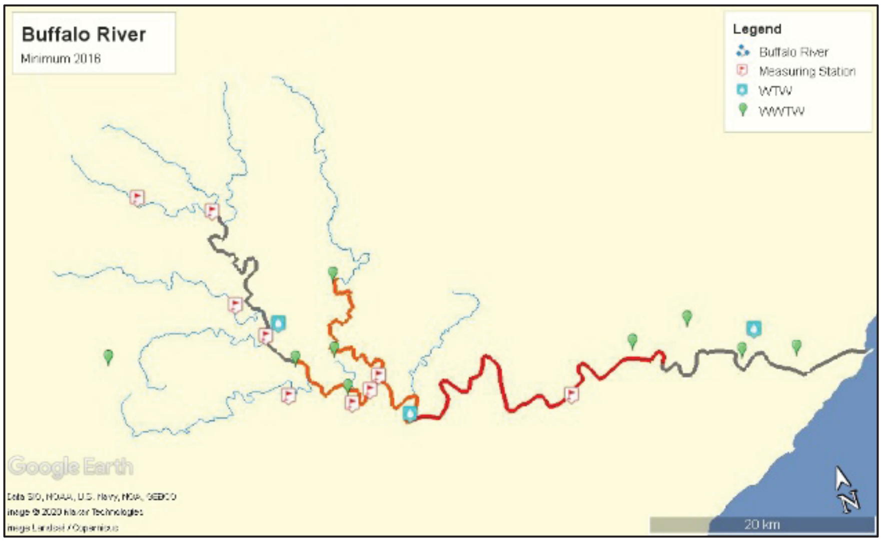
(b)



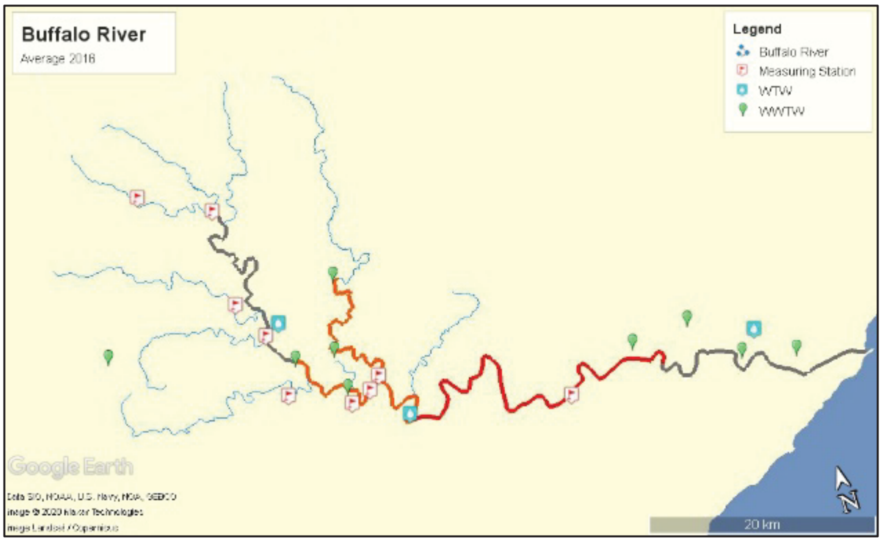
(c)

Figure D2.1: Wastewater contribution in the Buffalo River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

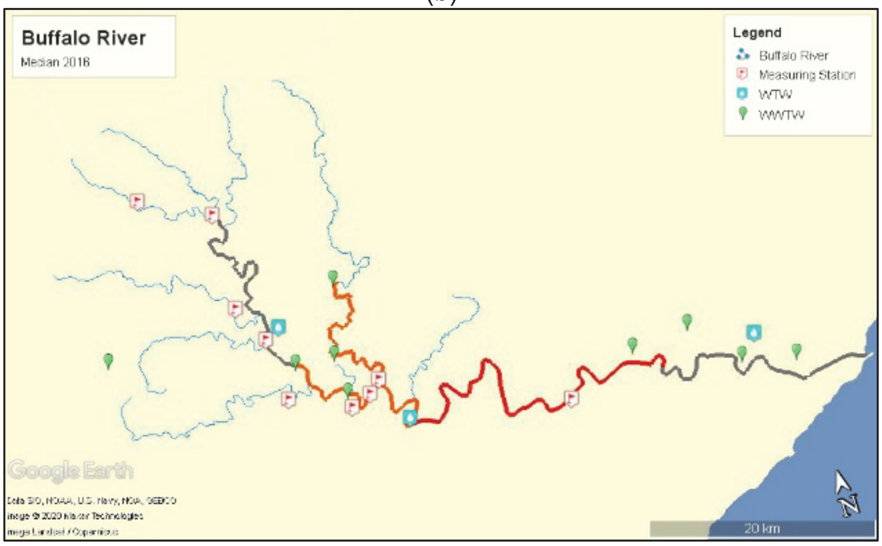
- **Wastewater Contributions in 2016**



(a)



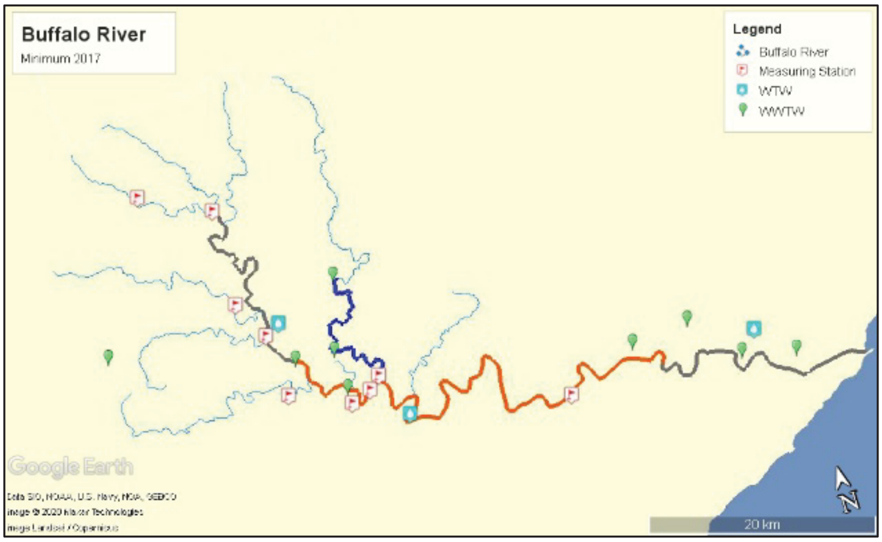
(b)



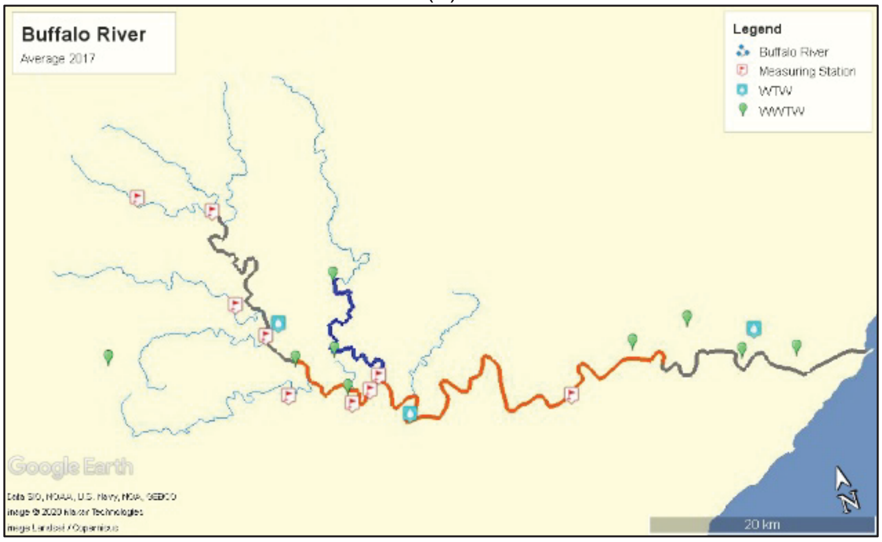
(c)

Figure D2.2: Wastewater contribution in the Buffalo River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

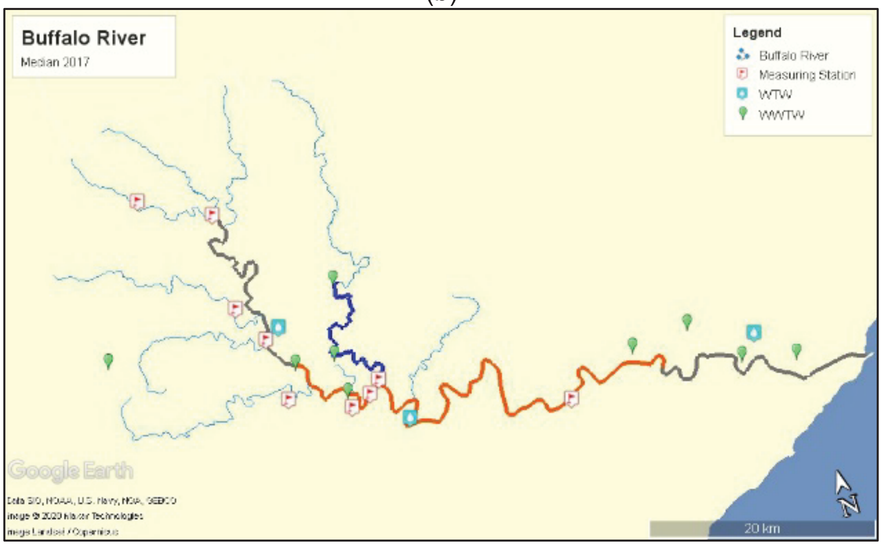
- **<u>Wastewater Contributions in 2017</u>**



(a)



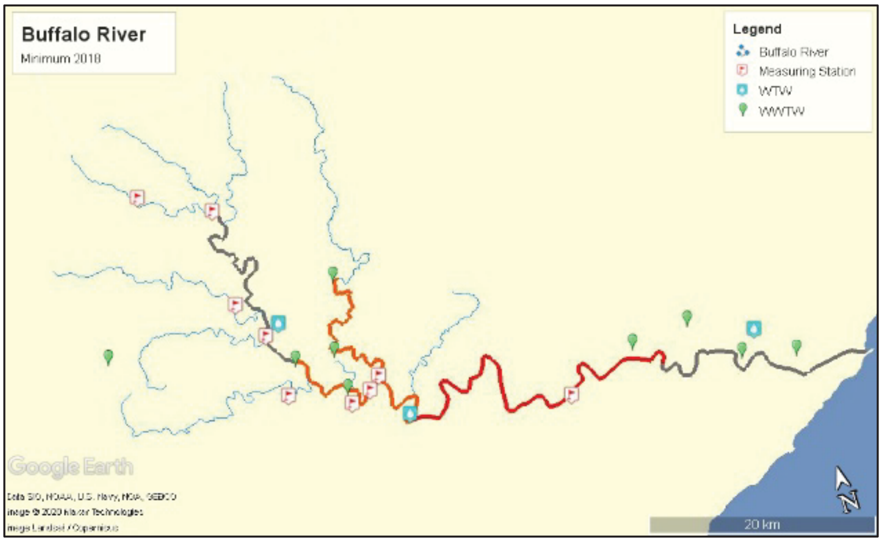
(b)



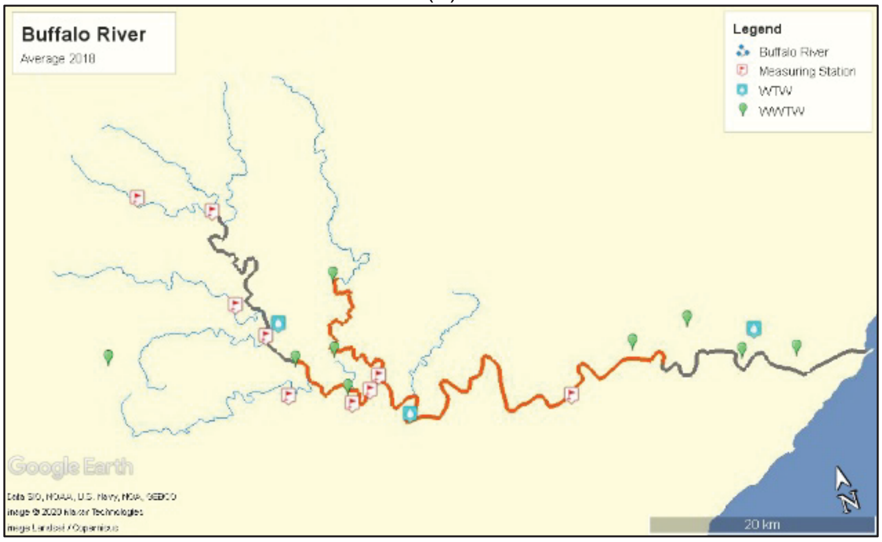
(c)

Figure D2.3: Wastewater contribution in the Buffalo River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

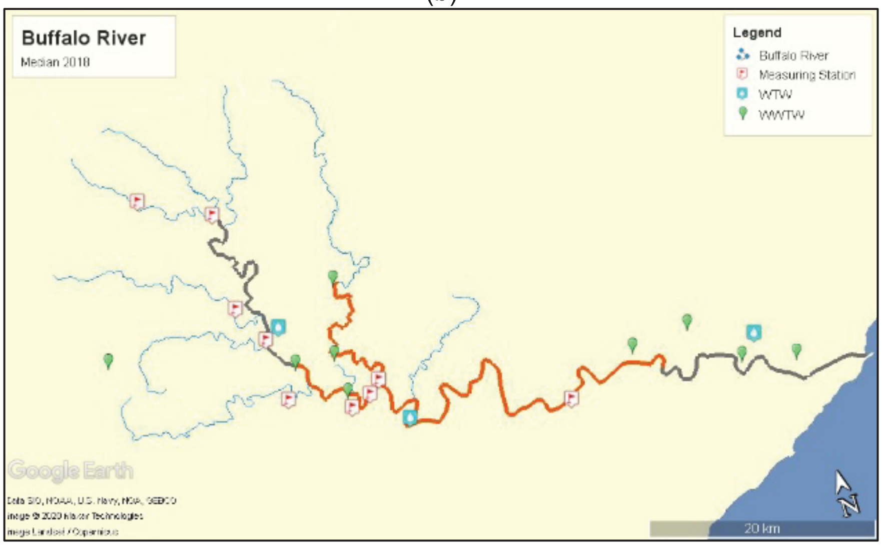
- **<u>Wastewater Contributions in 2018</u>**



(a)



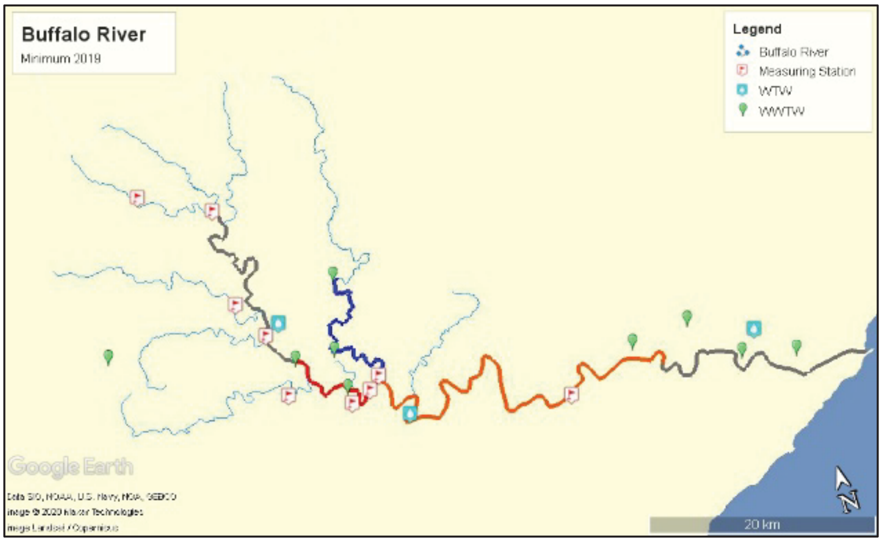
(b)



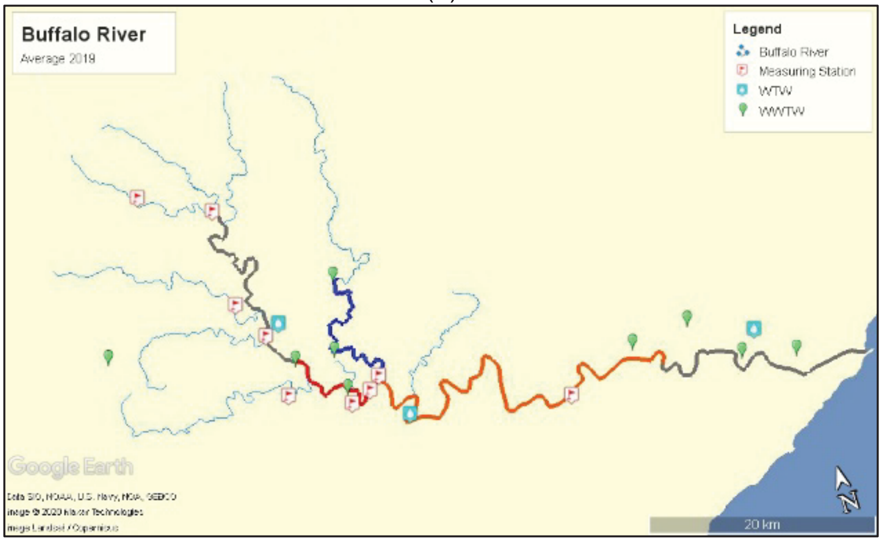
(c)

Figure D2.4: Wastewater contribution in the Buffalo River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

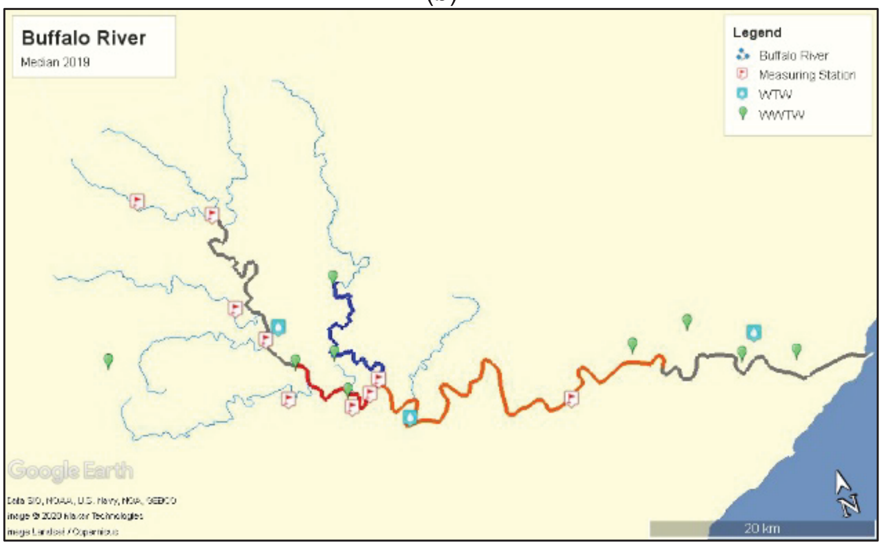
- **<u>Wastewater Contributions in 2019</u>**



(a)



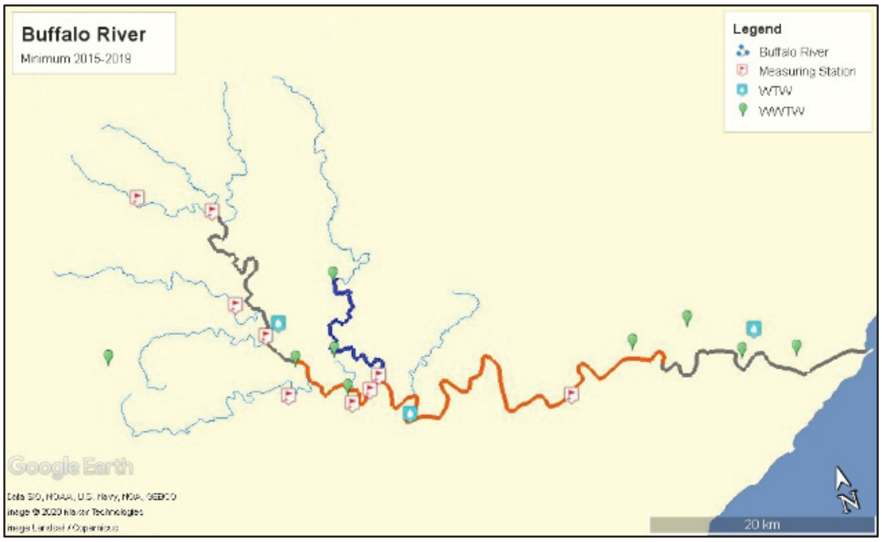
(b)



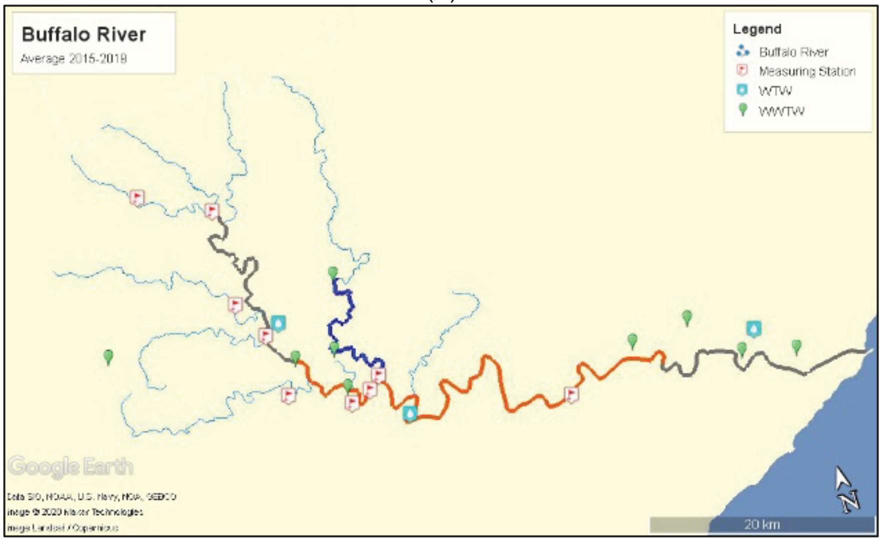
(c)

Figure D2.5: Wastewater contribution in the Buffalo River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

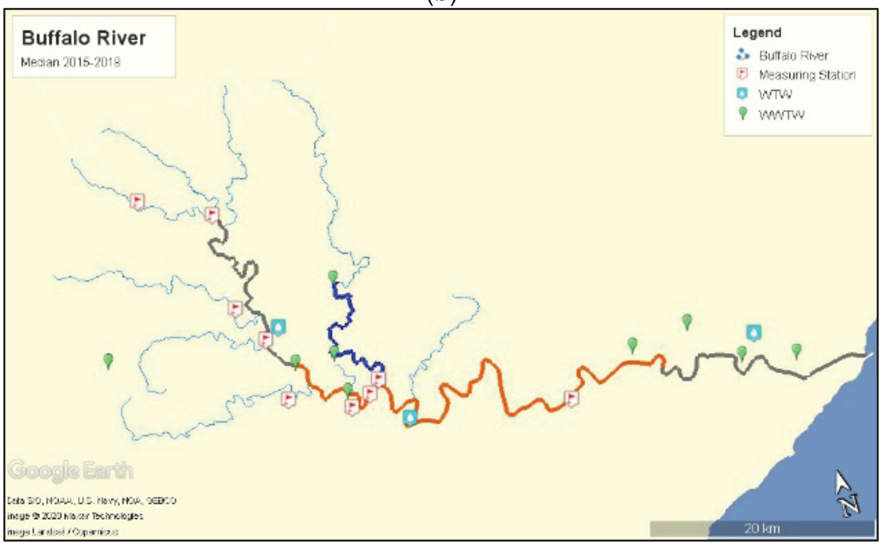
- **<u>Wastewater Contributions in 2015-2019</u>**



(a)



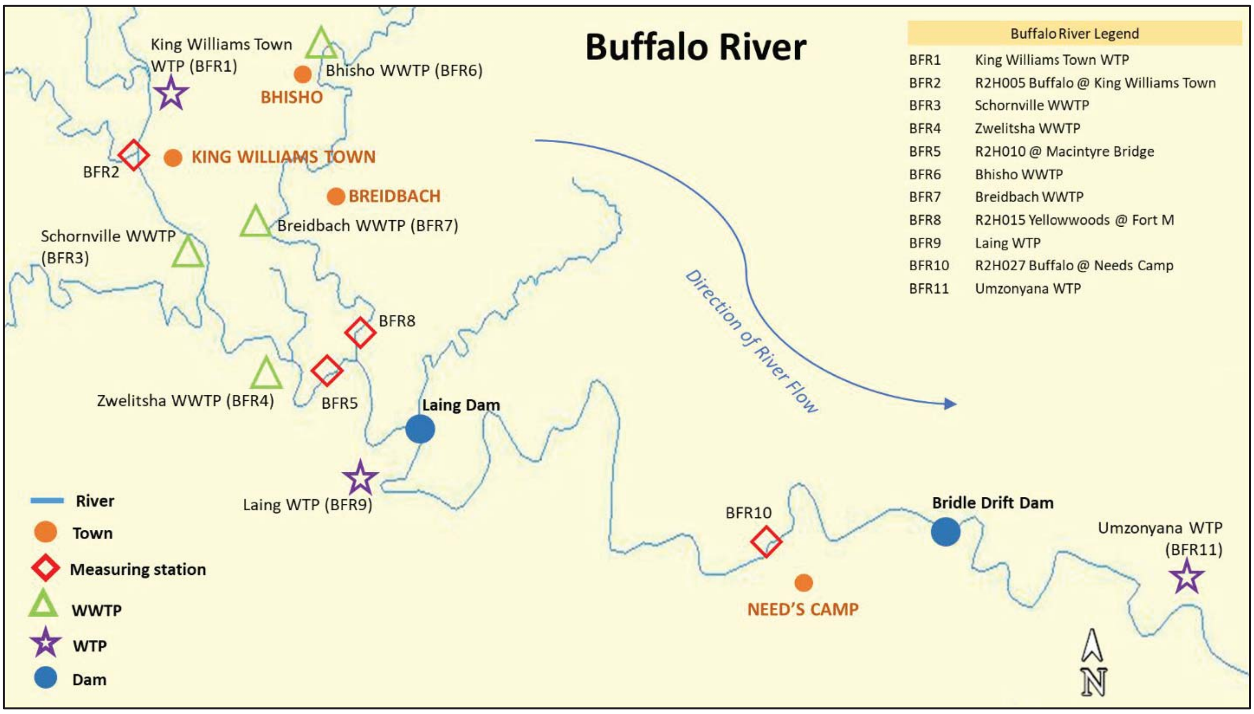
(b)



(c)

Figure D2.6: Wastewater contribution in the Buffalo River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

D3: Map of sampling points for CEC analysis in the Buffalo River



D4: CEC Concentration Results Legend for the Buffalo River

Buffalo River Legend	
BFR1	King Williams Town WTP
BFR2	R2H005 Buffalo @ King Williams Town
BFR3	Schornville WWTP
BFR4	Zwelitsha WWTP
BFR5	R2H010 @ Macintyre Bridge
BFR6	Bhisho WWTP
BFR7	Breidbach WWTP
BFR8	R2H015 Yellowwoods @ Fort M
BFR9	Laing WTP
BFR10	R2H027 Buffalo @ Needs Camp
BFR11	Umzonyana WTP

D5: Results of the CEC analysis for the Buffalo River

Table D5.1: Results of the CEC analysis for the Buffalo River

Constituent	Sample Points										
	King Williams Town WTW	R2H005 Buffalo @ King Williams Town	Schornville WWTW	Zwelitsha WWTW	R2H010 @ Macintyre Bridge	Bhisho WWTW	Breidbach WWTW	R2H015 Yellowwoods @ Fort M	Laing WTW	R2H027 Buffalo @ Needs Camp	Umzonyana WTW
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
10,11-dihydro-11-hydroxycarbamazepine	<IQL	<IQL	2.349	1.907	<IQL	7.073	22.6	<IQL	<IQL	<IQL	<IQL
Acetaminophen	7.508	97.47	<IQL	<IQL	74.95	<IQL	529.8	6.509	20.12	6.338	78.51
Benzotriazole	4.38	4.252	20.54	<IQL	11.79	25.03	26.87	4.057	8.373	11.86	9.576
Benzoylecgonine	<IQL	<IQL	23.55	24.93	9.434	47.03	43.83	<IQL	<IQL	3.12	<IQL
Caffeine	23.96	<IQL	209.2	1442	433.9	75.67	709.7	18.44	207.3	<IQL	83.37
Carbamazepine	<IQL	1.172	273.6	726.7	180.9	286.7	1533	24.02	59.34	56.95	49.96
Carbamazepine-10,11-epoxide	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	4.457	<IQL
Cocaine	1.879	1.128	<IQL	<IQL	2.552	<IQL	<IQL	<IQL	2.151	<IQL	<IQL
Codeine	<IQL	<IQL	1735	167.8	103.9	<IQL	33.97	<IQL	<IQL	<IQL	<IQL
Diclofenac	<IQL	2.413	1101	48.18	79.36	0	578.7	4.022	6.682	4.485	4.827
Efavirenz	14.98	32.72	15443	9844	3767	1694	4153	78.75	261.1	230.8	176.6
Emtricitabine	<IQL	4.969	27351	21.16	2294	30641	19616	188.1	36.53	19.28	45.67
MDMA	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Methamphetamine	<IQL	<IQL	49.96	82.94	4.865	<IQL	1861	<IQL	<IQL	<IQL	<IQL
Methaqualone	2.652	17.39	549.7	1034	313.2	521.8	3212	35.34	12.56	17.47	42.64
Naproxen	<IQL	<IQL	145	60.21	<IQL	26.44	186.8	<IQL	<IQL	<IQL	<IQL
Sulfamethoxazole	<IQL	<IQL	2151	1606	2474	1089	3454	<IQL	186.9	190.2	288.4

<IQL = Less than Instrument Quantification Limit

D6: Bar charts of indicator compound results in the Buffalo River

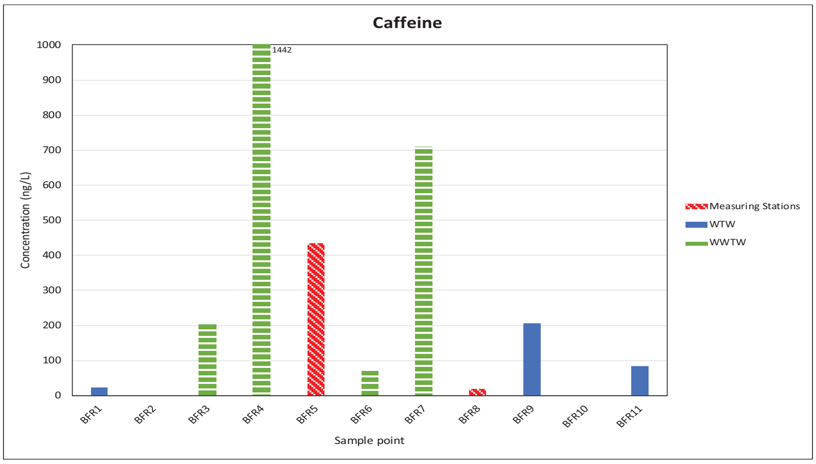


Figure D6.1: Concentrations of Caffeine in the Buffalo River

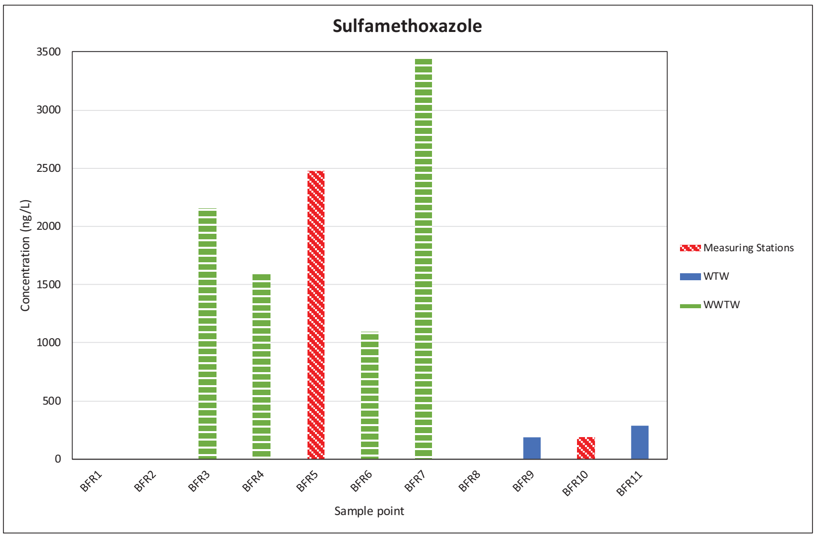


Figure D6.2: Concentrations of Sulfamethoxazole in the Buffalo River

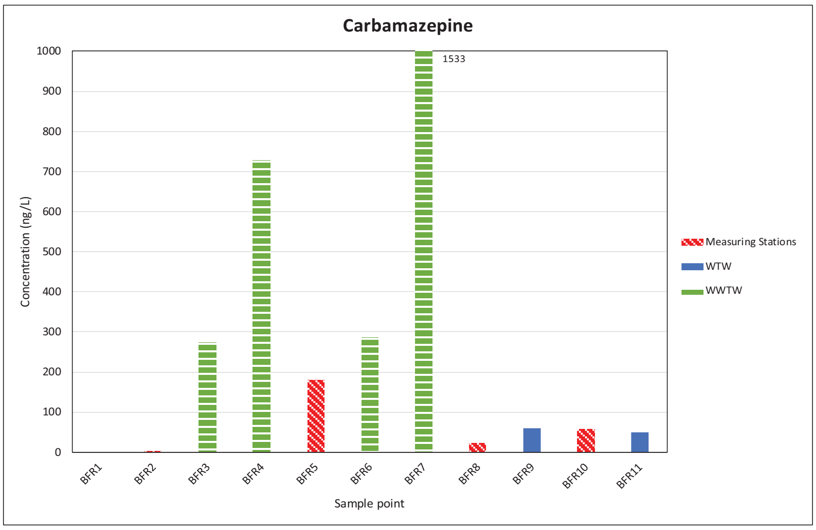


Figure D6.3: Concentrations of Carbamazepine in the Buffalo River

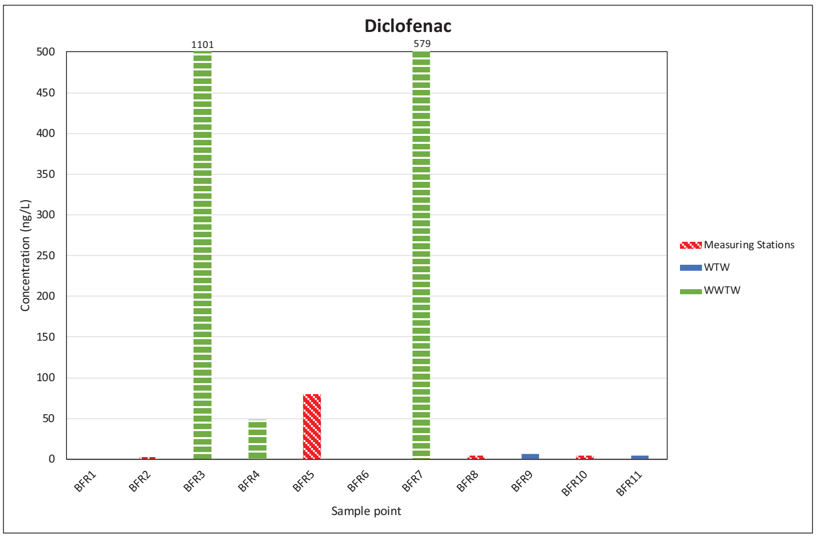


Figure D6.4: Concentrations of Diclofenac in the Buffalo River

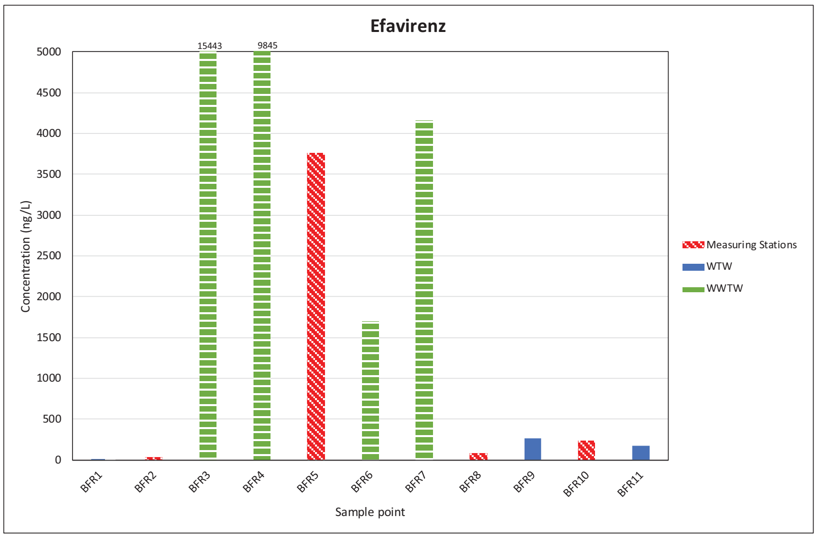


Figure D6.5: Concentrations of Efavirenz in the Buffalo River

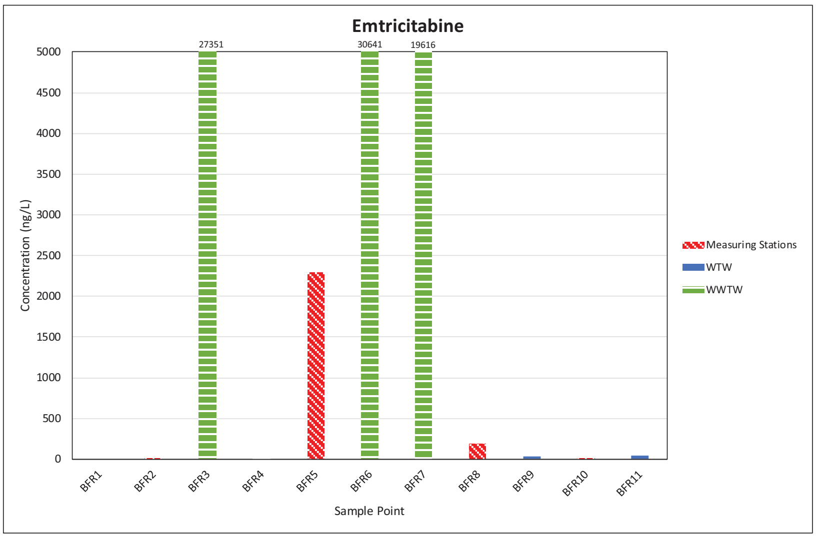


Figure D6.6: Concentrations of Emtricitabine in the Buffalo River

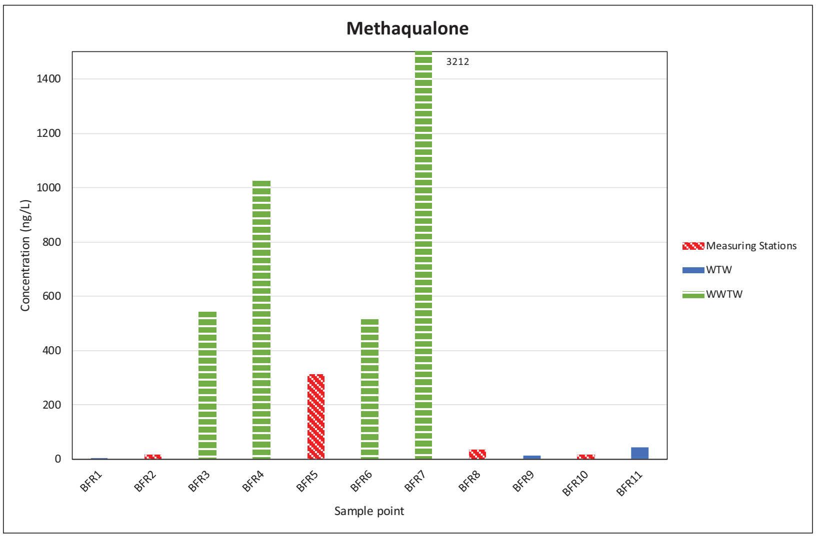


Figure D6.7: Concentrations of Methaqualone in the Buffalo River

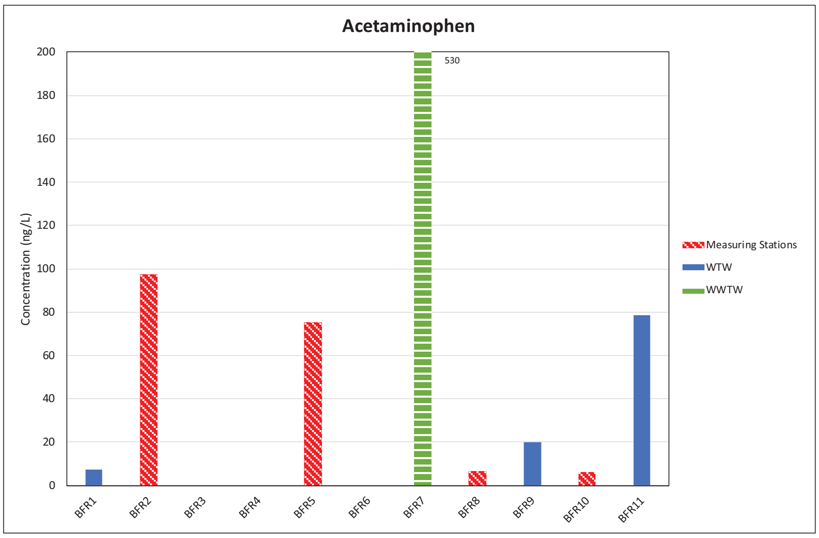


Figure D6.8: Concentrations of Acetaminophen in the Buffalo River

D7: Results of Other Water Quality Parameters for the Buffalo River

Sample Points	pH	EC	COD	UV 254	DOC
	-	mS/m	mg/L	m^{-1}	mg/L
King Williams Town WTP	7.82	7.07	41	0.10	2.94
R2H005 Buffalo @ King Williams Town	7.97	25.16	41	0.16	3.77
Schornville WWTP	7.81	61.38	76	0.25	5.07
Zwelitsha WWTP	8.21	76.35	86	0.26	5.26
R2H010 Macintyre Bridge	8.86	56.80	69	0.24	4.92
Bhisho WWTP	8.42	82.25	121	0.37	6.72
Breidbach WWTP	7.67	84.94	132	0.58	9.73
R2H015 Yellowwoods @ Fort M	8.24	23.20	40	0.15	3.70
Laing WTP	8.22	40.90	44	0.17	3.95
R2H027 Buffalo @ Needs Camp	8.33	42.56	44	0.19	4.14
Umzonyana WTP	8.53	31.79	40	0.14	3.51

APPENDIX E RESULTS FOR THE MODDER RIVER

E1: Flow-based data and calculations for the Modder River

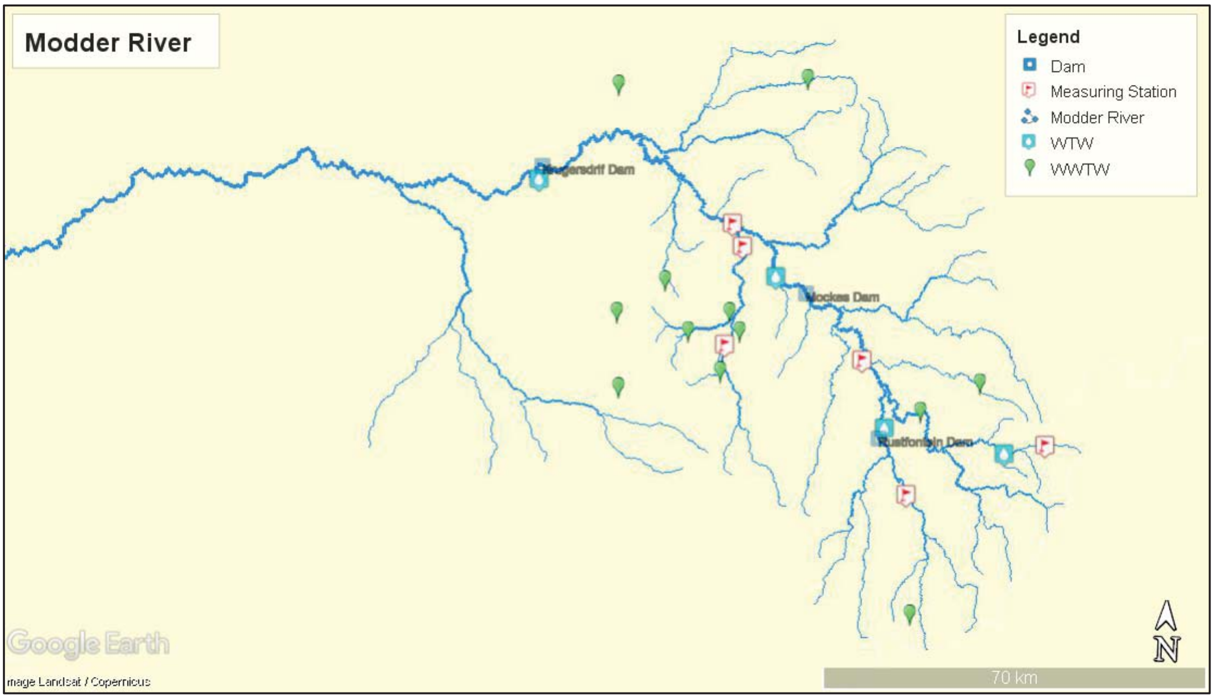


Figure E1.1: Modder River System, indicating all measuring stations, WWTP and WTP in this river.

Table E1.1: Summary of Wastewater Percentages for the Modder River for 2015-2019

Modder River									
Measuring station/ Water Treatment Works	**% wastewater in river (m³/s) when river flow is at its minimum, average and median flow**								
	2015			**2016**			**2017**		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C5H056 Modder @ Diepwater	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rustfontein WTW	0%	0%	0%	0%	0%	0%	0%	0%	0%
C5H003 Modder @ Likatlong	57%	30%	49%	66%	19%	47%	48%	18%	27%
Maselspoort WTW	64%	36%	55%	72%	24%	53%	55%	22%	32%
C5H007 Renoster Sp @ Shanno	42%	19%	33%	51%	11%	32%	33%	11%	17%
C5H054 Renoster Sp @ Bishop	76%	60%	65%	85%	61%	72%	89%	55%	65%
C5H053 Modder @ Glen	77%	59%	63%	84%	33%	62%	87%	36%	43%
Measuring station/ Water Treatment Works	**2018**			**2019**			**2015 -2019**		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C5H056 Modder @ Diepwater	1%	0%	0%	3%	0%	0%	0%	0%	0%
Rustfontein WTW	1%	0%	0%	3%	0%	0%	0%	0%	0%
C5H003 Modder @ Likatlong	39%	13%	24%	45%	17%	36%	50%	18%	34%
Maselspoort WTW	46%	16%	29%	52%	21%	42%	56%	22%	40%
C5H007 Renoster Sp @ Shanno	26%	7%	14%	31%	10%	23%	40%	22%	32%
C5H054 Renoster Sp @ Bishop	74%	52%	61%	80%	48%	62%	81%	55%	65%
C5H053 Modder @ Glen	82%	21%	38%	75%	16%	45%	78%	27%	48%

Table E1.2: Wastewater percentage calculations for the Modder River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Modder River																
Measuring station/ Water Treatment Works	Coordinates		2015													
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.6593	1.4165	1.4612	0.0006							0.0006	0%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.6593	1.4165	1.4612	0.0006							0.0006	0%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.1716	0.5370	0.2462	0.0006	0.2315						0.2321	57%	30%	49%
Maselspoort WTW	-29.032477°	26.405856°	0.1716	0.5370	0.2462	0.0006	0.2315	0.0694					0.3015	64%	36%	55%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.1716	0.5370	0.2462				0.1238				0.1238	42%	19%	33%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.2983	0.6338	0.5050				0.1238	0.0104	0.6481	0.1736	0.9560	76%	60%	65%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.3712	0.8842	0.7422	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	77%	59%	63%

(b)

Modder River																
Measuring station/ Water Treatment Works	Coordinates		2016													
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.5789	1.1713	1.1517	0.0006							0.0006	0%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.5789	1.1713	1.1517	0.0006							0.0006	0%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.1184	0.9674	0.2656	0.0006	0.2315						0.2321	66%	19%	47%
Maselspoort WTW	-29.032477°	26.405856°	0.1184	0.9674	0.2656	0.0006	0.2315	0.0694					0.3015	72%	24%	53%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.1184	0.9674	0.2656				0.1238				0.1238	51%	11%	32%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.1656	0.6168	0.3634				0.1238	0.0104	0.6481	0.1736	0.9560	85%	61%	72%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.2310	2.5621	0.7609	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	84%	33%	62%

(c)

Modder River																
			2017													
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.2998	1.0123	0.7763	0.0006							0.0006	0%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.2998	1.0123	0.7763	0.0006							0.0006	0%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.2467	1.0412	0.6263	0.0006	0.2315						0.2321	48%	18%	27%
Maselspoort WTW	-29.032477°	26.405856°	0.2467	1.0412	0.6263	0.0006	0.2315	0.0694					0.3015	55%	22%	32%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.2467	1.0412	0.6263				0.1238				0.1238	33%	11%	17%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.1189	0.7703	0.5210				0.1238	0.0104	0.6481	0.1736	0.9560	89%	55%	65%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.1868	2.2823	1.6918	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	87%	36%	43%

(d)

Modder River																
			2018													
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity							Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.0907	0.9827	0.6501	0.0006							0.0006	1%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.0907	0.9827	0.6501	0.0006							0.0006	1%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.3568	1.5711	0.7344	0.0006	0.2315						0.2321	39%	13%	24%
Maselspoort WTW	-29.032477°	26.405856°	0.3568	1.5711	0.7344	0.0006	0.2315	0.0694					0.3015	46%	16%	29%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.3568	1.5711	0.7344				0.1238				0.1238	26%	7%	14%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.3338	0.9001	0.5998				0.1238	0.0104	0.6481	0.1736	0.9560	74%	52%	61%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.2783	4.6875	2.0391	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	82%	21%	38%

(e)

Modder River

Measuring station/ Water Treatment Works	Coordinates		2019: River Flow Measurements (m³/s)			Wastewater treatment plants discharge into the river (m³/s) - Design Capacity							Cumulative flow	% wastewater in river (m³/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.0189	1.1293	1.1118	0.0006							0.0006	3%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.0189	1.1293	1.1118	0.0006							0.0006	3%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.2821	1.1605	0.4083	0.0006	0.2315						0.2321	45%	17%	36%
Maselspoort WTW	-29.032477°	26.405856°	0.2821	1.1605	0.4083	0.0006	0.2315	0.0694					0.3015	52%	21%	42%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.2821	1.1605	0.4083				0.1238				0.1238	31%	10%	23%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.2333	1.0228	0.5759				0.1238	0.0104	0.6481	0.1736	0.9560	80%	48%	62%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.4249	6.5242	1.5360	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	75%	16%	45%

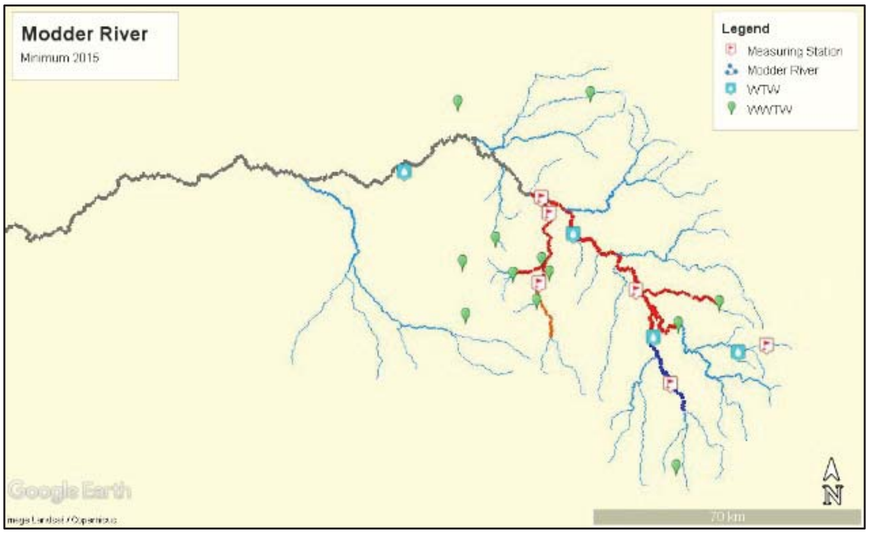
(f)

Modder River

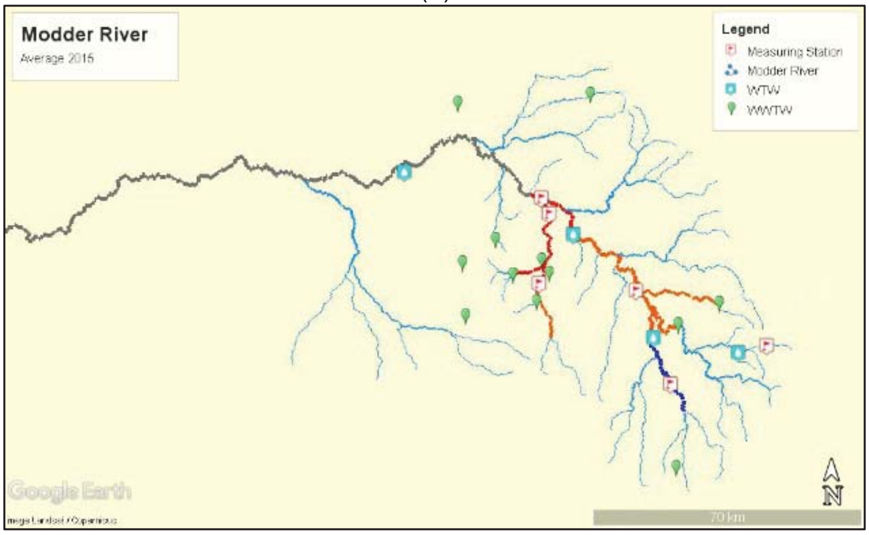
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019: River Flow Measurements (m³/s)			Wastewater treatment plants discharge into the river (m³/s) - Design Capacity							Cumulative flow	% wastewater in river (m³/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Dewtsdorp	Botshabelo	Selosesha	Sterkwater	Bloemdustria	Bloemspruit	North Eastern		Min	Average	Median
C5H056 Modder @ Diepwater	-29.375849°	26.665832°	0.3300	1.1420	2.0000	0.0006							0.0006	0%	0%	0%
Rustfontein WTW	-29.269701°	26.619559°	0.3300	1.1420	1.0300	0.0006							0.0006	0%	0%	0%
C5H003 Modder @ Likatlong	-29.160920°	26.572395°	0.2350	1.0550	0.4560	0.0006	0.2315						0.2321	50%	18%	34%
Maselspoort WTW	-29.032477°	26.405856°	0.2350	1.0550	0.4560	0.0006	0.2315	0.0694					0.3015	56%	22%	40%
C5H007 Renoster Sp @ Shanno	-29.145374°	26.315981°	0.1880	0.4430	0.2690				0.1238				0.1238	40%	22%	32%
C5H054 Renoster Sp @ Bishop	-28.985028°	26.341494°	0.2300	0.7890	0.5130				0.1238	0.0104	0.6481	0.1736	0.9560	81%	55%	65%
C5H053 Modder @ Glen	-28.948763°	26.321237°	0.3490	3.3880	1.3540	0.0006	0.2315	0.0694	0.1238	0.0104	0.6481	0.1736	1.2575	78%	27%	48%

E2: De facto wastewater percentage maps for the different time periods for the Modder River

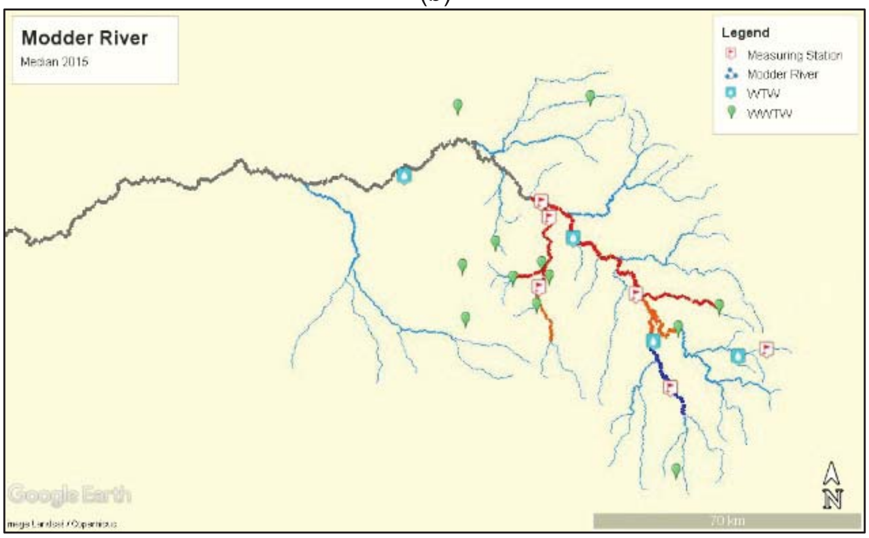
- **<u>Wastewater Contributions in 2015</u>**



(a)



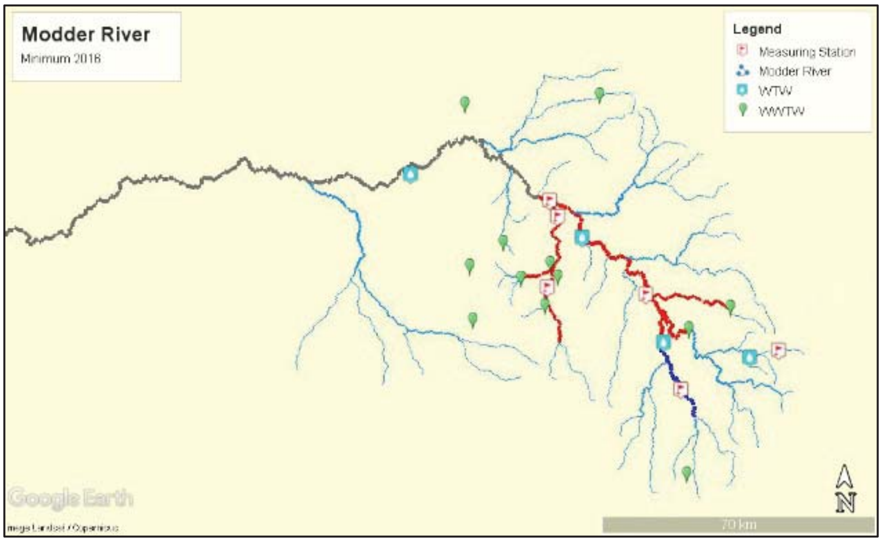
(b)



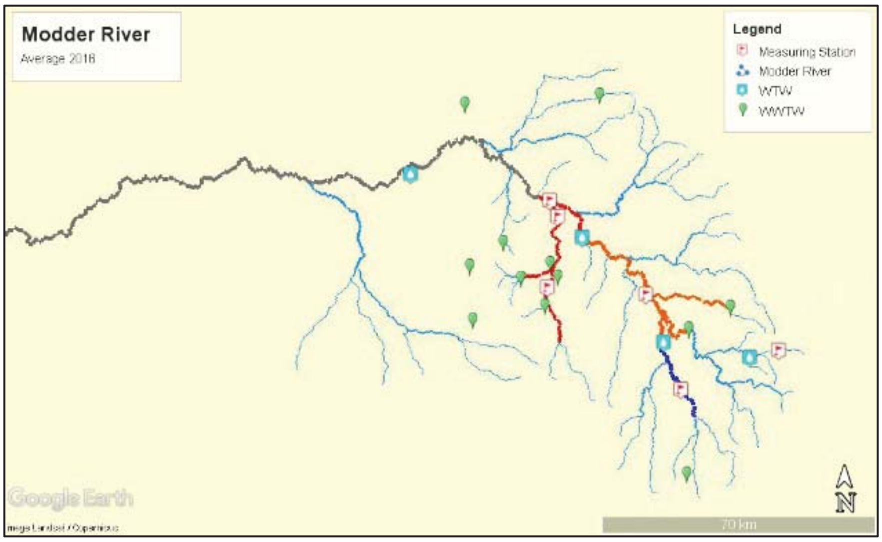
(c)

Figure E2.1: Wastewater contribution in the Modder River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

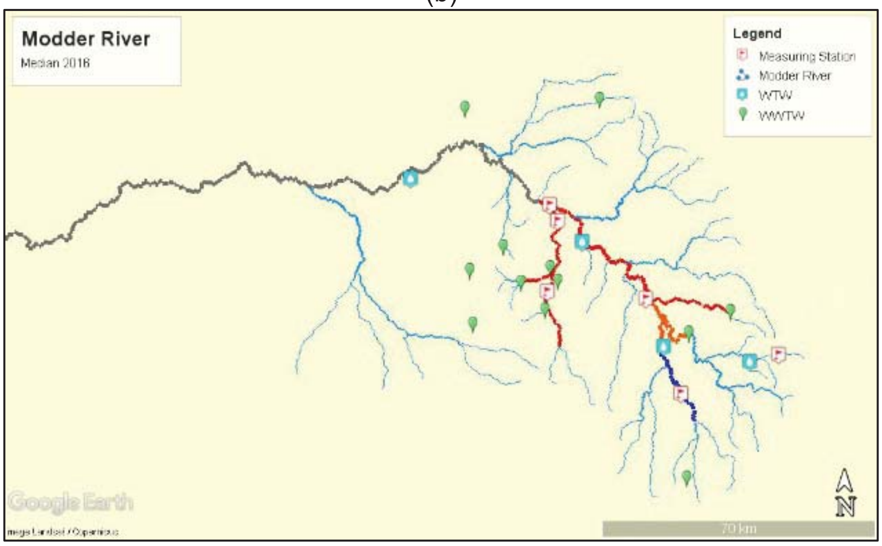
- **Wastewater Contributions in 2016**



(a)



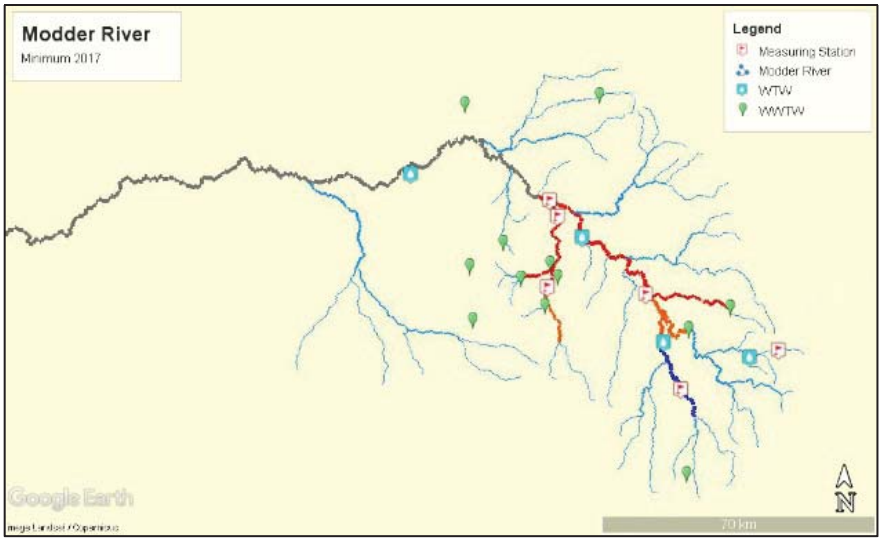
(b)



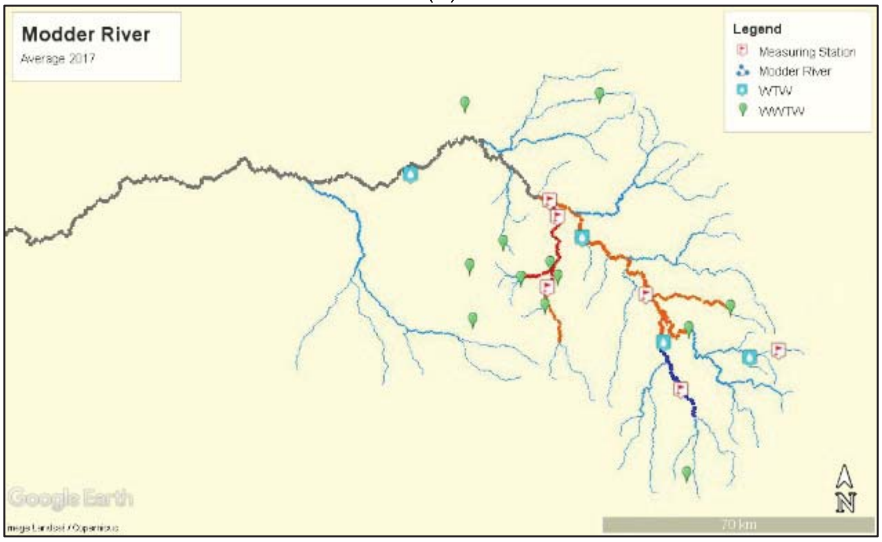
(c)

Figure E2.2: Wastewater contribution in the Modder River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

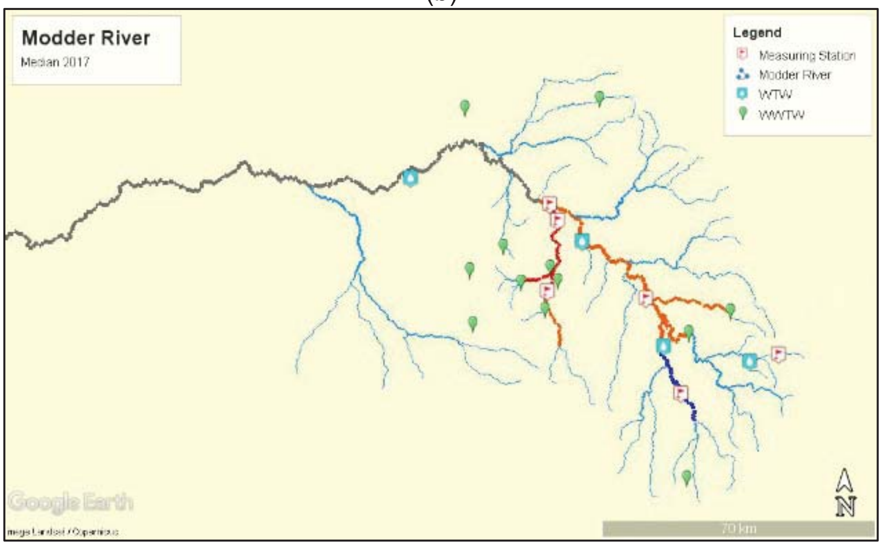
- **Wastewater Contributions in 2017**



(a)



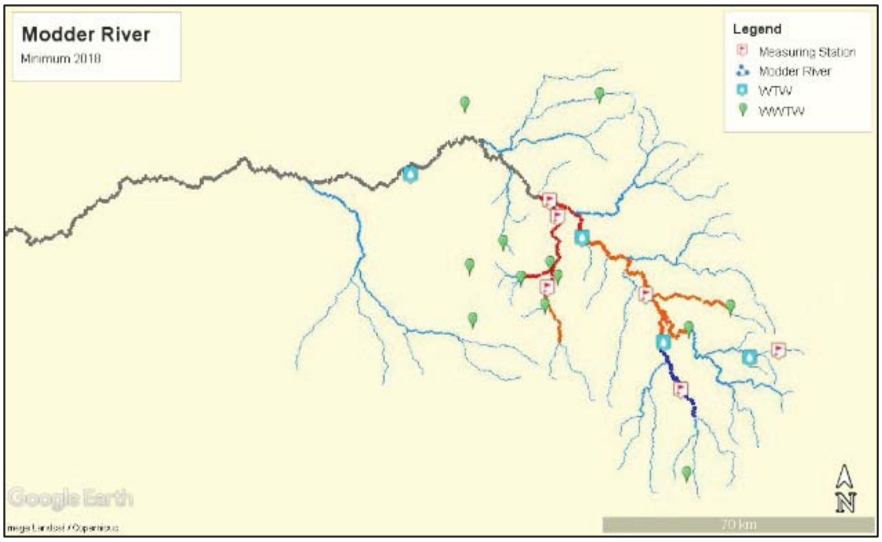
(b)



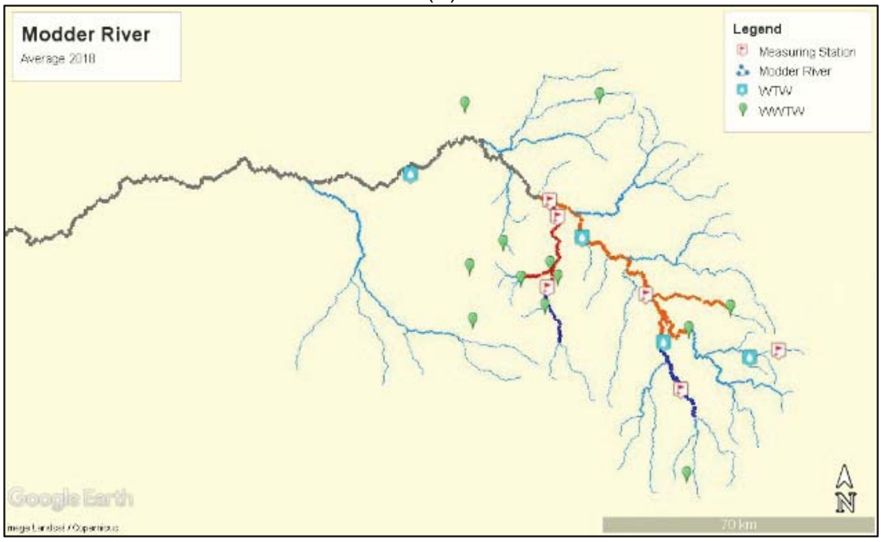
(c)

Figure E2.3: Wastewater contribution in the Modder River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

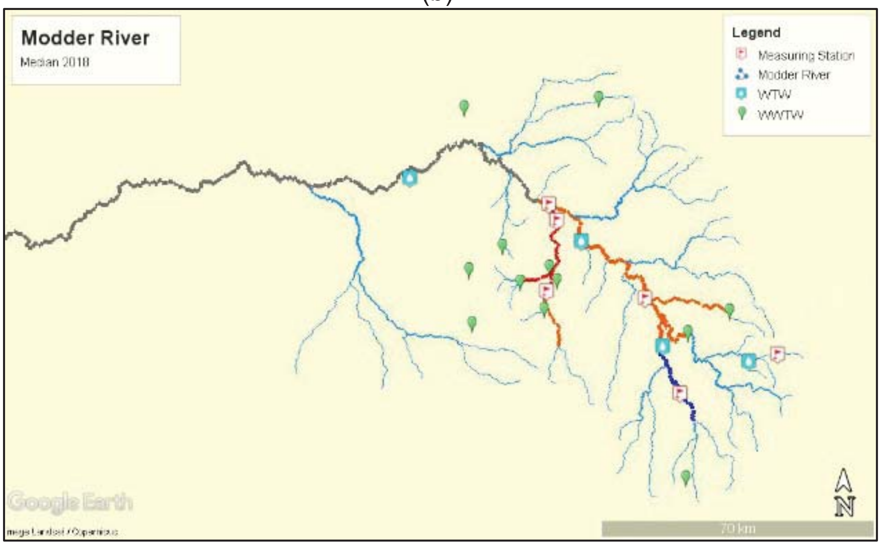
- **Wastewater Contributions in 2018**



(a)



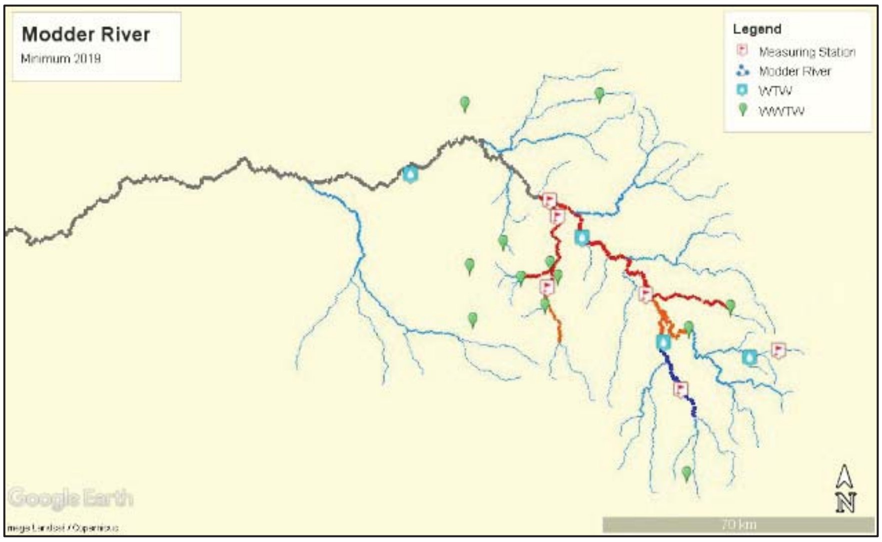
(b)



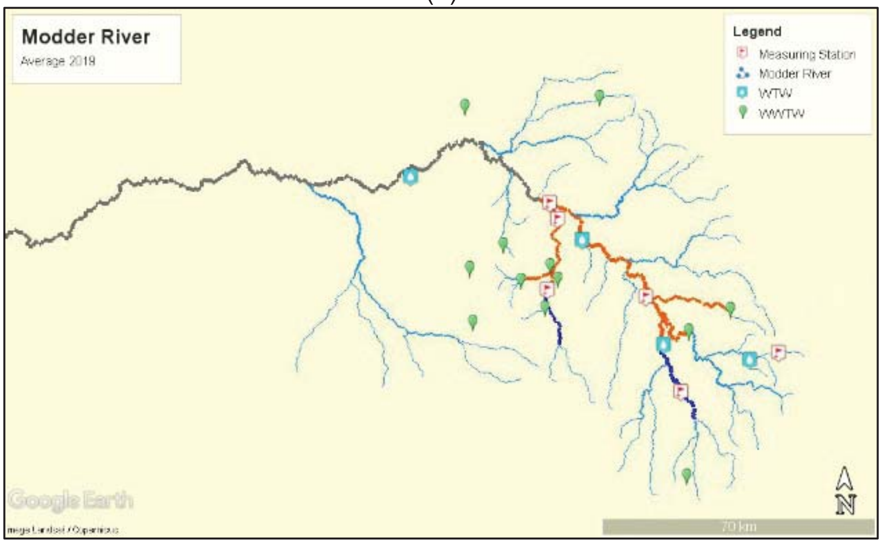
(c)

Figure E2.4: Wastewater contribution in the Modder River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

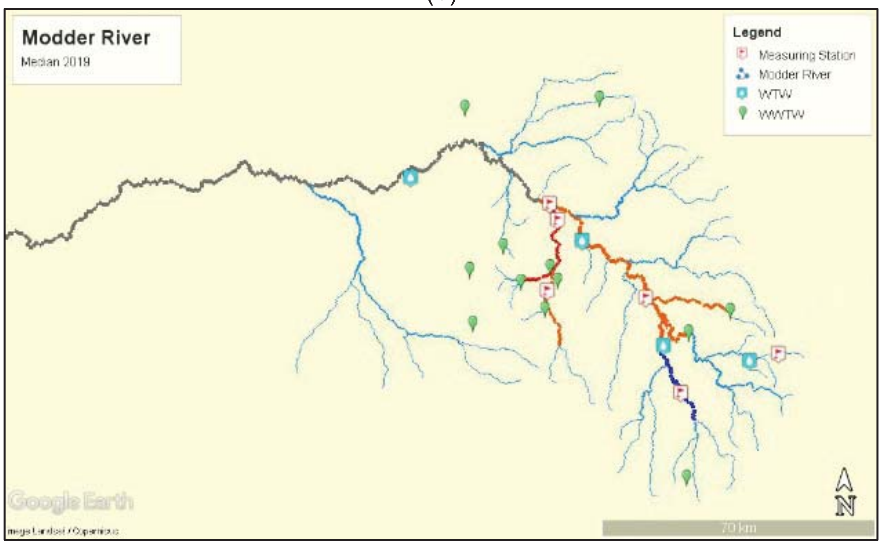
- **Wastewater Contributions in 2019**



(a)



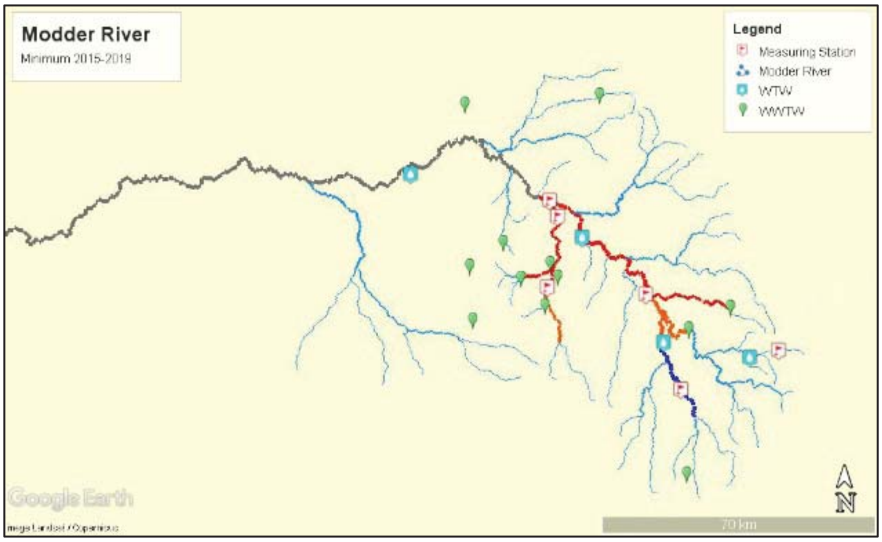
(b)



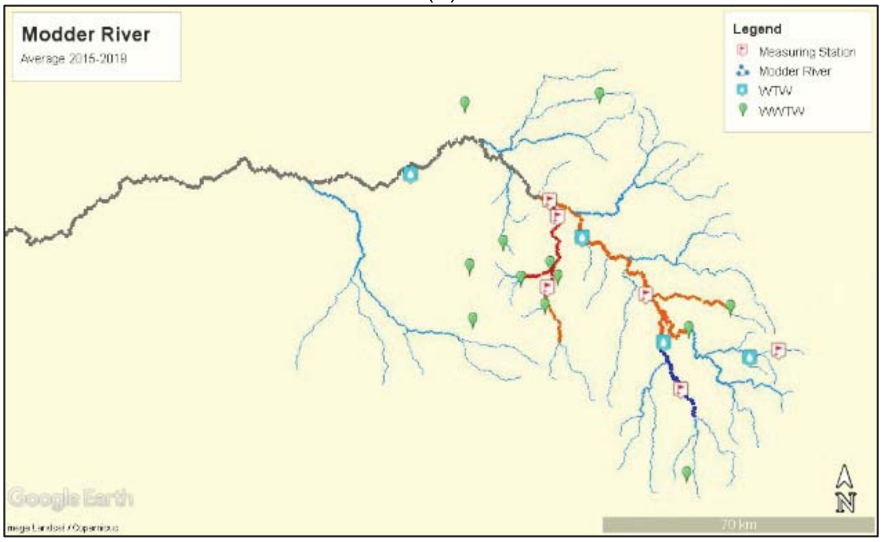
(c)

Figure E2.5: Wastewater contribution in the Modder River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

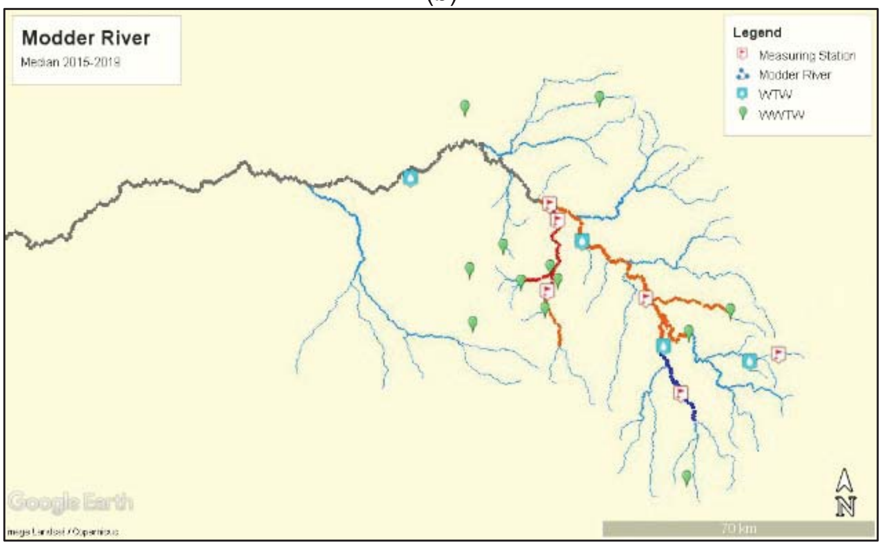
- **<u>Wastewater Contributions in 2015-2019</u>**



(a)



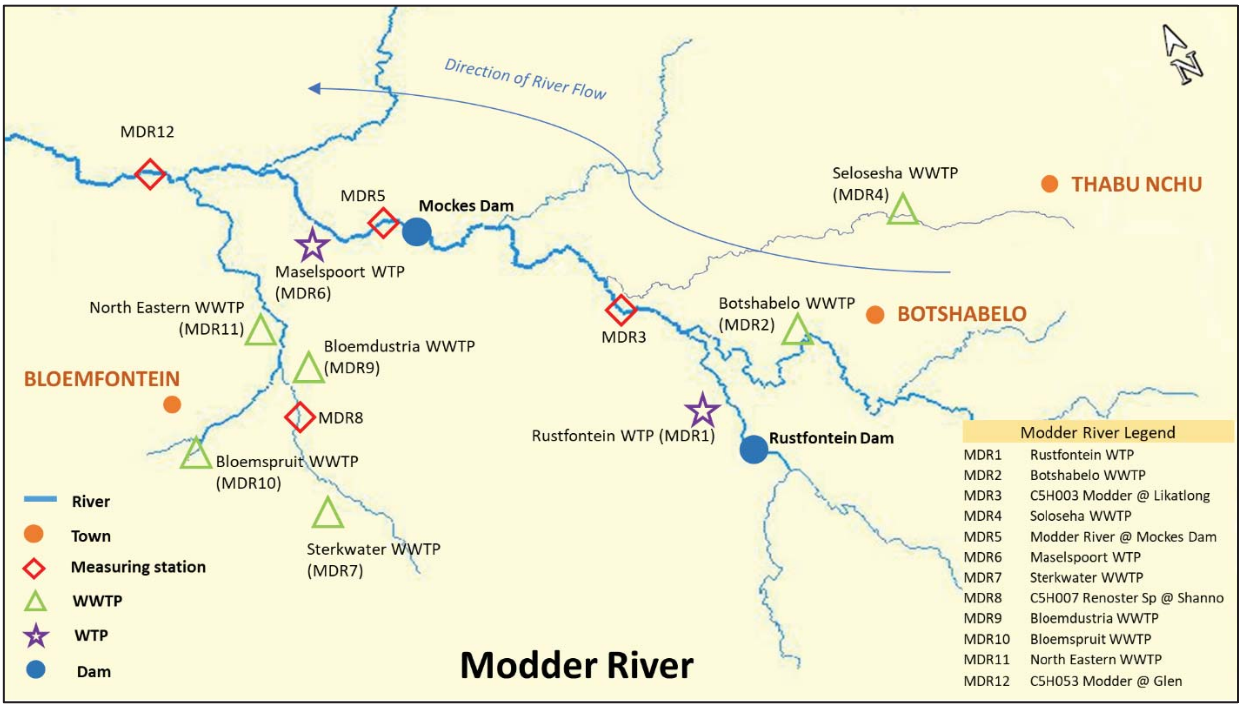
(b)



(c)

Figure E2.6: Wastewater contribution in the Modder River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

E3: Map of sampling points for CEC analysis in the Modder River



E4: CEC Concentration Results Legend for the Modder River

Modder River Legend	
MDR1	Rustfontein WTP
MDR2	Botshabelo WWTP
MDR3	C5H003 Modder @ Likatlong
MDR4	Soloseha WWTP
MDR5	Modder River @ Mockes Dam
MDR6	Maselspoort WTP
MDR7	Sterkwater WWTP
MDR8	C5H007 Renoster Sp @ Shanno
MDR9	Bloemdustria WWTP
MDR10	Bloemspruit WWTP
MDR11	North Eastern WWTP
MDR12	C5H053 Modder @ Glen

E5: Results of the CEC analysis for the Modder River

Table E5.1: Results of the CEC analysis for the Modder River

Constituents	Sampling Points											
	Rustfontein WTW	Botshabelo WWTW	C5H003 Modder @ Likatlong	Soloseha WWTW	Modder River @ Mockes Dam	Maselspoort WTW	Sterkwater WWTW	C5H007 Renoster Sp @ Shanno	Bloemdustria WWTW	Bloemspruit WWTW	North Eastern WWTW	C5H053 Modder @ Glen
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
10,11-dihydro-11-hydroxycarbamazepine	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	87.25	47.61	237.5	319.5	<IQL
Acetaminophen	328.8	39088	<IQL	32981	74.26	<IQL	<IQL	<IQL	<IQL	7832	<IQL	129.1
Benzotriazole	<IQL	<IQL	30.49	<IQL	32.4	<IQL	<IQL	<IQL	<IQL	95.85	86.11	<IQL
Benzoylecgonine	<IQL	<IQL	<IQL	<IQL	18.23	<IQL	55.91	28.69	<IQL	65.52	111	<IQL
Caffeine	61.01	4838	905.2	6533	961.2	102.5	8409	3384	124.1	4554	<IQL	59.35
Carbamazepine	14.33	1630	717.8	1060	454.7	170.1	710	763.6	<IQL	869.4	782.1	145.5
Carbamazepine-10,11-epoxide	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Cocaine	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	44.44	21.8	<IQL	47.18	46.05	<IQL
Codeine	<IQL	325.5	<IQL	455	61.9	<IQL	<IQL	108.3	<IQL	319.6	1011	<IQL
Diclofenac	<IQL	236.2	28.68	368.8	29.22	20.45	179.4	118.4	<IQL	161.3	418	20.16
Efavirenz	186.9	10036	2999	8932	1334	494.3	15501	8540	302	5859	5445	479.2
Emtricitabine	<IQL	75302	15991	43241	2320	96.76	81691	49322	1368	8899	27588	104.9
MDMA	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Methamphetamine	<IQL	<IQL	<IQL	29.52	<IQL	<IQL	37.37	29.46	<IQL	64.15	43.43	<IQL
Methaqualone	3.65	309.2	155.5	491.9	355	25.21	1271	985.3	21.35	307.4	995	30.14
Naproxen	<IQL	335.8	<IQL	954.8	149.6	<IQL	611.4	312.7	<IQL	1161	780.7	<IQL
Sulfamethoxazole	7.421	1248	583.3	1936	239.9	75.33	146.6	830.6	<IQL	654.7	510.3	41.49

* <IQL = Less than Instrument Quantification Limits

E6: Bar charts of indicator compound results in the Modder River

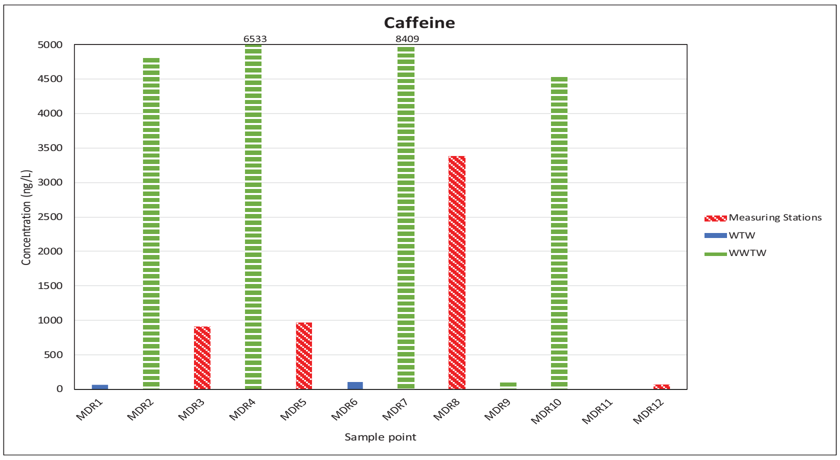


Figure E6.1: Concentrations of Caffeine in the Modder River

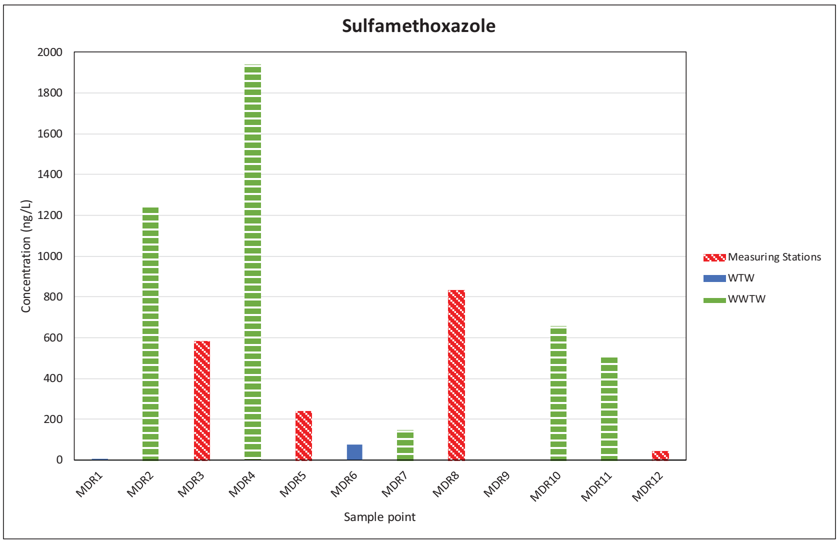


Figure E6.2: Concentrations of Sulfamethoxazole in the Modder River

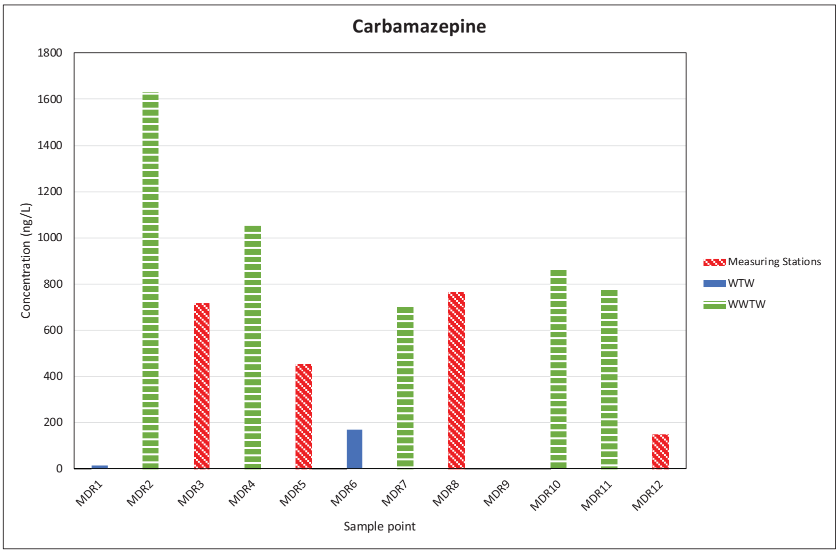


Figure E6.3: Concentrations of Carbamazepine in the Modder River

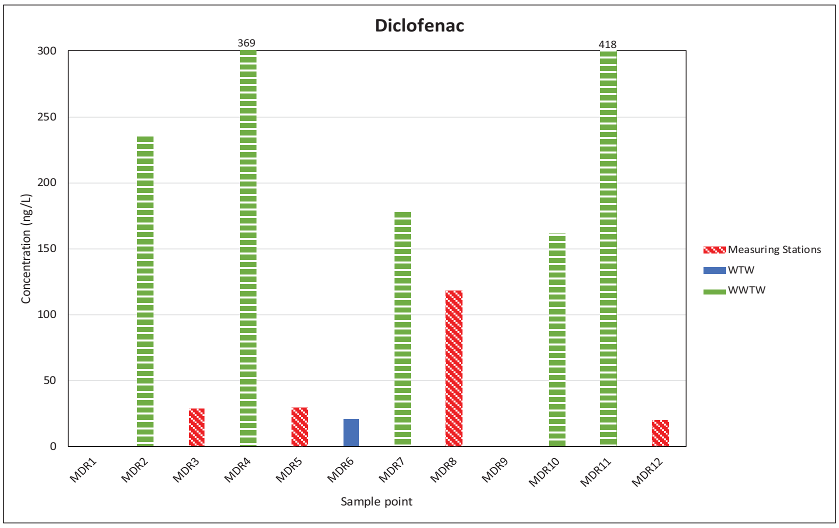


Figure E6.4: Concentrations of Diclofenac in the Modder River

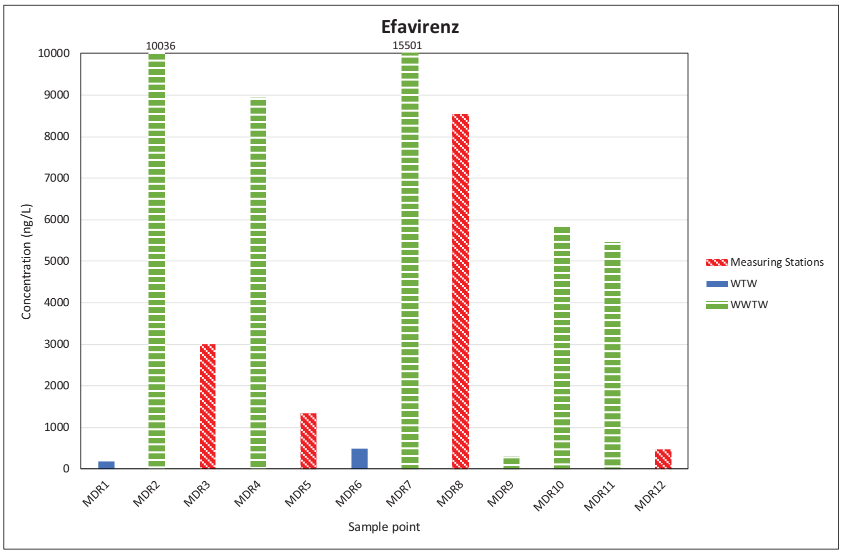


Figure E6.5: Concentrations of Efavirenz in the Modder River

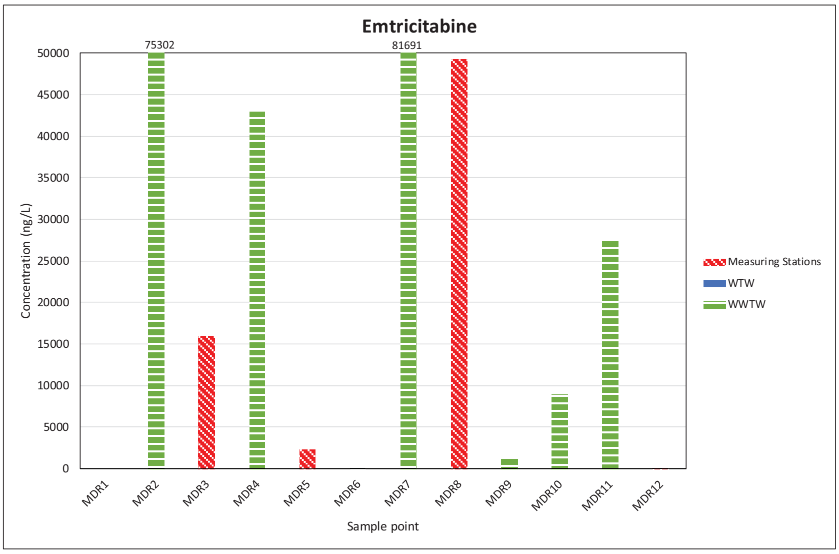


Figure E6.6: Concentrations of Emtricitabine in the Modder River

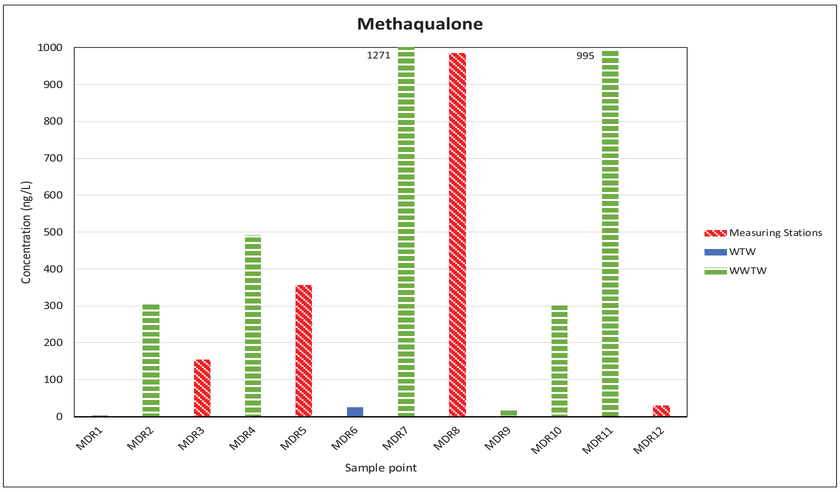


Figure E6.7: Concentrations of Methaqualone in the Modder River

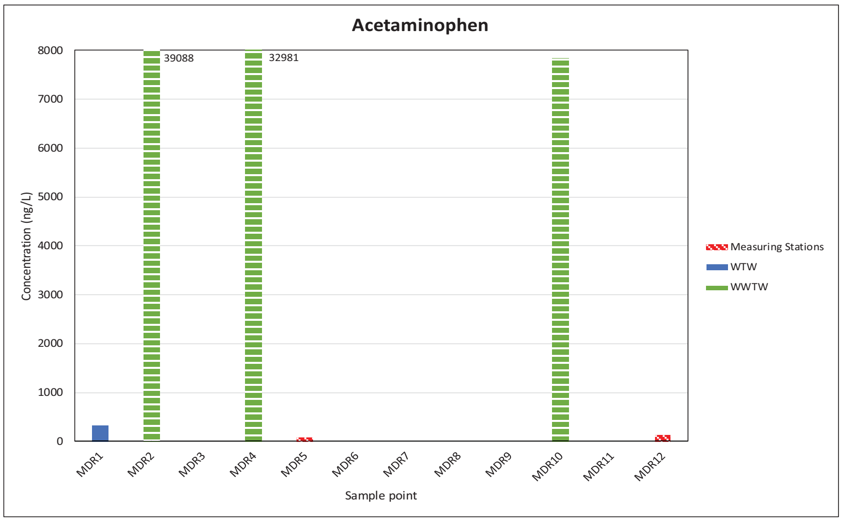


Figure E6.8: Concentrations of Acetaminophen in the Modder River

E7: Results of Other Water Quality Parameters for the Modder River

Sample Points	pH	EC	COD	UV 254	DOC
	-	mS/m	mg/L	m^{-1}	mg/L
Sterkwater WWTP	7.65	53.01	73	0.27	5.37
C5H007 Renoster Sp @ Shanno	8.13	64.77	77	0.22	4.57
Bloemspruit WWTP	7.69	68.6	130	0.34	6.38
North Eastern WWTP	7.91	70.55	87	0.59	9.85
Botshabelo WWTP	7.65	84.06	219	1.08	16.76
Seloseha WWTP	7.35	84.86	176	1.21	18.72
Rustfontein WTP	7.6	18.87	<25	0.37	6.70
C5H003 Modder @ Likatlong	7.65	58.82	27	0.40	7.19
Bloemdustria WWTP	8.12	83.81	91	0.72	11.78
Maselspoort WTP	8.19	21.64	<25	0.25	4.99
Modder @ Mockes Dam	8.02	18.68	<25	0.24	4.84
C5H053 Modder @ Glen	8.63	53.07	68	0.18	3.99

APPENDIX F RESULTS FOR THE UMGENI/DUZI RIVER

F1: Flow-based data and calculations for the Umgeni/Msunduzi River

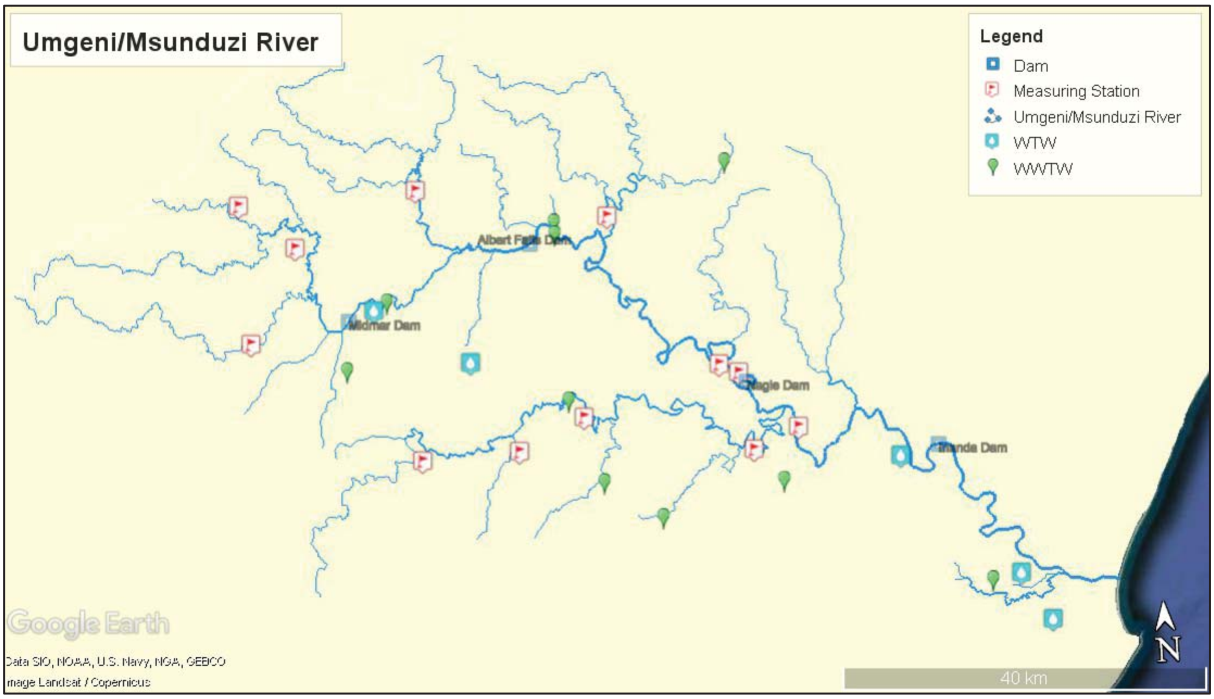


Figure F1.1: Umgeni/Msunduzi River System, indicating all measuring stations, WWTP and WTP in this river.

Table F1.1: Summary of Wastewater Percentages for the Umgeni/Msunduzi River for 2015-2019

Umgeni/Msunduzi River									
Measuring station/ Water Treatment Works	% wastewater in river (m³/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
U2H012 Mpolweni @ Sterk River	9%	4%	5%	4%	3%	3%	5%	2%	2%
U2H005 Table Mountain	2%	2%	2%	3%	2%	3%	3%	2%	2%
U2H041 Motor Cross	32%	17%	19%	37%	14%	17%	38%	12%	16%
U2H022 Duzi Bridge	85%	24%	26%	37%	22%	25%	55%	26%	29%
U2H055 Mgeni @ Inanda Loc.	47%	22%	25%	57%	26%	28%	39%	24%	29%
Measuring station/ Water Treatment Works	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
U2H012 Mpolweni @ Sterk River	1%	1%	1%	1%	1%	1%	2%	1%	1%
U2H005 Table Mountain	4%	2%	3%	3%	2%	2%	3%	2%	2%
U2H041 Motor Cross	24%	6%	7%	36%	12%	12%	32%	11%	13%
U2H022 Duzi Bridge	28%	18%	20%	27%	5%	6%	38%	13%	15%
U2H055 Mgeni @ Inanda Loc.	31%	19%	22%	31%	19%	23%	39%	22%	25%

Table F1.2: Wastewater percentage calculations for Umgeni/Msunduzi River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Umgeni/Msunduzi River																
Measuring station/ Water Treatment Works	Coordinates		2015													
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	0.1834	0.4101	0.3121				0.0174			0.0174	9%	4%	5%
U2H005 Table Mountain	-29.575521°	30.603528°	3.9970	5.8611	5.6890	0.0787	0.0006	0.0005	0.0174			0.0972	2%	2%	2%
U2H041 Motor Cross	-29.618221°	30.447286°	1.9414	4.5641	3.7447					0.9028		0.9028	32%	17%	19%
U2H022 Duzi Bridge	-29.661229°	30.636401°	0.1655	2.8978	2.6060					0.9028	0.0174	0.9201	85%	24%	26%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	1.1300	3.5661	3.0946	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	47%	22%	25%

(b)

Umgeni/Msunduzi River																
Measuring station/ Water Treatment Works	Coordinates		2016													
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	0.3719	0.6469	0.5904				0.0174			0.0174	4%	3%	3%
U2H005 Table Mountain	-29.575521°	30.603528°	2.9029	3.8295	3.6387	0.0787	0.0006	0.0005	0.0174			0.0972	3%	2%	3%
U2H041 Motor Cross	-29.618221°	30.447286°	1.5335	5.3741	4.4550					0.9028		0.9028	37%	14%	17%
U2H022 Duzi Bridge	-29.661229°	30.636401°	1.5984	3.2357	2.7857					0.9028	0.0174	0.9201	37%	22%	25%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	0.7608	2.8632	2.5560	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	57%	26%	28%

(c)

Umgeni/Msunduzi River															
			2017												
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	0.3214	0.9635	0.7682				0.0174			0.0174	5%	2%	2%
U2H005 Table Mountain	-29.575521°	30.603528°	2.9698	4.3593	4.3247	0.0787	0.0006	0.0005	0.0174			0.0972	3%	2%	2%
U2H041 Motor Cross	-29.618221°	30.447286°	1.4853	6.5214	4.6868					0.9028		0.9028	38%	12%	16%
U2H022 Duzi Bridge	-29.661229°	30.636401°	0.7660	2.6737	2.3012					0.9028	0.0174	0.9201	55%	26%	29%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	1.6010	3.2390	2.4566	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	39%	24%	29%

(d)

Umgeni/Msunduzi River															
			2018												
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	1.6139	2.4237	2.3617				0.0174			0.0174	1%	1%	1%
U2H005 Table Mountain	-29.575521°	30.603528°	2.3035	3.8887	3.6860	0.0787	0.0006	0.0005	0.0174			0.0972	4%	2%	3%
U2H041 Motor Cross	-29.618221°	30.447286°	2.8458	13.0191	11.4590					0.9028		0.9028	24%	6%	7%
U2H022 Duzi Bridge	-29.661229°	30.636401°	2.4077	4.1789	3.6922					0.9028	0.0174	0.9201	28%	18%	20%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	2.3081	4.2478	3.6643	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	31%	19%	22%

(e)

Umgeni/Msunduzi River

Measuring station/ Water Treatment Works	Coordinates		2019											
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	1.5568	2.1687	1.9440				0.0174			0.0174	1%	1%	1%
U2H005 Table Mountain	-29.575521°	30.603528°	3.0429	4.7871	4.3137	0.0787	0.0006	0.0005	0.0174			0.0972	3%	2%	2%
U2H041 Motor Cross	-29.618221°	30.447286°	1.6312	6.7942	6.4273					0.9028		0.9028	36%	12%	12%
U2H022 Duzi Bridge	-29.661229°	30.636401°	2.4413	18.4880	15.7284					0.9028	0.0174	0.9201	27%	5%	6%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	2.2316	4.2357	3.4250	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	31%	19%	23%

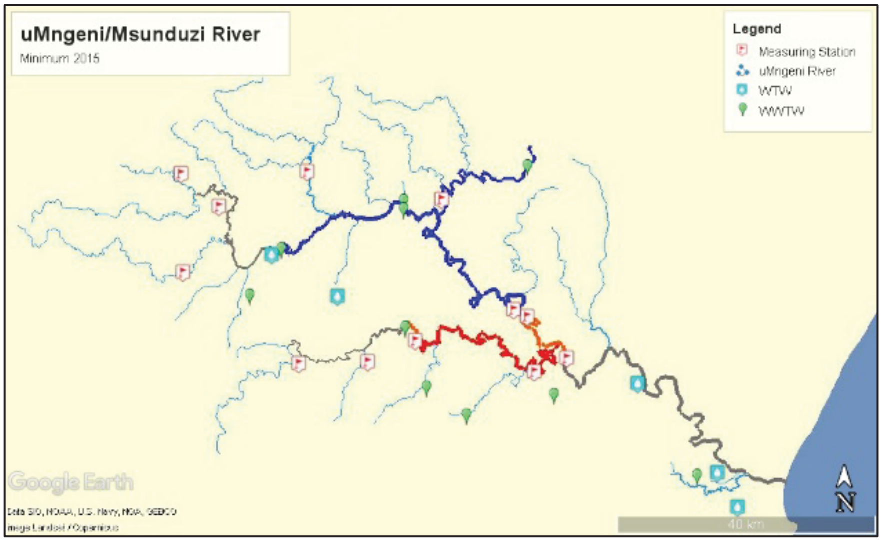
(f)

Umgeni/Msunduzi River

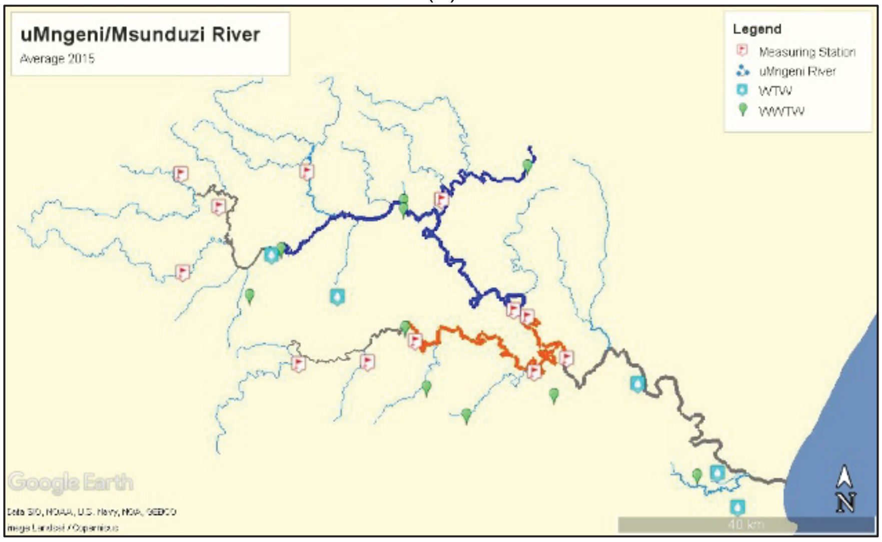
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019											
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity						Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Howick	Albert Falls (N)	Albert Falls (S)	Cool Air	Darvill	Camperdown		Min	Average	Median
U2H012 Mpolweni @ Sterk River	-29.423125°	30.488937°	0.8100	1.3230	1.1950				0.0174			0.0174	2%	1%	1%
U2H005 Table Mountain	-29.575521°	30.603528°	3.0430	4.5450	4.3300	0.0787	0.0006	0.0005	0.0174			0.0972	3%	2%	2%
U2H041 Motor Cross	-29.618221°	30.447286°	1.8870	7.2550	6.1550					0.9028		0.9028	32%	11%	13%
U2H022 Duzi Bridge	-29.661229°	30.636401°	1.4760	6.2950	5.4230					0.9028	0.0174	0.9201	38%	13%	15%
U2H055 Mgeni @ Inanda Loc.	-29.642109°	30.688150°	1.6060	3.6300	3.0390	0.0787	0.0006	0.0005	0.0174	0.9028	0.0174	1.0173	39%	22%	25%

F2: De facto wastewater maps for different time periods for Umgeni/Msunduzi River

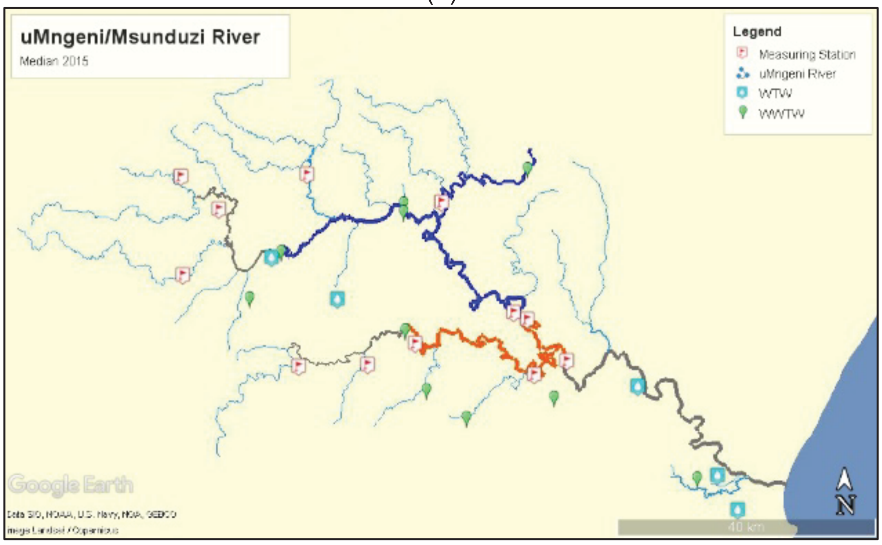
- **Wastewater Contributions in 2015**



(a)



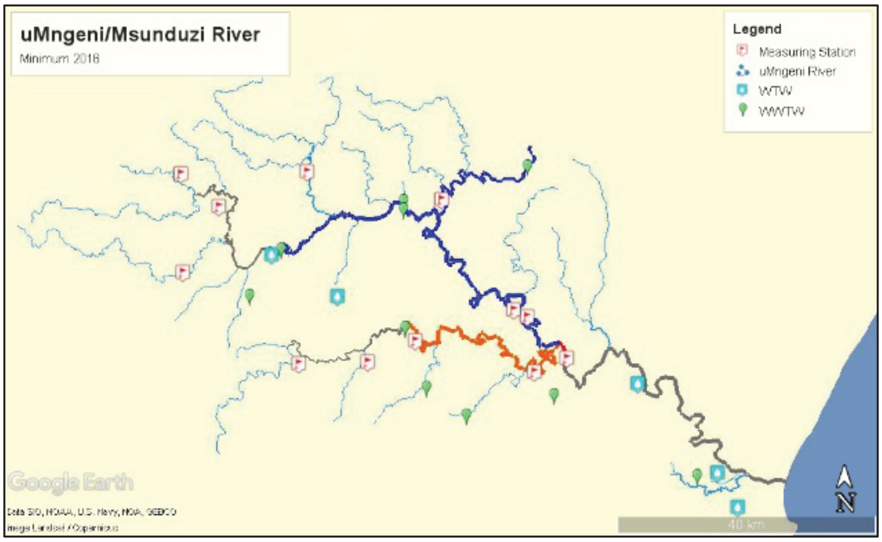
(b)



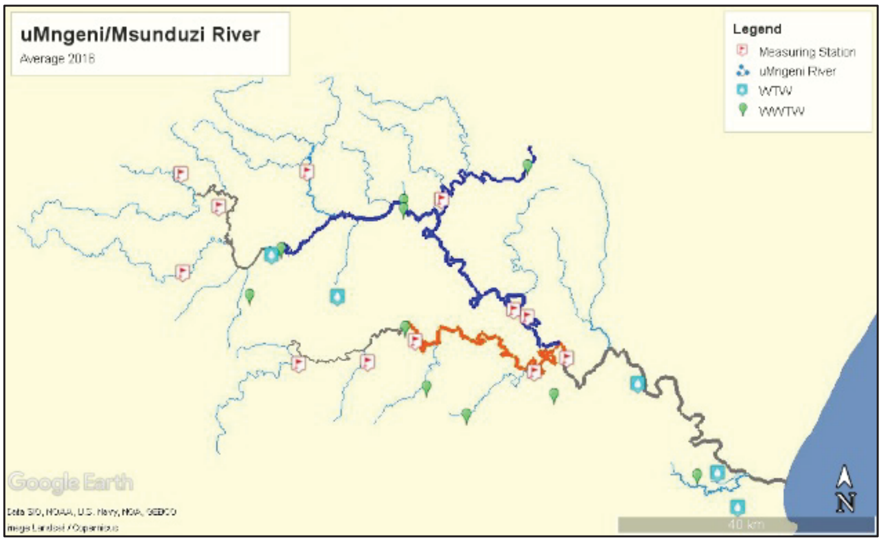
(c)

Figure F2.1: Wastewater contribution in the Umgeni River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

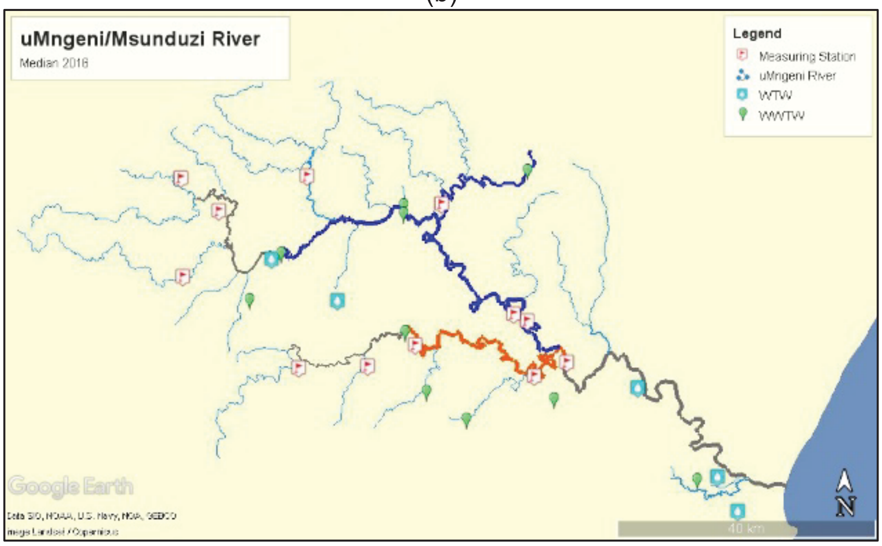
- **Wastewater Contributions in 2016**



(a)



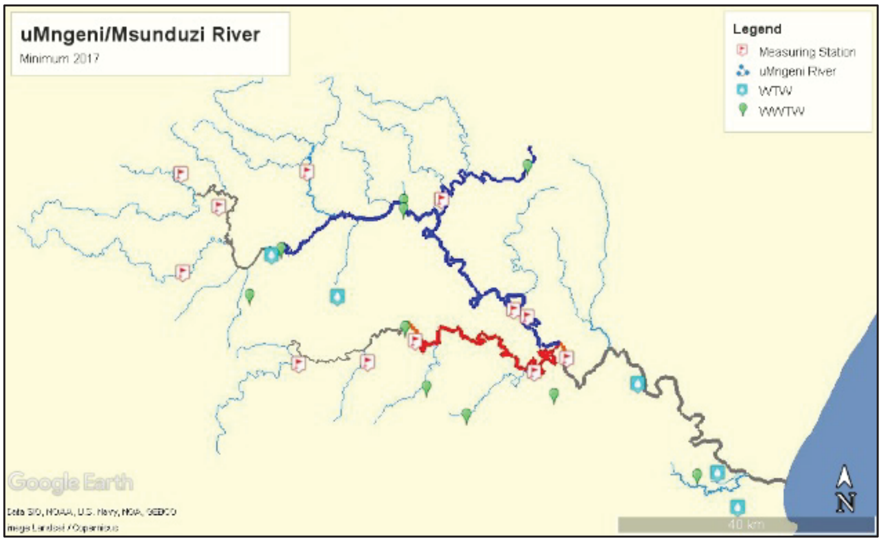
(b)



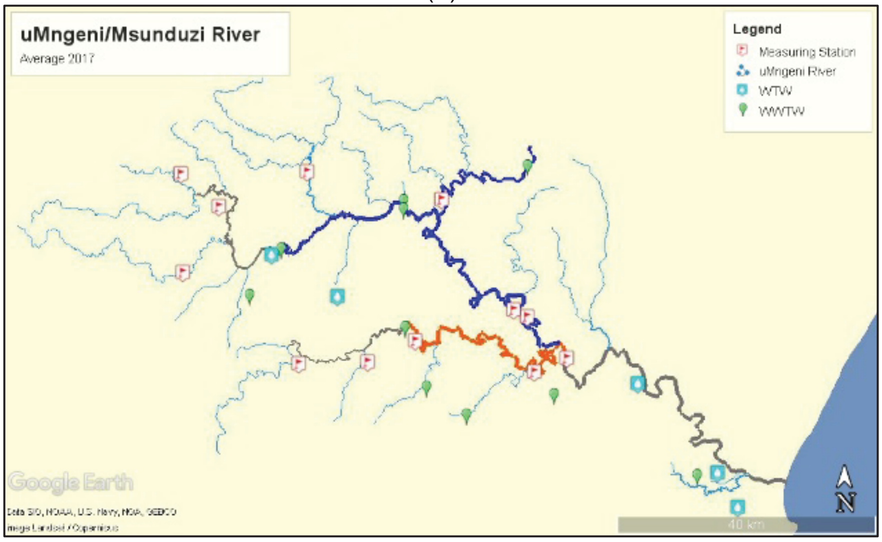
(c)

Figure F2.2: Wastewater contribution in the Umgeni River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

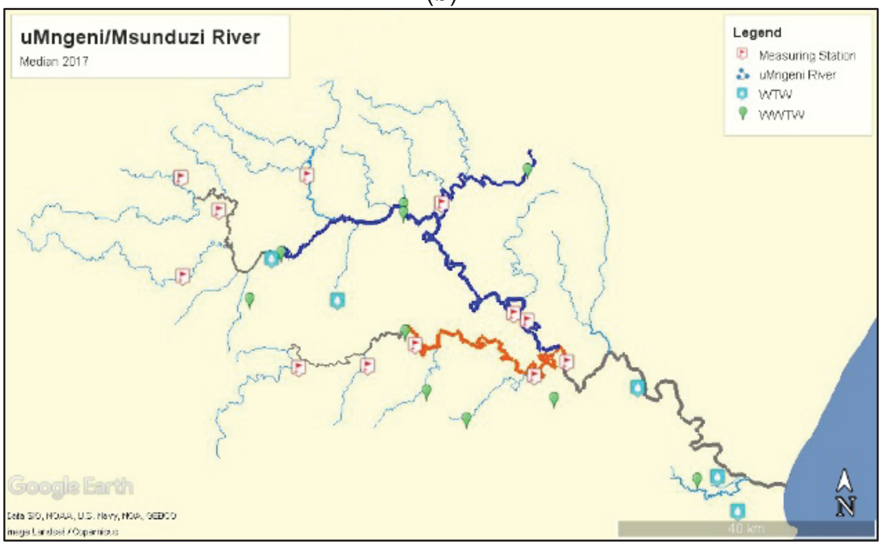
- **<u>Wastewater Contributions in 2017</u>**



(a)



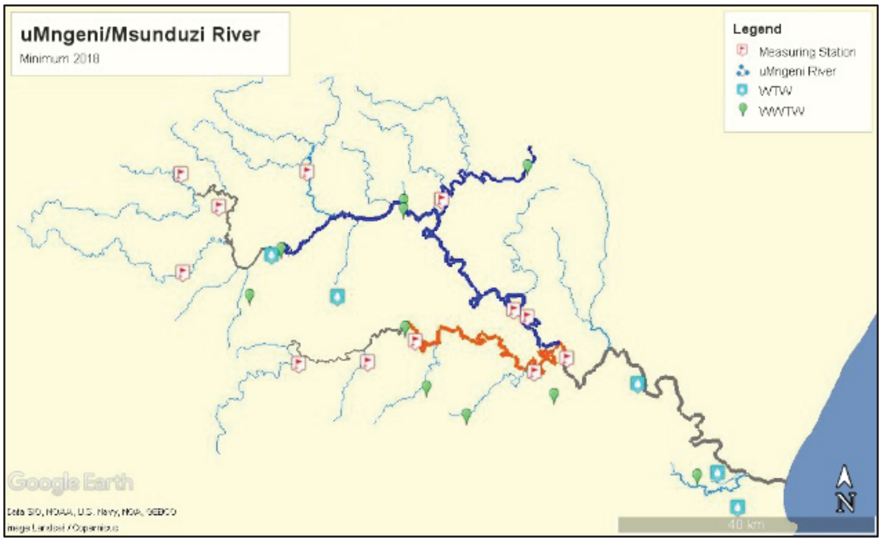
(b)



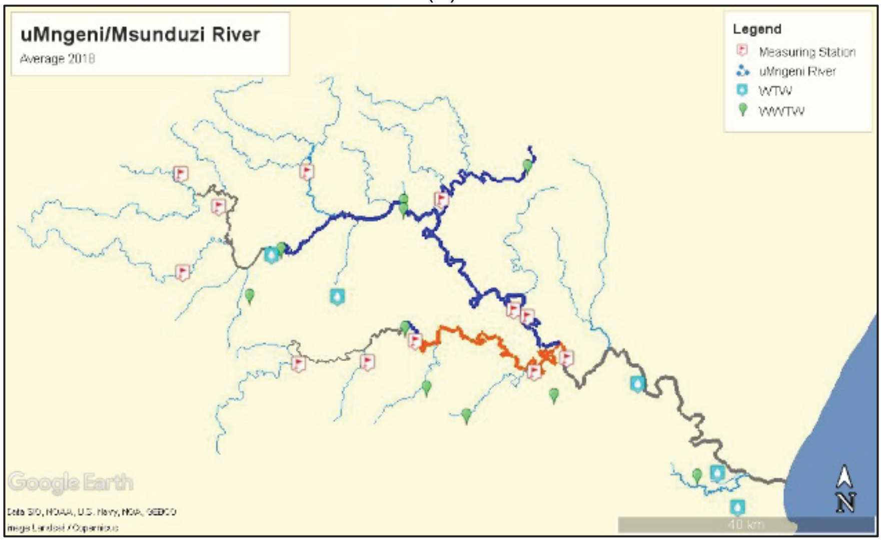
(c)

Figure F2.3: Wastewater contribution in the Umgeni River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

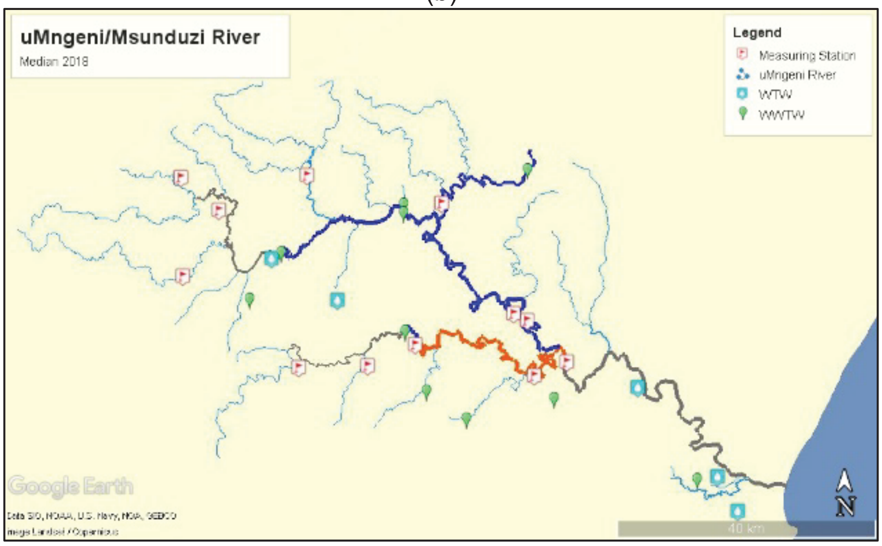
- **<u>Wastewater Contributions in 2018</u>**



(a)



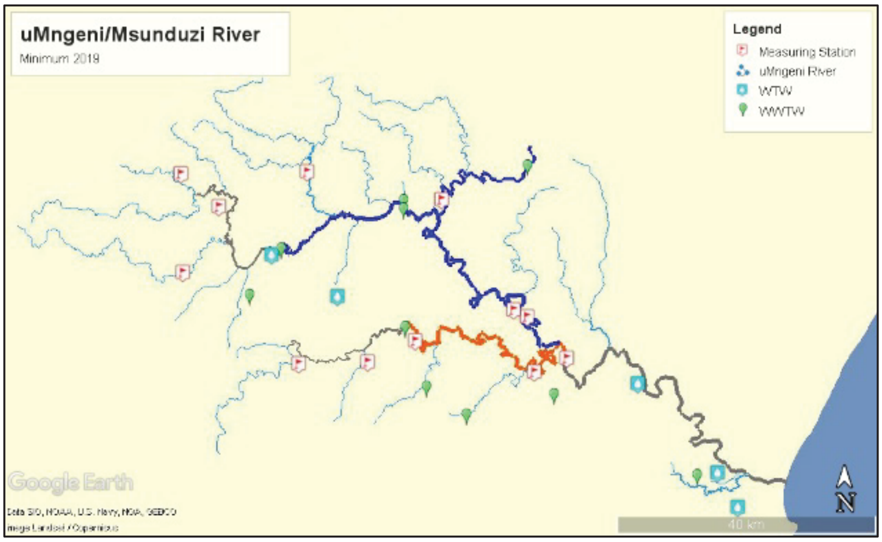
(b)



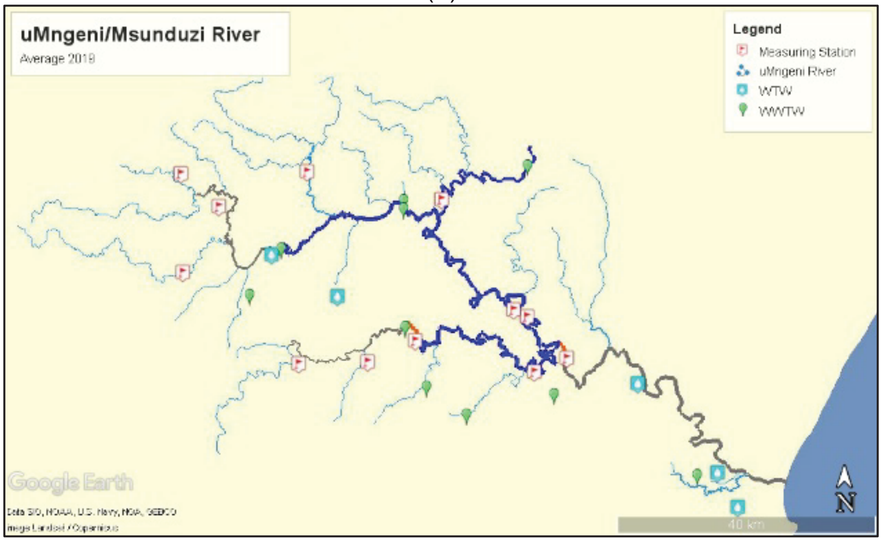
(c)

Figure F2.4: Wastewater contribution in the Umgeni River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

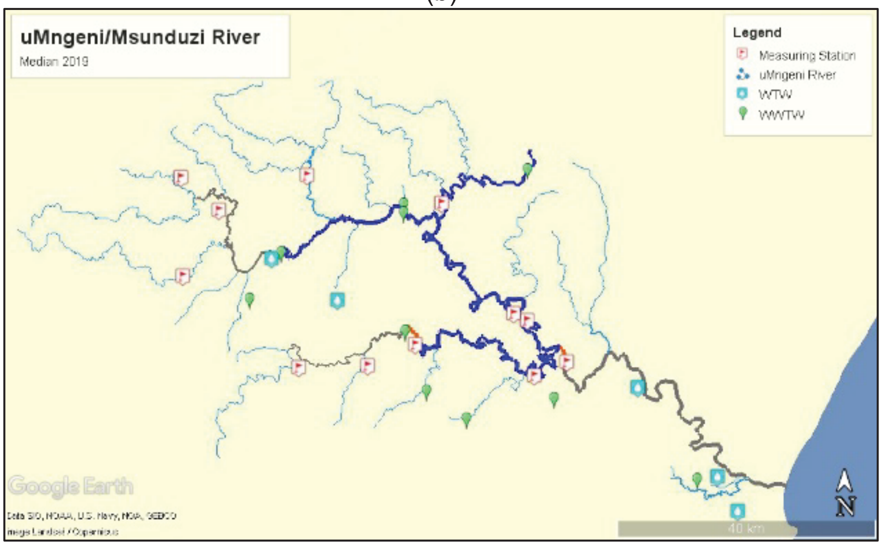
- **<u>Wastewater Contributions in 2019</u>**



(a)



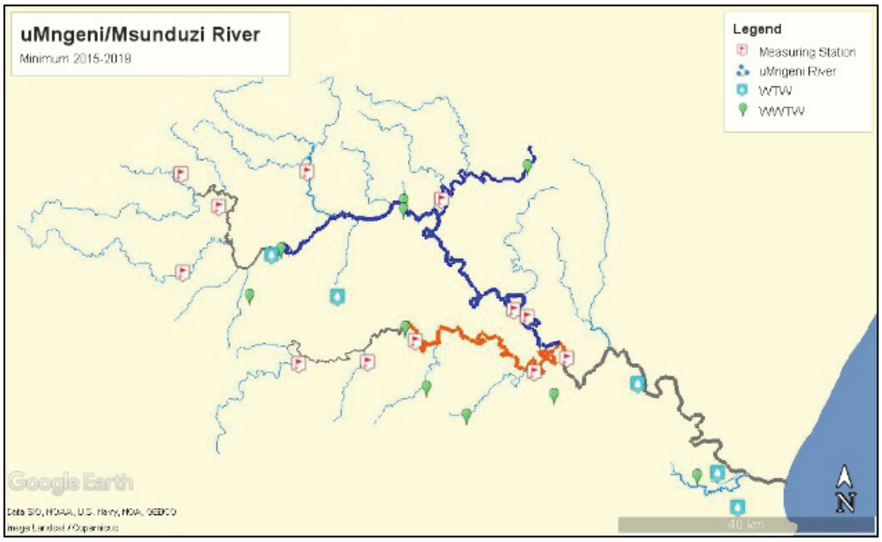
(b)



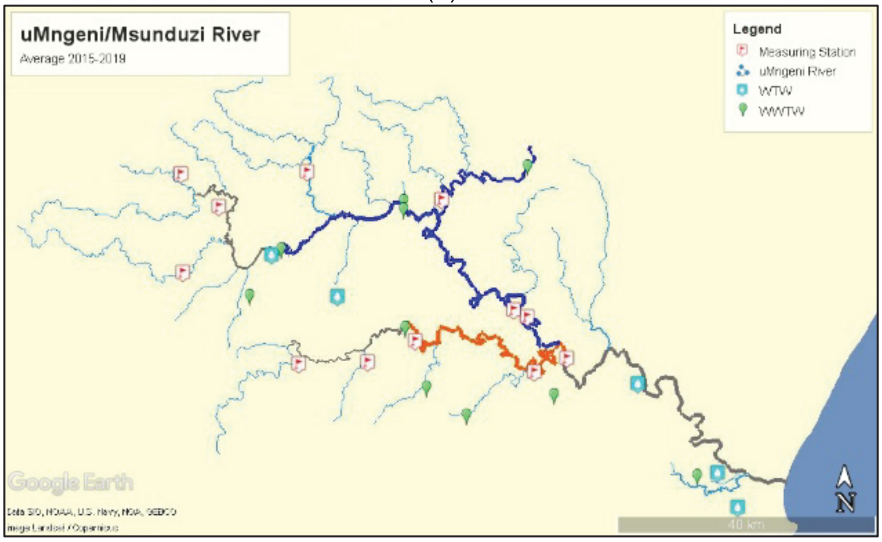
(c)

Figure F2.5: Wastewater contribution in the Umgeni River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

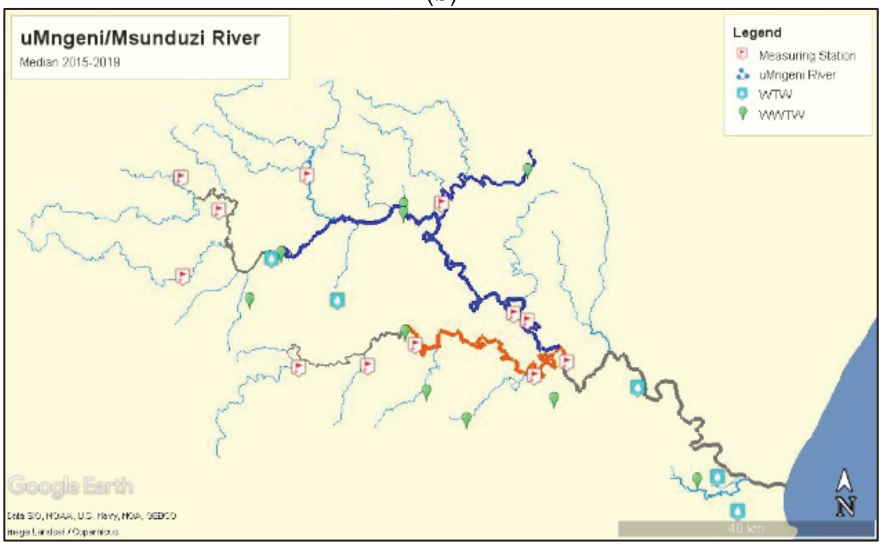
- **<u>Wastewater Contributions in 2015-2019</u>**



(a)



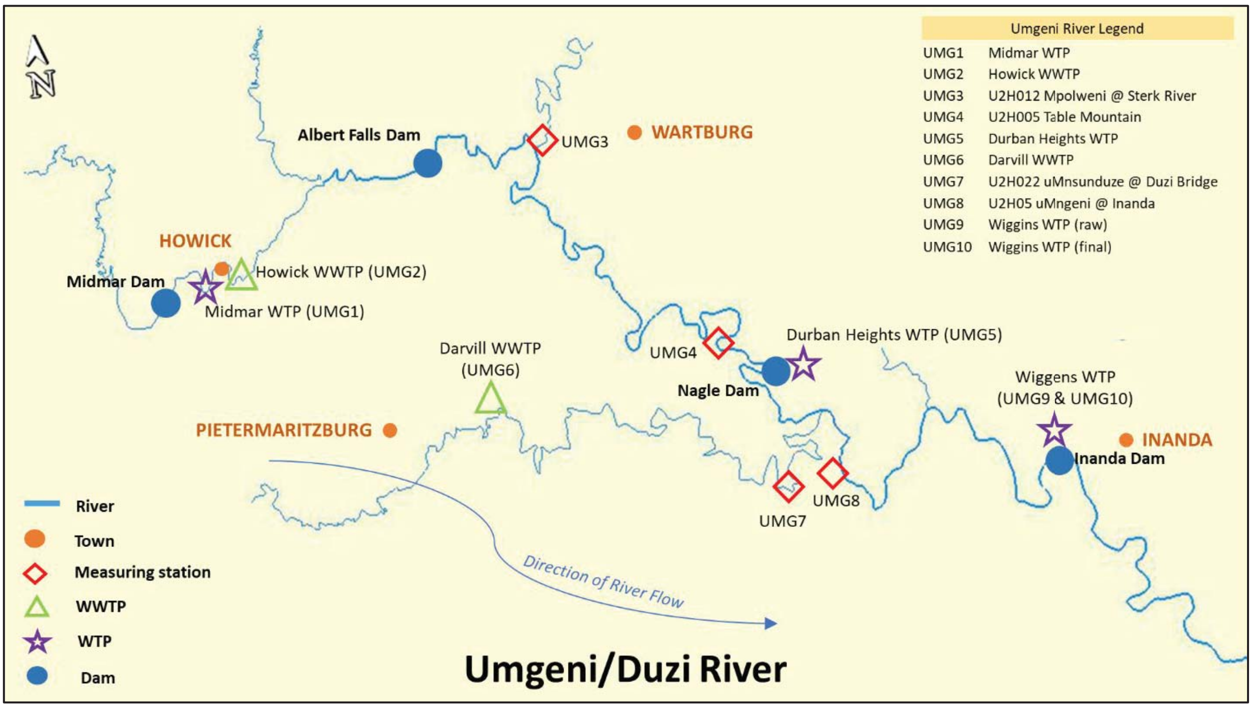
(b)



(c)

Figure F2.6: Wastewater contribution in the Umgeni River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

F3: Map of sampling points for CEC analysis in the Umgeni/Msunduzi River



F4: CEC Concentration Results Legend for the Umgeni/Msunduzi River

Umgeni River Legend	
UMG1	Midmar WTP
UMG2	Howick WWTP
UMG3	U2H012 Mpolweni @ Sterk River
UMG4	U2H005 Table Mountain
UMG5	Durban Heights WTP
UMG6	Darvill WWTP
UMG7	U2H022 uMnsunduze @ Duzi Bridge
UMG8	U2H05 uMngeni @ Inanda
UMG9	Wiggins WTP (raw)
UMG10	Wiggins WTP (final)

F5: Results of the CEC analysis for the Umgeni/Msunduzi River

Table F5.1: Results of the CEC analysis for the Umgeni/Msunduzi River

Constituents	Sample Points									
	Midmar WTW	Howick WWTW	U2H012 Mpolweni @ Sterk River	U2H005 Table Mountain	Durban Heights WTW	Darvill WWTW	U2H022 uMnsunduze @ Duzi Bridge	U2H05 uMngeni @ Inanda	Wiggins WTW (raw)	Wiggins WTW (final)
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
Methaqualone	3.06	181.8	2.77	2.665	<IQL	179.9	85.33	74.36	32.9	33.55
Acetaminophen	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Benzoylecgonine	<IQL	34.68	<IQL	<IQL	<IQL	<IQL	30.25	22.18	12.96	<IQL
Caffeine	2.489	<IQL	<IQL	9.835	<IQL	35.18	130.5	41.58	61.87	94.6
Carbamazepine	<IQL	644.4	11.24	9.26	34.4	622.3	235.2	279.2	74.45	56.75
Carbamazepine-10,11-epoxide	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	66.74	<IQL	<IQL	<IQL
Cocaine	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Codeine	<IQL	613.1	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Diclofenac	<IQL	633.9	<IQL	19.47	<IQL	242.1	30.22	23.73	<IQL	<IQL
Efavirenz	67.04	10744	290.5	127.7	151.9	6321	2088	1502	312.1	293.8
Emtricitabine	<IQL	3941	76.1	61.65	<IQL	374.8	1569	909.1	67.64	<IQL
MDMA	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Methamphetamine	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Naproxen	<IQL	198.9	<IQL	<IQL	<IQL	429.8	<IQL	53.28	<IQL	<IQL
Sulfamethoxazole	8.043	1154	<IQL	<IQL	102.7	1320	869.9	461.9	<IQL	<IQL

* <IQL = Less than Instrument Quantification Limits

F6: Bar charts of indicator compound results in the Umgeni/Msunduzi River

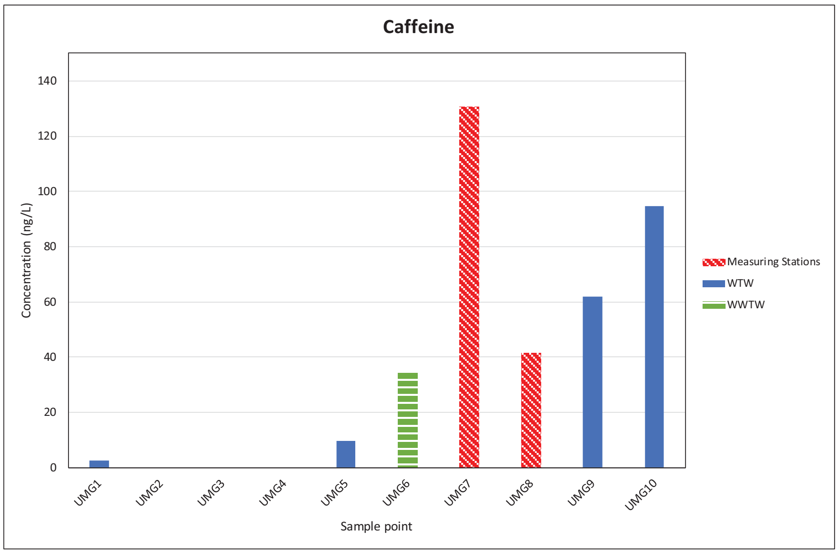


Figure F6.1: Concentrations of Caffeine in the Umgeni River

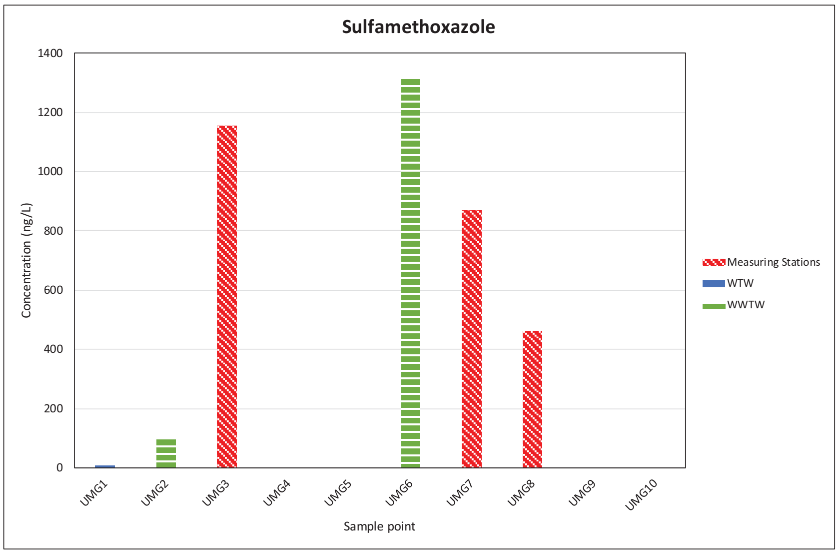


Figure F6.2: Concentrations of Sulfamethoxazole in the Umgeni River

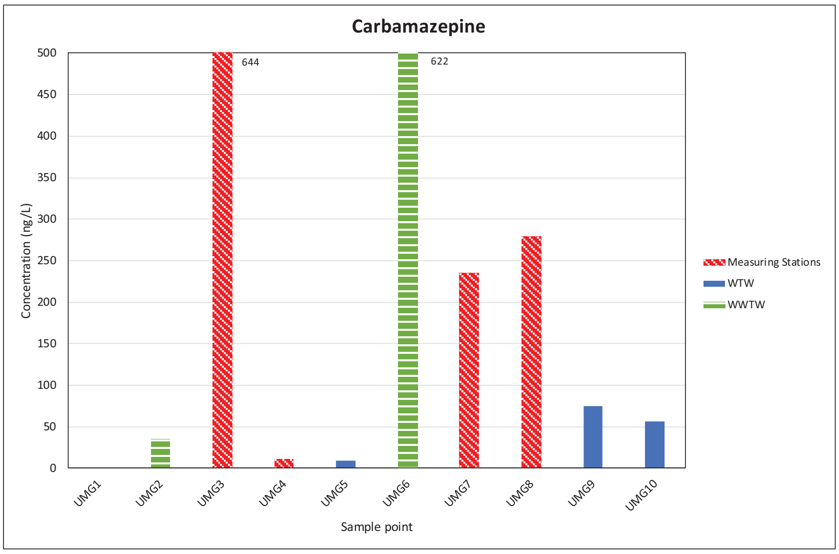


Figure F6.3: Concentrations of Carbamazepine in the Umgeni River

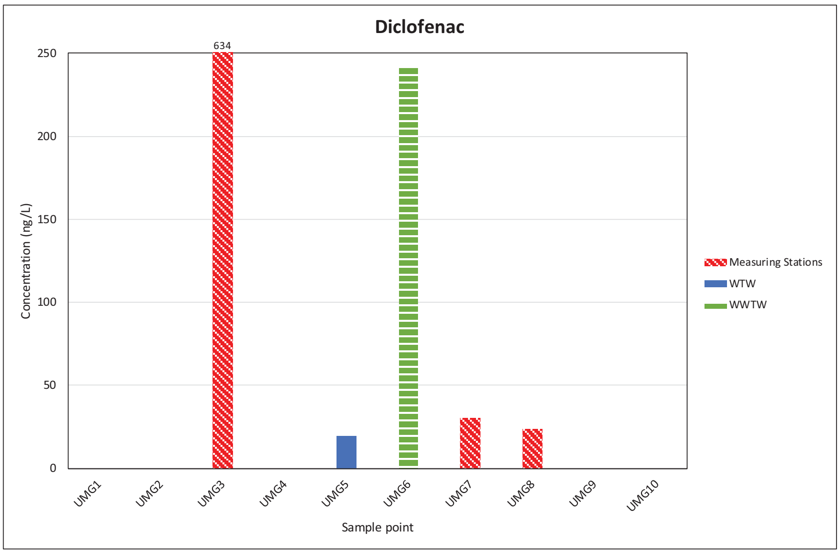


Figure F6.4: Concentrations of Diclofenac in the Umgeni River

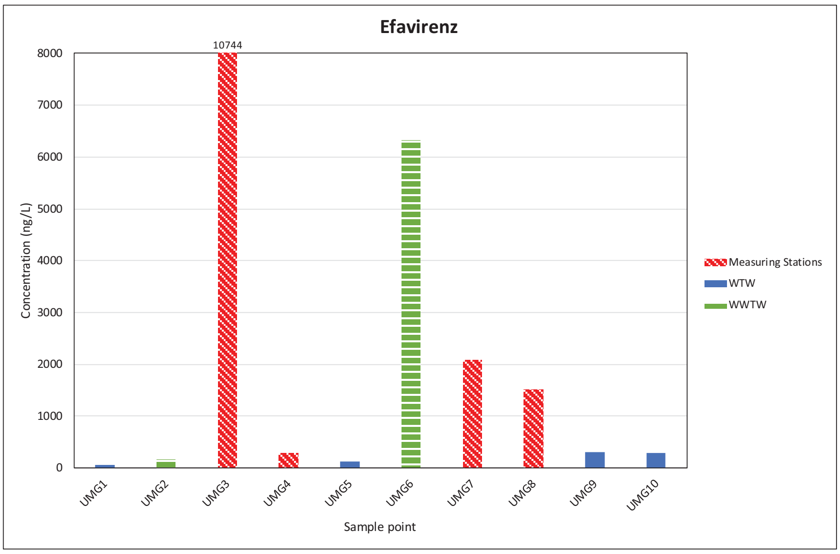


Figure F6.5: Concentrations of Efavirenz in the Umgeni River

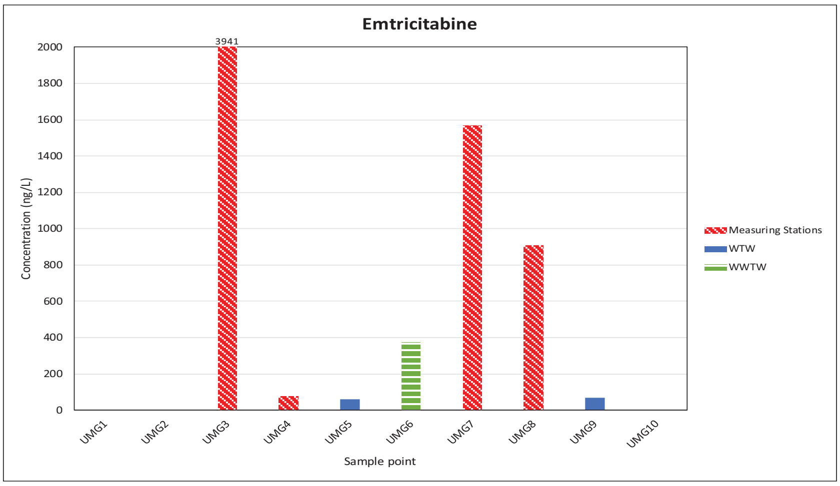


Figure F6.6: Concentrations of Emtricitabine in the Umgeni River

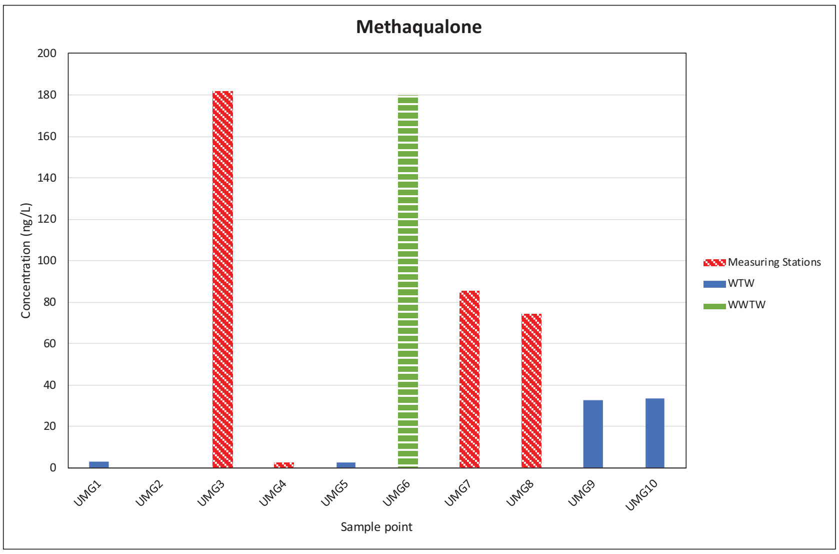


Figure F6.7: Concentrations of Methaqualone in the Umgeni River

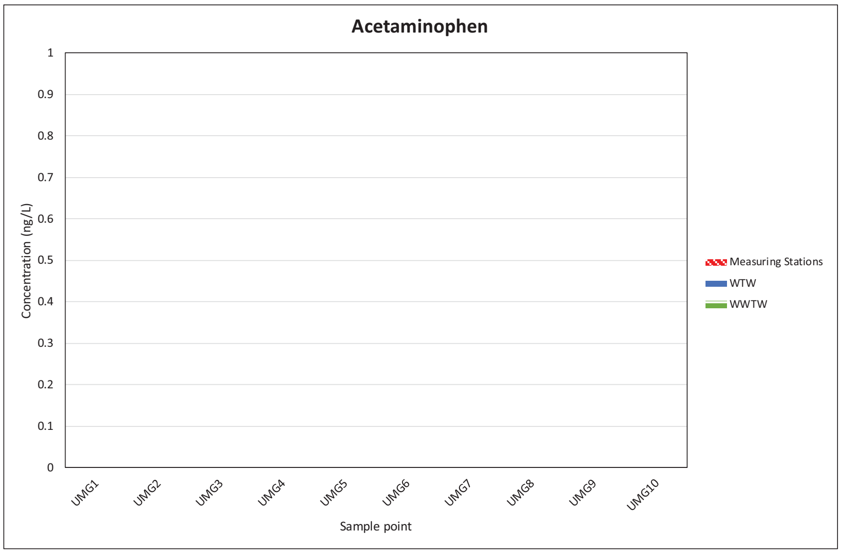


Figure F6.8: Concentrations of Acetaminophen in the Umgeni River

F7: Results of Other Water Quality Parameters for the Umgeni/Msunduzi River

Sample Points	pH	EC	COD	UV 254	DOC
	-	mS/m	mg/L	m^{-1}	mg/L
U2H055 uMngeni @ Inanda	8.45	39.17	<25	0.18	4.01
Durban Heights WTP	8.42	16.57	<25	0.29	5.68
Wiggins WTP Raw	8.32	28.44	<25	0.31	5.94
Darvill WWTP	7.98	70.24	58	0.52	8.85
Midmar WTP	8.21	6.944	<25	0.27	5.40
Howick WWTP	7.8	49.7	57	0.42	7.50
U2H012 Mpolweni @ Sterk River	7.84	15.41	<25	0.34	6.32
U2H022 uMnsunduze @ Duzi Bridge	8.25	9.923	<25	0.42	7.50
U2H005 Table Mountain	8.17	42.13	<25	0.48	8.34
Wiggins WTP Final	8.01	30.31	38	0.40	7.13

APPENDIX G RESULTS FOR THE SUNDAYS RIVER

G1: Flow-based data and calculations for the Sundays River

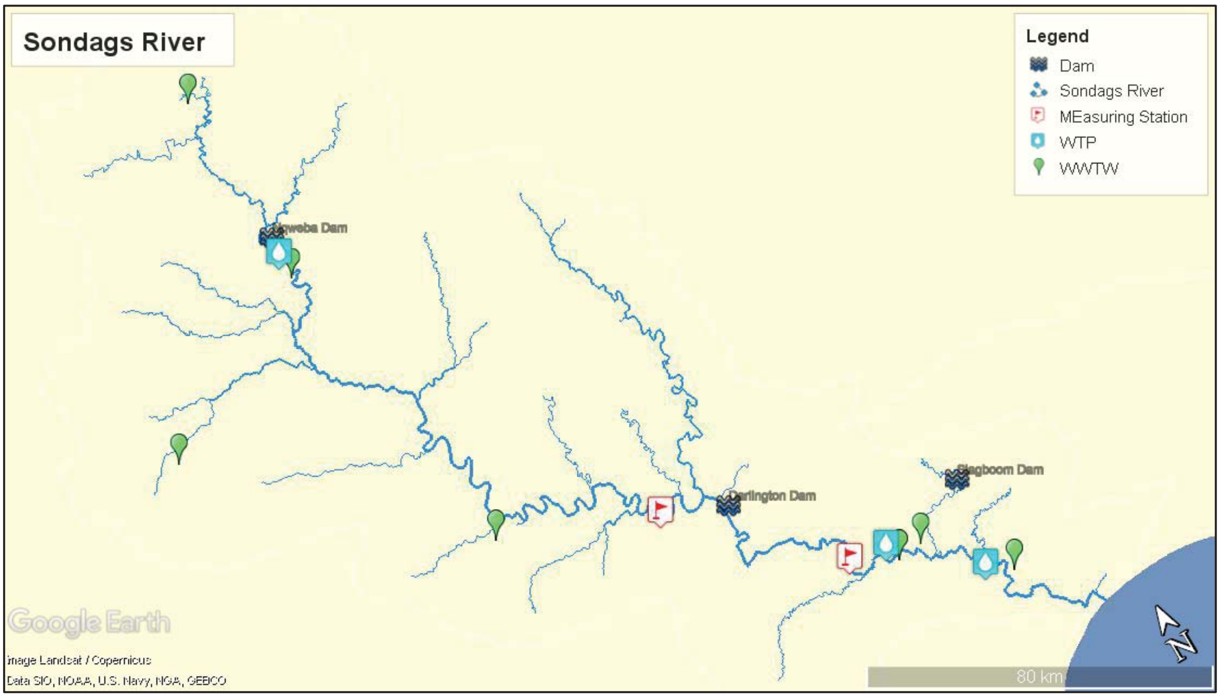


Figure G1.1: Sundays River System, indicating all measuring stations, WWTP and WTP in this river.

Table G1.1: Summary of Wastewater Percentages for the Sundays River for 2015-2019

Sundays River									
Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
Graaff-Reinet WTP	35%	0%	3%	63%	1%	87%	23%	0%	28%
N2H007 Sondags @ De Draay	99%	21%	82%	100%	52%	100%	98%	21%	98%
N4H001 Sondags @ Korhaanspo	36%	5%	6%	51%	8%	11%	59%	7%	11%
Kirkwood WTP	36%	5%	6%	51%	8%	11%	59%	7%	11%
Nooitgedacht WTP	44%	7%	8%	57%	10%	14%	65%	9%	13%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
Graaff-Reinet WTP	63%	1%	100%	50%	0%	100%	41%	0%	12%
N2H007 Sondags @ De Draay	100%	55%	100%	99%	41%	100%	99%	32%	96%
N4H001 Sondags @ Korhaanspo	33%	18%	47%	49%	18%	34%	43%	9%	13%
Kirkwood WTP	33%	18%	47%	49%	18%	34%	43%	9%	13%
Nooitgedacht WTP	38%	22%	54%	55%	22%	40%	50%	11%	16%

Table G1.2: Wastewater percentage calculations for Sundays River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Sundays River																	
Measuring station/ Water Treatment Works	Coordinates		2015														
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0011	0.3286	0.0190	0.0006								0.0006	35%	0%	3%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0011	0.3286	0.0190	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	99%	21%	82%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.1533	1.6278	1.3803	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	36%	5%	6%
Kirkwood WTP	-33.392645°	25.448418°	0.1533	1.6278	1.3803	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	36%	5%	6%
Nooitgedacht WTP	-33.530210°	25.637184°	0.1533	1.6278	1.3803	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1213	44%	7%	8%

(b)

Sundays River																	
Measuring station/ Water Treatment Works	Coordinates		2016														
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0003	0.0810	0.1215	0.0006								0.0006	63%	1%	0%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0003	0.0810	0.1215	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	100%	52%	42%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.0846	1.0314	1.5476	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	51%	8%	5%
Kirkwood WTP	-33.392645°	25.448418°	0.0846	1.0314	1.5476	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	51%	8%	5%
Nooitgedacht WTP	-33.530210°	25.637184°	0.0846	1.0314	1.5476	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1124	57%	10%	7%

(c)

Sundays River																	
Measuring station/ Water Treatment Works	Coordinates		2017														
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0019	0.3281	0.1727	0.0006								0.0006	23%	0%	0%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0019	0.3281	0.1727	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	98%	21%	34%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.0599	1.1197	1.5862	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	59%	7%	5%
Kirkwood WTP	-33.392645°	25.448418°	0.0599	1.1197	1.5862	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	59%	7%	5%
Nooitgedacht WTP	-33.530210°	25.637184°	0.0599	1.1197	1.5862	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1124	65%	9%	7%

(d)

Sundays River																	
Measuring station/ Water Treatment Works	Coordinates		2018														
			River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0003	0.0717	0.1385	0.0006								0.0006	63%	1%	0%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0003	0.0717	0.1385	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	100%	55%	39%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.1810	0.4026	0.7719	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	33%	18%	10%
Kirkwood WTP	-33.392645°	25.448418°	0.1810	0.4026	0.7719	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	33%	18%	10%
Nooitgedacht WTP	-33.530210°	25.637184°	0.1810	0.4026	0.7719	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1124	38%	22%	13%

(e)

Sundays River

Measuring station/ Water Treatment Works	Coordinates		2019														
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0006	0.1237	0.0000	0.0006								0.0006	50%	0%	100%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0006	0.1237	0.0000	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	99%	41%	100%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.0916	0.3977	0.1660	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	49%	18%	34%
Kirkwood WTP	-33.392645°	25.448418°	0.0916	0.3977	0.1660	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	49%	18%	34%
Nooitgedacht WTP	-33.530210°	25.637184°	0.0916	0.3977	0.1660	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1124	55%	22%	40%

(f)

Sundays River

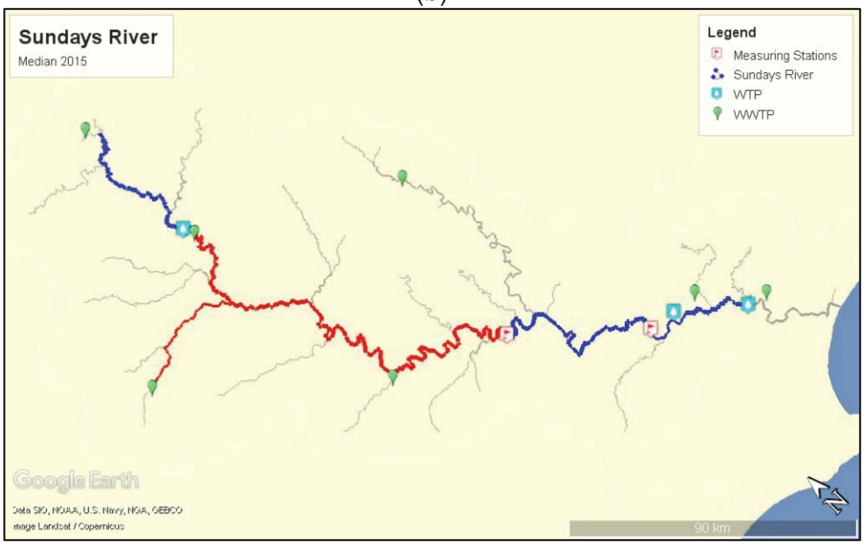
Measuring station/ Water Treatment Works	Coordinates		2015 - 2019														
	Latitude	Longitude	River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity								Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
			Min	Average	Median	Nieu-Bethesda	Graaff-Reinet	Abderdeen	Janseville	Pearston	Kirkwood	Enon	Addo		Min	Average	Median
Graaff-Reinet WTP	-32.243105°	24.533666°	0.0009	0.1866	0.0041	0.0006								0.0006	41%	0%	12%
N2H007 Sondags @ De Draay	-33.099064°	25.012160°	0.0009	0.1866	0.0041	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	99%	32%	96%
N4H001 Sondags @ Korhaanspo	-33.378608°	25.354582°	0.1141	0.9158	0.6114	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	43%	9%	13%
Kirkwood WTP	-33.392645°	25.448418°	0.1141	0.9158	0.6114	0.0006	0.0521	0.0116	0.0116	0.0116				0.0874	43%	9%	13%
Nooitgedacht WTP	-33.530210°	25.637184°	0.1141	0.9158	0.6114	0.0006	0.0521	0.0116	0.0116	0.0116	0.0231	0.0019	0.0089	0.1124	50%	11%	16%

G2: De facto wastewater maps for different time periods for Sundays River

- **<u>Wastewater Contributions in 2015</u>**

(a)

(b)



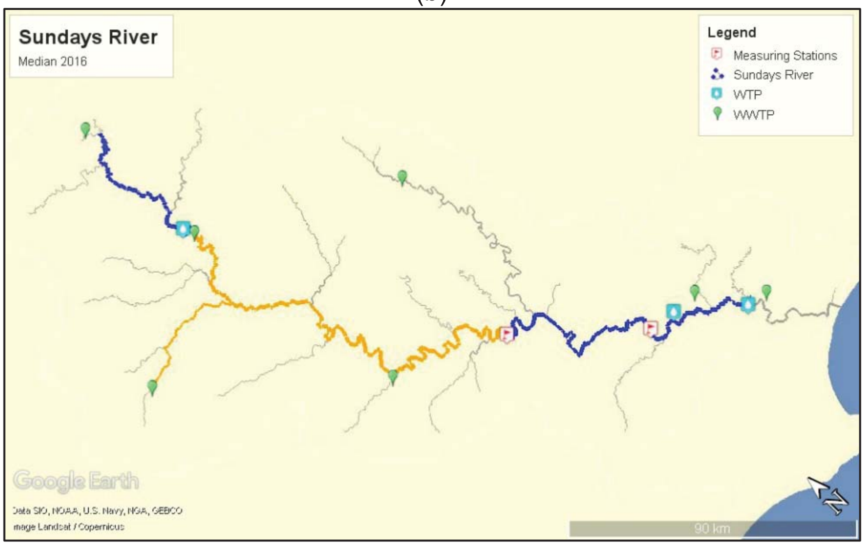
(c)

Figure G2.1: Wastewater contribution in the Sundays River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

- **<u>Wastewater Contributions in 2016</u>**

(a)

(b)



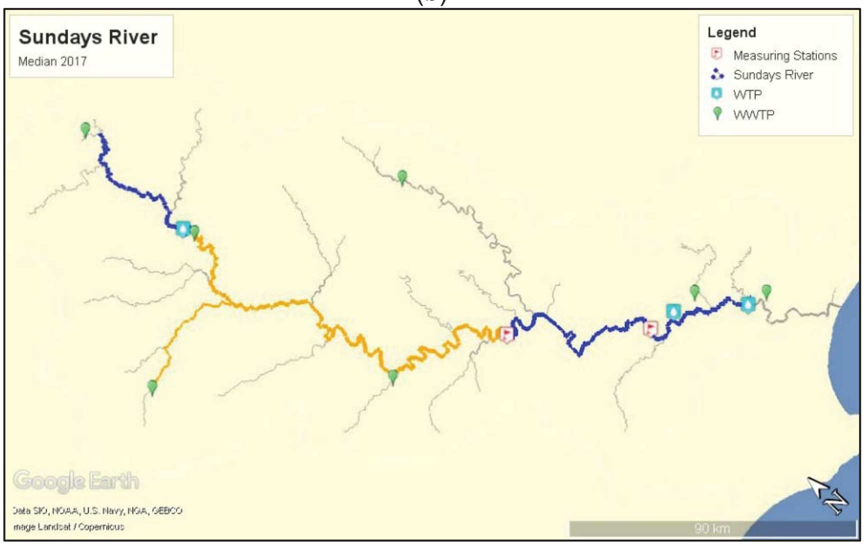
(c)

Figure G2.2: Wastewater contribution in the Sundays River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

- **<u>Wastewater Contributions in 2017</u>**

(a)

(b)



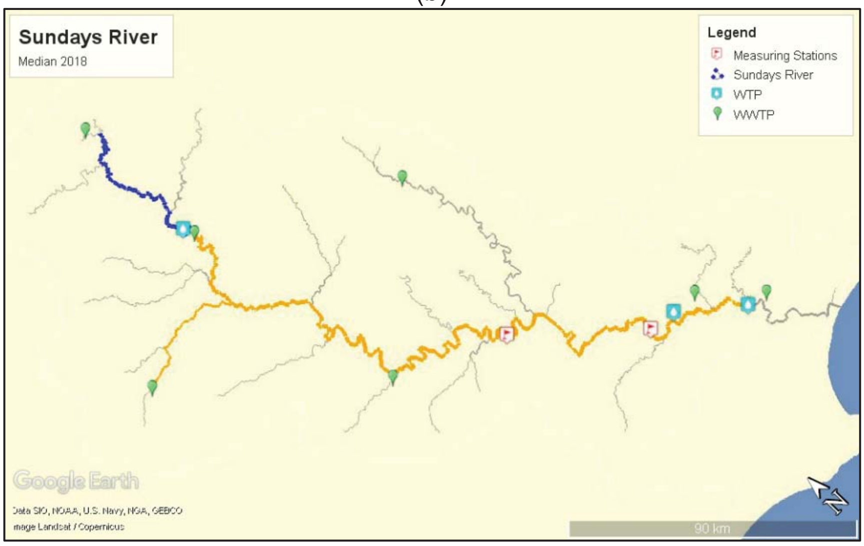
(c)

Figure G2.3: Wastewater contribution in the Sundays River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

- **<u>Wastewater Contributions in 2018</u>**

(a)

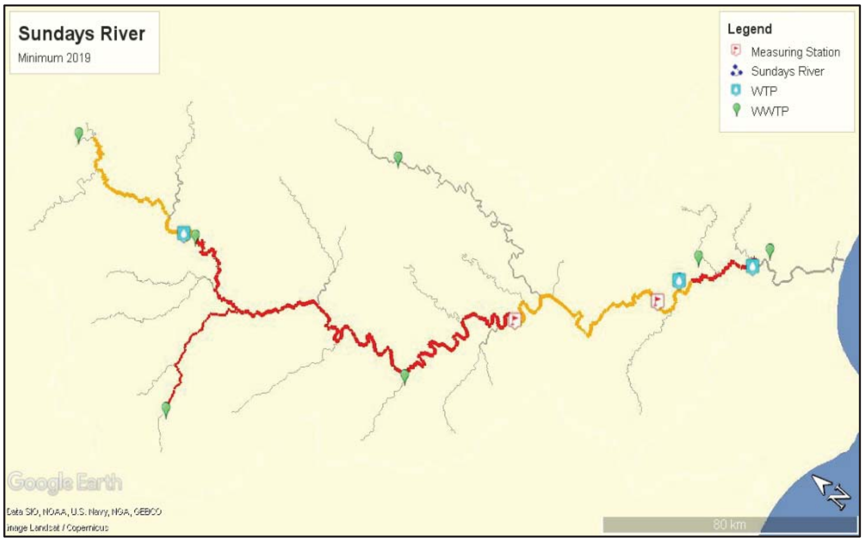
(b)



(c)

Figure G2.4: Wastewater contribution in the Sundays River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

- **<u>Wastewater Contributions in 2019</u>**



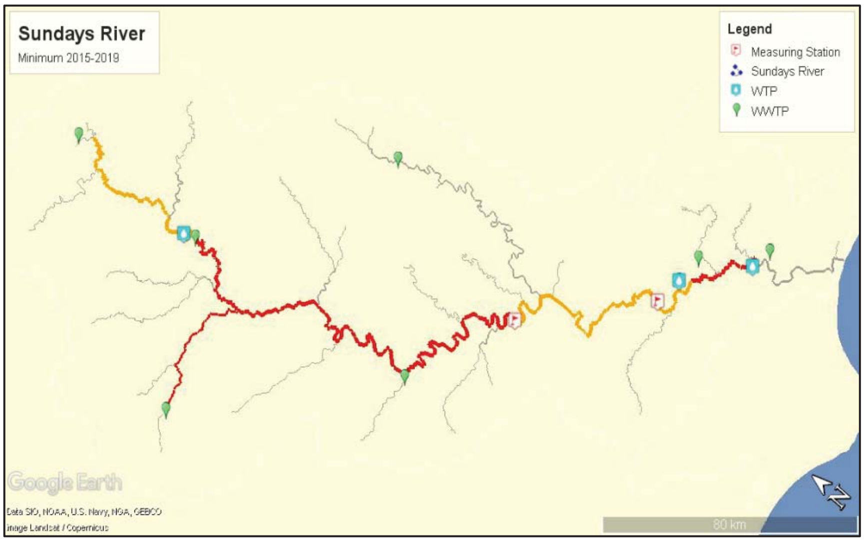
(a)

(b)

(c)

Figure G2.5: Wastewater contribution in the Sundays River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

- **<u>Wastewater Contributions in 2015-2019</u>**



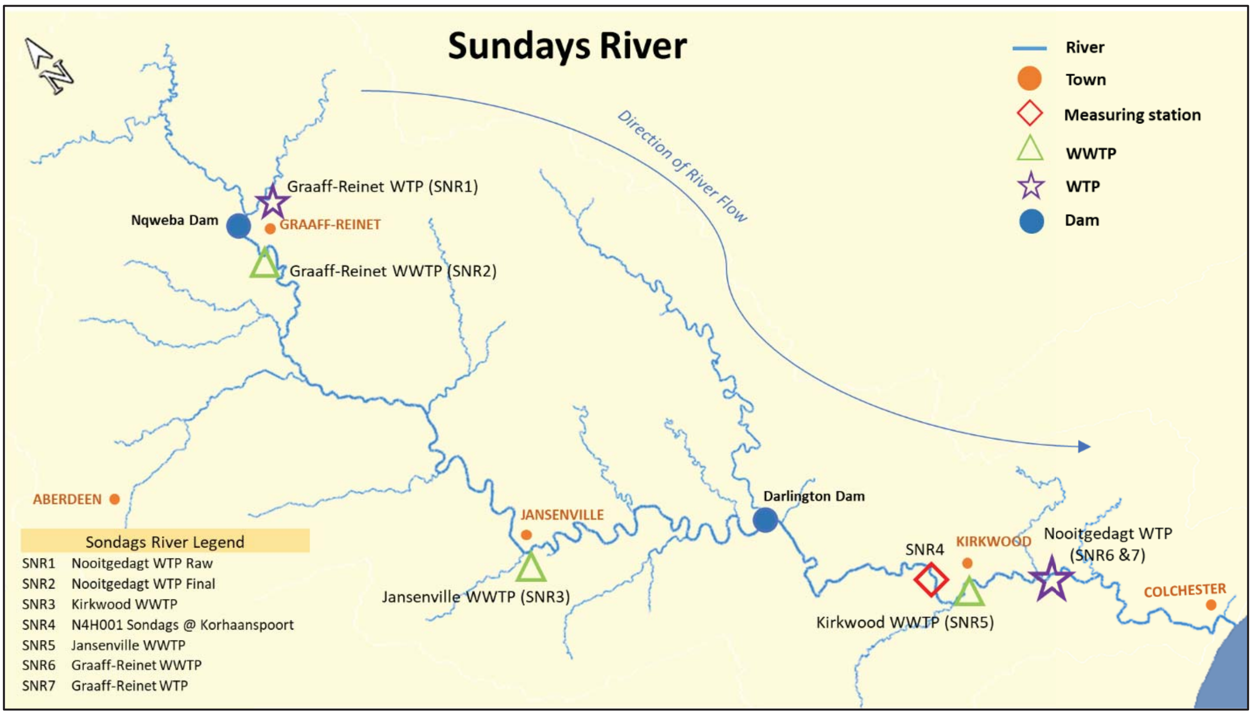
(a)

(b)

(c)

Figure G2.6: Wastewater contribution in the Sundays River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

G3: Map of sampling points for CEC analysis in the Sundays River



G4: CEC Concentration Results Legend for the Sundays River

Sundays River Legend	
SND1	Nooitgedacht WTP
SND2	Nooitgedacht WTP
SND3	Kirkwood WWTP
SND4	N4H001 Sundays @ Korhaanspoort
SND5	Jansenville WWTP
SND6	Graaff-Reinet WWTP
SND7	Graaff-Reinet WTP

G5: Results of the CEC analysis for the Sundays River

Table G5.1: Results of the CEC analysis for the Sundays River

Constituent	Sample Points						
	Graaff - Reinet WTP Raw	Graaff-Reinet WWTW	Jansenville WWTW	N4H001 Sondags @ Korhaanspo	Kirkwood WWTW	Nooitgedacht WTP Raw	Nooitgedacht WTP Final
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
1,7-dimethylxanthine	14.15	16.27	16118	42.76	344.2	<IQL	<IQL
Acetaminophen	<IQL	<MDL	433775	<IQL	<IQL	<MDL	<MDL
Atrazine	<MDL	<MDL	<MDL	<IQL	<IQL	<IQL	<IQL
Benzotriazole	<MDL	121.7	59.13	<MDL	22.41	<MDL	<MDL
Benzoylecgonine	<MDL	<IQL	<MDL	<MDL	100.1	<MDL	<MDL
Caffeine	55.57	20.3	9590	92.71	450.1	25.05	6.247
Carbamazepine	<MDL	749.1	2172	<IQL	6786	27.61	<MDL
Cetirizine	<IQL	235.6	132.3	<IQL	212.8	<IQL	<MDL
Cocaine	<IQL	<IQL	<IQL	<IQL	13.08	<IQL	<IQL
Codeine	<MDL	<MDL	9362	<MDL	<IQL	<MDL	<MDL
Diclofenac	<IQL	51.15	1909	8.141	154.2	<IQL	<MDL
Efavirenz	<IQL	4473	12723	119.2	11261	655	<MDL
Emtricitabine	<IQL	1728	72746	<IQL	12459	36.77	<IQL
MDMA	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Methamphetamine	<MDL	4.162	5203	<IQL	35.42	<MDL	<MDL
Methaqualone	<MDL	31.45	3332	6.091	76.02	1.438	<MDL
Naproxen	<MDL	32.03	<MDL	<MDL	<IQL	<MDL	<MDL
Sulfamethoxazole	<MDL	465.7	13515	<MDL	880	<IQL	<MDL
Tramadol	<MDL	1310	6295	<IQL	796.2	<IQL	<MDL
Trimethoprim	<MDL	69.13	3043	5.107	345.7	<IQL	<IQL
Venlafaxine	<MDL	176.5	10.34	<IQL	179.2	<IQL	<IQL

<IQL = Less than Instrument Quantification Limit

<MDL = Less than Method Detection Limit

G6: Bar charts of indicator compound results in the Sundays River

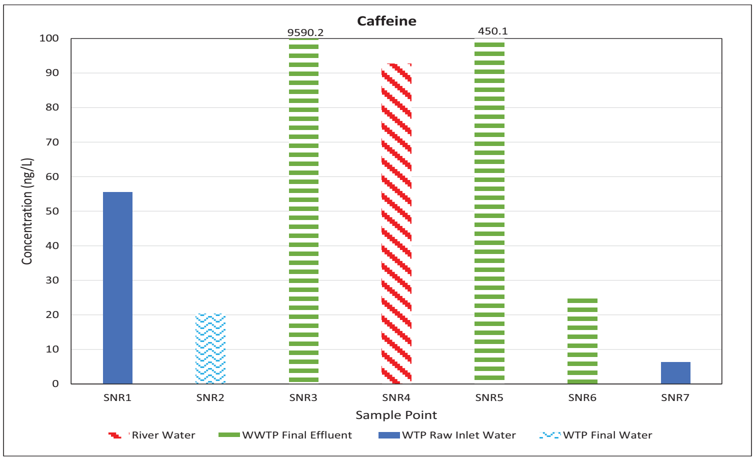


Figure G6.1: Concentrations of Caffeine in the Sundays River

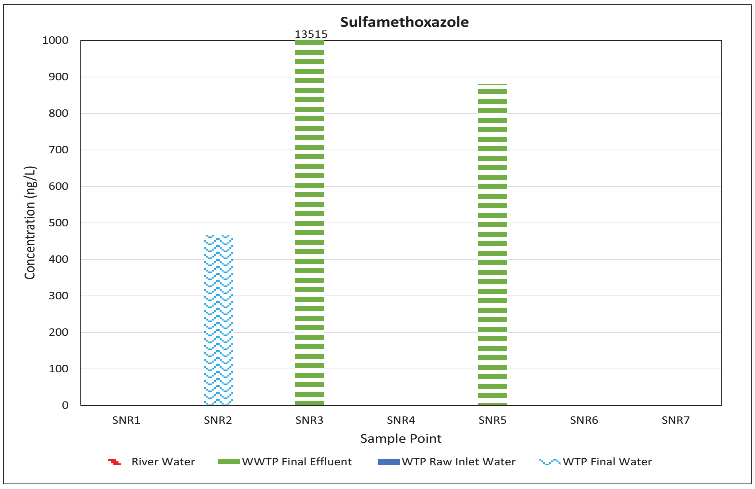


Figure G6.2: Concentrations of Sulfamethoxazole in the Sundays River

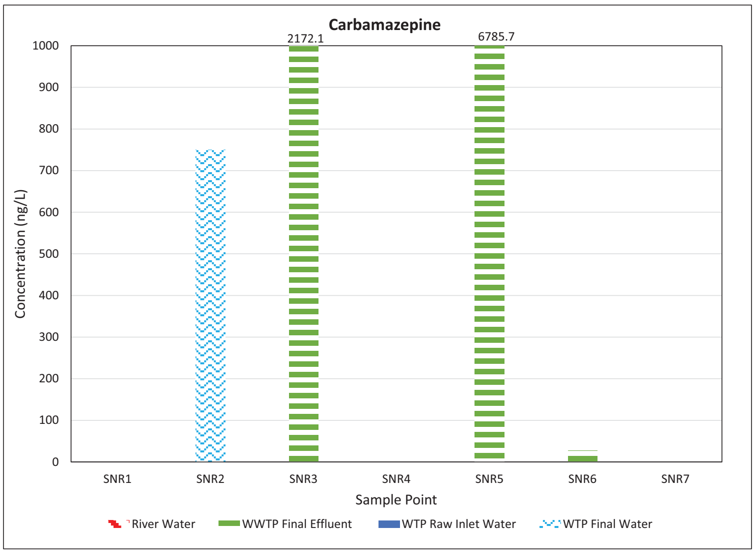


Figure G6.3: Concentrations of Carbamazepine in the Sundays River

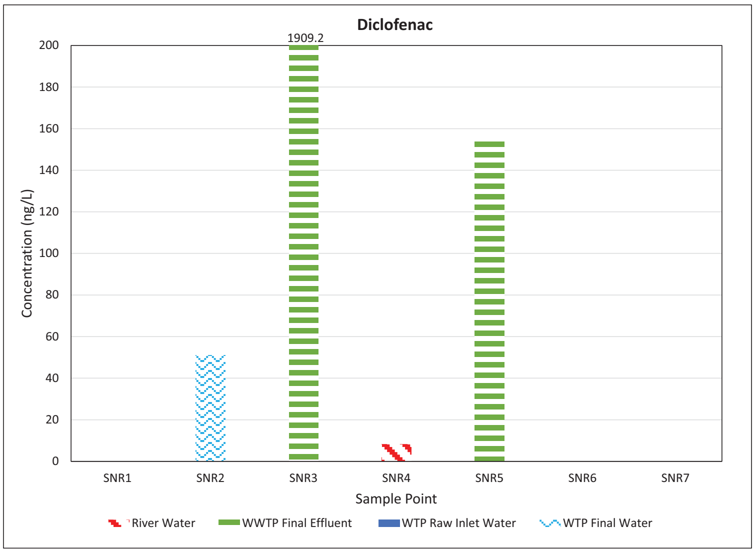


Figure G6.4: Concentrations of Diclofenac in the Sundays River

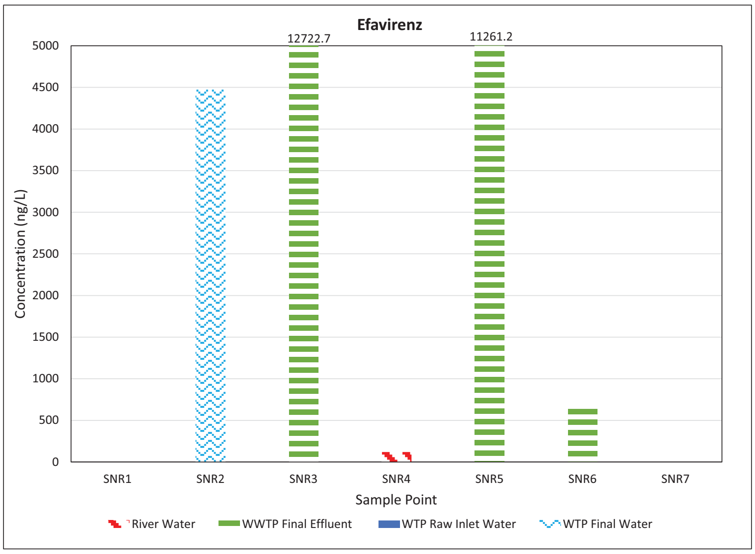


Figure G6.5: Concentrations of Efavirenz in the Sundays River

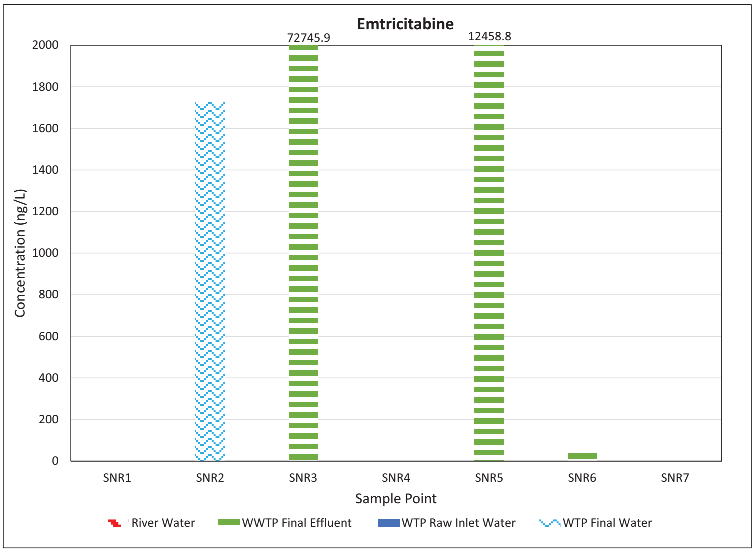


Figure G6.6: Concentrations of Emtricitabine in the Sundays River

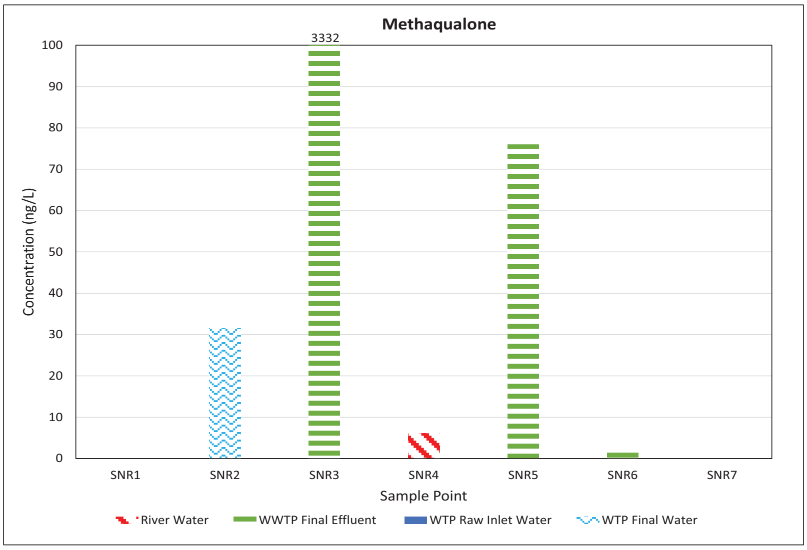


Figure G6.7: Concentrations of Methaqualone in the Sundays River

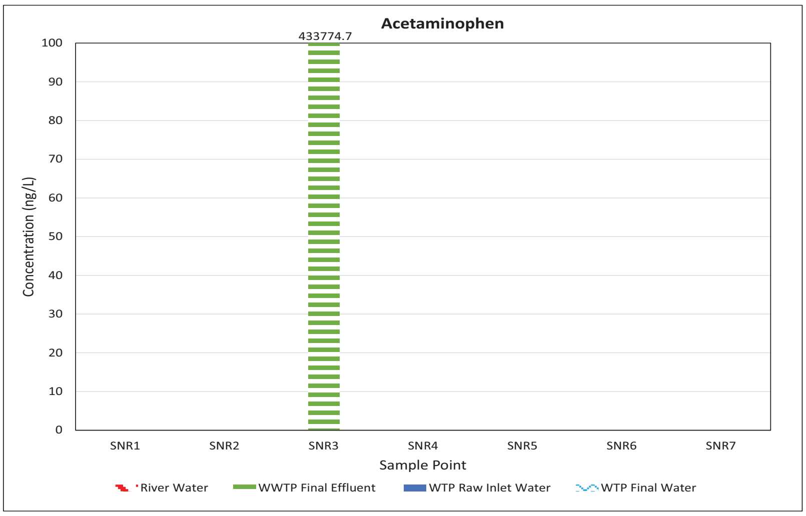


Figure G6.8: Concentrations of Acetaminophen in the Sundays River

G7: Results of Other Water Quality Parameters for the Sundays River

Sample Points	Sample Name	pH	EC	COD	UV 254	DOC	DO
		-	mS/m	mg/L	m^{-1}	mg/L	mg/L
Graaff-Reinet WTP	SNR1	8.00	72	126	0.176	4.01	7.39
Graaff-Reinet WWTW	SNR2	7.93	178	63	0.114	3.13	11.9
Jansenville WWTW	SNR3	7.62	43	335	0.636	10.5	8.44
N4H001 Sondags @ Korhaanspoort	SNR4	7.59	-	41	0.22	4.63	-
Kirkwood WWTW	SNR5	7.92	96	49	0.081	2.66	5.65
Nooitgedacht WTP Raw	SNR6	8.00	43	103	0.333	6.24	8.84
Nooitgedacht WTP Final	SNR7	7.50	44	35	0.014	1.71	9.23

APPENDIX H RESULTS FOR THE CROCODILE RIVER

H1: Flow-based data and calculations for the Crocodile River

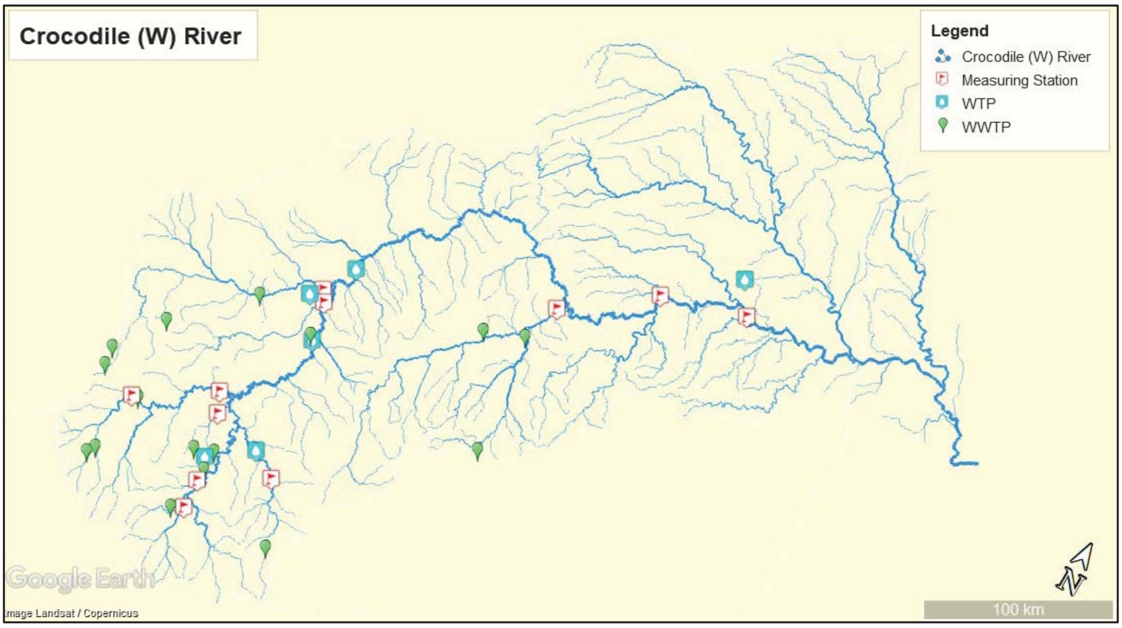


Figure H1.1: Crocodile River System, indicating all measuring stations, WWTP and WTP in this river.

Table H1.1: Summary of Wastewater Percentages for the Crocodile River for 2015-2019

Crocodile (W) River									
Measuring station/ Water Treatment Plant	% wastewater in river (m³/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	38%	35%	36%	38%	33%	35%	34%	29%	31%
A2H050 Krokodil River @ Zwartkop	88%	82%	84%	92%	85%	89%	89%	82%	86%
A2H045 Krokodil River @ Vlakfontein	83%	79%	80%	84%	76%	79%	80%	71%	76%
A2H023 Jukskei River @ Nietgedacht	15%	10%	12%	15%	8%	11%	14%	7%	11%
A2H044 Jukskei River @ Vlakfontein	12%	9%	10%	14%	5%	7%	14%	7%	9%
Rietvlei WTP	23%	18%	21%	23%	16%	19%	25%	14%	20%
A2H014 Hennops River @ Skurweberg	52%	46%	49%	52%	42%	47%	55%	38%	49%
A2H012 Krokodil River @ Kalkheuwel	46%	40%	43%	48%	37%	42%	45%	34%	39%
A2H058 Swart Spruit @ Rietfontein	87%	78%	82%	93%	74%	80%	87%	57%	65%
A2H013 Magalies River @ Scheerpoort	6%	4%	4%	11%	6%	8%	7%	2%	4%
Brits WTP	82%	61%	64%	83%	54%	67%	76%	43%	53%
A2H048 Krokodil River @ Krokodilpoort	82%	61%	64%	83%	54%	67%	76%	44%	54%
Vaalkop WTP	18%	10%	10%	21%	9%	12%	21%	9%	8%
A2H059 Krokodil River @ Vaalkop	80%	67%	67%	83%	65%	72%	83%	65%	61%
Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	51%	30%	32%	61%	40%	42%	42%	33%	35%
A2H050 Krokodil River @ Zwartkop	96%	84%	87%	97%	92%	92%	92%	85%	87%
A2H045 Krokodil River @ Vlakfontein	88%	72%	78%	89%	57%	75%	85%	70%	78%
A2H023 Jukskei River @ Nietgedacht	23%	9%	13%	15%	7%	11%	16%	8%	11%
A2H044 Jukskei River @ Vlakfontein	20%	8%	10%	25%	6%	9%	16%	7%	9%
Rietvlei WTP	27%	16%	21%	24%	14%	17%	24%	16%	20%
A2H014 Hennops River @ Skurweberg	58%	42%	50%	54%	37%	43%	54%	41%	47%
A2H012 Krokodil River @ Kalkheuwel	44%	34%	39%	48%	29%	34%	46%	35%	39%
A2H058 Swart Spruit @ Rietfontein	91%	77%	82%	84%	43%	66%	88%	62%	74%
A2H013 Magalies River @ Scheerpoort	16%	3%	5%	32%	4%	6%	10%	4%	5%
Brits WTP	92%	36%	53%	N/A			86%	47%	59%
A2H048 Krokodil River @ Krokodilpoort	92%	36%	53%				86%	47%	59%
Vaalkop WTP	31%	5%	8%	23%	3%	6%	20%	4%	8%
A2H059 Krokodil River @ Vaalkop	89%	49%	61%	84%	38%	52%	82%	44%	60%

Table H1.2: Wastewater percentage calculations for Crocodile River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Crocodile (W) River — 2015

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	0.8740	0.9979	0.9615	0.2315	0.3125											0.5440	38%	35%	36%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.7083	1.1261	0.9988			5.2083										5.2083	88%	82%	84%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	1.2169	1.5668	1.4348	0.2315	0.3125	5.2083										5.7523	83%	79%	80%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	3.6451	5.6014	4.4748				0.6366									0.6366	15%	10%	12%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	4.4624	6.4518	5.5590				0.6366									0.6366	12%	9%	10%
Rietvlei WTP	-25.877816°	28.264219°	2.4516	3.2283	2.8234					0.7292								0.7292	23%	18%	21%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	2.4516	3.2283	2.8234					0.7292	1.2153	0.7523						2.6968	52%	46%	49%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	10.5065	13.5804	12.0899	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	46%	40%	43%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0083	0.0162	0.0125								0.0579					0.0579	87%	78%	82%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.2117	0.3031	0.2834									0.0127				0.0127	6%	4%	4%
Brits WTP	-25.629855°	27.796783°	2.0138	5.8757	5.2270	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	82%	61%	64%
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°	2.0138	5.8757	5.2270	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183	82%	61%	64%
Vaalkop WTP	-25.307910°	27.483997°	2.4233	4.8938	4.7780											0.4861	0.0625	0.5486	18%	10%	10%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	2.4233	4.8938	4.7780	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	80%	67%	67%

(b)

Crocodile (W) River — 2016

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	0.8714	1.1215	1.0145	0.2315	0.3125											0.5440	38%	33%	35%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.4737	0.8983	0.6740			5.2083										5.2083	92%	85%	89%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	1.0940	1.8156	1.4978	0.2315	0.3125	5.2083										5.7523	84%	76%	79%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	3.6359	7.5752	5.0487				0.6366									0.6366	15%	8%	11%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	3.8893	11.1521	8.4715				0.6366									0.6366	14%	5%	7%
Rietvlei WTP	-25.877816°	28.264219°	2.4565	3.7996	3.0754					0.7292								0.7292	23%	16%	19%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	2.4565	3.7996	3.0754					0.7292	1.2153	0.7523						2.6968	52%	42%	47%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	9.7503	15.4264	12.4434	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	48%	37%	42%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0041	0.0202	0.0146								0.0579					0.0579	93%	74%	80%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.0986	0.1863	0.1504									0.0127				0.0127	11%	6%	8%
Brits WTP	-25.629855°	27.796783°	1.8663	7.8958	4.5052	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	83%	54%	67%
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°	1.8663	7.8958	4.5052	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183	83%	54%	67%
Vaalkop WTP	-25.307910°	27.483997°	2.0149	5.2687	3.8943											0.4861	0.0625	0.5486	21%	9%	12%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	2.0149	5.2687	3.8943	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	83%	65%	72%

(c)

Crocodile (W) River																					
			2017																		
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	1.0492	1.3471	1.2103	0.2315	0.3125											0.5440	34%	29%	31%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.6361	1.1619	0.8241			5.2083										5.2083	89%	82%	86%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	1.4183	2.3212	1.8382	0.2315	0.3125	5.2083										5.7523	80%	71%	76%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	3.8853	8.2620	5.2220				0.6366									0.6366	14%	7%	11%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	3.9181	8.5859	6.3564				0.6366									0.6366	14%	7%	9%
Rietvlei WTP	-25.877816°	28.264219°	2.1627	4.3241	2.8536					0.7292								0.7292	25%	14%	20%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	2.1627	4.3241	2.8536					0.7292	1.2153	0.7523						2.6968	55%	38%	49%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	11.0772	17.8720	14.0125	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	45%	34%	39%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0085	0.0434	0.0305								0.0579					0.0579	87%	57%	65%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.1655	0.5352	0.3235									0.0127				0.0127	7%	2%	4%
Brits WTP	-25.629855°	27.796783°	2.8730	11.9039	7.9932	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	76%	43%	53%
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°	2.8730	11.9039	7.9932	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183	76%	44%	54%
Vaalkop WTP	-25.307910°	27.483997°	2.0149	5.2687	6.3465											0.4861	0.0625	0.5486	21%	9%	8%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	2.0149	5.2687	6.3465	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	83%	65%	61%

(d)

Crocodile (W) River																					
			2018																		
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	0.5320	1.2486	1.1666	0.2315	0.3125											0.5440	51%	30%	32%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.2227	1.0276	0.7751			5.2083										5.2083	96%	84%	87%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	0.7582	2.1990	1.6671	0.2315	0.3125	5.2083										5.7523	88%	72%	78%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	2.1423	6.7776	4.3934				0.6366									0.6366	23%	9%	13%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	2.4787	7.0324	5.9138				0.6366									0.6366	20%	8%	10%
Rietvlei WTP	-25.877816°	28.264219°	1.9698	3.7499	2.7071					0.7292								0.7292	27%	16%	21%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	1.9698	3.7499	2.7071					0.7292	1.2153	0.7523						2.6968	58%	42%	50%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	11.6477	17.2531	14.3946	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	44%	34%	39%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0059	0.0176	0.0130								0.0579					0.0579	91%	77%	82%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.0645	0.3550	0.2585									0.0127				0.0127	16%	3%	5%
Brits WTP	-25.629855°	27.796783°	0.7786	16.3572	8.2258	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	92%	36%	53%
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°	0.7786	16.3572	8.2258	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183	92%	36%	53%
Vaalkop WTP	-25.307910°	27.483997°	1.2307	10.1848	6.2229											0.4861	0.0625	0.5486	31%	5%	8%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	1.2307	10.1848	6.2229	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	89%	49%	61%

(e)

Crocodile (W) River																					
			2019																		
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	0.3538	0.8043	0.7653	0.2315	0.3125											0.5440	61%	40%	42%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.1371	0.4560	0.4491			5.2083										5.2083	97%	92%	92%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	0.7393	4.3358	1.9009	0.2315	0.3125	5.2083										5.7523	89%	57%	75%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	3.6324	8.0959	5.3618				0.6366									0.6366	15%	7%	11%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	1.9288	9.5956	6.5031				0.6366									0.6366	25%	6%	9%
Rietvlei WTP	-25.877816°	28.264219°	2.3153	4.5659	3.5230					0.7292								0.7292	24%	14%	17%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	2.3153	4.5659	3.5230					0.7292	1.2153	0.7523						2.6968	54%	37%	43%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	9.7193	21.8460	17.3008	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	48%	29%	34%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0111	0.0767	0.0297								0.0579					0.0579	84%	43%	66%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.0275	0.3124	0.1834									0.0127				0.0127	32%	4%	6%
Brits WTP	-25.629855°	27.796783°	NO DATA AVAILABLE			0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	N/A		
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°				0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183			
Vaalkop WTP	-25.307910°	27.483997°	1.8831	15.9686	9.0793											0.4861	0.0625	0.5486	23%	3%	6%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	1.8831	15.9686	9.0793	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	84%	38%	52%

(f)

Crocodile (W) River																					
			2015-2019																		
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity												Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Randfontein	Percy Steward	Driefontein	Diepsloot	Hartebeesfonteint	Olifantsfontein	Sunderland Ridge	Rietfontein	Magalies	Brits	Rustenburg	Sun City		Min	Average	Median
A2H049 Bloubank Spruit @ Riet Spruit Zwartkop	-25.975745°	27.839180°	0.7361	1.1039	1.0236	0.2315	0.3125											0.5440	42%	33%	35%
A2H050 Krokodil River @ Zwartkop	-25.986083°	27.844254°	0.4356	0.9340	0.7442			5.2083										5.2083	92%	85%	87%
A2H045 Krokodil River @ Vlakfontein	-25.896290°	27.908020°	1.0454	2.4477	1.6678	0.2315	0.3125	5.2083										5.7523	85%	70%	78%
A2H023 Jukskei River @ Nietgedacht	-25.954481°	27.962468°	3.3882	7.2624	4.9001				0.6366									0.6366	16%	8%	11%
A2H044 Jukskei River @ Vlakfontein	-25.893820°	27.957460°	3.3354	8.5635	6.5608				0.6366									0.6366	16%	7%	9%
Rietvlei WTP	-25.877816°	28.264219°	2.2712	3.9336	2.9965					0.7292								0.7292	24%	16%	20%
A2H014 Hennops River @ Skurweberg	-25.832395°	27.992750°	2.2712	3.9336	2.9965					0.7292	1.2153	0.7523						2.6968	54%	41%	47%
A2H012 Krokodil River @ Kalkheuwel	-25.821939°	27.911167°	10.5402	17.1956	14.0482	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523						9.0856	46%	35%	39%
A2H058 Swart Spruit @ Rietfontein	-25.745480°	27.905270°	0.0076	0.0348	0.0201								0.0579					0.0579	88%	62%	74%
A2H013 Magalies River @ Scheerpoort	-25.775160°	27.767940°	0.1136	0.3384	0.2398									0.0127				0.0127	10%	4%	5%
Brits WTP	-25.629855°	27.796783°	1.5063	10.5081	6.4878	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127				9.1563	86%	47%	59%
A2H048 Krokodil River @ Krokodilpoort	-25.573352°	27.754668°	1.5063	10.5081	6.4878	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620			9.3183	86%	47%	59%
Vaalkop WTP	-25.307910°	27.483997°	2.1408	12.6519	6.5794											0.4861	0.0625	0.5486	20%	4%	8%
A2H059 Krokodil River @ Vaalkop	-25.199970°	27.575680°	2.1408	12.6519	6.5794	0.2315	0.3125	5.2083	0.6366	0.7292	1.2153	0.7523	0.0579	0.0127	0.1620	0.4861	0.0625	9.8669	82%	44%	60%

H2: De facto wastewater maps for different time periods for Crocodile River

- **Wastewater Contributions in 2015**

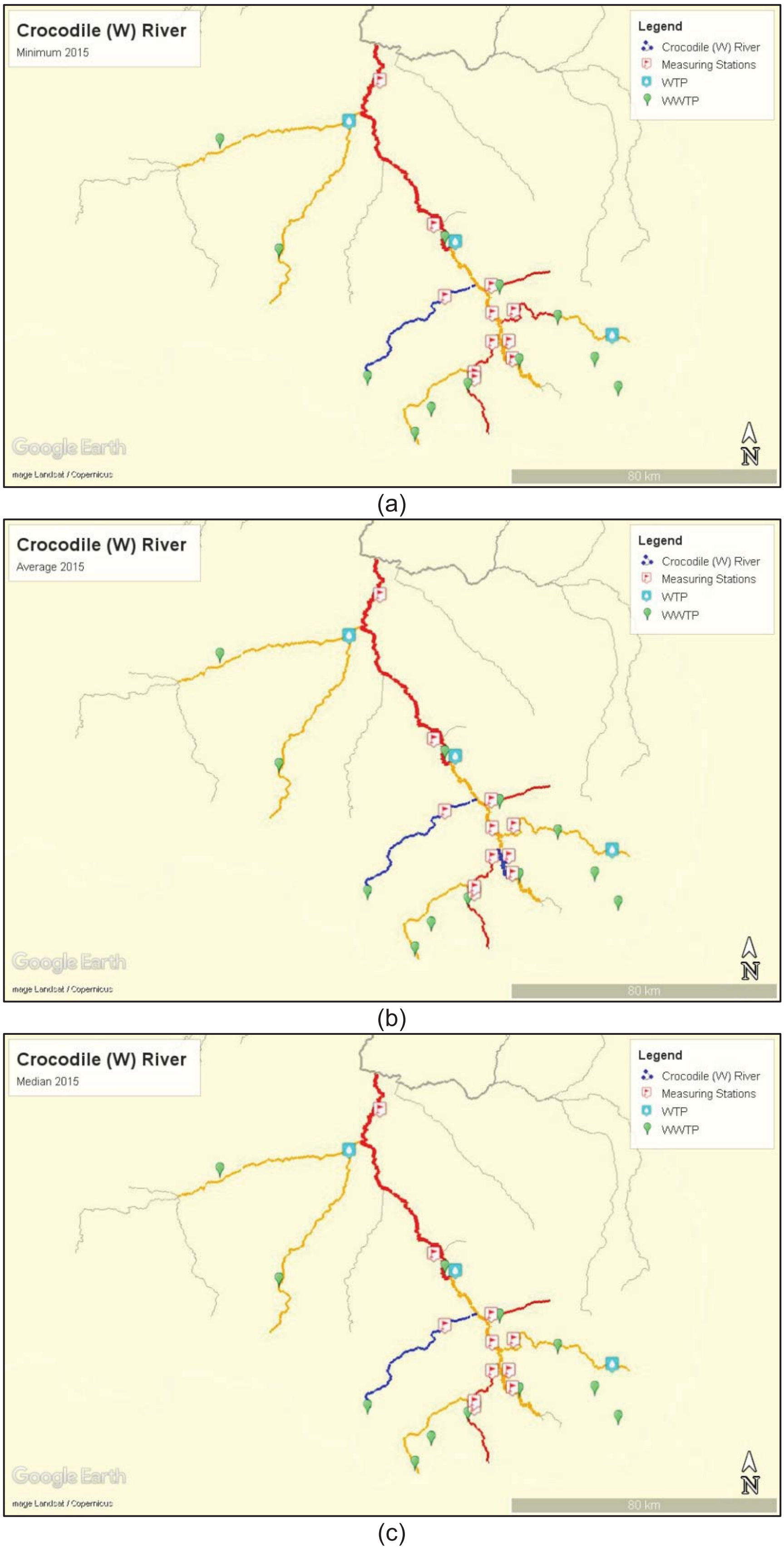
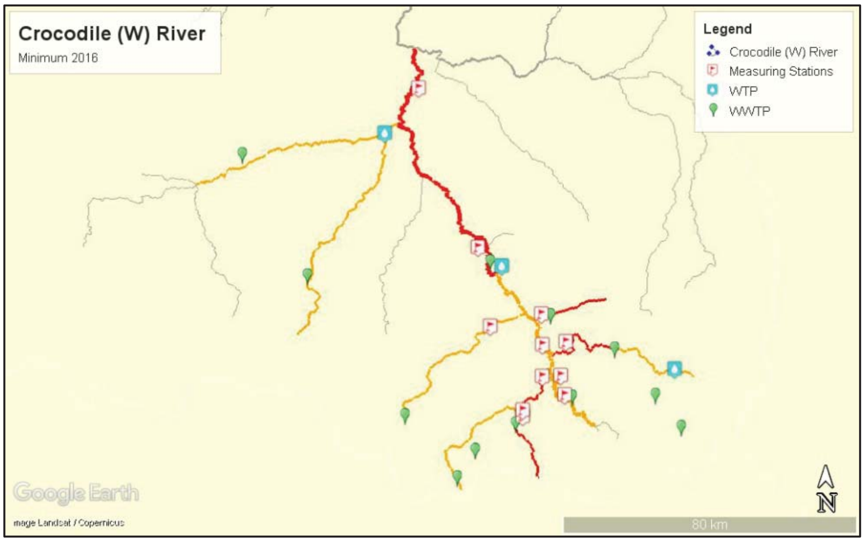
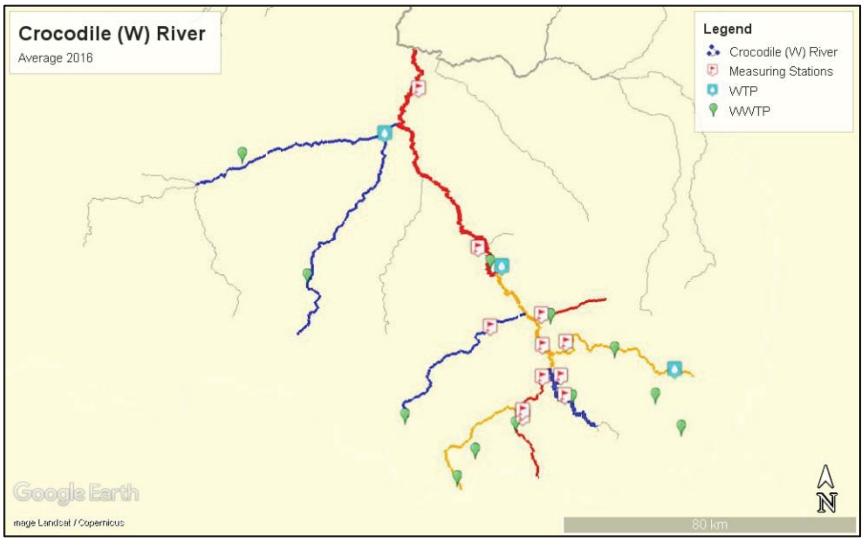


Figure H2.1: Wastewater contribution in the Crocodile River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

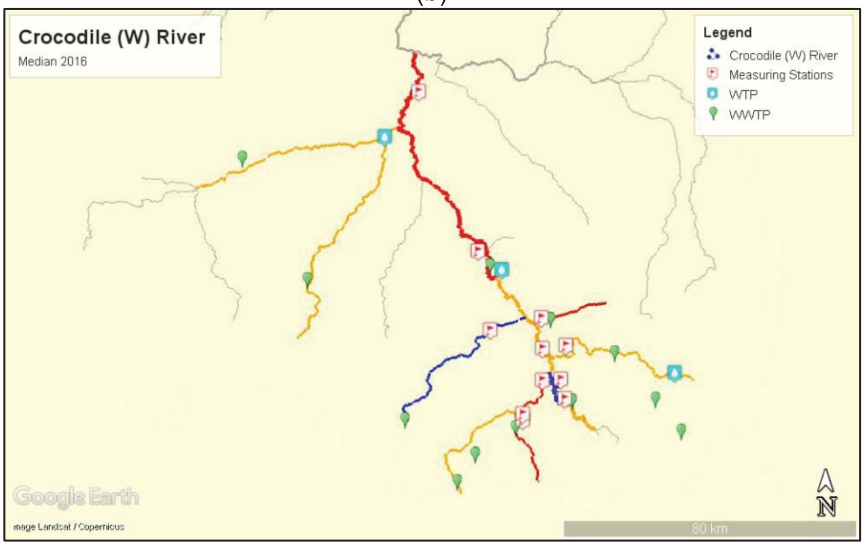
- **Wastewater Contributions in 2016**



(a)



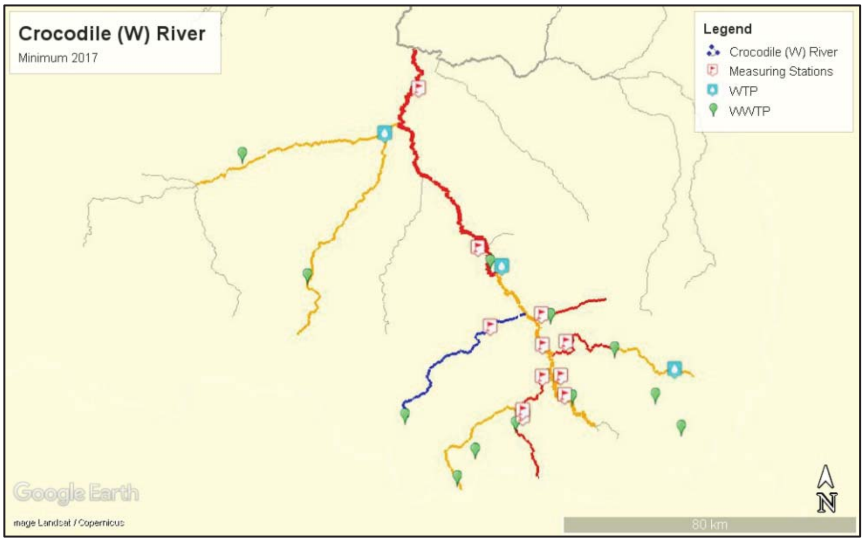
(b)



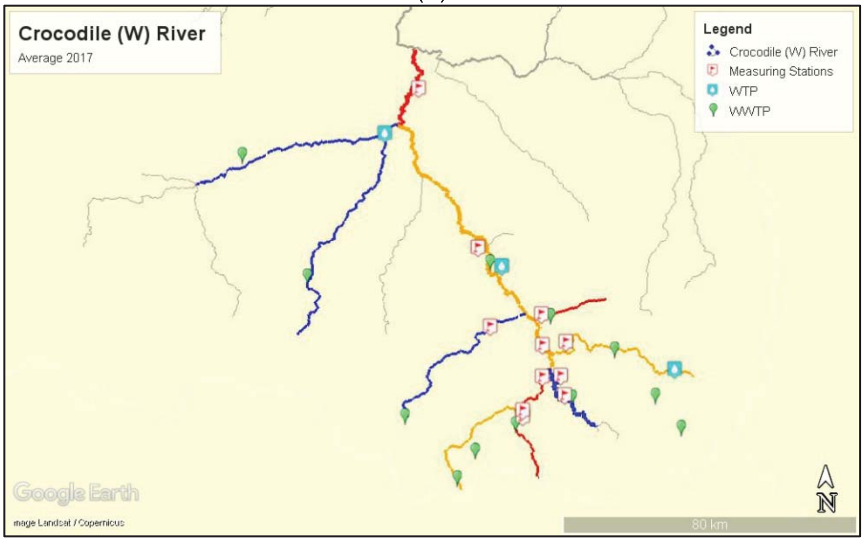
(c)

Figure H2.2: Wastewater contribution in the Crocodile River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

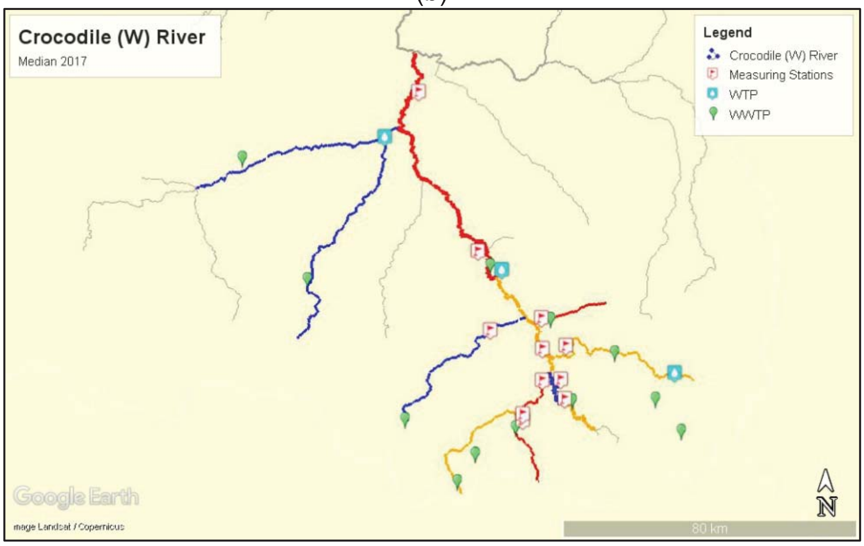
- **Wastewater Contributions in 2017**



(a)



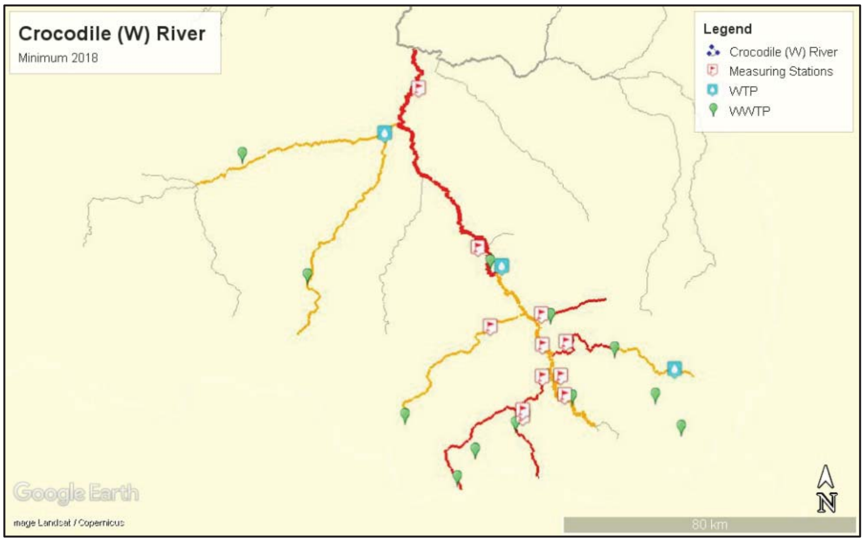
(b)



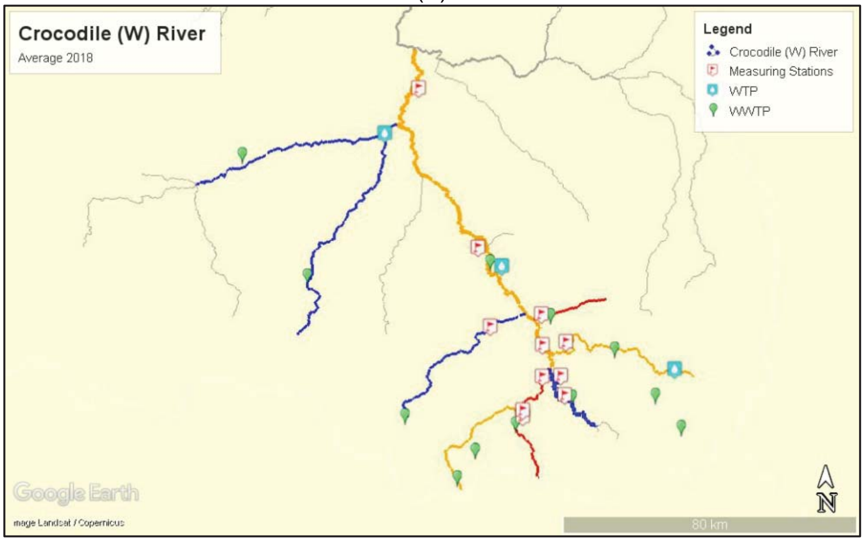
(c)

Figure H2.3: Wastewater contribution in the Crocodile River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

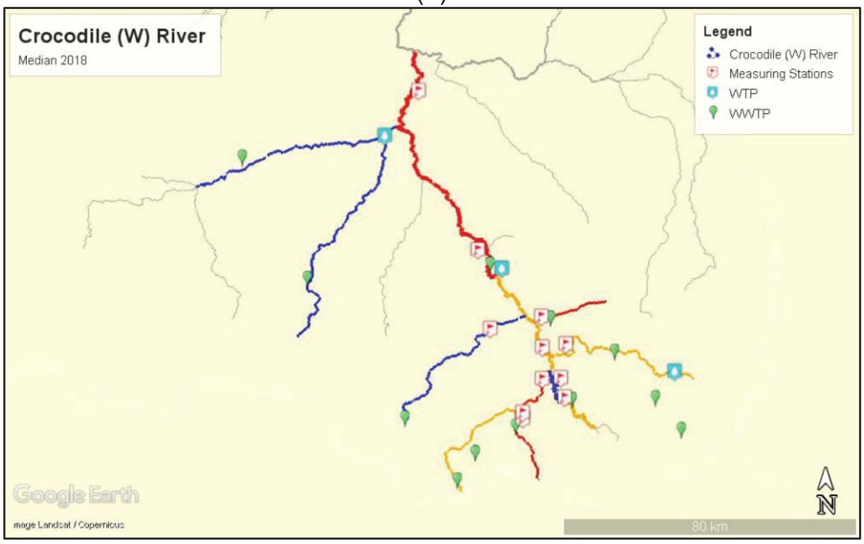
- **Wastewater Contributions in 2018**



(a)



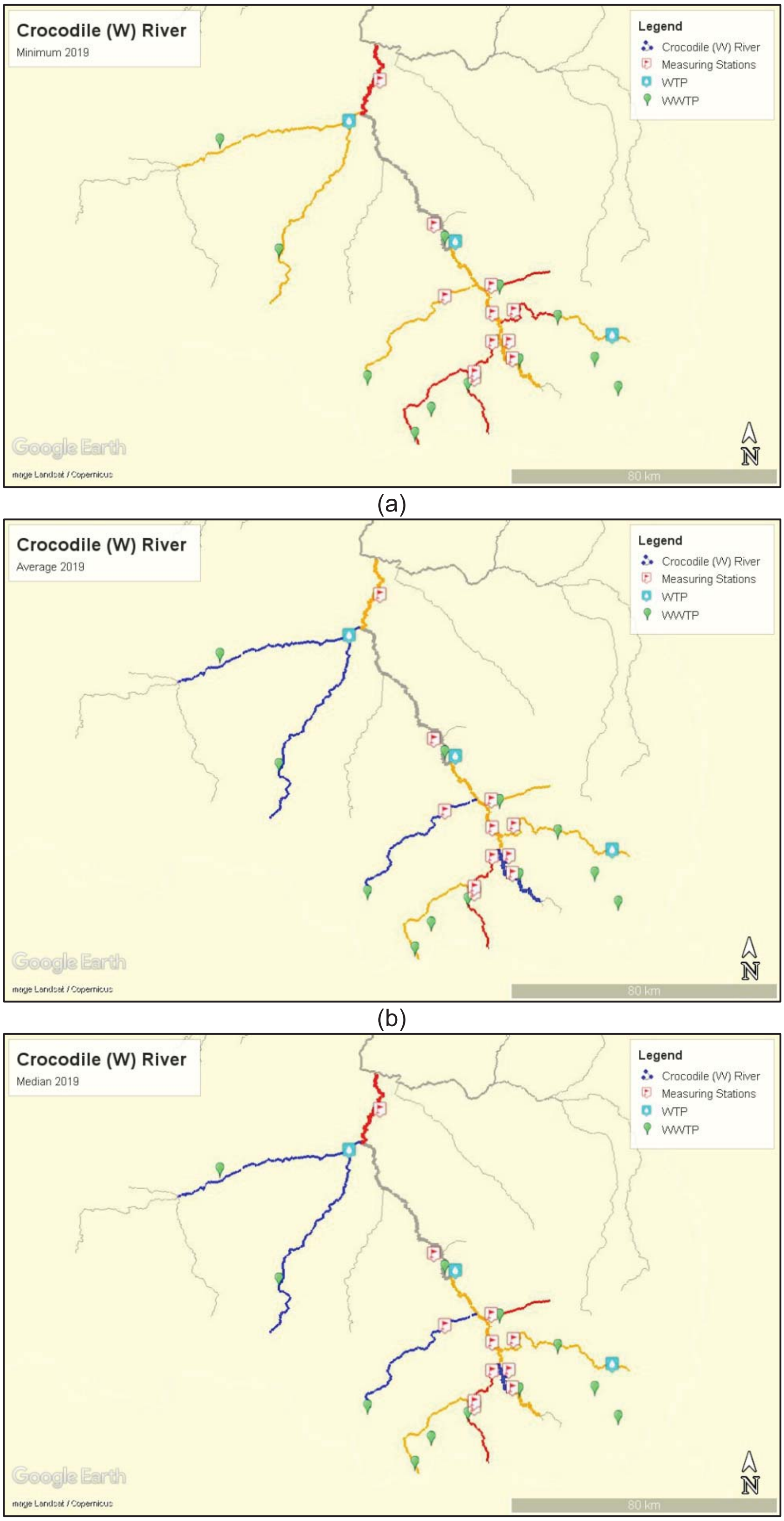
(b)



(c)

Figure H2.4: Wastewater contribution in the Crocodile River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

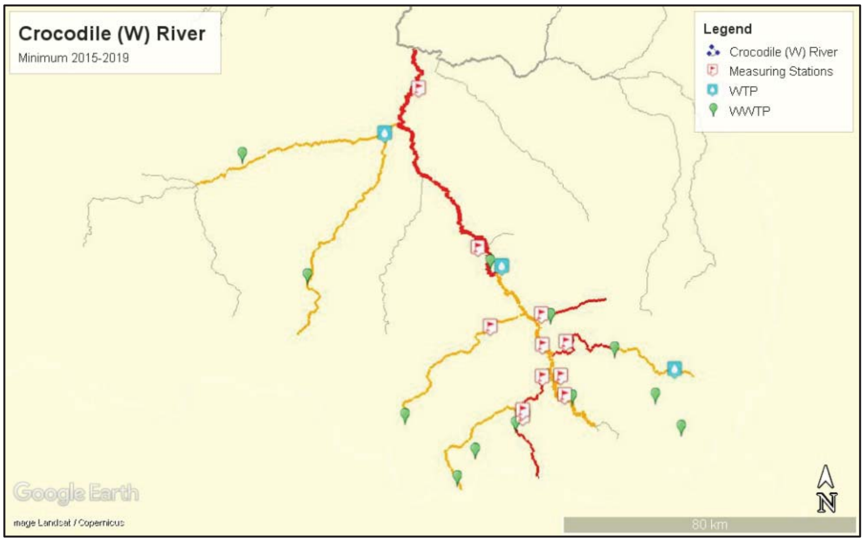
- **Wastewater Contributions in 2019**



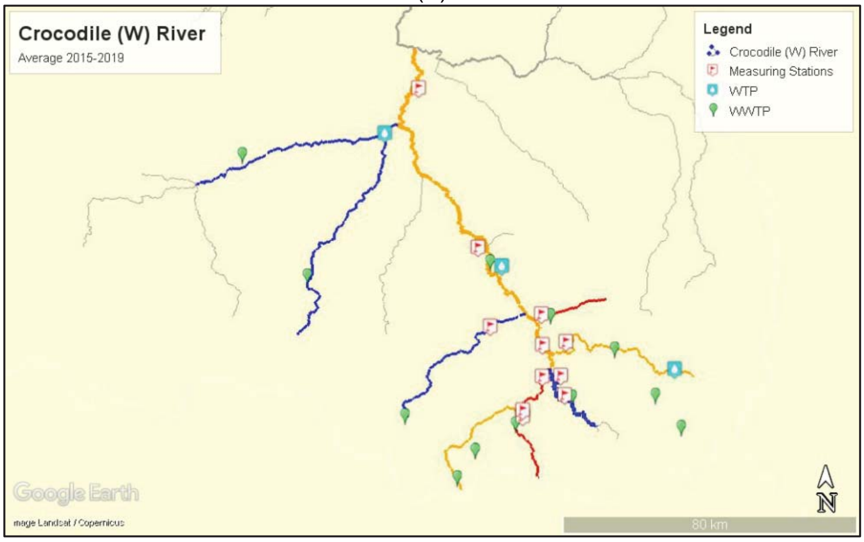
(c)

Figure H2.5: Wastewater contribution in the Crocodile River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

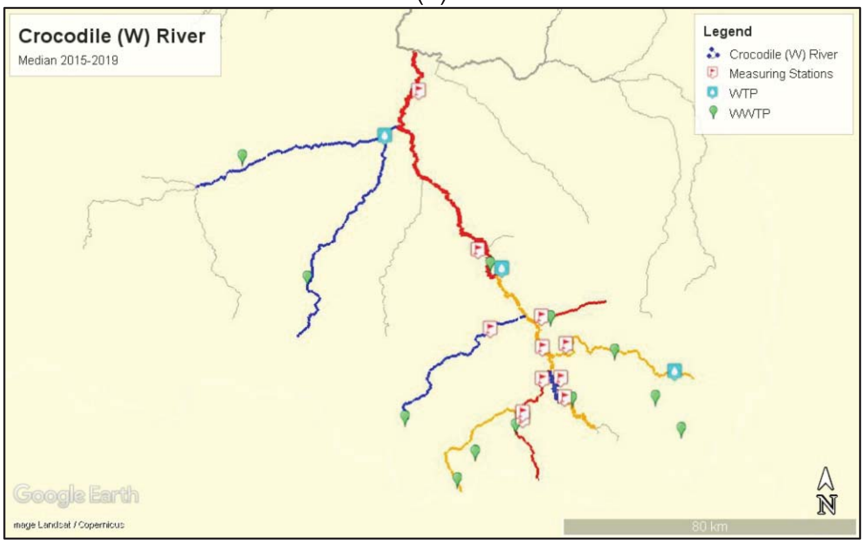
- **Wastewater Contributions in 2015-2019**



(a)



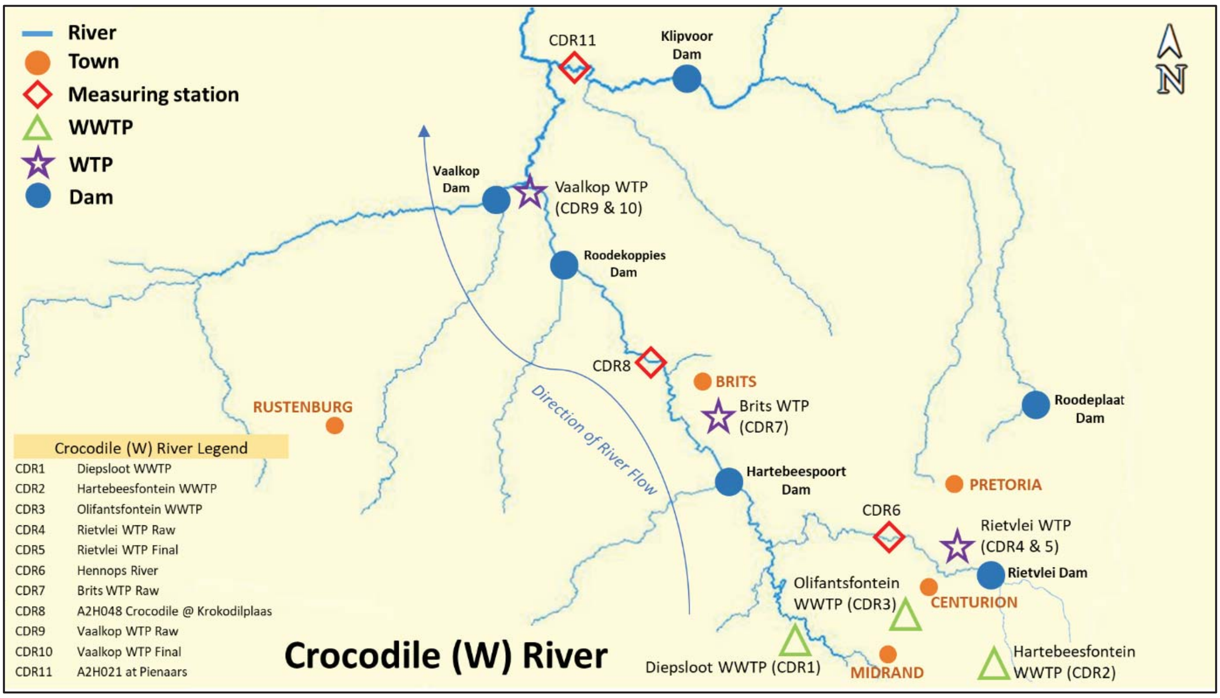
(b)



(c)

Figure H2.6: Wastewater contribution in the Crocodile River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

H3: Map of sampling points for CEC analysis in the Crocodile River



H4: CEC Concentration Results Legend for the Crocodile River

Crocodile River Legend	
CDR1	Diepsloot WWTP
CDR2	Hartbeesfontein WWTP
CDR3	Olifantsfontein WWTP
CDR4	Rietvlei WTP Raw
CDR5	Rietvlei WTP Final
CDR6	Hennops River
CDR7	Brits WTP Raw
CDR8	A2H048 Crocodile @ Krokodilplaas
CDR9	Vaalkop WTP Raw
CDR10	Vaalkop WTP Final
CDR11	A2H021 at Pienaars

H5: Results of the CEC analysis for the Crocodile River

Table H5.1: Results of the CEC analysis for the Crocodile River

Constituent	Diepsloot WWTP	Hartebeesfontein WWTP	Olifantsfontein WWTP	Rietvlei WTP Raw	Rietvlei WTP Final	Hennops River	Brits WTP Raw	A2H048 Crocodile @	Vaalkop WTP Raw	Vaalkop WTP Final	A2H021 at Pienaars
	Sample Points										
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
1,7-dimethylxanthine	22.32	32.3	735.7	30.42	7.188	835.9	118.7	107.8	40.42	<IQL	34.78
Acetaminophen	<MDL	330.7	<IQL	<IQL	<MDL	44.53	<IQL	187.5	<MDL	<MDL	<MDL
Atrazine	256.2	293.6	304.6	129.1	98.74	141.6	77.79	90.23	40.86	32.18	54.16
Benzotriazole	94.58	<IQL	31.86	24.01	22.14	33.2	35.69	68.89	22.68	6.763	<IQL
Benzoylecgonine	22.21	<IQL	20.56	<IQL	0.632	12.38	6.817	7.261	<MDL	<MDL	<IQL
Caffeine	13.58	147.8	3699	186.1	169.4	2942	197.2	114.6	27.04	<IQL	16.83
Carbamazepine	123.9	276.7	260.4	53.57	35.06	98.62	62.04	61.21	31.98	<MDL	100.1
Cetirizine	<IQL	132.5	105.6	15.31	<MDL	26.32	<IQL	22.56	3.662	<MDL	8.963
Cocaine	<IQL	<IQL	2.74	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<MDL	<IQL
Codeine	<MDL	<IQL	<IQL	<MDL	<MDL	664	<MDL	<MDL	<MDL	<MDL	<MDL
Diclofenac	<MDL	66.6	347.4	<IQL	<IQL	78.23	<MDL	9.012	<IQL	<IQL	<IQL
Efavirenz	2834	2329	6316	295	252.5	2333	552.5	608.2	119	<IQL	338.6
Emtricitabine	<IQL	328.9	13206	202.7	<IQL	6432	<IQL	656.9	85.89	<MDL	146
MDMA	<MDL	<MDL	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Methamphetamine	27.03	6.19	77.67	11.91	7.213	83.14	7.264	10.87	<MDL	<IQL	<IQL
Methaqualone	1006	182.6	389.3	18.96	12.94	150.3	111.2	98.2	21.8	<MDL	8.018
Naproxen	<MDL	<MDL	32.38	<IQL	<MDL	<IQL	<IQL	17.79	<MDL	<MDL	<IQL
Sulfamethoxazole	<IQL	202.2	1655	160.7	<MDL	698	<MDL	247.2	72.37	<MDL	131.8
Tramadol	1.065	778	1514	116.5	<IQL	342.3	52.03	115.2	13.38	<IQL	71
Trimethoprim	43.17	39.96	266.1	12.25	<IQL	254.9	<IQL	<IQL	<MDL	<IQL	<MDL
Venlafaxine	<MDL	149.1	29.58	3.055	<MDL	5.308	5.252	11.04	<IQL	<MDL	<IQL

<IQL = Less than Instrument Quantification Limit

<MDL = Less than Method Detection Limit

H6: Bar charts of indicator compound results in the Crocodile River

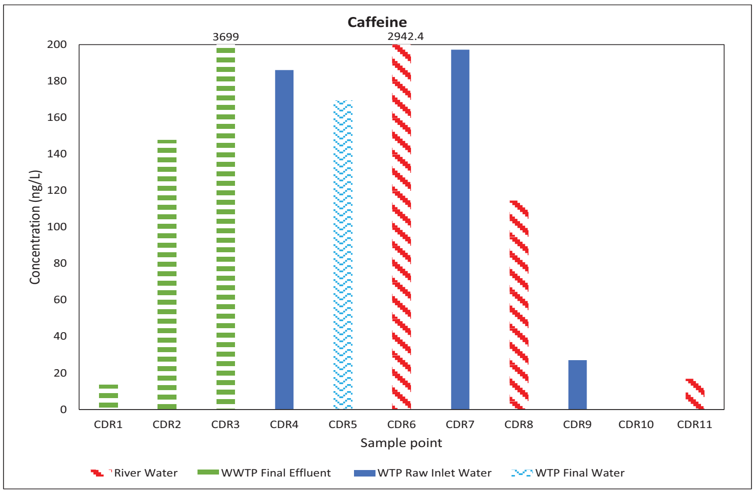


Figure H6.1: Concentrations of Caffeine in the Crocodile River

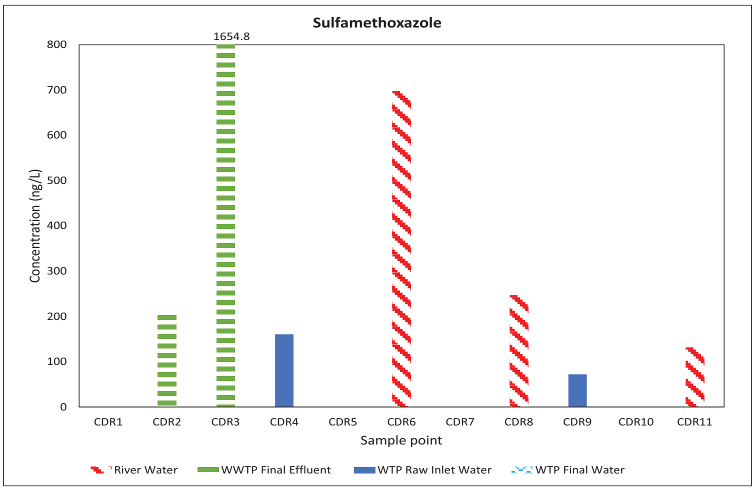


Figure H6.2: Concentrations of Sulfamethoxazole in the Crocodile River

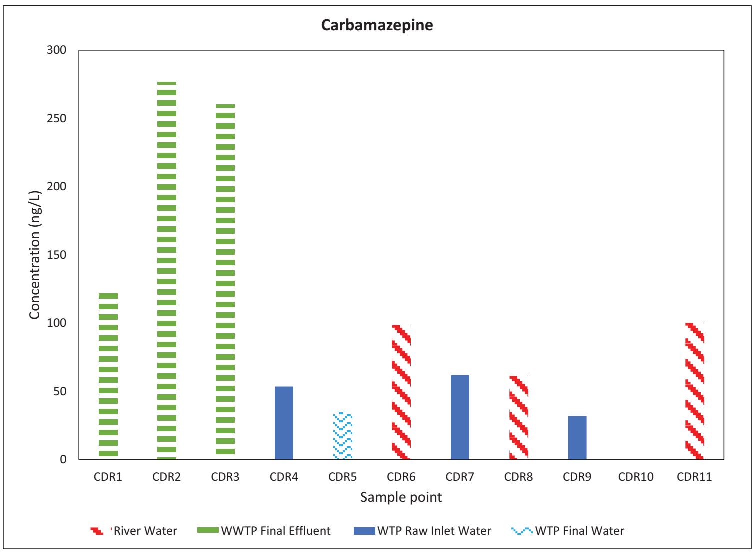


Figure H6.3: Concentrations of Carbamazepine in the Crocodile River

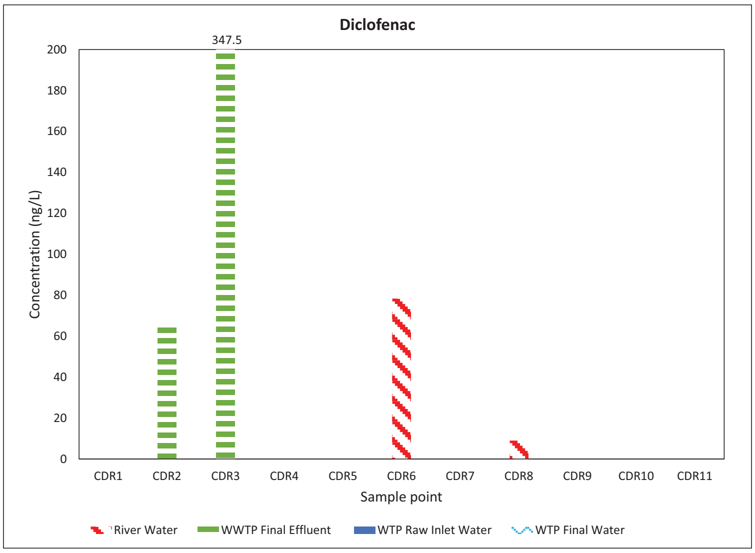


Figure H6.4: Concentrations of Diclofenac in the Crocodile River

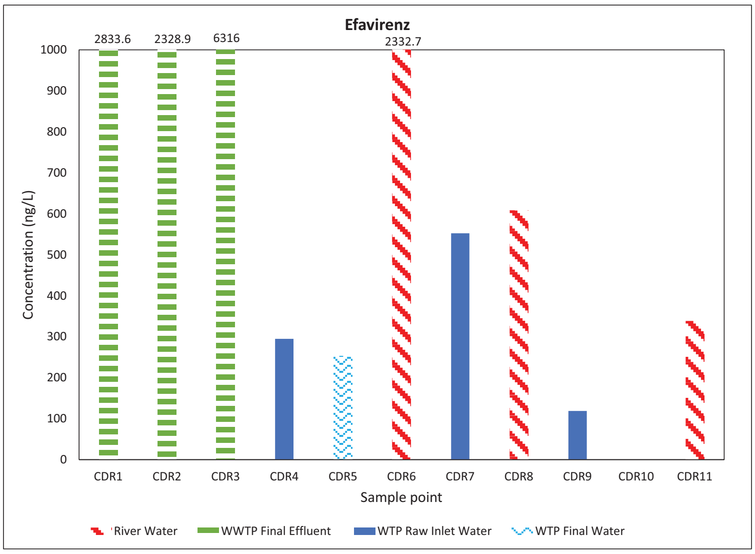


Figure H6.5: Concentrations of Efavirenz in the Crocodile River

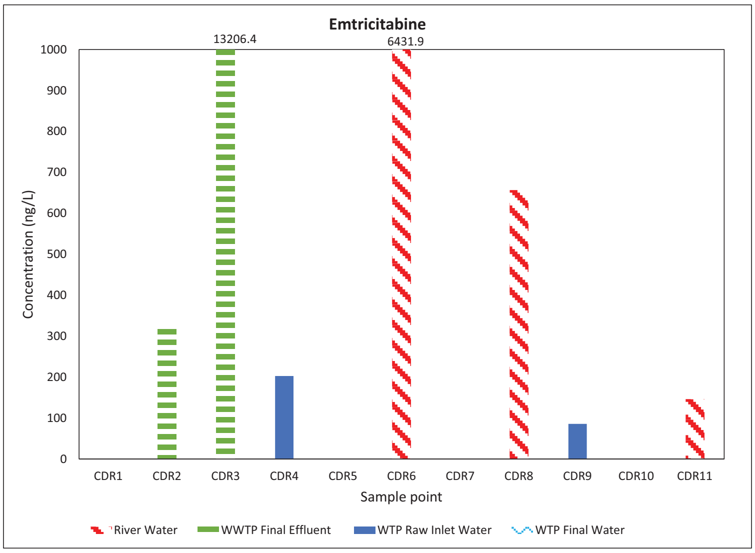


Figure H6.6: Concentrations of Emtricitabine in the Crocodile River

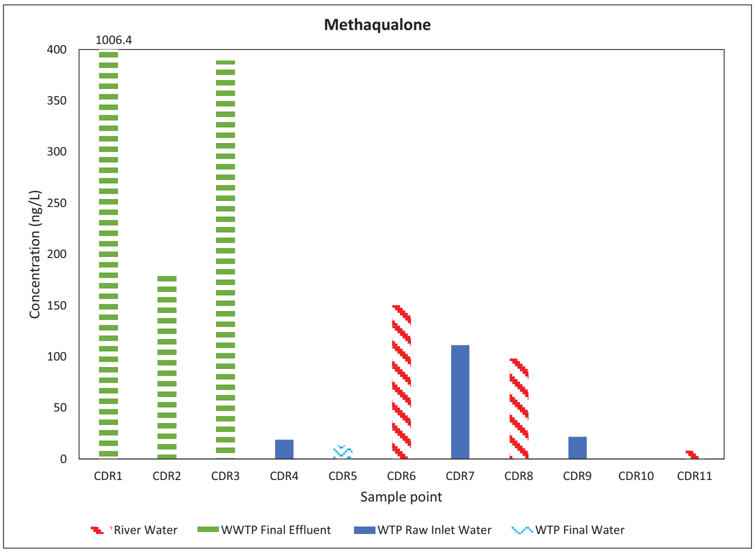


Figure H6.7: Concentrations of Methaqualone in the Crocodile River

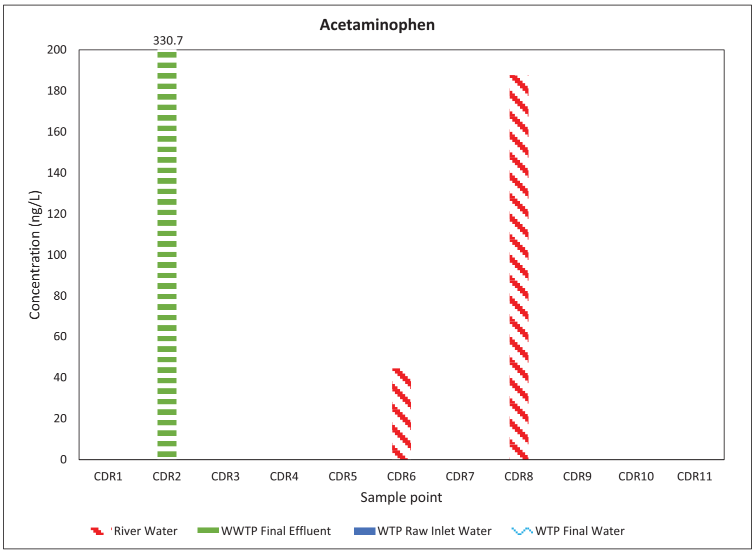


Figure H6.8: Concentrations of Acetaminophen in the Crocodile River

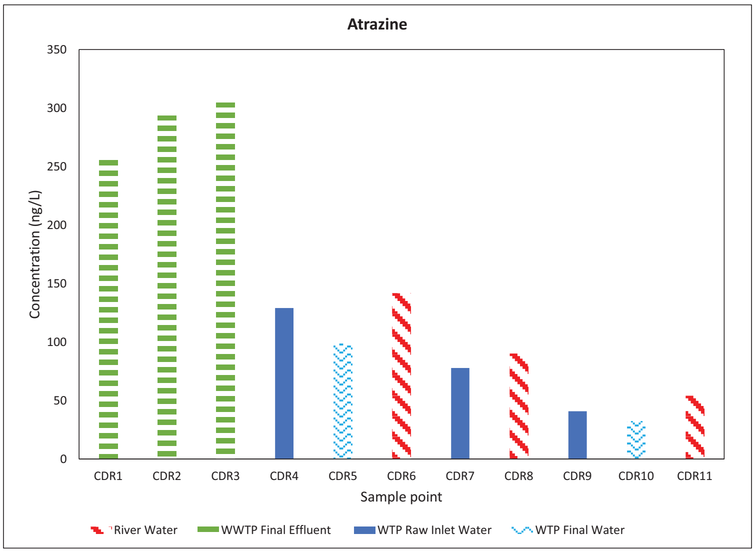


Figure H6: Concentrations of Atrazine in the Crocodile River

H7: Results of Other Water Quality Parameters for the Crocodile River

Sample Points	Sample Name	pH	EC	COD	UV 254	DOC	DO
		-	mS/m	mg/L	m^{-1}	mg/L	mg/L
Diepsloot WWTP	CDR1	7.86	74	46	0.032	1.96	8.05
Hartbeesfontein WWTP	CDR2	7.89	-	54	0.092	2.82	-
Olifantsfontein WWTP	CDR3	8.34	-	72	0.139	3.48	-
Rietvlei WTP Raw	CDR4	8.51	35	51	0.194	4.26	2.96
Rietvlei WTP Final	CDR5	7.73	34	33	0.011	1.67	7.54
Hennops River	CDR6	8.23	-	57	0.216	4.57	7.47
Brits WTP Raw	CDR7	8.09	59	50	0.082	2.67	7.2
A2H048 Crocodile @ Krokodilplaas	CDR8	8.42	58	41	0.050	2.22	6.97
Vaalkop WTP Raw	CDR9	8.25	55	33	0.078	2.62	3.97
Vaalkop WTP Final	CDR10	7.92	57	41	0.019	1.78	7.35
A2H021 at Pienaars	CDR11	8.47	-	47	0.184	4.12	-

APPENDIX I RESULTS FOR THE OLIFANTS RIVER

I: Flow-based data and calculations for the Olifants River

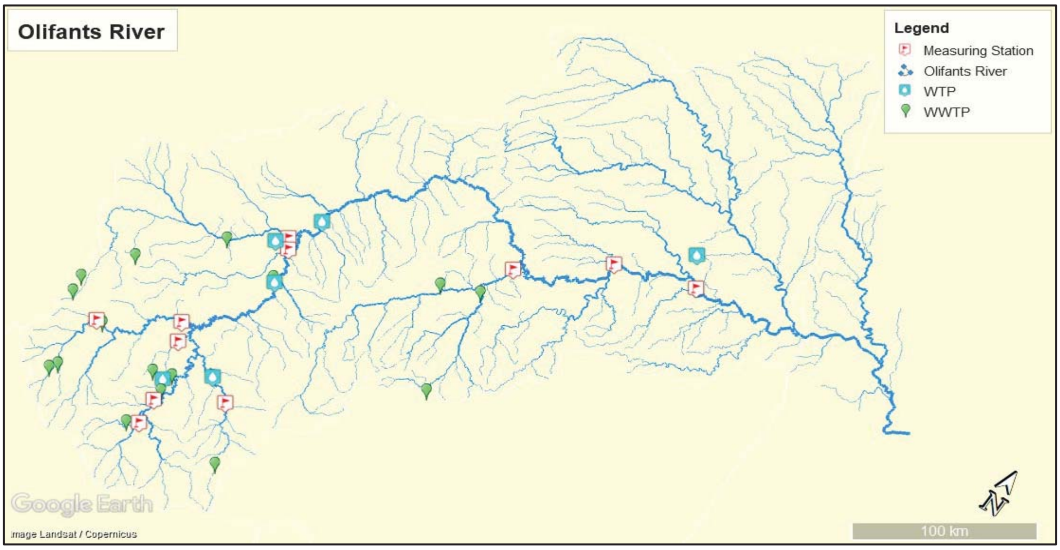


Figure I1.1: Olifants River System, indicating all measuring stations, WWTP and WTP in this river.

Table I1.1: Summary of Wastewater Percentages for the Olifants River for 2015-2019

Olifants River

Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	59%	29%	40%	57%	12%	19%	27%	6%	9%
B1H005 Olifants River @ Wolwekrans	51%	22%	29%	65%	7%	12%	17%	3%	6%
Witbank WTP	56%	26%	33%	70%	8%	15%	20%	4%	7%
B1H012 Little Olifants River @ Rondebosch	26%	10%	12%	33%	7%	9%	23%	5%	9%
Vaalbank WTP	26%	10%	12%	33%	7%	9%	23%	5%	9%
B1H004 Klipspruit @ Zaaihoek	38%	29%	31%	49%	8%	13%	13%	3%	6%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	85%	33%	38%	69%	8%	10%	12%	4%	6%
B2H016 Wilger River @ Waterval	25%	12%	15%	75%	11%	14%	91%	68%	76%
Groblersdal WTP	52%	29%	34%	68%	53%	59%	54%	34%	41%
B3H026 Eagle's Flight	39%	17%	22%	91%	75%	79%	93%	71%	78%
Marble Hall WTP	38%	17%	21%	83%	43%	53%	38%	17%	26%
B3H021 Elands River @ Skerp Arabie	90%	42%	60%		N/A		88%	59%	68%
Flag Boshielo WTP	48%	22%	28%	96%	47%	53%	56%	31%	38%
B4H025 Steelpoort River @ Taung	4%	1%	1%	1%	1%	1%	1%	1%	0%
B7H007 Olifants River @ Oxford	20%	11%	13%	39%	15%	22%	18%	10%	13%
Phalaborwa WTP	18%	8%	9%	42%	16%	21%	18%	8%	10%
B7H015 Olifants River @ Mamba KNP	18%	8%	9%	42%	16%	21%	18%	8%	10%

Measuring station/ Water Treatment Works	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	44%	12%	17%	38%	8%	12%	41%	10%	15%
B1H005 Olifants River @ Wolwekrans	24%	6%	10%	25%	11%	11%	29%	6%	11%
Witbank WTP	28%	7%	12%	29%	13%	13%	33%	8%	13%
B1H012 Little Olifants River @ Rondebosch	9%	3%	5%	18%	3%	4%	18%	4%	7%
Vaalbank WTP	9%	3%	5%	18%	3%	4%	18%	4%	7%
B1H004 Klipspruit @ Zaaihoek	15%	5%	8%	19%	4%	6%	20%	5%	8%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	14%	2%	4%	25%	1%	3%	15%	3%	5%
B2H016 Wilger River @ Waterval	95%	67%	78%	97%	25%	52%	95%	45%	67%
Groblersdal WTP	56%	43%	48%	61%	45%	50%	60%	44%	50%
B3H026 Eagle's Flight	97%	70%	86%	94%	43%	71%	94%	64%	79%
Marble Hall WTP	49%	25%	37%	54%	14%	21%	53%	23%	33%
B3H021 Elands River @ Skerp Arabie	93%	58%	70%	95%	18%	42%	93%	35%	57%
Flag Boshielo WTP	61%	15%	31%	76%	11%	24%	64%	20%	32%
B4H025 Steelpoort River @ Taung	1%	0%	0%	1%	0%	1%	1%	0%	1%
B7H007 Olifants River @ Oxford	29%	18%	19%	29%	15%	18%	25%	13%	16%
Phalaborwa WTP	32%	17%	19%	34%	11%	14%	25%	11%	13%
B7H015 Olifants River @ Mamba KNP	32%	17%	19%	34%	11%	14%	25%	11%	13%

Table I1.2: Wastewater percentage calculations for Olifants River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Olifants (E) River — 2015

Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.0924	0.3190	0.2026	0.0463							0.0868										0.1331	59%	29%	40%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.1266	0.4663	0.3329	0.0463							0.0868										0.1331	51%	22%	29%
Witbank WTP	-25.881586°	29.231528°	0.1266	0.4663	0.3329	0.0463	0.1157																0.1620	56%	26%	33%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.1258	0.4079	0.3119				0.0440														0.0440	26%	10%	12%
Vaalbank WTP	-25.820794°	29.482491°	0.1258	0.4079	0.3119				0.0440														0.0440	26%	10%	12%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	0.5430	0.7960	0.7259						0.2141	0.1157											0.3299	38%	29%	31%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	0.0263	0.2900	0.2390								0.0868	0.0579									0.1447	85%	33%	38%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.6133	1.4345	1.1752								0.0868	0.0579	0.0579								0.2025	25%	12%	15%
Groblersdal WTP	-25.161322°	29.412411°	0.8656	2.3086	1.8200	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	52%	29%	34%
B3H026 Eagle's Flight	-24.981080°	29.366460°	1.5322	4.7521	3.6065	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	39%	17%	22%
Marble Hall WTP	-24.977911°	29.283469°	1.5322	4.7521	3.6065	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	38%	17%	21%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	0.0146	0.1897	0.0926	0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	90%	42%	60%
Flag Boshielo WTP	-24.773469°	29.423674°	1.5468	4.9418	3.6991	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	48%	22%	28%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	0.5287	2.6689	2.2189																0.0023	0.0174	0.0197	4%	1%	1%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	5.8276	12.1197	9.4338	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	20%	11%	13%
Phalaborwa WTP	-24.069968°	31.141058°	6.5578	15.7175	14.1933	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	18%	8%	9%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	6.5578	15.7175	14.1933	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	18%	8%	9%

(b)

Olifants (E) River — 2016

Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.0991	0.9583	0.5505	0.0463							0.0868										0.1331	57%	12%	19%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.0710	1.7777	0.9448	0.0463							0.0868										0.1331	65%	7%	12%
Witbank WTP	-25.881586°	29.231528°	0.0710	1.7777	0.9448	0.0463	0.1157																0.1620	70%	8%	15%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.0883	0.5903	0.4459				0.0440														0.0440	33%	7%	9%
Vaalbank WTP	-25.820794°	29.482491°	0.0883	0.5903	0.4459				0.0440														0.0440	33%	7%	9%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	0.3480	3.6033	2.2106						0.2141	0.1157											0.3299	49%	8%	13%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	0.0661	1.5790	1.2622								0.0868	0.0579									0.1447	69%	8%	10%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.0661	1.5790	1.2622								0.0868	0.0579	0.0579								0.2025	75%	11%	14%
Groblersdal WTP	-25.161322°	29.412411°	0.4478	0.8338	0.6675	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	68%	53%	59%
B3H026 Eagle's Flight	-24.981080°	29.366460°	0.0963	0.3336	0.2627	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	91%	75%	79%
Marble Hall WTP	-24.977911°	29.283469°	0.1887	1.2353	0.8200	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	83%	43%	53%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	NO DATA AVAILABLE			0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	N/A		
Flag Boshielo WTP	-24.773469°	29.423674°	0.0661	1.5790	1.2622	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	96%	47%	53%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	2.0149	3.5967	3.2087																0.0023	0.0174	0.0197	1%	1%	1%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	2.2787	8.3196	5.0839	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	39%	15%	22%
Phalaborwa WTP	-24.069968°	31.141058°	2.0003	7.5218	5.4927	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	42%	16%	21%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	2.0003	7.5218	5.4927	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	42%	16%	21%

(c)

Olifants (E) River — 2017

Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.3680	1.9911	1.4313	0.0463							0.0868										0.1331	27%	6%	9%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.6420	4.0393	2.1809	0.0463							0.0868										0.1331	17%	3%	6%
Witbank WTP	-25.881586°	29.231528°	0.6420	4.0393	2.1809	0.0463	0.1157																0.1620	20%	4%	7%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.1494	0.9139	0.4425				0.0440														0.0440	23%	5%	9%
Vaalbank WTP	-25.820794°	29.482491°	0.1494	0.9139	0.4425				0.0440														0.0440	23%	5%	9%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	2.3015	9.6563	5.3040						0.2141	0.1157											0.3299	13%	3%	6%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	1.0784	3.0951	2.2878								0.0868	0.0579									0.1447	12%	4%	6%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.0192	0.0966	0.0655								0.0868	0.0579	0.0579								0.2025	91%	68%	76%
Groblersdal WTP	-25.161322°	29.412411°	0.7916	1.8507	1.3688	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	54%	34%	41%
B3H026 Eagle's Flight	-24.981080°	29.366460°	0.0732	0.4122	0.2828	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	93%	71%	78%
Marble Hall WTP	-24.977911°	29.283469°	1.5101	4.7031	2.6805	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	38%	17%	26%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	0.0192	0.0966	0.0655	0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	88%	59%	68%
Flag Boshielo WTP	-24.773469°	29.423674°	1.0976	3.1916	2.3533	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	56%	31%	38%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	2.0149	3.5967	4.4719																0.0023	0.0174	0.0197	1%	1%	0%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	6.4337	13.0834	9.7112	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	18%	10%	13%
Phalaborwa WTP	-24.069968°	31.141058°	6.5891	17.5776	12.4452	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	18%	8%	10%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	6.5891	17.5776	12.4452	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	18%	8%	10%

(d)

Olifants (E) River — 2018

Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.1665	1.0224	0.6658	0.0463							0.0868										0.1331	44%	12%	17%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.4166	2.2442	1.1541	0.0463							0.0868										0.1331	24%	6%	10%
Witbank WTP	-25.881586°	29.231528°	0.4166	2.2442	1.1541	0.0463	0.1157																0.1620	28%	7%	12%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.4598	1.4109	0.8545				0.0440														0.0440	9%	3%	5%
Vaalbank WTP	-25.820794°	29.482491°	0.4598	1.4109	0.8545				0.0440														0.0440	9%	3%	5%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	1.8496	6.4167	3.6238						0.2141	0.1157											0.3299	15%	5%	8%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	0.9049	8.0456	3.1303								0.0868	0.0579									0.1447	14%	2%	4%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.0099	0.0992	0.0584								0.0868	0.0579	0.0579								0.2025	95%	67%	78%
Groblersdal WTP	-25.161322°	29.412411°	0.7273	1.2503	1.0311	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	56%	43%	48%
B3H026 Eagle's Flight	-24.981080°	29.366460°	0.0310	0.4274	0.1688	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	97%	70%	86%
Marble Hall WTP	-24.977911°	29.283469°	0.9733	2.7616	1.6152	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	49%	25%	37%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	0.0099	0.0992	0.0584	0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	93%	58%	70%
Flag Boshielo WTP	-24.773469°	29.423674°	0.9148	8.1448	3.1887	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	61%	15%	31%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	3.4709	4.2621	3.9459																0.0023	0.0174	0.0197	1%	0%	0%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	3.6026	6.6301	6.0364	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	29%	18%	19%
Phalaborwa WTP	-24.069968°	31.141058°	3.0648	7.1114	6.0941	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	32%	17%	19%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	3.0648	7.1114	6.0941	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	32%	17%	19%

(e)

Olifants (E) River

2019

Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.2189	1.6396	1.0137	0.0463							0.0868										0.1331	38%	8%	12%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.4004	1.1266	1.0419	0.0463							0.0868										0.1331	25%	11%	11%
Witbank WTP	-25.881586°	29.231528°	0.4004	1.1266	1.0419	0.0463	0.1157																0.1620	29%	13%	13%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.1970	1.5963	0.9436				0.0440														0.0440	18%	3%	4%
Vaalbank WTP	-25.820794°	29.482491°	0.1970	1.5963	0.9436				0.0440														0.0440	18%	3%	4%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	1.4092	8.3974	5.4527						0.2141	0.1157											0.3299	19%	4%	6%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	0.4438	10.3669	4.1943								0.0868	0.0579									0.1447	25%	1%	3%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.0070	0.6218	0.1906								0.0868	0.0579	0.0579								0.2025	97%	25%	52%
Groblersdal WTP	-25.161322°	29.412411°	0.6010	1.1473	0.9480	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	61%	45%	50%
B3H026 Eagle's Flight	-24.981080°	29.366460°	0.0689	1.3121	0.4122	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	94%	43%	71%
Marble Hall WTP	-24.977911°	29.283469°	0.8118	5.6745	3.4672	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	54%	14%	21%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	0.0070	0.6218	0.1906	0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	95%	18%	42%
Flag Boshielo WTP	-24.773469°	29.423674°	0.4508	10.9887	4.3849	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	76%	11%	24%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	2.9223	3.9599	3.7370																0.0023	0.0174	0.0197	1%	0%	1%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	3.5986	8.0406	6.7226	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	29%	15%	18%
Phalaborwa WTP	-24.069968°	31.141058°	2.8360	11.6630	8.6682	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	34%	11%	14%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	2.8360	11.6630	8.6682	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	34%	11%	14%

(f)

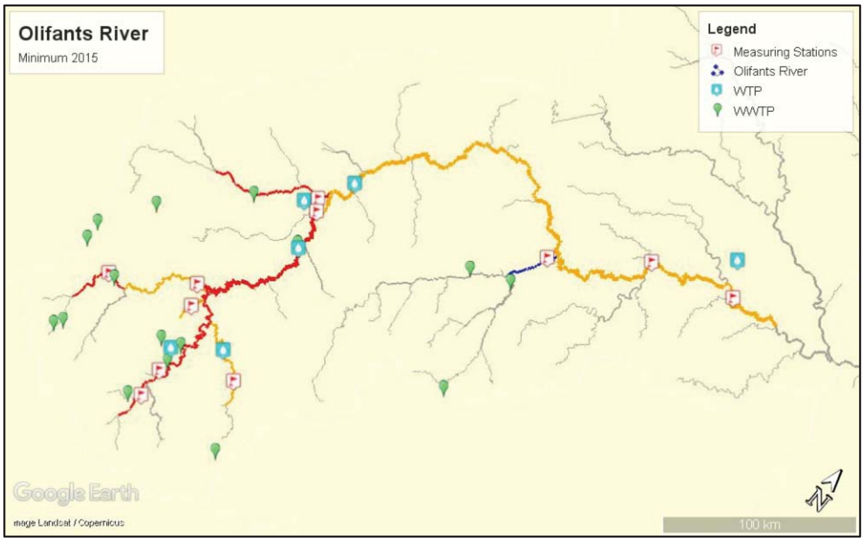
Olifants (E) River

2015-2019

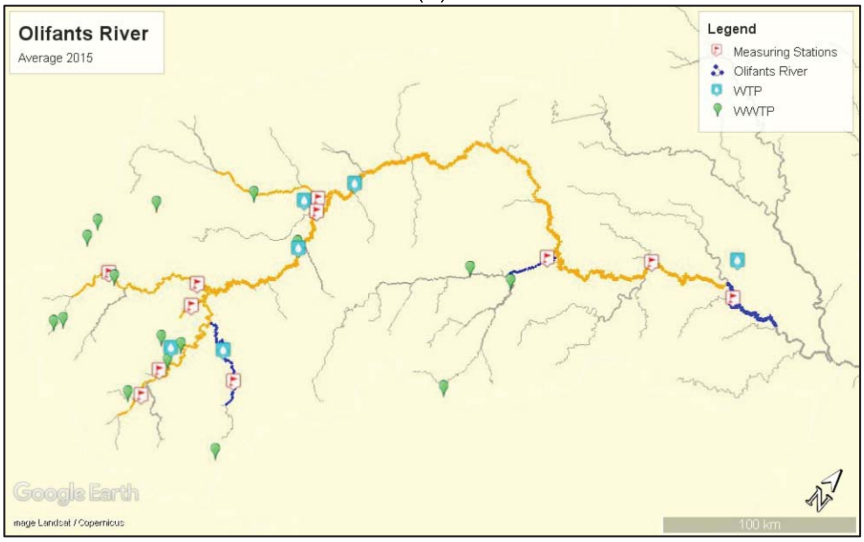
Measuring station/ Water Treatment Plant	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																	Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Rietspruit	Naaupoort	Riverview	Hendrina	Boskrans	Ferrobank	Klipspruit	Botleng	Delmas	Godrich	Groblersdal	Rayton	Refilwe	Siyabuswa	Kwanhlanga	Steelpoort	Burgersfort		Min	Average	Median
B1H021 Steenkoolspruit @ Middeldrift	-26.135710°	29.264830°	0.1890	1.1861	0.7728	0.0463							0.0868										0.1331	41%	10%	15%
B1H005 Olifants River @ Wolwekrans	-25.995080°	29.256590°	0.3313	1.9308	1.1309	0.0463							0.0868										0.1331	29%	6%	11%
Witbank WTP	-25.881586°	29.231528°	0.3313	1.9308	1.1309	0.0463	0.1157																0.1620	33%	8%	13%
B1H012 Little Olifants River @ Rondebosch	-25.817200°	29.583440°	0.2041	0.9838	0.5997				0.0440														0.0440	18%	4%	7%
Vaalbank WTP	-25.820794°	29.482491°	0.2041	0.9838	0.5997				0.0440														0.0440	18%	4%	7%
B1H004 Klipspruit @ Zaaihoek	-25.673710°	29.176940°	1.3548	6.0765	3.6822						0.2141	0.1157											0.3299	20%	5%	8%
B2H003 Bronkhorstspruit @ Bronkhorstspruit	-25.797420°	28.745730°	0.8051	5.5677	2.8962								0.0868	0.0579									0.1447	15%	3%	5%
B2H016 Wilger River @ Waterval	-25.579610°	29.130250°	0.0101	0.2518	0.1017								0.0868	0.0579	0.0579								0.2025	95%	45%	67%
Groblersdal WTP	-25.161322°	29.412411°	0.6221	1.1756	0.9483	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	60%	44%	50%
B3H026 Eagle's Flight	-24.981080°	29.366460°	0.0591	0.5551	0.2731	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579	0.0579							0.9988	94%	64%	79%
Marble Hall WTP	-24.977911°	29.283469°	0.8194	3.1618	1.9516	0.0463	0.1157	0.1273	0.0440	0.4051			0.0868	0.0579	0.0579								0.9410	53%	23%	33%
B3H021 Elands River @ Skerp Arabie	-24.931280°	29.330750°	0.0101	0.2518	0.1017	0.0463											0.0139	0.0133	0.0579	0.0058			0.1372	93%	35%	57%
Flag Boshielo WTP	-24.773469°	29.423674°	0.8152	5.8196	2.9980	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058			1.4196	64%	20%	32%
B4H025 Steelpoort River @ Taung	-24.474650°	30.401920°	2.6140	4.2401	3.8743																0.0023	0.0174	0.0197	1%	0%	1%
B7H007 Olifants River @ Oxford	-24.184340°	30.816650°	4.3482	9.6387	7.3976	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	25%	13%	16%
Phalaborwa WTP	-24.069968°	31.141058°	4.2096	11.9183	9.3787	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	25%	11%	13%
B7H015 Olifants River @ Mamba KNP	-24.069040°	31.245120°	4.2096	11.9183	9.3787	0.0463	0.1157	0.1273	0.0440	0.4051	0.2141	0.1157	0.0868	0.0579	0.0579	0.0579	0.0139	0.0133	0.0579	0.0058	0.0023	0.0174	1.4392	25%	11%	13%

I2: De facto wastewater maps for different time periods for Olifants River

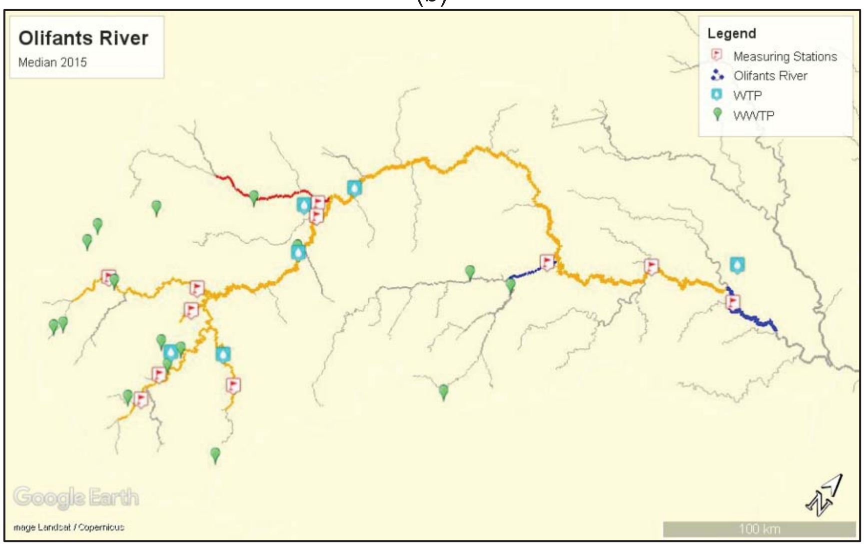
- **Wastewater Contributions in 2015**



(a)



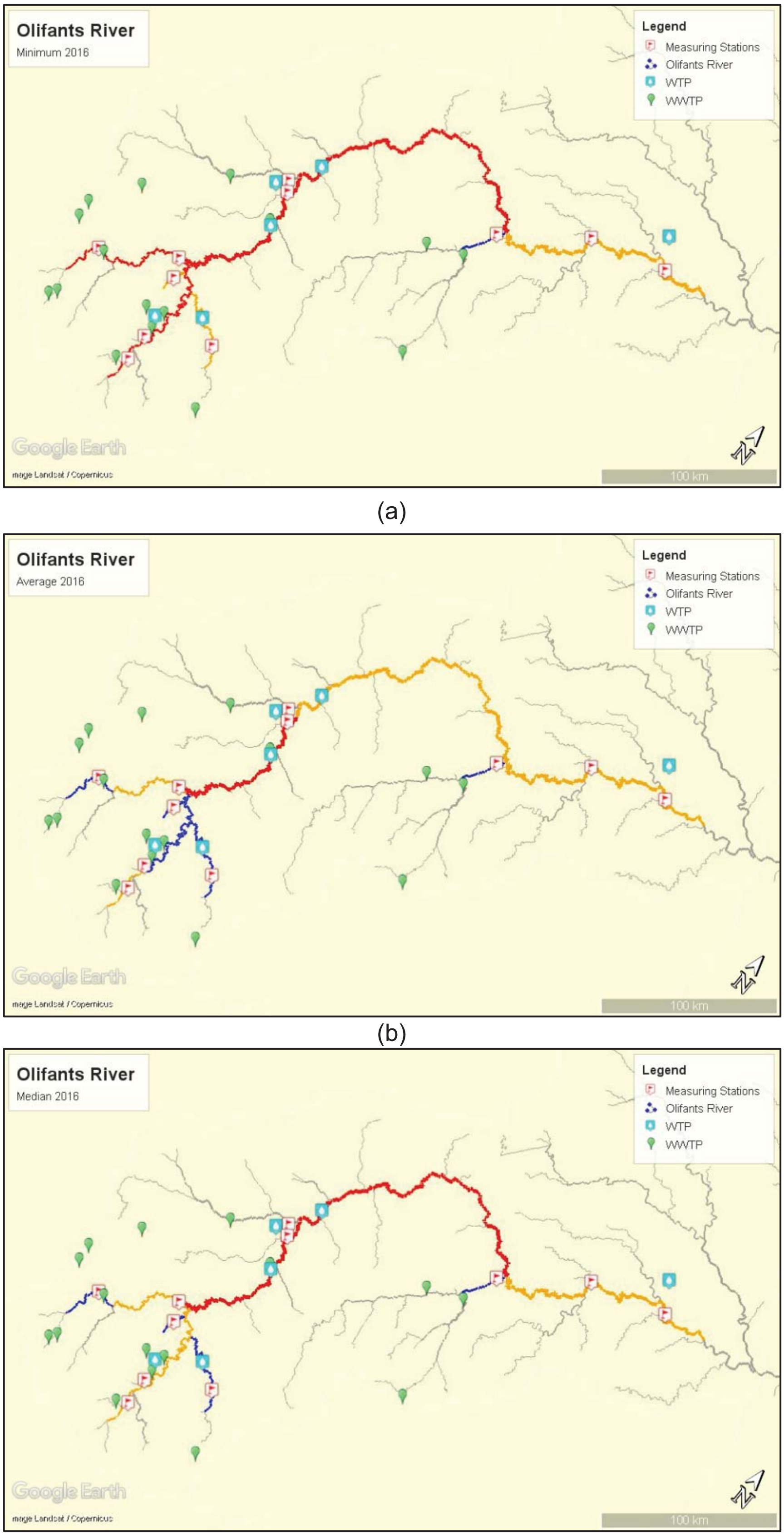
(b)



(c)

Figure I2.1: Wastewater contribution in the Olifants River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

- **Wastewater Contributions in 2016**



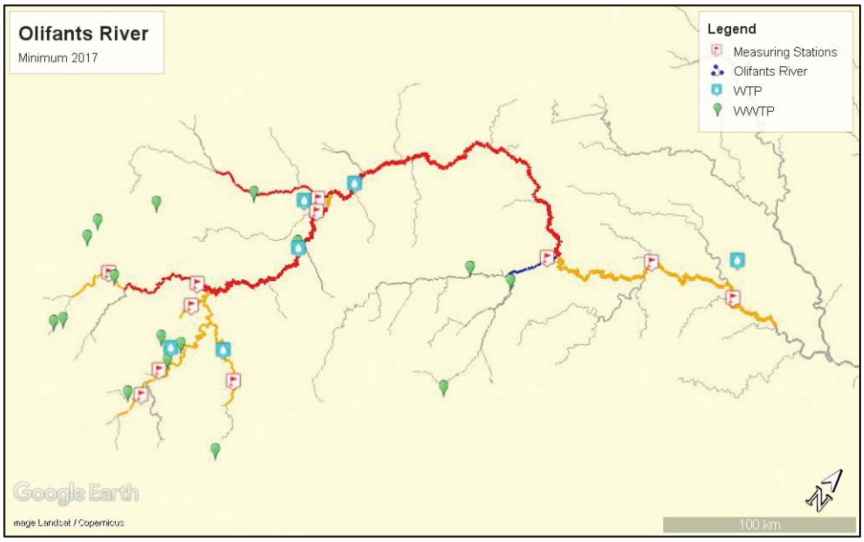
(a)

(b)

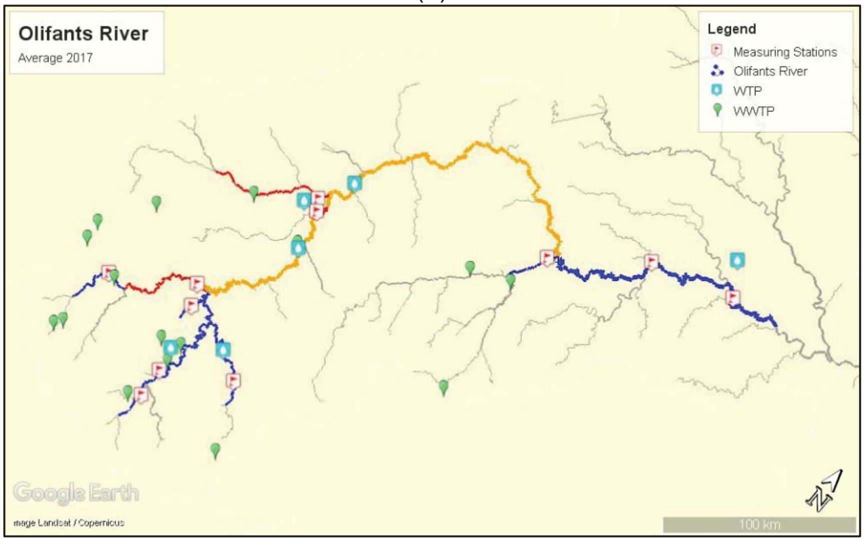
(c)

Figure I2.2: Wastewater contribution in the Olifants River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

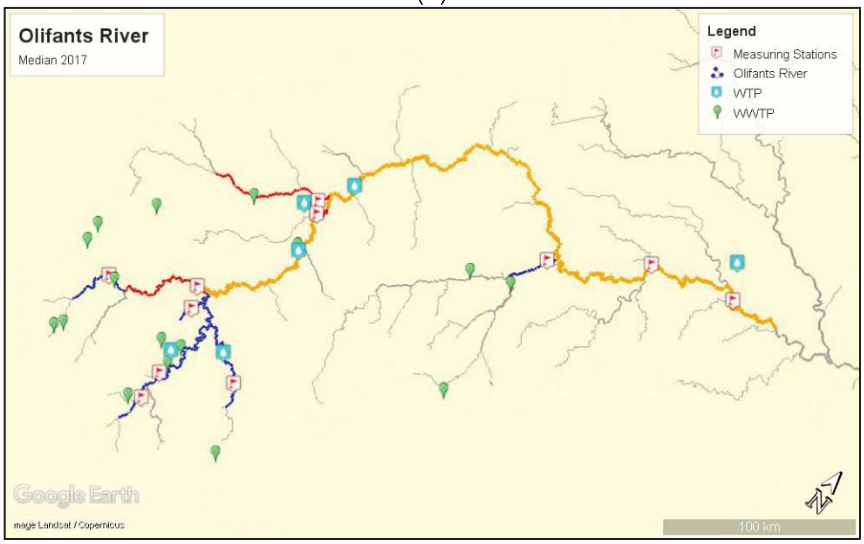
- **Wastewater Contributions in 2017**



(a)



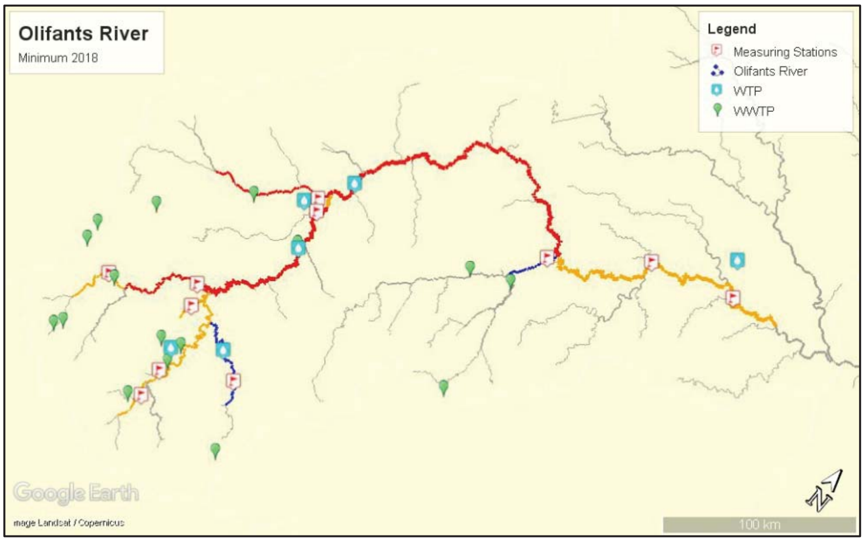
(b)



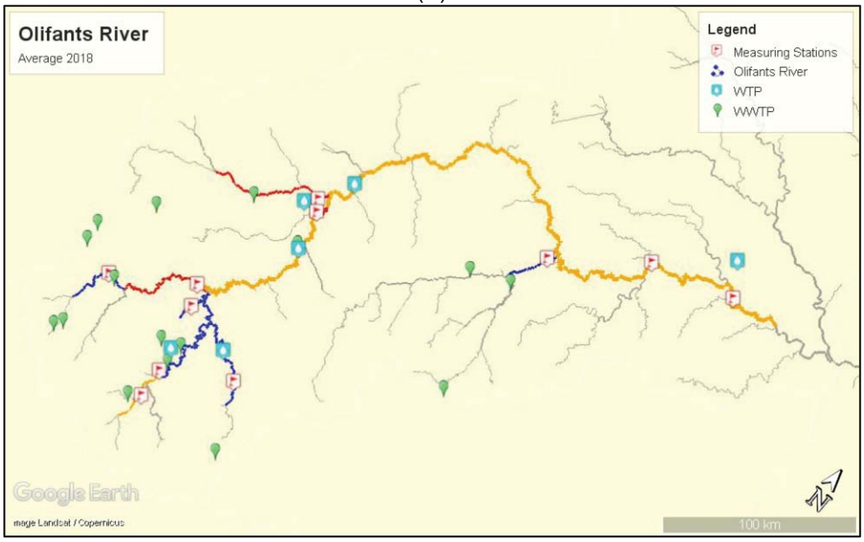
(c)

Figure I2.3: Wastewater contribution in the Olifants River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

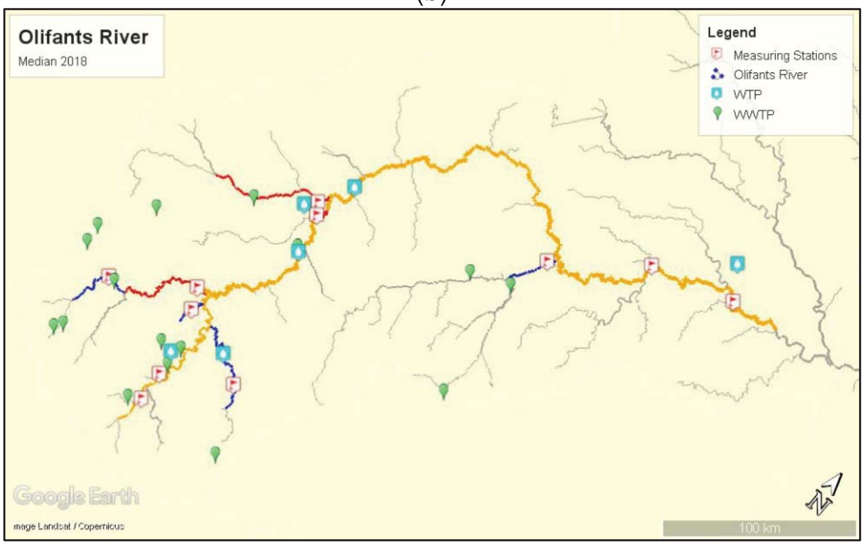
- **Wastewater Contributions in 2018**



(a)



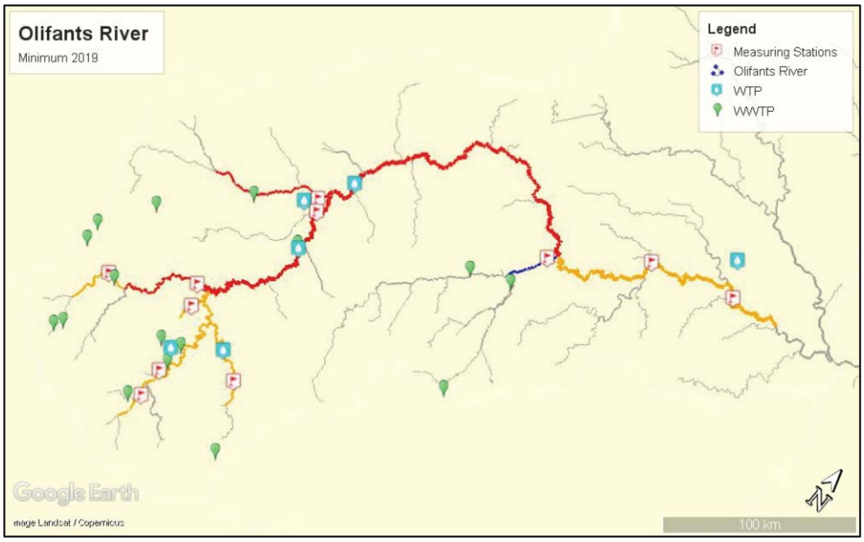
(b)



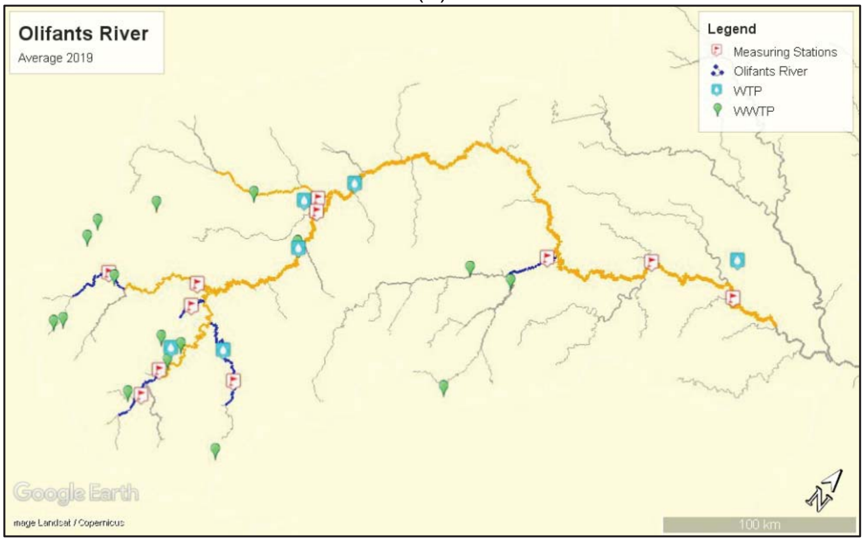
(c)

Figure I2.4: Wastewater contribution in the Olifants River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

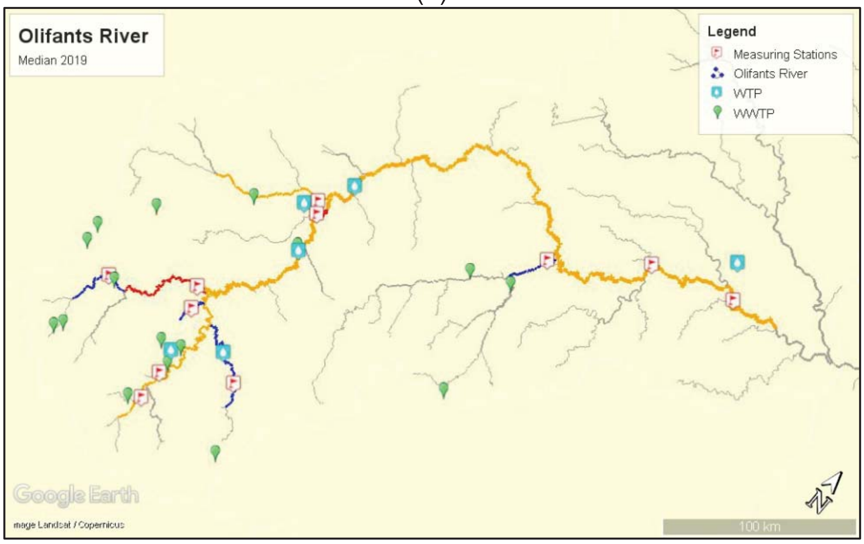
- **Wastewater Contributions in 2019**



(a)



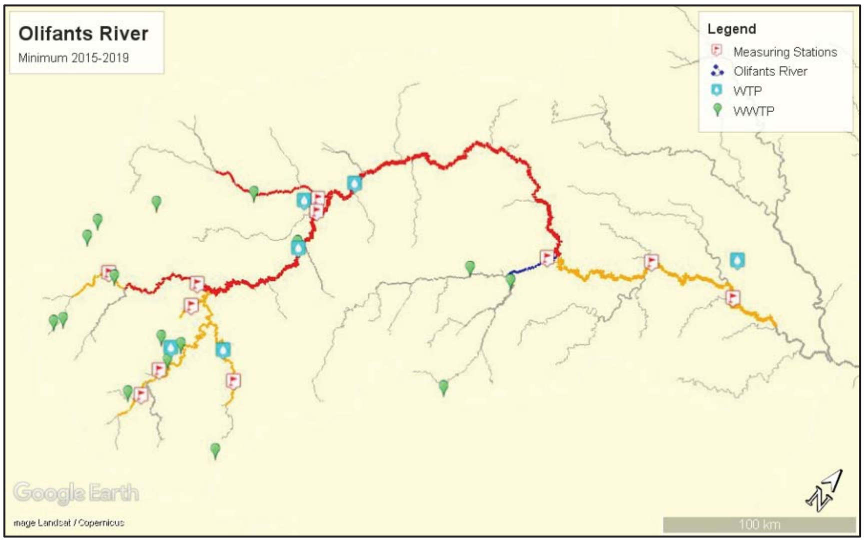
(b)



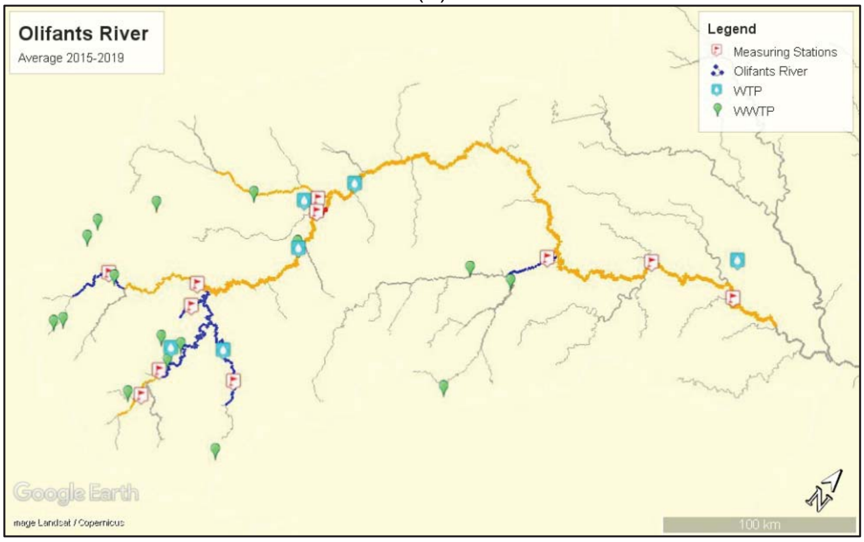
(c)

Figure I2.5: Wastewater contribution in the Olifants River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

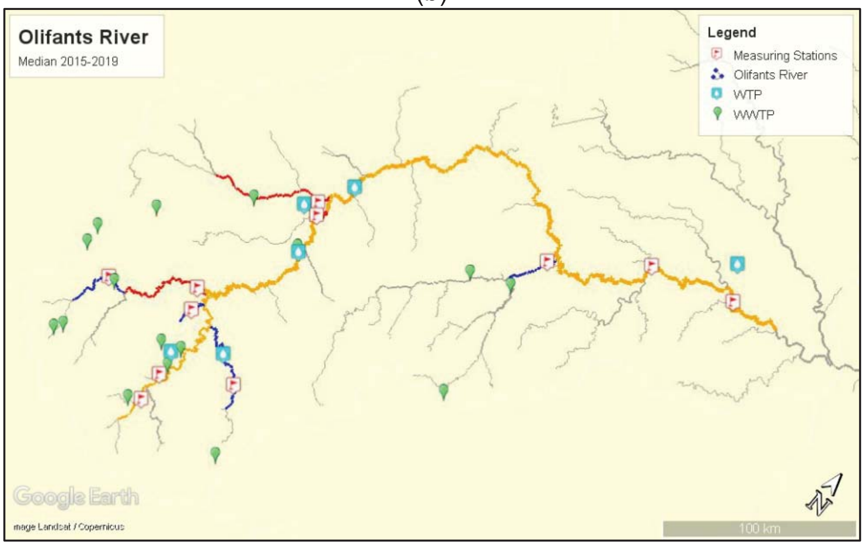
- **Wastewater Contributions in 2015-2019**



(a)



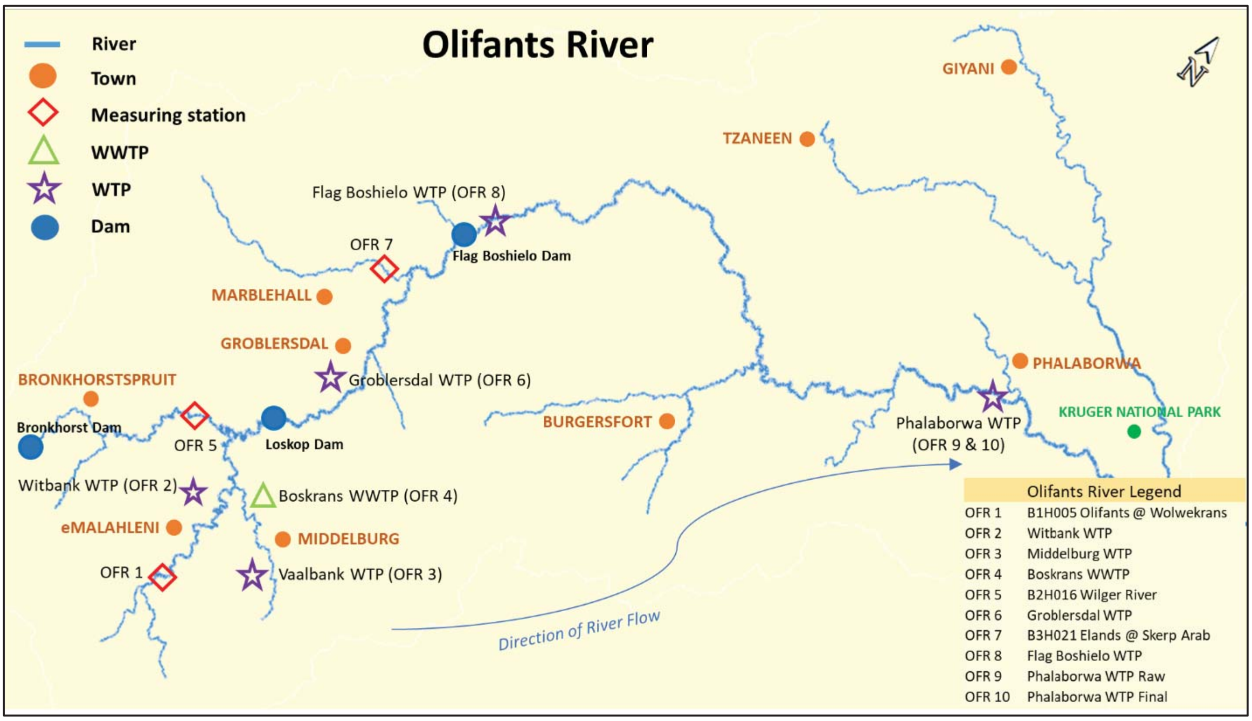
(b)



(c)

Figure I2.6: Wastewater contribution in the Olifants River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

I3: Map of sampling points for CEC analysis in the Olifants River



I4: CEC Concentration Results Legend for the Olifants River

Olifants River Legend	
OLF 1	B1H005 Olifants @ Wolwekrans
OLF 2	Witbank WTP
OLF 3	Middelburg WTP
OLF 4	Boskrans WWTP
OLF 5	B2H016 Wilger River
OLF 6	Groblersdal WTP
OLF 7	B3H021 Elands @ Skerp Arab
OLF 8	Flag Boshielo WTP
OLF 9	Phalaborwa WTP Raw
OLF 10	Phalaborwa WTP Final

I5: Results of the CEC analysis for the Olifants River

Table I5.1: Results of the CEC analysis for the Olifants River

Constituent	Sample Points									
	B1H005 Olifants @	Witbank WTP	Middelburg WTP	Boskrans WWTP	B2H016 Wilger River	Groblersdal WTP	B3H021 Elands @ Skerp Arab	Flag Boshielo WTP	Phalaborwa WTP Raw	Phalaborwa WTP Final
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
1,7-dimethylxanthine	24.4	18.03	17.98	2927	18.05	18.43	26.85	<IQL	9.153	<IQL
Acetaminophen	<IQL	<MDL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<MDL
Atrazine	106.7	440.3	190.3	107.5	81.92	164.8	17.12	121.8	37.81	43.02
Benzotriazole	<MDL	<MDL	<MDL	24.79	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL
Benzoylecgonine	<IQL	<MDL	<MDL	24.5	<MDL	<MDL	<MDL	<MDL	<IQL	<MDL
Caffeine	37.33	16.32	33.28	4340	38.91	50.66	63.23	16.57	72.86	128.4
Carbamazepine	4.57	14.82	<IQL	1154	<IQL	21.94	41.42	9.707	<IQL	<IQL
Cetirizine	<IQL	<IQL	<MDL	146.5	<IQL	<IQL	<IQL	<MDL	<MDL	<MDL
Cocaine	<IQL	<IQL	<MDL	4.08	<IQL	<IQL	<MDL	<MDL	<IQL	<IQL
Codeine	<MDL	<MDL	<MDL	1436	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Diclofenac	<IQL	<IQL	<MDL	377	<IQL	<IQL	<MDL	<MDL	<MDL	<IQL
Efavirenz	<MDL	<IQL	47.13	6924	<IQL	7.904	94.92	<MDL	40.67	<MDL
Emtricitabine	19.36	9.608	<IQL	20869	<IQL	7.658	32.82	<IQL	<IQL	<IQL
MDMA	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Methamphetamine	<IQL	<MDL	<IQL	255.8	<IQL	<IQL	<IQL	<MDL	<MDL	<IQL
Methaqualone	5.47	5.116	5.158	10.15	6.584	5.162	3.281	4.911	3.706	2.293
Naproxen	<MDL	<MDL	<MDL	695.7	<MDL	<MDL	<MDL	<IQL	<IQL	<IQL
Sulfamethoxazole	<IQL	<IQL	<MDL	3027	<IQL	<IQL	<IQL	<IQL	<IQL	<MDL
Tramadol	3.031	9.491	<IQL	1074	6.091	8.79	8.46	<IQL	<IQL	<IQL
Trimethoprim	<IQL	<MDL	<MDL	227.4	2.929	<MDL	<MDL	<IQL	<MDL	<IQL
Venlafaxine	<IQL	<IQL	<MDL	82.57	<IQL	<IQL	<MDL	<MDL	<MDL	<IQL

<IQL = Less than Instrument Quantification Limit

<MDL = Less than Method Detection Limit

I6: Bar charts of indicator compound results in the Olifants River

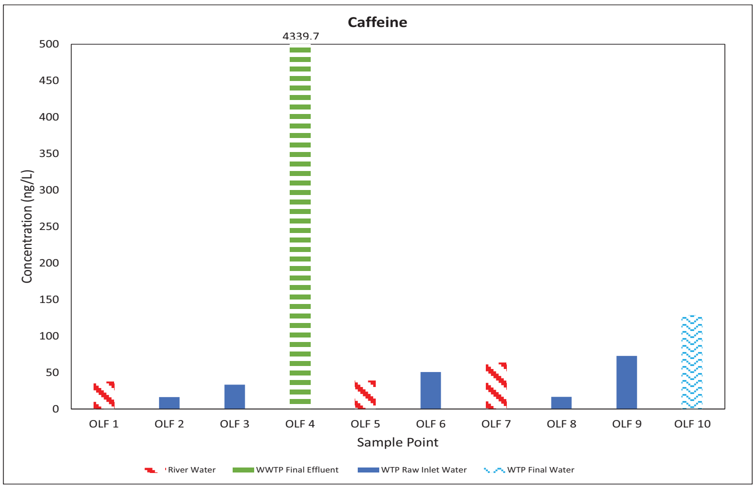


Figure I6.1: Concentrations of Caffeine in the Olifants River

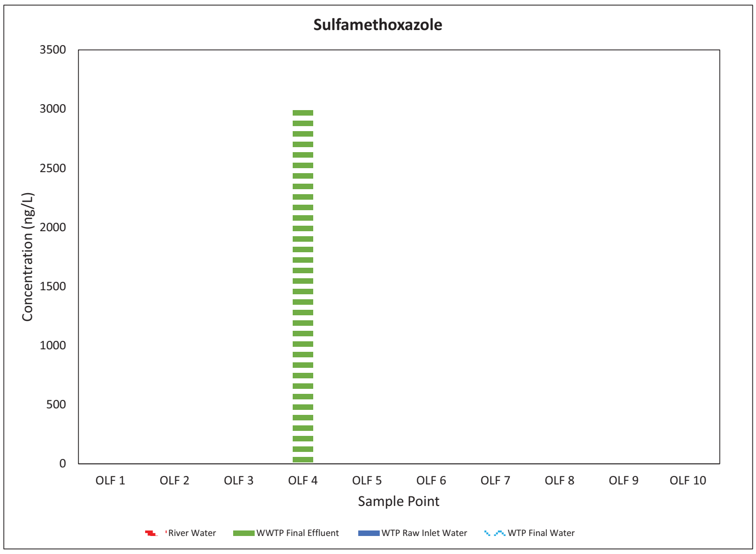


Figure I6.2: Concentrations of Sulfamethoxazole in the Olifants River

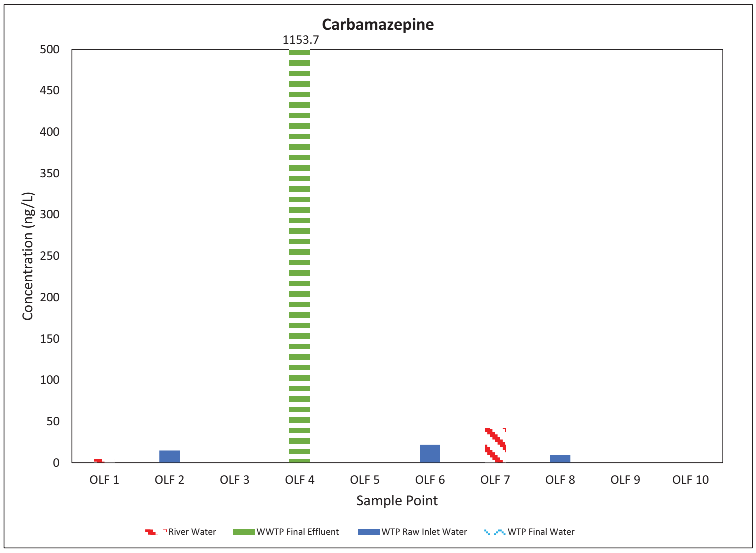


Figure I6.3: Concentrations of Carbamazepine in the Olifants River

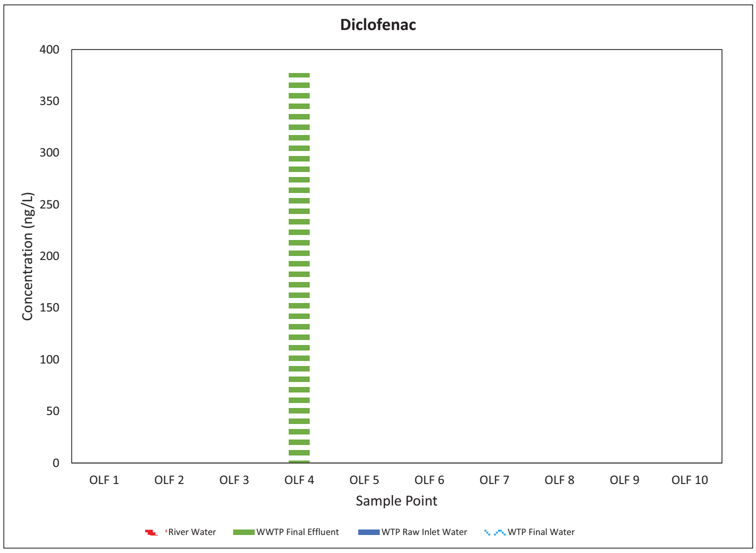


Figure I6.4: Concentrations of Diclofenac in the Olifants River

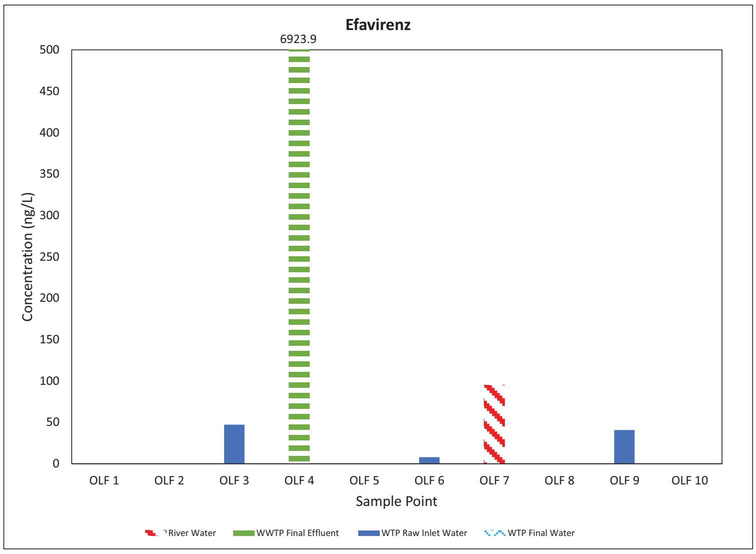


Figure I6.5: Concentrations of Efavirenz in the Olifants River

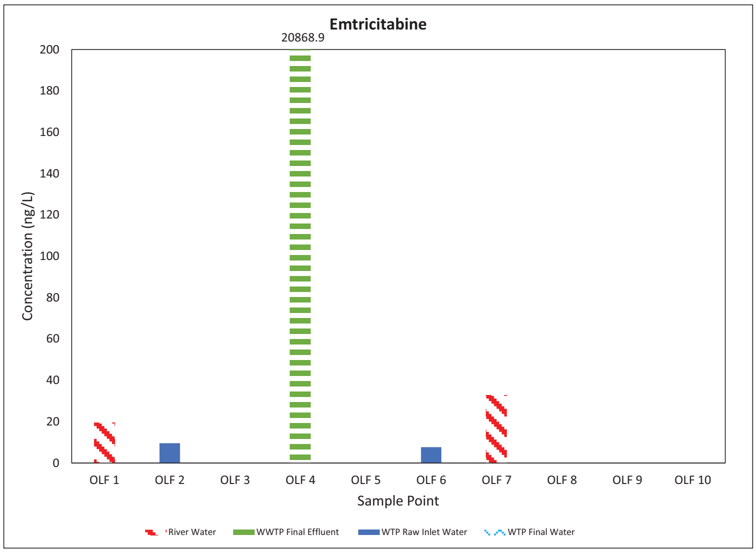


Figure I6.6: Concentrations of Emtricitabine in the Olifants River

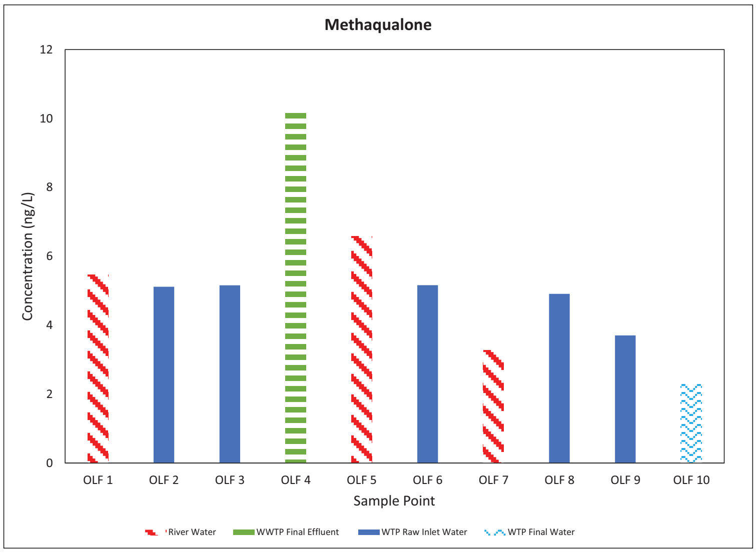


Figure I6.7: Concentrations of Methaqualone in the Olifants River

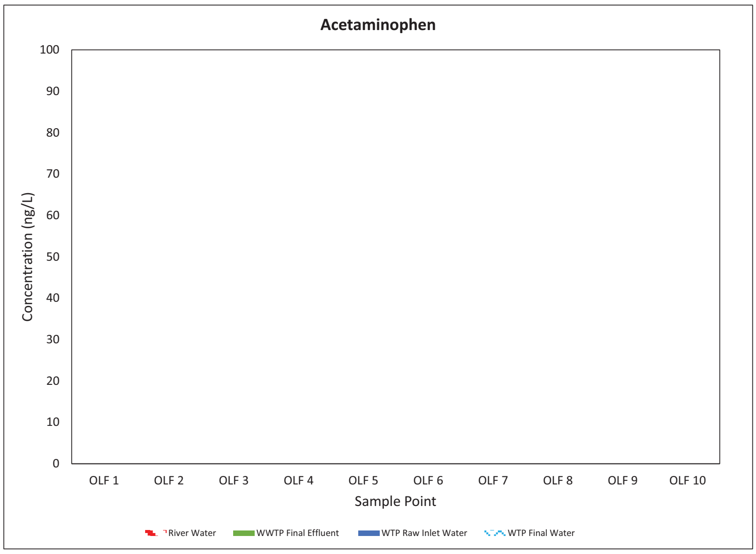


Figure I6.8: Concentrations of Acetaminophen in the Olifants River

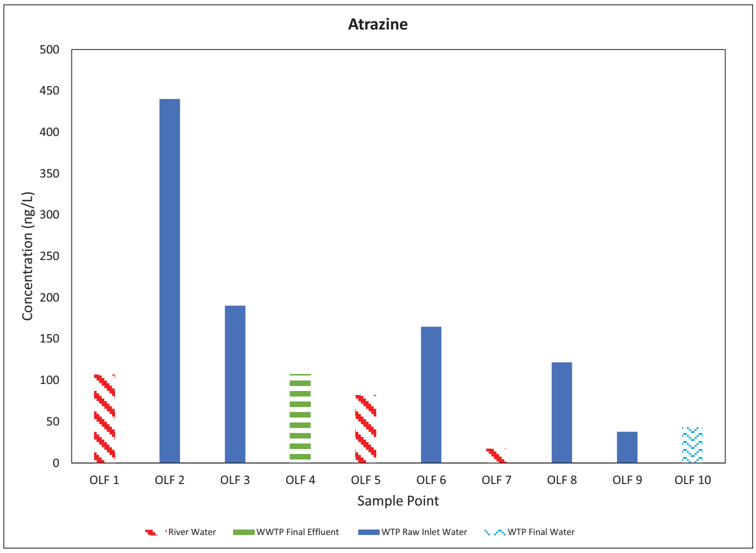


Figure I6.9: Concentrations of Atrazine in the Olifants River

I7: Results of Other Water Quality Parameters for the Olifants River

Sample Points	Sample Name	pH	COD	UV 254	DOC
		-	mg/L	m^{-1}	mg/L
B1H005 Olifants @ Wolwekrans	OFR1	8.16	119	0.101	2.94
Witbank WTP	OFR2	7.92	132	0.059	2.35
Middelburg WTP	OFR3	7.89	50	0.015	1.72
Boskrans WWTP	OFR4	7.34	132	0.114	3.13
B2H016 Wilger River	OFR5	7.55	74	0.042	2.11
Groblersdal WTP	OFR6	8.22	73	0.03	1.94
B3H021 Elands @ Skerp Arab	OFR7	7.94	83	0.075	2.57
Flag Boshielo WTP	OFR8	7.78	95	0.014	1.71
Phalaborwa WTP Raw	OFR9	7.81	56	0.101	2.94
Phalaborwa WTP Final	OFR10	7.72	47	0.004	1.57

APPENDIX J RESULTS FOR THE UPPER VAAL RIVER

J1: Flow-based data and calculations for the Upper Vaal River

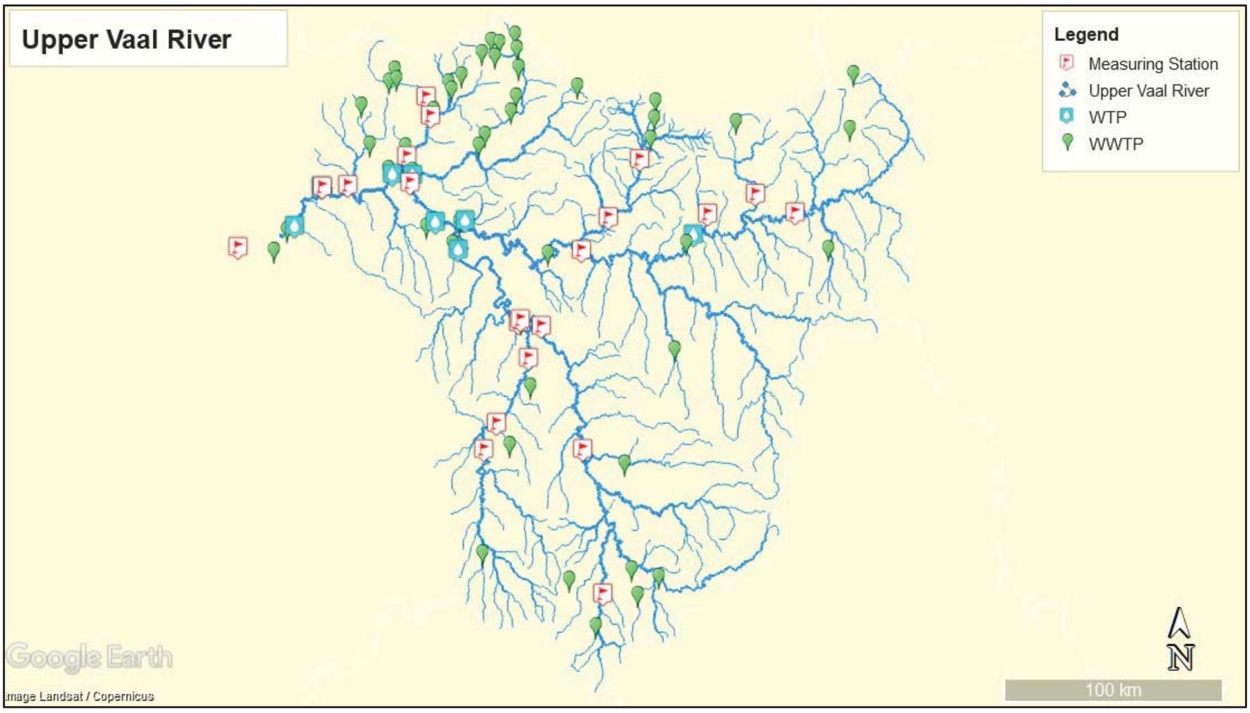


Figure J1.1: Upper Vaal River System, indicating all measuring stations, WWTP and WTP in this river.

Table J1.1: Summary of Wastewater Percentages for the Upper Vaal River for 2015-2019

Upper Vaal River

Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C1H007 Vaal River @ Goedgeluk	5%	4%	4%	4%	1%	2%	4%	1%	2%
C1H006 Blesbok Spruit @ Rietvley	70%	21%	44%	64%	6%	22%	33%	4%	17%
C1H005 Leeu Sp @ Welbedacht	0%	0%	0%	0%	0%	0%	0%	0%	0%
Standerton WTP	8%	5%	6%	7%	2%	4%	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	6%	3%	3%	17%	3%	4%	5%	1%	2%
C1H004 Waterval River @ Branddrift	43%	30%	34%	30%	17%	25%	34%	7%	17%
C1H008 Waterval River @ Elandslaagte	76%	44%	56%	78%	12%	45%	77%	9%	36%
Vaal Marina WTP	26%	12%	15%	49%	10%	18%	23%	2%	8%
C8H005 Elands River @ Elands River Drift	24%	12%	14%	37%	12%	18%	19%	5%	9%
C8H028 Wilge River @ Bavaria	5%	2%	2%	16%	2%	2%	19%	3%	7%
C8H027 Wilge River @ Ballingtomp	6%	2%	3%	14%	3%	3%	11%	2%	4%
C8H037 Liebenbergsvlei @ Reward	1%	1%	1%	1%	1%	1%	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	2%	1%	1%	2%	1%	1%	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	2%	1%	1%	2%	1%	1%	2%	1%	1%
C8H030 Wilge River @ Slabberts	3%	2%	2%	3%	2%	2%	3%	1%	2%
C8H001 Wilge River @ Frankfort	3%	2%	2%	4%	2%	2%	4%	2%	2%
Oranjeville WTP	3%	2%	2%	4%	2%	2%	4%	2%	2%
Deneysville WTP	6%	4%	4%	7%	4%	4%	7%	2%	4%
C2H272 Vaal @ Bankfontein (Lethabo)	63%	38%	40%	91%	57%	62%	58%	18%	39%
Zuikerbossie WTP	82%	62%	64%	96%	78%	81%	78%	37%	63%
C2H137 Klip River @ Zwartkopjes	50%	45%	46%	N/A			53%	38%	41%
C2H136 Riet Spruit @ Waterval	77%	70%	72%	74%	62%	66%	79%	61%	65%
C2H071 Klip River @ Kookfontein	52%	47%	48%	49%	40%	40%	73%	43%	44%
Vereeniging WTP	58%	50%	52%	57%	46%	47%	74%	41%	48%
C2H005 Riet Spruit @ Kaalplaats	34%	31%	31%	33%	30%	30%	31%	27%	27%
Vaal Barrage WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%
C2H140 Vaal River @ Woodlands	49%	39%	41%	70%	33%	40%	61%	32%	35%
Parys WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%
C2H018 Vaal River @ De Vaal	52%	41%	43%	50%	35%	41%	51%	25%	35%

Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2018			2019			2015-2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C1H007 Vaal River @ Goedgeluk	4%	2%	3%	4%	2%	2%	4%	2%	3%
C1H006 Blesbok Spruit @ Rietvley	50%	9%	32%	62%	2%	27%	52%	5%	26%
C1H005 Leeu Sp @ Welbedacht	0%	0%	0%	N/A			0%	0%	0%
Standerton WTP	6%	2%	4%	6%	2%	4%	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	4%	1%	2%	22%	2%	3%	7%	1%	2%
C1H004 Waterval River @ Branddrift	43%	18%	33%	38%	11%	25%	37%	13%	25%
C1H008 Waterval River @ Elandslaagte	84%	16%	55%	90%	12%	52%	81%	14%	47%
Vaal Marina WTP	18%	4%	8%	58%	6%	14%	28%	5%	11%
C8H005 Elands River @ Elands River Drift	16%	5%	8%	35%	15%	20%	24%	8%	12%
C8H028 Wilge River @ Bavaria	10%	3%	4%	33%	9%	13%	11%	3%	3%
C8H027 Wilge River @ Ballingtomp	7%	2%	4%	25%	6%	8%	10%	3%	4%
C8H037 Liebenbergsvlei @ Reward	1%	1%	1%	2%	1%	1%	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H030 Wilge River @ Slabberts	2%	1%	2%	6%	1%	2%	3%	1%	2%
C8H001 Wilge River @ Frankfort	3%	2%	2%	5%	3%	3%	4%	2%	2%
Oranjeville WTP	3%	2%	2%	5%	3%	3%	4%	2%	2%
Deneysville WTP	5%	3%	4%	9%	4%	5%	6%	3%	4%
C2H272 Vaal @ Bankfontein (Lethabo)	78%	21%	20%	68%	42%	50%	70%	30%	36%
Zuikerbossie WTP	90%	41%	39%	85%	66%	72%	86%	52%	60%
C2H137 Klip River @ Zwartkopjes	52%	38%	39%	83%	44%	44%	63%	41%	42%
C2H136 Riet Spruit @ Waterval	72%	65%	66%	74%	62%	64%	75%	64%	67%
C2H071 Klip River @ Kookfontein	N/A			N/A			68%	43%	44%
Vereeniging WTP	97%	71%	69%	95%	87%	90%	72%	45%	47%
C2H005 Riet Spruit @ Kaalplaats	28%	26%	26%	35%	26%	26%	32%	28%	28%
Vaal Barrage WTP	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H140 Vaal River @ Woodlands	45%	32%	35%	42%	30%	33%	51%	33%	36%
Parys WTP	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H018 Vaal River @ De Vaal	55%	34%	37%	56%	31%	36%	53%	32%	38%

Table J1.1: Summary of Wastewater Percentages for the Upper Vaal River for 2015-2018

Upper Vaal River																		
Measuring station/ Water Treatment Works	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow																	
	2015			2016			2017			2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median	Min	Average	Median	Min	Average	Median	Min	Average	Median
C1H007 Vaal River @ Goedgeluk	5%	4%	4%	4%	1%	2%	4%	1%	2%	4%	2%	3%	4%	2%	2%	4%	2%	3%
C1H006 Waterval River @ Elandslaagte	70%	21%	44%	64%	6%	22%	33%	4%	17%	50%	9%	32%	62%	2%	27%	52%	5%	26%
C1H005 Leeu Sp @ Welbedacht	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%		N/A		0%	0%	0%
Standerton WTP	8%	5%	6%	7%	2%	4%	6%	2%	4%	6%	2%	4%	6%	2%	4%	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	6%	3%	3%	17%	3%	4%	5%	1%	2%	4%	1%	2%	22%	2%	3%	7%	1%	2%
C1H004 Waterval River @ Branddrift	43%	30%	34%	30%	17%	25%	34%	7%	17%	43%	18%	33%	38%	11%	25%	37%	13%	25%
C1H008 Waterval River @ Elandslaagte	76%	44%	56%	78%	12%	45%	77%	9%	36%	84%	16%	55%	90%	12%	52%	81%	14%	47%
Vaal Marina WTP	26%	12%	15%	49%	10%	18%	23%	2%	8%	18%	4%	8%	58%	6%	14%	28%	5%	11%
C8H005 Elands River @ Elands River Drift	24%	12%	14%	37%	12%	18%	19%	5%	9%	16%	5%	8%	35%	15%	20%	24%	8%	12%
C8H028 Wilge River @ Bavaria	5%	2%	2%	16%	2%	2%	19%	3%	7%	10%	3%	4%	33%	9%	13%	11%	3%	3%
C8H027 Wilge River @ Ballingtomp	6%	2%	3%	14%	3%	3%	11%	2%	4%	7%	2%	4%	25%	6%	8%	10%	3%	4%
C8H037 Liebenbergsvlei @ Reward	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	2%	1%	1%	2%	1%	1%	2%	1%	1%	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	2%	1%	1%	2%	1%	1%	2%	1%	1%	1%	1%	1%	2%	1%	1%	2%	1%	1%
C8H030 Wilge River @ Slabberts	3%	2%	2%	3%	2%	2%	3%	1%	2%	2%	1%	2%	6%	1%	2%	3%	1%	2%
C8H001 Wilge River @ Frankfort	3%	2%	2%	4%	2%	2%	4%	2%	2%	3%	2%	2%	5%	3%	3%	4%	2%	2%
Oranjeville WTP	3%	2%	2%	4%	2%	2%	4%	2%	2%	3%	2%	2%	5%	3%	3%	4%	2%	2%
Deneysville WTP	3%	6%	4%	3%	7%	4%	3%	7%	2%	3%	5%	3%	3%	9%	4%	3%	6%	3%
C2H272 Vaal @ Bankfontein (Lethabo)	63%	38%	40%	91%	57%	62%	58%	18%	39%	78%	21%	20%	68%	42%	50%	70%	30%	36%
Zuikerbossie WTP	82%	62%	64%	96%	78%	81%	78%	37%	63%	90%	41%	39%	85%	66%	72%	86%	52%	60%
C2H137 Klip River @ Zwartkopjes	50%	45%	46%		N/A		53%	38%	41%	52%	38%	39%	83%	44%	44%	63%	41%	42%
C2H136 Riet Spruit @ Waterval	77%	70%	72%	74%	62%	66%	79%	61%	65%	72%	65%	66%	74%	62%	64%	75%	64%	67%
C2H071 Klip River @ Kookfontein	52%	47%	48%	49%	40%	40%	73%	43%	44%		N/A			N/A		68%	43%	44%
Vereeniging WTP	58%	50%	52%	57%	46%	47%	74%	41%	48%	97%	71%	69%	95%	87%	90%	72%	45%	47%
C2H005 Riet Spruit @ Kaalplaats	34%	31%	31%	33%	30%	30%	31%	27%	27%	28%	26%	26%	35%	26%	26%	32%	28%	28%
Vaal Barrage WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H140 Vaal River @ Woodlands	49%	39%	41%	70%	33%	40%	61%	32%	35%	45%	32%	35%	42%	30%	33%	51%	33%	36%
Parys WTP	49%	39%	41%	70%	33%	40%	61%	32%	35%	45%	32%	35%	42%	30%	33%	51%	33%	36%
C2H018 Vaal River @ De Vaal	52%	41%	43%	50%	35%	41%	51%	25%	35%	55%	34%	37%	56%	31%	36%	53%	32%	38%

Table J1.2: Wastewater percentage calculations for Upper Vaal River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Upper Vaal River

2015

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																																															Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.0472	3.8994	3.3950	0.0174	0.1042	0.0243																																													0.1458	5%	4%	4%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.0503	0.4383	0.1448				0.1157																																												0.1157	70%	21%	44%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	0.0718	0.4419	0.3207																																																0.0000	0%	0%	0%
Standerton WTP	-26.93477	29.26428	3.1693	4.7796	3.8605	0.0174	0.1042	0.0243	0.1157																																												0.2616	8%	5%	6%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	2.0186	4.8472	4.0700					0.1356	0.0046																																								0.1403	6%	3%	3%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.4393	0.7595	0.6262							0.0231	0.1910	0.1111																																					0.3252	43%	30%	34%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.1000	0.4187	0.2504							0.0231	0.1910	0.1111																																					0.3252	76%	44%	56%
Vaal Marina WTP	-26.87654	28.24047	2.1186	5.2659	4.3204	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208																																						0.7479	26%	12%	15%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	0.5966	1.4280	1.1736														0.1921																																		0.1921	24%	12%	14%
C8H028 Wilge River @ Bavaria	-27.80277	28.76750	6.5923	20.5963	21.2588											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	5%	2%	2%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	5.6615	13.9091	13.5183											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	6%	2%	3%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	23.1758	28.7078	28.7702																0.2963																																0.2963	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.37500	20.6673	28.1243	28.2910																0.2963	0.0405																															0.3368	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	20.0972	26.7714	26.7260																0.2963	0.0405	0.0116																														0.3484	2%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	26.6220	38.8705	38.3705											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	3%	2%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	22.2370	31.1449	31.0008											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	3%	2%	2%
Oranjeville WTP	-26.99379	28.20866	22.2370	31.1449	31.0008											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	3%	2%	2%
Deneysville WTP	-26.88210	28.10678	56.4491	24.3556	36.4108	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	3%	6%	4%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	0.8698	2.4450	2.2427	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	63%	38%	40%
Zuikerbossie WTP	-26.69313	28.00501	0.8698	2.4450	2.2427	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166														3.9390	82%	62%	64%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.07080	6.7063	8.2379	7.9692																																						1.7361	2.7778	2.3148								6.8287	50%	45%	46%
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	3.0439	4.3467	3.8930																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676							10.0231	77%	70%	72%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	9.3632	11.4774	10.9733																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						10.1389	52%	47%	48%
Vereeniging WTP	-26.68884	27.91420	10.2329	13.9224	13.2160	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						14.0895	58%	50%	52%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.71800	2.3828	2.8411	2.8060																																												0.0926	1.1574			1.2500	34%	31%	31%
Vaal Barrage WTP	-26.73570	27.59347	16.2271	24.5197	23.1179	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	49%	39%	41%
C2H140 Vaal River @ Woodlands	-26.73828	27.59197	16.2271	24.5197	23.1179	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	49%	39%	41%
Parys WTP	-26.89201	27.47120	16.2271	24.5197	23.1179	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	49%	39%	41%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	14.5144	22.9606	20.9125	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694	15.9679	52%	41%	43%

(b)

Upper Vaal River

2016

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m3/s) - Design Capacity																																															Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.3187	10.1272	5.8614	0.0174	0.1042	0.0243																																													0.1458	4%	1%	2%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.0655	1.8596	0.4090				0.1157																																												0.1157	64%	6%	22%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	0.1302	0.6369	0.3656																																																0.0000	0%	0%	0%
Standerton WTP	-26.934772	29.264281	3.5143	12.6237	6.6359	0.0174	0.1042	0.0243	0.1157																																												0.2616	7%	2%	4%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	0.6728	4.5444	3.1079					0.1356	0.0046																																								0.1403	17%	3%	4%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.7423	1.5572	0.9535							0.0231	0.1910	0.1111																																					0.3252	30%	17%	25%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.0904	2.3269	0.4025							0.0231	0.1910	0.1111																																					0.3252	78%	12%	45%
Vaal Marina WTP	-26.876544	28.240469	0.7633	6.8713	3.5103	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208																																						0.7479	49%	10%	18%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	0.3231	1.3738	0.8606														0.1921																																		0.1921	37%	12%	18%
C8H028 Wilge River @ Bavaria	-27.80277	28.7675	1.7721	15.8844	18.7436											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	16%	2%	2%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	2.0618	11.8113	13.0347											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	14%	3%	3%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	20.1595	27.3933	27.6148																0.2963																																0.2963	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.375	19.4293	29.1287	28.7615																0.2963	0.0405																															0.3368	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	18.2786	28.5570	28.3088																0.2963	0.0405	0.0116																														0.3484	2%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	23.3494	39.4398	40.9604											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	3%	2%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	18.6378	29.8670	30.7546											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	4%	2%	2%
Oranjeville WTP	-26.993789	28.208661	18.6378	29.8670	30.7546											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	4%	2%	2%
Deneysville WTP	-26.882103	28.106781	56.4491	19.4011	36.7382	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	3%	7%	4%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	0.1560	1.1271	0.9380	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	91%	57%	62%
Zuikerbossie WTP	-26.693128	28.005014	0.1560	1.1271	0.9380	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166														3.9390	96%	78%	81%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.0708	NO DATA AVAILABLE																																								1.7361	2.7778	2.3148								6.8287	N/A		
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	3.4663	6.1867	5.1763																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676							10.0231	74%	62%	66%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	10.5432	15.3274	15.1405																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						10.1389	49%	40%	40%
Vereeniging WTP	-26.688836	27.914197	10.6992	16.4544	16.0785	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						14.0895	57%	46%	47%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.718	2.4883	2.9864	2.9465																																												0.0926	1.1574			1.2500	33%	30%	30%
Vaal Barrage WTP	-26.73828	27.59197	6.8498	32.1405	23.9905	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	70%	33%	40%
C2H140 Vaal River @ Woodlands	-26.735704	27.593471	6.8498	32.1405	23.9905	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	70%	33%	40%
Parys WTP	-26.892006	27.471203	6.8498	32.1405	23.9905	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	70%	33%	40%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	15.7338	29.7537	22.5872	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694	15.9679	50%	35%	41%

(c)

Upper Vaal River

2017

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																																															Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.7672	11.1431	5.8763	0.0174	0.1042	0.0243																																													0.1458	4%	1%	2%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.2369	3.0045	0.5493				0.1157																																												0.1157	33%	4%	17%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	0.3131	1.5317	0.7846																																																0.0000	0%	0%	0%
Standerton WTP	-26.934772	29.264281	4.3172	15.6793	7.2101	0.0174	0.1042	0.0243	0.1157																																												0.2616	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	2.4744	26.6410	7.6498					0.1356	0.0046																																								0.1403	5%	1%	2%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.6351	4.4907	1.5818							0.0231	0.1910	0.1111																																					0.3252	34%	7%	17%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.0968	3.4871	0.5905							0.0231	0.1910	0.1111																																					0.3252	77%	9%	36%
Vaal Marina WTP	-26.876544	28.240469	2.5712	30.1282	8.2403	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208																																						0.7479	23%	2%	8%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	0.8125	3.5308	1.9474														0.1921																																		0.1921	19%	5%	9%
C8H028 Wilge River @ Bavaria	-27.80277	28.7675	1.5133	12.8043	4.8780											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	19%	3%	7%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	2.7294	19.5721	8.2826											0.0347	0.0694	0.0463	0.1921	0.0058																																	0.3484	11%	2%	4%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	24.2773	30.6092	29.9285																0.2963																																0.2963	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.375	22.1021	33.1722	29.6336																0.2963	0.0405																															0.3368	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	22.2000	35.5710	31.0743																0.2963	0.0405	0.0116																														0.3484	2%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	27.4478	57.4207	37.8280											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	3%	1%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	18.6378	29.8670	30.3112											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	4%	2%	2%
Oranjeville WTP	-26.993789	28.208661	18.6378	29.8670	30.3112											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324																													0.7292	4%	2%	2%
Deneysville WTP	-26.882103	28.106781	56.4491	21.2090	59.9951	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	3%	7%	2%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	1.1066	6.6825	2.3104	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231																											1.5058	58%	18%	39%
Zuikerbossie WTP	-26.693128	28.005014	1.1066	6.6825	2.3104	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166														3.9390	78%	37%	63%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.0708	6.0366	11.2897	9.7287																																						1.7361	2.7778	2.3148								6.8287	53%	38%	41%
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	2.7195	6.3801	5.4166																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676							10.0231	79%	61%	65%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	3.7429	13.5194	12.8865																																			0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						10.1389	73%	43%	44%
Vereeniging WTP	-26.688836	27.914197	4.8495	20.2019	15.1969	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157						14.0895	74%	41%	48%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.718	2.7392	3.3700	3.3980																																												0.0926	1.1574			1.2500	31%	27%	27%
Vaal Barrage WTP	-26.73828	27.59197	10.0643	33.1858	29.9568	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	61%	32%	35%
C2H140 Vaal River @ Woodlands	-26.735704	27.593471	10.0643	33.1858	29.9568	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	61%	32%	35%
Parys WTP	-26.892006	27.471203	10.0643	33.1858	29.9568	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574			15.8140	61%	32%	35%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	15.2497	48.3204	29.3299	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694	15.9679	51%	25%	35%

(d)

Upper Vaal River

2018

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.5048	7.9779	4.7458	0.1458	4%	2%	3%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.1178	1.1959	0.2428	0.1157	50%	9%	32%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	0.2808	1.7639	1.0790	0.0000	0%	0%	0%
Standerton WTP	-26.934772	29.264281	3.9034	10.9377	6.0676	0.2616	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	3.3326	14.5708	8.8874	0.1403	4%	1%	2%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.4318	1.4790	0.6457	0.3252	43%	18%	33%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.0635	1.7309	0.2656	0.3252	84%	16%	55%
Vaal Marina WTP	-26.876544	28.240469	3.3961	16.3017	9.1530	0.7479	18%	4%	8%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	1.0132	3.6076	2.2718	0.1921	16%	5%	8%
C8H028 Wilge River @ Bavaria	-27.80277	28.7675	3.2923	11.7497	7.6288	0.3484	10%	3%	4%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	4.7293	14.2480	9.2399	0.3484	7%	2%	4%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	25.2891	32.6924	32.8314	0.2963	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.375	24.0924	32.6665	31.3037	0.3368	1%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	23.8708	33.2180	31.6577	0.3484	1%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	31.8058	49.5506	41.9796	0.7292	2%	1%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	23.8063	36.0271	30.5216	0.7292	3%	2%	2%
Oranjeville WTP	-26.993789	28.208661	23.8063	36.0271	30.5216	0.7292	3%	2%	2%
Deneysville WTP	-26.882103	28.106781	56.4491	27.2024	52.3288	1.5058	3%	5%	3%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	0.4201	5.6705	6.2099	1.5058	78%	21%	20%
Zuikerbossie WTP	-26.693128	28.005014	0.4201	5.6705	6.2099	3.9390	90%	41%	39%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.0708	6.2693	11.3437	10.6037	6.8287	52%	38%	39%
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	3.8287	5.4842	5.0556	10.0231	72%	65%	66%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	NO DATA AVAILABLE			10.1389	N/A		
Vereeniging WTP	-26.688836	27.914197	0.4201	5.6705	6.2099	14.0895	97%	71%	69%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.718	3.2126	3.5846	3.6148	1.2500	28%	26%	26%
Vaal Barrage WTP	-26.73828	27.59197	19.5500	33.4980	29.1386	15.8140	45%	32%	35%
C2H140 Vaal River @ Woodlands	-26.735704	27.593471	19.5500	33.4980	29.1386	15.8140	45%	32%	35%
Parys WTP	-26.892006	27.471203	19.5500	33.4980	29.1386	15.8140	45%	32%	35%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	13.0582	31.6714	27.6179	15.9679	55%	34%	37%

Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity

Measuring station/ Water Treatment Works	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield
C1H007 Vaal River @ Goedgeluk	0.0174	0.1042	0.0243																					
C1H006 Waterval River @ Elandslaagte				0.1157																				
C1H005 Leeu Sp @ Welbedacht																								
Standerton WTP	0.0174	0.1042	0.0243	0.1157																				
C1H012 Vaal River @ Nooitgedacht					0.1356	0.0046																		
C1H004 Waterval River @ Branddrift							0.0231	0.1910	0.1111															
C1H008 Waterval River @ Elandslaagte							0.0231	0.1910	0.1111															
Vaal Marina WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208														
C8H005 Elands River @ Elands River Drift														0.1921										
C8H028 Wilge River @ Bavaria											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H027 Wilge River @ Ballingtomp											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H037 Liebenbergsvlei @ Reward																0.2963								
C8H020 Liebenbergsvlei River @ Roodekraal																0.2963	0.0405							
C8H026 Liebenbergsvlei River @ Frederiksdal																0.2963	0.0405	0.0116						
C8H030 Wilge River @ Slabberts											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
C8H001 Wilge River @ Frankfort											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Oranjeville WTP											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Deneysville WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
C2H272 Vaal @ Bankfontein (Lethabo)	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
Zuikerbossie WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157
C2H137 Klip River @ Zwartkopjes																								
C2H136 Riet Spruit @ Waterval																								
C2H071 Klip River @ Kookfontein																								
Vereeniging WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H005 Riet Spruit @ Kaalplaats																								
Vaal Barrage WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H140 Vaal River @ Woodlands	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
Parys WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H018 Vaal River @ De Vaal	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157

Measuring station/ Water Treatment Works	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort
C1H007 Vaal River @ Goedgeluk																							
C1H006 Waterval River @ Elandslaagte																							
C1H005 Leeu Sp @ Welbedacht																							
Standerton WTP																							
C1H012 Vaal River @ Nooitgedacht																							
C1H004 Waterval River @ Branddrift																							
C1H008 Waterval River @ Elandslaagte																							
Vaal Marina WTP																							
C8H005 Elands River @ Elands River Drift																							
C8H028 Wilge River @ Bavaria																							
C8H027 Wilge River @ Ballingtomp																							
C8H037 Liebenbergsvlei @ Reward																							
C8H020 Liebenbergsvlei River @ Roodekraal																							
C8H026 Liebenbergsvlei River @ Frederiksdal																							
C8H030 Wilge River @ Slabberts																							
C8H001 Wilge River @ Frankfort																							
Oranjeville WTP																							
Deneysville WTP																							
C2H272 Vaal @ Bankfontein (Lethabo)																							
Zuikerbossie WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166													
C2H137 Klip River @ Zwartkopjes														1.7361	2.7778	2.3148							
C2H136 Riet Spruit @ Waterval											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676						
C2H071 Klip River @ Kookfontein											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
Vereeniging WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
C2H005 Riet Spruit @ Kaalplaats																				0.0926	1.1574		
Vaal Barrage WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H140 Vaal River @ Woodlands	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
Parys WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H018 Vaal River @ De Vaal	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694

(e)

Upper Vaal River

2019

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.9745	7.5713	6.3690	0.1458	4%	2%	2%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.0723	5.6678	0.3209	0.1157	62%	2%	27%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	NO DATA AVAILABLE			0.0000	N/A		
Standerton WTP	-26.934772	29.264281	4.0468	13.2391	6.6898	0.2616	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	0.5109	8.8091	4.2253	0.1403	22%	2%	3%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.5208	2.5885	0.9980	0.3252	38%	11%	25%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.0361	2.4456	0.3018	0.3252	90%	12%	52%
Vaal Marina WTP	-26.876544	28.240469	0.5470	11.2547	4.5271	0.7479	58%	6%	14%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	0.3538	1.0673	0.7458	0.1921	35%	15%	20%
C8H028 Wilge River @ Bavaria	-27.80277	28.7675	0.7088	3.4481	2.3625	0.3484	33%	9%	13%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	1.0667	5.4670	3.9209	0.3484	25%	6%	8%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	16.6106	25.8556	26.2540	0.2963	2%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.375	17.2752	28.4153	25.9550	0.3368	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	16.6499	28.8555	26.5839	0.3484	2%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	11.3463	54.2914	41.8619	0.7292	6%	1%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	13.9833	26.0938	22.9698	0.7292	5%	3%	3%
Oranjeville WTP	-26.993789	28.208661	13.9833	26.0938	22.9698	0.7292	5%	3%	3%
Deneysville WTP	-26.882103	28.106781	56.4491	14.5303	37.3485	1.5058	3%	9%	4%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	0.7013	2.0575	1.5150	1.5058	68%	42%	50%
Zuikerbossie WTP	-26.693128	28.005014	0.7013	2.0575	1.5150	3.9390	85%	66%	72%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.0708	1.3575	8.6641	8.6840	6.8287	83%	44%	44%
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	3.5903	6.2708	5.6396	10.0231	74%	62%	64%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	NO DATA AVAILABLE			10.1389	N/A		
Vereeniging WTP	-26.688836	27.914197	0.7013	2.0575	1.5150	14.0895	95%	87%	90%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.718	2.3341	3.5931	3.6004	1.2500	35%	26%	26%
Vaal Barrage WTP	-26.73828	27.59197	22.0468	36.9684	32.7742	15.8140	42%	30%	33%
C2H140 Vaal River @ Woodlands	-26.735704	27.593471	22.0468	36.9684	32.7742	15.8140	42%	30%	33%
Parys WTP	-26.892006	27.471203	22.0468	36.9684	32.7742	15.8140	42%	30%	33%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	12.6366	35.0219	28.4540	15.9679	56%	31%	36%

Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity

Measuring station/ Water Treatment Works	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield
C1H007 Vaal River @ Goedgeluk	0.0174	0.1042	0.0243																					
C1H006 Waterval River @ Elandslaagte				0.1157																				
C1H005 Leeu Sp @ Welbedacht																								
Standerton WTP	0.0174	0.1042	0.0243	0.1157																				
C1H012 Vaal River @ Nooitgedacht					0.1356	0.0046																		
C1H004 Waterval River @ Branddrift							0.0231	0.1910	0.1111															
C1H008 Waterval River @ Elandslaagte							0.0231	0.1910	0.1111															
Vaal Marina WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208														
C8H005 Elands River @ Elands River Drift														0.1921										
C8H028 Wilge River @ Bavaria											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H027 Wilge River @ Ballingtomp											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H037 Liebenbergsvlei @ Reward																0.2963								
C8H020 Liebenbergsvlei River @ Roodekraal																0.2963	0.0405							
C8H026 Liebenbergsvlei River @ Frederiksdal																0.2963	0.0405	0.0116						
C8H030 Wilge River @ Slabberts											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
C8H001 Wilge River @ Frankfort											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Oranjeville WTP											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Deneysville WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
C2H272 Vaal @ Bankfontein (Lethabo)	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
Zuikerbossie WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157
C2H137 Klip River @ Zwartkopjes																								
C2H136 Riet Spruit @ Waterval																								
C2H071 Klip River @ Kookfontein																								
Vereeniging WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H005 Riet Spruit @ Kaalplaats																								
Vaal Barrage WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H140 Vaal River @ Woodlands	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
Parys WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H018 Vaal River @ De Vaal	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157

Measuring station/ Water Treatment Works	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort
C1H007 Vaal River @ Goedgeluk																							
C1H006 Waterval River @ Elandslaagte																							
C1H005 Leeu Sp @ Welbedacht																							
Standerton WTP																							
C1H012 Vaal River @ Nooitgedacht																							
C1H004 Waterval River @ Branddrift																							
C1H008 Waterval River @ Elandslaagte																							
Vaal Marina WTP																							
C8H005 Elands River @ Elands River Drift																							
C8H028 Wilge River @ Bavaria																							
C8H027 Wilge River @ Ballingtomp																							
C8H037 Liebenbergsvlei @ Reward																							
C8H020 Liebenbergsvlei River @ Roodekraal																							
C8H026 Liebenbergsvlei River @ Frederiksdal																							
C8H030 Wilge River @ Slabberts																							
C8H001 Wilge River @ Frankfort																							
Oranjeville WTP																							
Deneysville WTP																							
C2H272 Vaal @ Bankfontein (Lethabo)																							
Zuikerbossie WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166													
C2H137 Klip River @ Zwartkopjes														1.7361	2.7778	2.3148							
C2H136 Riet Spruit @ Waterval											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676						
C2H071 Klip River @ Kookfontein											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
Vereeniging WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
C2H005 Riet Spruit @ Kaalplaats																				0.0926	1.1574		
Vaal Barrage WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H140 Vaal River @ Woodlands	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
Parys WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H018 Vaal River @ De Vaal	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694

(f)

Upper Vaal River

2015-2019

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median		Min	Average	Median
C1H007 Vaal River @ Goedgeluk	-26.84108	29.72336	3.5225	8.1438	5.2495	0.1458	4%	2%	3%
C1H006 Waterval River @ Elandslaagte	-26.86133	28.88461	0.1086	2.4332	0.3333	0.1157	52%	5%	26%
C1H005 Leeu Sp @ Welbedacht	-26.85425	29.32531	0.1592	1.0936	0.6375	0.0000	0%	0%	0%
Standerton WTP	-26.934772	29.264281	3.7902	11.6706	6.2203	0.2616	6%	2%	4%
C1H012 Vaal River @ Nooitgedacht	-27.00231	28.76528	1.8019	11.8825	5.5881	0.1403	7%	1%	2%
C1H004 Waterval River @ Branddrift	-26.62792	29.02453	0.5539	2.1750	0.9611	0.3252	37%	13%	25%
C1H008 Waterval River @ Elandslaagte	-26.91658	28.43661	0.0774	2.0818	0.3622	0.3252	81%	14%	47%
Vaal Marina WTP	-26.876544	28.240469	1.8792	13.9643	5.9502	0.7479	28%	5%	11%
C8H005 Elands River @ Elands River Drift	-28.37583	28.86027	0.6198	2.2015	1.3998	0.1921	24%	8%	12%
C8H028 Wilge River @ Bavaria	-27.80277	28.7675	2.7757	12.8966	10.9743	0.3484	11%	3%	3%
C8H027 Wilge River @ Ballingtomp	-27.30138	28.58555	3.2497	13.0015	9.5993	0.3484	10%	3%	4%
C8H037 Liebenbergsvlei @ Reward	-27.68961	28.37803	21.9025	29.0517	29.0798	0.2963	1%	1%	1%
C8H020 Liebenbergsvlei River @ Roodekraal	-27.68972	28.375	20.7133	30.3014	28.7890	0.3368	2%	1%	1%
C8H026 Liebenbergsvlei River @ Frederiksdal	-27.43083	28.52638	20.2193	30.5946	28.8701	0.3484	2%	1%	1%
C8H030 Wilge River @ Slabberts	-27.29388	28.48888	24.1143	47.9146	40.2001	0.7292	3%	1%	2%
C8H001 Wilge River @ Frankfort	-27.27166	28.49111	19.9991	35.0664	28.9808	0.7292	4%	2%	2%
Oranjeville WTP	-26.993789	28.208661	19.9991	35.0664	28.9808	0.7292	4%	2%	2%
Deneysville WTP	-26.882103	28.106781	56.4491	21.8783	49.0307	1.5058	3%	6%	3%
C2H272 Vaal @ Bankfontein (Lethabo)	-26.73147	27.99183	0.6507	3.5965	2.6432	1.5058	70%	30%	36%
Zuikerbossie WTP	-26.693128	28.005014	0.6507	3.5965	2.6432	3.9390	86%	52%	60%
C2H137 Klip River @ Zwartkopjes	-26.38025	28.0708	4.0740	9.8838	9.2464	6.8287	63%	41%	42%
C2H136 Riet Spruit @ Waterval	-26.45078	28.08933	3.3297	5.7337	5.0362	10.0231	75%	64%	67%
C2H071 Klip River @ Kookfontein	-26.61994	27.98052	4.7299	13.4414	13.0001	10.1389	68%	43%	44%
Vereeniging WTP	-26.688836	27.914197	5.3806	17.0379	15.6433	14.0895	72%	45%	47%
C2H005 Riet Spruit @ Kaalplaats	-26.72867	27.718	2.6314	3.2751	3.2731	1.2500	32%	28%	28%
Vaal Barrage WTP	-26.73828	27.59197	14.9476	32.0625	27.7956	15.8140	51%	33%	36%
C2H140 Vaal River @ Woodlands	-26.735704	27.593471	14.9476	32.0625	27.7956	15.8140	51%	33%	36%
Parys WTP	-26.892006	27.471203	14.9476	32.0625	27.7956	15.8140	51%	33%	36%
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	14.2385	33.5456	25.7803	15.9679	53%	32%	38%

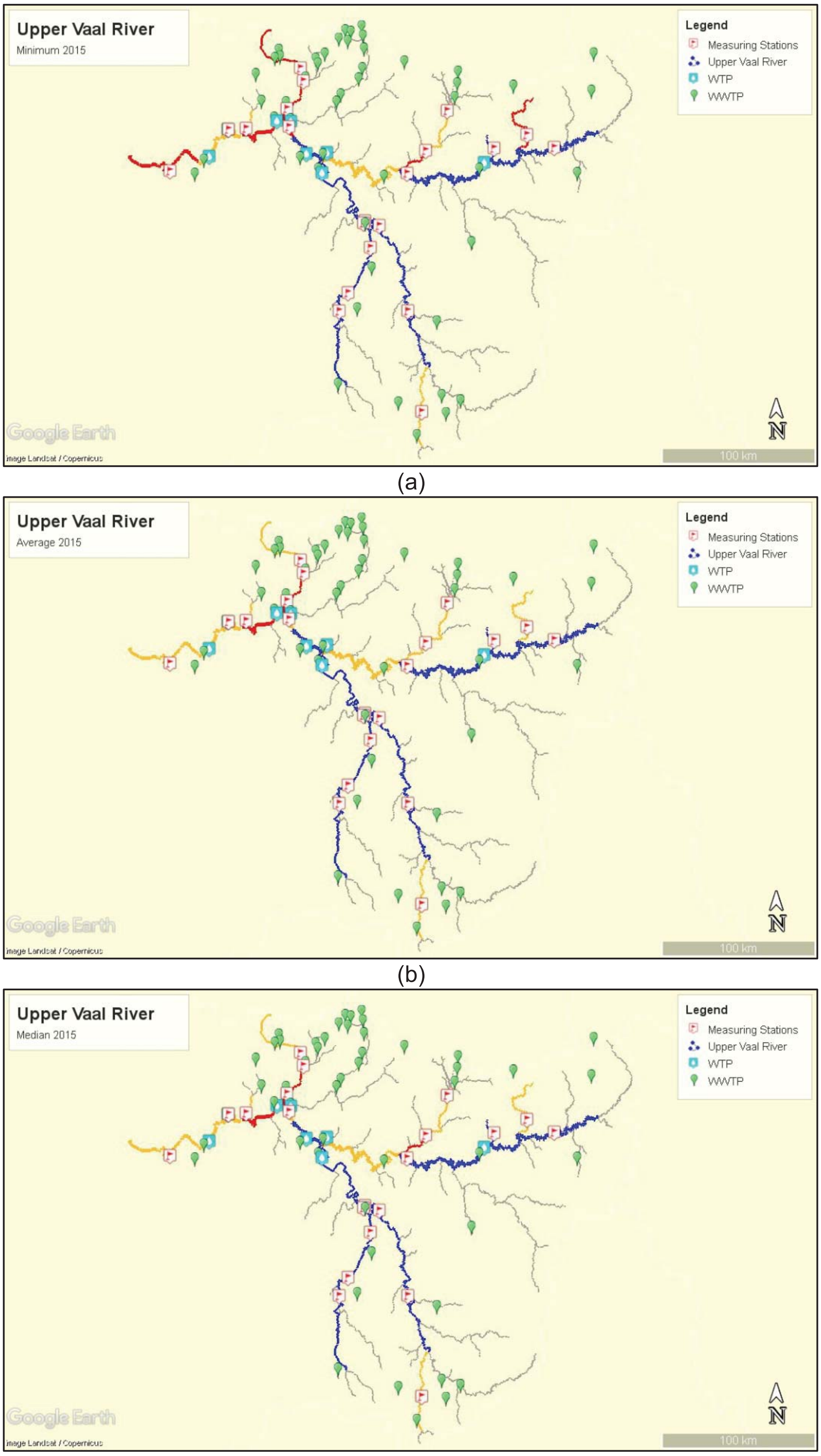
Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity

Measuring station/ Water Treatment Works	KwaZanele	Ermelo	Amersfoort	Bethal	Standerton	Vrede	Kinross	Evander	Embalenhle	Villiers	Elands	Wilge	Tshiame	Phuthaditjhaba	Warden	Bethlehem	Reitz	Tweeling	Frankfort	Oranjevile	Vaal Marina	Klipplaatdrift	Benoni	Rynfield
C1H007 Vaal River @ Goedgeluk	0.0174	0.1042	0.0243																					
C1H006 Waterval River @ Elandslaagte				0.1157																				
C1H005 Leeu Sp @ Welbedacht																								
Standerton WTP	0.0174	0.1042	0.0243	0.1157																				
C1H012 Vaal River @ Nooitgedacht					0.1356	0.0046																		
C1H004 Waterval River @ Branddrift							0.0231	0.1910	0.1111															
C1H008 Waterval River @ Elandslaagte							0.0231	0.1910	0.1111															
Vaal Marina WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208														
C8H005 Elands River @ Elands River Drift														0.1921										
C8H028 Wilge River @ Bavaria											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H027 Wilge River @ Ballingtomp											0.0347	0.0694	0.0463	0.1921	0.0058									
C8H037 Liebenbergsvlei @ Reward																0.2963								
C8H020 Liebenbergsvlei River @ Roodekraal																0.2963	0.0405							
C8H026 Liebenbergsvlei River @ Frederiksdal																0.2963	0.0405	0.0116						
C8H030 Wilge River @ Slabberts											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
C8H001 Wilge River @ Frankfort											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Oranjeville WTP											0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324					
Deneysville WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
C2H272 Vaal @ Bankfontein (Lethabo)	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231			
Zuikerbossie WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231		0.1852	0.1157
C2H137 Klip River @ Zwartkopjes																								
C2H136 Riet Spruit @ Waterval																								
C2H071 Klip River @ Kookfontein																								
Vereeniging WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H005 Riet Spruit @ Kaalplaats																								
Vaal Barrage WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H140 Vaal River @ Woodlands	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
Parys WTP	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157
C2H018 Vaal River @ De Vaal	0.0174	0.1042	0.0243	0.1157	0.1356	0.0046	0.0231	0.1910	0.1111	0.0208	0.0347	0.0694	0.0463	0.1921	0.0058	0.2963	0.0405	0.0116	0.0324	0.0056	0.0231	0.0116	0.1852	0.1157

Measuring station/ Water Treatment Works	JP Marais	Jan Smuts	Daveyton	Welgedatch	Ancor	Carl Grundlingh	Herbert Bickley	Heidelberg	Ratanda	Devon	Rondebult	Dekema	Vlakplaats	Goudkoppies	Olifantsvlei	Bushkoppie	Waterval	Meyerton	Leeuwkuil	Ennerdale	Sebokeng	Parys	Vredefort
C1H007 Vaal River @ Goedgeluk																							
C1H006 Waterval River @ Elandslaagte																							
C1H005 Leeu Sp @ Welbedacht																							
Standerton WTP																							
C1H012 Vaal River @ Nooitgedacht																							
C1H004 Waterval River @ Branddrift																							
C1H008 Waterval River @ Elandslaagte																							
Vaal Marina WTP																							
C8H005 Elands River @ Elands River Drift																							
C8H028 Wilge River @ Bavaria																							
C8H027 Wilge River @ Ballingtomp																							
C8H037 Liebenbergsvlei @ Reward																							
C8H020 Liebenbergsvlei River @ Roodekraal																							
C8H026 Liebenbergsvlei River @ Frederiksdal																							
C8H030 Wilge River @ Slabberts																							
C8H001 Wilge River @ Frankfort																							
Oranjeville WTP																							
Deneysville WTP																							
C2H272 Vaal @ Bankfontein (Lethabo)																							
Zuikerbossie WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166													
C2H137 Klip River @ Zwartkopjes														1.7361	2.7778	2.3148							
C2H136 Riet Spruit @ Waterval											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676						
C2H071 Klip River @ Kookfontein											0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
Vereeniging WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157					
C2H005 Riet Spruit @ Kaalplaats																				0.0926	1.1574		
Vaal Barrage WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H140 Vaal River @ Woodlands	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
Parys WTP	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574		
C2H018 Vaal River @ De Vaal	0.1736	0.0706	0.1331	1.0995	0.1736	0.1736	0.1748	0.0625	0.0544	0.0166	0.2315	0.3588	0.6366	1.7361	2.7778	2.3148	1.9676	0.1157	0.4745	0.0926	1.1574	0.0845	0.0694

J2: De facto wastewater maps for different time periods for Upper Vaal River

- **Wastewater Contributions in 2015**



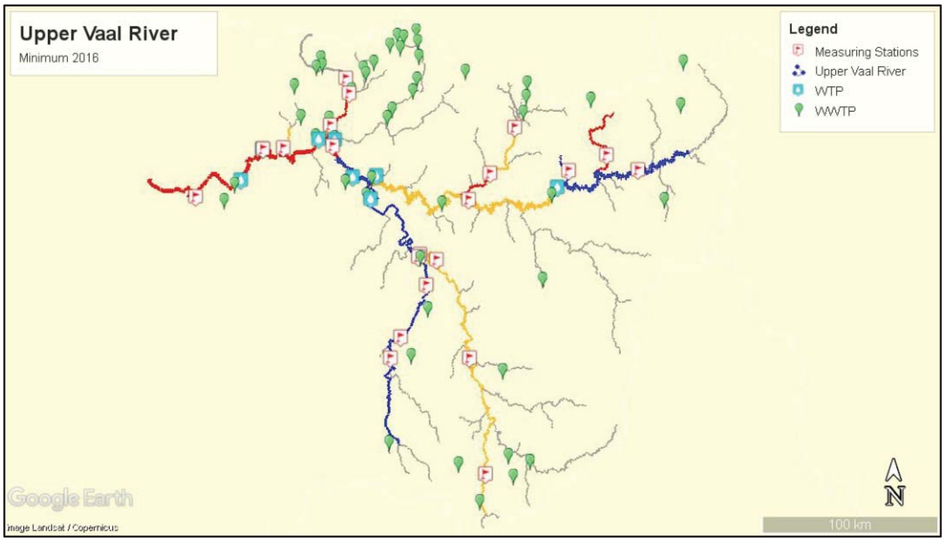
(a)

(b)

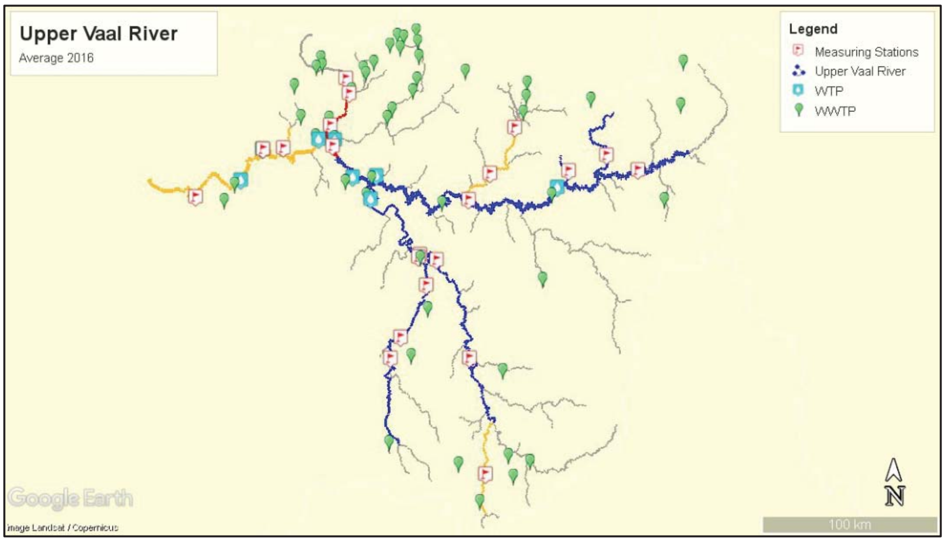
(c)

Figure J2.1: Wastewater contribution in the Upper Vaal River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

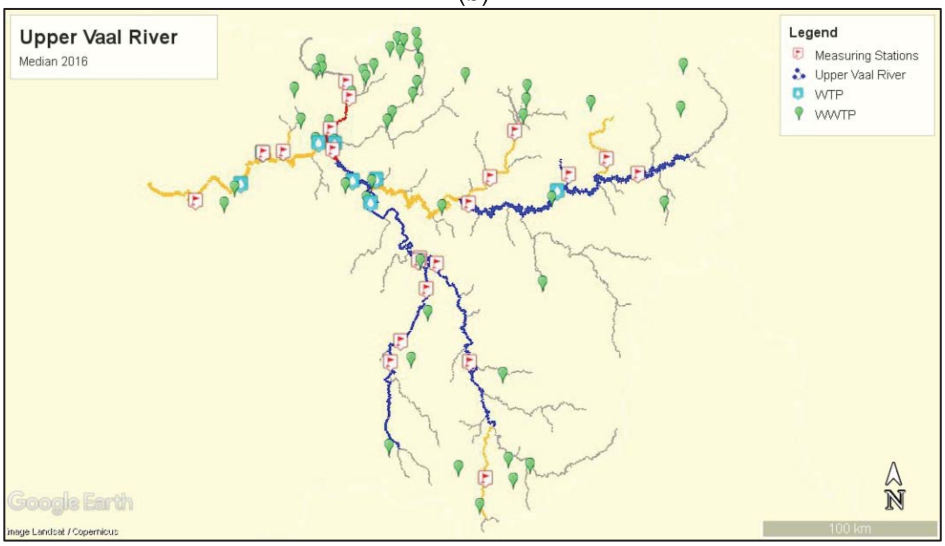
- **Wastewater Contributions in 2016**



(a)



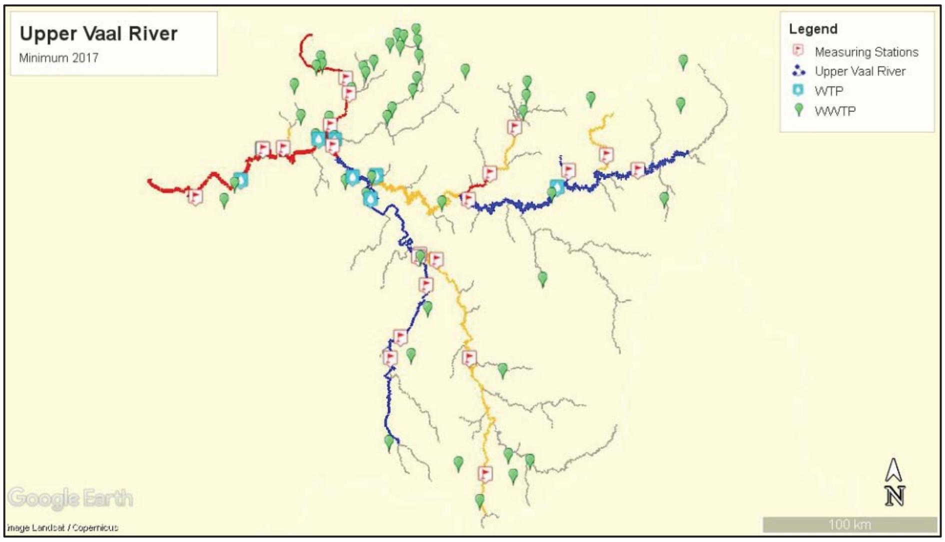
(b)



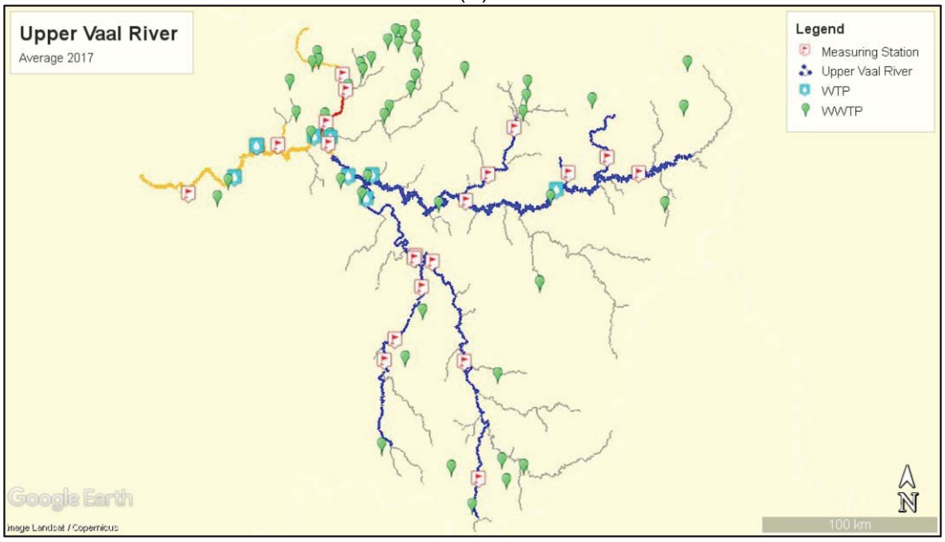
(c)

Figure J2.2: Wastewater contribution in the Upper Vaal River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

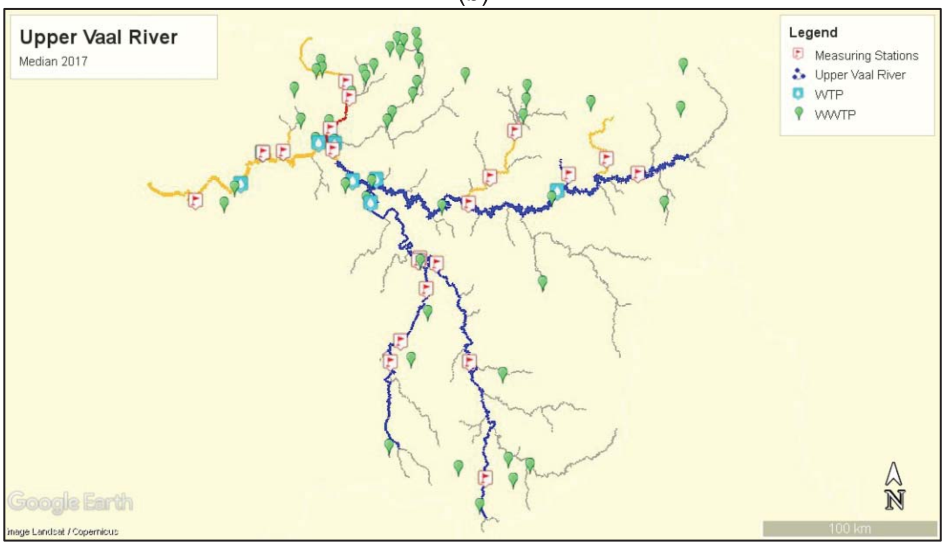
- **Wastewater Contributions in 2017**



(a)



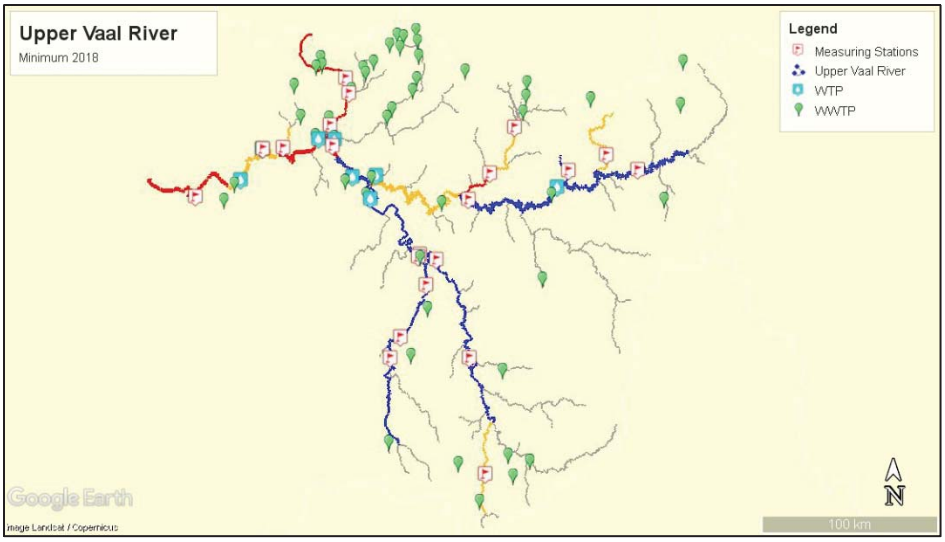
(b)



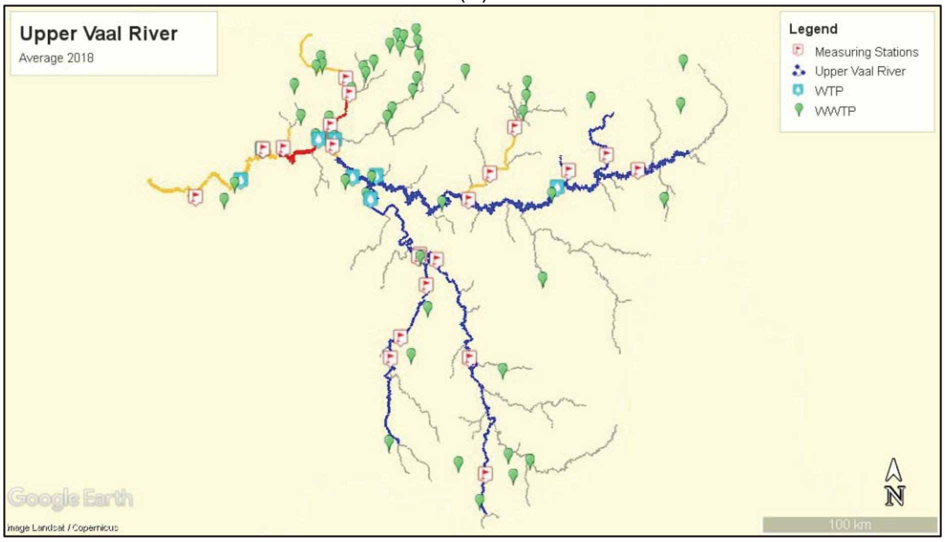
(c)

Figure J2.3: Wastewater contribution in the Upper Vaal River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

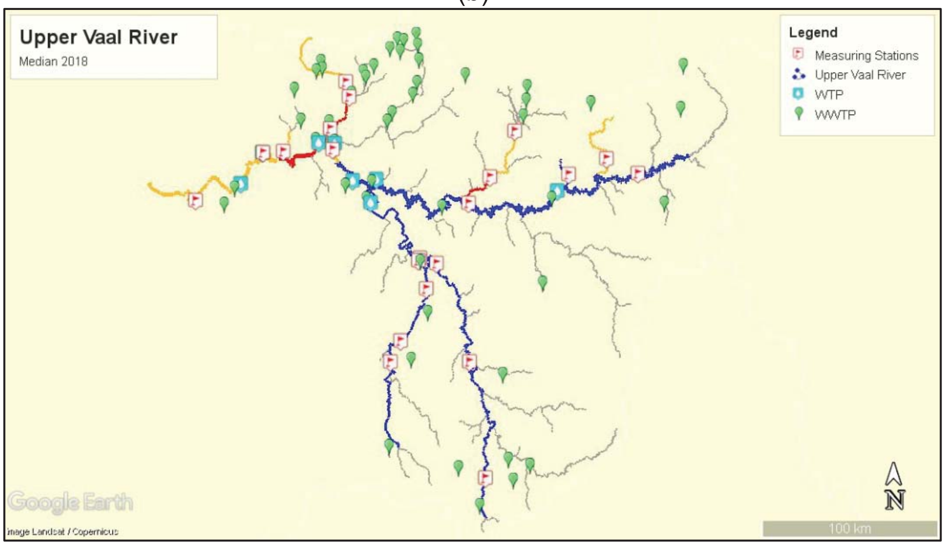
- **<u>Wastewater Contributions in 2018</u>**



(a)



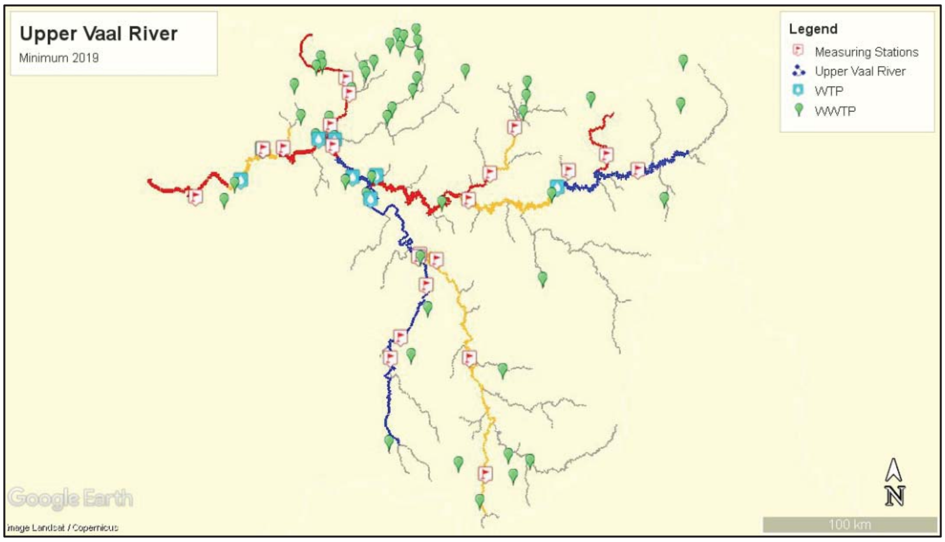
(b)



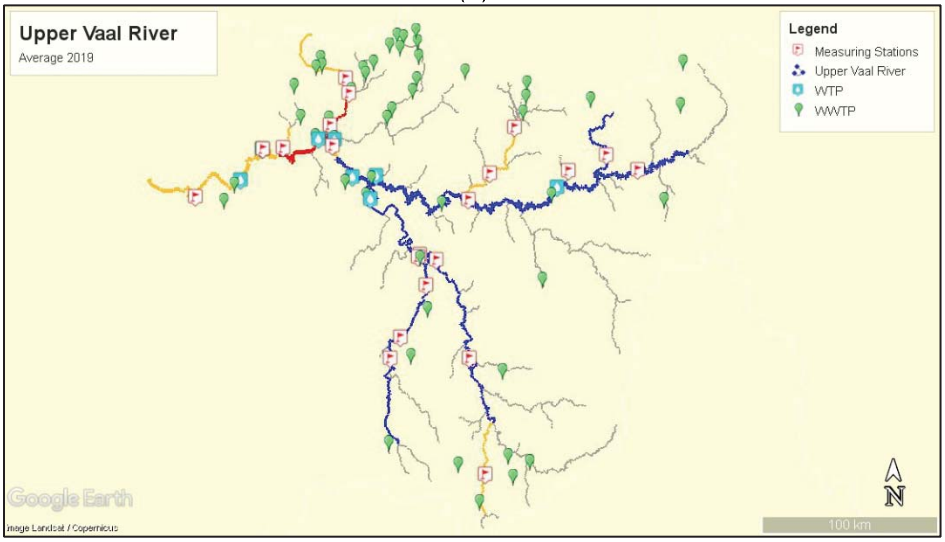
(c)

Figure J2.4: Wastewater contribution in the Upper Vaal River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

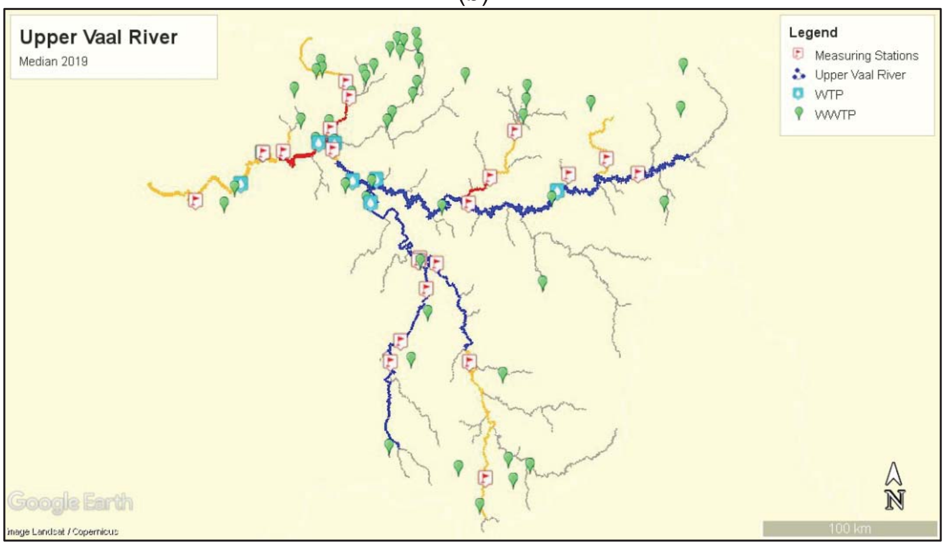
- **Wastewater Contributions in 2019**



(a)



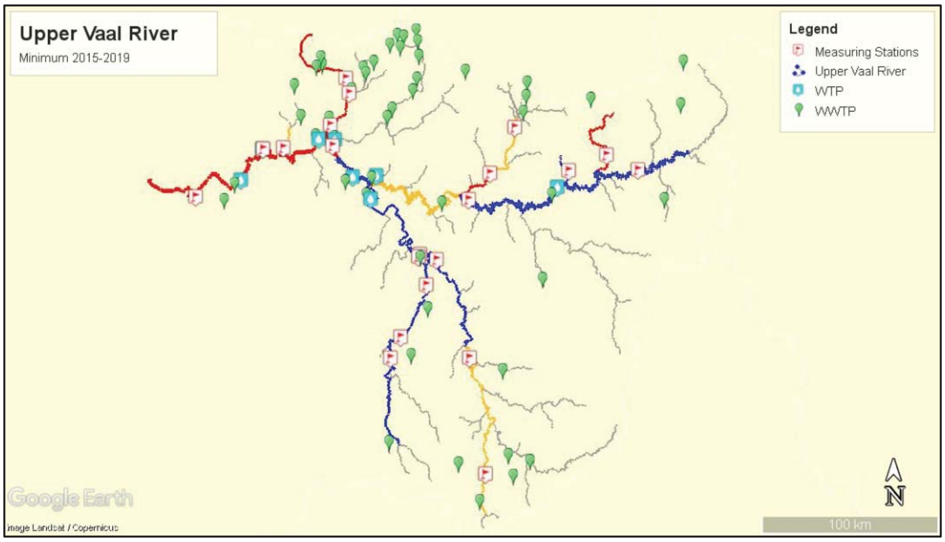
(b)



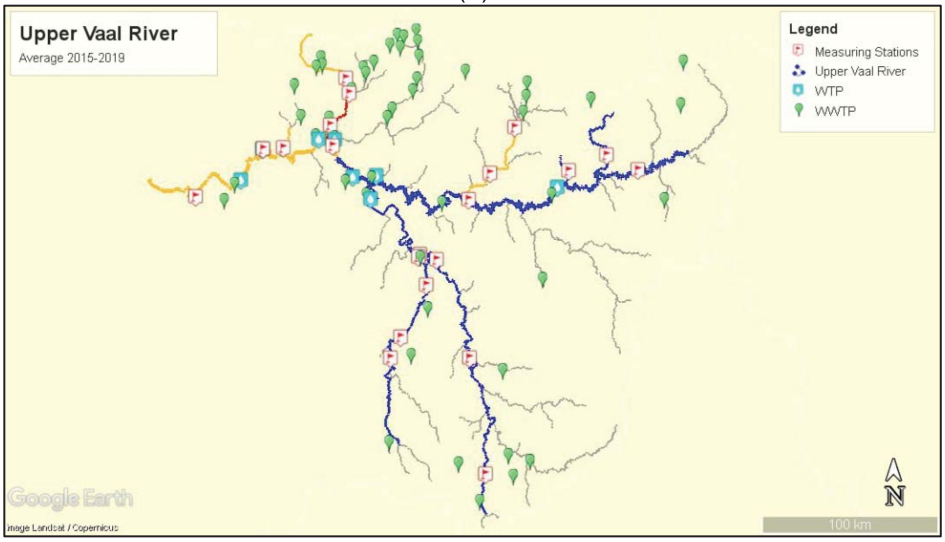
(c)

Figure J2.5: Wastewater contribution in the Upper Vaal River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

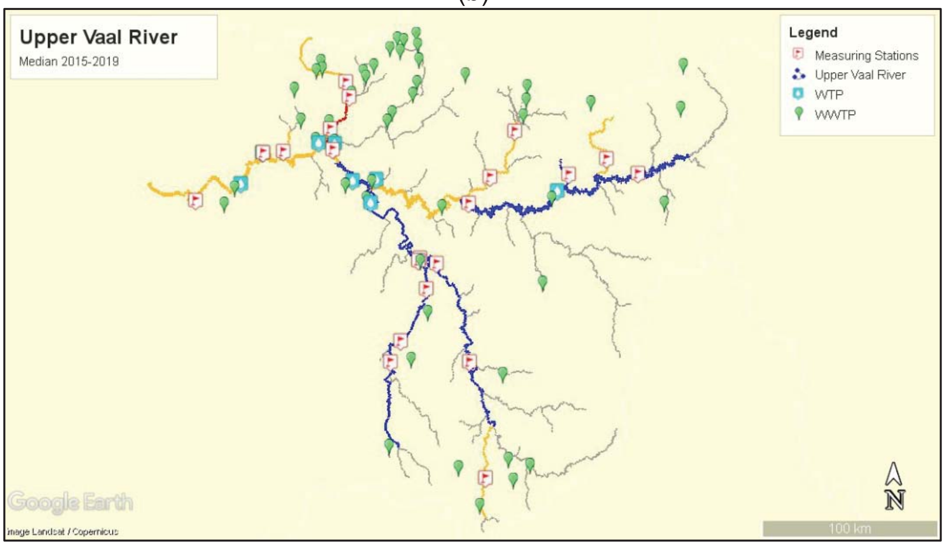
- **<u>Wastewater Contributions in 2015-2019</u>**



(a)



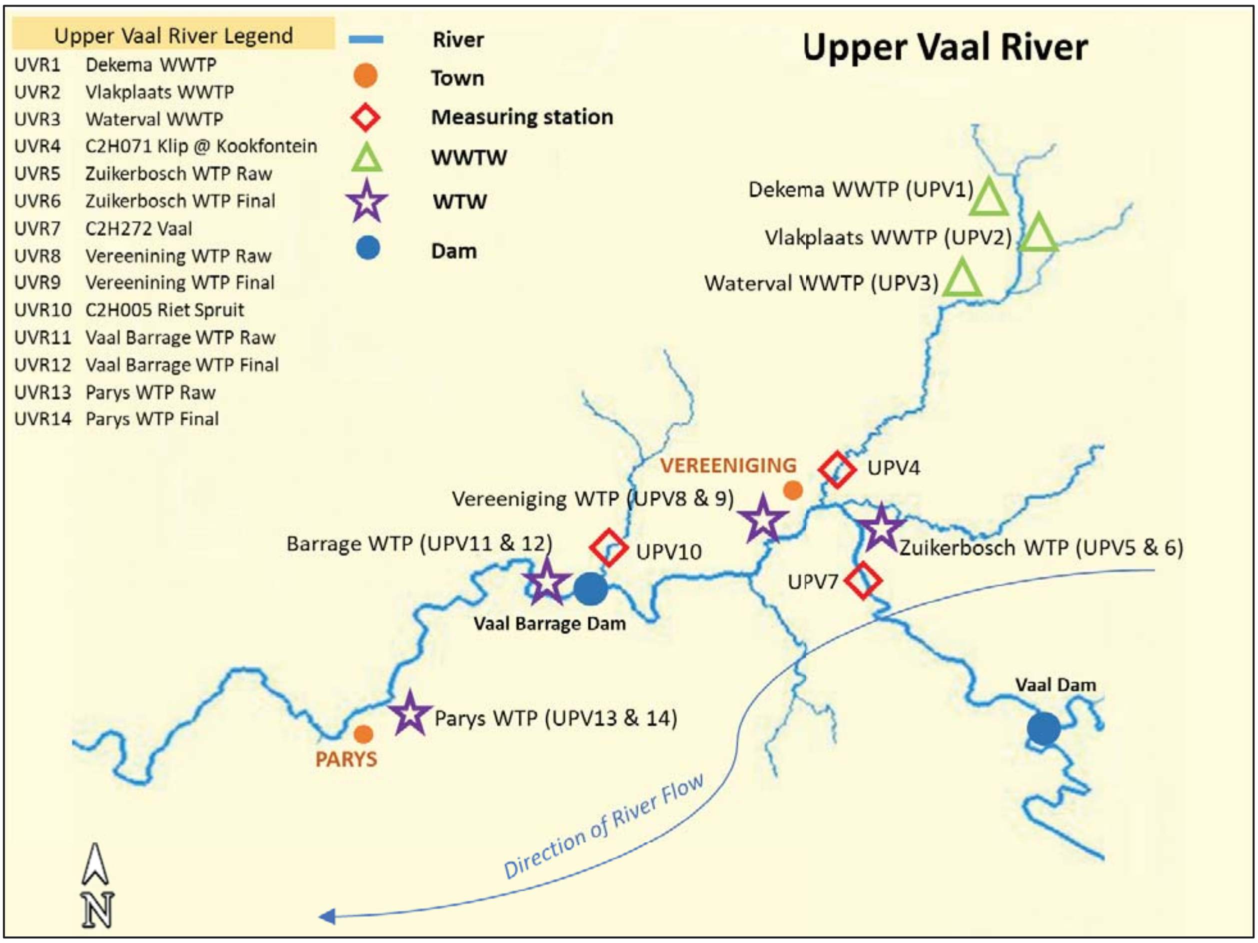
(b)



(c)

Figure J2.6: Wastewater contribution in the Upper Vaal River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

J3: Map of sampling points for CEC analysis in the Upper Vaal River



J4: CEC Concentration Results Legend for the Upper Vaal River

Upper Vaal River Legend	
UVR1	Dekema WWTP
UVR2	Vlakplaats WWTP
UVR3	Waterval WWTP
UVR4	C2H071 Klip @ Kookfontein
UVR5	Zuikerbosch WTP Raw
UVR6	Zuikerbosch WTP Final
UVR7	C2H272 Vaal
UVR8	Vereeniging WTP Raw
UVR9	Vereeniging WTP Final
UVR10	C2H005 Riet Spruit
UVR11	Vaal Barrage WTP Raw
UVR12	Vaal Barrage WTP Final
UVR13	Parys WTP Raw
UVR14	Parys WTP Final

J5: Results of the CEC analysis for the Upper Vaal River

Table J5.1: Results of the CEC analysis for the Upper Vaal River

Constituent	Sample Points													
	Dekema WWTP	Vlakplaats WWTP	Waterval WWTP	C2H071 Klip @ Kookfontein	Zuikerbosch WTP Raw	Zuikerbosch WTP Final	C2H272 Vaal	Vereeniging WTP Raw	Vereeniging WTP Final	C2H005 Riet Spruit	Vaal Barrage WTP Raw	Vaal Barrage WTP Final	Parys WTP Raw	Parys WTP Final
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
1,7-dimethylxanthine	577.5	2317	57.56	280.9	12.57	<MDL	<IQL	12.74	<IQL	431	11.94	<IQL	46.68	<IQL
Acetaminophen	2710	94.56	20.05	<MDL	<MDL	<MDL	<IQL	<IQL	<IQL	<IQL	<MDL	<MDL	<MDL	<MDL
Atrazine	382.3	678.2	564.5	551.6	381.6	353.5	385.3	387.9	370.8	196.6	316.3	347.9	332.1	311.5
Benzotriazole	77.96	74.92	127.8	47.96	<MDL	<MDL	<MDL	<MDL	<MDL	139.4	34.2	158.1	5.825	<IQL
Benzoylecgonine	10.65	65.98	12.2	11.1	<MDL	<MDL	<MDL	<MDL	<MDL	2.575	<MDL	<MDL	<IQL	<IQL
Caffeine	4205	8869	38.55	544.5	20.24	12.27	<IQL	<IQL	39.07	549.4	4.854	10.01	62.67	<IQL
Carbamazepine	278	564	522.9	216	<IQL	<IQL	9.83	10.52	8.496	184.1	<IQL	7.263	36.3	<IQL
Cetirizine	39.09	56.95	64.67	19.21	<IQL	<MDL	<IQL	<IQL	<IQL	13.32	3.26	<MDL	3.788	<MDL
Cocaine	<IQL	10.22	<IQL	0.728	<MDL	<IQL	<IQL	<IQL	<IQL	<IQL	<MDL	<MDL	<MDL	<MDL
Codeine	<IQL	2432	<IQL	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL	137.4	<MDL	<MDL	<MDL	<MDL
Diclofenac	134.9	225	190.6	53.56	<MDL	<MDL	<IQL	<MDL	<IQL	51.11	<IQL	<IQL	<IQL	<IQL
Efavirenz	3535	3588	5693	2087	<IQL	<IQL	96.82	<IQL	<IQL	3144	444.5	<IQL	328.5	<IQL
Emtricitabine	814.3	14412	6508	3068	<IQL	<MDL	15.41	<IQL	<IQL	6472	79.66	<IQL	241.3	<IQL
MDMA	<IQL	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Methamphetamine	125.9	432.5	74.4	80.62	<IQL	<MDL	<IQL	<IQL	<IQL	115.6	<IQL	<IQL	<IQL	<IQL
Methaqualone	163.9	674.8	310.2	797.6	5.432	3.889	8.442	6.908	6.918	362.9	103.4	4.168	172.6	30.11
Naproxen	247	215.6	89.82	48.21	<MDL	<MDL	<MDL	<MDL	<MDL	58.71	<MDL	<MDL	<IQL	<MDL
Sulfamethoxazole	306.2	1000	736.5	167.2	<MDL	4.254	<MDL	<IQL	<MDL	259.1	<IQL	<IQL	<IQL	2.918
Tramadol	323.7	527.5	516.3	146.3	2.627	<MDL	<IQL	<IQL	<IQL	108.2	15	<MDL	17.02	<MDL
Trimethoprim	212.5	334.1	80.12	45.33	<MDL	3.325	<MDL	<MDL	<MDL	129	<IQL	<MDL	<MDL	<MDL
Venlafaxine	51.91	40.64	49.91	8.107	<MDL	<MDL	<MDL	<MDL	<IQL	1.083	<IQL	<MDL	<IQL	<MDL

<IQL = Less than Instrument Quantification Limit

<MDL = Less than Method Detection Limit

J6: Bar charts of indicator compound results in the Upper Vaal River

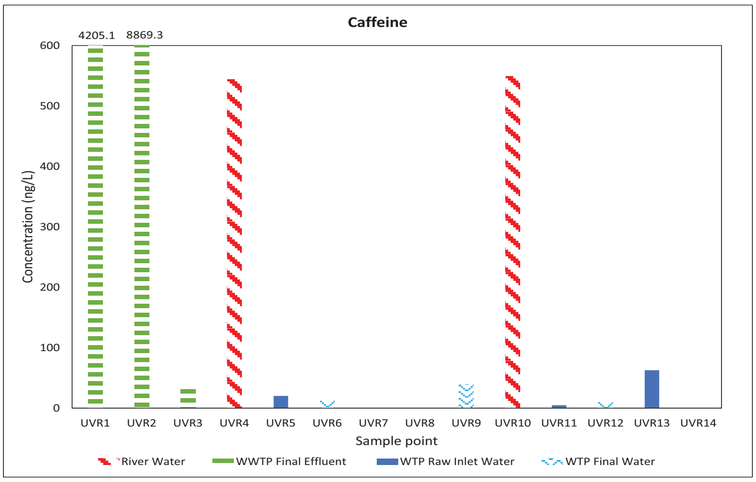


Figure J6.1: Concentrations of Caffeine in the Upper Vaal River

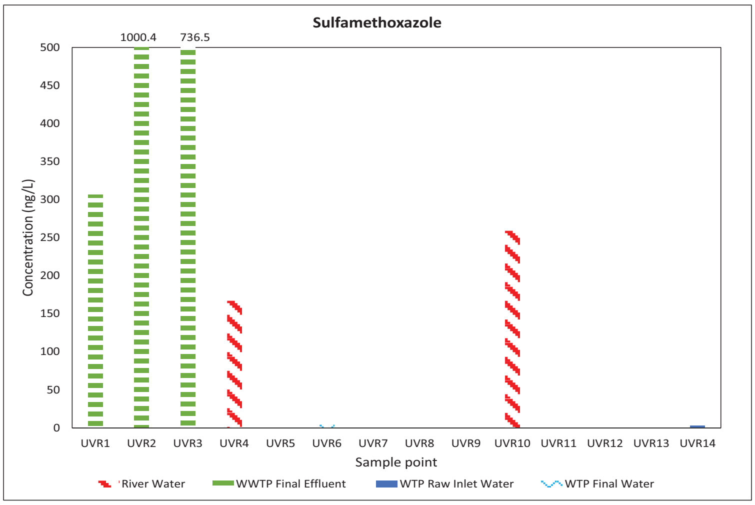


Figure J6.2: Concentrations of Sulfamethoxazole in the Upper Vaal River

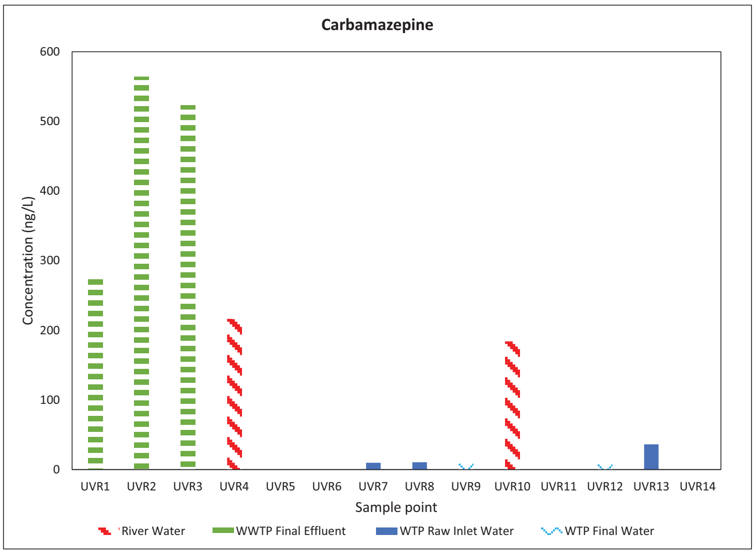


Figure J6.3: Concentrations of Carbamazepine in the Upper Vaal River

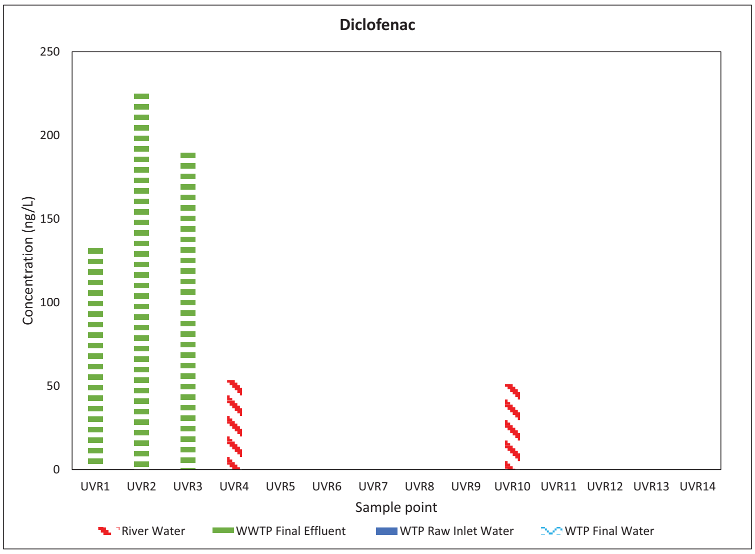


Figure J6.4: Concentrations of Diclofenac in the Upper Vaal River

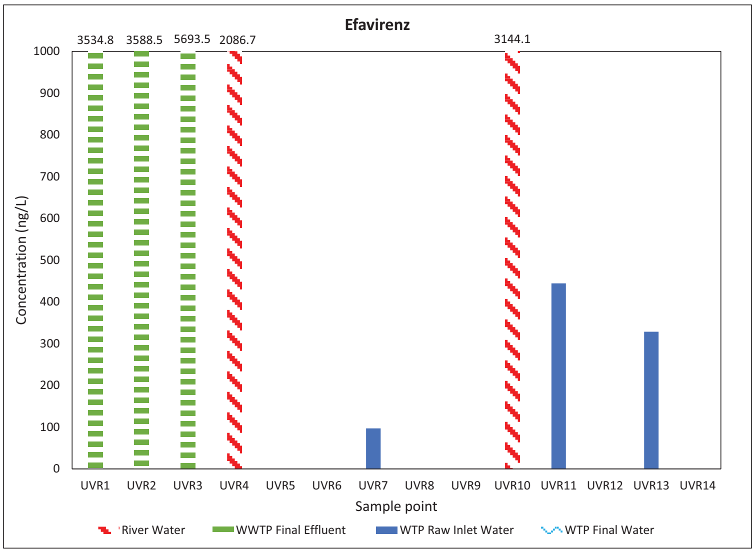


Figure J6.5: Concentrations of Efavirenz in the Upper Vaal River

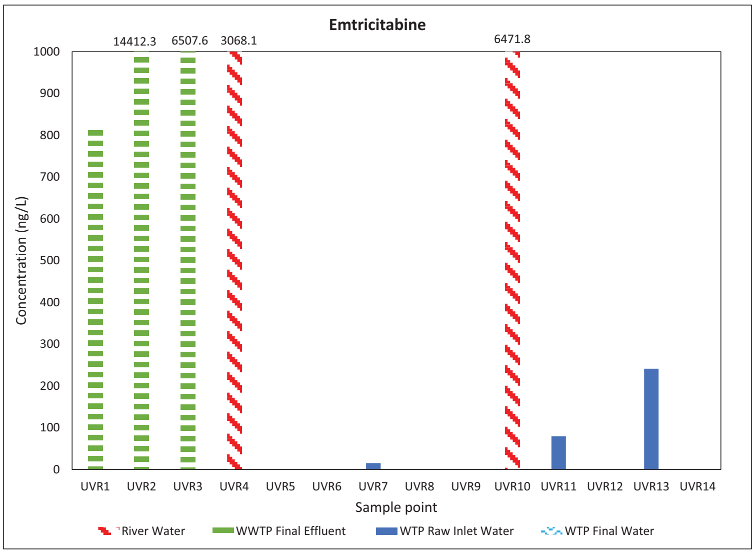


Figure J6.6: Concentrations of Emtricitabine in the Upper Vaal River

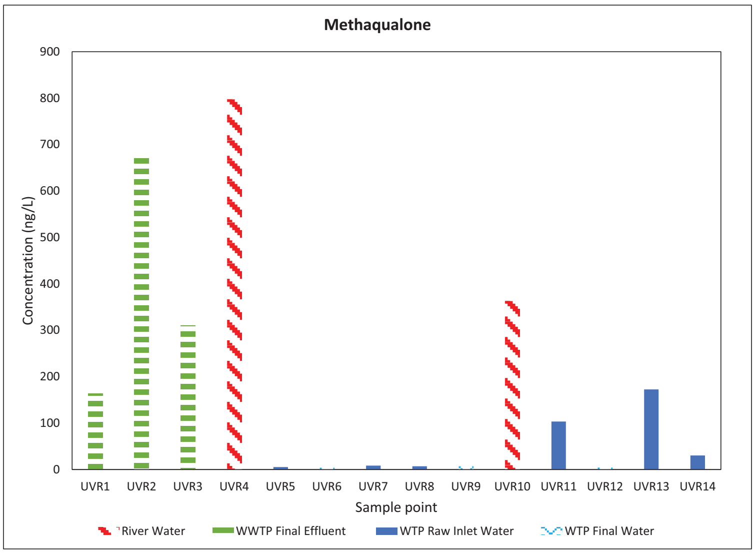


Figure J6.7: Concentrations of Methaqualone in the Upper Vaal River

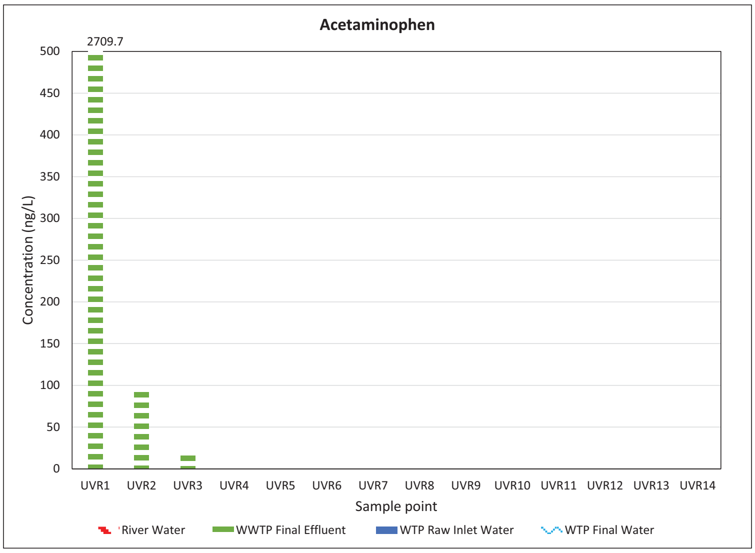


Figure J6.8: Concentrations of Acetaminophen in the Upper Vaal River

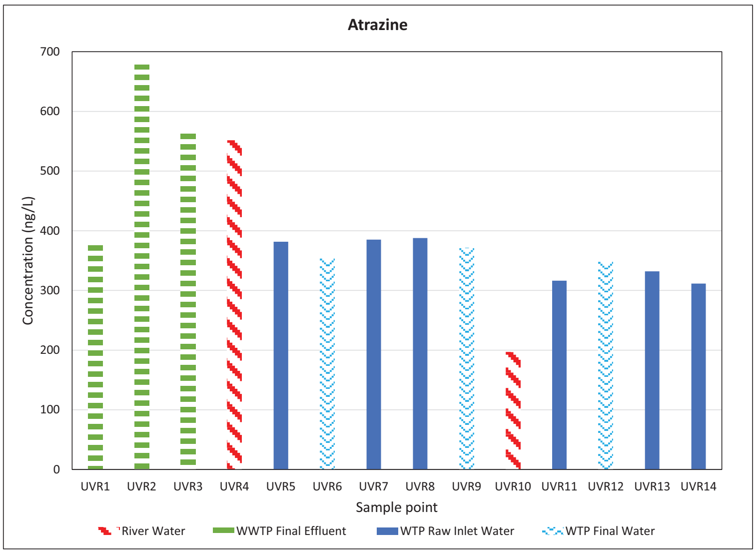


Figure J6.9: Concentrations of Atrazine in the Upper Vaal River

J7: Results of Other Water Quality Parameters for the Upper Vaal River

Sample Points	Sample Name	pH	EC	COD	UV 254	DOC	DO
		-	mS/m	mg/L	m^{-1}	mg/L	mg/L
Dekema WWTP	UPV 1	7.95	-	56	0.06	2.36	-
Vlakplaats WWTP	UPV 2	8.09	-	58	0.084	2.70	-
Waterval WWTP	UPV 3	8.21	-	55	0.034	1.99	-
C2H071 Klip @ Kookfontein	UPV 4	8.02	59	38	0.032	1.96	7.09
Zuikerbosch WTP Raw	UPV 5	8.26	19	34	0.104	2.99	8.71
Zuikerbosch WTP Final	UPV 6	8.11	22	35	0.022	1.82	9.01
C2H272 Vaal	UPV 7	8.42	19	33	0.106	3.01	8.05
Vereeniging WTP Raw	UPV 8	7.94	19	35	0.198	4.32	9.19
Vereeniging WTP Final	UPV 9	8.34	21	35	0.037	2.04	9.07
C2H005 Riet Spruit	UPV 10	7.75	58	42	0.026	1.88	6.12
Vaal Barrage WTP Raw	UPV 11	8.11	26	31	1.17	18.1	6.23
Vaal Barrage WTP Final	UPV 12	8.78	22	33	0.007	1.61	9.16
Parys WTP Raw	UPV 13	7.90	25	36	0.149	3.62	7.30
Parys WTP Final	UPV 14	8.20	25	29	0.03	1.94	7.63

APPENDIX K RESULTS FOR THE MIDDLE VAAL RIVER

K1: Flow-based data and calculations for the Middle Vaal River

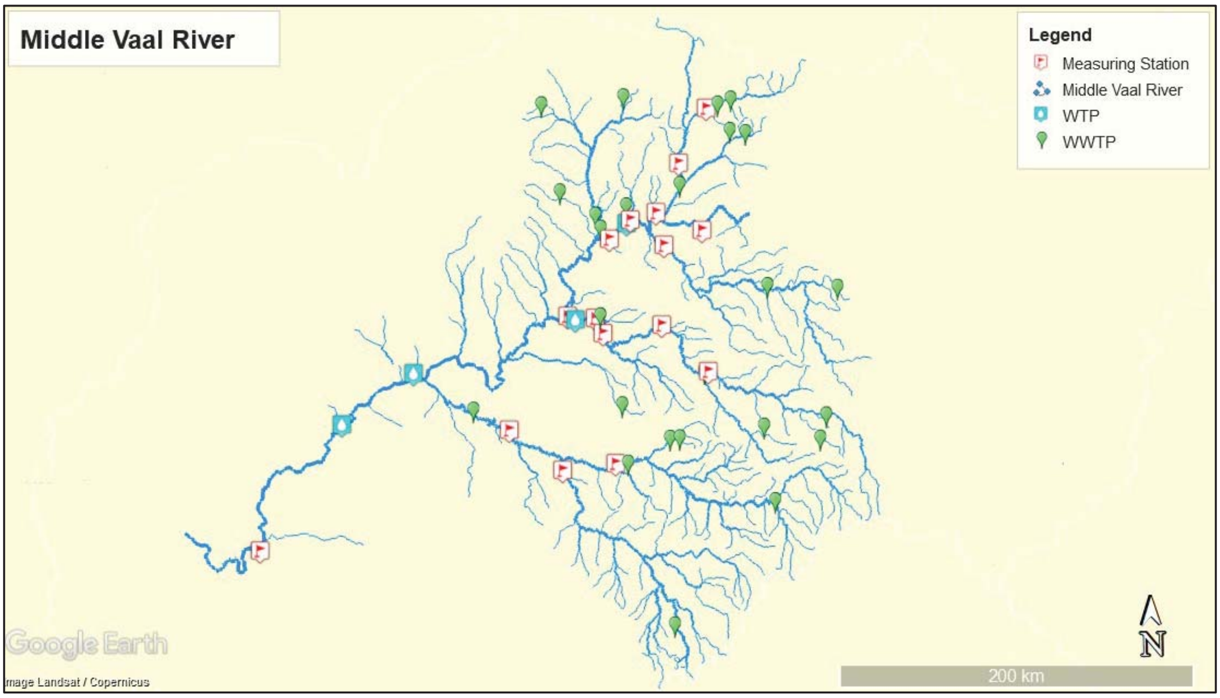


Figure K1.1: Middle Vaal River System, indicating all measuring stations, WWTP and WTP in this river.

Table K1.1: Summary of Wastewater Percentages for the Middle Vaal River for 2015-2019

Middle Vaal River

Measuring station/ Water Treatment Plant	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow								
	2015			2016			2017		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C2H018 Vaal River @ De Vaal	0%	0%	0%	0%	0%	0%	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	33%	29%	30%	44%	25%	25%	35%	30%	31%
C2H001 Mooi River @ Witrand	18%	12%	12%	33%	20%	26%	22%	14%	15%
C2H085 Mooi River @ Hoogekraal	71%	62%	65%	72%	41%	64%	54%	18%	27%
C7H006 Renoster River @ Arriesrust		N/A		23%	2%	4%	12%	0%	1%
C2H139 Koekemoer Spruit @ Buffelsfontein	92%	87%	88%	88%	80%	83%	87%	70%	78%
Midvaal WTP	7%	4%	5%	6%	3%	4%	6%	1%	3%
C2H007 Vaal River @ Pilgrims Estate	8%	5%	5%	7%	4%	4%	5%	2%	3%
C6H007 Vals River @ Kroonstad	22%	1%	1%	45%	0%	0%	16%	0%	1%
C6H001 Vals River @ Roodewal	55%	35%	46%	74%	27%	54%	70%	5%	24%
C6H006 Vals River @ Tweefontein	91%	6%	6%	46%	5%	7%	58%	2%	4%
C6H002 Vals River @ Grootdraai	88%	77%	82%	92%	73%	82%	60%	47%	51%
Balkfontein WTP	15%	10%	11%	14%	8%	10%	10%	4%	6%
C2H061 Vaal River @ Klipplaatdrift	17%	11%	12%	16%	8%	10%	16%	8%	7%
C4H016 Sand River @ Bloudrif	55%	45%	48%	57%	26%	48%	37%	10%	16%
C4H015 Vet River @ Vaalkoppies	2%	2%	2%	2%	1%	2%	2%	1%	2%
C4H004 Vet River @ Fizantkraal	82%	49%	58%	87%	27%	62%	62%	13%	20%
Bloemhof WTP	20%	13%	14%	19%	9%	12%	18%	8%	9%
Christiana WTP	20%	13%	14%	19%	9%	12%	18%	8%	9%
C9H003 Vaal River @ Riverton	16%	13%	13%	16%	13%	13%	15%	9%	11%

Measuring station/ Water Treatment Plant	2018			2019			2015 - 2019		
	Min	Average	Median	Min	Average	Median	Min	Average	Median
C2H018 Vaal River @ De Vaal	0%	0%	0%	0%	0%	0%	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	42%	36%	37%	57%	40%	39%	41%	31%	31%
C2H001 Mooi River @ Witrand	37%	20%	20%	37%	27%	31%	27%	17%	18%
C2H085 Mooi River @ Hoogekraal	59%	31%	47%	66%	12%	49%	64%	24%	46%
C7H006 Renoster River @ Arriesrust	6%	2%	2%	79%	3%	56%	16%	1%	3%
C2H139 Koekemoer Spruit @ Buffelsfontein	96%	77%	83%		N/A		92%	78%	83%
Midvaal WTP	7%	3%	3%	7%	2%	3%	6%	2%	3%
C2H007 Vaal River @ Pilgrims Estate	5%	3%	3%	7%	3%	4%	6%	3%	4%
C6H007 Vals River @ Kroonstad	4%	0%	1%	11%	0%	0%	10%	0%	0%
C6H001 Vals River @ Roodewal	76%	9%	44%	71%	6%	40%	68%	9%	38%
C6H006 Vals River @ Tweefontein	89%	2%	3%	76%	1%	4%	67%	2%	4%
C6H002 Vals River @ Grootdraai	81%	51%	57%	74%	50%	57%	77%	57%	63%
Balkfontein WTP	10%	6%	7%	14%	6%	8%	12%	6%	8%
C2H061 Vaal River @ Klipplaatdrift	11%	6%	8%	14%	5%	8%	13%	6%	8%
C4H016 Sand River @ Bloudrif	42%	18%	31%	49%	7%	32%	47%	14%	30%
C4H015 Vet River @ Vaalkoppies	2%	1%	1%	2%	0%	1%	2%	1%	2%
C4H004 Vet River @ Fizantkraal	51%	19%	31%	47%	7%	20%	62%	15%	30%
Bloemhof WTP	13%	7%	9%	16%	6%	9%	15%	7%	10%
Christiana WTP	13%	7%	9%	16%	6%	9%	15%	7%	10%
C9H003 Vaal River @ Riverton	30%	12%	12%	35%	10%	12%	20%	11%	12%

Table K1.2: Wastewater percentage calculations for Middle Vaal River for (a) 2015, (b) 2016, (c) 2017, (d) 2018, (e) 2019 and (f) 2015-2019

(a)

Middle Vaal River

2015

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	14.5144	22.9606	20.9125																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.3637	0.4435	0.4341	0.0961	0.0868																									0.1829	33%	29%	30%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.8551	1.3908	1.3461	0.0961	0.0868																									0.1829	18%	12%	12%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.3343	0.5104	0.4491	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	71%	62%	65%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464									0.0475	0.0231																				0.0706			
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	0.0129	0.0215	0.0200								0.1424																			0.1424	92%	87%	88%
Midvaal WTP	-26.9345	26.796933	14.8616	23.4925	21.3815	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	7%	4%	5%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	12.6965	20.4963	18.6882	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	8%	5%	5%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.1244	5.9792	6.1787														0.0174	0.0178												0.0352	22%	1%	1%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.3742	0.8350	0.5286														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	55%	35%	46%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.0468	7.3404	7.3335														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	91%	6%	6%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.0715	0.1676	0.1217														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	88%	77%	82%
Balkfontein WTP	-27.404422	26.50355	12.7680	20.6639	18.8098	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	15%	10%	11%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	11.3195	19.4907	17.7090	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	17%	11%	12%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.3343	0.5104	0.4491																					0.0463	0.0463	0.0231	0.3009			0.4167	55%	45%	48%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	2.9861	3.3647	3.3395																									0.0579		0.0579	2%	2%	2%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.1013	0.5022	0.3444																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	82%	49%	58%
Bloemhof WTP	-27.65075	25.595642	11.4208	19.9929	18.0534	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	20%	13%	14%
Christiana WTP	-27.894194	25.185728	11.4208	19.9929	18.0534	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	20%	13%	14%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	15.3113	20.1211	19.9349	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	16%	13%	13%

(b)

Middle Vaal River

2016

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	15.7338	29.7537	22.5872																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.2290	0.5588	0.5631	0.0961	0.0868																									0.1829	44%	25%	25%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.3706	0.7202	0.5280	0.0961	0.0868																									0.1829	33%	20%	26%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.3143	1.1875	0.4528	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	72%	41%	64%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464	0.2349	3.7484	1.6506						0.0475	0.0231																				0.0706	23%	2%	4%
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	0.0190	0.0347	0.0287								0.1424																			0.1424	88%	80%	83%
Midvaal WTP	-26.9345	26.796933	16.3019	34.7244	24.7193	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	6%	3%	4%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	13.8854	28.0322	21.9900	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	7%	4%	4%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.0436	23.5074	20.3650														0.0174	0.0178												0.0352	45%	0%	0%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.1548	1.2366	0.3820														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	74%	27%	54%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.5273	9.1126	5.6189														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	46%	5%	7%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.0452	0.1987	0.1221														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	92%	73%	82%
Balkfontein WTP	-27.404422	26.50355	13.9306	28.2310	22.1121	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	14%	8%	10%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	12.6431	28.5224	21.7825	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	16%	8%	10%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.3143	1.1875	0.4528																					0.0463	0.0463	0.0231	0.3009			0.4167	57%	26%	48%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	2.3207	3.8442	2.9772																									0.0579		0.0579	2%	1%	2%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.0726	1.2776	0.2958																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	87%	27%	62%
Bloemhof WTP	-27.65075	25.595642	12.7157	29.8000	22.0783	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	19%	9%	12%
Christiana WTP	-27.894194	25.185728	12.7157	29.8000	22.0783	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	19%	9%	12%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	15.5949	19.6278	19.6480	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	16%	13%	13%

(c)

Middle Vaal River

2017

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	15.2497	48.3204	29.3299																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.3445	0.4214	0.4081	0.0961	0.0868																									0.1829	35%	30%	31%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.6301	1.0981	1.0285	0.0961	0.0868																									0.1829	22%	14%	15%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.7021	3.7468	2.2023	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	54%	18%	27%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464	0.5163	23.9795	4.9454						0.0475	0.0231																				0.0706	12%	0%	1%
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	0.0213	0.0624	0.0394								0.1424																			0.1424	87%	70%	78%
Midvaal WTP	-26.9345	26.796933	16.4894	76.1091	36.5170	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	6%	1%	3%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	21.5778	55.1843	34.6277	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	5%	2%	3%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.1828	10.8019	5.1003														0.0174	0.0178												0.0352	16%	0%	1%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.1910	8.7949	1.4573														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	70%	5%	24%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.3288	27.1664	12.2710														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	58%	2%	4%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.3637	0.6253	0.5346														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	60%	47%	51%
Balkfontein WTP	-27.404422	26.50355	21.9414	55.8096	35.1623	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	10%	4%	6%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	12.6431	28.5224	29.2328	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	16%	8%	7%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.7021	3.7468	2.2023																					0.0463	0.0463	0.0231	0.3009			0.4167	37%	10%	16%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	3.0229	4.7639	3.7795																									0.0579		0.0579	2%	1%	2%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.2873	3.1564	1.8610																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	62%	13%	20%
Bloemhof WTP	-27.65075	25.595642	12.9304	31.6789	31.0939	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	18%	8%	9%
Christiana WTP	-27.894194	25.185728	12.9304	31.6789	31.0939	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	18%	8%	9%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	16.3198	30.0201	23.2825	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	15%	9%	11%

(d)

Middle Vaal River

2018

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s)			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	13.0582	31.6714	27.6179																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.2530	0.3269	0.3168	0.0961	0.0868																									0.1829	42%	36%	37%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.3077	0.7458	0.7371	0.0961	0.0868																									0.1829	37%	20%	20%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.5708	1.8441	0.9390	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	59%	31%	47%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464	1.1413	4.0403	3.0449						0.0475	0.0231																				0.0706	6%	2%	2%
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	0.0059	0.0428	0.0289								0.1424																			0.1424	96%	77%	83%
Midvaal WTP	-26.9345	26.796933	14.7761	37.5986	31.6307	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	7%	3%	3%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	19.9677	33.7763	28.9169	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	5%	3%	3%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.8996	9.4916	5.2954														0.0174	0.0178												0.0352	4%	0%	1%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.1446	4.7610	0.5631														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	76%	9%	44%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.0585	29.0229	14.9598														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	89%	2%	3%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.1314	0.5336	0.4139														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	81%	51%	57%
Balkfontein WTP	-27.404422	26.50355	20.0991	34.3099	29.3309	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	10%	6%	7%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	19.2213	35.4890	28.5175	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	11%	6%	8%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.5708	1.8441	0.9390																					0.0463	0.0463	0.0231	0.3009			0.4167	42%	18%	31%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	3.3552	4.6687	4.1403																									0.0579		0.0579	2%	1%	1%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.4478	2.0470	1.0470																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	51%	19%	31%
Bloemhof WTP	-27.65075	25.595642	19.6691	37.5360	29.5645	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	13%	7%	9%
Christiana WTP	-27.894194	25.185728	19.6691	37.5360	29.5645	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	13%	7%	9%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	6.7046	20.8581	20.4825	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	30%	12%	12%
C9H009 Vaal River @ De Hoop 65	-28.51622	24.60069	3.8058	9.1444	6.0110	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	43%	24%	32%

(e)

Middle Vaal River

Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s) 2019			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	12.6366	35.0219	28.4540																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.1400	0.2800	0.2806	0.0961	0.0868																									0.1829	57%	40%	39%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.3163	0.4904	0.4127	0.0961	0.0868																									0.1829	37%	27%	31%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.4286	5.8202	0.8699	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	66%	12%	49%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464	0.0190	2.0679	0.0545						0.0475	0.0231																				0.0706	79%	3%	56%
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	NO DATA AVAILABLE										0.1424																			0.1424	N/A		
Midvaal WTP	-26.9345	26.796933	13.0842	42.9100	29.3784	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	7%	2%	3%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	14.5234	34.2514	28.0359	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	7%	3%	4%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.2936	23.1281	10.1111														0.0174	0.0178												0.0352	11%	0%	0%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.1814	7.0345	0.6696														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	71%	6%	40%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.1441	33.0229	10.2224														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	76%	1%	4%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.1932	0.5546	0.4114														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	74%	50%	57%
Balkfontein WTP	-27.404422	26.50355	14.7166	34.8060	28.4473	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	14%	6%	8%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	14.1281	40.8486	26.3953	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	14%	5%	8%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.4286	5.8202	0.8699																					0.0463	0.0463	0.0231	0.3009			0.4167	49%	7%	32%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	2.6222	13.1910	4.6134																									0.0579		0.0579	2%	0%	1%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.5304	6.3841	1.8637																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	47%	7%	20%
Bloemhof WTP	-27.65075	25.595642	14.6585	47.2326	28.2590	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	16%	6%	9%
Christiana WTP	-27.894194	25.185728	14.6585	47.2326	28.2590	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	16%	6%	9%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	5.3586	26.3827	20.7446	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	35%	10%	12%

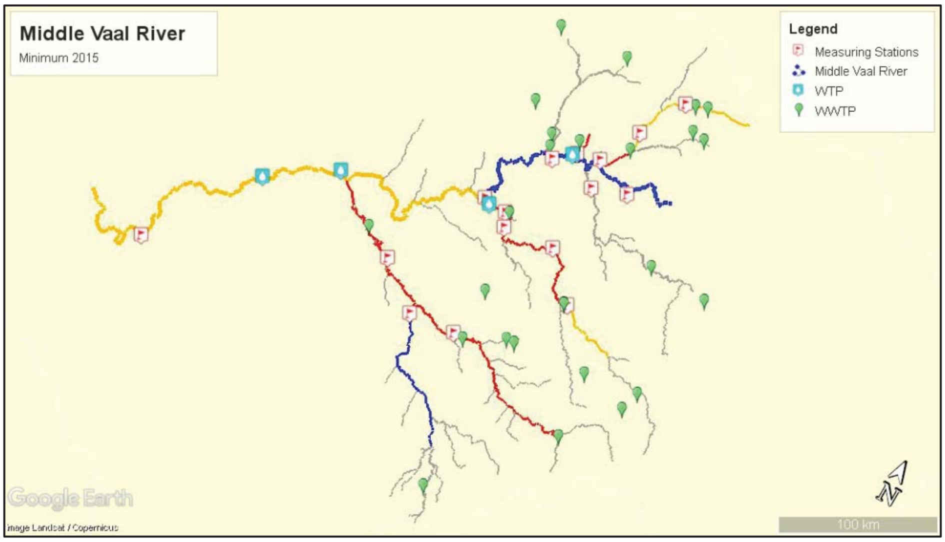
(f)

Middle Vaal River

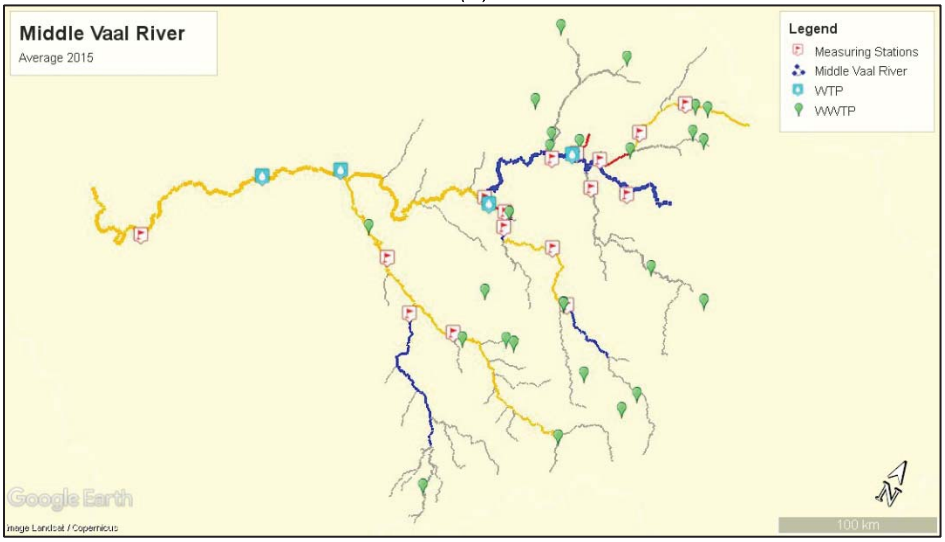
Measuring station/ Water Treatment Works	Coordinates		River Flow Measurements (m^3/s) 2015-2019			Wastewater treatment plants discharge into the river (m^3/s) - Design Capacity																										Cumulative flow	% wastewater in river (m^3/s) when river flow is at its minimum, average and median flow		
	Latitude	Longitude	Min	Average	Median	Oberholzer	Khutsong	Kokosi	Wedela	Potchefstroom	Heilbron	Koppies	Stilfontein	Ventersdorp	Coligny	Klerksdorp	Orkney	Hartebeesfontein	Lindley	Arlington	Kroonstad	KST PVT	Steynsrus	Bothaville	Kutlwanong	Phomolong	Hennenman	Senekal	Virginia	Excelsior	Hoopstad		Min	Average	Median
C2H018 Vaal River @ De Vaal	-26.97056	27.20967	14.2385	33.5456	25.7803																											0.0000	0%	0%	0%
C2H069 Mooirivierloop @ Blaauwbank	-26.37022	27.24811	0.2660	0.4061	0.4005	0.0961	0.0868																									0.1829	41%	31%	31%
C2H001 Mooi River @ Witrand	-26.64428	27.09033	0.4959	0.8890	0.8105	0.0961	0.0868																									0.1829	27%	17%	18%
C2H085 Mooi River @ Hoogekraal	-26.8805	26.96428	0.4700	2.6218	0.9826	0.0961	0.0868	0.0868	0.0303	0.5208																						0.8208	64%	24%	46%
C7H006 Renoster River @ Arriesrust	-27.04628	27.00464	0.3823	8.4590	2.4238						0.0475	0.0231																				0.0706	16%	1%	3%
C2H139 Koekemoer Spruit @ Buffelsfontein	-26.91606	26.81722	0.0118	0.0403	0.0292								0.1424																			0.1424	92%	78%	83%
Midvaal WTP	-26.9345	26.796933	15.1026	44.6668	29.2160	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	6%	2%	3%
C2H007 Vaal River @ Pilgrims Estate	-27.01011	26.69808	16.5302	34.3481	26.4517	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424																			1.0338	6%	3%	4%
C6H007 Vals River @ Kroonstad	-27.67138	27.23694	0.3088	14.5816	9.4101														0.0174	0.0178												0.0352	10%	0%	0%
C6H001 Vals River @ Roodewal	-27.44138	26.98583	0.2092	4.5324	0.7201														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	68%	9%	38%
C6H006 Vals River @ Tweefontein	-27.47611	26.65694	0.2211	21.1330	10.0811														0.0174	0.0178	0.2546	0.1157	0.0451									0.4507	67%	2%	4%
C6H002 Vals River @ Grootdraai	-27.39861	26.61333	0.1610	0.4160	0.3208														0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								0.5491	77%	57%	63%
Balkfontein WTP	-27.404422	26.50355	16.6911	34.7641	26.7725	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	12%	6%	8%
C2H061 Vaal River @ Klipplaatdrift	-27.38972	26.46388	15.6981	37.9819	26.3606	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984								2.3352	13%	6%	8%
C4H016 Sand River @ Bloudrif	-28.11722	26.71916	0.4700	2.6218	0.9826																					0.0463	0.0463	0.0231	0.3009			0.4167	47%	14%	30%
C4H015 Vet River @ Vaalkoppies	-28.14444	26.41805	2.8614	5.9665	3.7700																									0.0579		0.0579	2%	1%	2%
C4H004 Vet River @ Fizantkraal	-27.935	26.12444	0.2879	2.6734	1.0824																					0.0463	0.0463	0.0231	0.3009	0.0579		0.4745	62%	15%	30%
Bloemhof WTP	-27.65075	25.595642	15.9860	40.6554	27.4430	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	15%	7%	10%
Christiana WTP	-27.894194	25.185728	15.9860	40.6554	27.4430	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	15%	7%	10%
C9H003 Vaal River @ Riverton	-28.51344	24.69708	11.8579	23.4020	20.8185	0.0961	0.0868	0.0868	0.0303	0.5208	0.0475	0.0231	0.1424	0.0347	0.0231	0.4167	0.1852	0.0926	0.0174	0.0178	0.2546	0.1157	0.0451	0.0984	0.0694	0.0463	0.0463	0.0231	0.3009	0.0579	0.0127	2.8919	20%	11%	12%

K2: De facto wastewater maps for different time periods for Middle Vaal River

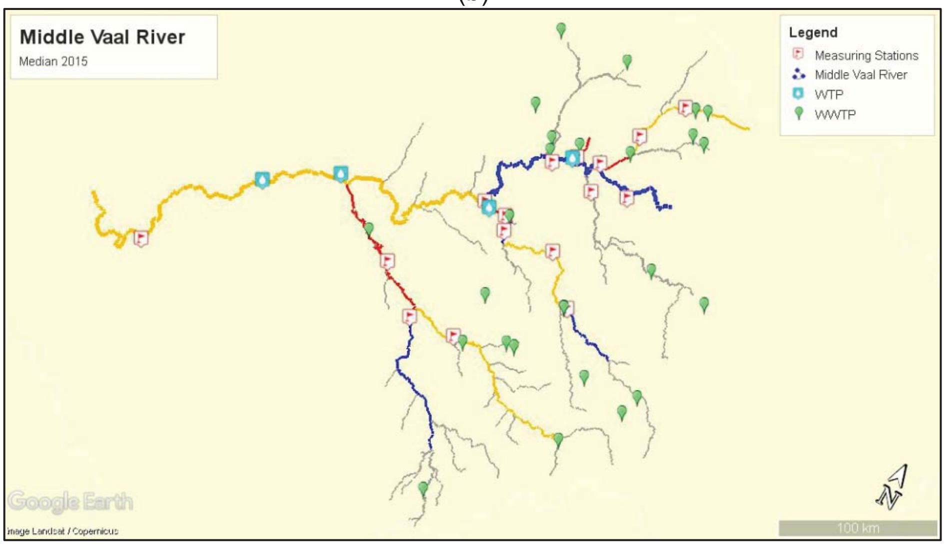
- **<u>Wastewater Contributions in 2015</u>**



(a)



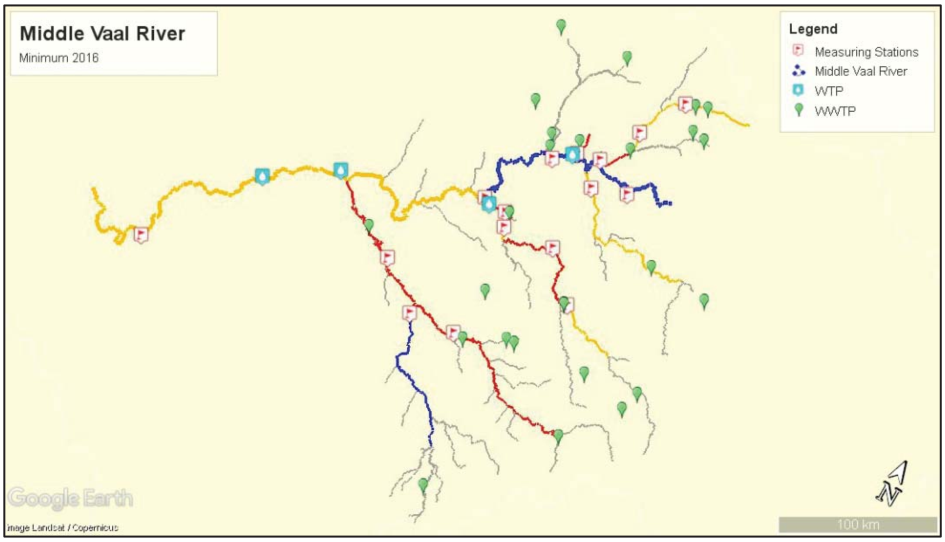
(b)



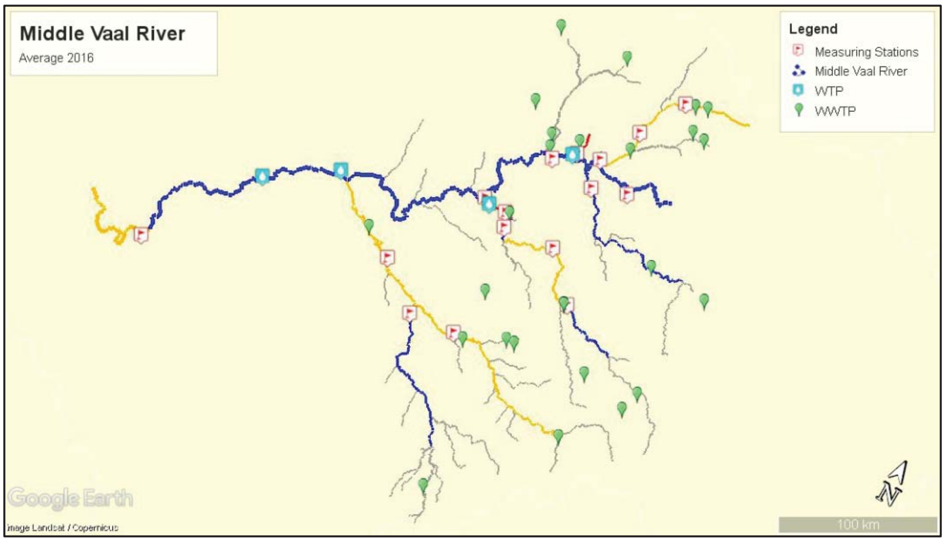
(c)

Figure K2.1: Wastewater contribution in the Middle Vaal River in 2015 during (a) minimum flow, (b) average flow and (c) median flow

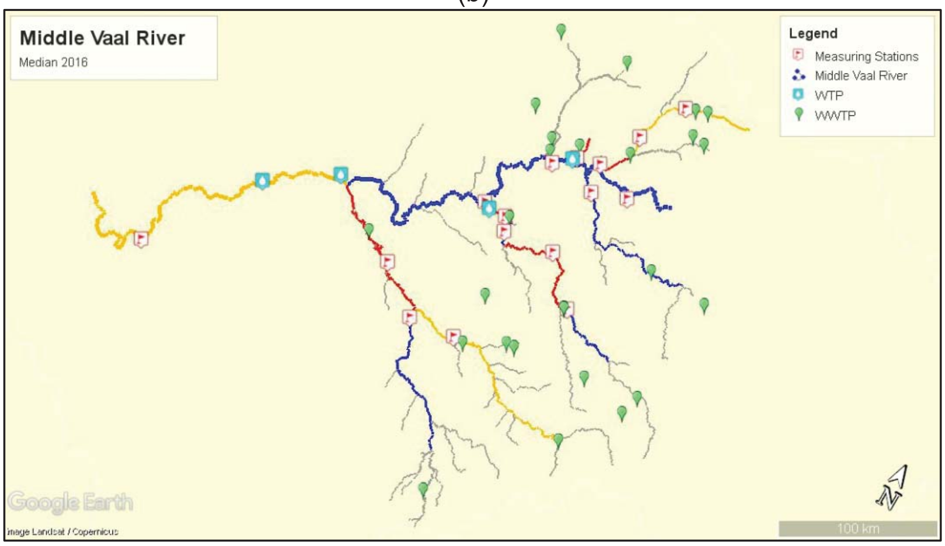
- **Wastewater Contributions in 2016**



(a)



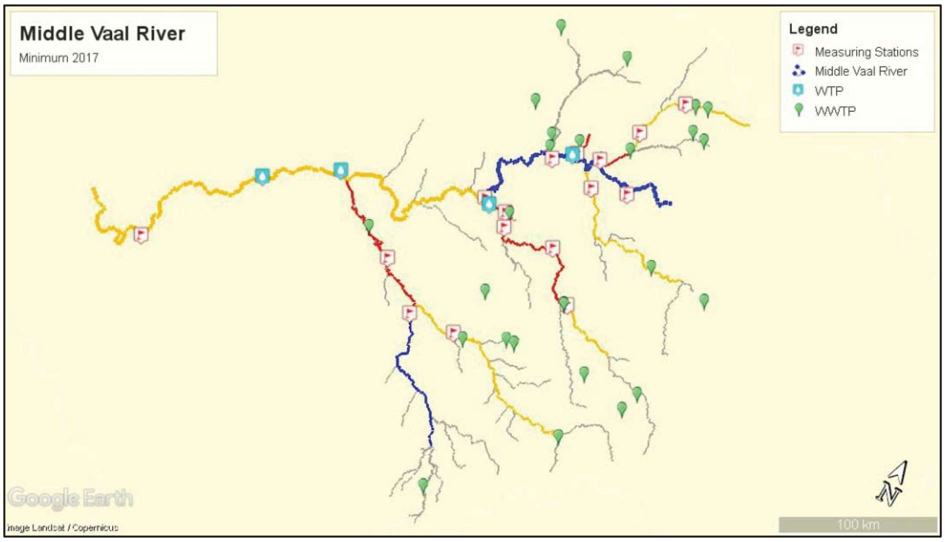
(b)



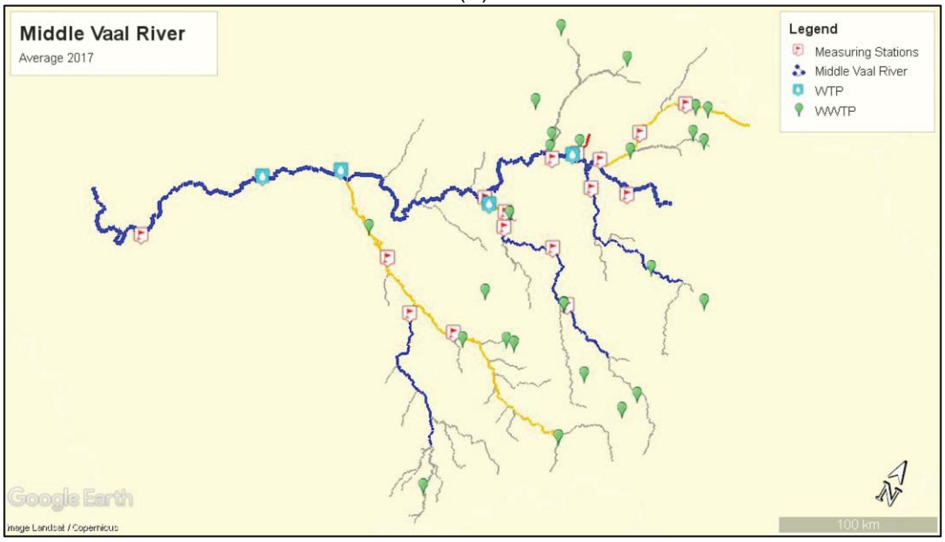
(c)

Figure K2.2: Wastewater contribution in the Middle Vaal River in 2016 during (a) minimum flow, (b) average flow and (c) median flow

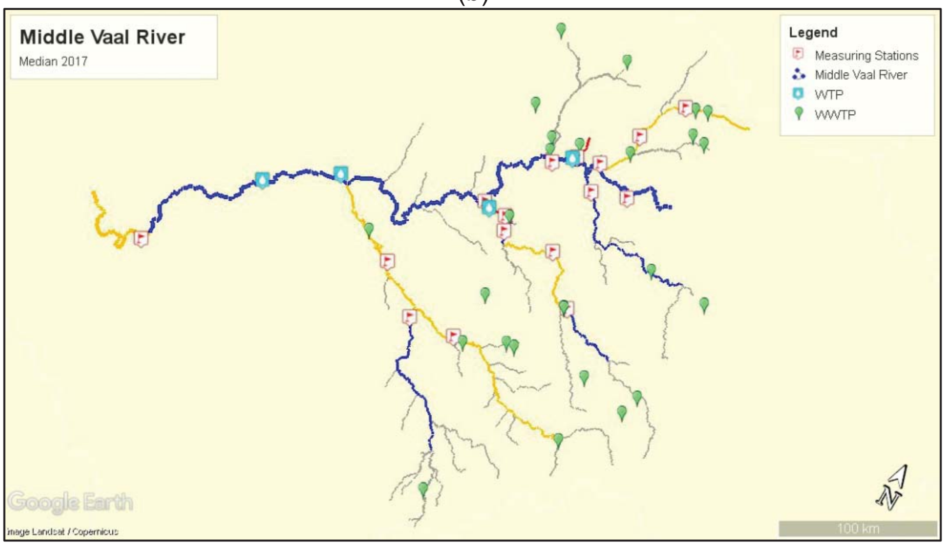
- **Wastewater Contributions in 2017**



(a)



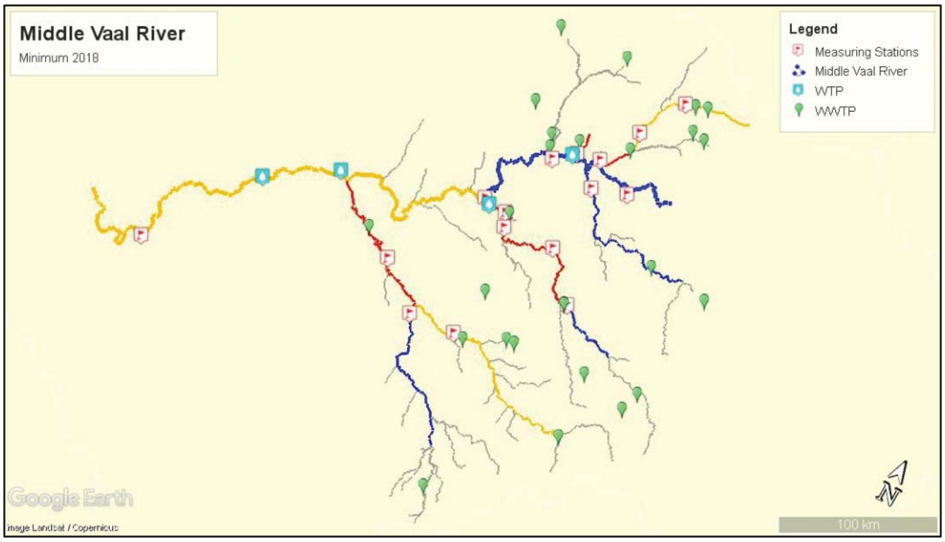
(b)



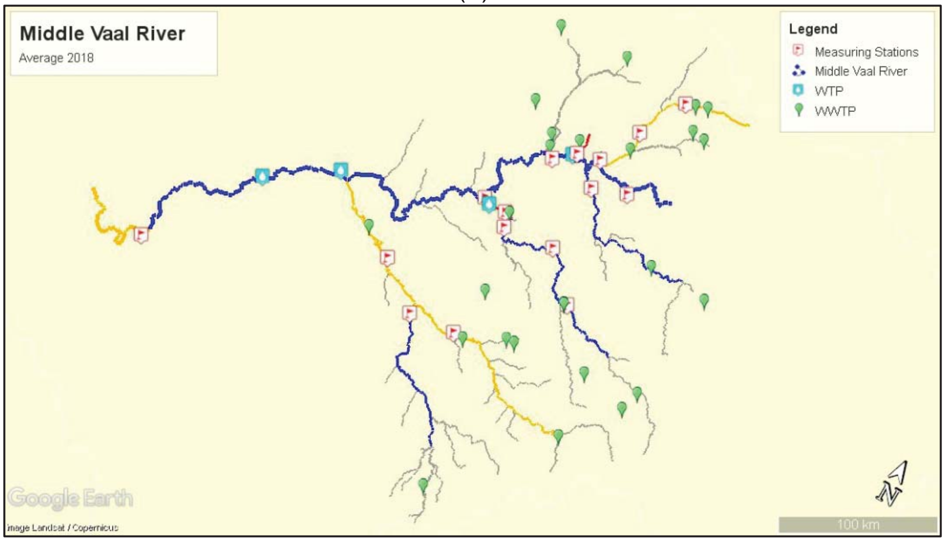
(c)

Figure K2.3: Wastewater contribution in the Middle Vaal River in 2017 during (a) minimum flow, (b) average flow and (c) median flow

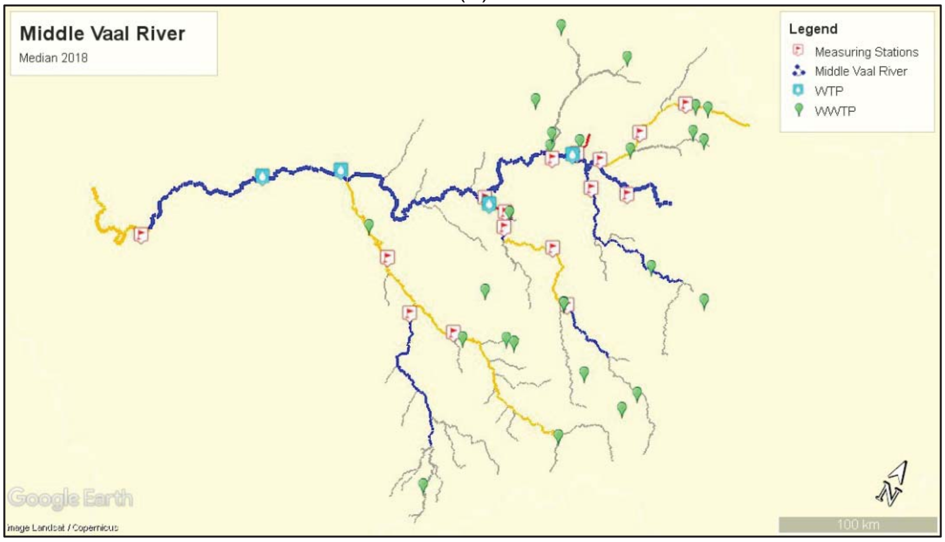
- **Wastewater Contributions in 2018**



(a)



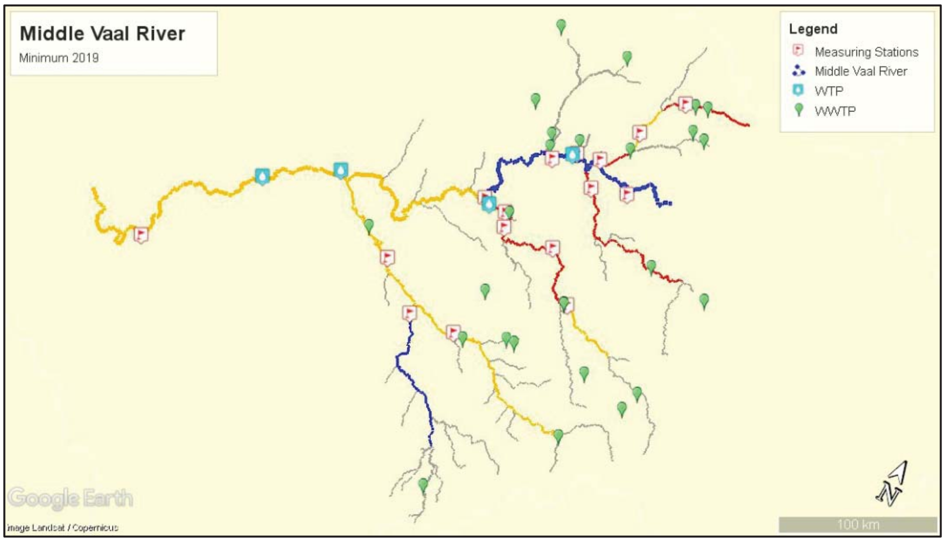
(b)



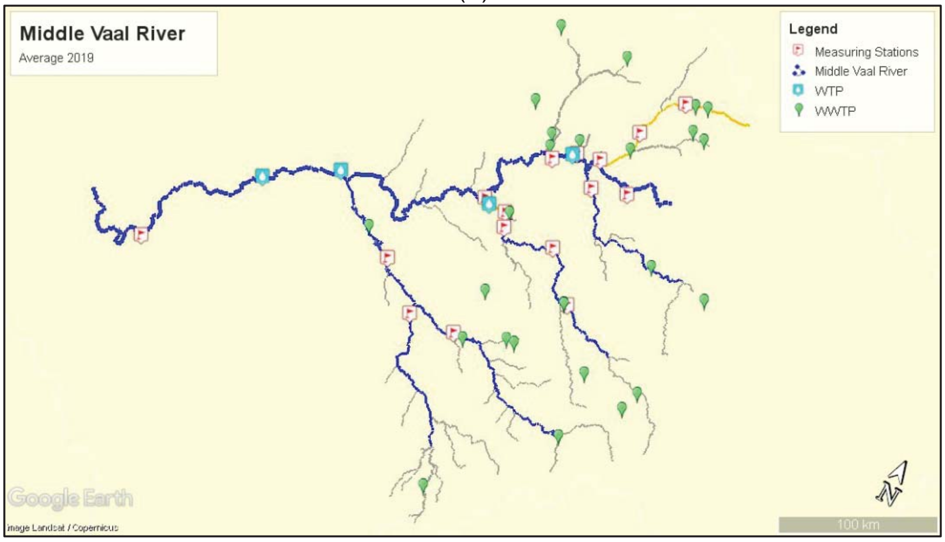
(c)

Figure K2.4: Wastewater contribution in the Middle Vaal River in 2018 during (a) minimum flow, (b) average flow and (c) median flow

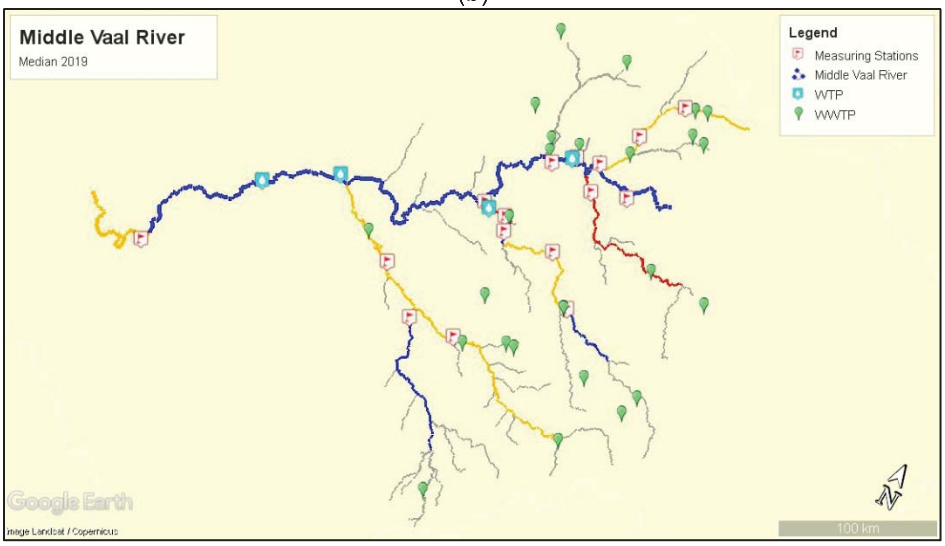
- **<u>Wastewater Contributions in 2019</u>**



(a)



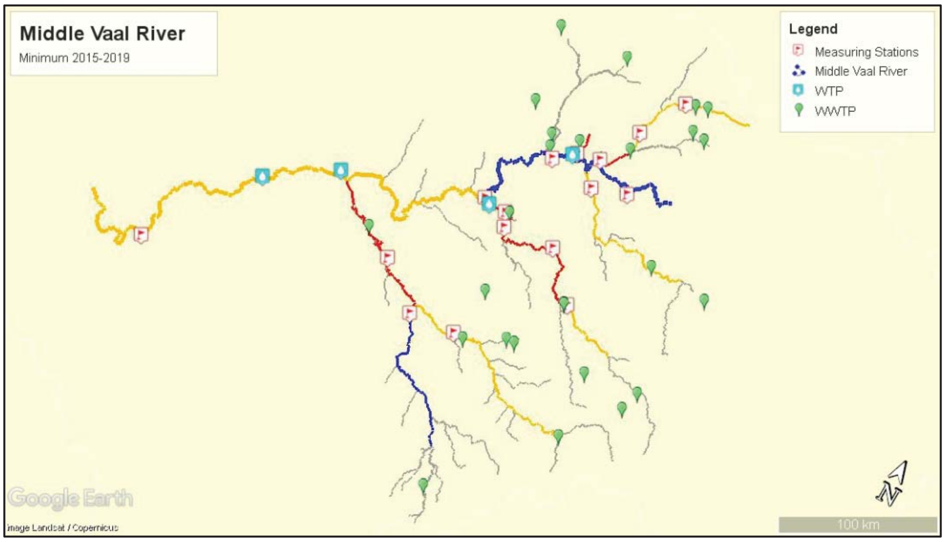
(b)



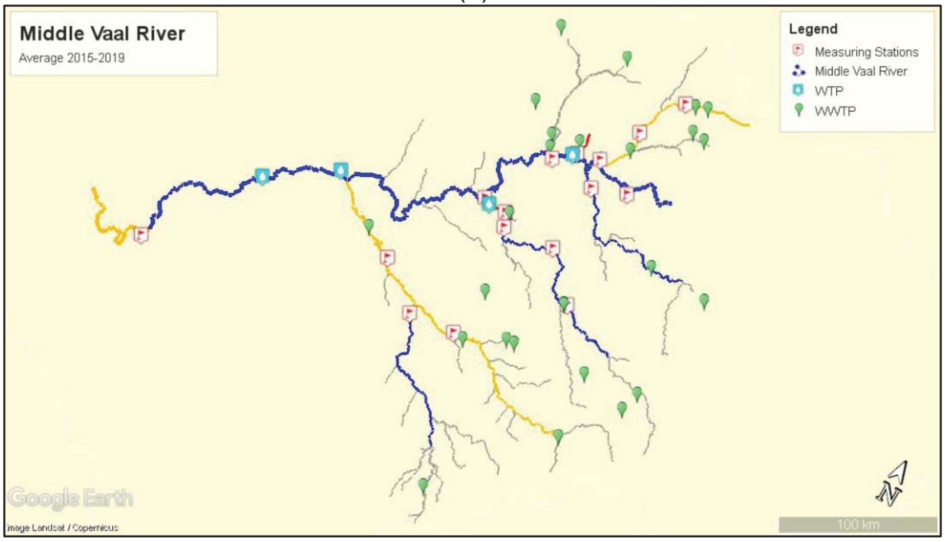
(c)

Figure K2.5: Wastewater contribution in the Middle Vaal River in 2019 during (a) minimum flow, (b) average flow and (c) median flow

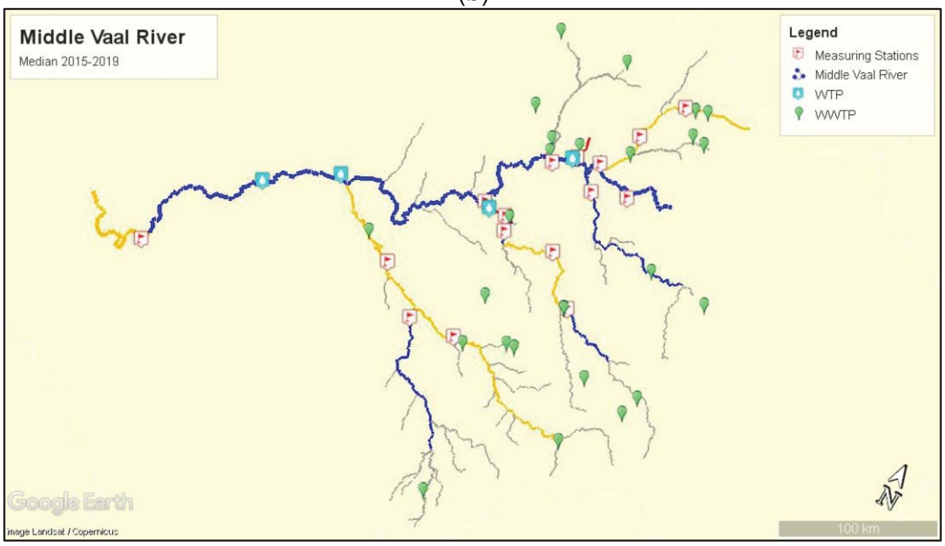
- **Wastewater Contributions in 2015-2019**



(a)



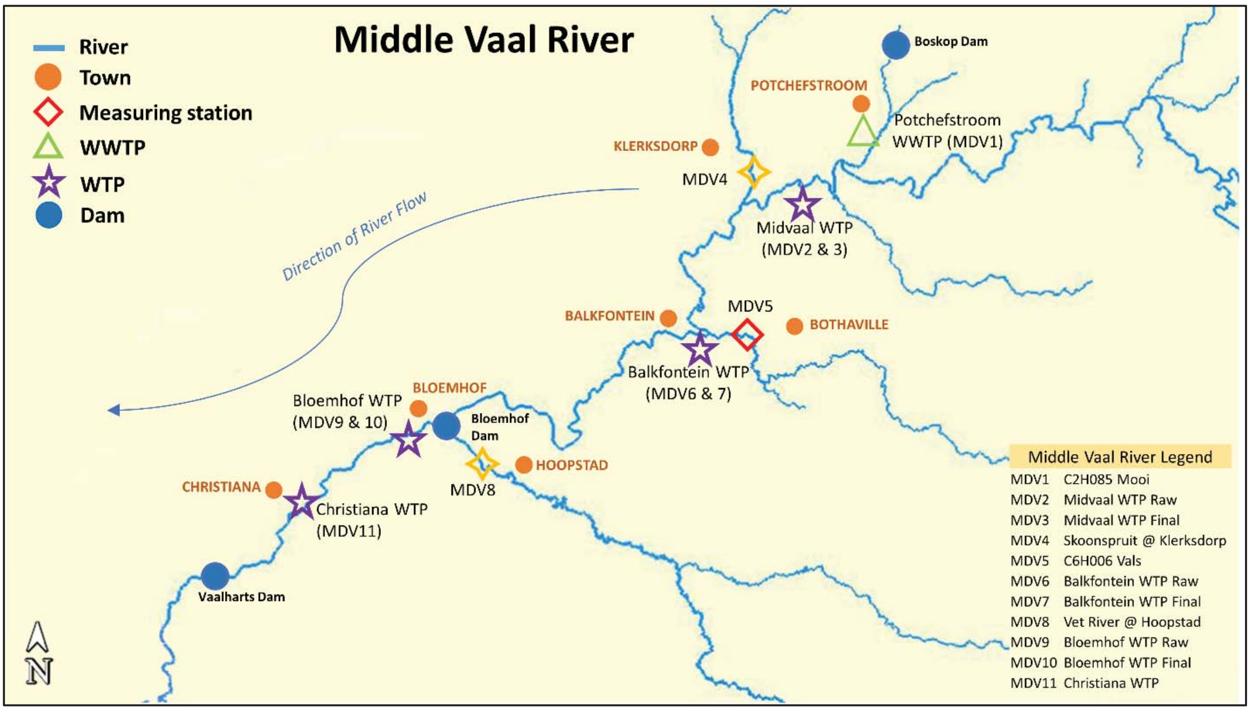
(b)



(c)

Figure K2.6: Wastewater contribution in the Middle Vaal River in 2015-2019 during (a) minimum flow, (b) average flow and (c) median flow

K3: Map of sampling points for CEC analysis in the Middle Vaal River



K4: CEC Concentration Results Legend for the Middle Vaal River

Middle Vaal River Legend	
MVR1	Potchefstroom WWTP
MVR2	Midvaal WTP Raw
MVR3	Midvaal WTP Final
MVR4	Schoonspruit @ Orkney
MVR5	C6H002 Vals @ Grootdraai
MVR6	Balkfontein WTP Raw
MVR7	Balkfontein WTP Final
MVR8	Vet River @ Hoopstad
MVR9	Bloemhof WTP Raw
MVR10	Bloemhof WTP Final
MVR11	Christiana WTP

K5: Results of the CEC analysis for the Middle Vaal River

Table K5.1: Results of the CEC analysis for the Middle Vaal River

Constituent	Sample Points										
	Potchefstroom WWTP	Midvaal WTP Raw	Midvaal WTP Final	Skoonspruit @ Orkney	C6H002 Vals @ Grootdraai	Balkfontein WTP Raw	Balkfontein WTP Final	Vet River @ Hoopstad	Bloemhof WTP Raw	Bloemhof WTP Final	Christiana WTP
	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)	Concentration (ng/L)
1,7-dimethylxanthine	792.9	35.55	<IQL	834.5	118	34.17	17.86	19.41	23.77	<IQL	16.72
Acetaminophen	<IQL	<MDL	<IQL	<IQL	381.8	<IQL	24.08	<IQL	<IQL	<MDL	<MDL
Atrazine	68.11	386.2	290.7	118.6	98.78	378.1	347.8	197.5	328.8	292	232.5
Benzotriazole	35.55	5.91	<MDL	28.55	<IQL	7.201	7.366	<MDL	6.37	4.465	6.286
Benzoylecgonine	2.257	<IQL	<IQL	7.499	<MDL	<IQL	<IQL	<MDL	<MDL	<MDL	<MDL
Caffeine	399.5	29	<MDL	1113	250.9	31.12	32.92	20.6	15.79	<IQL	25.58
Carbamazepine	355.3	27.22	<MDL	169.2	36.64	30.49	19.88	<IQL	33.92	29.03	39.58
Cetirizine	162.1	4.888	<IQL	38.48	2.752	3.87	<MDL	<IQL	2.729	<MDL	1.754
Cocaine	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Codeine	<IQL	<MDL	<MDL	<IQL	<MDL	<MDL	<MDL	91.8	<MDL	<MDL	<MDL
Diclofenac	301.8	<IQL	<IQL	110	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL	<IQL
Efavirenz	3329	338.3	226	1503	448.2	365.5	368.5	<IQL	<IQL	180.2	<IQL
Emtricitabine	6705	116	<MDL	3793	389.5	<IQL	<IQL	<IQL	<IQL	<MDL	24.88
MDMA	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Methamphetamine	27.38	5.249	<IQL	124.2	<IQL	3.734	<IQL	<MDL	<MDL	<MDL	<IQL
Methaqualone	209.5	56.66	25.89	190.6	40.97	83.06	77.14	5.807	68.19	62.2	73.33
Naproxen	392	<MDL	<MDL	277.4	<IQL	<MDL	<MDL	<MDL	<MDL	<MDL	<MDL
Sulfamethoxazole	1344	48.14	4.073	854.8	48.92	<IQL	12.21	<IQL	42.44	<MDL	<IQL
Tramadol	815	21.13	<IQL	442.8	27.67	23.93	<IQL	3.511	20.11	<MDL	12.5
Trimethoprim	104.2	<IQL	<MDL	118.4	<IQL	<MDL	<MDL	3.484	3.125	<MDL	3.203
Venlafaxine	114	<IQL	<IQL	11.89	<IQL	<IQL	<MDL	<MDL	<IQL	<MDL	<MDL

<IQL = Less than Instrument Quantification Limit

<MDL = Less than Method Detection Limit

K6: Bar charts of indicator compound results in the Middle Vaal River

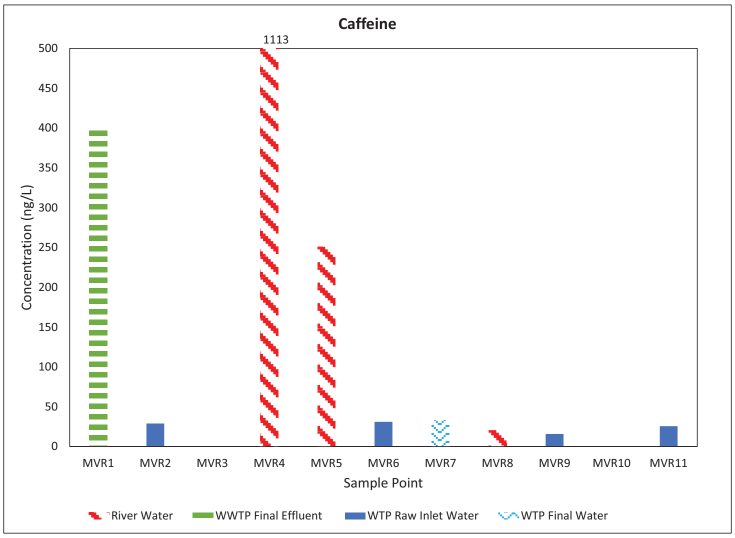


Figure K6.1: Concentrations of Caffeine in the Middle Vaal River

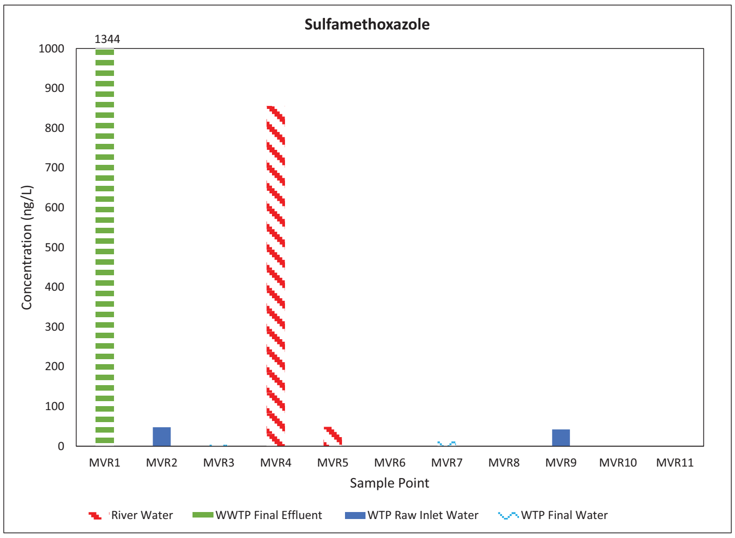


Figure K6.2: Concentrations of Sulfamethoxazole in the Middle Vaal River

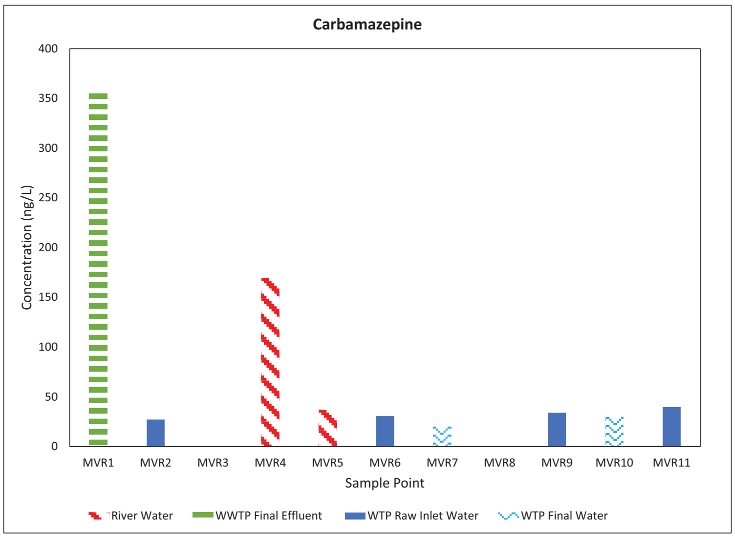


Figure K6.3: Concentrations of Carbamazepine in the Middle Vaal River

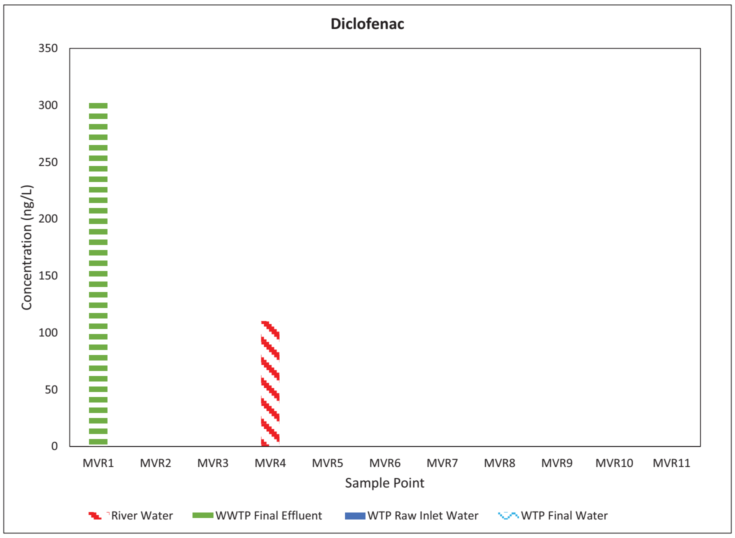


Figure K6.4: Concentrations of Diclofenac in the Middle Vaal River

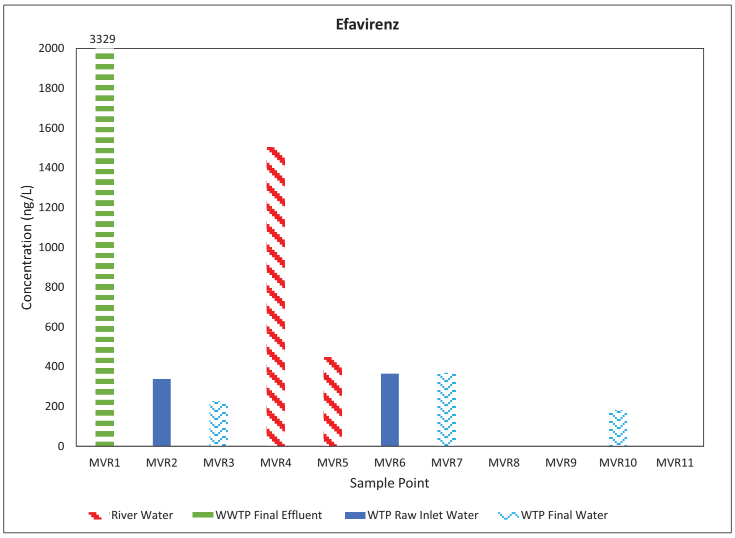


Figure K6.5: Concentrations of Efavirenz in the Middle Vaal River

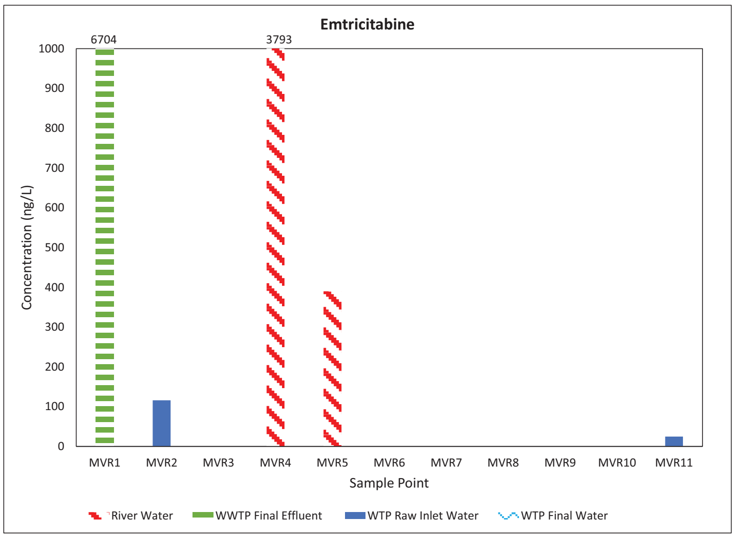


Figure K6.6: Concentrations of Emtricitabine in the Middle Vaal River

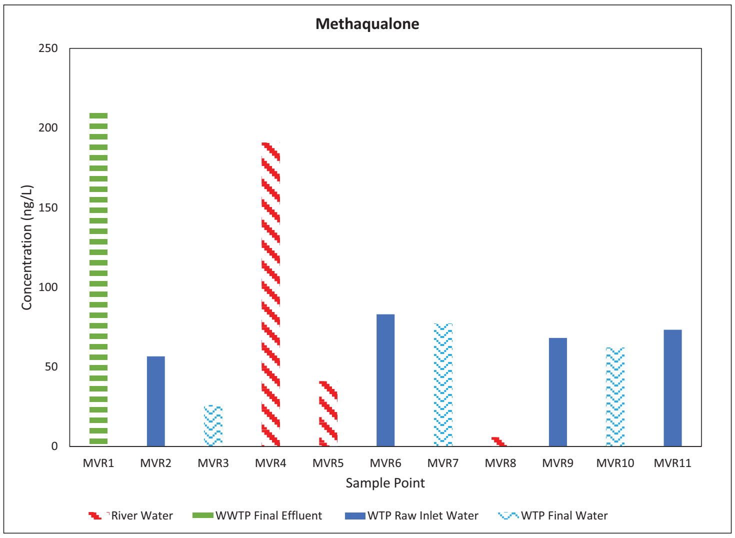


Figure K6.7: Concentrations of Methaqualone in the Middle Vaal River

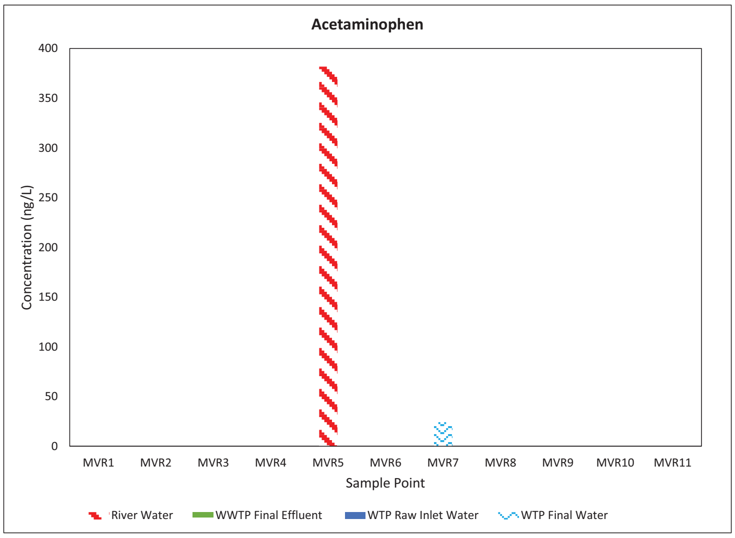


Figure K6.8: Concentrations of Acetaminophen in the Middle Vaal River

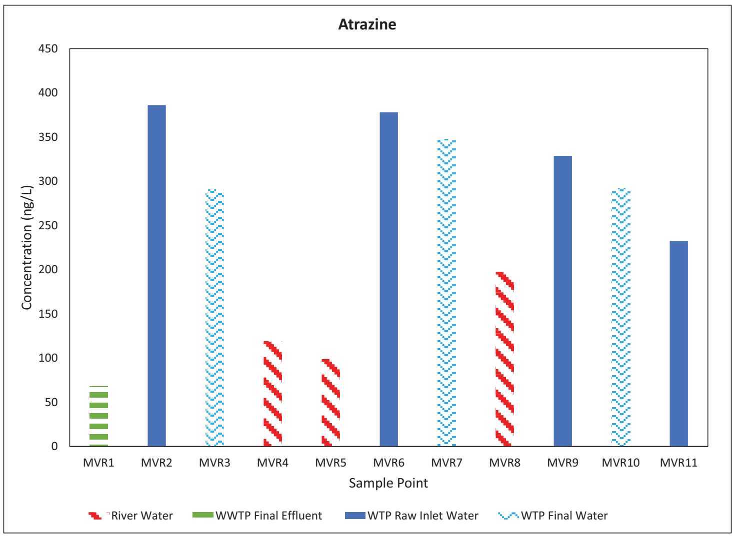


Figure K6.8: Concentrations of Atrazine in the Middle Vaal River

K7: Results of Other Water Quality Parameters for the Middle Vaal River

Sample Points	Sample Name	pH	EC	COD	UV 254	DOC	DO
		-	mS/m	mg/L	m^{-1}	mg/L	mg/L
Potchefstroom WWTP	MVR1	7.65	106	47	0.058	2.33	5.34
Midvaal WTP Raw	MVR2	7.90	-	47	0.057	2.32	8.08
Midvaal WTP Final	MVR3	7.37	-	47	0.011	1.67	8.24
Schoonspruit @ Orkney	MVR4	7.54	63	36	0.207	4.45	3.95
C6H002 Vals @ Grootdraai	MVR5	7.88	28	62	0.137	3.45	8.23
Balkfontein WTP Raw	MVR6	7.60	27	34	0.157	3.74	6.64
Balkfontein WTP Final	MVR7	7.18	30	41	0.044	2.13	7.98
Vet River @ Hoopstad	MVR8	7.63	47	58	0.136	3.44	8.81
Bloemhof WTP Raw	MVR9	7.56	38	117	0.095	2.86	7.94
Bloemhof WTP Final	MVR10	7.57	39	30	0.037	2.04	8.04
Christiana WTP	MVR11	7.40	53	49	0.105	3.00	7.21

APPENDIX L POTENTIAL INDICATOR COMPOUNDS INVESTIGATED FOR SUITABILITY OF INDICATING WASTEWATER CONTENT

Constituent	Class	Type	Trade Name	Description	Health Risk
Caffeine	Stimulant	Central Nervous System (CNS)	Caffeine	Caffeine works by stimulating the brain. It is used to restore mental alertness or wakefulness during fatigue or drowsiness.	Can lead to sleep disruption or anxiety and is also a risk during pregnancy. It can also produce a mild drug dependence
Sulfamethoxazole	Pharmaceutical	Antibiotic	Bactrim	A bacteriostatic antibacterial agent that interferes with folic acid synthesis in susceptible bacteria	Common side effects include nausea, vomiting, loss of appetite, and skin rashes.
Carbamazepine	Pharmaceutical	Anticonvulsant	Tegretol	Carbamazepine is an anticonvulsant drug and analgesic drug used to control seizures and to treat pain resulting from trigeminal neuralgia	Minimum to no health risks.
Diclofenac	Pharmaceutically Active Compound (PhAC)	Anti-Inflammatory	Voltaren	Diclofenac is a nonsteroidal anti-inflammatory drug used to treat pain and inflammatory diseases such as gout. It is taken by mouth or applied to the skin	Leads to an increased vascular and coronary risk, as well as upper gastrointestinal complications. It affects the heart, gastrointestinal, liver and kidneys, also mental health.

Constituent	Class	Type	Trade Name	Description	Health Risk
Efavirenz	Pharmaceutical	Antiretroviral (ARV)	Sustiva/Stocrin	Efavirenz is an antiviral medicine that prevents human immunodeficiency virus (HIV) from multiplying in your body	Adverse effects include disturbed sleep, dizziness, headaches, vertigo, blurred vision, anxiety, fatigue, confusion, memory and concentration problems and depression.
Emtricitabine	Pharmaceutical	Antiretroviral (ARV)	Emtrivia	Efavirenz is an antiviral medicine that prevents human immunodeficiency virus (HIV) from multiplying in your body	The compound is not toxic. But may result in mild to moderate events of diarrhea, headache, nausea and rash.
Methaqualone	Recreational Drug	Sedative-hypnotic drug	Mandrax/Quaaludes	Methaqualone is a synthetic, barbiturate-like, central nervous system depressant. The active ingredient, is an anxiolytic (lowers anxiety) and a sedative-hypnotic drug that leads to a state of drowsiness	High concentrations could end in nervous system shutdown, coma and death.
Acetaminophen	Pharmaceutical	Paracetamol	Tylenol	Acetaminophen is used to treat mild to moderate and pain, to treat moderate to severe pain in conjunction with opiates, or to reduce fever	Some toxicity in higher doses include liver damage, skin reactions, asthma, other factors, overdose, pregnancy complications and cancer.
10,11-dihydro-11-hydroxycarbamazepine	Pharmaceutical	Anticonvulsant/ Active metabolite of oxcarbazepine	Licarbazepine	Licarbazepine is a voltage-gated sodium channel blocker with anticonvulsant and mood-stabilizing effects that is related to oxcarbazepine.	

Constituent	Class	Type	Trade Name	Description	Health Risk
Benzotriazole	Heterocyclic compound	Anticorrosive and ultraviolet stabilizer	Benzotriazole	Benzotriazoles are a class of organic compounds that have been used as metal anticorrosive and ultraviolet stabilizer additives in a wide range of commercial and industrial applications. Some BZT compounds exhibit behaviours characteristic of persistent organic pollutants, and emerging evidence indicates long-term preservation and persistence in sediments.	Very low toxicity and a low health hazard to humans
Benzoylecgonine	Pharmaceutical	Cocaine metabolite	Benzoylecgonine	Benzoylecgonine can be found in medical products as a topical muscle relaxer, anaesthetic or to relieve muscle pain. It is also a metabolite that is created in the liver after drug use, in particular, the use of cocaine, making it the main compound tested for cocaine use during drug screenings.	Minimum to no health risks.

Constituent	Class	Type	Trade Name	Description	Health Risk
Carbamazepine-10,11-epoxide	Metabolite/Epoxide	Active metabolite of Carbamazepine	Carbamazepine-10,11-epoxide	Carbamazepine-10,11-epoxide is an epoxide and metabolite of carbamazepine. It has a role as a marine xenobiotic metabolite, a drug metabolite and an allergen. It is an epoxide, a member of ureas and a dibenzoazepine. It derives from a carbamazepine.	Carbamazepine-10,11-epoxide may be responsible for the congenital abnormalities that are sometimes associated with the use of carbamazepine during early pregnancy. There have been cases of severe seizures exacerbation when serum epoxide levels were increased.
Cocaine	Recreational Drug	Psychoactive stimulant drug	Cocaine/ "Crack"	Cocaine is a powerfully addictive, psychoactive, stimulant drug. On the street it is usually sold as a fine, white powder. The powdered, hydrochloride salt form can be snorted or dissolved in water and injected.	As a central nervous system stimulant, cocaine elevates vital life functions, such as blood pressure, body temperature, and heart rate.
Codeine	Pharmaceutical	Opioid Analgesic	Codeine	Codeine is classified as an opioid. Opioids are narcotics with a known potential for dependence. Codeine is administered in liquid or solid form (tablet/capsule), either alone or in combination with other active pharmaceutical ingredients. When used under the direction of a health professional, codeine-containing combination medicines are a relatively safe way to treat minor pain or	The most frequent side effects of codeine include: Light-headedness, Dizziness, Nausea, Vomiting, Shortness of breath, Sedation, Allergic reactions, Constipation, Abdominal pain, Rash, Itching Serious side effects of codeine include: Life-threatening respiratory depression, Severe low blood pressure, Adrenal insufficiency ,Accidental ingestion of codeine can result in fatal overdose

Constituent	Class	Type	Trade Name	Description	Health Risk
				suppress non-productive coughs.	
MDMA (3,4-methylenedioxy-methamphetamine)	Recreational Drug	Psychoactive drug	Ecstasy/Molly	MDMA is an illegal drug that acts as both a stimulant and psychedelic, producing an energizing effect, as well as distortions in time and perception and enhanced enjoyment from tactile experiences.	MDMA is an anti-diuretic, so it makes you retain water, which can increase risk of water intoxication. People may feel nausea with vomiting, confusion, severe fatigue, muscle weakness and cramps.

Constituent	Class	Type	Trade Name	Description	Health Risk
Methamphetamine	Recreational Drug	Central Nervous System (CNS)	Desoxyn / Meth / Crystal Meth	Methamphetamine is a powerful, highly addictive stimulant that affects the central nervous system. Also known as meth, blue, ice, and crystal, among many other terms, it takes the form of a white, odourless, bitter-tasting crystalline powder that easily dissolves in water or alcohol	Methamphetamine use can lead to a number of other health problems, including dependence, heart problems, and other physical and mental health issues.
Naproxen	Pharmaceutical	Nonsteroidal anti-inflammatory drug (NSAID	Naproxen	Naproxen is used to treat pain or inflammation caused by conditions such as arthritis, ankylosing spondylitis, tendinitis, bursitis, gout, or menstrual cramps.	Upset stomach, nausea, heartburn, headache, drowsiness, or dizziness.
Atrazine	Herbicide	Chlorotriazine herbicide	Atrazine	Atrazine is used for broadleaf weeds both before and after they sprout. It is also used on some grassy weeds	Human exposure to atrazine is linked to a number of serious health effects. A potent endocrine disrupter, atrazine interferes with hormonal activity of animals and humans at extremely low doses.
Cetirizine	Pharmaceutical	Antihistamine	Zyrtec	Cetirizine is an antihistamine that reduces the natural chemical histamine in the body.	One study has reported a more serious long-term effect, a 3.5-fold increase in the risk of gliomas, a common type of brain tumour in patients with long-term antihistamine use for allergic conditions.

Constituent	Class	Type	Trade Name	Description	Health Risk
Tramadol	Pharmaceutical	Opioid Analgesic	Tramadol	Tramadol is a centrally acting synthetic opioid analgesic and SNRI (serotonin/norepinephrine reuptake-inhibitor) that is structurally related to codeine and morphine.	Long-term use of tramadol could lead to the following: Altered brain chemistry to develop a tolerance, physical dependence, and cognitive decline. Other serious side effects may include fever, hives, blisters, rash, difficulty breathing/swallowing, hallucinations, agitation, lack of coordination and rapid heartbeat
Venlafaxine	Pharmaceutical	Antidepressant	Effexor	Venlafaxine (Effexor) is an antidepressant within the serotonin-norepinephrine reuptake inhibitor (SNRI) class of medications.	Venlafaxine oral tablet may cause drowsiness. It may also affect your ability to make decisions, think clearly, or react quickly. You should not drive, use heavy machinery, or do things that require you to be alert until you know you can function normally. Venlafaxine may also cause other side effects.