# DETECTION AND REMOVAL OF ILLEGAL DISCHARGES INTO STORMWATER SYSTEMS

*YAW OWUSU-ASANTE*

WATER RESEARCH COMMISSION

TT 808/19

# DETECTION AND REMOVAL OF ILLEGAL DISCHARGES INTO STORMWATER SYSTEMS

Report to the
**WATER RESEARCH COMMISSION**

by

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# EXECUTIVE SUMMARY

Today's urban sprawl and the emergence of aging and overburdened sewer and stormwater infrastructure in the urban areas have contributed to pollution in urban watercourses and ecosystem impairment. Interactions between aging wastewater and stormwater infrastructure systems and the natural water environment have also contributed to increased public health hazards including bacteria, pathogens and heavy metals in drinking water supplies and recreational waters. While much attention has been focused on stormwater pollution as a major contributor to current water quality problems, dry weather pollution also has a significant impact on water quality and ecosystem sustainability. A requirement to adequately prevent polluted non-storm water discharges into urban watercourses and environment is linked to the provisions of water use permits in the National Water Act and the National Environmental Management Act of South Africa. A comprehensive study to systematically detect and remove sources of illegal discharges into municipal stormwater drainage system has not been undertaken in South Africa to date. Thus, the aim of this study was to develop procedures and techniques for detecting and removing illegal discharges for local conditions and to provide guidance to municipalities whose task it is to control polluted non-storm water entries into the stormwater drainage system.

The study reviewed procedures, methodologies and techniques of illegal discharge detection and elimination program components as practiced internationally and applied these in a local case study to verify their feasibilities and challenges. A risk analysis and risk mapping procedure was developed and applied. The usefulness of illegal discharge potential risk map is recognised in the prioritisation of illegal discharge detection and elimination program components. By prioritising the program components and locations, municipalities should be in a better position to achieve higher cost-efficiency in their illegal discharge control efforts. A flowchart method was developed for Cape Town locality to determine if flows observed at outfalls (or anywhere in stormwater drainage system) would be an illegal discharge. The flowchart method is a primary tool to detect and isolate specific sources of illegal discharges. The findings of the report also support the notion that illegal discharges contribute significant pollutant loads to receiving watercourses in Cape Town and require an immediate attention from the municipality.

As population, urbanisation and industrialisation continue and pollution problems increase amidst climate change impacts on water availability, illegal discharges will move further into the spotlight of environmental, water and sanitation regulators. Enforcement and public awareness campaigns will be critical components of Local government's plans to affect changes in human behaviours and practices that lead to many illegal discharges. Local governments and national regulatory institutions need to appreciate the importance of illegal discharge detection and elimination program as a non-structural best

management practice (BMP) to meet resource water quality objectives and the requirements for ecosystem sustainability. Local governments should include in their stormwater management plan a control measure for an Illegal (illicit) Discharge Detection and Elimination (IDDE) program. A replicate research study in different municipalities across the country is recommended. More work is needed to better quantify the pollutant removal and costs associated with correction of illegal discharges, to evaluate the effectiveness of proactive prevention strategies (e.g. inspection of laterals) that rely on systematic inspections of the system rather than outfall monitoring and tracking and to develop improved strategies for tracking down and eliminating these discharges.

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| | |
|---|---|
| BMP | Best Management Practice |
| CoCT | City of Cape Town |
| COV | Coefficient of variation |
| DWS | Department of Water and Sanitation |
| ID | Illegal discharge |
| IDDE | Illegal (illicit) discharge detection and elimination |
| IDP | Illegal discharge potential |
| MS4 | Municipal separate storm sewer system |
| OI | Outfall inspection |
| ORI | Outfall reconnaissance investigation |
| SIC | Standard Industrial Classification |
| WWTW | Wastewater treatment works |

## GLOSSARY

**Catchment** – in relation to a watercourse or watercourses or part of a watercourse, means the area from which all rainfall will drain into the watercourse or watercourses or part of a watercourse, through surface flow to a common point or common points.

**Continuous (illegal) discharge** – Uninterrupted flow in a storm drainage system occurring in the absence of rain.

**Direct (illegal) discharge** – Dry-weather or non-stormwater sources which enter a storm drainage system directly, usually by direct piping connections between the wastewater conduit and the storm drain.

**Drainage area** – The area of land from which a stormwater drainage system collects precipitation and storm runoff and then delivers the resulting stormwater to a specific point.

**Dry-weather flow** – Flow in a stormwater drainage system occurring in the absence of storm flow. Also called **non-storm flow**.

**Illegal (or Illicit) discharge** – Any non-stormwater (dry-weather) flow entering storm drain, with some exceptions, including firefighting and those deemed an insignificant source of pollution to the local waterway. Also called inappropriate discharge.

**Inappropriate discharge** – See Illegal discharge

**Indicator** – In this study, an indicator is a distinct component, or combination of components ("fingerprint") of a polluting source which is identified in order to confirm the entry of the polluting source to a storm drainage system. Also referred to as a **tracer** or **parameter**.

**Indirect (illegal) discharge** – Dry-weather or non-stormwater sources which enter a storm drainage system indirectly, usually by floor, areaway and yard drains or inlets; and spills and illegal dumping.

**Industrial (illegal) discharge** – Any solid or liquid waste coming from industrial sources which enter storm drainage systems during periods of dry weather.

**Infiltration** – The process whereby water enters a drainage system underground through such means as defective pipes, pipe joints, connections, manhole walls, etc.

**Inflow** – The process whereby water enters a sanitary wastewater system from surface locations (e.g. through depressed manhole covers, yard and areaway inlets, roof leaders, etc.).

**Outfall** – In this study, an outfall refers to a point at which a stormwater drainage system discharges to a watercourse (or receiving water). There is sometimes a concrete structure or retaining wall at this location to protect the end of the discharge pipe and prevent erosion of the receiving water bank.

**Pathogen** – A disease-causing microorganism.

**Pollutant** – Any material in water or wastewater interfering with designated beneficial uses.

**Potable water** – Water that has been treated, or raw water that is naturally fit for drinking, i.e. the water has no harmful contents to make it unsuitable for human consumption.

**Sanitary sewer** – A sanitary wastewater drainage system intended to carry wastewaters from residences, commercial buildings, industrial plants and institutions together with minor quantities of groundwater, stormwater and surface water that are not admitted intentionally.

**Sanitary wastewater** – Wastewater of human origin. This includes sewage and septage (from septic tank system).

**Septic tank** – A tank which receives sanitary wastewater direct from its source (usually residential) and permits settling of the heavy solids and floatation of greases and fats along with anaerobic digestion.

**Sewage** – In this text, the term "sewage" refers to sanitary wastewater or wastewaters generated from residential, commercial, or industrial operations; it does not include stormwater.

**Sewer** – A pipe or conduit generally closed, but normally not flowing full, for carrying sanitary, industrial and commercial wastewater flows.

**Storm drain (stormwater drain)** – A pipe, or natural or man-made channel, or ditch, that is designed to carry only stormwater, surface runoff, street wash waters and drainage from source to the point of discharge.

**Storm(water) drainage discharge** – Flow from a storm(water) drain that is discharged to a watercourse or receiving water.

**Stormwater (storm water)** – Water resulting from precipitation which either infiltrates into the ground, impounds/puddles and/or runs freely from the surface, or is captured by storm drainage and to a limited degree, by sanitary sewer facilities.

**Surfactants** – Surface-active agents and common components in detergents which affect the surface tension of water and can cause foaming.

**Wet-weather flow** – Any flow resulting from rainfall which may introduce contaminants into storm drainage or sanitary sewerage systems.

# 1 INTRODUCTION

## 1.1 Background

Urban sprawl and the emergence of aging and overburdened sewer and stormwater infrastructure in the urban areas have undoubtedly, contributed to pollution in urban watercourses and ecosystem impairment. Studies by Gaffield et al. (2003) and Swann (2001) indicated that the interactions between aging wastewater and stormwater infrastructure systems and the natural water environment have contributed to increased public health hazards including bacteria, pathogens and heavy metals in drinking water supplies and recreational waters. While stormwater pollution is a major contributor to the current water quality problems, studies (such as Pitt and Rittenhouse, 2001; Brown et al., 2004; RHP, 2005; Baird, 2009; Nel et al., 2013; Chandler and Lerner, 2015) have shown that dry weather discharge pollution also has a significant impact on water quality and ecosystem sustainability. Through natural or anthropogenic pathways, dry weather discharges enter stormwater conveyance systems and they comprise a wide range of non-stormwater flows (Brown et al., 2004:i). Illegal discharges must of necessity be considered "unlawful" because stormwater drainage systems, in contrast with wastewater sewer systems, are not planned, designed and constructed to receive and/or discharge contaminated non-storm water. Photos of outfalls in Cape Town identified with illegal discharges are presented in Appendix A.

## 1.2 Basics of illegal discharges

Several non-stormwater or dry-weather discharges originate from illegal connections, illegal dumping, or spills, which are collectively termed as inappropriate or illegal discharges in this study. An inappropriate or illegal discharge is defined as any non-stormwater (dry-weather) flow entering the stormwater drainage system, with exceptions including firefighting and those considered an insignificant source of pollution to the local waterway (USEPA, 1999, 2010). They have characteristic frequency, composition and mode of entry; they often result from synergies of stormwater drainage and wastewater sewer systems and are produced from "generating sites" such as residential, commercial and industrial land-uses. Illegal discharges may be characterised based on four main attributes namely their; discharge frequency (as: continuous, intermittent or transitory), discharge flow type or composition (as: sewage and septage, washwater, industrial liquid waste, tap water, groundwater and spring water flows) and mode of entry (as: direct or indirect) into stormwater drainage system.  Details of different classifications of illegal discharges are reviewed in Table B3 in Appendix B2.

According to Brown et al. (2004), illegal discharges originate from many sources and they result from: illegal dumping practices, cracked sewer pipes, illegal cross-connections between sewer and drainage systems, connection of floor drains to stormwater drains, sanitary sewer overflows into storm drains, inflow/infiltration, straight pipe sewer discharge into open channels and streams, failing septic systems and pump station failure. Notable and serious sources include sanitary wastewater, industrial and commercial liquid waste discharges and vehicle repair operations (Pitt et al., 1993). Illegal or illicit connections are pipes which are improperly connected to the stormwater network and represent fixed locations where sewage, wash water, industrial wastes and other pollutants may enter the storm drain network. Illegal dumping occurs when a substance is improperly disposed of in a stormwater drain and is a common pathway for paint, spent motor vehicle fluids and similar wastes. Spills occur when a discharge reaches the stormwater drainage network unintentionally, often during vehicular accidents, or because of poor pollution management at a business or construction site. Unlike illicit connections, illegal dumping and spills are often intermittent or one-time occurrences and are not constrained to a geographic location, although entities that dump materials are more likely to repeat the offense. A high number of illegal discharge occur independent of precipitation events; therefore, illegal discharges are normally detected by inspecting stormwater infrastructure for dry weather flows. Illegal discharges generally include, but are not limited to the following (City of Camas, 2016:5)

- Acids, alkalis, or bases
- Animal carcasses
- Antifreeze and other automotive products
- Bark and other fibrous materials
- Batteries
- Chemicals not normally found in uncontaminated water
- Chlorine, bromine, or other disinfectants
- Construction materials
- Degreasers and/or solvents
- Domestic animal wastes
- Drain cleaners
- Dyes
- Flammable or explosive materials
- Food wastes
- Heated water
- Lawn clippings, leaves, or branches
- Litter (trash or any other solid waste)
- Metals in either particulate or dissolved form
- Paints, stains, resins, lacquers, or varnishes
- Pesticides, herbicides, or fertilizers
- Petroleum products, including but not limited to, oil, gasoline, grease, fuel oil and heating oil

- Radioactive material
- Recreational vehicle waste
- Sewage
- Silt, sediment, concrete, cement or gravel
- Soaps, detergents, or ammonia
- Steam cleaning wastes
- Swimming pool or spa filter backwash
- Any other process-associated discharge except as otherwise allowed by the State law
- Any hazardous material or waste not listed above

## 1.3 Problem statement

Provisions of the National Water Act (South Africa, 1998) require water use permits or licenses for polluted non-storm discharges to watercourses. A requirement to adequately prevent polluted non-storm discharges into the stormwater drainage systems is linked to the provisions of water use license in the Act. It would suggest therefore that emphasis should be focused on the control of illegal connections and discharges to municipal stormwater drainage systems. This would require concerned municipalities to detect sources of illegal discharges into the stormwater drainage system so they may implement corrective measures to eliminate them. Selected evidence of dry-weather (or non-storm) discharge in the City of Cape Town is presented in Figures A1 to A5 in Appendix A. Improvement in urban waterways conditions would be insignificant if limited or no attention is paid to these dry-weather loadings (and only wet-weather or stormwater loadings are considered). Eliminating illegal discharges is an essential element in the restoration of urban sub-catchments. Brown et al. (2004:15-16) affirm that

> *When bodies of water cannot meet designated uses for drinking water, fishing, or recreation, tourism and waterfront home values may fall; fishing can be restricted or halted; and illegal discharges can close beaches, primarily as a result of bacterial contamination. In addition to the public health and economic impacts associated with illegal discharges, significant impacts to aquatic life and wildlife are realised. Numerous fish kills and other aquatic life losses have occurred in sub-catchments as a result of illegal or accidental dumping and spills that have resulted in lethal pollutant concentrations in receiving waters*.

Guidance manual for illicit discharge detection and elimination program has been developed by Brown et al. (2004) based on extensive research in North America, particularly in the United States. However, blindly adopting Brown et al.'s (2004) work to local conditions will be inappropriate considering the wide differences that exist between the two geographical locations in terms of spatial planning, level of developments, level of institutional arrangements and coordination, socio-economic challenges, level of service provision and management, climatic and other factors. As with all guidance manuals, some procedures and methodologies may be generic and applicable to many situations; while some would require analysis of local information to be applicable to a particular area. A comprehensive study to systematically detect sources and control illegal discharges into municipal storm drainage system has not been undertaken in South Africa to improve water quality in urban watercourses. As this study sought to review and outline procedures for detecting and removing illegal discharges for local conditions, the research questions are stated as follows:

a) What are the procedures to identify and prioritise target areas in urban sub-catchment having illegal discharge potential?

b) What are the optimum techniques to track, detect and remove sources of illegal discharges?

c) What are the tools to guide municipalities to detect and reduce illegal discharges into stormwater drainage system?

## 1.4 Study objectives

The aim of the project is to outline procedures that are technically feasible and cost-effective to detect and remove illegal discharges in local conditions. The specific objectives are as follows:

a) Develop new procedures for identifying priority areas in urban sub-catchment with a low, medium and high risk of illegal discharges.

b) Outline methodologies and techniques for identification, detection, monitoring and removal of illegal discharges.

c) Collate information to guide municipalities to detect and remove illegal discharge entries into stormwater drainage systems.

## 1.5 Organisation of the report

This report contains seven main chapters and is supported by appendices materials, as appropriate:

Chapter 1: Introduction – Presents the fundamentals of illegal discharges, defines the problem statement and study objectives.

Chapter 2: Literature review – Reviews local and international perspectives on illegal discharge detection and the elimination program. Supplementary reviews are provided in Appendix B.

Chapter 3: Risk mapping to locate priority areas – The chapter seeks to develop procedures for identifying priority areas in an urban catchment with illegal discharges. It accomplishes this by outlining effective risk analysis and risk mapping procedures to prioritise catchments into low, medium and high-risk areas. These procedures are supported by results from two case study catchments in the City of Cape Town metropolitan area.

Chapter 4: Outfall illegal discharge detection and indicator monitoring – The chapter describes the methodology and techniques; such as complaint hotline, outfall inspections and flow types monitoring; to detect or identify illegal discharges. The methodologies and techniques are applied in the case study catchments and the results are presented and discussed.

Chapter 5: Tracking illegal discharge to a source – The chapter outlines the methodology and techniques; such as drainage area investigations, storm drain investigations and on-site investigations; to track illegal discharges to their sources. The methodologies and techniques are applied in one of the case study catchments and the results are presented and discussed.

Chapter 6: Corrective measures to remove illegal discharges – The chapter presents review of some corrective measures including; education and enforcement, public education and other methods such rehabilitation of storm drain and sanitary sewers.

Chapter 7: Conclusions and recommendation – Salient findings from the project are concluded and recommendations to municipalities and future research are provided.

# 2 LITERATURE REVIEW

The purpose of the review, as it were, was to consolidate previous work done in the subject area nationally and globally to come up with a state of knowledge report that provides information such as the extent, achievements, gaps, issues and current norms of illegal discharge detection and removal upon which present and future needs will be assessed and addressed in South African context. International literature indicates that components of an IDDE program principally involves in sequence: (1) establishing regulatory framework, (2) prioritising illegal discharge potential areas and (3) field operations consisting of outfall screening, water quality monitoring, public complaints, drainage area and storm drain investigations and corrective actions. It is along this sequence that this chapter is presented for both international and local reviews. The chapter ends with a summary that provides a basis for this research study.

## 2.1 International perspective of IDDE

There exist various international imperatives that assist with urban pollution control of the receiving environment. The UN development agenda, "Transforming Our World: The 2030 Agenda for Sustainable Development" describes 17 Sustainable Development Goals (SDG) to be achieved by 2030, including one explicitly directed to water and sanitation (SDG 6) to *"ensure availability and sustainable management of water and sanitation for all"*. Goal 6, Target 3 of the SDG aims to

> *improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. Goal 6, Target 6 of the SDG aims to protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes* (UN, 2015:22-23).

In North America and in recognition of negative impacts that polluted non-storm water have on receiving waters and environment, USEPA mandates municipalities

> *to develop, implement and enforce an illicit discharge detection and elimination (IDDE) program, which is one of six minimum control measures required under the stormwater management program. The IDDE program must include the following: (1) A storm sewer system map, showing the location of all outfalls and the names and location of all waters of the United States that receive discharges from those outfalls; (2) Through an ordinance, or other regulatory mechanism, a prohibition (to the extent allowable under State, Tribal, or local law) on illicit*

*discharges into the municipal separate storm sewer system (MS4), and appropriate enforcement procedures and actions; (3) A plan to detect and address illicit discharges, including illegal dumping, into the MS4; (4) The education of public employees, businesses, and the general public about the hazards associated with illicit discharges and improper disposal of waste; and (5) The determination of appropriate best management practices (BMPs) and measurable goals for this minimum control measure* (USEPA, 2000:2).

The preceding regulatory framework requirements are the central support and machinery driving illegal discharge detection and elimination initiatives and it is no surprise that much research, enforcement and implementation of the program have been undertaken in North America. A survey was conducted by Zielinski and Brown (2003) over 24 municipalities representing various geographical areas in the US that have implemented illicit discharge detection and elimination programs. The purpose of the survey was to determine the status quo of practices employed by municipalities for illicit discharge detection and elimination. Reporting on legal authority, the survey (Zielinski and Brown (2003:38) finding was that about *96%* of the jurisdictions surveyed have regulations prohibiting illegal discharges into storm drains that include:

*a) A stormwater ordinance that addresses illicit discharges to the storm sewer system or receiving waters;*
*b) A plumbing code that addresses illicit connections to the storm sewer system; or*
c) *A health code that regulates the discharge of harmful substances to the storm sewer system or receiving waters*.

The survey also found that usually compliance was not difficult to achieve because of established legal authority in-place to inspect private and corporate properties; and also the owners are usually cooperative with inspectors of illicit discharges (Zielinski and Brown, 2003:43). A mapping and evaluation methodology has been used to find areas to investigate and to provide a basis to prioritise the areas by their potential to contribute illegal discharges into the storm drainage system (Pitt and Rittenhouse, 2001). In the survey of Zielinski and Brown (2003), many communities used sub-catchment data to prioritise outfalls and other sites for inspections or dye-testing.

Mapping and risk analysis methods have been reviewed in several publications (Brown et al., 2004; Pitt and Rittenhouse, 2001; Tuomari et al., 1995; Johnson and Tuomari, 1998; Versar Inc., 2014; Lilly, 2015). The risk factor datasets used in some of these publications are illustrated in Table B4 in Appendix B3. A typical example is illustrated in Brown et al. (2004) and it is usually undertaken in a stakeholder workshop. The limitation of this type of risk analysis based on professional judgement is that it can affect or bias the outcome. Further, the accuracy of these judgements and their effects on the outcome of the analysis are not assessed. Nel et al. (2013) undertook a similar risk analysis in a water pollution study in Cape Town and indicated the following limitations: (1) workshop was time-consuming and (2) agreeing on points allocated for each prioritisation criteria was an obstacle. Hence, a quest for an 'improved' risk analysis method that examines the consequences of various land, hydraulic, hydrological and environmental risk factors on the location or occurrence of illegal discharge is required and the determination of uncertainty surrounding the quality or accuracy of these factors is essential.

Bender (2016) improved on the current method of risk analysis and risk mapping by performing the analysis in ArcGIS environment to transform spatial and non-spatial datasets into spatial layers to account for the spatial variability of the datasets. The shortcoming of 'professional judgment' mentioned above was overcome in Bender (2016) through the use of standard classification methods (Jenks Natural Breaks algorithm) in ArcGIS to define the thresholds of low, medium and high-risk classifications. The shortcoming in Bender (2016) was the re-introduction of 'professional judgement' methodology to assign weights to the risk factors in the production of composite maps (by combining all the risk factors into one composite map). In the end, however, we visualise that the processes of risk analysis and risk mapping provide a means to assign priority levels to geographic areas more likely to exhibit illegal discharge problems, which allows for a more cost-efficient approach.

Field detective methods seek to characterise discharges and isolate sources. One of the most widely used and well-known field methodologies is the Outfall Reconnaissance Inventory (ORI), also known as 'dry-weather screening' or 'outfall screening'. The ORI generally consists of visual observations of outfall structures combined with analysis of dry weather flow, if present, for water chemistry parameters. The ORI is often complemented with further rigorous indicator monitoring procedures to check suspect outfalls. The ORI program was standardised by Brown et al. (2004) and has been the subject of multiple studies (Christian et al., 2004; Irvine et al., 2011; Zielinski and Brown, 2003; Lilly, 2015) comparing the effectiveness of methods involved in IDDE program.

For an overall perspective of field detective methods, three reviews have been identified in the literature. Brown et al. (2004) has found wider applications especially in North America, but does not cover recent methods, e.g. the distributed temperature sensing (Hoes et al., 2009). A subsequent improvement by Irvine et al. (2011) concentrated on low-cost approaches to advance economical and vigorous procedures for IDDE program principally for municipalities with limited resources. A more recent and comprehensive review by Panasiuk et al. (2015) incorporates up-to-date and new indicators for monitoring methods, including caffeine and carbamazepine. Ibid also affirm that to detect illegal discharge into storm drain effectively and accurately, it is important to use suitable monitoring and analytical methods and techniques for relevant indicator parameters. Panasiuk et al. (2015:242) reported that:

> *several studies have been undertaken to date that focused on single parameters, e.g. temperature, (e.g. Hoes et al., 2009; Lega and Napoli, 2010; Hoppe et al., 2011; Langeveld et al., 2012), single groups of parameters, e.g. microbiological indicators (e.g. Jagals and Grabow, 1996; Scott et al., 2002; Selvakumar and Borst, 2006; Mushi et al., 2010), and combinations of several groups, e.g. indicator bacteria and nutrients (e.g. Sankararamakrishnan and Guo, 2005; Peeler et al., 2006; Sauve et al., 2012)*.

Panasiuk et al. (2015) reviewed methods and indicator parameters used for identifying illegal discharges as summarised in Table B5 in Appendix B4. Information presented in Table B5 suggests that caffeine and carbamazepine are indicators for illegal discharges. DNA fingerprinting and sorbitol-fermenting bifidobacteria have also shown greater potential in the area of indicator microorganisms. Brown et al. (2004:F-8) have, however, indicated that chemical indicators such as caffeine, carbamazepine and microbiological indicators (including antibiotic resistance, carbon utilisation profiling, bacteriophage methods, sorbitol-fermenting bifidobacteria and DNA fingerprinting) "require sophisticated equipment and specific expertise that limit their utility as a general indicator, given the high sampling cost and long turn-around times needed. To date, field tests of these 'research indicators' have yielded mixed results and they are currently thought to be more appropriate for special research projects than for routine outfall testing". Future research studies may advance their usefulness in routine field applications. An integrated approach of detecting sources of illegal discharges and applying corrective and preventive measures has considerable merit. Brown et al. (2004:173-176) and Pitt et al. (1993:143-148) discuss several corrective actions to eliminate and prevent illegal discharges including the following: a) Infrastructure modification, repair and disconnections b) Public education and c) zoning and ordinances.

## 2.2 South African perspective of IDDE

The subject of illegal discharge detection and elimination is very immature among the research community in South Africa, in fact, in the developing world. Related subject area such as pollution assessment and control in urban areas, river and catchment pollution investigations and a host of similar studies are, however, well-studied locally in the research domain. Nevertheless, one can perceive a common trend between IDDE programs as practiced internationally and their surrogate studies in South Africa; i.e. they are all supported and given effect by a regulatory framework; there are desktop and field methods to assess pollution sources and their impacts and there are preventive and remedial actions to control pollution. What seems lacking in the South African context is a tool to systematically isolate or track down the sources of illegal discharges and eliminate them. Illegal discharges are the main causes of poor water quality of South African streams and rivers and are mainly illegal dumping of solid and liquid waste by domestic, commercial and industrial users. By far, the most comprehensive research works on illegal discharge is on litter into storm drains, by Armitage et al. (1998) and Marais and Armitage (2003). Illegal discharges are further exacerbated by the lack of infrastructure, including solid waste disposal facilities especially in informal settlements. The paths of the waste streams are often merged in these settlements and sewage, sullage, solid waste and runoff chronically enter stormwater drainage system that goes untreated to urban watercourses.

On national, provincial and local government levels, there are various legislative and policy frameworks that assist with urban pollution control. Some of these are outlined below. The right to a cleaner environment conducive to good human health and wellbeing for present and future generations are enshrined in Section 24 of the Constitution of the Republic of South Africa. Prohibition against water pollution is addressed in Section 19 of the National Water Act, Act 36 of 1998 (South Africa, 1998a). Regulation on use of water is similarly addressed in Section 151 (1) (i) and (j) of the Act. According to this Section, *"it is an offence to unlawfully and intentionally or negligently commit any act or omission which pollutes or is likely to pollute a water resource; or which detrimentally affects or is likely to affect a water resource"*. For control of illegal discharge, the Act "requires that reasonable measures must be taken to prevent any substance other than storm water to enter any storm water drain and any watercourse, except in accordance with the Act". On conditions for issue of general authorisations and licenses, Section 29(1) of the Act authorises conditions to be attached to every water use general authorisation or license and in relation to water management ((b)(i)), by *"specifying the management practices and general requirements for any water use…"* and in the case of controlled activity ((d)(ii)) by "*specifying the management practices to be followed to prevent pollution of any water resource"*. With regards to illegal discharges into stormwater systems, implementing these Sections of the Act would require municipalities to develop, implement and enforce IDDE program, based on adaptive management principles to prevent and reduce pollution to urban watercourses. Prohibition against pollution is further outlined in section 28(1) of the National Environmental Management Act (NEMA), Act 107 of 1998 (South Africa, 1998b) as well as sections 16(1) and 26(1) of National Environmental Management: Waste Act (NEM: WA), Act 59 of 2008 (South Africa, 2008):

The major metros in South Africa have by-laws that assist in the prevention of an illegal discharge of non-compliant water and other materials from any property into the stormwater systems. In Cape Town, the by-laws for Stormwater Management (CoCT, 2005), Integrated Waste Management (CoCT, 2009), Wastewater and industrial effluent

(CoCT, 2006) are examples and they make provision for appropriate penalties and convictions. The City of Johannesburg Stormwater Management by-law (CoJ, 2010) also prohibits illegal discharges and connections to stormwater system. Unfortunately, national and local governments are unable to effectively enforce their by-laws and regulations. This is principally due to the concept of cooperative governance prescribed by the constitution of South Africa. According to this concept, the national and local governments are required to function as a single, unified system, collaborating rather than competing. In addition, these spheres of governments are required to cooperate with each other in mutual trust and good faith through fostering friendly relations, ensuring communication and coordination and avoiding taking their disputes to court. It is with the latter that Department of Water and Sanitation is unable to litigate against local governments when they fail to comply with waste discharge requirements. And because DWS is unable to act in this manner, municipalities are taking advantage and slumbering while their waste discharges go unchecked. It has become known that municipalities are the biggest polluters to watercourses. Because of this, national and local governments are unable to take action against private and corporate entities for non-compliance of similar offences.

Determining potential severity of pollution within a settlement and identify areas that merit priority investigation is well-documented in a study by the Department of Water Affairs and Forestry (DWAF, 1999a; DWAF, 1999b; DWAF, 2001a; DWAF, 2001b; DWAF, 2001c) – now the Department of Water and Sanitation (DWS). These studies developed a strategy to manage the water quality effects of settlements and formulated a “structured-facilitated process” as a guide to prioritise for methods or interventions to manage pollution principally from informal settlements. Risk analysis has also been employed locally in water pollution studies to prioritise and recommend catchments for management actions. Similar to the methodology used internationally, the analysis is based on expert knowledge. Nel et al. (2013) study is a notable example and the limitations are discussed under section 2.1. Field methods to track down sources of pollution in South Africa have been used on ad hoc basis (i.e. as reactive measures) by many municipalities to deal with specific pollution incidents; these methods include dye and smoke testing. Monitoring is another field method commonly used in South Africa, but only to detect occurrence of pollution and not to track down the source of illegal discharges. A similar risk assessment study in Klip River catchment in Gauteng was undertaken by Wepener et al. (2015). In both studies as with all others locally, no attempt was made to systematically isolate or track down the sources of pollution for corrective actions to be taken. A multitude of monitoring indicators is used in South Africa depending on the objectives of each case study.

The City of Cape Town undertakes other programs besides field detection and facility inspections, including education and training for staff and the public, door to door project (reactive measure to pollution), as well as hotline or online reporting systems through which complaints or reports of pollution incidents can be logged for follow-up action by authorities (Adams, 2016). Incidents which are commonly reported, in the City of Cape Town for example, include, but are not limited to: blocked and overflowing sewer, pollution to stormwater and river, illegal use of water, damaged or vandalized communal taps or toilets in informal settlements. This reactive approach involving a combination of field and programmatic methods in dealing with pollution is common in the major metros in South Africa and it is a good strategy to control illegal discharges.

The City of Cape Town employs corrective actions such as infrastructure modifications, repairs, disconnections, blockage removals, public education or outreach programs and in few instances enforcement of City's ordinances (Adams, 2016; Nel, 2016). Department of Water and Sanitation (DWS) initiated adopt-a-river programme to create an awareness of the importance of protecting and managing freshwater resources within an integrated natural resources management framework. Methods used to deal with illegal discharges (solid wastes) under this programme are often a 'reactive approach' type to control the impacts after pollution has occurred. Such discharges are dealt with using various methods including site inspection, clean-ups and education or awareness campaigns to sensitise the public about solid wastes and their impacts (Buwa, 2015 and 2016).

Introducing the concept of Water Sensitive Urban Design (WSUD) in South African context, Armitage et al. (2014) identifies a range of activities under the umbrella of WSUD, with two main components (i) urban water infrastructure and (ii) design and planning. One of the activities under the component of urban water infrastructure is sanitation/wastewater minimisation which has to be considered and managed concurrently with other activities to maintain water quality improvement and ecosystem sustainability. Illegal discharges are by definition wastewaters that are wrongfully discharged into stormwater drainage systems and cause pollution to urban watercourses. To control such pollution and as a precursor to the implementation of WSUD, a priority project that tracks and identifies sources of this pollution to stormwater drains and urban other watercourses is essential. There is no doubt that successful achievement of a 'water sensitive city' anywhere is contingent on water quality and the extent of its fitness for use. It can be perceived how illegal discharge detection and elimination program could articulate to the WSUD concept.

## 2.3 Summary of Literature Review

Taylor and Wong (2002) contend that the task of embarking on illegal discharge detection and elimination program is often offset by challenges which may include the following:

- IDDE programs tend to be labour-intensive and require a sizable budget to undertake the program.
- Willingness and ability of municipality to fund and carry out the program (due to lack of capacity) are not always favourable.
- Access to private and business property for inspection are often difficult. A legal authority that warrants right of entry is critical in tracing sources of illegal discharges.
- Illegal discharges to groundwater in sub-catchments with high permeable soils are more difficult to identify than discharges into impermeable sub-catchments and drainage network
- Likewise, for sub-catchments wherein the storm drain network is not continuous (i.e. where stormwater infiltration controls are practiced), illegal discharges may rapidly infiltrate to groundwater system and be difficult to detect through normal inspection methods.

Even when the above challenges are absent, detecting illegal discharge and tracking its source into stormwater drainage systems can be an arduous undertaking, unless it is addressed using suitable procedures and techniques. Review of international literature has revealed that an effective IDDE program is founded on one basic principle, namely an IDDE program ought to progress along a hierarchy of locations and procedures: from higher to lower potential risk areas in a catchment; from using desktop assessment (risk mapping) through exploratory outfall inspections to confirmatory source tracking methods. It is on this basic principle that South African approach to IDDE has not yet conformed wholly. Alignment to this principle will not only streamline and formalise the procedures involve in IDDE, but will establish a uniform baseline upon which different studies can be compared and correlated locally and abroad.

Much refinement in risk analysis and risk mapping is necessary to prioritise illegal discharge potential (IDP) areas. Municipalities are required to carry out resource-intensive IDDE programs to prevent or reduce pollution to urban watercourses. Risk analysis and risk mapping procedures present a significant opportunity for municipalities to prioritise their IDDE efforts, target programs to specific geographic areas and improve the cost-effectiveness of their operations. While guidance documentation has been created for municipalities in the US, in particular, more can be done to standardise the risk mapping process, establish a set of indicators (risk factors) which are related to the location or occurrence of illegal discharges and alert municipalities (or decision-makers) to the uncertainty inherent in the data used to perform such analyses (Bender, 2016). Current application of risk analysis is largely based on professional judgement (or expert knowledge) which tends to affect or bias the outcome. Further, the accuracy of this ‘expert knowledge’ and its effect on the outcome is not assessed. The search for an ‘optimized’ risk analysis that investigates the effect of various land, hydraulic, hydrological and environmental risk factors on the location and spatial variability of illegal discharge is required locally and abroad.

On the aspects of field methods to detect illegal discharge, a range of methods and indicators (Table B5) have come under focus in some research studies and still need further refinements to find their applications in IDDE programs. As these methods undergo refinements, municipalities in developing areas are likely to depend on the use of low cost options (e.g. that proposed by Irvine et al., 2011) for source detection of illegal discharges. Further concerns are intermittent inflows of illegal discharges into stormwater drainage systems which often evade scheduled monitoring. Innovations such as automatic or passive sampling as well as electronic nose and tongue technologies deserve attention. Vrana et al. (2005) and Stuer-Lauridsen (2005) provide insights into passive sampling, however their applicability to IDDE program needs to be explored.

### 2.3.1 The Gap filled by this research

Available guidance in the literature can be described as providing:

- Recommendations regarding how to identify areas within a community with potential severity of illegal discharges that merit priority investigation, but these recommendations are fraught with ‘professional judgement’ without application of classical risk mapping and risk analysis involving multi-criteria evaluation.
- General methodologies and techniques to track down sources of illegal discharges using ‘flowchart method’ that serve as decision-making tool in distinguishing between flow types, but the flowchart has to be developed locally using local monitoring data.
- Comprehensive procedures for undertaking IDDE programs in advanced countries, but these have not been tested and applied locally with different conditions and set-ups in terms of spatial planning, level of developments, level of institutional arrangements and coordination, socio-economic challenges, level of service provision and management, climatic and other factors.

In conclusion, this literature review has shown that the risk analysis and mapping method should be improved. In addition, the ‘flowchart method’ to track down sources of illegal discharge needs to be developed and applied locally. There is also a need to heighten local awareness creation and knowledge dissemination on the IDDE program as an effective non-structural BMP to manage pollution to urban watercourses. Hence, the need for the research outlined in this report is supported.

# 3 RISK MAPPING TO LOCATE PRIORITY AREAS

## 3.1 Introduction

This component of IDDE program aims to use mapping and existing datasets to assess the severity of illegal discharge potential in the municipal area and determine which sub-catchments deserve priority investigation. Desktop assessment as recommended in Brown et al. (2004) provides methods on how to narrow down the illegal discharge search to likely areas. This is achieved by utilising available datasets as well as anecdotal information to primarily characterise illegal discharge potential (IDP) at sub-catchment scale. Sub-catchments are then evaluated based on their composite score and are classified as having a low, medium or high risk of IDP.

In spite of the benefits of IDDE programs to prevent or control pollution to urban watercourses, it still requires a significant investment of local resources to administer (Brown et al., 2004). It then becomes imperative that IDDE intervention should be cost-effective and financially feasible to attract large scale implementation by municipalities. This challenge greatly typifies municipalities in developing countries with limited available resources, experience and skilled labour and provides an opportunity for further research to search for optimised methods for IDDE. In other words, the challenge facing many municipalities in developing areas who would venture to control pollution resulting from illegal discharges, is to implement IDDE programs while operating with limited available resources and expertise. To overcome this challenge, the implementation of IDDE programs should progress along a hierarchy of procedures and locations: commencing from areas with high illegal discharge potential (IDP) to areas with low IDP; from using desktop assessment (e.g. risk analysis and risk mapping) through exploratory techniques to confirmatory procedures. Desktop analysis such as risk analysis and risk mapping is an indispensable tool to increase the cost-effectiveness of field operations. The procedure offered in this study recognises that municipalities are inadequately resourced and hence, would make optimum use of existing datasets that are typically available.

In this study, risk analysis is integrated with mapping requirements to form a valuable tool in prioritising IDP. Data from two case study catchments in Cape Town municipality are used to investigate potential spatial relationships among risk factors and illegal discharges. The primary requirement of the IDDE program is the mapping of stormwater drainage and wastewater sewer systems. Maintaining and updating accurate maps of these systems will make it easier for municipalities to track down suspected illegal discharges to their source. The mapping information is also an input to undertaking risk analysis and risk mapping to prioritise areas with high IDP. The maps should provide the following information as a basic requirement:

- Location of all stormwater drainage outfalls, watercourses (including wetlands and ponds) within the municipal geographic boundary.
- Stormwater drainage conveyances (types, materials, age and sizes) leading to outfalls or watercourses. Mapping should focus on locating, in particular outfalls, pipes, channels, catch-pits, manholes and other stormwater drainage infrastructure.
- Wastewater sewer systems (types, materials, age and sizes).
- All sub-catchments or drainage areas in the municipal area whether or not they contribute to an outfall or surface water.
- Land uses or zoning for all sub-catchments or drainage areas.

The ArcGIS program is recommended for mapping as it combines a geo-referenced database with mapping capability allowing different geographical features such as pipes, outfalls, land uses, etc. to be mapped as 'layers' and displayed separately or together. Procedures described in this report assume that mapping of stormwater drainage and wastewater sewer systems exist and where they do not, the municipality in question must make every effort to complete the systems mapping. Section 3.2 deals with the procedures involved in risk analysis and risk mapping. Section 3.3 outlines a case study application of risk analysis and risk mapping procedures.

## 3.2 Methods

Risk analysis and risk mapping method is selected in this study to overcome the limitations of using professional judgements to prioritise sub-catchment areas. Methods involving frequency analysis and multi-criteria evaluation (MCE) were coupled to achieve the objective of risk analysis and risk mapping. Procedures proposed in the prioritisation are presented in a flow chart in Figure 3.1 and discussed below.

### 3.2.1 Data collection and compilation

A large volume of data is required for mapping and prioritising IDP areas; some of which are also needed for follow-up field investigations for tracking down discharges to their source. Table 4.1 lists some recommended data to be collected and compiled and the extent and quality of these data deserve special attention. As with all modelling study, the popular phrase "garbage in, garbage out" should be the guiding principle. Where available, metadata should be collected and reviewed to determine the data generation method and evaluate the completeness and accuracy of datasets. It is advantageous if the datasets are in GIS format (shapefiles), else they would have to be converted or digitised to create new GIS data layers and this can be a labour- and time-intensive exercise. Care must be taken to convert all data layers into the same coordinate system and clip to sub-catchment boundaries to enable calculations in ArcGIS such as length, area and density of some factors in each sub-catchment. Required datasets are often owned and maintained by the municipalities themselves; however, few may be obtained from national government departments and research institutions.

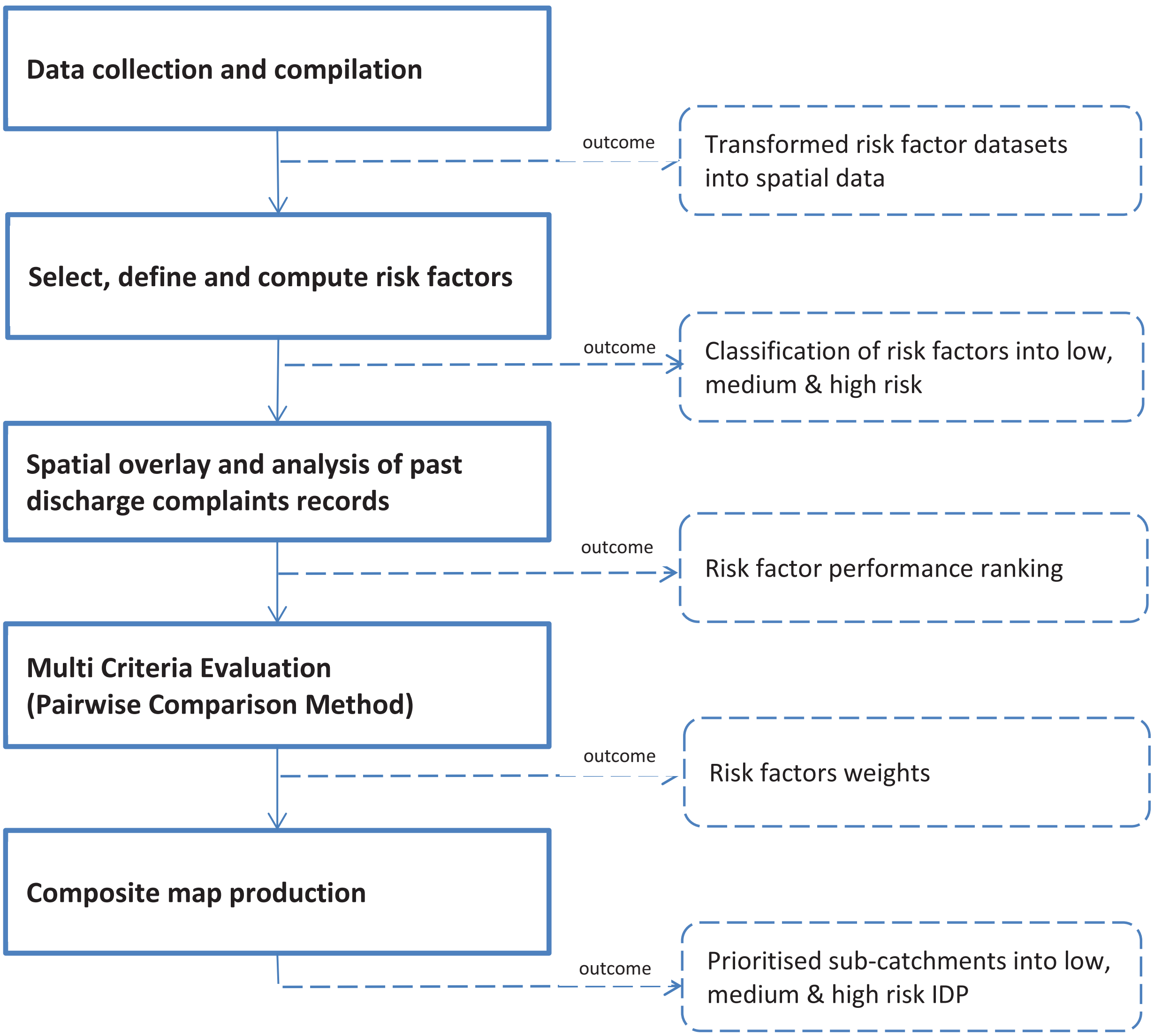



**Figure 3-1: Flow chart for risk analysis and risk mapping procedure**

### 3.2.2 Select, define and classify risk factors

This step of prioritisation selects, defines and derives risk factors (illegal discharge indicators) to screen or evaluate sub-catchments based on their potential to locate or cause illegal discharges. Some of the datasets (in Table 3.1) may be used as ‘risk factors’ based on the hypothesis that they are associated with occurrence or location of illegal discharges. Definitions and descriptions of risk factors used in previous studies are summarised in Table 3.2. Program managers must select risk factors that apply in their locality. Derivations and metric ranking of risk factors depend on classification method used, such as:

- Professional judgement (assigned scores agreed upon in workshops)
- Frequency analysis of datasets
- Standard classification methods in ArcGIS (e.g. Jenks Natural Breaks algorithm).

**Table 3-1: Useful data for prioritisation of IDP areas**

| Recommended datasets | Optional datasets |
|---|---|
| Aerial photos or orthophotos | Septic tank locations |
| Sub-catchment and catchment boundaries | As built- or construction drawings |
| Drainage including piped streams | Condition of infrastructure |
| Land use or zoning | Field inspection records |
| Outfalls | Depth to the water table and groundwater quality |
| Sewer system | Historical industrial uses or landfills |
| Standard Industrial Classification codes for all industries | Known locations of illegal discharges (current and past) |
| Storm drain system | Percent imperviousness |
| Streetmap or equivalent GIS layers | Plot boundaries |
| Topography (1 m contours) | Pollution complaints |
| Population | Sanitary sewer Infiltration and Inflow (I/I) surveys |
| Age of development | Domestic animals population/neighbourhoods |
| Generating sites | Sewer system evaluation surveys |
| Outfall and stream monitoring data | Thermal imaging data |

The complexity and accuracy of these methods increases from professional judgement through frequency analysis to Jenks Natural Breaks algorithm and the choice among these methods depends on the expertise and skills available on the one hand and the extent and quality of data available on the other hand. The mapping unit upon which the analysis is to be undertaken requires serious consideration as it may affect the accuracy of the analysis. The approaches are to use (in decreasing order of scale): municipal boundaries, catchment boundaries and sub-catchment or drainage areas boundaries. Municipal boundaries utilise political or jurisdictional boundaries and are very coarse. The catchment boundaries are determined based on hydrology and are usually coarse in scale. While the catchments boundaries are often publicly available and inexpensive to obtain, the boundaries do not commonly take into account subsurface drainage infrastructure. Sub-catchments or drainage areas are often delineated by surveying stormwater network and identifying drainage areas to each outfall. However, many adjoining sub-catchments or drainage areas may drain to a single outfall.

**Table 3-2: Descriptions of plausible risk factors to evaluate sub-catchments**

| Risk Factor | Definition/Description |
|---|---|
| **Land cover** | Indicates a general level of development in a region which may have importance in determining the type or number of discharges present in certain areas. |
| **Land use** | Gives a better indication of the types of activities and potential pollution that may be present when compared to land cover. |
| **Population Density** | Defined as the number of people per square kilometre. The risk factor functions as an indicator of development intensity as more people living in the same area could indicate that the region is more urbanised (Bender, 2016). |
| **Percent Imperviousness** | Percent impervious is a well-known indicator of development and has a direct effect on sub-catchment hydrology. It also creates more potential surfaces for the accumulation and wash-off of pollutants and can therefore be used as a risk factor for illegal discharges. |
| **Development Age** | Development age is defined as the number of years since a structure was built on a plot. The plot ages may be aggregated over sub-catchment to determine the median or average age of each sub-catchment. Provides an idea of the age of infrastructure such as stormwater pipes or water/sanitary hook-ups for residences and businesses. This risk factor may be considered a surrogate for the age of infrastructure if data for age of infrastructure is not available. |
| **Outfall Density** | Outfall density measures the number of outfalls from the stormwater drainage network per kilometre of municipal watercourses or streams. In theory, the higher the outfall density, the more connections there are between the stormwater drainage system and the watercourses, which may indicate dense stormwater drainage network with many sub-catchments of different sizes. |
| **Aging Sanitary Infrastructure** | Brown et al. (2004) defined this risk factor as the age and condition of the sub-catchment sewer network. The factor evaluates the condition of the sanitary sewer network and the potential for the sanitary sewer system to contribute illegal discharges to the drainage area through leaks, overflows, or illegal connections. Ibid alludes that "high IDP is indicated when the sewer age exceeds design life of its construction materials or when clusters of pipe breaks, spills, overflows or I/I are reported by sewer authorities". |
| **Drainage Density** | Drainage density is typically defined as the length of stream channels divided by the sub-catchment drainage area. This risk factor uses stormwater drainage infrastructure to provide a qualitative indication of drainage network development in the sub-catchment. The more built out the drainage network, the higher the drainage density, the more the network will receive illegal discharges and the quicker the sub-catchment will drain to its outlet. |
| **Generating Site Density** | The generating site risk factor is defined as the number of potential generating sites per square kilometre, where potential generating sites are facilities ranging from gas stations to restaurants to industrial plants which inherently carry the risk of contributing illegal discharges of various pollutants to the sub-catchment. |
| **Infrastructure Access Density** | Infrastructure access density is defined as the number of access points to the stormwater drainage network per square kilometre, where access points are defined as catch basins, pond outlet structures, pipe ends and other features open to the atmosphere, allowing for materials to enter the drainage network. |
| **Construction Site Density** | Construction site density measures the number of active construction sites per square kilometre of sub-catchment. |
| **(Aging) Septic System Density** | (Aging) septic system density measures the number of aging septic systems per square kilometre, which provides an indication of the potential for aging or failing septic systems to contribute pollutant load to drainage systems. |
| **Domestic Animal Density** | Domestic animal density measures the number of domestic animal per square kilometre. Considered as a risk factor because of the high potential for improper disposal of domestic animal waste, as well as polluted runoff from high-density domestic animal neighbourhoods. |

The limitation in using sub-catchments as a mapping unit is that it has tendency to neglect areas that are not serviced by stormwater drainage system and it requires extensive survey work. Consequently, the decision on which mapping unit or scale to use for risk analysis and mapping will depend on local problems, type and quality of available data and the resources at hand to collect new data.

### 3.2.3 Spatial overlay and analysis of complaints records

As the risk factors were hypothesised as being illegal discharge indicators, there is a need to test this hypothesis and also to rank the factors in terms of their significance to predict occurrence or location of illegal discharges. This also affords the means to assign weights to the factors. This is achieved by spatial overlay of past discharge complaints records (PDCRs) of illegal discharges over each risk factor layer and counting the number of PDCRs that lies in the high-risk region. The high-risk regions are of paramount interest because those are areas we seek to assign high priority for further investigations. Hence, a PDCR is considered to be 'captured' by a risk factor if the PDCR fell within the high-risk overlay for that factor. The numbers of captured records enable risk factors 'performances' (to predict the occurrence or location of illegal discharge) to be derived. Significant tests may be performed to compare the differences between risk factors 'performances' (or captured rates) and also to confirm the relative ranking that describes the ability of an individual risk factor to predict location of illegal discharge.

### 3.2.4 Multi-Criteria Evaluation (Pairwise Comparison Method)

In an approach to produce composite maps, it is first necessary to determine the risk factors' relative 'weights'. The weights are a measure of risk factors ratings (or priority or importance) in predicting the risk of IDP. Multi-criteria evaluation (MCE) is a methodology for ranking series of management alternatives from high priority to the least priority based on structured approach. Normally, the outcome of the evaluation is a variety of weights assigned to the various alternatives relative to each other. The structured approach used in this study is that of Analytical Hierarchy Process (AHP) (Saaty, 1980), in the category of Pairwise Comparison Method (PCM). Besides its proven and wide applications in different fields, the AHP provides means of evaluating judgement consistency in the process. The basic procedure and mathematics of AHP applied in this study is as follows:

- Develop a pairwise comparison matrix *($M_{ij}$)*:

$$M_{ij} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$

- Sum the values in each column of the pair-wise matrix:

$$M'_{ij} = \sum_{i=1}^{n} M_{ij}$$

- Normalise the pairwise comparison matrix by dividing each element in the column by its column total to generate a normalised pair-wise matrix *($N_{ij}$)*:

$$N_{ij} = M_{ij} / \sum_{i=1}^{n} M_{ij} = \begin{bmatrix} N_{11} & N_{12} & N_{13} \\ N_{21} & N_{22} & N_{23} \\ N_{31} & N_{32} & N_{33} \end{bmatrix}$$

- Calculate the weights *($W_{ij}$)* by averaging the normalised values in each row:

$$W_{ij} = \sum_{j=1}^{n} N_{ij} / n = \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix}$$

Next is to test for consistency. Consistency Vector *($CV_{ij}$)* is calculated by multiplying the pair-wise matrix by the weights vector:

$$CV_{ij} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} * \begin{bmatrix} W_{11} \\ W_{12} \\ W_{13} \end{bmatrix} = \begin{bmatrix} CV_{11} \\ CV_{12} \\ CV_{13} \end{bmatrix}$$

and dividing the weighted sum vector by the criterion weight:

$$CV_{11} = 1/W_{11} \, [M_{11}W_{11} + M_{12}W_{21} + M_{13}W_{31}]$$

$$CV_{21} = 1/W_{21} \, [M_{21}W_{11} + M_{22}W_{21} + M_{23}W_{31}]$$

$$CV_{31} = 1/W_{31} \, [M_{31}W_{11} + M_{32}W_{21} + M_{33}W_{31}]$$

- Lambda *($\lambda$)*, defined as the average of the values of the Consistency Vector is calculated:

$$\lambda = \sum_{i=1}^{n} CV_{ij} / n$$

- Consistency Index *(CI)*, measures the deviation which reflects the consistency of one's judgement, is calculated as:

$$CI = (\lambda - n)/(n - 1)$$

- Finally, Consistency Ratio *(CR)*:

$CR = CI/RI$ ; where *RI* is Randomness Index obtained from tables derived by Saaty (1980), who asserts that a *CR* value of 0.1 or less is considered acceptable, that is the judgements are consistent.

### 3.2.5 Composite map production

To obtain a composite map, the results of initial risk factor IDP classification score for each sub-catchment (section 3.2.2) would be multiplied by the corresponding risk factor weight (section 3.2.4). The products are summed and reclassified into three qualitative levels of risk (low, medium and high) to produce the composite map. For a sub-catchment composite score, the equation below is used:

$$subcatchment\ composite\ score = r_1w_1 + r_2w_2 + \cdots + r_{10}w_{10}$$

where: *r = risk factor IDP classification score and*
*w = corresponding risk factor weight*

## 3.3 Case study application of risk analysis and risk mapping procedures

### 3.3.1 Study area data collection, processing and analysis

Interviews (through meetings, phone calls and emails) were conducted with the City of Cape Town's Water and Sanitation Department as well as the Catchment, Stormwater and River Management Branch (CSRM) to appraise, in terms of datasets availability, the City's infrastructure profile, existing legal authority or ordinances, available mapping, past discharge complaints and reports and others. The City of Cape Town maintains a large public database of GIS data used to manage the City's programs and services. These include hydrology (catchment boundaries, rivers, streams and canals), land-use or zoning, plots, streets, population, generating sites (Standard Industrial Classification codes for industries and commercial sites). Coordination with the City's departments was required to obtain additional datasets which were maintained offline for privacy and security reasons, including: sub-drainage watersheds delineated from twenty-five meters Digital Elevation Model (DEM), stormwater drainage system and sanitary infrastructure, septic field locations and detailed records of illegal discharges. Spatial data was downloaded as shape files and organised in a geodatabase, while non-spatial data was downloaded as excel spreadsheets and stored outside of the geodatabase.

ArcGIS 10.3 for Desktop (Environmental Systems Research Institute, 2014) was the primary tool used to compile and transform spatial and non-spatial input data into spatial layers describing the IDP within each catchment. Each spatial layer is assigned to one of the ten risk factors chosen for this study (Table 3-3) describing levels of risk of occurrence of illegal discharge. Risk mapping of all datasets was performed using sub-catchments as the minimum mapping unit because they were the smallest scale or hydrologic unit available at the municipality and did not require significant resources and effort to acquire. The breakdown and metric ranking of each risk factor are summarised in Table 3-3. IDP risk classifications for the risk factors' layers are shown Figures C1.1 to C1.10 in Appendix C1.

**Land use (Residential, Commercial and Industrial):** "Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. Definition of land use in this way establishes a direct link between land cover and the actions of people in their environment" Di Gregorio (2005). Land use gives a better indication of the types of activities and potential pollution that may be present, when compared to land cover. Land use data was unavailable; hence zoning data (for residential, commercial and industrial) was used as a surrogate as it is related to the types of land uses permitted on a plot. Land use metric was broken down as a percent of sub-catchment with residential/commercial/industrial. Thus in each sub-catchment, percent residential, commercial and industrial areas were evaluated in GIS platform to classify them into low, medium and high risks. The metric ranking, indicated in Table 3-3 were based on criteria recommended by Brown et al. (2004). The residential, commercial and industrial land use IDP risk classification is illustrated in Figures C1.1 to C1.3, respectively in Appendix C1. There is uncertainty in the zoning data for both catchments as it reflects a 5-year old ordinance and several plots are suspected of having changed zoning since that time. There was no metadata and a lot of blanks (no information) existed in the dataset and these blanks were interpreted as missing information and discarded.

**Aging Sanitary Infrastructure:** The process used to classify this factor involved determining the average age of sanitary pipes in each sub-catchment. Thereafter, statistical frequency analysis (Figure 3-2) of the average ages across all sub-catchments was performed to obtain breakpoints between low, medium and high-risk IDP. The thresholds for medium and high risk were 20 and 45 years at 16 and 94 percentiles respectively (Figure 3-2). The IDP risk classification is illustrated in Figure C1.4 in Appendix C1.

Use of sub-catchments as a unit of analysis may have resulted in some inaccuracies given that these sub-catchments are not completely delineated to incorporate subsurface infrastructure and therefore do not completely represent the drainage areas which would catch leaking sewage or overflows. Sub-catchment sanitary infrastructure age was quite variable and accuracy could not be confirmed in some cases. Some sub-catchments had scores of zero because they were completely unserved. In addition, each catchment dataset had about 10% missing records.

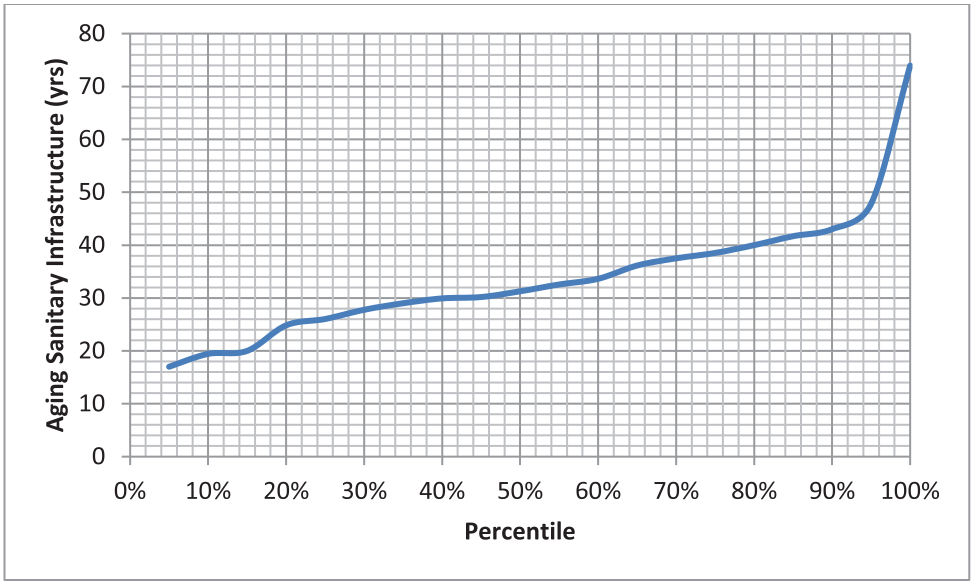



**Figure 3-2: Aging sanitary infrastructure frequency analysis**

**Population Density:** Population density was defined as the number of people per square kilometre, measured within block groups (polygon) for each sub-catchment, which was the smallest census unit for which population data was available. The datasets for both catchments were obtained from the City of Cape Town. Population density of each sub-catchment was classified as low, medium or high-risk IDP. Breakpoints for the classification (Table 3-4) were obtained from statistical analysis of population density based on their frequency across all sub-catchments. The thresholds for medium and high risk were 580 and 2052 respectively. The population density IDP risk classification is illustrated in Figure C1.5 in Appendix C1.

**Development Age (Age of stormwater infrastructure):** Age of development may predict the potential for illegal discharge occurrences. A catchment with development age of more than 100 years would presumably have a higher risk of IDP because of deterioration in the pipes and connections and also due to substandard old construction materials, codes and inspections. On the other hand, a newly developed catchment may have a lower IDP risk because of "improved construction materials, codes and inspections" (Brown et al., 2004:52). Age of development was defined as the number of years since a structure was built on a plot and these plot ages are then aggregated over sub-catchments to determine the average age. Age of development, by this definition, provides an idea of the age of infrastructure such as stormwater pipes or water/sanitary hookups for residences and businesses.

**Table 3-3: Risk factors metric breakdown and ranking**

| S/No. | Risk Factor | Metric Breakdown | Metric Ranking | | | Comments |
|---|---|---|---|---|---|---|
| | | | Low (1) | Medium (2) | High (3) | |
| 1 | Land use: Residential | Percent of sub-catchment area that is residential | <30% | 30 -- 45 | >45% | Based on recommendations by CWP (2004) |
| 2 | Land use: Commercial | Percent of sub-catchment area that is commercial | <10% | 10 -- 20 | >20% | |
| 3 | Land use: Industrial | Percent of sub-catchment area that is industrial | <5% | 5 -- 10 | >10% | |
| 4 | Population Density | Number of persons per square km or per sub-catchment area | <580 | 580-2052 | >2052 | Breakpoints were obtained from statistical analysis of population density based on their frequency across all sub-catchments. |
| 5 | Development Age (or Age of stormwater infrastructure) | Average age of development or stormwater infrastructure per sub-catchment area | <25 | 25-45 | >45 | Breakpoints were obtained from statistical analysis of development age based on their frequency across all sub-catchments. |
| 6 | Outfall Density | Average number of outfalls per kilometre of stream in a sub-catchment | <4.5 | 4.5-57 | >57 | Breakpoints were obtained from statistical analysis of outfalls based on their frequency across all sub-catchments. |
| 7 | Aging Sanitary Infrastructure | Average age of sub-catchment area sewer network | <20 | 20-45 | >45 | Breakpoints were obtained from statistical analysis of sanitary infrastructure age based on their frequency across all sub-catchments. |
| 8 | Drainage Density | Kilometres of pipes and open water course per square kilometre of sub-catchment area | <0.5 | 0.5-2 | >2 | Breakpoints were obtained from statistical analysis of drainage density based on their frequency across all sub-catchments. |
| 9 | Generating Site Density | Generating Site Density (# of generating sites per square km) | <3 | 3-10 | >10 | Based on recommendations by Brown et al. (2004) |
| 10 | Infrastructure Access Density | Infrastructure Access Density (# of storm drain inlets/outlets per square km) | <1 | 1-5 | >5 | Breakpoints were obtained from statistical analysis of infrastructure access density based on their frequency across all sub-catchments. |

In 2006, CoCT assigned categories for Age of Infrastructure by a spatial-join to associate the ages of sewer, water and the general plan polygons layers to the stormwater pipes layer as historical records for the age of stormwater infrastructure was not available (Kane, pers. Comm., 2017). Therefore, in this analysis age of development was considered a surrogate for age of stormwater infrastructure for both Diep- and Kuils River catchments. Similar to aging sanitary infrastructure risk factor, breakpoints for the classification (Table 3-4) were obtained from statistical analysis of average ages based on their frequency across all sub-catchments. The thresholds for medium and high risk were 25 and 45 years respectively. The development age IDP risk classification is illustrated in Figure C1.6 in Appendix C1. Uncertainty in the datasets is centred on a huge number of “null” entries (30% for Diep River and 8% for Kuils River catchments). “Nulls” entries were interpreted as unrecorded or missing information and were excluded from analysis.

**Generating Site Density:** Generating site density risk factor is defined as the number of potential generating sites per square kilometre, where potential generating sites are facilities that include fuel stations, restaurants, industrial plants and others which inherently carry the risk of contributing illegal discharges with various pollutants. Research suggests that certain land use generating sites are sources of possible pollutant loads where routine operations can present a higher risk for spills, leaks or illegal discharges. Brown et al. (2004:A5) presented a ‘Reference Table’ listing potential generating sites under common land uses where illegal discharges can occur based on regular activities or practices. These generating sites listed in the ‘Reference Table’ are associated with Standard Industrial Classification (SIC) codes for the United States. Datasets for industries and commercial facilities with their SIC codes pertaining to Cape Town were obtained from the City and were matched with the ‘Reference Table’ in Brown et al. (2004:A5) to derive the land use generating sites with IDP classified into high, medium and low risk (Table C1.1 in Appendix C1). Generating site density for each sub-catchment was computed and classified as low, medium or high-risk IDP. The metric ranking, indicated in Table 3-4 were based on criteria recommended by Brown et al. (2004). The thresholds for medium and high risk were set at 3 and 10 respectively. The generating site density IDP risk classification is illustrated in Figure C1.7 in Appendix C1.

The extent and data format (non-spatial) in the records may have contributed to uncertainty in the risk factor. Data must be geospatially located, which is an arduous process that sometimes results in improper matches, or the inability to locate records due to a lack of data describing the business location or metadata describing how the data was captured. However, diligent geolocation in both Diep- and Kuils River catchments was done, but the results could not be verified due to the limited time frame of the study. The datasets were compiled in 2014, thus they are not complete lists of sites which could potentially produce an illegal discharges. Moreover the "Reference Table" was compiled from information in the US and its applicability in South Africa is unverified.

**Drainage Density:** Drainage density is typically defined as the length of stream channels divided by the catchment or sub-catchment drainage area, however this definition was modified in this study as the length of drainage conveyances (open channels, pipes and streams) divided by the sub-catchment area. Breakpoints for the IDP risk classification (Table 3-4) were obtained from statistical analysis of drainage density based on their frequency across all sub-catchments. The thresholds for medium and high risk were 0.5 and 2, respectively. This risk factor IDP classification is illustrated in Figure C1.8 in Appendix C1. Sub-catchments delineation did not take into account subsurface infrastructure. In addition, sub-catchments that are small in size often showed exaggerated densities in either the high or low direction. Some sub-catchments had no infrastructure included due to incomplete surveying. The stormwater drainage network datasets used to calculate drainage lengths were also highly uncertain. Some localities have pieces of infrastructure along streams (i.e. where streams have been piped or channelized) but generally do not contain the full stream network. Lack of connectivity between conveyances in both Diep- and Kuils River catchments datasets suggests that neither of them is truly complete and that more surveys would reveal more conveyances and increase density values in both catchments.

**Outfall Density:** The density of outfalls in a sub-catchment is an effective illegal discharge screening factor and is expressed in terms of the number of outfalls per kilometre of sub-catchment streams. Hypothetically, the higher the outfall density, the more connections there are between the storm drainage network and the stream, which may infer dense stormwater drainage network with many sub-catchments. Outfalls that discharge into other open water courses (OWCs) and water bodies such as ponds and wetlands were also included in the analysis. For each sub-catchment, the total number of outfalls into all OWCs were determined and divided by the total length of OWCs to obtain outfall density for each sub-catchment. Breakpoints were obtained from statistical analysis of outfall densities based on their frequency across all sub-catchments to classify each sub-catchment as low, medium or high-risk IDP. The metric ranking derived is indicated in Table 3-4 with the thresholds for medium and high risk set at 4.5 and 57 respectively. The outfall density IDP risk classification is illustrated in Figure C1.9 in Appendix C1.

Outfall density risk factor used five different layers (sub-catchment, outfall nodes, open watercourses or streams, ponds and wetlands layers) and all this information was collected from the City of Cape Town. Uncertainty is inherent in all datasets and their combined effect may be pronounced. Sub-catchments are generally high quality, which is important as they are the subunit of analysis used for overlays. Data on OWCs was missing in some places and some no longer existed due to development or stream burial and rerouting. In some areas, outfall nodes were at the stream bank whereas in other areas, outfall nodes were at a considerable distance from stream centerline. For this reason a 20-metre buffer selection method was chosen by the City (Kane, pers. Comm. 2016). The buffer distance significantly impacted density values since outfalls were located at variable distances from the stream, pond and wetland in both catchments.

**Infrastructure Access Density (IAD):** Infrastructure access density is defined as the number of access points to storm drain network per square kilometre; where access points are defined as catch basins, pond outlet structures, pipe ends, inlets/outlets and other features open to the atmosphere, allowing for materials to enter storm drain network. For each sub-catchment, point-counts of these features were made and divided by the sub-catchment area. Breakpoints were obtained from statistical analysis of the resulting infrastructure access densities, based on their frequency across all sub-catchments to classify each sub-catchment as low, medium or high-risk IDP. The metric ranking derived is indicated in Table 3-4 with the thresholds for medium and high risk set at 1 and 5, respectively. The infrastructure access density IDP risk classification is illustrated in Figure C1.10 in Appendix C1. Uncertainty in IAD is associated with the node or access point types as well as the completeness and accuracy of the data. There is a larger range of node types which had to be filtered for this process. As detailed descriptions of these types were not given in metadata, it is possible that some nodes may have been included or omitted when in reality, they should not have.

**Spatial analysis:** Past discharge complaints records (PDCR) associated with illegal discharges were obtained from the CoCT's notification database. Before the spatial analysis was performed, the PDCR (from June 2011 to June 2012) for four discharge pathways namely water, greywater, wastewater and solid waste were selected and grouped. It was hypothesised that some risk factors may be associated with illegal discharges from these four discharge pathways. Each PDCR pathway group was spatially overlaid on top of individual risk factor layers. An example of the spatial overlay process performed for the drainage density risk factor is shown in Figure 3-3. Spatial overlay for all risk factors is presented in Figures C2.1 to C2.10 in Appendix C2. An illegal discharge was considered to be "captured" by a risk factor if the discharge fell within the high-risk overlay for that factor. A table was created to capture the data for both catchments such that each risk factor occupied a row and for each discharge pathway group, a column was created and populated with the number of discharge records captured by the corresponding risk factor (Table 3-4, in percentages).

**Table 3-4: Discharge capture rates for risk factors**

| RISK FACTORS | Percentage of group total captured by high risk factor overlay | | | | |
|---|---|---|---|---|---|
| | PDCR: Wastewater | PDCR: Water | PDCR: Greywater | PDCR: Solid Waste | PDCR: All |
| ***Records in Cluster*** | ***19776*** | ***1382*** | ***903*** | ***6655*** | ***44316*** |
| LU: Residential | 15 | 3 | 24 | 14 | 14 |
| LU: Commercial | 29 | 36 | 31 | 24 | 27 |
| LU: Industrial | 16 | 33 | 14 | 10 | 13 |
| Population Density | 76 | 87 | 73 | 76 | 75 |
| Development Age | 20 | 6 | 20 | 16 | 18 |
| Outfall Density | 27 | 26 | 28 | 35 | 31 |
| Aging Sanitary Infrastructure | 9 | 1 | 7 | 6 | 7 |
| Drainage Density | 92 | 88 | 90 | 95 | 91 |
| Generating Site Density | 22 | 40 | 24 | 23 | 26 |
| Infrastructure Access Density | 32 | 14 | 48 | 34 | 33 |

Statistical methods were employed to compare risk factor performance and determine a relative ranking that describes the ability of individual risk factors to predict overall IDP. Statistical analysis was undertaken using online chi-square calculator (www.socscistatistics.com/test/chisquare) where the discharge capture records for each discharge pathway or cluster (Table C2.1 in Appendix C2) were used to construct contingency tables (Table C2.2 in Appendix C2) pairing all risk factors against each other; for each discharge pathway group. Chi-square test was used to evaluate the contingency tables as it is capable of testing 2×2 tables and is robust against high frequencies in observed data (greater than or equal to 5 data points). A chi-square test with $\alpha = 0.05$ was used to determine if there was a significant difference in performance between any two risk factors. Performance was measured by the proportion of captured records in a discharge pathway group. The chi-square analyses and capture proportions were then used to rank risk factors in both Diep- and Kuils River catchments, according to the factors' ability to predict the occurrence or locations of discharges in each discharge pathways.

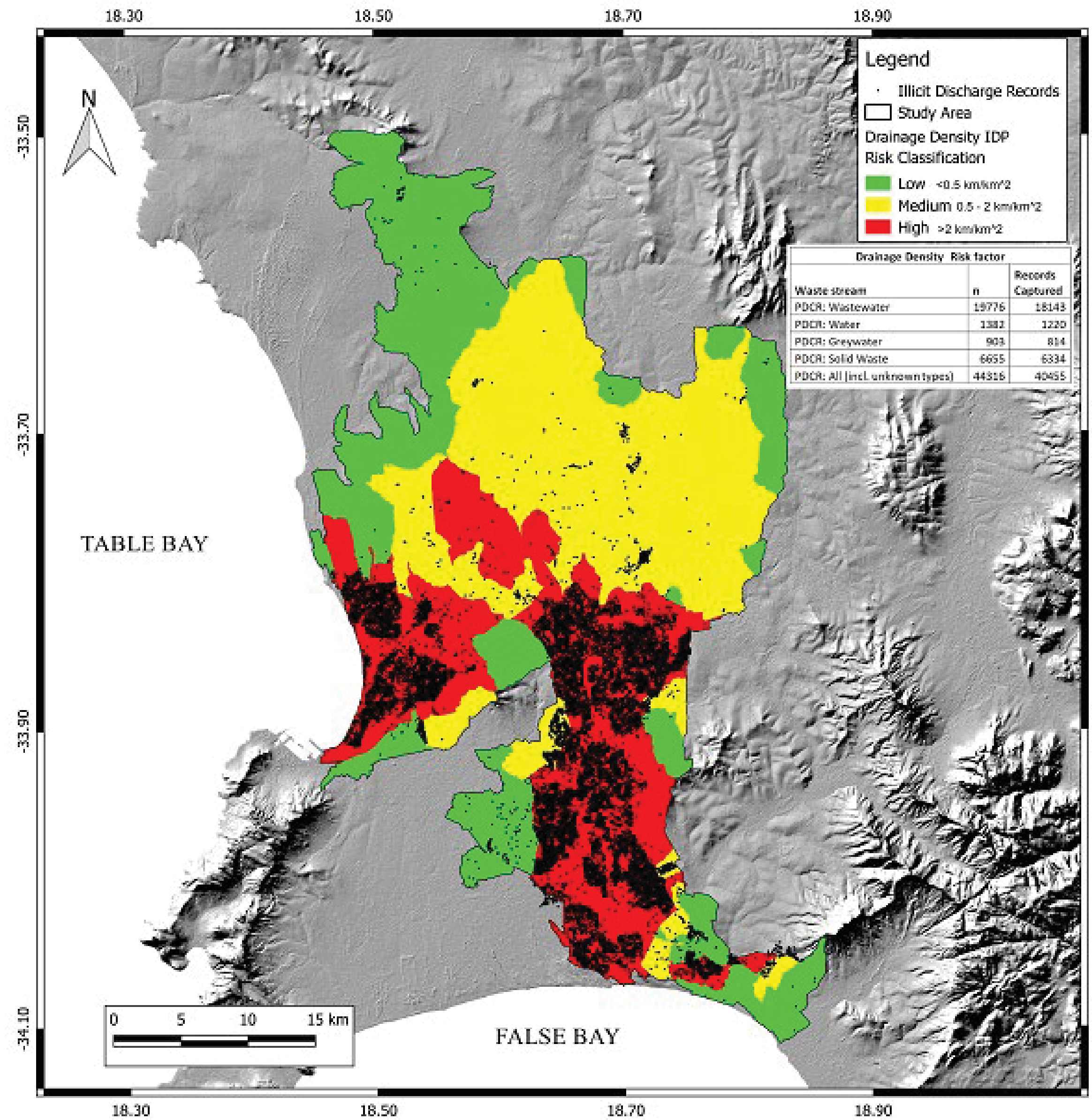



**Figure 3-3: Example of the spatial overlay for drainage density risk factor**

**Risk factor weightings and composite map production:** The discharge capture rates (Table 3-4), together with Saaty scale of comparison (Table 3-5) were used to develop a pairwise comparison matrix to derive weightings for the risk factors under each group of discharge pathways. A subjective approach was adopted in assigning the percent capture rates to Saaty's scale of comparison.

**Table 3-5 : Saaty scale of comparison**

| Intensity of Importance | Definition | Explanation | *Difference between risk factors' capture rates (range in %) |
|---|---|---|---|
| 1 | Equal Importance | Two factors contribute equally to the objective | 0-4 |
| 2 | Weak or Slight Importance | | 5-10 |
| 3 | Moderate Importance | Experience and judgment slightly favour one over the other. | 11-20 |
| 4 | Moderate Plus Importance | | 21-30 |
| 5 | Strong Importance | Experience and judgment strongly favour one over the other. | 31-40 |
| 6 | Strong Plus Importance | | 41-50 |
| 7 | Very Strong Importance | Experience and judgment very strongly favour one over the other. Its importance is demonstrated in practice. | 51-60 |
| 8 | Very very Strong Importance | | 61-80 |
| 9 | Extreme Importance | The evidence favouring one over the other is of the highest possible validity. | 81-100 |

* Not part of Saaty (1980) scale of comparison; only adopted in this study.

**Table 3-6: Weights applied to corresponding risk factors**

| | Weights | | | | |
|---|---|---|---|---|---|
| Risk Factors | wastewater | water | greywater | solid waste | All |
| LU: Residential | 0.029 | 0.020 | 0.042 | 0.030 | 0.030 |
| LU: Commercial | 0.068 | 0.081 | 0.066 | 0.051 | 0.060 |
| LU: Industrial | 0.031 | 0.072 | 0.026 | 0.023 | 0.028 |
| Population Density | 0.254 | 0.301 | 0.234 | 0.255 | 0.255 |
| Development Age | 0.041 | 0.024 | 0.038 | 0.034 | 0.037 |
| Outfall Density | 0.072 | 0.056 | 0.054 | 0.091 | 0.075 |
| Aging Sanitary Infrastructure | 0.021 | 0.019 | 0.018 | 0.022 | 0.020 |
| Drainage Density | 0.361 | 0.301 | 0.355 | 0.361 | 0.358 |
| Generating Site Density | 0.053 | 0.088 | 0.042 | 0.050 | 0.057 |
| Infrastructure Access Density | 0.072 | 0.038 | 0.124 | 0.083 | 0.080 |

Two risk factors are considered equal importance if the difference between their percent captures rates is not more than four percent. Weak or slight importance is assigned if the difference is between five and ten percent. For differences in capture rates that are within the following ranges: 11-20, 21-30, 31-40, 41-50, 51-60, 61-80, 81-100 the following were respectively assigned: moderate importance, moderate plus importance, strong importance, strong plus importance, very strong importance, very very strong importance and extreme importance (Table 3-5). With these assignments, the pair-wise comparison matrix (order of 10) was developed where 10 criteria were compared against each other as described in section 3.2.4 and the derived weighs are presented in Table 3-6. Risk factor IDP scores for each sub-catchment was multiplied by the corresponding risk factor weight (Table 3-6). The products are summed and reclassified into three qualitative levels of risk (low, medium and high) to produce the composite map for each discharge pathways as discussed in the next section.

### 3.3.2 Results and Discussion of risk mapping application

**Spatial analysis:** After data compilation, generation of risk factors and spatial overlay, summary tables were constructed to show the discharge capture rates for each risk factor overlay. Table 3-4 shows the results of the spatial analysis for both Diep- and Kuils River catchments. Each cell in Table 3-4 contains the percentage of PDCRs in the corresponding pathway group that was captured by a high-risk overlay; also indicated by the cell shading (darker shading indicates a higher percentage). The results indicate that many illegal discharges are concentrated in areas dominated with high population and drainage densities in all the discharge pathway groups. The characteristics of developed areas will often determine the risk present for various types of discharges. For example, developments with high population and drainage densities provide more opportunities for illegal connections (of water, wastewater and greywater) and dumping of solid wastes, toxic and spilt materials to enter stormwater network.

Moderate illegal discharges were also located in regions with easy access to stormwater infrastructure, especially in greywater (48%) discharge pathway. Among land uses, commercial areas seem to be relatively higher (24-36%) with illegal discharges across all the pathways. Commercial areas have more concentrated businesses and infrastructure which facilitates illegal connections and discharges. Very small percentages of illegal discharges in all the discharge pathways are associated with development age and in particular, aging sanitary infrastructure. That is, development age and aging infrastructure do not appear to influence the locations of illegal discharges. This was a surprise because older developments occur in both Diep- and Kuils River catchments and illegal discharges associated with failing infrastructure were expected. The reasons for these weak associations could be attributed to infrastructure upgrade and replacement in recent times in the City; although illegal discharges via illegal connections are known to occur in more recent developments when construction is not thoroughly reviewed and inspected. Massive new developments in both Diep- and Kuils River catchments (namely Parklands, Parklands North, Sunningdale, Brakenfelds and others) may have masked the effects of aging infrastructure in the older parts of the catchments. Apart from the highs and lows mentioned above, the performance of other individual risk factors across all discharge pathways is very uniform. The spatial overlay process indicated the relative importance of risk factors, but when combined with the results of the chi-square analysis, a more comprehensive assessment of risk factor performance could be made. The chi-square test ($\alpha = 0.05$) provided an idea of which risk factors were statistically different in their performance. Thus, the null hypothesis asserts that the performance or proportion of captured rates between any two (compared) risk factors is not different.

**Table 3-7: Final ranking of risk factors to predict IDP**

<table>
<tr><th rowspan="2">Rank number</th><th>Wastewater</th><th>Water</th><th>Greywater</th><th>Solid Waste</th><th>All/combined</th></tr>
<tr><th colspan="5">Risk Factors (% captured)</th></tr>
<tr><td>1</td><td>Drainage density (92)</td><td rowspan="2">Drainage density (88) & Population density(87)</td><td>Drainage density (90)</td><td>Drainage density (95)</td><td>Drainage density (91)</td></tr>
<tr><td>2</td><td>Population density (76)</td><td>Population density (73)</td><td>Population density (76)</td><td>Population density (75)</td></tr>
<tr><td>3</td><td>Infrastructure access density (32)</td><td>Generating site density (40)</td><td>Infrastructure access density (48)</td><td rowspan="2">Outfall density (35) & Infrastructure access density (34)</td><td>Infrastructure access density (33)</td></tr>
<tr><td>4</td><td>LU: commercial (29)</td><td rowspan="2">LU: commercial (36) & LU: Industrial (33)</td><td rowspan="2">LU: commercial (31) & Outfall density (28)</td><td>Outfall density (31)</td></tr>
<tr><td>5</td><td>Outfall density (27)</td><td>LU: commercial (24)</td><td>LU: commercial (27)</td></tr>
<tr><td>6</td><td>Generating site density (22)</td><td>Outfall density (26)</td><td rowspan="3">LU: Residential (24) & Generating site density (24) & Development age (20)</td><td>Generating site density (23)</td><td>Generating site density (26)</td></tr>
<tr><td>7</td><td>Development age (20)</td><td>Infrastructure access density (14)</td><td>Development age (16)</td><td>Development age (18)</td></tr>
<tr><td>8</td><td>LU: Industrial (16)</td><td>Development age (6)</td><td>LU: Residential (14)</td><td>LU: Residential (14)</td></tr>
<tr><td>9</td><td>LU: Residential (15)</td><td>LU: Residential (3)</td><td>LU: Industrial (14)</td><td>LU: Industrial (10)</td><td>LU: Industrial (13)</td></tr>
<tr><td>10</td><td>Aging sanitary infrastructure (9)</td><td>Aging sanitary infrastructure (1)</td><td>Aging sanitary infrastructure (7)</td><td>Aging sanitary infrastructure (6)</td><td>Aging sanitary infrastructure (7)</td></tr>
</table>

Generally, the chi-square test results (Tables C2-3 to C2-7) revealed that the differences between the risk factors' performances were statistically different and that these performances (Table 3-4) could be used to prioritise the factors. The final ranking of risk factors to predict locations of illegal discharges across the various discharge pathway groups is presented in Table 3-7. Few exceptions are noted though. In the water pathway group, two comparisons were insignificant: commercial vs. industrial risk factors ($\alpha < 0.065$) and population density vs. drainage density risk factors ($\alpha < 0.273$); suggesting that their performances are more or less same. All the comparisons in the solid waste pathway group were significant except for outfall density vs. infrastructure access density risk factors ($\alpha < 0.412$). Other comparisons which produced insignificance in performance were in greywater pathway group: residential vs. development age ($\alpha < 0.059$); residential vs. generating site density ($\alpha < 0.069$); commercial vs. outfall density ($\alpha < 0.110$) and outfall density vs. generating site density risk factors ($\alpha < 0.086$).

**Composite map production:** Results from the Analytical Hierarchy Process (AHP) for determining risk factors weights are presented in Table 3-6. Applications of risk factors weightings (for each discharge pathway group) allowed composite maps to be generated, each reflecting the effect of the discharge pathways on illegal discharges in the two catchments. The distribution of land area and discharge records over the three risk levels in each composite map provide a numerical measure of the 'qualitative sensitivity' of the overall risk map to different weight schemes associated with the discharge pathway groups. The number of sub-catchments with high risk, percent area and discharges captured in high-risk areas depicted on the composite maps are summarised in Table 3-8. The composite map for all combined discharge pathways is presented in Figure 3-4. The composite maps for the separate pathway groups namely; wastewater, water, greywater and solid waste are presented respectively in Figures C3.1 to C3.4 in Appendix C3.

Two scenarios were considered in the production of the composite maps. In scenario (a) all sub-catchments were evaluated with all the 10 risk factors. The results of scenario (a) are shown in Figure 3-4a and also in Figures C3.1a, C3.2a, C3.3a and C3.4a in Appendix C3. These figures indicate that the informal settlements in southern Kuils River catchment (Mfuleni, Khayelitsha, Macassar, etc.) are medium risk whereas conditions on the ground indicate high risk areas. The disagreement stem from the fact that 6 risk factors (namely industrial & commercial land uses, development age, generating site density, infrastructure access density and aging sanitary infrastructure) do not apply in informal settlements. The inclusion of these 6 risk factors had an effect of moderating the risk levels in these areas. Scenario (b) applied only four risk factors (namely residential land use, population, drainage and outfall densities) to informal settlements' sub-catchments while rest of the sub-catchments were analysed with all 10 risk factors. Results of the second scenario are shown in Figure 3-4b and also in Figures C3.1b, C3.2b, C3.3b and C3.4b in Appendix C3, all depicting high risk for informal settlements and consistent with conditions on the ground. The results in both scenarios underscore the importance of selecting risk factors that correctly applies to the areas under investigation.

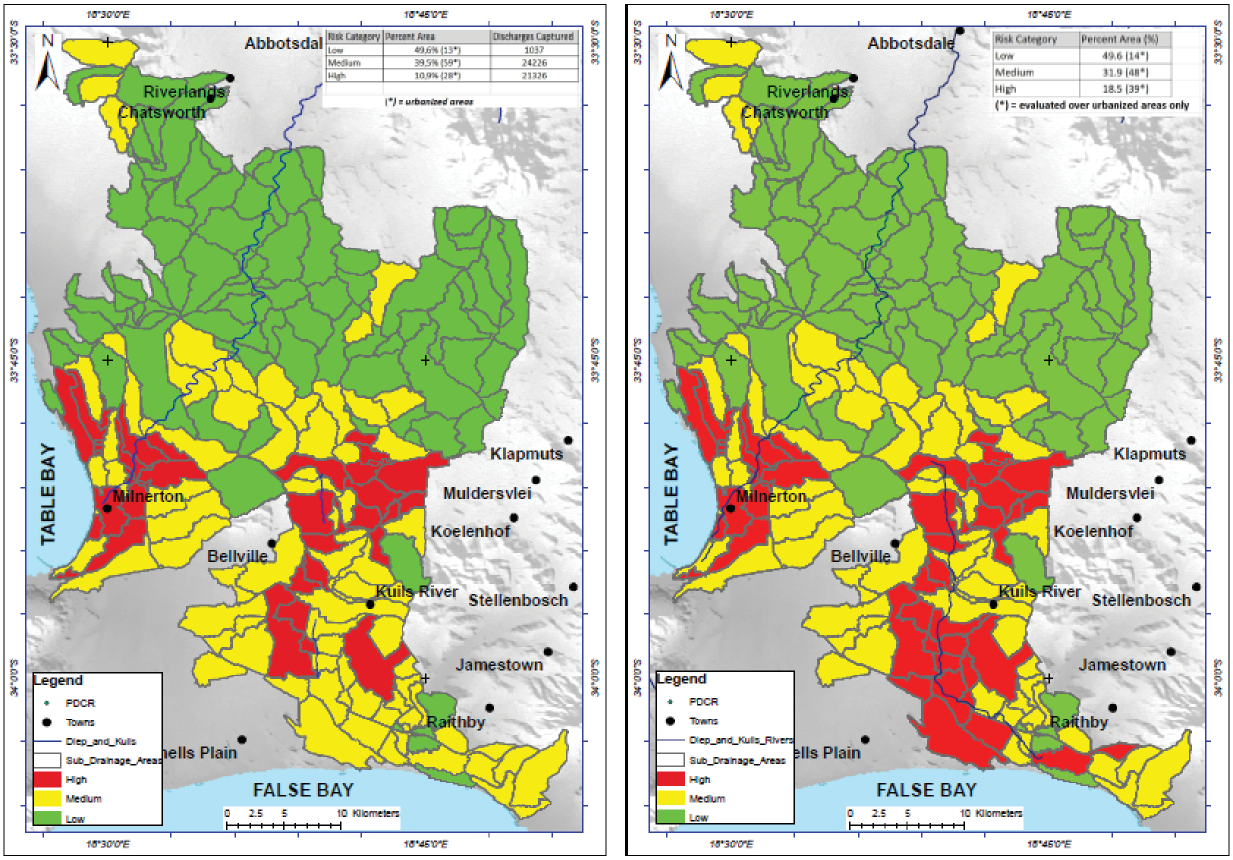
Generally, the high-risk sub-catchments repeat themselves in all the pathway groups. Thus, the percent high-risk areas (about 12% and 18% in scenario (a) and (b) respectively) are quite uniform across discharge pathway groups when evaluated over the entire catchments. These percent areas may give a wrong impression that the area of concern is very small; but when the percent area is evaluated over the developed or urbanised area, these figures are more than doubled (about 27% and 38%). The reason for same high-risk sub-catchments repeating across all the discharge pathway groups is due to the fact that these sub-catchments are characterised by high population and drainage densities and mostly include informal settlements and other low-income areas. In these areas, water and sanitation services are lacking, operation and maintenance of the limited services are woefully inadequate. The pathways in these areas are often merged and a problem in one affects other pathways as well. For example, improper disposals of solid waste often ends up and block storm drainage and sewer systems causing overflow of greywater and wastewater to be illegally discharged into urban watercourses.

Bender (2016) used four different weight schemes in two catchments in a similar study. In one of the catchments, the high-risk area was about 27% of the total catchment area in all the weight schemes used to produce the composite maps; however, in the second catchment the high-risk area varied between 26 to 39%. The methods applied in ibid are different from this study, yet the results are fairly comparable. Bender (2016) used natural breaks algorithm to classify IDP into low, medium and high risks whereas this study used statistical frequency analysis theorem. Moreover, as this study applied AHP to develop risk factors' weightings, ibid derived his weighting schemes based on 'expert knowledge' of local conditions.

**Table 3-8: Summary of high-risk sub-catchments in the composite maps**

| Discharge pathway groups | Number of sub-catchments with high risk | Percent high-risk area (%) | Discharges captured in high-risk area |
|---|---|---|---|
| ***Scenario-1: All sub-catchments were evaluated with all 10 risk factors*** | | | |
| Wastewater | 33 | 12 (26*) | 8790 |
| Water | 25 | 13 (29*) | 595 |
| Greywater | 33 | 11 (28*) | 471 |
| Solid waste | 33 | 12 (26*) | 3628 |
| All/combined | 33 | 11 (27*) | 21326 |
| ***Scenario-2: Informal settlements sub-catchments were evaluated with 4 risk factors; all else with the 10 risk factors*** | | | |
| Wastewater | 42 | 18.3 (37*) | |
| Water | 32 | 15.2 (32*) | |
| Greywater | 42 | 17.4 (36*) | |
| Solid waste | 42 | 18.5 (39*) | |
| All/combined | 42 | 18.5 (39*) | |

(*) percentage evaluated over urbanised area only




**(a)** **(b)**

**Figure 3-4: Composite illegal discharge potential risk map for all/combined discharge records.**
**(a) all sub-catchments were evaluated with all 10 risk factors; (b) Informal settlements sub-catchments were evaluated with 4 risk factors, all else with 10.**

### Limitations in the risk mapping

The limitation of composite risk mapping is inherent in four variables: (1) risk factor performance, (2) risk factors' relative weights, (3) risk factor interactions and (4) uncertainties inherent in the datasets. While risk factor performance and relative weights were adequately investigated, risk factor interactions and uncertainties were not accounted for in this study. The mapping scale used in this study is still coarse which may have an effect of over or under ranking sub-catchments' risk levels. All datasets were obtained from the City of Cape Town and their accuracies cannot be vouched by the project team.

## 3.4 Summary of locating priority areas

This chapter has demonstrated in the case study catchments that many land use, hydraulic and hydrologic characteristics affect the location of illegal discharges. The spatial analysis yielded rankings of risk factor performance which indicated a handful of risk factors, namely drainage density, population density, infrastructure access density, commercial land use, outfall density and generating site density, which are most important in determining IDP in Diep- and Kuils River catchments. The municipality should focus their mapping efforts on analysing these risk factors, especially since many of the datasets already exist in their database. Other smaller or more cash-strapped municipalities with similar characteristics of developed areas, as in Diep- and Kuils catchments, may narrow their risk mapping efforts to just drainage density, population density, infrastructure access density and commercial land use risk factors to achieve comparable, cost-effective results. Additional risk factors may be added but it must be noted that interactions between the additional and the recommended factors may exaggerate IDP risk if not properly accounted for during production of the composite map. In fact, such interactions were not investigated in this study and require further research. The significance of the IDP risk map is that it enables municipalities to prioritise target areas to direct or implement IDDE program investigations to achieve higher cost-efficiency.

Bender (2016:50) affirms that the usefulness of an IDP risk map to municipalities is recognised in the prioritisation of illegal discharge control programs. Outfalls, industrial facilities and other generating sites inspections can be prioritised based on the local IDP risk level, such that these hotspots in high-risk areas are inspected before (or more frequently) than those in low-risk areas. Public education and other programs designed to help prevent illegal discharges can be targeted at specific high-risk areas. By prioritising these programs, municipalities should be in a better position to demonstrate compliance with effluent discharge and ecosystem integrity requirements and achieve a higher cost-efficiency in their illegal discharge control efforts. Ibid notes that:

> *"there is an important distinction between illegal discharge potential (IDP) and illegal discharge occurrence. A risk map made with high-quality data will still only point to areas with high discharge potential, meaning that it is more likely that discharges will occur in high-risk areas, but that discharges will likely still occur in areas with a very low perceived risk. Therefore, risk maps should not be used to eliminate regions for inspections or other control activities, but serve as a tool to focus or direct those activities towards larger high-risk areas to improve efficiency. After the major problem areas are addressed, a second round of investigations may be run to focus on smaller high-risk hot spots, and a third round may*

*attend to low-risk areas to identify smaller, more isolated problems that may go unnoticed during risk analysis. The ultimate goals of IDP risk mapping are to integrate the risk mapping process with ongoing and emerging programs/activities and initiatives, and for the risk map to act as a tool to guide program planning”*.

# 4 OUTFALL ILLEGAL DISCHARGE DETECTION AND MONITORING

## 4.1 Introduction

The next stage following location of priority areas is the detection of illegal discharges at outfalls and monitoring of flow types. In certain communities, detection would also include pollution complaint hotline and on-site sanitation system inspections where they are prevalent. Initial and long-term outfall inspection is a popular and effective detection method to identify illegal discharges considering the many different types and sources from where these discharges originate. The condition at an outfall is a reflection of occurrences of illegal discharge potential in the sub-drainage area of the outfall and thus justifies further investigations in the area. A sub-drainage area with no illegal discharge into stormwater drainage system will have a clean or no flow during dry-weather conditions. Outfall inspection is thus an indispensable component of IDDE program to effectively and comprehensively manage illegal discharges in larger municipalities with different land uses. Stepwise procedures involve in accomplishing outfall inspections is presented in Figure 5-1. If flow is identified at an outfall, knowledge of the flow type (sewage, washwater, groundwater, tap water, etc.) is essential to assist in tracing to the source. Consequently, a complementary monitoring of flow or source types is mandatory in order to develop a tool to distinguish between flow types. Section 4.2 presents methodology and techniques employed in detection and indicator monitoring of illegal discharges and section 4.3 outlines case study application.

## 4.2 Methodology and Techniques

### 4.2.1 Complaint hotline

A pollution complaint hotline is a devoted phone number (landline/mobile) or website or any social media platform that enable citizens to report incidences of pollution, including illegal discharges. There are benefits and challenges associated with complaint hotlines, thus the need must be strongly supported. Benefits include early identification and removal of illegal discharges; ability to identify and reveal suspect generating sites for future investigation and corrective measures and ability to create and stimulate public awareness and active participation. Due to usually swift response required to investigate any reported complaints, this technique is very effective in dealing with intermittent and transitory illegal discharges. Resources to provide 24/7 hotline services, advertise hotline number and establish processes and responsibilities may be challenging to some municipalities. The stepwise procedures to institute and sustain complaint hotline dedicated for IDDE program are outlined in Table 4-1. A detailed description of the stepwise procedures is provided in Brown et al. (2004) from which the following excerpts are taken.

**Table 4-1: Stepwise procedures to establish effective IDDE hotline (Source: Brown et al., 2004:71)**

| Steps | Key Elements |
|---|---|
| 1. Define the scope | • Determine if a hotline is needed<br>• Define the intent of the hotline<br>• Define the extent of the hotline |
| 2. Create a tracking and reporting system | • Design reporting method<br>• Design response method |
| 3. Train personnel | • The basics and importance of IDDE<br>• The complaint hotline reporting, investigation and tracking process<br>• How to provide good customer service<br>• Expected responsibilities of each department/agency |
| 4. Advertise | • Advertise hotline frequently through flyers, newspapers, displays, etc.<br>• Publicise success stories |
| 5. Respond to complaints | • Provide friendly, knowledgeable customer service<br>• Send an investigator to respond to complaints in a timely manner<br>• Submit incident reports to the hotline database system |
| 6. Track incidents | • Identify recurring problems and suspected offenders<br>• Measure program success<br>• Comply with annual report requirements |

In defining the scope, the intent must be clearly established such as to process the complaint, investigate and institute the necessary enforcement procedures. The extent of the scope should include elements such as area coverage for the hotline, types of pollution streams to report, departments involved and their responsibilities. Effective planning and coordination is essential if the hotline is established to serve different departments. A phone call-in and/or a website may be used as a technique for reporting. With phone call-in, the number must be easy to remember and the line should be active 24/7 to encourage citizens to report as quickly as a problem is detected. Incident Report and Response Form is a basic tool to accomplish detection and investigation through hotline and a type of this form is provided in Appendix D1, which needs to be completed in full. Advertising hotline regularly using tools such as television, newspapers and flyers, preserves the communication fresh in public memory. When success stories are included in the advertisement, it builds public confidence and encourages stewardship and responsibility in the community. All pollution complaints should be logged instantly on computer for follow-up action, if possible, not more than 24 hours later. To help evaluate the success and improve the hotline detection method, the following data need to be assembled:

- ❖ annual number of complaints (or calls);
- ❖ annual number of incidents investigated;

- ❖ annual number of actual IDDE incidents;
- ❖ average time to follow up on incident report per year;
- ❖ average time to remedy identified illegal discharge per year; and
- ❖ most common problem identified by public per year.

### 4.2.2 On-site sanitation system inspection

Typical an on-site sanitation system includes septic tank system which consists of three components: the septic tank that serves as anaerobic digestion and sedimentation unit; the leaching field (soak-away area) where the discharged water from the tank infiltrate into the ground and the piping system that transports wastewaters into the tank and leaching field. A failing septic tank system often transports solids that should have settled in the tank to the leaching field, which tends filling up the pore spaces between the soil grains and thus reducing the soil permeability. This result in ponding on the ground surface as the soil pores become clogged, permitting wastewater to run off and enter stormwater drainage systems and watercourses during both dry and wet weather conditions. Inspection of septic tanks in a community provides the prospect of identifying the failing ones and applying corrective measures. There are various types of on-site sanitation, which are described and illustrated in PDG (1994). On-site sanitation systems refer to those where the sanitary wastes are not transported to an off-site location for primary treatment. In South Africa three types are more generally used:

- VIPs (Ventilated improved pit latrines)
- LOFLOS (Low Flush on Site sanitation systems; also referred to as aqua privies)
- Septic tanks.

Both VIPs and LOFLOS are similar in that they generally receive only human excreta from a household (with occasional greywater addition); septic tanks on the other hand generally receive both greywater and human excreta. These systems are prevalent in low-income or informal communities and they are characterised by poor usage and lack of regular maintenance resulting in frequent overflows. The overflows may enter directly or are washed by stormwater runoff into nearby drainage systems. Conventional standard operating procedures for IDDE program, however, are not applicable in typical low-income communities because the on-site sanitation problems are characterised by physical, institutional and socio-economic challenges. Thus, the National Strategy to manage water quality effects of settlements was developed by DWAF (1999) to purposely deal with pollution emanating from informal settlements in all waste streams. The National Strategy and the supporting operational guidelines are as useful and effective now as they were two decades ago. Soak-away areas of septic systems in formal communities, however need to be inspected to check for odours and damp areas, which will provide clues of clogging in the leaching field and suggest the need for corrective measures.

### 4.2.3 Outfall inspection and flow types monitoring

The outfall inspection is intended to geographically locate all stormwater drain outfalls, inventory their physical and discharge characteristics, evaluate their illegal discharge potential and severity. The inspection involves walking all urban watercourses to measure and record requisite information about each outfall. Training of field crews is a pre-requisite to outfall inspection and flow types monitoring although the level of expertise required is low and since these activities are the most expensive component of IDDE program, effective planning cannot be underestimated. Inspection and indicator monitoring should be adapted to serve the distinct requirements of each municipality and should be undertaken when personnel and funds allow. Dry weather discharge may be an indication of an illegal connection to the drainage system since the drainage system should not be receiving polluted flows in dry weather conditions, except for few discharges, e.g. excess urban lawn and parks irrigation return flows.

Outfall inspections and indicator monitoring must be conducted under dry weather conditions, normally during dry season or when there has been no runoff producing rainfall for the previous 48 hours. Visual inspections should be performed to locate indicators of illegal discharge (evidence of toilet paper, grease, excessive plant growth, foul odour). If there is no flow at the time of inspection, but visual or olfactory evidence of illegal discharge is observed the outfall is re-visited. The result of outfall inspection is to provide direction as to which outfall drainage area or stormwater drain segment warrants further investigation to locate the source of illegal discharge. The flow type monitoring also provides a technique or decision-making tool to distinguish between flow types, which is necessary for isolating illegal discharges to their sources. Stepwise methodology and techniques to conduct outfall inspection and flow types monitoring is presented in Figure 4-1 and discussed below. Steps 6 and 7 should be periodically revised to account for temporal variation in outfall discharge and flow type water quality characteristics.

**Step 1: Acquire necessary resources**

Preparation for outfall inspection consists of acquiring the resources needed to conduct outfall investigation. The resources to consider include field maps, field equipment, staffing and training. Stormwater plans (indicating stormwater infrastructure, hydrological features and urban landmarks such as streets and property boundaries) should be obtained from the relevant sources. Outfalls, stormwater conveyances and delineated sub-drainage areas captured on these plans should be used as field maps. Outfall Inspection (OI) Form (Appendix D1) must be prepared and be ready for field use.

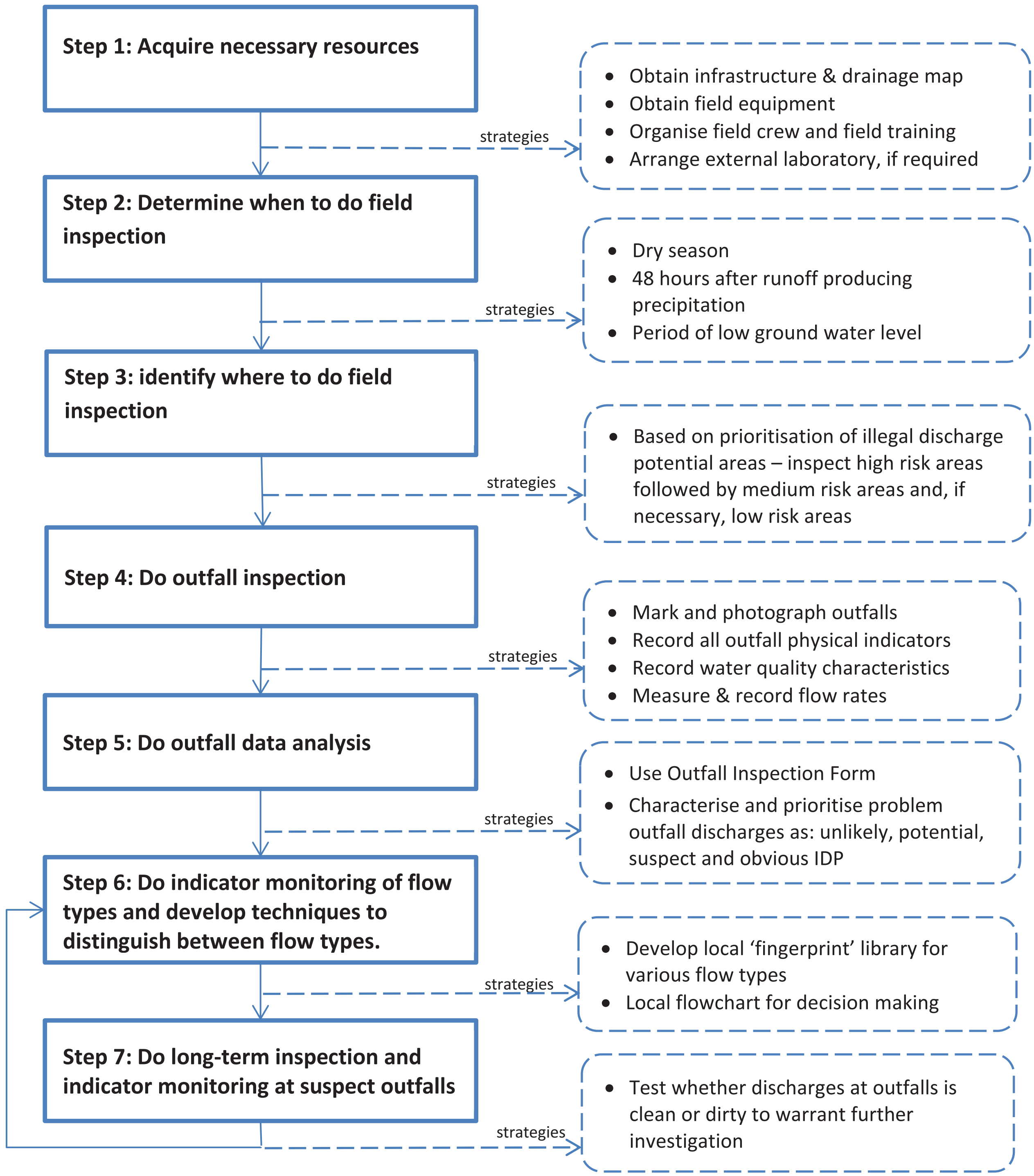



**Figure 4-1: Flow chart for outfall inspection and flow types monitoring**

Field equipment to acquire for outfall and flow type monitoring include, but limited to the following:

- Outfall Inspection Form
- Backpack
- Sample bottles
- Cooler box with ice bricks
- Digital camera
- Cell phones
- Clipboards and pencils
- First aid kit
- GPS unit
- Spray paint
- pH and Temperature meter
- Conductivity meter
- Flashlight (with spare batteries)
- Hand gloves and sanitiser
- Tape measure
- Waders and gumboots
- Stopwatch
- Machetes

At least two or three field staff crew is required for fieldwork to provide greater safety and flexibility to divide the tasks accordingly. All crew members should be trained on how to complete the OI form, how to use the field equipment, how to measure the various quantitative parameters, how to take samples and other field operations including health and safety considerations. Basic understanding of illegal discharges is required from field crew members. Use of tertiary education interns can be cost-effective if they are adequately trained. Laboratory to analyse water quality samples must be identified and arrangement has to be made concerning commencement and frequency of sample deliveries and other necessary requirements such as parameters of concern, analytical methods, detection limits, quality control and quality assurance and others.

**Step 2: Determine when to do fieldwork**

Field preparation must also include defining when to conduct the inspection and monitoring. The best time is during dry season or at least, 48 hours after runoff generated rainfall must be allowed to lapse before fieldwork commences. This is to ensure that only non-storm discharges were investigated.

**Step 3: Identify where to do field inspection**

Field preparation must also include defining where to conduct the filed screening investigations. For the initial run, all outfalls irrespective of their sizes may be inventoried including outfalls terminating within 100 metres buffer zones or anywhere within the stream corridor or floodplain. In the subsequent runs, sub-catchments prioritised as high risk may be given primary consideration followed by medium risk, then low-risk sub-catchments if budget permits.

**Step 4: Do initial outfall inspection**

The Outfall Inspection Form provides a record of each site visit and shall be filled out in the field. If a site cannot be inspected, field crews shall record an explanation of the circumstances on the form. The form and instructions for completion are presented in Appendix D1 together with some guidance information. The form consists of six sections and a brief description of each section is as follows:

a) ***Section 1 – Background Data:*** Record current date, physical location, GPS location, investigators name and other background data.
b) ***Section 2 – Outfall Description:*** Enter information describing the outfall, including outfall ID, whether closed pipe or open channel, physical dimensions, shape and material type. Indicate if water is flowing from the outfall (with yes or no) and describe (e.g. trickle, moderate, substantial).
c) ***Section 3 – Quantitative Characterisation:*** If flowing water is observed, measure flow rate and take a water sample for lab testing. Also measure physical water quality parameters (pH, conductivity and temperature).
d) ***Section 4 – Physical Indicators for Flowing Outfalls Only:*** Collect information on physical features of flowing outfalls (e.g. odour, colour, turbidity, floating materials) and indicate their relative severity.
e) ***Section 5 – Physical Indicators for Flowing and Dry Outfalls:*** Collect and enter information on physical features of both flowing and dry outfalls. Examine outfall for presence and type of algae, abnormal vegetation, damage, stains, trash and condition of plunge pool (if any). Structural problems (*e.g.* cracking, holes in corrugated metal pipes, dissolved concrete) should also be noted.
f) ***Section 6 – Overall outfall characterisation:*** Information from sections 1 to 5 is used to characterise the severity of illegal discharge at the outfall as unlikely, potential, suspect and obvious according to the following criteria:
    - ***Unlikely:*** non-flowing outfalls with no physical indicators of illegal discharge.
    - ***Potential:*** the presence of two or more indicators in Section 5 only
    - ***Suspect:*** the presence of one or more indicator(s) in Section 4 with a severity index of 3.
    - ***Obvious:*** the presence of one or more water quality indicator in Section 3 exceeding recommended limit.

Standard operating procedure (SOP) for conducting outfall inspection is presented in Appendix D2 with references to sampling protocols to be observed. Ensuring the health and safety of field personnel is the responsibility of both Project leader and field crews themselves. The safety of field crew overrides all other considerations. In general, the following safety protocol has to be observed:

a) Carry a mobile phone and first aid kit on all field site visits.
b) Exercise caution when encountering ants, stinging insects, ticks, snakes, mice, rats and the like, as well as off-leash pets.
c) Many outfalls are located in remote areas that may be near gathering places for homeless or transient individuals. Do not enter a potentially hostile area.
d) Exercise caution when accessing outfall areas and encountering uneven or slippery terrain (rip rap), steep slopes and possible sharp objects such as broken glass, gabion baskets, metal, fencing, needles, or any debris with sharp or pointed edges or corners.
e) Perform fieldwork in teams of at least two whenever possible.
f) Storm drain outfalls contain a variety of waterborne bacteria and other harmful chemicals. Wash hands or use antibacterial wipes or hand gels liberally, especially prior to lunch breaks, etc.
g) Any work in confined spaces will be performed by technicians who are appropriately trained and certified for such work.

**Step 5: Do initial outfall data analysis**

Methods for outfall data analysis consisted of: data management, outfall characterisation, problem outfall counts and mapping of OI data. At the conclusion of each field day work, hardcopy of Outfall Inspection Form should be filed and stored in a secure location and information on the form should be electronically captured and entered directly into a database. The list of outfall sites visited should be checked periodically against the target list of outfalls to be inspected to be sure that none have been missed and no data have been lost. The database will allow OI information to be linked to GIS to generate maps that show, for example, the spatial distribution of flowing and problem outfalls. The OI data are used to characterise outfalls as having an unlikely, potential, suspect or obvious illegal discharge potential. The criteria used to characterise the outfalls are described above in step 4, section 6 of Outfall Inspection Form. Following the characterisation, problem outfalls may then be determined and mapped to indicate their spatial distribution. The maps are simply tools for understanding the OI data. Results of the characterisation can be used to:

- Validate the outcome of locating priority areas from risk analysis and risk mapping component.
- Develop long-term monitoring strategy of problem outfalls.

**Step 6: Do indicator monitoring of flow types and develop techniques to distinguish between flow types**

Indicator monitoring of flow types is a program to collect and analyse representative samples from the source of major flow types in the catchment to build what is often called “fingerprint” library. This library is simply a databank and statistical summary of water quality characteristics (or signatories, or “fingerprint”) of various discharge flow types (such as sanitary wastewater, washwater (laundry and car wash), industrial, landscape irrigation, groundwater or tap water). On the basis of this library, a decision-making tool (or flowchart technique) is developed to identify illegal discharges and to distinguish them according to flow types. Design and implementation of indicator monitoring of flow types involve the following methodology and techniques: (1) selection of indicator parameters that could identify illegal discharges, (2) sampling protocol and methods to analyse sample, (3) a “fingerprint” library and (4) flowchart technique to distinguish between flow types. The first two of these methodologies and techniques are also applicable to indicator monitoring of suspect outfalls.

**Selection of indicator parameters:** Detection of illegal discharges into storm water drains necessitates measurement of particular parameters of the identified outfall discharge. Indicator parameters of greatest concern should be quite unique for each flow type so that their presence in a discharge can be used to infer likely flow type source. A methodology used in this study is based on detection and quantification of clean waters (e.g. tap and spring waters) and dirty waters (e.g. wastewaters, wash-waters, irrigation return flows, etc.). If the relative concentrations of these flow types are known, then the outfall discharge can be assessed as polluted or not. According to Brown et al. (2004:121), an ideal indicator parameter should meet the following notable criteria: (a) for major flow types, there should be significant variation in concentrations among them (b) in each flow type, there should be fairly minor variations in concentrations (c) parameter should be conservative (i.e. physical, chemical or biological processes do not result in changes in concentration) (d) easy measurements and repeatability.

Table 4-2 summarises some chemical parameters that meet most of the above criteria and compares their ability to detect different flow types. Table 4-2 also include physical indicators (often observed at outfalls) that may provide clues about different flow types. Physical indicators are very effective in identifying obvious and gross pollution at outfalls without detail laboratory analysis. Based on information in Table 4-2 and in particular, recent studies such as Irvine et al. (2011), Panasiuk et al., 2015 and 2016, indicator parameters selected for chemical monitoring in this study are: (1) ammonia, (2) boron, (3) conductivity, (4) copper, (5) detergents (surfactants), (6) *E. coli*, (7) fluoride, (8) fluorescence, (9) pH, (10) potassium, (11) temperature, (12) total chlorine, (13) total hardness and (14) turbidity. Brown et al. (2004:121) assert that no single indicator parameter is ideal and suggested that one needs to look for combination of indicators suitable for their local conditions. Overview of indicator parameters selected for this study is presented in Appendix D3.

**Table 4-2: Candidate indicator parameters to identify flow sources types (after Pitt, 2001:69)**

| Candidate parameter | Natural water | Potable water | Sanitary sewage | Septage water | Industrial water | Wash water | Rinse water | Irrigation water |
|---|---|---|---|---|---|---|---|---|
| **Chemical parameters** | | | | | | | | |
| Fluoride | ❍ | • | • | • | ▲ | • | • | • |
| Hardness | ❍ | ▲ | • | • | ▲ | • | • | ❍ |
| Surfactants | ❍ | ❍ | • | ❍ | ❍ | • | • | ❍ |
| Fluorescence | ❍ | ❍ | • | • | ❍ | • | • | ❍ |
| Potassium | ❍ | ❍ | • | • | ❍ | ❍ | ❍ | ❍ |
| Ammonia | ❍ | ❍ | • | • | ❍ | ❍ | ❍ | ❍ |
| **Physical parameters** | | | | | | | | |
| Odour | ❍ | ❍ | • | • | • | ▲ | ❍ | ❍ |
| Colour | ❍ | ❍ | ❍ | ❍ | • | ❍ | ❍ | ❍ |
| Clarity | ❍ | ❍ | • | • | • | • | ▲ | ❍ |
| Floatables | ❍ | ❍ | • | ❍ | • | ▲ | ▲ | ❍ |
| Deposits and stains | ❍ | ❍ | • | ❍ | • | ▲ | ▲ | ❍ |
| Vegetation change | ❍ | ❍ | • | • | • | ▲ | ❍ | • |
| Structural damage | ❍ | ❍ | ❍ | ❍ | • | ❍ | ❍ | ❍ |
| Conductivity | ❍ | ❍ | • | • | • | ▲ | • | • |
| Temperature | ❍ | ❍ | ▲ | ❍ | • | ▲ | ▲ | ❍ |
| pH | ❍ | ❍ | ❍ | ❍ | • | ❍ | ❍ | ❍ |
| Note: ❍ implies relatively low concentration; • implies relatively high concentration; ▲ implies variable conditions | | | | | | | | |

**Develop sampling protocols and methods to analyse samples:** Eight essential features underlie a worthy field sampling protocol:

a) When to do field sampling
b) Where to do field sampling
c) Preparation of sample bottles
d) Technique to collect sample
e) Samples preservation and storage
f) Chain of custody plan and labelling of sample
g) Quality assurance/control samples
h) Health and safety concerns

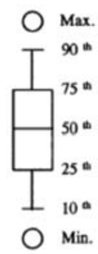
Similar to outfall inspection, sampling flow type should be done during dry weather periods or at least 48 hours after runoff generated rainfall had been allowed to lapse before field sampling commences. This is to ensure that only flow type discharges are investigated. Although 72 hours without rainfall has been the usual designation of dry weather, many studies involving IDDE program have reduced this period to 48 hours to make sampling more applicable. The following water sampling Standard Operation Procedures are recommended for adoption:

- SANS 5667-1, Water Quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques.
- SANS 5667-3, Water Quality – Sampling – Part 3: Guidance on the preservation and handling of water samples.
- SANS 5667-5, Water Quality – Sampling – Part 5: Guidance on sampling of rivers and streams.
- SANS 5667-10, Water Quality – Sampling – Part 10: Guidance on sampling waste waters.
- SANS 5667-11, Water Quality – Sampling – Part 11: Guidance on the sampling of groundwaters.
- SANS 5667-14, Water Quality – Sampling – Part 14: Guidance on quality assurance and quality control of environmental water sampling and handling.

Basic analytical methods suitable for IDDE program in terms of cost-effectiveness, ease and rapidity of analysis, minimum staff training requirements and high-level precision are outlined in Appendix D3 and also discussed extensively in Pitt (2001:78-95).

**Develop "fingerprint" library:** As defined above, "fingerprint" library is simply a databank and statistical summary of water quality characteristics of various flow types. The purpose of the library is to locally characterise these flow types in the community. In order to compile fingerprint library, local flow types need to be sampled and analysed for indicator parameters of concern. Pitt (2001:72-77) discusses the statistical procedure to determine sample size required for the library and emphasizes that *"obtaining relatively large database library for the flow types indicator parameter concentrations is very important and should be a significant portion of dry-weather flow source identification project"*. A large database required to statistically estimate sample size for the library is often unavailable. In such situations Brown et al. (2004:136), however states that *"as a general rule, about 10 samples are typically needed to characterise each flow type, although more samples may be needed if the flow type has a high coefficient of variation"*. Data from the library should be analysed to (1) determine which parameters contribute unique and significant information to the flow type characterisations and (2) determine the degree to which individual flow types could theoretically be separated and identified based on these flow type characterisations. This is achieved by the use of statistical analyses such as the use of box and whisker plots as described below.

A box and whisker plot is a graphical method of displaying variation or distribution in a set of data (such as concentration, loads and flow rates datasets); and to evaluate if significant differences occur. The box's upper and lower borders represent 75$^{th}$ and 25$^{th}$ percentile values in the dataset and the horizontal line in the box represents the median (50$^{th}$ percentile). Extending from the box are the whiskers (i.e. upper and lower vertical lines); with the upper and lower ends of the whiskers denoting the 90th and 10th percentiles respectively and beyond these are the maximum and minimum values in the dataset represented by circles.




Where the data distribution is not normal, log-transformed data is used in the analyses in order to approximate a normal distribution. A box-and-whisker plot for each flow or source category data needs to be prepared using a suitable software package. Box and whisker plot of each parameter graphically summarises the concentrations at which one indicator parameter occurs within each flow type category. Comparisons of source box plots should be made to visually assess significant differences. At least at 95% confidence level, boxes are generally and significantly different if they do not overlap

**Develop techniques to distinguish between flow types:** The goal of the decision-making tool (i.e. the flowchart technique) is to be able to relate or attribute a water sample in stormwater drainage system to one of the flow type categories (tap water, spring water, wash-waters, wastewater, etc.) with a known level of confidence. To achieve this aim, a technique must be used to relate water sample data from each outfall (or from any point in the drainage system) to the library of non-storm flow type data to identify which outfalls (or drainage points) correlate to which category of source flow type. This is the stage where the fingerprint library is used to evaluate the effectiveness of a test parameter as an indicator of illegal discharge. Library datasets are analysed to evaluate reasonable thresholds (or cut-off) limits of test parameters as indicators of illegal discharges. Subsequent to establishing a hierarchy of threshold limits of parameters, a flowchart is formulated for decision making in identifying the most likely origin of illegal discharge. Upstream of the outfalls, the flowchart generally describes a technique to detect which flow type constitute the main proportion of non-stormwater discharge samples in mostly residential and commercial land use areas. The flowchart allows discharges at outfalls and anywhere in the drainage system, to be classified as polluted or unpolluted and also to identify and distinguish between sanitary wastewaters and wash-waters. This enables outfalls to be prioritised for long-term inspection, monitoring and tracking to the discharge source.

The first step in the flowchart methodology is to visually analyse the data using the box and whisker plots and check for overlap or non-overlap of the boxes for significant differences among the source or flow type categories. Next is to evaluate the library tabula data to estimate 'cut-off' value to apply as an indicator threshold limit and also to estimate a quantified number of "false positives" and "false negatives". Brown et al. (2004:120) define false positives as identifying a non-illegal (uncontaminated) flow as illegal (contaminated) and false negative as identifying an illegal flow as non-illegal. Finally, a determination or verdict has to be made as to whether the parameter in question is a good candidate for flowchart technique. It could be seen from the flowchart methodology outlined above that the accuracy to which a discharge at an outfall can be classified or related to a particular flow type is contingent on the accuracy of local flow type water quality characteristics measured. Thus, the importance of local data for fingerprint library and to characterise the source flow types cannot be over emphasised.

**Step 7: Do long-term inspection and indicator monitoring at suspect outfalls**

For long-term inspection and monitoring at suspect outfalls all the stepwise procedures detailed above would re-apply. Fieldwork preparation will consist of acquiring necessary resources as in step 1, determining when and where to do inspections as in steps 2 and 3, respectively. Where to do long-term monitoring will be determined by the outcomes of steps 4 and 5 (outfall characterisation). Same indicator parameters selected in step 6 would be used to screen outfalls to confirm if identified discharges are in fact illegal. The tool for long-term inspection and monitoring is also Outfall Inspection Form and the procedures are same as detailed in step 4 and standard operating procedure in Appendix D2.

A notable addition in this step is in-depth field and/or laboratory sample analysis to quantify water quality characteristics and application of flowchart technique (developed in step 6) to identify predominant flow type in the discharge. Results of water quality characteristics should be used to quantify pollutant loads at problem outfalls based on selected indicator parameters to assess pollution levels from the outfall drainage area. Some illegal discharges observed at outfalls may be intermittent or transitory discharges. Thus, when discharge is confirmed as illegal, field crew should immediately investigate surrounding areas to find the source, or initiate tracking investigation.

## 4.3 Case study application of illegal discharge detection procedures

Methodology and techniques described under section 5.2.3 (outfall inspections and flow types monitoring) were applied in the case study catchments (Diep- and Kuils River catchments) in Cape Town and the results are presented below.

### 4.3.1 Fieldwork preparation

Preparation of outfall inspection consisted of acquiring the resources listed in section 5.2.3, step 1 above. Stormwater plans (indicating stormwater infrastructure, hydrological features and urban landmarks such as streets and property boundaries) were obtained from the CoCT's Catchment and Stormwater Management department. Outfalls, stormwater conveyances and delineated sub-drainage areas are located on these plans and were used as field maps. Outfall Inspection Form, Appendix D1, was used as a tool to screen outfalls. In-service Diploma students were recruited under this project to undertake among other duties the outfall inspection and flow types indicator monitoring. A total of 5 persons were involved which helped provide greater safety and flexibility to divide the tasks accordingly. All crew members were trained on how to complete the OI field sheet, how to use the field equipment, how to measure the various quantitative parameters, how to take samples and other field operations including health and safety considerations. An attempt was made to inspect all outfalls discharging into Diep- and Kuils River within the metro, including those terminating within 50 metres buffer zones or anywhere within the stream corridor. At least, 48 hours after runoff generated rainfall was allowed to lapse before fieldwork commences and this criterion was easy to achieve by virtue of recent Cape Town's prolonged drought.

### 4.3.2 Initial outfall inspection and data analysis

Initial outfall inspection and data analysis were conducted according to methodology and techniques described in section 5.2.3, steps 4 and 5 and outfall inspection standard operating procedures presented in Appendix D2. Outfalls were inspected by walking along both Diep- and Kuils River. About 199 outfalls (47 on Diep and 152 on Kuils) were located, numbered and inventoried. Recorded outfall diameters ranged from 100 to 1800 mm (with a median value of 450 mm), excluding open channels. Non-storm flows were observed at a total of 107 outfalls (27 on Diep and 80 on Kuils). Tables D4.1 and D4.2 in Appendix D4 contain all qualitative and quantitative outfall data captured during the site visits respectively. Of 199 outfalls located on both rivers, 36 (18%) had flows that were described as trickle (< 0.5 L/s), 30 (15%) as moderate (0.5 to 5 L/s) and 41 (21%) substantial (>5 L/s). The detail of the flow descriptions for each catchment is presented in Table D4.3 in Appendix D4. Statistics of flow rates measured on both rivers is presented in Table D4.4 in Appendix D4. The mean and median flow rates for both rivers were 21.94 and 3 L/s respectively. Considering recent drought and water use restrictions in Cape Town during the period of outfall monitoring, one is inclined to assume that the data presented in Table D4.4 (Appendix D4) are very conservative. That being agreed upon, it would suggest the problem of dry-weather flow is a concern if the discharges are contaminated.

All flowing outfalls were sampled, iced and delivered to the laboratory for analysis. Physical parameters and observations were measured and recorded in the field. Chemical analyses were conducted in Civil Engineering Water Quality Laboratory, Cape Peninsula University of Technology. Analytical results are presented in Table D4.2, Appendix D4. A closer look at the statistical summary of the results in Table D4.5 in Appendix D4 shows that the nutrients are problematic (i.e. they exceed ecosystem health criteria, Table D4.6 in Appendix D4) and identifies most of the outfall discharges as illegal, at the time of inspections.

Physical indicators of illegal discharges observed at the outfalls are also summarised in Table D4.1 in Appendix D4. Evaluation of uncommon situations of flow, odour, colour, turbidity, floatables, deposits/stains, vegetation conditions and damage to drainage structures enabled to qualitatively characterise the outfalls as outlined in step 4, section 4.2.3 above. Applying visual observations alone to designate outfall discharge as illegal, will potentially produce many false conclusions, especially false negatives (i.e. identifying an illegal flow as non-illegal), because it does not allow quantifiable estimates of the flow components. The physical observations or indicators, however, were most useful for identifying gross contamination, i.e. only the most significantly contaminated outfalls could therefore be recognised. Results of the chemical analysis of some selected parameters, the nutrients in particular, were used to quantitatively confirm contamination at the outfalls as obvious when one or more of the nutrients ($NH_3$, $PO_4$) exceed 0.25 mg/L. The overall outfall characterisations are presented in Table D4.1 in Appendix D4 and summarised in Table D4.7 (Appendix D4). It is interesting to note that most of the outfalls receiving discharges from industrial and commercial land use areas are characterised as obvious and/or suspect. This suggests that the City must intensify its efforts to clamp down contaminated discharges from these areas. Spatial distribution of outfall flow description and characterisation is presented in Figures D4.1 to D4.8 in Appendix D4.

### 4.3.3 Flow types monitoring and development of flowchart technique

The results of the flow types monitoring characteristics ("fingerprint library") are presented in Tables D5.1 to D5.7 in Appendix D5. The results are further presented in box and whisker plots in Figures D5.1 to D5.25 in Appendix D5. Table D5.8 in Appendix D5 is a statistical summary of the "library" data describing the source flow types. Median and coefficient of variation (COV) values shown in Table D5.8 are important information. The

COV is a measure of variability in the data and it is determined as ratio of standard deviation to the mean. A high COV value designates a large range of data compared to a dataset with a smaller value of COV. Thus, some of the generalised inferences presented in Table 4-2 could not be verified in this project, underlying the need for local source flow data.

According to Pitt (2001), suitable indicator parameters are characterised by having considerably dissimilar concentrations in source flow types required to be distinguished. Again, suitable parameters also require low COV values for each flow type. Table 4-2 indicated the expected concentration variations for each flow type and Table D5.8 (Appendix D5) shows how these expectations compared with the local monitoring results. Table D5.8 indicates that the COV values are generally high for each flow type. A low COV values (less than about 0.4) are desirable for a parameter to be recommended as a quantitative indicator to evaluate flow types. An essential feature of any sampling program is that the sample sizes should be adequate to yield statistically significant conclusions. Various methods exist to define sample size ranging from traditional 'best professional judgment', to a resource-driven (e.g. funding, time and/or personnel) approach, to statistically-based process. The latter uses the COV values and allowable errors to estimate sample size (Pitt, 2001); the higher the COV values the more sizes are required. Our approach in this study in defining sample size (10) was one of resource-driven approach. Information presented in Table D5.8 suggests a need to increase the sample sizes in order to reduce the COV values. The library of each flow or source type is outlined below.

**Tap Water Samples:** Results of tap water sampling are presented in Table D5.1 in Appendix D5. The range of chlorine in tap water was comparatively similar to spring water (low concentrations). Treated water supply in the CoCT is not fluoridated; thus fluoride concentrations are also low. Fluoride is therefore not a suitable parameter to differentiate between treated tap water and natural spring water. Conductivity and hardness had low COV values.

**Spring Water Samples:** Samples were collected from spring sources during the recent drought period in Cape Town. Table D5.2 (Appendix D5) presents analytical results of spring water samples. Hardness and conductivity were the most notable indicator parameters for the spring samples with mean concentrations of about 26 mg/L and 170 μS/cm, respectively. Other parameters were in very low concentrations and the pH was a bit acidic with a mean of 5.87. Samples were clear and odour free, with no floatables, sediments or sheens, except BG00271 and BG00287 which had reddish brown suds.

**Irrigation Water Samples:** Irrigation return flows were collected from sprinkler runoff over lawns and landscaped areas. Sources of water used for irrigation are mainly effluent from wastewater treatment plants. Results are presented in Table D5.3 (Appendix D5). Chlorine concentrations were quite low (similar to tap and spring water samples). Fluorescence concentrations were relatively higher compared with tap and spring water samples. There were traces of colour in irrigation water samples and some were slightly cloudy owing to soil particles in suspension.

**Car Wash and Laundry Samples:** Tables D5.4 and D5.5 (Appendix D5) present test results from car wash and laundry samples, respectively. These two wash water sample groups were similar for turbidity, fluoride, total hardness and detergent. However, conductivity, pH, ammonia, potassium, total chlorine and fluorescence were higher in laundry relative to car wash samples. Carwash and laundry samples were coloured and cloudy.

**Industries Samples:** Characteristics of industrial flows tend to be associated to the raw materials used, final product and the waste or by-products created. Thus, various pollutants with different levels of concentrations may be associated with a variety of different industrial activities. Only few industries gave the research team limited access to sample their effluent discharges. These industries consisted of pulp and paper, textile, brewery and plastic recycling plant and they were organised into one category – namely ‘industries’. Due to limited number of industries sampled and limited sample size for each, the results presented in Table D5.6 (Appendix D5) are only indicative and no further analysis is provided in this report.

**Sanitary wastewater (Sewage) Samples:** Raw wastewater samples were collected from four wastewater treatment works in the CoCT, namely; Athlone, Bellville, Potsdam and Zandvliet Wastewater Treatment Plants (WWTPs). Bellville and Zandvliet WWTPs are both located in Kuils River catchment whereas Potsdam is the only WWTP in Diep River catchment. Results are presented in Table D5.7 (Appendix D5). Samples from wastewater were grey in colour and cloudy. Turbidity, detergents, fluorescence, ammonia and ammonia/potassium ratio are all distinguishable for these samples. Of critical importance is the ammonia/potassium ratio, which was always greater than unity. This observation has also been noted by researchers in the US (Pitt, 2001). A distinct and easily perceptible odour was obvious in all samples.

**Box and whisker plots of flow type characteristics**

Data from the ‘fingerprint library’ were used to create box and whisker plots (Figures D5.1 to D5.25 in Appendix D5) to establish concentration pattern for each parameter. According to Pitt (2001:153), *“the extent to which these concentration patterns differed from one flow type to the next and the variation observed in the patterns within a single flow type, would eventually determine the extent to which information from the outfall screening methodology could be used to identify the source or sources of non-storm flow* *from a specific outfall"*. For example, Figure 4-2 shows the box and whisker plots for ammonia/potassium ratio parameter. It is clear that the box for sewage does not overlap with any of flow types boxes. The inference here is that ammonia/potassium ratio for sewage is significantly different and could be used to distinguish sewage flows from wash-waters and all other flow types, at least at the 95% confidence level. Figures (D5.1 through to D5.25) visually illustrate for different indicator parameters, significant groupings in which flow types may be distinguishable. Analysis of flow type characterisation revealed that the 'fingerprint library' collected from non-storm flow types is sufficient to permit dirty or contaminated non-storm flows to be distinguished from non-contaminated or clean non-storm flows. It is also sufficient to allow a decision-making tool (flowchart technique) to be developed.

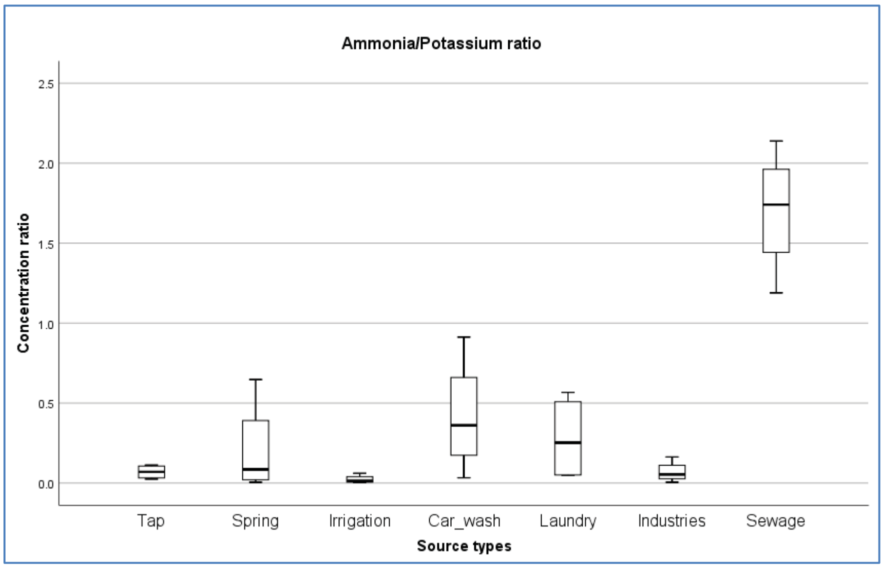



**Figure 4-2: Ammonia/Potassium ratio comparison for different source types**

**Development of flowchart technique to distinguish between flow types**

Industrial sites generate significant polluted storm and non-storm water discharges into stormwater system. Additional investigations at industrial areas are required to identify industrial operations that significantly generate these polluted discharges to urban watercourses and drainage systems. Pollutants discharged from industrial areas are so varied depending on factors such as type of activities or processes, raw and finished products, environmental and waste management compliance. In this regard, application of the flowchart technique (developed in this study) in industrial areas will only be limited to detecting flow types that are not typically industrial.

Library data from the flow types (tap, spring, irrigation, car wash, laundry, industries and sewage) are analysed to define a good threshold value for each parameter to use as an indicator of illegal discharges. The research team studied both the library tabular data and box plots in detail to select concentration values as ‘indicators’ of illegal discharges. Examination of the box plots indicated that uncontaminated waters (tap and spring waters) could be distinguished from the contaminated waters (irrigation, car wash, laundry and sewage) by the following indicator parameters: detergents, fluorescence, potassium, total chlorine, total hardness and turbidity. These inferences were made because the flow types’ boxes for these parameters do not overlap. Of these parameters, detergents and fluorescence are of much interest as they result from the use (anthropogenic) of water and are in various ways present in sanitary wastewater (sewage) and wash-waters.

Further, among the contaminated waters, the box plots revealed that irrigation waters could be distinguished from sewage and wash-waters by ammonia, detergent and turbidity. Again, wash-waters could be distinguished from sewage by ammonia, ammonia/potassium ratio and detergents. Analysis of 1-year records of raw sewage data from the CoCT, showed that ammonia/potassium ratio was always greater than unity. This observation has been noted by Pitt (2001) in several studies in the US but could not establish such observation for wash-waters and neither in this study as well. It was therefore logical to give preference to ammonia/potassium ratio as a parameter to distinguish between sewage and the wash-waters. Between the uncontaminated waters, the box plots revealed that tap water may be distinguished from spring water by the following parameters: conductivity, detergents, fluorescence. In uncontaminated waters, however, detergents and fluorescence (optical brighteners) are least expected. Preference was thus given to conductivity as a parameter to distinguish between local tap and spring waters. An example is used to illustrate how the threshold for detergents was determined as a parameter to distinguish between contaminated and uncontaminated waters. The log space box plot for detergent (Figure 4-3) differentiates between the contaminated and uncontaminated waters.

Next is the determination of a threshold value to differentiate between contaminated and uncontaminated waters and also a numeric estimate of “false positives” and “false negatives” that may result from applying the threshold value. The data used for this example is shown in Table 4-3. Using the data from spring and irrigation sources in Table 4-3, the research team selected a concentration of >0.25 mg/L as an indicator of contaminated water (irrigation, washwater or sewage). Using this threshold value, zero out of 10 spring samples is likely to be identified as illegal or contaminated (a 0% false-positive rate) and two out of 10 irrigation samples are likely to be identified as non-illegal or uncontaminated (a 20% false-negative rate). The false-positive and negative rates are sample concentrations above or below the chosen threshold value. Based on these local data and assessment, the research team concludes that detergent demonstrates great potential as an indicator parameter of illegal discharges in the CoCT. It appropriately classifies all flow types and has fairly low “false positive or negative rates” for detecting spring water and irrigation discharges. Similar assessments were undertaken for other parameters to distinguish between different flow types and the results are summarised in Table 4-4. The threshold indicators in Table 4-4 are based on local data from the CoCT, however, other thresholds established by other researchers are also indicated (where available) for comparison. On the basis of these results, a flowchart is developed (Figure 4-4) as a decision-making tool or a guide to identifying illegal discharges in the locality of Cape Town.

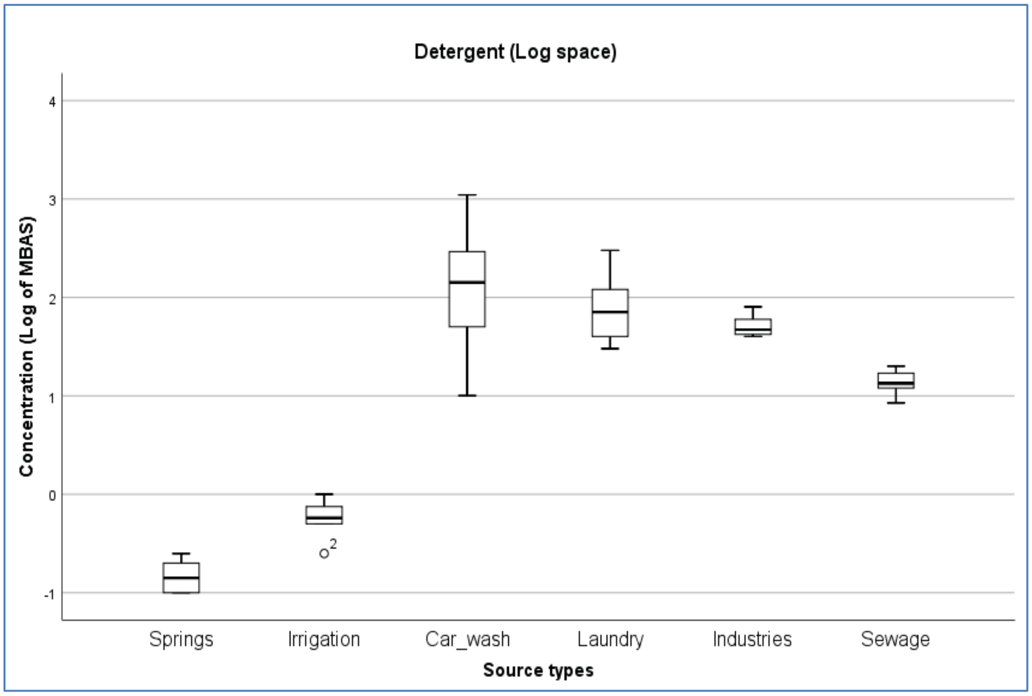



**Figure 4-3: Detergent comparison for different source types in Log space**

**Table 4-3: Detergent concentration for seven source types**

| Detergent concentration for seven source types | | | | | | |
|---|---|---|---|---|---|---|
| Concentrations > 0.25 mg/L indicates illegal discharge (contaminated) | | | | | | |
| **Tap** | **Spring** | **Irrigation** | **Car wash** | **Laundry** | **Industries** | **Sewage** |
| N/A | 0.10 | 0.25 | 10.05 | 30.15 | 40.20 | 8.50 |
| N/A | 0.10 | 0.25 | 50.25 | 40.20 | 42.21 | 10.40 |
| N/A | 0.10 | 0.50 | 80.40 | 50.25 | 44.22 | 12.00 |
| N/A | 0.20 | 0.50 | 100.50 | 100.50 | 50.20 | 12.00 |
| N/A | 0.20 | 0.55 | 150.75 | 100.50 | 50.25 | 12.00 |
| N/A | 0.25 | 0.57 | 200.00 | 120.60 | 58.00 | 15.00 |
| N/A | - | 0.60 | 201.00 | 301.50 | 60.00 | 17.00 |
| N/A | - | 0.75 | 291.45 | 400.00 | 60.30 | 17.50 |
| N/A | - | 0.75 | 600.00 | 1200.00 | 80.40 | 18.00 |
| N/A | - | 1.00 | 1100.00 | 5012.50 | 100.50 | 20.00 |
| Yellow shading indicates a likely false positive | | | | | = 0% | |
| Pink shading indicates a likely false negative | | | | | = 20% | |

**Table 4-4: Dry weather non-storm screening water quality indicators**

| **Parameter** | **Distinguishing source flow types** | **Local Threshold values** | **Other studies Threshold values** |
|---|---|---|---|
| Detergents | Uncontaminated vs. contaminated | >0.25 mg/L | >0.25 mg/L (Brown et al., 2004) |
| Fluorescence | | >5.7 RFU | >15 RFU (CWP, 2017 exclude irrigation) |
| Potassium | | >3.7 mg/L | |
| *E. coli* | | > 45 MPN/100 ml | |
| Detergents | Irrigation vs. (wash-waters & sewage) | >1 mg/L | |
| Ammonia | | >0.43 mg/L | >0.3 mg/L (CWP, 2010) |
| Ammonia | Wash-waters vs. sewage | >7 mg/L | |
| Ammonia/ potassium ratio | | >0.91 mg/L | >1 mg/L (Pitt, 2001; Brown et al., 2004) |
| Detergents | | >20 mg/L | |
| Conductivity | Spring vs. Tap water | >0.27 mg/L | |
| Potassium | | >0.3 mg/L | |

### 4.3.4 Quantifying illegal discharge pollutant loads

Due to security reasons and limited timeframe to complete this study, long-term outfall monitoring was conducted only at two outfalls receiving discharges from Du Noon informal settlement in the Diep River catchment. Fieldwork involved seven days continuous flow monitoring and water quality sampling to enable reliable determination of flow and concentrations of parameters of concern and to establish representative daily dry-weather pollutant loads discharged from the settlements into Diep River. Flows were logged at 10 minutes intervals using Greyline MantaRay Portable Area Velocity Flow Meter (AVFM). The meter includes an ultrasonic sensor that was mounted at the bottom of the pipe (Figure 4-5) to measure both level and velocity. Once the diameter of the pipe is entered, the meter automatically calculates and stores the flow which can be downloaded at any time.

Water quality sampling was undertaken using Isco 6712 Portable Sampler (Figure 4-6) installed in a manhole near outfalls D6 and D5 in Du Noon industrial area to automatically take discrete samples at one-hour intervals. Figure 4-7 show photos of discharges observed at the outfall D6 and D5. The 24 discrete samples are removed from the sampler each day and flow-composited for laboratory analysis. Constituents' analyses were performed at Civil Engineering Water Quality Laboratory (CPUT) and some duplicates were sent to AL Abbott laboratory (Cape Town) for quality assurance checks. Both flow and water quality results allowed for pollutant loads to be estimated and to derive average daily pollutant loads from the settlements transported into the Diep River. Quantitative estimates of pollutant loads also provided collaborative evidence to scientifically infer the extent of water quality problems in the settlements and to afford a basis for decision making and future monitoring and evaluation of the problem. Hydrographs of six-days and a single day continuous flow monitoring at outfall D6 are presented in Figures D5.26 and D5.27 respectively in Appendix D5. Figure D5.28 in Appendix D5 also presents a hydrograph of one-day flow monitoring at outfall D5. The hydrographs show that the outfalls discharge 24/7 with flow ranging from under 10 to 50 L/s; higher flows occurring in the morning (rising from 06:00 to 11:00) and also in the evening (17:00 and decreasing to midnight). The flows are manifestation of illegal connections to storm drains but leakages from potable water distribution network is also possible. The median and mean volume discharges during the eight day monitoring period were both about 2.9 mega-litres per day (Table D5.9 in Appendix D5).

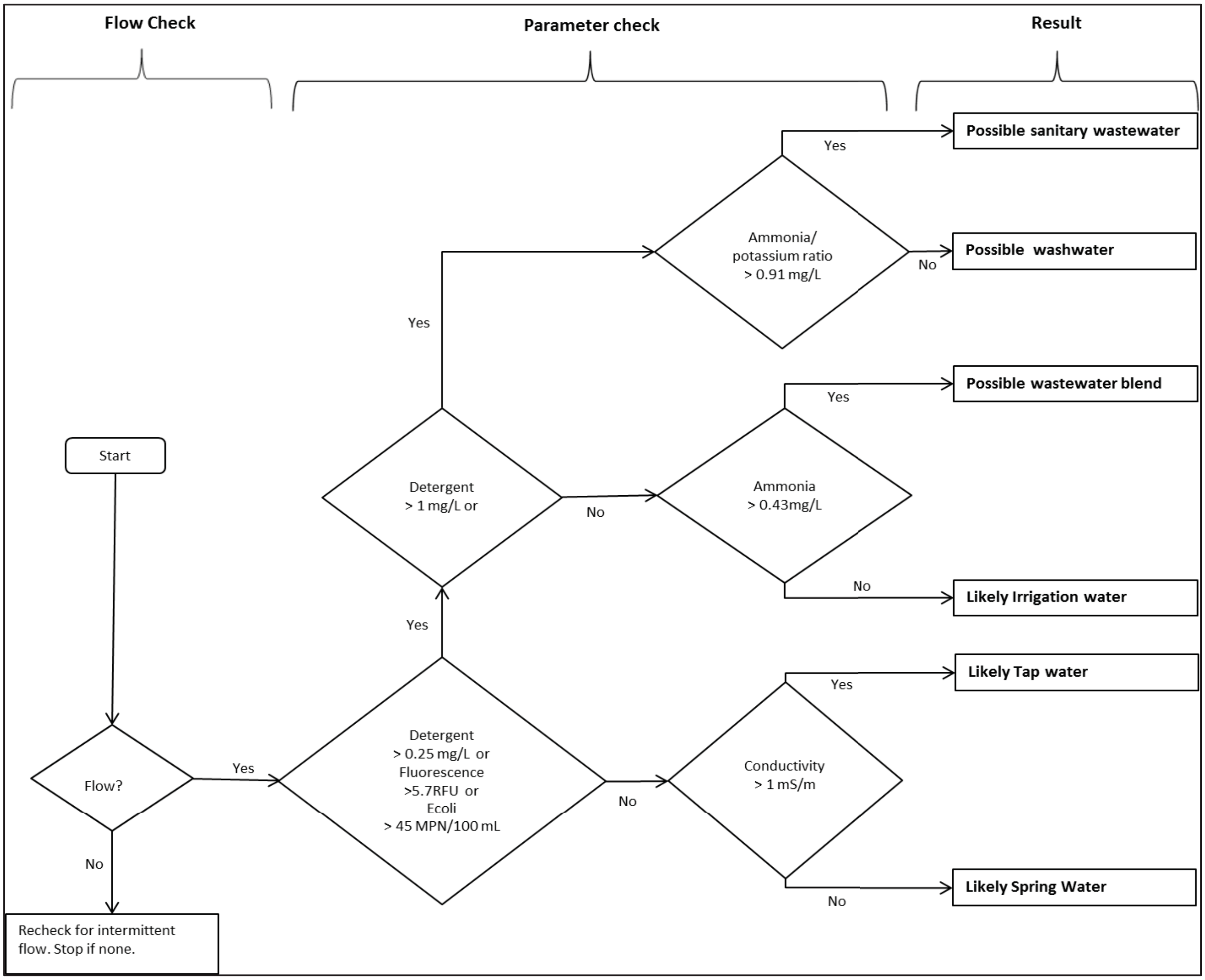



**Figure 4-4: Flow chart method to determine if flow has an illegal discharge**

**Figure 4-5: Greyline MantaRay Portable Area Velocity Flow Meter**

**Figure 4-6: Isco 6712 Portable Sampler – installation in a manhole**

Sampling results of water quality parameters ($NH_3$, $PO_4$, K, TSS, COD and *E. coli*) are presented in Table D5.9 in Appendix D5 in terms of concentrations (mg/L) and daily pollutant load estimates (kg/day). Elevated concentrations of $NH_3$ and *E. coli* indicate that the sources of the illegal discharges are mainly sewage type. This inference is also supported by ammonia-potassium ratio all exceeding unity (Brown et al., 2004) and corroborated by Figure 4-4 (a flow chart to determine if a flow has an illegal discharge). Elevated concentrations of $NH_3$, $PO_4$, TSS, COD and *E. coli* indicate the adverse impacts to the Diep River in terms of its use for recreational purpose and ecosystem sustainability. Site inspection in the settlements identified causes of elevated concentration of pollutants monitored and the associated sources of waste streams (Table 4-5). The inspection also indicated that the pollution problems in the settlements are very diffused and pervasive. As water quality problems in informal settlements typically originate from physical, institutional and socio-economic factors, conventional IDDE procedures to track and correct the problems is inapt. It would require the community, local and national government and other stakeholders to find and implement a sustainable solution to the problem through a “structured facilitated” consultation workshop.

**Table 4-5: Findings from site investigations and sampling in Du Noon**

| Water quality problems | Identified (possible) causes | Waste stream |
|---|---|---|
| Elevated nutrient concentrations | • Washing of cars in the streets<br>• Greywater (domestic washwater) flowing on streets<br>• Sewer/sanitation overflows and misconnections<br>• Bush toileting<br>• Domestic animals droppings | Sewage<br>Greywater<br>Stormwater |
| Elevated suspended solids concentrations | • Poor erosion and sediment control at construction activities<br>• Erosion from road surfaces and alleys<br>• Sewer/sanitation overflows<br>• Washing of cars in the streets | Sewage<br>Greywater<br>Stormwater |
| Elevated bacteria concentrations | • Faecal contamination from domestic animal droppings<br>• Sewer/sanitation overflows and misconnections<br>• Bush toileting | Sewage<br>Greywater<br>Solid waste<br>Stormwater |
| Litter in storm drains and watercourses | • Inadequate number of rubbish bins and skips<br>• Infrequent emptying of rubbish bins and skips<br>• Littering in settlement | Solid waste<br>Stormwater |
| Elevated organic concentrations | • sewer overflows and misconnections<br>• discharges from industrial and commercial sites | Sewage |

(a) Outfall D6

(b) Outfall D5

**Figure 4-7: Photos of discharges at outfall D6 and D5**

### 4.3.5 Quality control and quality assurance results

**Certified standard analysis with Palintest Photometer**

A calibration certificate supplied with Palintest Photometer 7500 Bluetooth validates the performance of the instrument. "Palintest Check Standards set is supplied with certified values expressed as %T (Transmission), derived from traceable reference materials. Acceptable tolerances defined on the certificate are automatically specified within the Photometer 7500 Bluetooth", (www.palintest.com). Routine validation was conducted to check standard values and measurements to ensure the instrument is operating within defined specification and that the results are credible. Results of check standard values and measurements (Figure 4-8) indicate that the Palintest Photometer instrument was capable of producing reliable results.

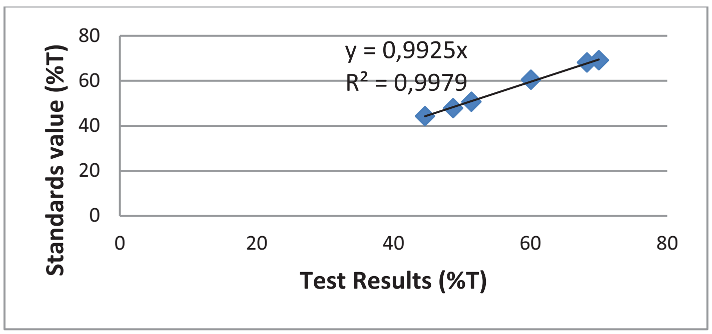



**Figure 4-8: Palintest Photometer 7500 compliance with certified standards**

**Comparison of results between Palintest Photometer and certified laboratory**

Thirty percent (30%) of the "fingerprint library" (i.e. 21 water samples) were analysed in duplicates using Palintest Photometer and a certified laboratory (Bemlab laboratory) and statistics of the results are summarised in Table 4-6. Apart from copper and total hardness that showed marked differences in the results, the rest of the parameters generally showed relatively close comparisons. Irvine et al. (2011), however, obtained a poor comparison between Hanna photometer and a certified laboratory in a similar study. Recommendations provided by ibid to improve reliability was implemented in this study and they included:

- Filter samples with unsettleable solids as they cause interference which affects the quality of the results.
- Anomalous result values must be flagged and re-done in triplicate.

Besides implementing the above recommendations, other photometric testing hints and tips discussed in detail in Palintest Photometer 7500 Bluetooth manual were always applied to improve accuracy of results. These included but were not limited to:

- Using genuine Palintest photometer reagents (expired reagents were discarded).
- Always correcting for the blanks value as colour in sample can affect accuracy of the result.
- Always adhering to the recommended reaction time specified in the manual for each parameter.
- Diluting samples with high concentrations before analysis.
- Calibrating/validating the photometer frequently. Checking standard values and measurements using procedures described in the manual.

**Table 4-6: Statistical summary of Palintest photometer and certified laboratory results**

| Statistics | Ammonia, $NH_3$ (mg/L) | | Boron, B (mg/L) | | Potassium, K (mg/L) | | Fluoride, F (mg/L) | | Tot Hardness (mg/l CaCO3) | | Tot Chlorine, $Cl_2$ (mg/l) | | Copper, Cu (mg/l) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CL | PP | CL | PP | CL | PP | CL | PP | CL | PP | CL | PP | CL | PP |
| Mean | 11.55 | 12.58 | 0.17 | 0.15 | 17.15 | 16.52 | 0.38 | 0.46 | 184.30 | 136.31 | 2.27 | 2.36 | 0.33 | 0.14 |
| Median | 0.78 | 1.60 | 0.16 | 0.10 | 15.00 | 12.00 | 0.30 | 0.31 | 99.40 | 85.50 | 1.51 | 1.21 | 0.14 | 0.03 |
| Std Dev | 25.89 | 26.18 | 0.08 | 0.08 | 13.03 | 14.95 | 0.42 | 0.43 | 275.97 | 230.44 | 2.76 | 3.09 | 0.46 | 0.23 |
| COV | 2.24 | 2.08 | 0.44 | 0.50 | 0.76 | 0.90 | 1.13 | 0.93 | 1.50 | 1.69 | 1.22 | 1.31 | 1.39 | 1.69 |

CL = Certified Lab; PP = Palintest Photometer

### 4.3.6 Limitations of load estimates and flowchart technique

Limitations on pollutant load estimations and flowchart technique are discussed below.

- Pollutant loads were estimated from eight continuous days monitoring only and assumed to remain constant despite temporal variation of water quality.
- Flow and water quality monitoring were conducted over several months as field schedules and weather allowed.
- The sample size used to compile the "fingerprint library" and subsequently to develop the flowchart technique was based on a resource-driven approach (cost, time and/or personnel constraints) and recommendation by Brown et al. (2004). Additional sampling to increase the sample size of the library is required to decrease the COV values as discussed in section 4.3.3.
- Discharges in storm drainage systems are often mixtures of different flow types; however, the mixing condition was not evaluated and considered in developing the flowchart technique. The flowchart technique would therefore be effective in

identifying the presence of most contaminated or dominated flow type. Contributions of different categories of flow types may not be identified by this technique.

- The flowchart technique was developed using local data for Cape Town. Use of the flowchart outside Cape Town may result in “false positives” or “false negatives”.

## 4.4 Summary of detection and indicator monitoring

This chapter focused on illegal discharge detection and indicator monitoring. The methodologies and techniques compiled were applied in Diep- and Kuils River catchments in Cape Town and results were discussed. The methodologies and techniques consisted of complaint hotline, on-site sanitation system inspection, outfall inventory and data analysis, design and implementation of indicator monitoring and, development of decision-making tool (flowchart technique). Outfalls geospatial locations were fixed on Diep- and Kuils River and their basic characteristics were inventoried and captured on a database. Outfalls information were analysed and characterised as unlikely, potential, suspect and obvious of illegal discharge potential based on qualitative and quantitative records and measurements at the outfalls. Candidate parameters were reviewed and selected to detect illegal discharges. Appropriate analytical methods for IDDE program were reviewed and compiled. Standard Operating Procedures for outfall inspections were developed to guide in the field and laboratory operations. Developed “fingerprint library” was sufficient to allow dirty or polluted flow types to be distinguished from unpolluted flow types. Based on the library, a decision-making tool (flowchart technique) was developed to determine if flows observed at outfalls (or anywhere in stormwater drainage system) would have illegal discharge, based on thresholds established for various indicator parameters. The flowchart will be the primary tool to isolate or locate specific sources of illegal discharges in the next chapter.

# 5 TRACKING ILLEGAL DISCHARGES TO A SOURCE

## 5.1 Introduction

The fundamental activities in the IDDE program involve (1) locating priority areas, (2) outfall inspection, (3) isolating or tracing the source of illegal discharge, and (4) corrective action (Brown et al., 2004). The first two activities have been covered in the previous two chapters. The third activity, isolating the source of an illegal discharge is the focus of this chapter. Isolating illegal discharge activity uses a variety of methodologies and techniques and the purpose is to trace and identify the sources of illegal discharges so that corrective measures may be applied to remove them. Two primary methods namely drainage area and storm drain investigations are often employed to trace the source of illegal discharge if the source is unknown. The choice between these two methods relies on type and understanding of available information such as drainage network, land use, operation and activities of industries and commercial facilities (or generating sites) in the sub-catchments. In particular, when monitoring in the sub-catchment has indicated strong hints of likely generating sites discharging polluted non-stormwater, drainage area investigation method is more favoured because it is rapid, direct and cost-effective.

## 5.2 Methodology and techniques to track discharges

The methodology to achieve the purpose of isolating the source of illegal discharge largely consist of (1) fieldwork preparation, (2) drainage area investigation, (3) storm drain investigation, (4) on-site investigation, and (5) data management. Techniques employed in these methodologies include visual inspections at manholes and/or catch basins, sampling discharges, sandbagging or damming, optical brightener monitoring traps, dye testing, smoke testing and televising. Once a problem has been verified through outfall investigation or a complaint call, if the source of the problem is unknown, then source tracking is a follow-up step to investigate further up the storm drain network to narrow down the source of the discharge to a specific pipe segment or point of entry. A single or a combination of these techniques may be required to track to the source of the discharge. Discharges can be classified broadly into (1) continuous (where flow is present all or most of the time) and (2) non-continuous (i.e. intermittent – where flow is seldom present. or transitory flow – where flow is once-off). For both of these classifications, Figure 5-1 presents a flowchart to select potential tracking techniques. The details of the methodologies and techniques are outlined below. Techniques to track intermittent discharges include sandbagging and optical brightener monitoring traps and are described extensively in Brown et al. (2004:157) and elsewhere.

### 5.2.1 Fieldwork preparation

It is important to evaluate the following information: (a) previous outfall inspection forms or incident report forms, (b) past investigation reports in the area (e.g. complaint hotline). Most important information is the stormwater drainage system map; sewer map is also useful in the field to assist in distinguishing between drain and sewer manholes. Illegal discharge source tracking form (example in Appendix D6) must be prepared and be ready for field use to capture visual observations and quantitative measurements. Similar to outfall investigation, preparation for fieldwork consisted of acquiring the resources needed to conduct source tracking investigation, determining when and where to do fieldwork as discussed in steps 1 to 3 in section 4.2.3. Equipment listed in section 4.2.3 is also required for source tracking in addition to the following:

- Flow meter (to measure flow rate)
- Pickaxe, crowbar and a hammer (to open manholes)
- Swing sampler with pole and bottle (to take sample from manholes)

### 5.2.2 Drainage area investigation

Survey and evaluation of the drainage area of a problem outfall often lead to source identification of illegal discharges. The effectiveness of drainage area investigation is realised if the flow observed at an outfall has unique characteristics that enable field workers to rapidly determine possible generating site or facility that is producing it. Thus this method is not effective to isolate sanitary wastewater since they originate from all types of land uses or generating sites. Two approaches to drainage area investigation are often used. In the first approach, a rapid drive-by (windshield) survey is applied in *small sub-catchments* wherein the field workers endeavour to relate the discharge characteristics at outfalls to most probable generating sites. The second approach is applicable in *large and complex sub-catchments*, wherein GIS data are analysed to identify likely generating sites (after matching outfall discharge characteristics with operation and waste streams of industrial and commercial facilities) to identify the source of illegal discharge. This is based on the fact that some industries and commercial establishments usually produce discharges with distinct colour, smell or off-the-chart indicator parameter sample reading (Brown et al., 2004:158).

### 5.2.3 Storm drain investigation

The source of illegal discharges may be identified by systematically isolating the area from where the discharge originated. Storm drain investigation involves progressive inspection and sampling at manholes farther up or down the drainage network to narrow down the source to an isolated pipe segment.

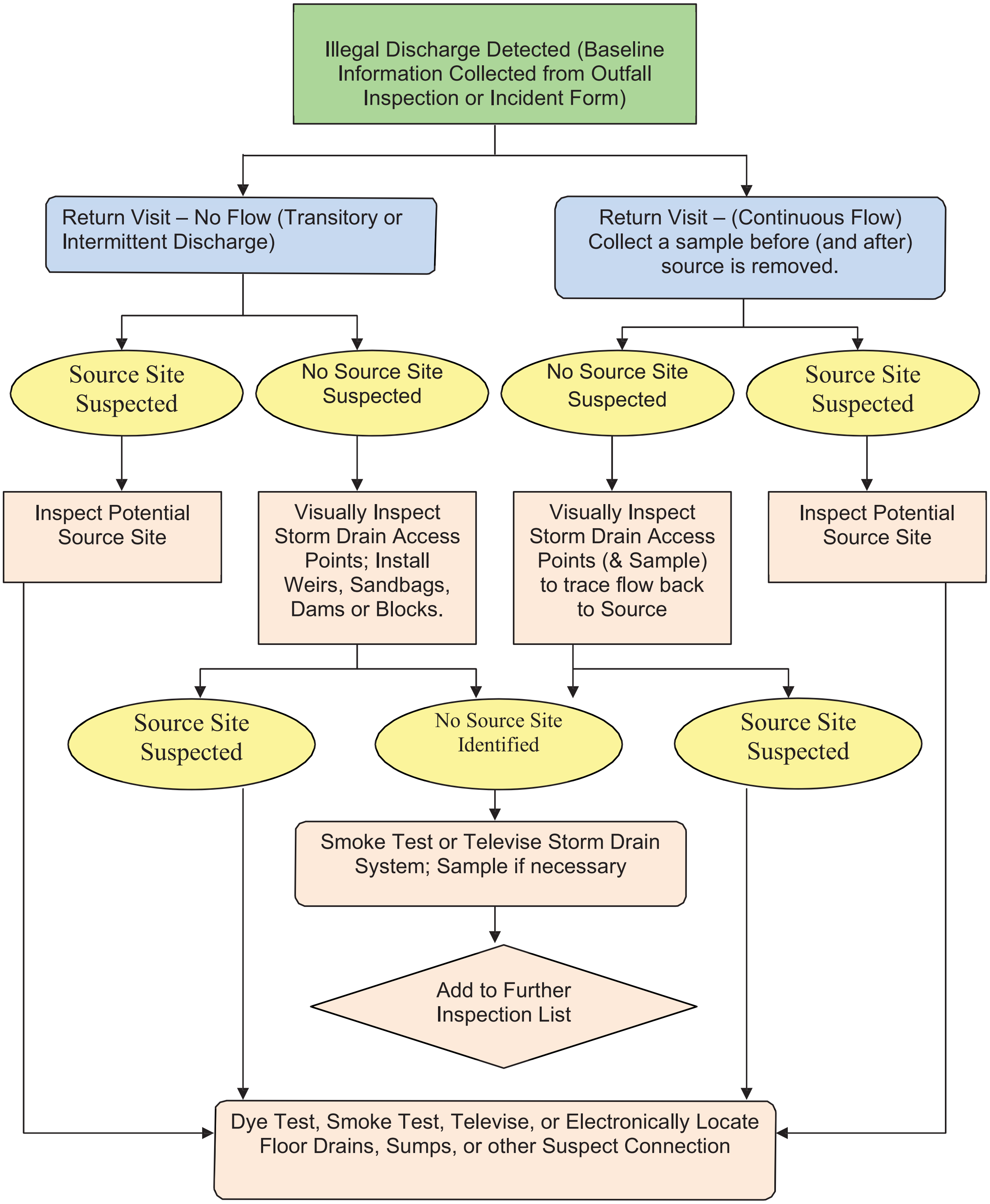



**Figure 5-1: Flowchart for selecting tracking techniques (source: New Hampshire, 2006:25)**

Three alternative ways are available to execute the storm drain investigation:

a) Starting from the outfalls, crews may move progressively upstream along the main pipe to inspect and test samples from manholes until indicator parameters concentrations show a trace of illegal discharge. This option is often used because the investigation can start immediately after illegal discharge is observed at an outfall. The technique include the steps below and Figure 5-2 illustrates the monitoring steps to find the entry point of illegal discharge into the drainage system:
   - Check stormwater drainage system plan and note the major branches.
   - Beginning from the outfall or nearest manhole, visually inspect and sample periodically to assess changes in water quality concentrations to reveal entry of other discharges. Record all observations and measurements as per illegal discharge source tracking form (Appendix D6).
   - Move upstream (in succession) to each manhole or junction and repeat previous step (visual inspection, sampling, measurements, etc.) until the illegal discharge is observed no more. The source of the illegal discharge will be between the last observed manhole with ‘clean’ discharge and the next downstream manhole with illegal discharge.
   - Now from the ‘clean’ manhole, move downstream to find the entry point of the illegal discharge into the drainage network.
   - Investigate the immediate area of this location to find the source. If private property is suspected, seek site entry procedures.
   - Record all observations and measurements at each point or site on the illegal discharge source tracking form as well as with photographs.

b) Starting from upstream parts of the drainage network, crews move progressively downstream of the main pipe to inspect and test samples from manholes. If a branch is identified with illegal discharge, upstream of the branch is investigated to locate and remove the source before continuing downstream on the main pipe. It requires an advanced preparatory work to clearly understand the complexity of the upstream segments of the drainage system and potential generating sites in order to find a suitable starting point.

c) The storm drainage system may be split into segments or branches; then inspect and test samples from manholes at strategic points or junctions. This option requires little preparatory work before the commencement of the investigation. The storm drain system has to be studied to select the best strategic manholes to sample.

Often the choice among these three alternatives is influenced by the size, nature and land use of the contributing sub-catchment.

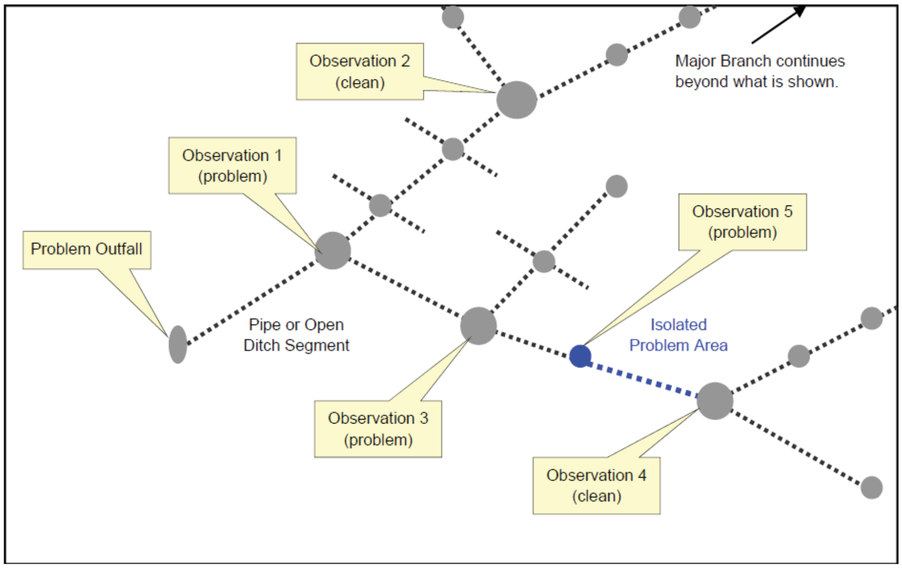



**Figure 5-2: Stormwater drainage system observation steps (source: City of Camas, 2016:14)**

## 5.2.4 Techniques for on-site investigation

While techniques in both drainage area and storm drain investigations involve visual inspections at manholes or catch basins as well as water quality sampling and testing, techniques for on-site investigations include dye testing, smoke testing, or closed-circuit television inspection (CCTV). When the source of illegal discharge could not be pinpointed by drainage area or storm drain investigations alone, an on-site investigation may be used to finally locate the illegal discharge source. Techniques for on-site investigation are discussed below (centralmastormwater, 2018:3):

- ***Dye Testing:*** *Dye testing is used to confirm a suspected illegal connection to a storm drain system. Prior to testing, permission to access the site should be obtained. Dye is discharged into the suspected fixture and nearby storm drain structures and sanitary sewer manholes observed for the presence of the dye. Each fixture, such as sinks, toilets and sump pumps, should be tested separately. A third-party contractor may be required to perform this testing activity.*
- ***Smoke Testing:*** *Smoke testing is a useful method of locating the source of illegal discharges when there is no obvious potential source. Smoke testing is an appropriate tracking technique for short sections of pipe and for pipes with small diameters. Smoke added to the storm drain system will emerge in connected locations. A third-party contractor may be required to perform this testing activity.*

- ***Closed Circuit Television Inspection (CCTV):*** *Televised video inspection can be used to locate illegal connections and infiltration from sanitary sewers. In CCTV, cameras are used to record the interior of the storm drain pipes. They can be manually pushed with a stiff cable or guided remotely on treads or wheels. A third-party contractor may be required to perform this testing activity.*

### 5.2.5 Data capture and management

The storm drain investigations are systematically documented in the field using illegal discharge tracking form (Appendix D6) and captured onto a spreadsheet database after each day field activity. The form consists of four parts: (1) background data, (2) visual observation data, (3) field testing data, and (4) assessment of whether there is contamination or not. The background data captures the site's general information such as date, time, site address, coordinates and sample number. Visual observation data are concern with the conditions in the manhole that may indicate contamination by illegal discharges. Records of key observations include presence of flow, colours, odours, floatable materials, sediment deposition and blockages. If flow is observed, swing sampler (with pole and bottle) is used to collect sample from manhole to test for selected parameters on-site and also in the laboratory. Physical parameters such as pH, conductivity and temperature are always measured on-site. The number of parameters selected for testing at each site is dictated by the visual observations made. If any contamination is found by visual observation or confirmed by testing results, such an assessment is recorded in the last section of the form. The flow rate may be determined, where possible, by using the depth-slope or Manning's method or the area velocity method, or any suitable method. Flow depth and velocity may be measured, for example, with Global Water Flow Probe meter whereas pipes slopes may be obtained from storm drainage network GIS shapefile record.

## 5.3 Case study application of tracking techniques

Results of outfall investigation (section 4.3.2) classified many outfalls as 'obvious' and 'suspects' of illegal discharges. The drainage networks connected to some of these outfalls were selected for source tracking investigation in Diep River catchment. Illegal discharges in most residential areas are diffused especially in informal settlements where these discharges are chronic and pervasive. For reasons including project time, budget constraints, safety and security, it was recommended in the Project Reference Group meeting that the source tracking investigations should be focused mostly in industrial and commercial areas. Again, as there are no established legal authority to enable the research team to undertake inspection and monitoring at private and business properties, it was further recommended that the source tracking investigation should be confined to public roads that are accessible to the research team. In essence, this translated to tracing sources to segments of pipe mains rather than to the very sources where the discharges originate. The results of source tracking investigation are presented in Tables D7.1 and D7.2 in Appendix D7. Table D7.1 shows a summary of qualitative (field visual observation) data at manholes inspected in Killarney and Montague Gardens while Table D7.2 also shows a summary of quantitative data (field and laboratory measured physico-chemical parameters) of water samples taken from the manholes. Manholes and branch segments inspected and identified as problematic are discussed below.

### 5.3.1 Drainage area investigation application

Drainage area investigation was conducted for outfalls receiving discharges from Doornbach and Dunoon informal settlements. These settlements are connected at their downstream ends with Dunoon industrial and commercial area. The outfalls are numbered as D1, D2, D3, D4, D5 and D6 (Figure 5-3). Drainage areas for outfalls D10, D11 and D12 (Figure 5-3) receiving discharges from Killarney Gardens industrial area were also investigated. The drainage area investigation was also conducted at selected car wash centres in both Diep- and Kuils River catchments. The results and discussions are presented below:

**Drainage area investigation of outfalls D1-D6:** Discharges from outfalls D1 to D6 (Figure 5-3) are mainly from diffused sources in the two informal settlements (Doornbach and Dunoon). Lack of basic water and sanitation services and poor operation and maintenance of the inadequate systems in place has contributed to litter, overflow of toilet systems and discharge of greywater unto streets and gutters (Figures 5-4a and b). This problem is typical of many informal settlements in developing world, but the solution has always been fraught with elements of difficulties and inevitable failure, some of which are rooted in political, socio-economic, institutional and physical factors. Outfall D2, however, was found to be receiving discharges from a failing stabilisation ponds which is overgrown with vegetation (Figure 5-4c) located within the premises of MyCity Bus Services yard. Common observation and characteristic indicators of discharges in these areas reveal that the source type is sewage. The colour, odour, floatables are all indicators of sewage flow. The water quality characteristics in outfall D6 was identical to that measured in manhole D6M3 (upstream of the industrial area) confirming the discharge originate mainly from Dunoon settlement. Results of chemical analyses reveal high ammonia concentrations (73.4 mg/L) as well as ammonia-potassium ratio (3.3), all exceeding the local threshold or action criteria limit (Table 4-4). Table 5-1 indicates the likely source type is sewage.

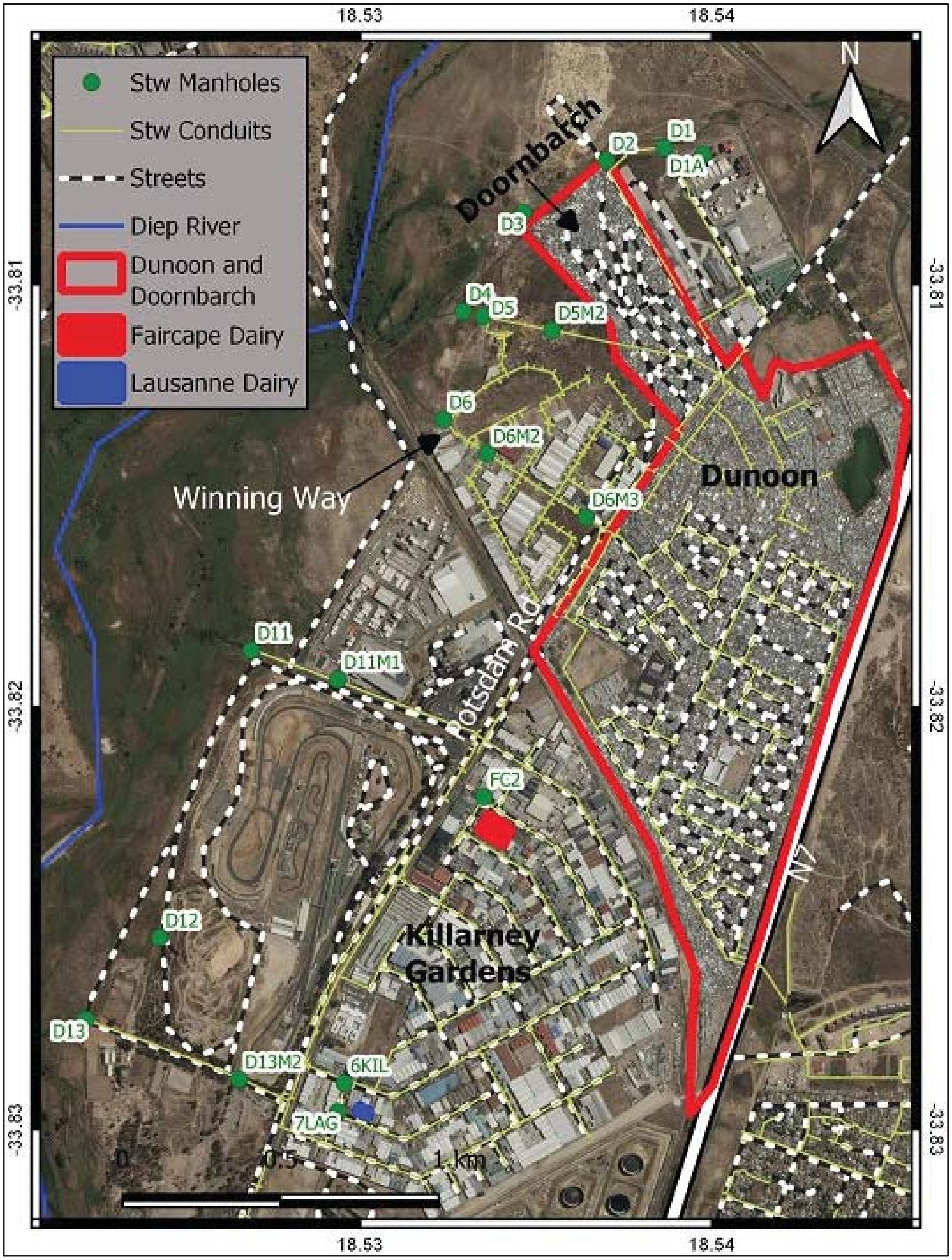



**Figure 5-3: Killarney and Du Noon sub-catchments map**


(a) Surface flow (b) Open channel flow (c) Failing stabilisation pond

**Figure 5-4: Polluted dry-weather flows from Doornbach settlement**

**Table 5-1: Source tracing investigation results for Outfall D6**

| **Sample Number** | **Inspection date** | **Site Address or coordinates** | **$NH_3$/K ratio** | **Local $NH_3$/K ratio Action criteria** | **Flow chart method, most likely source** |
|---|---|---|---|---|---|
| D6M3 | 14/05/2018 | 1 Winning Way, Du Noon industrial | 3.3 | 0.91 | Sewage |

**<u>Drainage area investigation of outfalls D11:</u>** A photo of outfall D11 is shown in Figures 5-5a and b. Physical indicators observed at the outfall include: white colour spoiled milk and rancid odour as wells as spoiled milk products as floatables and excessive vegetation. Within the drainage area of outfall D11 (Figure 5-3) there was only one dairy factory (Fair Cape Dairy), thus it was suspected of being a culprit of the observed illegal discharge. A drainage area investigation was initiated and two manholes in front of Fair Cape Dairy factory were inspected. A fresh white and warm (Temperature = 30.4°C) discharge was observed coming from the factory premise (Figures 5-5c and d) in manhole FC2 (Figure 5-3) to confirm our suspicion. The physical observations at the outfall matched those observed in the manholes in front of the dairy factory. The next upstream manhole from the factory was dry.



(a) White milky colour flow-Outfall D11 (b) White spoiled milk floatables-Outfall D11

(c) White milky flow-Manhole (d) White milky flow-Manhole

**Figure 5-5: Photos illegal discharges tracked from outfall D11 to source**.

**<u>Drainage area investigation of outfalls D13:</u>** Outfall D13 (Figure 5-3) has similar physical indicators as outfall D11: white colour spoiled milk and rancid odour, as wells as spoiled milk products as floatables and excessive vegetation. Lausanne Dairy was the only dairy factory located in the drainage area of outfall D13. Several inspections were done in manholes around the premises of Lausanne Dairy but most of them were dry, Manholes numbered 6KIL and 7LAG (Figure 5-3) were flowing but had no physical indicators matching that of outfall D13. Perhaps Lausanne Dairy discharges during night time and could not be identified during day the hours of inspection. Table D7.2 in Appendix D7, however, suggest that manholes 6KIL and 7LAG have detergents (3.39 and 0.99 mg/L as MBAS respectively) and fluorescence (115 and 105.9 RFU respectively) values exceeding action criteria and indicating a washwater source type. Both manholes samples also indicated high COD values (1040 and >2000 mg/L respectively). The City is advised to monitor night discharges from Lausanne Dairy to confirm the physical indicators at outfall D13 and also investigate the source(s) of wash-waters observed in manholes 6KIL and 7LAG.

**Drainage area investigation of outfalls D12:** Outfall D12 was initially observed as surface flow during outfall investigation; however, a review of stormwater drainage map could not reveal any stormwater pipe or channel to the proximity of the outfall. Drainage area investigation was initiated to find the source of the discharge. A chronic sewer overflow was observed (Figure 5-6a), which has created a pond upstream of the outfall location. Location of the overflow is on the sewer mains from Dunoon industrial area to Potsdam wastewater treatment works. A worker at nearby horse boarding stable (Milnerton Riding Club) attested that the overflow is chronic and the City does not respond to their complaints. The fact that the overflow has created a large pond/wetland in the area indicates that the problem is indeed a chronic. The research team reported the incident to the City and on our next trip to the site, we were happy to find the overflow repaired and the site restored (Figure 5-6)

(a) Pond created by chronic sewer overflow (b) Sewer overflow repaired

**Figure 5-6: Photo of chronic sewer overflow near Milnerton Riding Club**

**Drainage area investigation at Car wash centres:** Drainage area investigations for car wash centres in Diep- and Kuils River catchments were undertaken concurrently with 'fingerprint' library monitoring for car wash flow type. During the sampling exercises, the car-wash centres' drainage infrastructures were inspected to ascertain whether the discharges are routed to stormwater drains or sanitary sewer. For all the car wash centres visited, it was found that their discharges were routed to stormwater drainage systems (example in Figure 5-7). Table 5-2 presents some results of detergents and fluorescence measured in comparison with local action criteria. The City is advised to develop a comprehensive strategy to clamp down illegal connections of car wash discharges to stormwater drainage system. An organised and systematic program to disconnect car wash discharge entries into stormwater drainage system is required. This could include a regulatory framework such as a plumbing code that addresses illegal connections of car wash discharges to storm drains. For such an enforcement practice to be effective, the penalty must be a deterrent.

**Figure 5-7: Car wash effluent discharging into manhole 19MON**

**Table 5-2: Source tracing investigation results for car wash centres**

| Sample ID | Sample date | Location | Detergent (mg/L as MBAS) | Local action criteria for Detergent (mg/L as MBAS) | Fluor-escence (RFU) | Local action criteria for Fluorescence (RFU) | Flowchart method, most likely source |
|---|---|---|---|---|---|---|---|
| CW1 | 02/11/2017 | Parklands | 200.00 | 0.25 | 50.23 | 5.7 | Contaminated water (wash-waters) |
| CW2 | 02/11/2017 | Parklands | 50.25 | | 184.30 | | |
| CW3 | 06/11/2017 | Bellville | 150.75 | | 31.94 | | |
| CW4 | 06/11/2017 | Kuilsriver | 80.40 | | 24.53 | | |
| CW5 | 06/11/2017 | Kuilsriver | 10.05 | | 61.52 | | |
| CW6 | 06/11/2017 | Kuilsriver | 291.45 | | 38.65 | | |
| CW7 | 06/11/2017 | Kuilsriver | 100.50 | | 33.19 | | |
| CW8 | 06/11/2017 | Bellville | 201.00 | | 118.00 | | |
| CW9 | 17/12/2017 | Epping 2 | 1100.00 | | 96.10 | | |
| CW10 | 17/12/2017 | Bellville | 600.00 | | 219.00 | | |
| 19MON | 23/07/2018 | Montague | 137.17 | | 68.80 | | |

## 5.3.2 Storm drain investigation application

Montague Garden industrial area discharges through Montague channel to outfall D20 (not shown on map). Due to the vastness of this area, the drainage network was split into segments and storm drain investigation was conducted for selected manholes. Visual indicators and physico-chemical parameters monitored are summarised respectively in Tables D7.1 and D7.2 in Appendix D7. Concentrations of detergent (10.23 mg/L as MBAS) and fluorescence (79.76 RFU) at outfall D20 exceeded the action criteria and since ammonia-potassium ratio was very small (0.03 and less than action criteria), the source type was inferred to be wash-waters and our task was to look for their sources. Discussion of some of the results from the investigation are summarised as follows:

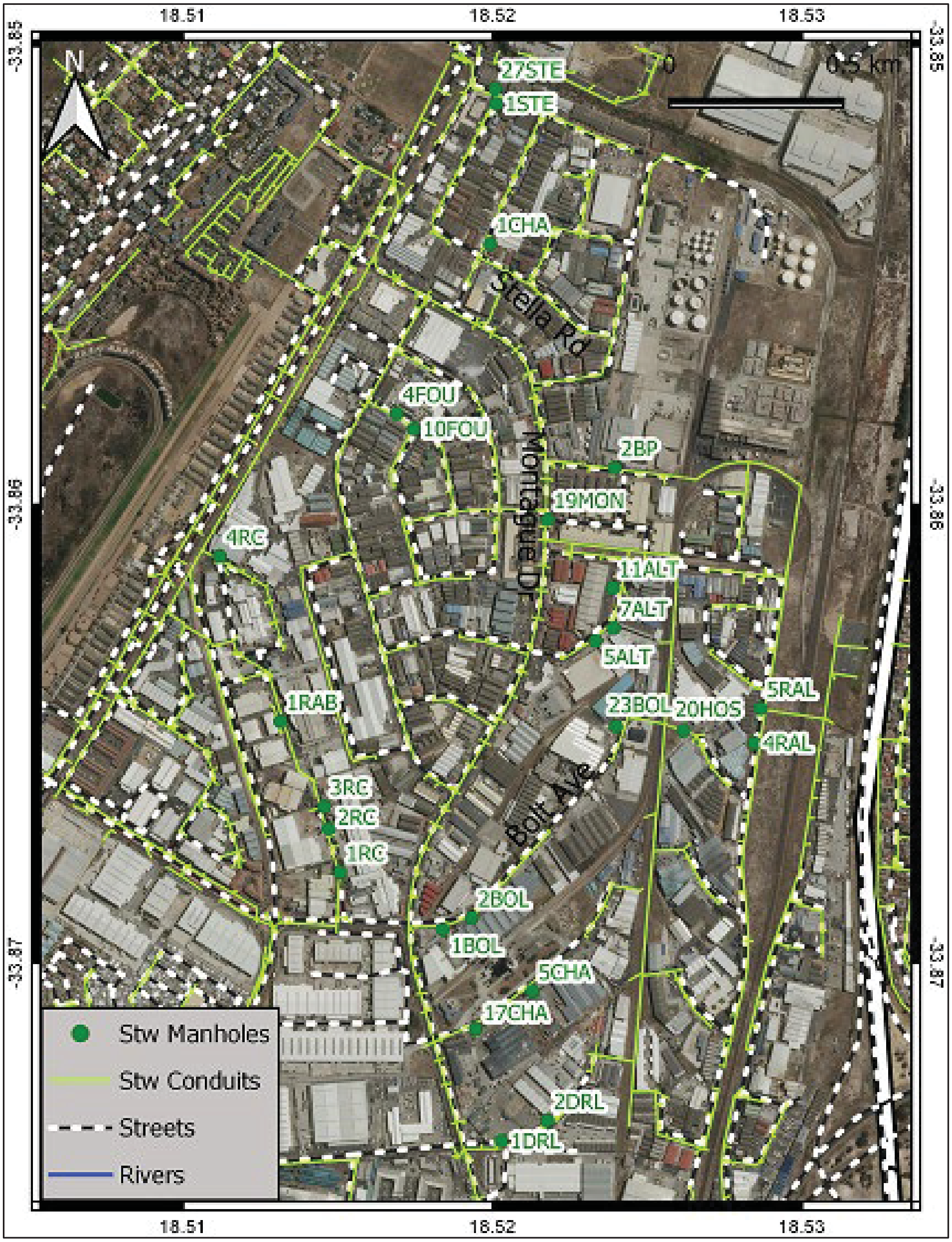



**Figure 5-8: Montague Garden sub-catchments map**

**Manhole 1STE and Inlet 27STE:** Locations of manholes 1STE and 27STE are shown in Figure 5-8. Manhole 1STE is at a junction between Stella road and Stella Cove and discharge observed in this manhole had a brownish grey colouration (Figure 5-9a). Inlet 27STE is in front of Unit 27 (Chemical Factory) on Stella Cove and a whitish discharge (Figure 5-9b) was observed in the drain flowing from the factory premise. Concentrations of detergent for manholes 1STE and 27STE are 35 and 109 mg/L as MBAS, respectively. Concentrations of fluorescence for 1STE and 27STE manholes are 168.6 and 104.4, respectively. These concentrations exceed the established local action criteria and with low ammonia concentrations at each location, a wash-water source type is confirmed. The City is advised to conduct a site investigation to identify the culprit(s).

(a) Brownish flow in manhole 1STE

(b) Whitish flow in manhole 27STE

**Figure 5-9: Photos of illegal discharges observed in manholes on Stella road.**

**Manhole 4FOU:** Locations of manholes 4FOU and 10FOU are shown in Figure 5-8. Manhole 4FOU is located on 4 Fourth Street in front of Eurostyle Bulkstores premise in Montague. The discharge rate was substantial and had a deep maroon colour (Figure 5-10). Concentrations of detergent and fluorescence were 31.5 mg/L as MBAS and 164.32 RFU respectively, both exceeding local action criteria limit. Source type is inferred as factory wash-water. The next upstream manhole (10FOU) had a small and clear discharge. The potential culprit may be discharging into pipe segment between these two manholes.

**Figure 5-10: Photo of deep maroon colour discharge in manhole 4FOU**

**Manholes 1RC, 2RC, 3RC and 1Rainbow:** These manholes are located on Rainbow Close in Montague industrial area (Figure 5-8). Manhole 1RC is at upstream part of the branch followed by 2RC, 3RC and 1Rainbow towards the downstream section. Concentrations of detergent and fluorescence (Table 5-3) exceed local action criteria, whereas ammonia-potassium ratios are all lower than action criteria for sanitary wastewater. Wash-water source type is inferred and effort must be made by the City to identify the industries responsible for the discharges.

**Table 5-3: Source tracing investigation results on Rainbow Close**

| Sample ID | Sample date | Location | Detergent (mg/L as MBAS) | Local action criteria for Detergent (mg/L as MBAS) | Fluore scence (RFU) | Local action criteria for Fluores-cence (RFU) | Flowchart method, most likely source |
|---|---|---|---|---|---|---|---|
| RC1 | 02/11/17 | Montague | 200.00 | 0.25 | 50.23 | 5.7 | Contaminated water (wash-waters) |
| RC2 | 02/11/17 | Montague | 50.25 | | 184.30 | | |
| RC3 | 06/11/17 | Montague | 150.75 | | 31.94 | | |
| 1RAB | 06/11/17 | Montague | 80.40 | | 24.53 | | |

**Manholes 1DRL and 2DRL:** These manholes are located on Drill Avenue in Montague industrial area (Figure 5-8). Manhole 1DRL is at downstream of 2DRL. During the inspection, there was a trickling flow in 1DRL whereas a white milky discharge was observed in 2DRL. Detergent and fluorescence concentrations in 2DRL are 3.49 mg/L as MBAS and 140 RFU respectively; all exceeding the local action criteria. Further site investigation to identify industry discharging wash-water into 2DRL manhole is recommended.

**Manholes 1CHA, 5CHA and 17CHA:** These manholes are located on Chain Avenue in Montague industrial area (Figure 5-8). Manhole 17CHA is at downstream of 1CHA and 5CHA is on the upstream part of the branch. Detergent and ammonia-potassium ratio in all three manholes are low but fluorescence concentration exceeds the local action criteria. The concern with discharge in 17CHA manhole (Figure 5-11) is high conductivity (7.096 mS/m) and COD concentration (470 mg/L). Wash water may not be the source type, but high conductivity and COD concentrations suggest industrial discharge and must be further investigated.

**Figure 5-11: Photo of illegal discharge in manhole 17CHA**

**Manholes 5ALT, 7ALT and 11ALT:** These manholes are located on Alternator Avenue in Montague industrial area (Figure 5-8). Manhole 5ALT is at upstream followed by manholes 7ALT and 11ALT at the downstream in succession. Manhole 5ALT was blocked and filled up with stones and thrash (Figure 5-12a). Discharge rates of about 2.5 and 10 L/s were measured in 7ALTand 11ALT, respectively. Colour of discharge in 11ALT was pinkish (Figure 5-12b) whereas 7ALT which was about 40 m away upstream had clear water flowing. Between these two manholes was the Duram Group factory that produces paint. It's highly likely that polluted discharge observed in 11ALT was coming from Duram Group factory. A white soapy foam was observed in manhole 7ALT (Figure 5-12c) and with concentrations of detergent and fluorescence exceeding local action criteria (Table 5-4), it was not difficult to confirm that source type in manhole 7ALT is wash-water. A stormwater inlet in front Alternator Park complex connected to manhole 7ALT indicated stains of paint (Figure 5-12d) which suggest dumping has been taking place into stormwater drainage system. The COD measured in both manholes are in excess of 2000 mg/L also confirming that the discharges are of industrial origin. The discharge source type is inferred in Table 5-4.

**Table 5-4: Source tracing investigation results on Alternator street.**

| Sample ID | Sample date | Location | Detergent (mg/L as MBAS) | Local action criteria for Detergent (mg/L as MBAS) | Fluore scence (RFU) | Local action criteria for Fluores cence (RFU) | Flowchart method, most likely source |
|---|---|---|---|---|---|---|---|
| 7ALT | 03/08/18 | Montague | 3.49 | 0.25 | 57.42 | 5.7 | Contaminated water (wash-waters) |
| 11ALT | 03/08/18 | Montague | 3.49 | | 61.54 | | |

(a) Manhole 5ALT filled with stones (b) Manhole 11ALT with pinkish discharge

(c) Manhole 7ALT with white soapy foam discharge. (d) Stormwater inlet with stain.

**Figure 5-12: Photos of illegal discharges in manholes on Alternator Avenue.**

**Manhole 2BP:** This manhole is located on BP Road on Montague industrial area (Figure 5-8). Flow in manhole 2BP was substantial and concentrations of detergent and fluorescence were measured as 0.36 mg/L as MBAS and 45.37RFU, respectively. The manhole is located on Montague channel and because the channel receives discharges from many branches, concentrations of contaminants were lower (Table D7.2 in Appendix D7) due to dilution effect.

**Manhole 20HOS:** This manhole is located on Hoist street in Montague industrial area (Figure 5-8). Detergent and fluorescence concentrations in 20HOS were 1.18 mg/L as MBAS and 53.47 RFU respectively, all exceeding the local action criteria limit and wash-water source type is inferred. A COD concentration (380 mg/L) was also high. Next upstream manhole was observed to be dry. Further site investigation to identify industry discharging polluted water into manhole 20HOS is recommended.

**<u>Manhole 23BOL:</u>** This manhole is located on Bolt Avenue in Montague industrial area (Figure 5-8). Detergent and fluorescence concentrations in 23BOL were 0.47 mg/L as MBAS and 78.14 RFU respectively; all exceeding the local action criteria limit and wash-water source type is inferred. Further site investigation to identify industry discharging illegally into 23BOL manhole is essential.

## 5.4 Summary of tracking illegal discharges

Source tracking investigation conducted in this study has identified certain areas and storm drain segments which, if followed up by the City, will pinpoint sources of illegal discharges. In Dunoon area, the sources are diffused in the settlements, most of which are chronic sanitary sewer overflows. The source type in this area is mainly sewage. In Killarney industrial area, drainage area investigation revealed Fair Cape and Lausanne Dairies are responsible for illegal discharges at outfalls D11 and D13 respectively, although more investigation is required to confirm Lausanne Dairy discharge. The source type in these outfalls is industrial dairy waste products. Sanitary sewer overflows is also chronic in Killarney industrial area along the main sewer line. For all the car wash centres visited, it was found that their effluent discharges are routed to stormwater drainage systems. An organised and systematic program to disconnect car wash discharge entries into stormwater drainage system is required. Storm drain investigation at Montague industrial area was to trace illegal discharge at outfall D20. Locations of the sources were narrowed down to several storm drain segments and the source types are mainly wash-waters. Additional site investigation is required to locate specific industries responsible for the discharges so that corrective actions can be applied.

# 6 CORRECTIVE MEASURES TO REMOVE ILLEGAL DISCHARGES

## 6.1 Introduction

Removing illegal discharge is a logical follow-up step after detection of the discharge source. Due to different types and sources of illegal discharges, procedures and techniques to employ for source removal vary and the choice depends largely on factors such as responsible person to fix, effective method to use, duration and cost of the repair, and method to evaluate the success of removal. The National Environmental Management Act No. 107 of 1998 of South Africa emphasise on sustainable development principles and section 2(4)(a)(viii) states *"… that negative impacts on the environment and on people´s environmental rights be anticipated and prevented, and where they cannot be altogether prevented, are minimised and remedied…"* The principles further place emphasis on 'polluter pays' ethics. Section (2)(4)(p) states *"… the costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment…"* Costs of remedying sources of illegal discharges will inherently be borne by property owners and municipalities using, owning and/or operating the infrastructure.

Rapid and effective removal of illegal discharges is dependent on having well established legal authority and responsibilities to regulate illegal discharges through prohibition and enforcement actions (Brown et al., 2004). Generally, a mix of education and enforcement is usually common and cost-effective methods to remove illegal discharges. The initial objective of this chapter was to report on corrections made to remove sources of identified illegal discharges in the sub-catchments investigated. Achieving this objective, however, was heavily compromised by the inability of the City to grant the research team any form of authority to access industrial and commercial facilities' drainage infrastructure. The consequence was that the research team was unable to track any of the identified discharges to their source. Consequently, procedures to eliminate illegal discharge presented in this chapter are largely based on literature review that is locally untested.

## 6.2 Methods

There are several methods available to remove sources of illegal discharges such as enforcement, education, commercial and industrial site disconnections, service lateral disconnection and reconnection, cleaning or flushing of blocked sewers, excavation and replacement of collapsed sewer lines, manhole repairs to prevent surface water ingress and several other forms of repairs, rehabilitation and replacement works (Brown et al., 2004). Corrective actions to remove different types of discharges from different sources are presented in Table 6-1.

**Table 6-1: Methods to Fix Illegal Discharges (source: Brown et al., 2004:74)**

| Type of Discharge | Source | Removal Action(s) |
|---|---|---|
| Sewage | Break in right-of-way | Repair by municipality |
| | Commercial or industrial direct connection | Enforcement; Incentive or aid |
| | Residential direct connection | Enforcement |
| | Infrequent discharge (e.g. recreational vehicle dumping) | Enforcement; Spill response |
| | Straight pipes/septic | Enforcement; Incentive or aid |
| Wash water | Commercial or industrial direct connection | Enforcement; Incentive or aid |
| | Residential direct connection | Enforcement; Incentive or aid |
| | Power wash / car wash (commercial) | Enforcement |
| | Commercial wash down | Enforcement |
| | Residential car wash or household maintenance related activities | Education |
| Liquid wastes | Professional oil change/car maintenance | Enforcement; Spill response |
| | Heating oil/solvent dumping | Enforcement; Spill response |
| | Homeowner oil change and other liquid waste disposal (e.g. paint) | Warning; Education; Fines |
| | Spill (trucking) | Spill response |
| | Other industrial wastes | Enforcement; Spill response |

### 6.2.1 Education and Enforcement

A combination of education and enforcement are basic and common methods for removing sources of illegal discharges. One can conceive that an ill-informed and apathetic public is a fertile ground for individuals, commercial and industrial entities to consciously or unconsciously discharge waste illegally into a storm drainage system. At the same time, one also knows the power of education to arouse awareness and change behaviour of an individual who had assumed that stormwater drainage inlet on the curb is a site to dump liquid and solid wastes. An implicit assumption that educated public will have a right change in behaviour is often not the case unless education is complemented with enforcement. The limitation with education as a method to remove illegal discharges is that it does not end, it's a continuing process (Pitt et al., 1993).

The success of any method to remedy illegal discharges is underpinned by a well-established legal authority and responsibilities to regulate illegal discharges by developing either a new ordinance or amending an existing one. This usually includes developing a tracking system to report illegal discharges and citizen complaints, as well as developing a system to document management responses and enforcement efforts.

Common ordinances that may address illegal discharges include sanitary sewer ordinances, stormwater ordinances, plumbing codes, solid waste management ordinances, litter control regulation, septic system regulations, pollution control permits and others. Usually establishing legal authority and developing requisite ordinances are the responsibility of national and local governments and is beyond the scope of this study. Municipalities may prefer to use a phased approach (i.e. progressive enforcement actions) for eliminating illegal discharges. The initial phase is directed towards education to stimulate voluntary compliance (VC) and then escalated increasingly to severe phases of enforcement actions if VC is not achieved. Nonetheless, the administrator may promptly impose penalties if the discharge is initially established to be perverse, deliberate or outstandingly bad.

**Voluntary Compliance through education**

The favoured corrective measure to fix illegal discharges is to work toward voluntary compliance by educating responsible parties. Many a time, industrial and commercial operators and other responsible parties are ignorant or oblivious of the occurrence of illegal discharge on their properties. In such a situation, educating responsible parties about the discharge and its impacts on human health and environment and providing recommendations on how to mitigate or eliminate the problem may be enough to achieve voluntary compliance. Education should commence once the source of illegal discharge has been confirmed during the source tracking investigation. The responsible party should be made aware that the identified illegal discharge must be removed as soon as possible and the Municipality would be making a follow-up site inspection to confirm compliance. Field crew may deliver to the responsible party educational materials explaining illegal discharge violations.

There are many (industrial and commercial facilities) operational problems that result in illegal discharges and the remedying of these problems is the responsibility of property owners. These remedial actions may include moving outdoor storage area indoors or undercover, preventing overflow and leakage of dumpsters, avoiding discharge of process water effluent into storm drains, avoiding uncovered outdoor fuelling areas and similar other operational modifications. Site inspections and education can be used by the municipality to offer assistance to property owners to identify suitable interventions required to correct operational problems.

**Enforcement actions**

Most often education and voluntary compliance do not produce the expected result and in such cases a municipality may follow-up with enforcement action, as described by the City of Camas (2016) in Table 6-2 and Figure 6-1. The first phase of enforcement is preceded by education and voluntary compliance as discussed above. When education and voluntary compliance have failed to achieve a desired outcome, the municipality is required to send a summary letter to the responsible party (property owner). The summary letter must explain the problem and request a written assurance and expected date (not more than 30 days) to correct the problem. The municipality may provide technical assistance and resources required for the corrective action, if possible. It is important for a municipality to request evidence of corrected problem and also to conduct site inspection to confirm compliance. Phase 2 of enforcement actions is a follow-up or an escalation to first Notice of Violation (NOV) due to non-compliance of Phase 1 initial action. The responsible party must again provide the municipality with an undertaking that she/he is committed to correct the problem as well as the expected compliance date. The municipality must again inspect the site to verify compliance. If compliance is achieved and sustained for some time, the illegal discharge problem is considered abated. Failure of the municipality to receive an undertaking from the responsible party to comply, or if compliance is not met by the set date, the municipality escalates the enforcement to Phase 3 final action. In Phase 3, the municipality forwards a second NOV and may post a “stop-work order” on the property and issues a “civil citation” fine to the responsible party.

The fine must be paid and the discharge problem removed or the “civil citation” is litigated in court. The fine should be substantial to cover the full cost of remedying the problem and to serve as deterrent, else enforcement as a method will yield no significant outcome. If the responsible person is not implementing corrective action in good time to remove the source of the detected illegal discharge, the municipality may step in to undertake the necessary corrective measures and the responsible party will be required to reimburse the municipality for any costs incurred in remedying the problem. An alternative to civil infraction fine is “community service” activities as a potential penalty to violators who cannot afford to pay heavy fines. Enforcement actions including penalties must all be well-defined in the specific municipality’s ordinance(s). City of Bainbridge Island (2010:27-28) suggests the following guides to set appropriate community service activities:

- *The activity should take a time equivalent to the staff time spent investigating the illegal discharge incident.*
- *The activity should also require the violator to learn more about stormwater or water quality issues, so that they have a better understanding of their role in protecting water quality in the future.*
- *The activity should provide a benefit to the City’s water quality program, either directly through participation in water quality program activities or indirectly through education of the public.*

Ibid suggests community service activities such as:

- *Produce an educational brochure about IDDE and distribute among surrounding neighbours and/or businesses.*
- *Help set-up and staff the City's Water Resources program booth at a local community event.*
- *Provide field assistance to City staff working on mapping the stormwater drainage system or conducting outfall inspections.*
- *Provide field assistance to City staff in collecting water quality or groundwater monitoring data.*
- *Give a presentation about IDDE regulations at a local business networking group.*
- *Assist with preparations for the annual Water Resources program open events.*

**Table 6-2: Illegal discharge enforcement phases (after City of Camas, 2016:19)**

| **Enforcement step** | **Details** | **Responsibility** |
|---|---|---|
| Phase 1 – Initial Actions | • Provide educational materials (e.g. brochure)<br>• Encourage voluntary compliance<br>• Provide summary letter setting expected compliance date<br>• Additional staff support or technical assistance<br>• Request evidence of the corrected problem (if applicable)<br>• Site visit to verify compliance | Assigned staff |
| Phase 2 – Follow-up Actions | • Send "notice of violation" letter to the property owner regarding unresolved issues<br>• Set second compliance date (determined on an individual incident basis)<br>• Site visit to verify compliance | Enforcement Officer,<br>City Attorney |
| Phase 3 – Final Actions | • Send second "notice of violation" letter indicating that unresolved issues will be referred to the prosecutor<br>• The city may correct problems and send bill to property owner<br>• Levy fines | Enforcement Officer,<br>City Attorney |

Table 6-2 and Figure 6-1 present detailed enforcement phases. To ensure that all enforcement actions have been duly and procedurally followed, it is necessary to have a comprehensive record-keeping and documentation system (Case Log) in place. For every incident of identified illegal discharge source, the responsible party and accompanied corrective actions taken must be case logged. For a successful IDDE program in particular, the corrective actions component is reliant on good long-term record keeping as it helps in appropriately directing the activities and identifying repeat offenders. Records that need to be kept include citizen complaints, outfall inspections (completed field sheets), source tracking investigations (completed field sheets), and all corrective action procedures undertaken.

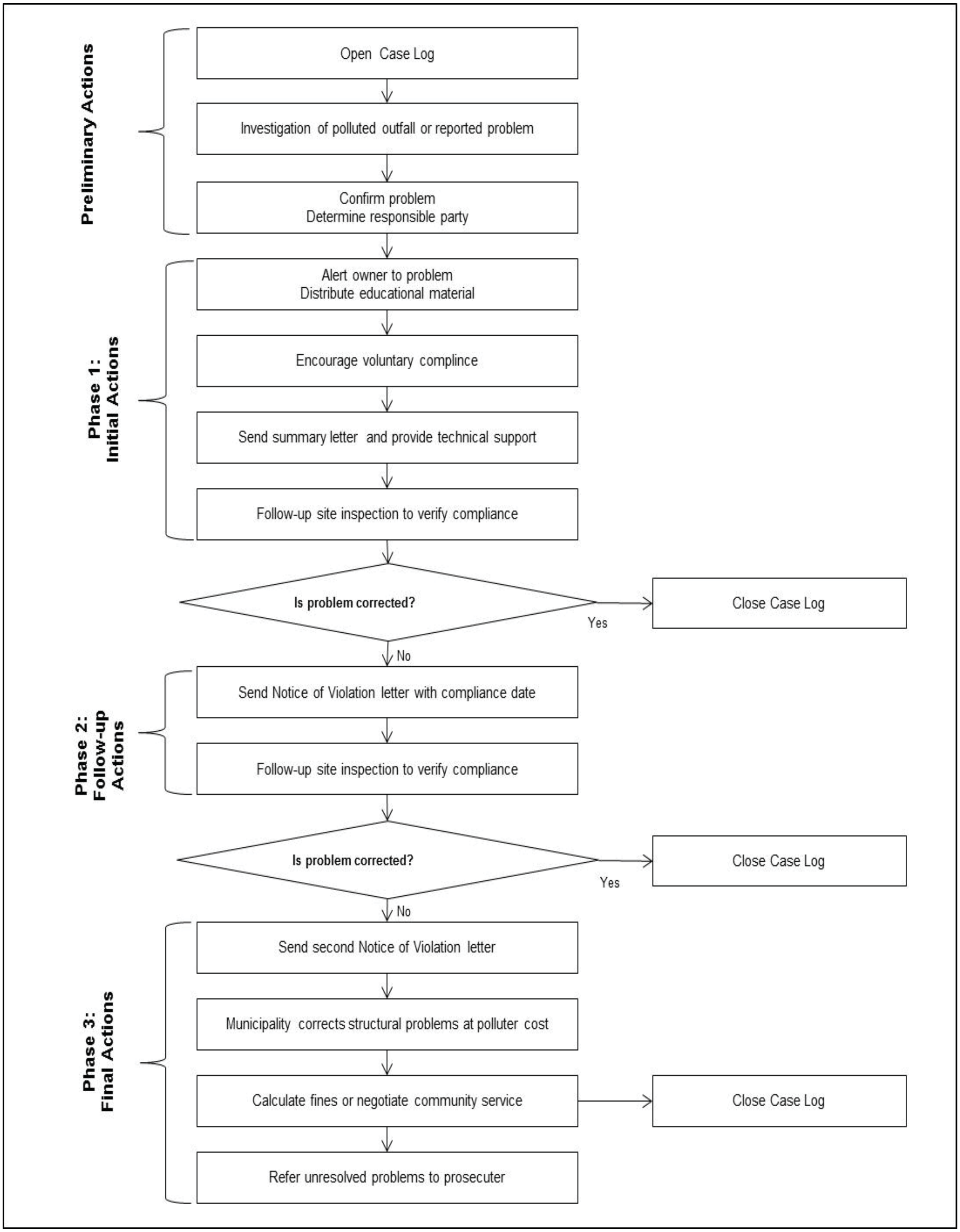



**Figure 6-1: Illegal discharge enforcement phases (after City of Camas, 2016:20)**

### 6.2.2 Other corrective methods

Corrective actions to most illegal discharges require structural modifications to the existing stormwater drainage and sewer infrastructure due to illegal connections. Illegal connections are direct discharges such as sanitary wastewater cross-connections, small diameter straight pipes bypassing wastewater connections and discharging into open channels and streams, as well as industrial and commercial cross-connections. Measures to deal with direct discharges range from simple plumbing projects to excavation and replacement of faulty connections. For sources located inside buildings, internal plumbing corrections may be all that is required with relatively low cost. Sources located outside buildings (e.g. in the right of way) such as service laterals or mains will require certified contractors with specialised equipment; hence, the cost tends to be comparatively high. These illegal connections to stormwater system must be removed and re-connected to wastewater sewer lines. Although the municipality may provide technical assistance to repairs and replacements resulting from structural modifications, the polluter pays principle places the responsibility (cost) squarely upon the property owner. Indirect discharges are discharges that enter storm drain inlets and by infiltration through joints of pipes. Sources of indirect discharges include breaks in sanitary sewer pipes and pump stations, sewer overflows and are commonly removed with spill containment, unblocking or flushing of drains and clean-up methods. A range of corrective techniques to eliminate illegal discharges including their estimated costs is presented in Table 6-3. The last six methods in Table 6-3 are employed in repair and rehabilitation of sanitary sewer lines (Brown et al., 2004). The cost rates in Table 6-3 are for the specific pay item only and do not include other costs; thus, total project unit cost per metre will be more. Total project average unit costs are provided in Table 6-4 which will include other items like site set up, compliance with Health and Safety specifications, day works, contract administration and others (Nel, 2019).

### 6.2.3 Public education

The purpose of public education or outreach program, as a preventive measure, is to avoid the occurrence of pollution at source by educating the public, including commercial and industrial enterprises about the impacts of their activities and operations on the environment. A significant proportion of the public is apt to come to a wise decision on any matter to fine-tune their behaviour if the content of such matter is fairly presented to their better judgement. Environmental awareness is heightened in recent decades and people are more prone to amend their behaviour and actions once they understand the potential adverse consequences. National and local governments have to date, conducted several outreach programs to educate the public about waste management, litter control, pollution to water bodies, habitat protection and others. Very few, if any, of these outreach programs have targeted commercial and industrial sectors and none has focused on illegal discharges into storm drains. Now, the time has come for outreach programs to include illegal discharge detection and elimination (IDDE) and to target local business community (commercial and industrial sectors). The business community is often profit-oriented, as it were and many of them care very little about the environment. They tend to pay heed only to the municipality to whose laws, policies and ordinances their activities are mostly subjected to. For this reason, it is prudent for the municipality to take responsibility for outreach programs to the business community (commercial and industrial sectors) and focus on IDDE.

Eliminating illegal discharges from low income, high density informal residential areas take on a special form of outreach activity known locally as “structured facilitated” consultation process to find root causes of pollution problems and to identify suitable interventions (DWAF, 2001a; 2001b). Problems of polluted discharges from these poorly serviced communities are so complex “because pollution in the settlements is rooted in the socio-economic, political and institutional conditions in the settlements” (DWAF, 2001a; 2001b). Consequently, the direct application of IDDE corrective measures, as outlined above, may not yield positive outcome in informal settlements.

## 6.3 Summary of corrective actions

Administration of illegal discharge detection and elimination program is a direct responsibility of local governments or municipalities as they own, operate, maintain and manage the entire infrastructure associated with illegal discharges. The success of the program is highly skewed towards how effective and efficient the municipality will implement or administer the program. The inability of the research team to access business properties for inspection and monitoring prevented the practical application of this component of the study. However, literature review of corrective action methodologies and techniques presented in this chapter are generic and should suffice.

**Table 6-3: Techniques to eliminate Illegal discharges (modified after Brown et al., 2004:175)**

| Technique | Application | Description | #Range of rates (R) | #Comments |
|---|---|---|---|---|
| Service Lateral Disconnection, Reconnection | Lateral is connected to the wrong line | Lateral is disconnected and reconnected to the appropriate line | R1500 per connection | Connection cost only |
| Cleaning | Line is blocked or capacity diminished | Flushing (sending a high-pressure water jet through the line); pigging (dragging a large rubber plug through the lines); or rodding. | R52-R200 per meter | Jetting cost only |
| Excavation and Replacement | Line is collapsed, severely blocked, significantly misaligned, or undersized | Existing pipe is removed, new pipe placed in same alignment; Existing pipe abandoned in place, replaced by a new pipe in parallel alignment | Trench: R184-R2000 per meter<br>Pipe: R729-R1200 per meter | Excavation and laying new pipe costs only |
| Manhole Repair | Decrease ponding; prevent flow of surface water into manhole; prevent groundwater infiltration | Raise frame and lid above grade; install lid inserts; grout, mortar or apply shortcrete inside the walls; install new precast manhole. | -<br>Replacement:<br>Brick: R9 000-R18 000 per manhole.<br>Concrete: R8 000-15 000 per manhole | Repair: Rates vary based on $m^2$ of repair.<br>Replacement: Manhole costs only. |
| Grouting | Seal leaking joints and small cracks | Seals leaking joints and small cracks. | R490-R3500 per meter | Grout cost only |
| Pipe Bursting | Line is collapsed, severely blocked, or undersized | Existing pipe used as guide for inserting expansion head; expansion head increases area available for new pipe by pushing existing pipe out radially until it cracks; bursting device pulls new pipeline behind it | R749-R1457 per meter | HDPE cost only |
| Slip Lining | Pipe has numerous cracks, leaking joints, but is continuous and not misaligned | Pulling of a new pipe through the old one. | R478-R4370 per meter | HDPE cost only |
| Fold and Formed Pipe | Pipe has numerous cracks, leaking joints | Similar to slip lining but is easier to install, uses existing manholes for insertion; a folded thermoplastic pipe is pulled into place and rounded to conform to internal diameter of existing pipe | - | - |
| Inversion Lining | Pipe has numerous cracks, leaking joints; can be used where there are misalignments | Similar to slip lining but is easier to install, uses existing manholes for insertion; a soft resin impregnated felt tube is inserted into the pipe, inverted by filling it with air or water at one end and cured in place. | R1 500-R8 000 per meter | Liner cost only |

# (Rates and comments were provided by Nel, 2019)

**Table 6-4: Renewal techniques unit costs for complete project (source: Nel, 2019)**

| | Pipe sealing | Slip lining | CIPP (cure-in-place pipe) | CIPP short length | Fold and formed pipe | Pipe bursting | Open cut |
|---|---|---|---|---|---|---|---|
| Cost/meter - 2016 | R 1 442 | R 4 195 | R 7 013 | R 27 854 | R 6 292 | R 2 818 | R 4 915 |
| Cost/meter - 2012 | R 1 100 | R 3 200 | R 5 350 | R 21 250 | R 4 800 | R 2 150 | R 3 750 |

# 7 CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Conclusions

This study has shown that stormwater drainage system discharging non-storm water adds substantial pollutant loadings to urban watercourses with adverse impacts to water quality and ecosystem sustainability. Thus, a program to eliminate these discharges can be a highly effective non-structural BMP to improve water quality. Conventional pollution control investigations may be unsuccessful if these pollutant sources are not detected and removed. A requirement to adequately prevent polluted non-storm water discharges into stormwater drainage systems is linked to the provisions of water use permits in the National Water Act. The study reviewed procedures, methodologies and techniques of IDDE program components as practiced internationally and applied these in a local condition to verify their feasibilities and challenges. A new risk mapping procedure was developed and applied successfully in case study catchments. Methodologies and techniques for identification, detection and monitoring of illegal discharges were evaluated and applied successfully in case study catchments. This report contains useful information to guide municipalities to develop and implement local investigations of illegal discharges into stormwater drainage systems. The report will enable municipalities to locate priority areas in urban catchments for the investigation; to identify illegal discharges at outfalls; to track discharges to their sources and; to apply corrective actions. Challenges encountered in the study include lack of legal authority to undertake inspection, surveillance and monitoring at private and corporate properties and to undertake requisite enforcement measures to remove sources of illegal discharges.

## 7.2 Recommendations

The following recommendations are made for future work

**National government (Department of Water and Sanitation):** On the premise that water quality deterioration is one of the main challenges facing the water sector in South Africa, the Department of Water and Sanitation (DWS) should specify and regulate management practice to prevent or control pollution to urban watercourses that relates to contaminated non-storm water discharges. A regulation mandating local governments to develop, implement and enforce illegal discharge detection (IDDE) program would be a suitable management practice to mitigate the scourge of water quality deterioration. Requirements of such IDDE program must be defined to include the following:

- Stormwater drainage map showing all drainage conveyances and BMPs, outfalls and receiving watercourses.

- A regulatory mechanism or by-law to prohibit illegal discharges (i.e. contaminated non-storm discharges).
- Develop and implement an IDDE plan to prevent, detect and remove illegal discharges and connections to the stormwater drainage system. The plan should include the following seven components:
    - Procedures for locating priority areas with illegal discharge potential
    - Procedures for complaint hotline
    - Procedures for outfall inspections and water quality monitoring
    - Procedures for tracking to the source of an illegal discharge
    - Procedures for removing the source of the discharge
    - Enforcement response procedures to compel compliance with illegal discharge prohibition
    - Procedures for program evaluation and assessment.

The concept of cooperative governance as embodied in the Constitution of South Africa needs to be reviewed to allow all levels of government to hold each other to account on their actions and inactions that result in pollution to watercourses. Penalties must be set for non-compliance of water pollution prohibitions to ensure local governments implement and enforce the rules.

**Local governments:** Some municipalities may need to establish new or modify existing by-laws to achieve the following objectives:

- To prohibit contaminated non-storm water discharges and connections to the stormwater drainage system and other urban watercourses.
- To establish legal authority to undertake inspection, surveillance and monitoring at private and business properties.
- To establish legal authority and responsibility to undertake requisite enforcement measures to support compliance with the by-laws.

It is important for local government to identify the department(s) to administer, implement and enforce an IDDE program. For smaller municipalities, administration and implementation may be delegated to a small group of staff, but for bigger municipalities, establishing the program under one or combination of departments is essential. Departments within a municipality that can take responsibility to administer and implement an IDDE program include, but is not limited to the following: Stormwater, Water and Sanitation, Water Pollution and Control, Environmental Resources/Protection and others. Irrespective, the identified individuals or department(s) should be well-trained to provide clear understanding of program goals, objectives, procedures, actions and expected outcomes. Often, different departments in the municipality may have certain functions and authority over some aspects of illegal discharges. Thus, close coordination and communication with different departments is essential and consideration should be given to consolidated responsibility and authority.

**Future research work:** This study provides a starting point to systematically detect and remove contaminated discharges to urban watercourses. There is a need for similar IDDE studies in different municipalities to provide adequate information. A benchmarking survey of these future studies would result in improved guidance manual that integrate results and other knowledge gained.

More work is needed to better quantify the pollutant removal and costs associated with correction of illegal discharges, to evaluate the effectiveness of proactive prevention strategies (e.g. inspection of laterals) that rely on systematic inspections of the system rather than outfall monitoring and tracking, and to develop improved strategies for tracking down and eliminating these discharges.

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# APPENDIX A: Photos of illegal discharges in Diep river catchment


**Figure A1: Dry-weather flow from stormwater headwall/outfall on the corner of Grey and Vrystaat Streets, Paarden Eiland, upstream of Zoarvlei, 29 Jan 2017**

**Figure A2 Dry-weather flow in stormwater canal, Plattekloof Road near N7, 29 Jan 2017**

**Figure A.3: Dry-weather flow in stormwater channel, Blaauwberg Road in front of Tableview Mall, 29 Jan 2017**

**Figure A4: Dry-weather flow in Bayside canal, corner of Blaauwberg Road and West Coast Road, 29 Jan 2017**

**Figure A5: Main stormwater outfalls from DuNoon informal settlement discharging dry-weather flow into Diep River (Milnerton), 29 Jan 2017**

# APPENDIX B: Supplementary literature review

# APPENDIX B1 – Case study catchments descriptions

Location of the case study catchments (Diep River and Kuils River catchments) is shown in Figure B1 below. Both catchments extend beyond Cape Town municipal boundaries. The City maintains an inland surface water quality monitoring network with monitoring sites within all the major catchment areas.

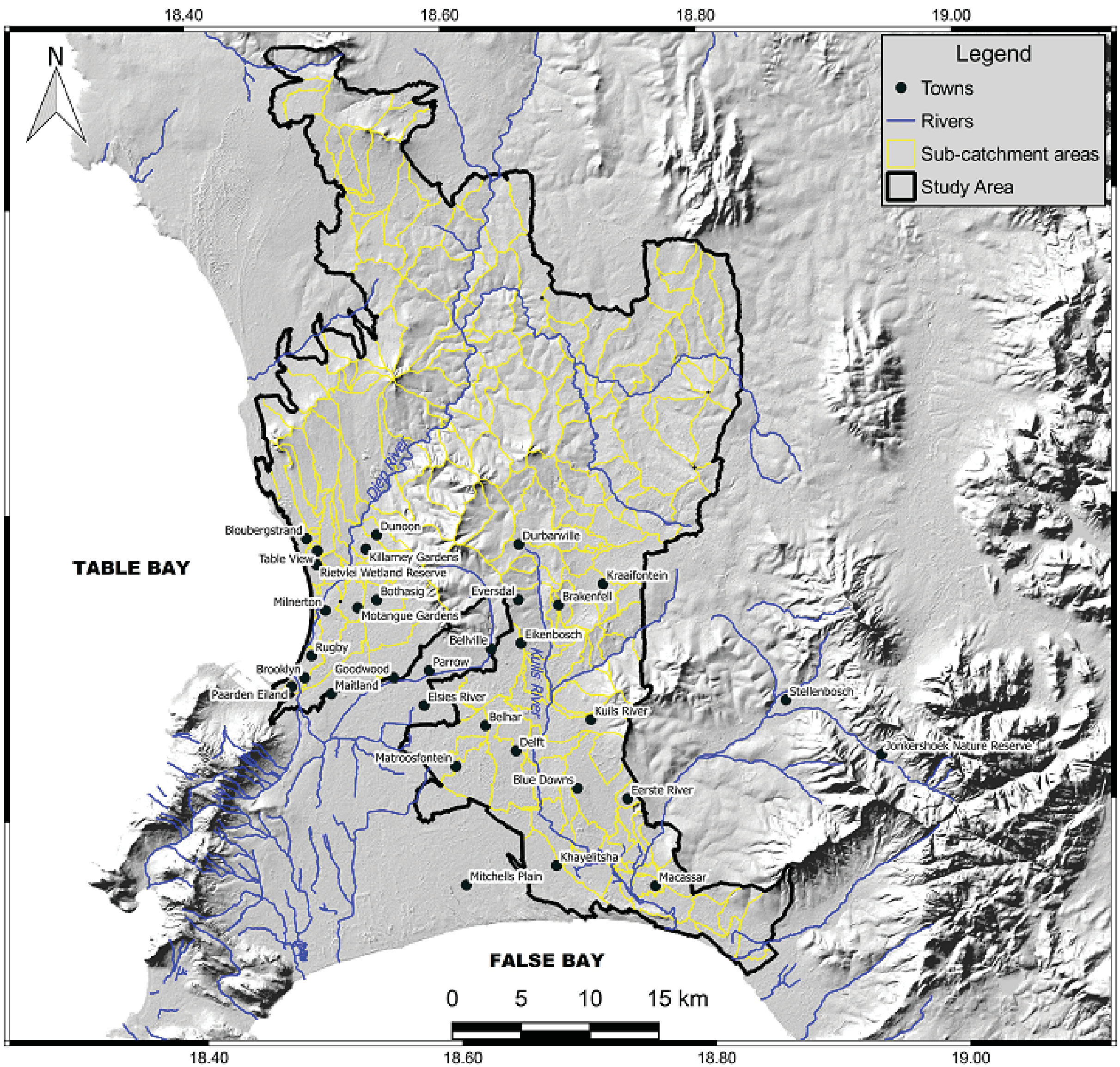


Figure B1: Drainage catchments in the City of Cape Town metro area and environs

**Motivation for the selected catchment**

The Diep- and Kuils River catchments afford an excellent case study of highly impacted urban systems and demonstrating the whole spectrum of land uses, socio-economic variations and housing types found in typical South African cities. They also exhibit acute ecological stresses, highly impaired water bodies and significant loss of biodiversity. A study by PDNA (2011) for the City of Cape Town undertook risk assessment of catchments in the City's water management areas to determine their vulnerability to pollution and prioritised the catchments, rivers and wetlands for management intervention. Both the Diep- and Kuils River catchments and their rivers/streams were ranked most vulnerable to pollution and accorded high priority for management actions. The presence of various land-uses in both catchments affords the opportunity of tracking illegal discharges from all land use types and development types.

**Diep River (West Coast) Catchment**

The Diep River takes its source outside the municipal area of Cape Town, rising from the Riebeek-Kasteel Mountains. From the upper reaches of the catchment, it flows in a south-westerly direction through Malmesbury where it receives effluent from Swartland wastewater treatment works (WWTW). In the middle undeveloped reaches, it flows through agricultural lands (livestock and crops). Lower downstream, near Cape Town; it flows through informal areas including Doornbach and Dunoon and more developed residential areas including the suburbs of Table View and Blaauwberg. The lower reaches of Diep River are the Milnerton Lagoon, Rietvlei and Zoarvlei before entering the Atlantic Ocean. The Potsdam WWTW discharges treated effluent slightly upstream of the wetland and estuary. The Milnerton Lagoon is in the residential suburb of Milnerton and is used extensively for recreational purposes, particularly by canoeists. There are eight sewage pump-stations in the vicinity of the lagoon. Rietvlei is a large wetland complex in the floodplain of the Diep River between the suburbs of Milnerton and Table View. The vlei drains into Table Bay via the Milnerton Lagoon. The wetland complex comprises areas of reed beds, seasonal pans and a large deepwater lake. There are three sewage pump-stations in the vicinity of Rietvlei. Zoarvlei in the Paarden Eiland industrial area receives runoff from the suburbs of Rugby and Brooklyn. Its outlet is located in the Milnerton Estuary near the mouth. Water quality indications in the middle and lower reaches of Diep River are summarised in Table B1.

Non-storm water pollution may originate from: livestock agriculture in the middle and upper reaches of the Diep river; poor quality of effluent from Potsdam WWTW; non-storm water discharges from the informal settlements (DuNoon, Doornbach and Joe Slovo Park); overflowing sewage pump-stations; sewer overflows due to blockages in the sewer lines; Milnerton Riding Stables; non-storm water discharges from Killarney and Montague Gardens industrial areas and; illegal dumping and disposal of solid waste in the catchment. The Diep River delivers goods and services such as: ecotourism and recreation; water supply (irrigation); flood attenuation at Rietvlei; breakdown and dilution of pollutants (RHP, 2005:33).

**Table B1: Water quality indications in the middle and lower reaches of Diep River (compiled from PDNA, 2011)**

| **Diep river reaches/points** | **Water quality characteristics** |
|---|---|
| Middle reach | Sporadic to persistently unacceptable counts of *E. coli* and persistently unacceptable levels of the physical and chemical constituents, particularly phosphates. |
| Lower reach | Persistently unacceptable counts of *E. coli* with extremely high counts at times and persistently unacceptable levels of the physical and chemical constituents, particularly ammonia and phosphates. |
| Theo Marais Park stormwater outfall | Persistently unacceptable counts of *E. coli* with extremely high counts at times. There are persistently unacceptable levels of ammonia and sporadic to persistently unacceptable levels of phosphates and total nitrogen and sporadically unacceptable dissolved oxygen levels |
| Duikersvlei Stream | Occasional unacceptable counts of *E. coli* and persistently unacceptable levels of ammonia and total nitrogen with sporadically unacceptable levels of phosphates. |
| Milnerton Lagoon | Sporadic to persistently unacceptable counts of *E. coli* and persistently unacceptable levels of ammonia and phosphates. |
| Rietvlei outlet (at Otto Du Plessis drive bridge) | Persistently unacceptable counts of *E. coli* and persistently unacceptable levels of all physical and chemical constituents. |
| Bayside Mall (storm water channel flowing into Rietvlei) | Fair to unacceptable levels of dissolved oxygen and total nitrogen, unacceptable levels of ammonia and fair levels of phosphates. The *E. coli* counts are persistently unacceptable. |

### Kuils River Catchment

The Kuils/Eerste Catchment area extends from the municipal area of Cape Town into the Stellenbosch municipal area. The Eerste River (largely in Stellenbosch municipal area) has its source in the Jonkershoek mountains above Stellenbosch. It is only the lower reaches of the Eerste River that are within the Cape Town municipal boundaries. The Kuils River, however, flows entirely within the Cape Town municipal boundaries in south and south-easterly direction over a progressively flatter terrain to join the Eerste River, then the Eerste Estuary to the False Bay. The Kuils River catchment area is developed with extensive impervious areas.

Land-use is mostly a combination of residential, industrial, commercial, natural areas and agriculture. Residential areas include Macassar, Kuils River, Eerste River, Bellville, Eversdal and Durbanville. Informal settlements include Khayelitsha and others in the Cape Flats. The middle to lower reaches of the Kuils River are mostly canalised and receive treated effluent from the Bellville, Zandvliet and Macassar WWTW. There are also four sewage pump-stations in the middle to lower reaches of the Kuils River. Two main sewer lines run the length of the Kuils River; one flows to Sarepta pump-station and the other to Rietvlei pump-station. Overflows from these lines would have an adverse impact on the river. The Eerste River estuary passes through coastal dunes near Macassar before entering False Bay. As a result of wastewater discharges into the Kuils- and Eerste River, high volume of poor quality freshwater is often input into the estuary. The estuary is an attractive area supporting a variety of aquatic birds. (RHP, 2005:23). Water quality indications in the middle and lower reaches of Kuils River are summarised in Table B2.

**Table B2: Water quality indications in the middle and lower reaches of the Kuils River (compiled from PDNA, 2011)**

| Kuils River reaches | Water quality characteristics |
|---|---|
| Upper reach (of the Bottelary confluence) | Persistently unacceptable counts of *E. coli* with many incidents of extremely high counts. The physical and chemical constituents are sporadically unacceptable. |
| Middle reach | Persistently unacceptable counts of *E. coli* with extremely high counts at times and persistently unacceptable levels of ammonia, total nitrogen and phosphates. |
| Lower reach | Sporadic to persistently unacceptable counts of *E. coli* and persistently unacceptable levels of phosphates and sporadic to persistently unacceptable levels of ammonia, total nitrogen and dissolved oxygen. |

Non-storm water pollution may originate from: poor effluent quality from Bellville, Macassar and Zandvliet WWTWs; return flows from irrigation (especially those using effluent from WWTWs); leaking sections of the two main sewer lines along the Kuils River; non-storm water discharges from the informal settlements and backyard dwellers in the more formal (Reconstruction and Development Programme (RDP) /Subsidised Housing) areas (Khayelitsha, etc.); overflowing sewage pump-stations; sewer overflows due to blockages in the sewer lines; non-storm water discharges from Stikland Industrial areas and; illegal dumping and disposal of solid waste in the catchment. The Kuils River delivers goods and services such as: ecotourism and recreation; subsistence farming (arum lilies and thatch reed along the Kuils River); water supply; flood attenuation in the wetlands of the lower Kuils River; breakdown and dilution of pollutants (RHP, 2005:23).

**References**

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# APPENDIX B2 – Classifications of illegal discharges

## Table B3: Different classifications of illegal discharge (compiled from Brown et al., 2004:5-11)

| **Classification in terms of Discharge frequency** | | |
|---|---|---|
| **Key Terms** | **Description** | **Example** |
| Continuous discharge | Occur most or all of the time | Sewage cross-connection to a storm drain |
| Intermittent discharge | Occur over a shorter period | Liquid waste dumping and discharges from over-watering or misdirected irrigation sprinklers (often a few hours per day or a few days per year). |
| Transitory discharge | Occasional occurrence, usually accompanying a singular event | an industrial spill, ruptured tank, sewer break, transport accident or illegal dumping episode |
| **Classification in terms of Discharge Flow Types/Compositions** | | |
| **Key Terms** | **Description** | **Example** |
| Sewage & septage | flows produced from sewer pipes and septic systems | Sanitary wastewater |
| Washwater | Wastewater flows from many washing activities and operations from residential, commercial and industrial areas containing higher concentrations of detergents and surfactants. | Discharges of greywater (laundry) from homes, commercial carwash wastewater, fleet washing, commercial laundry wastewater and floor washing to shop drains. |
| Liquid wastes | Rinse water and wash water during maintenance and cleanup operations. | Oil, grease, paint, solvents, various automotive fluids and process water (radiator flushing water, plating bath wastewater, etc.) entering the storm drain. |
| Tap water | Flows from leaks and losses in the drinking water supply system. | Leaks & other losses; fire |
| Landscape irrigation flows | Return flows from residential or commercial irrigation ends up in the storm drain system. | Over-watering or misdirected irrigation sprinklers. |
| Groundwater & spring water flows | Discharge from subsurface systems due to rising water tables. | Springs flowing into urban watercourses, groundwater seepages. |
| **Classification in terms of Discharge Categories** | | |
| **Key Terms** | **Description** | **Example** |
| Pathogenic or toxicant pollutant sources | Most severely polluted and can cause illness upon water contact or consumption and requires significant water treatment to downstream users. | Sanitary wastewater (from all land uses). Other sources include disposal of toxicants from households, de-greasing of vehicle engines and excessive use of chemicals (pesticides). |
| Nuisance and aquatic life- | They cause excessive dissolved oxygen depletions and algal growths, tastes and odours in downstream water supplies, offensive | Wash waters (from laundry and car wash centers), lawn irrigation return flows, dewatering operations at construction sites and washing of concrete ready-mix trucks. |

| | | |
|---|---|---|
| threatening pollutant sources | coarse solids and floatables and other aesthetic impacts. | |
| Clean or unpolluted water | Normally unpolluted | They come from natural springs, infiltrating groundwater, potable waterline leaks, firefighting activities, etc. |
| **Classification in terms of Mode of Entry** | | |
| **Key Terms** | **Description** | **Example** |
| Direct entry | Direct connection from either a sewer, shop drain, etc. to a storm drain pipe and usually as a result of "plumbing" defects. They can originate from residential, commercial, industrial, or institutional establishments. | *Sewage cross-connection*: A sewer pipe that is improperly connected to the storm drain system produces a continuous discharge of raw sewage to the pipe |
| | | *Straight pipe*: small diameter pipes that intentionally bypass the sanitary connection or septic drain fields, producing a direct discharge into open channels or streams |
| | | *Industrial and commercial cross-connections: T*hese occurs when a drainpipe is improperly connected to the storm drain system producing a discharge of wash water, process water or other illegal flows into the storm drain pipe; e.g. a floor shop drain that is illicitly connected to the storm drain system. |
| Indirect entry | There is no direct connection, but discharges enter storm drainage system through their inlets or by infiltrating through their joints and cracks. They are often intermittent or transitory discharges. The five main modes of entry are noted: | *Groundwater seepage:* can be continuous or intermittent, depending on the depth of the water table and the season. |
| | | *Spills:* Transitory discharges. When a spill (at industrial, commercial and transport-related sites; or from a road accident) travels across an impervious surface and enters a storm drain inlet. |
| | | *Dumping*: Liquid waste dumping occurs intermittently at sites that improperly dispose of rinse water and wash water during maintenance and cleanup operations into storm drains. A common example is cleaning deep fryers in the parking lot of fast food operations. Transitory discharge is created when liquid wastes such as oil, grease, paint, solvents and various automotive fluids are dumped into the storm drain. |
| | | *Outdoor washing activities: Create ID discharge to a storm drain inlet* depending on the nature of the site; e.g., hosing off individual driveways, routine washing of fueling areas, outdoor storage areas and parking lots (power washing) and construction equipment cleanouts. |
| | | *Non-target irrigation from landscaping or lawns that reaches the storm drain system*: Intermittent discharges from over-watering or misdirected sprinklers that send water over impervious areas. Return flow from non-target irrigation can produce unacceptable loads of nutrients, organic matter or pesticides; e.g., discharge from commercial landscaping areas adjacent to parking lots connected to the storm drain system. |

## References

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# APPENDIX B3 – Recommended risk factors

## Table B4: Risk factors used by different authors (after Bender, 2016:17)

| Dataset (Risk Factors) | Description | Wayne County, MI[a] | WNYSC, Buffalo, NY[b] | Fairfax County, VA[c] | Arlington County, VA[d] | City of Roanoke, VA[e] | Town of Blacksburg, VA[f] | Zielinski and Brown, 2003 | Brown et al., 2004 | Pitt and Rittenhouse, 2001 | Bender, 2016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stormwater Infrastructure (Outfall density) | Location, age, condition of outfalls, pipes and drainage channels. (Number of outfalls per kilometre of municipal waters or streams). | X | X | X | X | X | X | X | X | X | X |
| Sanitary Infrastructure | Location, age, condition, of the sanitary sewer network | | | X | X | X | | | X | X | X |
| Combined Sewer Infrastructure | Location, age, condition, of any combined sewer service areas | X | | | | | | | X | | |
| Septic or Onsite Disposal Systems | Existence and performance of septic or onsite disposal systems | | | | | X | | | X | X | X |
| Plot Records, Development Age | Aging infrastructure, cross-connections, out-of-code construction | | X | X | X | X | X | | X | | X |
| Land Use or Zoning | High-risk activities specific to land use or industry | X | X | X | X | X | X | X | | X | X |
| SSO Reports or I/I Studies | Failing or underperforming sanitary infrastructure | | | | | | | | X | X | |
| Receiving Waterbodies | Aquatic ecosystems sensitive to or impaired by pollution | | X | | X | | | X | X | X | |
| Watersheds | Drainage area defined by topography and/or subsurface drainage | X | X | X | | X | X | | | X | |
| Land Cover or Impervious Surface | Indicator of pollution sources, measure of development intensity | | | | X | X | X | | | | X |
| Business and Special Facilities (Generating sites density) | Standard Industrial Classifications (SIC) or discharge permits. (Number of potential generating sites per square kilometre) | X | | X | X | X | X | | X | X | X |
| Population Density | Intensity of development and urbanisation | | | | | | | | | X | X |
| Historic Complaints and Reports | Locations where discharges have occurred in the past | X | X | | X | X | | | X | | |
| Water Quality Data | Past and current sampling efforts and monitoring programs | X | | | | | | | X | | |
| Historical Knowledge or Experience | Seasoned employees, personnel with professional experience | X | | | X | X | | | X | X | |
| Easements and Rights-of-Way | Land designated for streets, utilities, or other linear use rights | X | | X | | X | | | X | X | |
| Aerial Imagery | Aerial photographs of the land surface | X | | | | | | | X | X | |
| Percent imperviousness | Proportion of area covered by impervious surfaces (e.g. concrete or rooftops), evaluated over individual watersheds. | | | | | | | | | | X |
| Drainage density | Length of drainage conveyances (open channels, pipes and streams) divided by the watershed drainage area. | | | | | | | | | | X |
| Infrastructure Access Density | Number of access points (i.e. catch basins and other inlets) to storm drain network per square kilometre. | | | | | | | | | | X |
| Construction Site Density | Number of active construction sites per square kilometre. | | | | | | | | | | X |
| Dog License Density | Number of dogs per square kilometre | | | | | | | | | | X |

a (Johnson and Tuomari, 1998; Tuomari and Thompson, 2003; Tuomari et al., 1995)
b (Irvine et al., 2011)
c (Fairfax County Stormwater Planning Division, 2014; Versar Inc., 2014a)
d (Versar Inc., 2014b, 2014c)
e (Dymond et al., 2015a, 2015b)
f (Howard and Schirmer, 2013).

Note: SSO stands for sanitary sewer overflow and I/I stands for inflow and infiltration.

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Versar Inc. (2014c). Arlington County Wet Weather and High Risk Screening Program: Site Selection and Screening Plan. Arlington County, VA.

# APPENDIX B4 – Review of illegal discharge detection methods

**Table B5: Detection methods identified in the literature survey, (modified after Panasiuk et al., 2015:246)**

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| *Sensory methods* | | | *Generally inexpensive* | *Difficulties in detecting low wastewater inflows that are relatively low, so that the senses of the field crew are confounded, resulting in failure to detect the pollution (Brown et al., 2004)* |
| Visual inspection | Irvine et al. (2011), Brown et al. (2004) | Used for initial characterisation of the flow appearance and location of obvious sources of contamination in preliminary investigations. Focused on obvious tracers (e.g. toilet tissue) | Quick, no need for special equipment | Shown to be subjective (Dirksen and Clemens, 2008); may be ineffective if wastewater inflows are low; so that the visual indications of wastewater (e.g. unusual colour) are masked due to the dilution by the flow in stormwater sewers (Brown et al., 2004); can be used only at manholes or in large-enough pipes (safety concerns). |
| Dye testing | Tuomari and Thompson (2003) | Flushing dye into the wastewater system and observing entrances into the stormwater system to identify illicit and cross-connections | Simple, source-specific method | Often requires access to private properties; high turbidity or elevated stormwater flow rates make the dye less detectable; low-flow rates in the connections render the method time-consuming (Brown et al., 2004). |
| Smoke testing | Larsen et al. (2002); Tuomari and Thompson (2003) | Blowing smoke into the stormwater system and observing where the smoke leaves the sewers to identify cross connections and or damaged sewers. | Rather inexpensive | Can detect only direct connections from wastewater to stormwater sewers (Brown et al., 2004) |
| Video inspection or closed-circuit televisions (CCTV) | Butler and Davies (2004) | Locating connections in the system and monitoring stormwater sewer conditions using a TV camera that is moved along the sewers. | Detects both illicit connections and defects allowing infiltration through pipe cracks and joints | Observing illicit discharges during non-peak hours is less likely than during morning and evening wastewater inflow (diurnal) peaks (Butler et al., 1995); requires time-consuming processing of the video footage in the office (Brown et al., 2004) |

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| Odour inspection | Brown et al. (2004); Fermanich (2009) | Preliminary investigation of the condition of the flow in a stormwater sewer used for location of obvious sources of contamination. The type (e.g. sewage, petroleum, sulphate, etc.) of odour and its relative strength is of interest. | Quick, no need for special equipment | Subjective; possible only at manholes or in large-enough pipes (safety concerns) (Brown et al., 2004) |
| Public complaints | Brown et al. (2004) | Observation and reporting of severe contamination by the public or municipal field staff (e.g. unusual colour, odour, etc. of discharges) | Rather inexpensive; covers large areas; empowers the public to get involved in pollution protection | Contamination may be detected/reported only if the wastewater inflows are severe, or when dealing with specific industrial wastewaters that are easy to observe (Brown et al., 2004) |
| *Monitoring Temperature* | | | *A common characteristic of both wastewater and stormwater that can be measured inexpensively on-line* | *Non-conservative parameter; stormwater temperatures may rise or fall during storms (a source of uncertainty); observed thermal anomalies during normal flow patterns* |
| Grab sampling | Brown et al. (2004) | Indication of obvious pollution. Could be included in the first stage of illegal discharge survey (outfall screening) | Simple and robust measurements; relatively inexpensive equipment | Provides temperatures over relatively short periods at a fixed measuring point; due to heat losses may be inefficient if wastewater inflow (t=28°C) into the stormwater flow (t=18°C) was undetectable 50 m downstream from the inflow location (Hoes et al., 2009) |
| On-line monitoring | Schilperoort et al. (2006) | Used for the detection of intermittent discharges of wastewater carrying enough heat energy to be detected (i.e. warmer than the baseflow in storm sewers and relatively high inflow of wastewater) | Simple and robust measurements that can extend over long-time periods | Fixed measuring point. Not only wastewater discharges but also storm events can cause increases in the temperature of the flow in storm sewers (Schilperoort et al., 2006). |

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| Distributed temperature sensing | Hoes et al. (2009); Schilperoort and Clemens (2009) | Temperature measurements in the storm sewer over some distance (1-5 km), with high temporal (15-30 s) and spatial resolutions (1-2 m) using fibre-optic cable with high precision level (0.1-0.2°C) | Measurements can cover long distances and periods; high spatial and temporal resolution; high precision | Very expensive; equipment (cable) installation is time-consuming. One kilometre of cable installation requires 5-7 persons working almost a full day; one week of measurements costs about US$10,000 at 2009 prices (Hoes et al., 2009; Schilperoort and Clemens, 2009) |
| Aerial infrared photography | Lega and Napoli (2010) | Use of infrared cameras mounted on a plane or helicopter to detect abnormal temperatures at stormwater outlets. Un-manned aircraft (drones) can decrease the costs of the method. | Relatively fast coverage of large areas. Works well for high wastewater inflows of sufficient high temperatures. | Relatively expensive equipment; works well for high wastewater inflows of sufficiently high temperatures; applications are recommended for seasons with minimum vegetation interference and maximum temperature differences; daylight solar radiation could reduce method efficiency, flights during nights are recommended; requires an experienced pilot (Lega and Napoli, 2010); further advances and cost reductions could be achieved by using drones for aerial photography |
| *Monitoring Chemical parameters* | | | *Can detect human-waste specific indicators with high accuracy; common chemical indicators (conductivity and ammonia) can be applied inexpensively* | *Chemical indicators except for conductivity and electronic nose/tongue cannot be measured online and the time delay between the sampling procedure and obtaining the results may slow down the survey implementation* (Brown et al., 2004) |
| Ammonia | Brown et al. (2004) | Indicator of wastewater contamination in stormwater, especially if concentrations exceeds a benchmark level of 0.3 mg/L. | Common parameter; a good indication of wastewater presence | Non-conservative parameter; present both in stormwater and wastewater, therefore benchmark levels indicating wastewater contamination should be used (Irvine et al., 2011; Brown et al., 2004) |

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| Conductivity | Deffontis et al. (2013) | Indicator parameter for the detection of ID into storm sewers, especially for industrial flows, but also wastewater | Simple, robust measurements; determine total dissolved solids content | Sharp variations during measurements; observed anomalies in normal flow behavior (Schilperoort et al., 2006); readings could be confounded by an inflow of salt-laden runoff into storm sewers (in regions where salt is used as a de-icing agent during the winter and spring) (Marsalek, 2003) |
| Caffeine | Sankararam-akrishnan and Guo (2005); Sauve et al. (2012) | Indicator of human faecal contamination, also used as a chemical marker for microbiological source tracking. An indicator of recent contamination by wastewater. | Conservative tracer; few natural sources (especially in Northern hemisphere) | Present in very low concentrations in the flow (0.14-37 μg/L) (Sankararamakrishnan and Guo, 2005) that requires methods with low detection limits (Chen et al., 2002), making the method expensive (Hagerdorn and Weisberg, 2009) |
| Carbamazepine | Sauve et al. (2012) | An anticonvulsant drug and mood stabiliser; a human-specific tracer of faecal contamination. Less widespread than caffeine but more persistent, even after the treatment processes. Can be used as an indication of cumulative wastewater discharges. | Very conservative; persistent even when subject to wastewater treatment processes | Same as for caffeine with even lower concentrations (0.1-5 μg/L) (Clara et al., 2004; Sauve et al., 2012); consumption of this drug is less widespread than of caffeine-containing products, resulting in localized discharges of carbamazepine into wastewater sewers (Sauve et al., 2012) |
| Indicator parameters measured by the electronic nose and tongue | Fenner and Stuetz (1999); Dewettinck et al. (2001); Campos et al. (2012) | Electronic nose and tongue technologies based on electronic sensors mimicking human sensory receptors. The sensors generate a signal pattern related to a specific compound. Can be used for predicting concentrations of $NH_4$, $NO_2$, $SO_4$, COD, BOD, VOC, TSS, turbidity, etc. | Detection of specific compounds, odours or water quality characteristics | Recently developed technology based on complex instruments (Capelli et al., 2014) – not yet adequately tested; some types are not so effective in measuring concentrations (quantitative information) of the detected compounds (Wilson, 2012); investment and operational cost can limit practical applicability of these sensors (Campos et al., 2012) |
| Passive sampling of optical brighteners (OBs) | Chandler & Lerner (2015) | An inexpensive method of passive sampling using cotton tampons placed in storm sewers. OBs adsorbed to the tampon fluoresce in UV light indicating wastewater contamination. | An inexpensive and simple method; passive sampling over a longer period. | Suspended solids in the flow can mask the pollution; some ID may not contain optical brighteners (Chandler and Lerner, 2015); do not provide quantitative information |

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| *Monitoring Microbiological parameters* | | | *Broadly ranging methods employing both common indicator bacteria as well as source-specific indicators (microbial source tracking-MST)* | *Non-conservative parameters; common indicator bacteria may not distinguish between specific bacteria sources; may require up to a couple of days for obtaining the results for the microbiological analysis (Brown et al.,2004); microbial tracking methods are still subject to research and development* |
| Common faecal indicator bacteria | Brown et al. (2004); Irvine et al. (2011) | Indicator bacteria used for faecal contamination detection: *faecal coliform, E. coli, Enterococci, total coliforms,* etc. | Widely used indicators of faecal pollution | Detection of these bacteria is not necessarily an indication of wastewater contamination of the stormwater flow as faecal indicator bacteria can originate from either human or animal sources (Brown et al., 2004) |
| Antibiotic resistance | Field and Samadpour (2007) | Methods include assumptions about the differences in antibiotic resistance in both the type and strength for bacteria originating from humans and domestic and wild animals. | Distinguishes human, agricultural and wild animal sources | Not geographically stable, i.e. the library of antibiotic resistance profile is country-specific (Ebdon and Taylor,2006); poor results from blind samples (Field and Samadpour, 2007), i.e. less than half (45.5%) of isolates correctly classified the source of bacteria (Moore et al., 2005) |
| Carbon utilisation profiling | | Based on an analysis of utilisation profiles of carbon sources by faecal indicator bacteria. Commercially available micro-plate systems are used for pattern generation. | Distinguishes human, agricultural and wild animal sources; passed biological likelihood test | Showed ineffective results in some comparative studies (Field and Samadpour, 2007), as some overlaps in the differentiating values for animal and human samples were found (Blanch et al., 2006) |
| Bacteriophage methods | | Based on certain strains of *Bacteroides* that are only able to grow bacteriophages from specific sources of sewage. | Distinguishes human and non-human sources | Various species of *Bacteroides* have different ability to discriminate between sources of faecal pollution and this ability also varies geographically, e.g. strains of *Bacteroides* from Mediterranean region fail to detect phages in Northern Europe and the United States (Payan et al., 2005) |
| Sorbitol-fermenting bifidobacteria | | Based on host-specific species of *Bifidobacteria* (*B. dentium* and *B. adolescentis* that are human host-specific). | Distinguishes human and non-human sources; considered as a strong method in Europe | Short survival time in the environment, especially during summertime; cannot be detected if the water temperature is high (Field and Samadpour, 2007) |

| Detection method/ Indicator parameters | References | Short description | Advantages | Limitations |
|---|---|---|---|---|
| DNA fingerprinting | | e.g. ribotyping, repetitive extragenic palindromic polymerase chain reaction (REP-PCR), pulse-field gel electrophoresis (PFGE). Based on the detection of known host-specific strains in DNA of analysed microorganisms in a storm sewer. | Distinguishes any source | Relatively time-consuming and expensive analyses (Call et al., 2007; Tourlousse et al., 2008); extreme importance of the DNA library size; high temperature and sunlight accelerates the decay of DNA markers (He et al., 2015) |

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# APPENDIX C: Illegal discharge potential risk classification maps and table

# APPENDIX C1 – Risk Classification maps

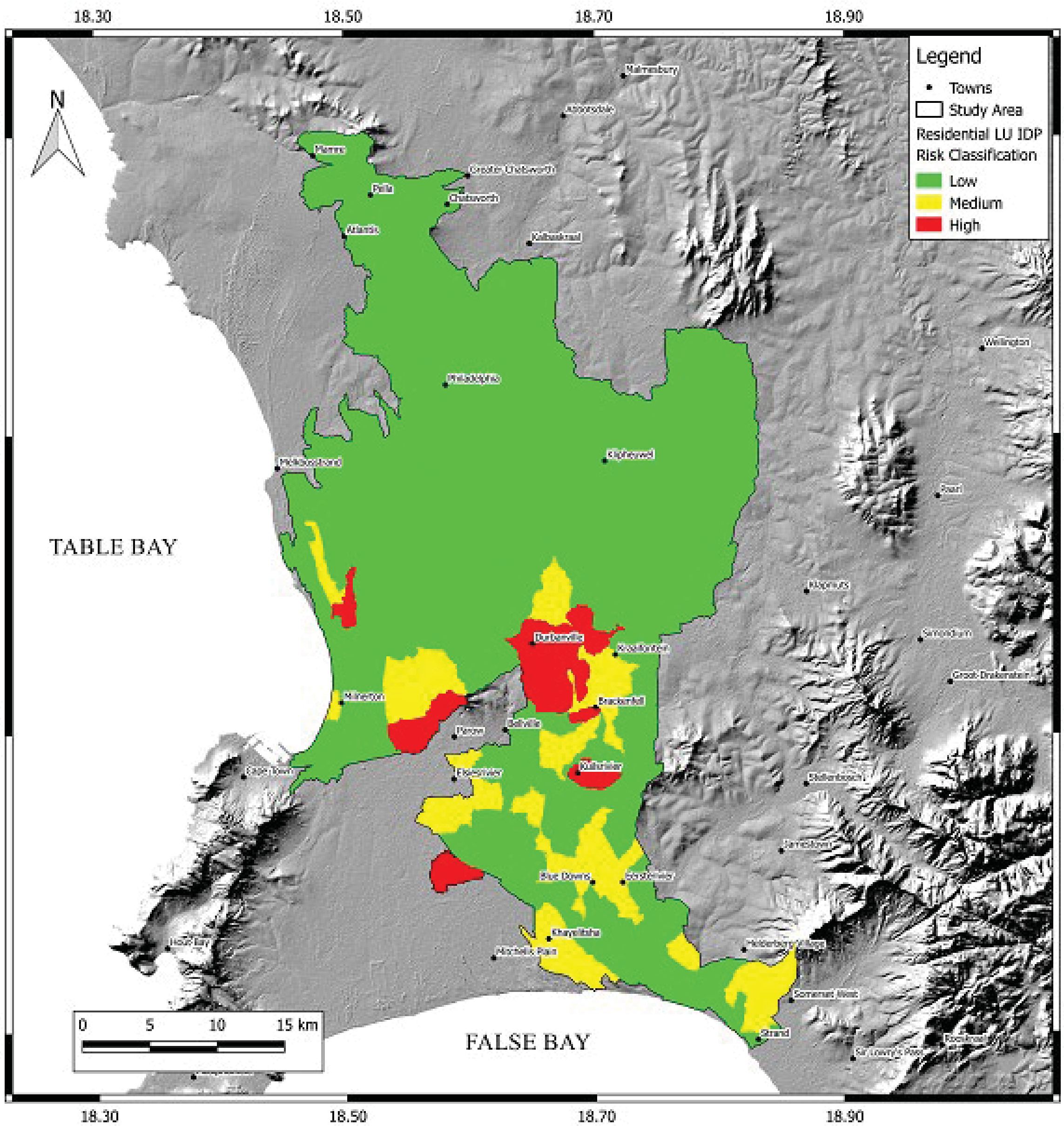



**Figure C1.1: Risk classification map for residential land use risk factor**

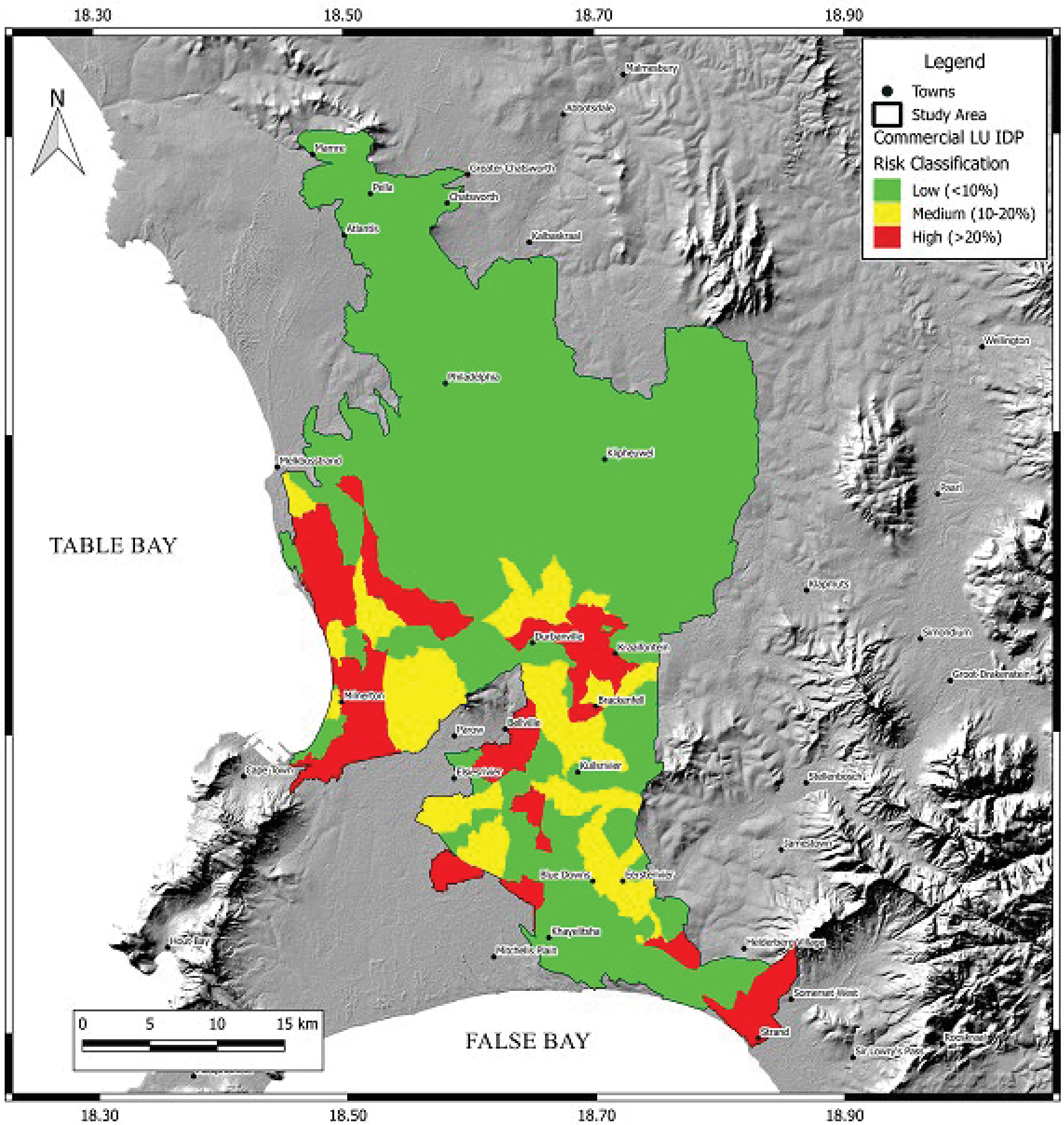



**Figure C1.2: Risk classification map for commercial land use risk factor**

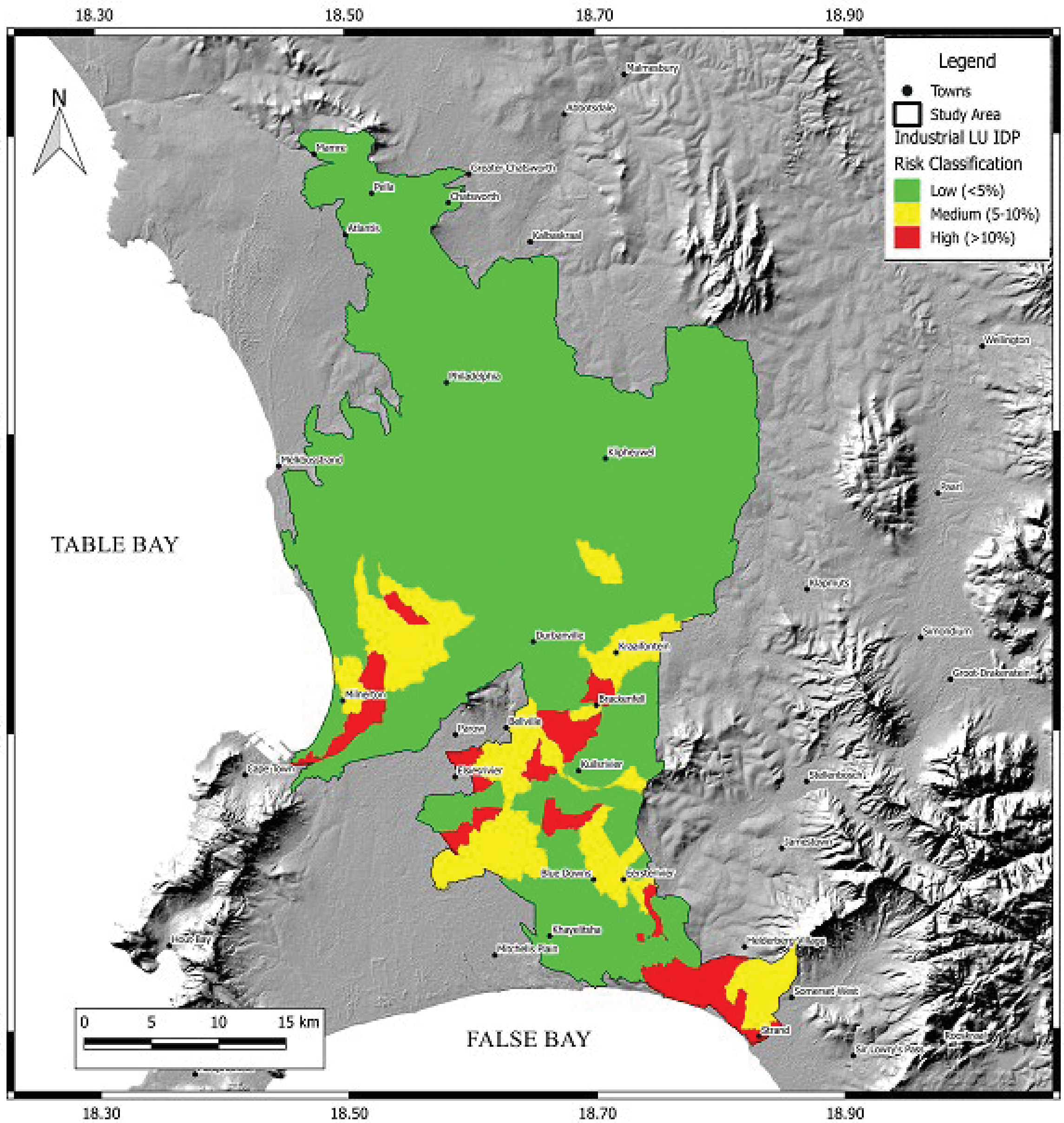



**Figure C1.3: Risk classification map for industrial land use risk factor**

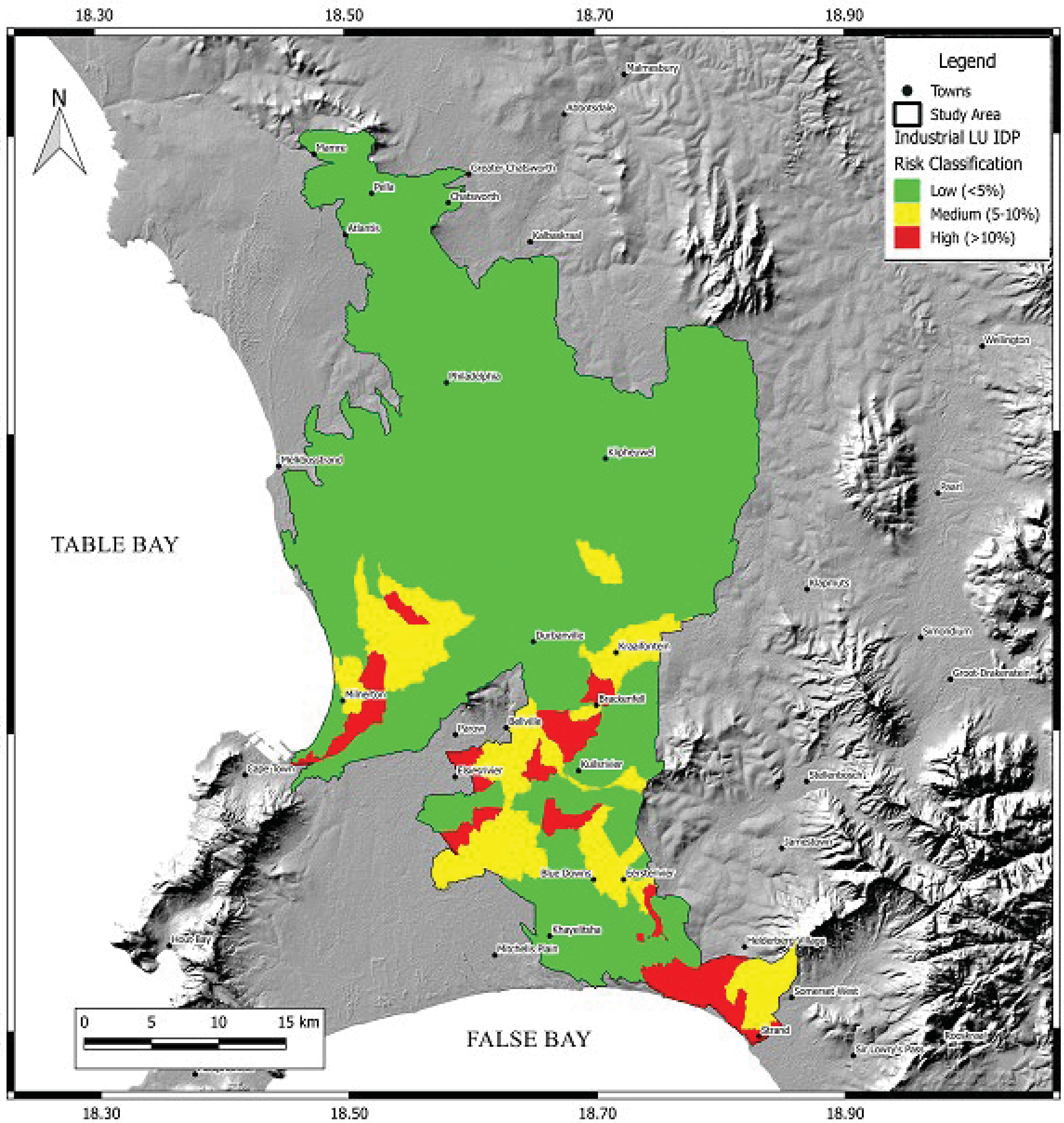



**Figure C1.4: Risk classification map for aging sanitary infrastructure risk factor**

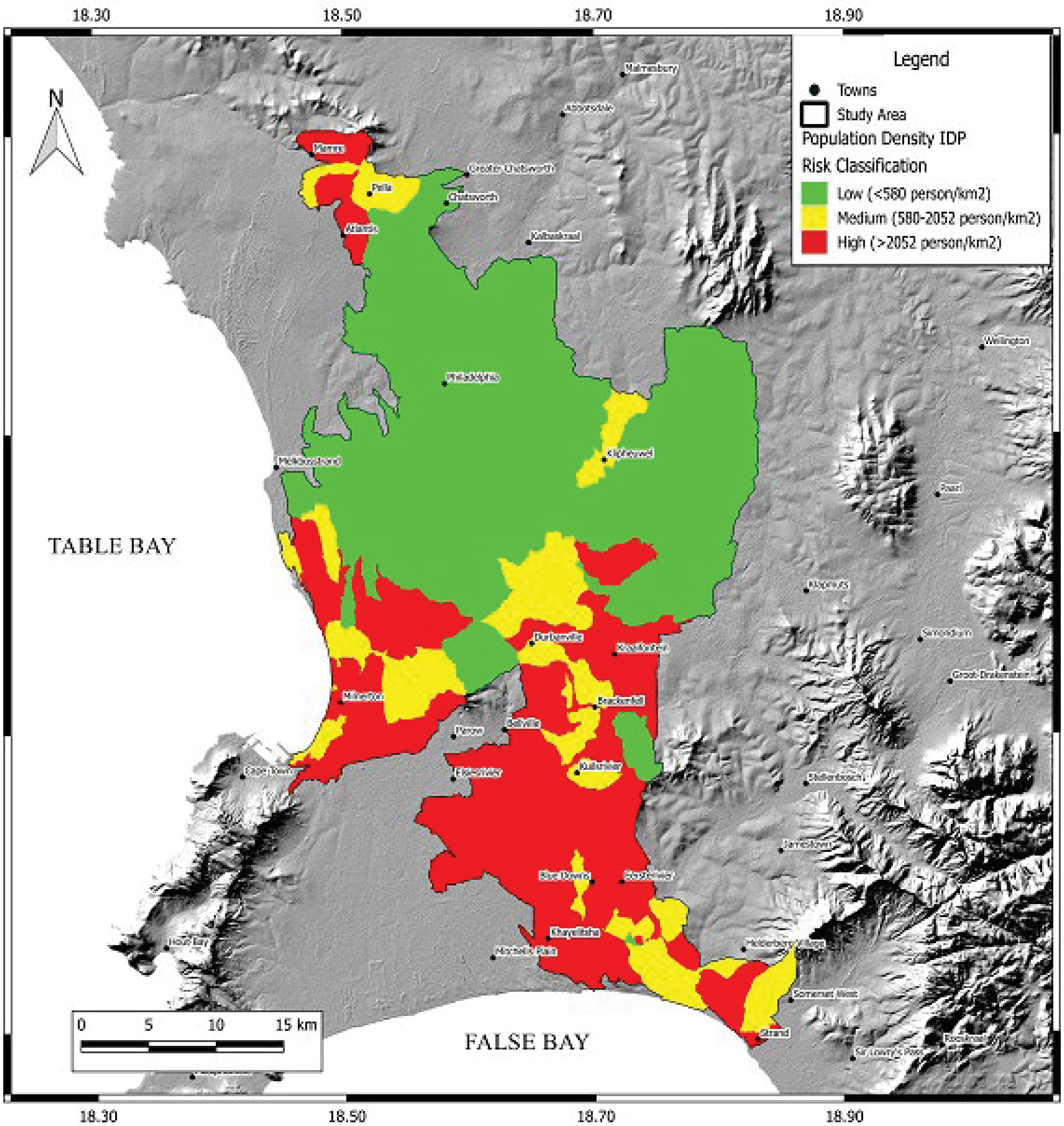



**Figure C1.5: Risk classification map for population density risk factor**

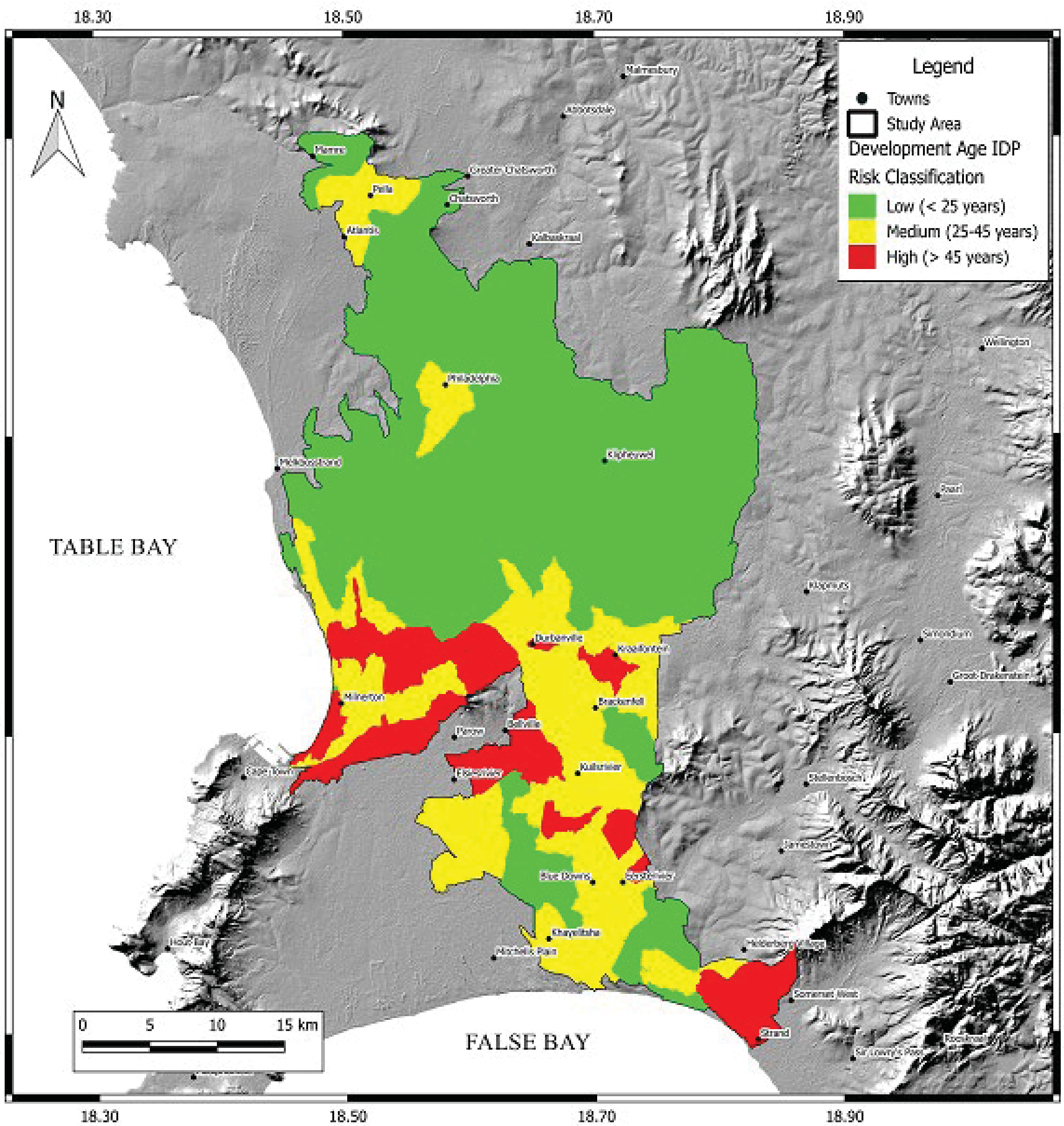



**Figure C1.6: Risk classification map for development age risk factor**

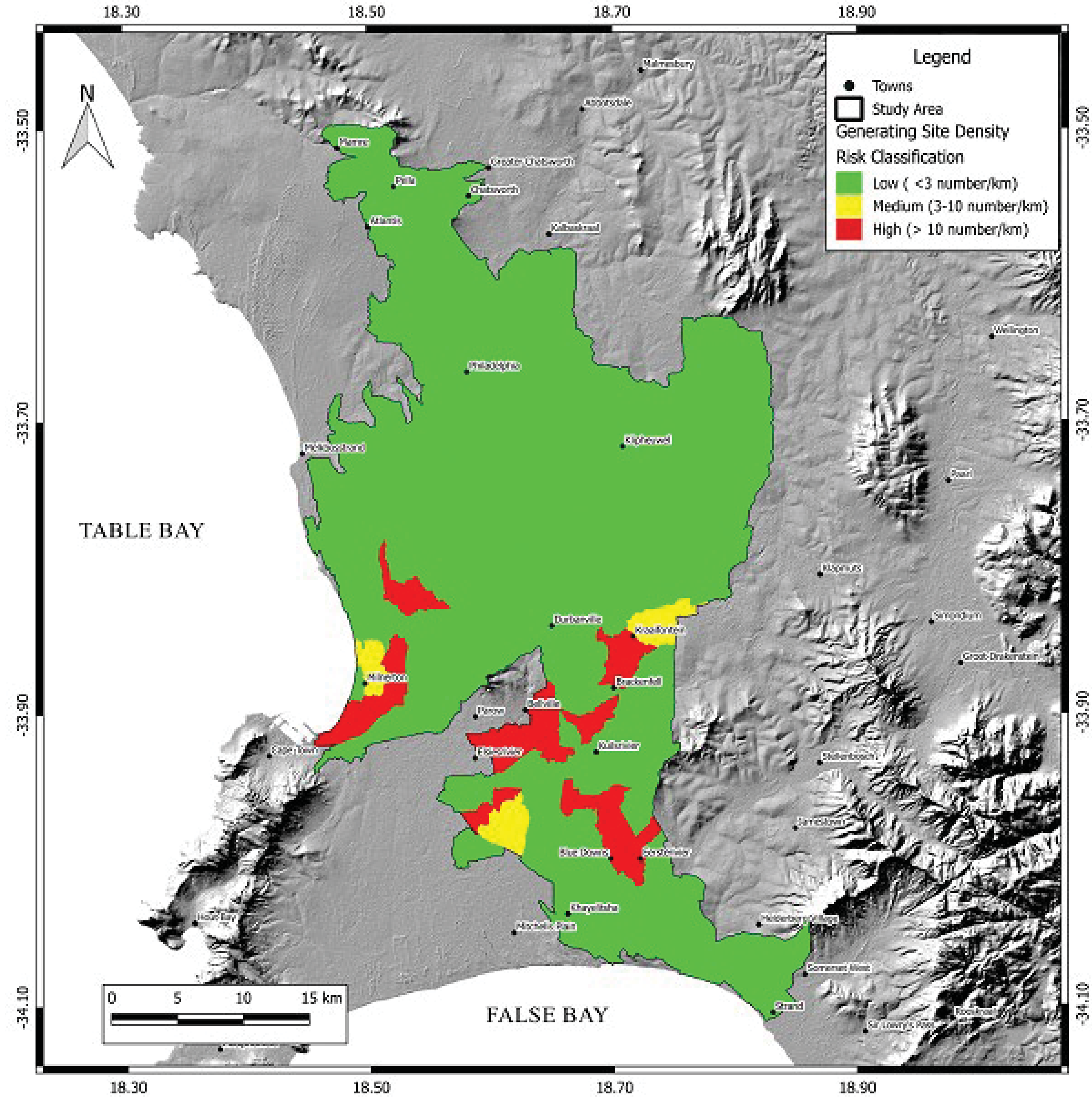



**Figure C1.7: Risk classification map for generating site density risk factor**

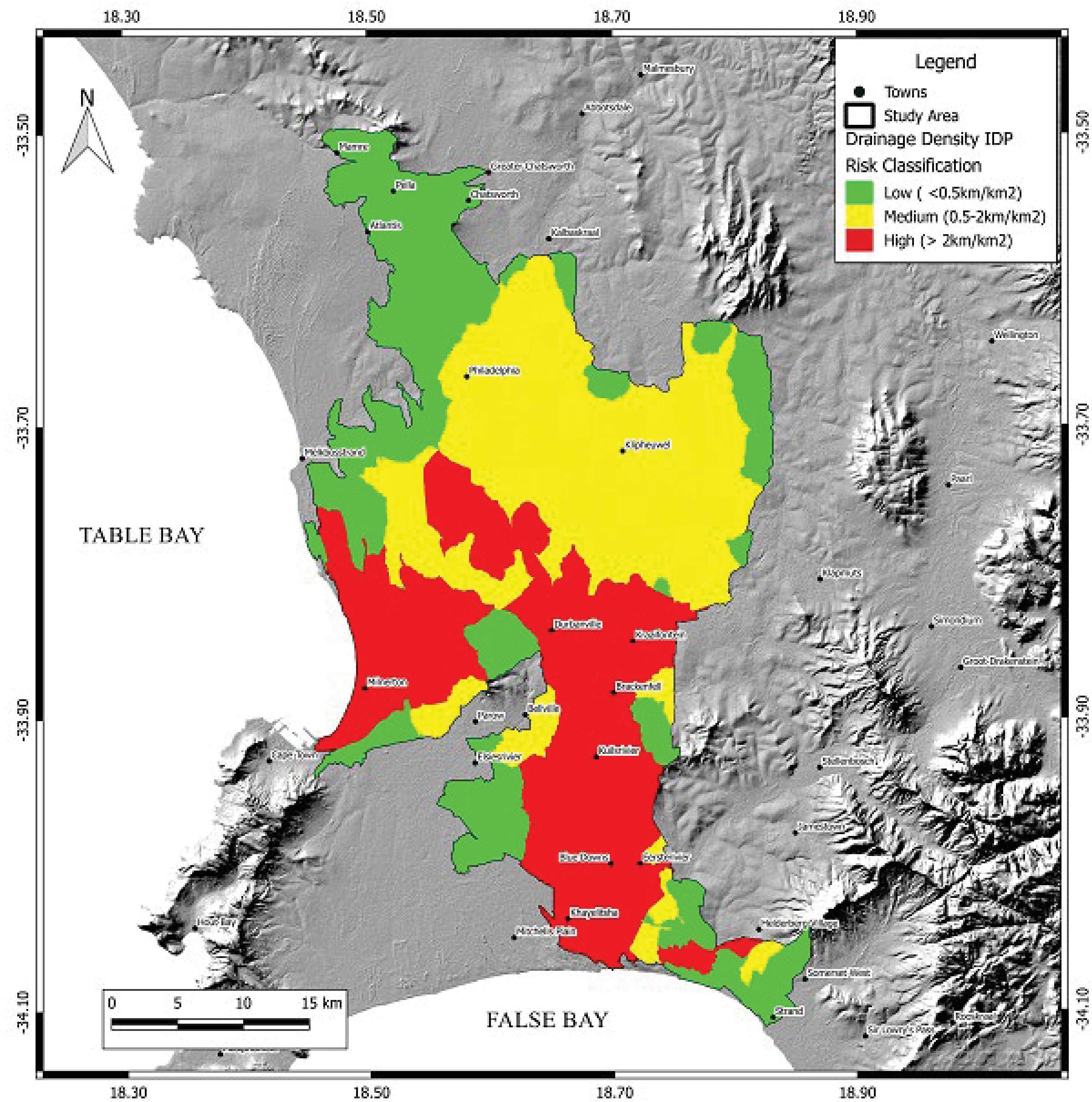



**Figure C1.8: Risk classification map for drainage density risk factor**

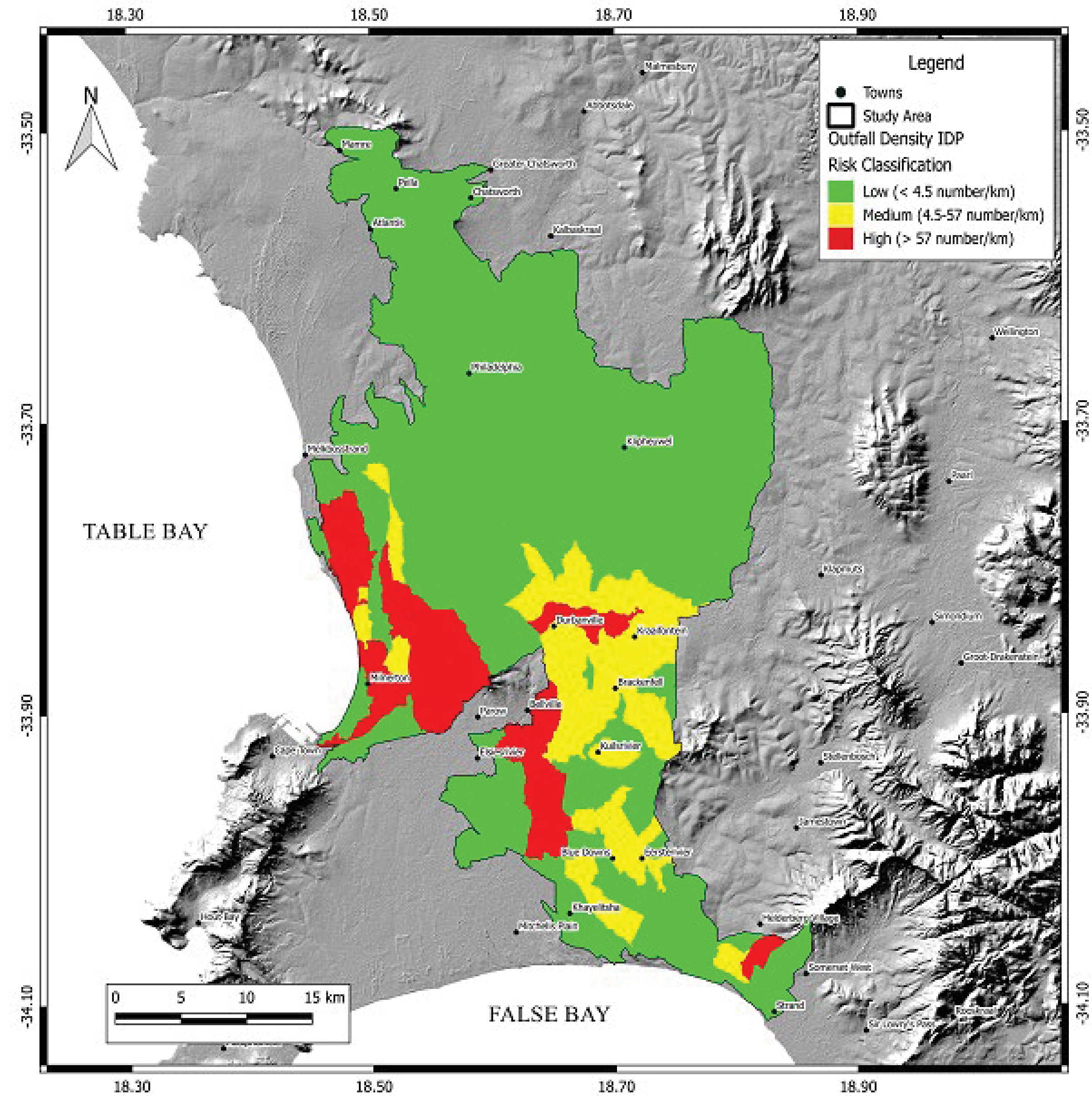



**Figure C1.9: Risk classification map for outfall density risk factor**

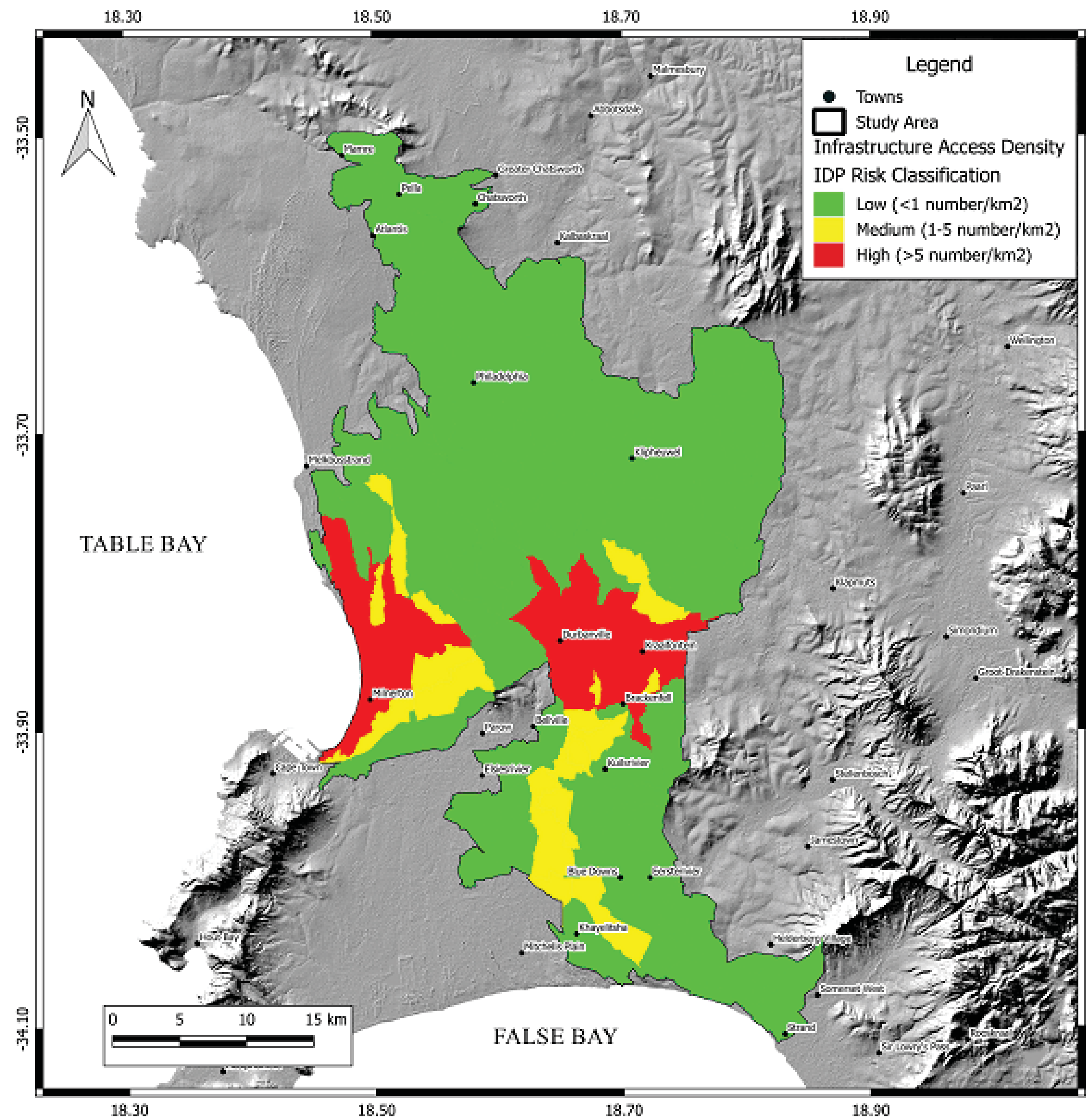



**Figure C1.10: Risk classification map for infrastructure access density risk factor**

**Table C1.1: Common Generating Sites and their SIC codes and Pollution Potential (modified after Brown et al., 2004)**

| South Africa SIC Code(s) | Land Use Generating Site Description | Associated USA SIC Code(s) | Illicit Discharge Potential* (US) | |
|---|---|---|---|---|
| | | | Direct | Indirect |
| **Commercial** | | | | |
| 9320, 93200, 1140, 11400 | Animal Care Services | 0742, 0752 | L | L |
| 6311, 6312, 6320, 6331, 6332, 6340, 6350, 63110, 63121, 63122, 63201, 63202, 63203, 63204, 63311, 63319, 63400, 63500 | Auto Repair | 7532-7539, 7549 | M | M |
| 74131 | Automobile Parking | 7521 | L | M |
| 6141, 6142, 6143, 6149, 61410, 61420, 61430, 61490 | Building Materials | 5211-5251 | L | L |
| 9649, 96490 | Campgrounds/Recreational Vehicle parks | 7033 | L | M |
| 6311-6312, 63110-63122 | Car Dealers | 5511-5599, | M | M |
| | Car Washes | 7542 | L | L |
| 9901-9909, 99010-99090 | Commercial Laundry/Dry Cleaning | 7211-7219 | L | L |
| 6231-6232, 62310-62324 | Convenience Stores | 5399 | L | L |
| 6211-6220, 62110-62209 | Food Stores and Wholesale Food and Beverage | 5141-5149, 5411-5499 | L | M |
| | Equipment Repair | 7622-7699 | L | L |
| 6350,63500 | Gasoline Stations | 5541 | M | M |
| 5050, 50500 | Heavy Construction Equipment Rental and Leasing | 7353 | L | H |
| 5010-5024, 50100-50240 | Building and Heavy Construction (For land disturbing activities) | 1521-1542, 1611-1629 | L | H |
| 7211-7220, 72111-72200 | Marinas | 4493 | L | M |
| 6121, 61210 | Nurseries and garden centers | 5261 | L | M |
| 6350, 63500 | Oil Change Shops | 7549 | | M |
| 6410-6420, 64101-64209 | Restaurants | 5812,5813,7011 | M | L |
| 9641-9649, 96410-96490 | Swimming Pools | 7997, 7999 | L | L |
| 7411-7413, 74110-74120 | Warehouses | 4221-4226 | L | L |
| 61394, 61901, 61909 | Wholesalers of Chemical and Petroleum | 5162-5169,5172 | L | L |
| **Industrial** | | | | |
| 3121-3129, 31211-31290, 3130-3150, 31301-31500, 3161-3170, 31610-31700 | Apparel and Other Fabrics | 2311-2399, 3131-3199 | 2300 L, 3100 H | 2300 L, 3100 M |
| 6110-6190, 61101-61909 | Auto Recyclers and Scrap Yards | 5015, 5093 | L | H |
| 3051-3053, 30510-30530 | Beverages and Brewing | 2082-2087 | L | L |

| | | | | |
|---|---|---|---|---|
| 7413, 74131-74133 | Boat Building and Repair | 3731,3732 | L | H |
| 3341-3380, 33410-33800 | Chemical Products | 2812-2899 | 2810 H, 2820 H, 2840 H, 2860 M, 2830 L, 2850 L, 2870 L, 2890 L | 2811 L, 2820 L, 2840 L, 2860 L, 2830 L, 2850 L, 2870 L, 2890 L |
| 3011-3049, 30111-30499 | Food Processing | 2011-2141 | 2010 H, 2020 H, 2030 H, 2040 H, 2050 L, 2060 L, 2070 M, 2090 L, 2110 M | 2011 L, 2020 L, 2030 L, 2040 L, 2050 L, 2060 L, 2070 L, 2090 L, 2110 L |
| 74139 | Garbage Truck Washout Activities | 4212 | L | H |
| 3510-3879, 35101-38790 | Industrial or Commercial Machinery, Electronic Equipment | 3511-3599, 3612-3699 | L | L |
| 3741-3760, 3921-3952, 39211-39520, 37411-37600 | Instruments; Photographic and Optical Goods, Watches and Clocks and other Miscellaneous Manufacturing | 3812-3873, 3933-3999 | L | L |
| 35591 | Leather Tanners | 3411 | H | M |
| 35530, 35599, 3510-3532, 35101-35320, 3541-3559, 35411-35599 | Metal Production, Plating and Engraving Operations | 2514, 2522, 2542, 3312-3399, 3411-3499, 3590 | H | L |
| 3210-3229, 32101-32299, 3910-1-39103, 3231-3239, 32310-32399 | Paper and Wood Products | 2411-2499, 2511, 2512, 2517, 2519, 2521, 2541, 2611-2679 | 2400 L, 2500 L, 2600 H | 2401 H, 2500 L, 2600 H |
| 3310-3330, 33100-33300 | Petroleum Storage and Refining | 2911 | 2911 H | H |
| 3241-3268, 32410-32600 | Printing | 2711-2796 | L | L |
| 3371-3380, 33711-33800 | Rubber and Plastics | 3011-3089 | M | L |
| 3411-3429, 34111-34299 | Stone, Glass, Clay, Cement, Concrete and Gypsum Product | 3211-3299 | L | L |
| 3111-3129, 31111-31290 | Textile Mills | 2211-2299 | H | L |
| 3810-3830, 38100-38309, 3841-3879, 38410-38790 | Transportation Equipment | 3711-3728, 3743-3799 | H | M |
| **Institutional** | | | | |
| 9903, 99030 | Cemeteries | 6554 | L | L |
| 9330, 93300, 9591, 95910 | Churches | 8661 | L | L |

| | | | | |
|---|---|---|---|---|
| 92004-92008 | Colleges and Universities | 8221-8222 | L | M |
| 9511-9599, 95110-95990 | Corporate Office Parks | | L | L |
| 9311-9319, 93111-93199 | Hospitals | 8062-8069, 8071-8072 | L | L |
| 9641-9649, 96410-96490 | Private Golf Courses | 7997 | L | L |
| 92001-92003, 92009 | Private Schools | 8211 | L | L |
| **Municipal** | | | | |
| 9400, 94000 | Composting Facilities | 2875 | L | L |
| 9641-9649, 96410-96490 | Public Golf Courses | 7992 | L | L |
| 9400, 94000 | Landfills and Hazardous Waste Material Disposal | 4953, HZ, LF | L | H |
| | Local Streets | | L | H |
| 7419, 74190, 74132, 74139 | Maintenance Depots | 4173 | M | H |
| 7419, 74190, 74132, 74140 | Municipal Fleet Washing | 4100 | L | M |
| 9130, 91300 | Public Works Yards | | M | H |
| | Steam Electric Plants | SE | L | L |
| 9400, 94000 | Treatment Works | TW | L | L |
| 7300, 73000, 74134 | Airports | 4581 | L | M |
| 5022-5023, 50220-50230 | Streets and Highways Construction | 1611, 1622 | L | H |
| 74133 | Ports | 4449, 4499 | L | H |
| 74135 | Railroads | 4011, 4013 | L | H |
| 7122, 71221-71229 | Rental Car Lots | 7513-7519 | L | M |
| 7511, 75110 | US Postal Service | 4311 | L | M |
| 7123, 71231, 7512, 75120 | Trucking Companies and Distribution Centers | 4212-4215, 4231 | L | M |
| 61901-61909 | Petroleum Bulk Stations or Terminals | 5171 | L | H |
| *Modified after Pitt (2001) | | | | |

# APPENDIX C2 – Spatial analysis of discharge complaints records

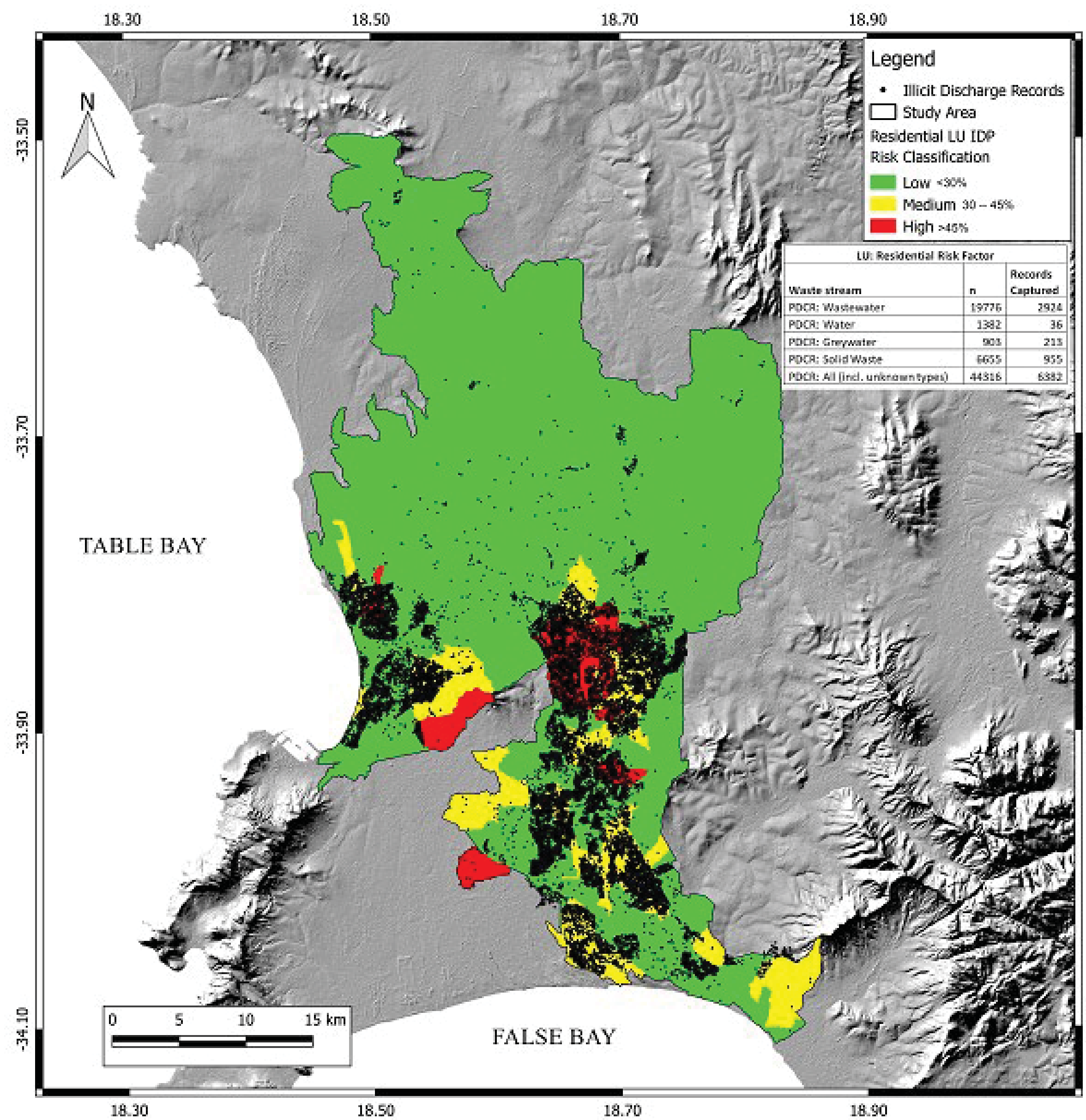



**Figure C2.1: Spatial overlay for residential land use risk factor**

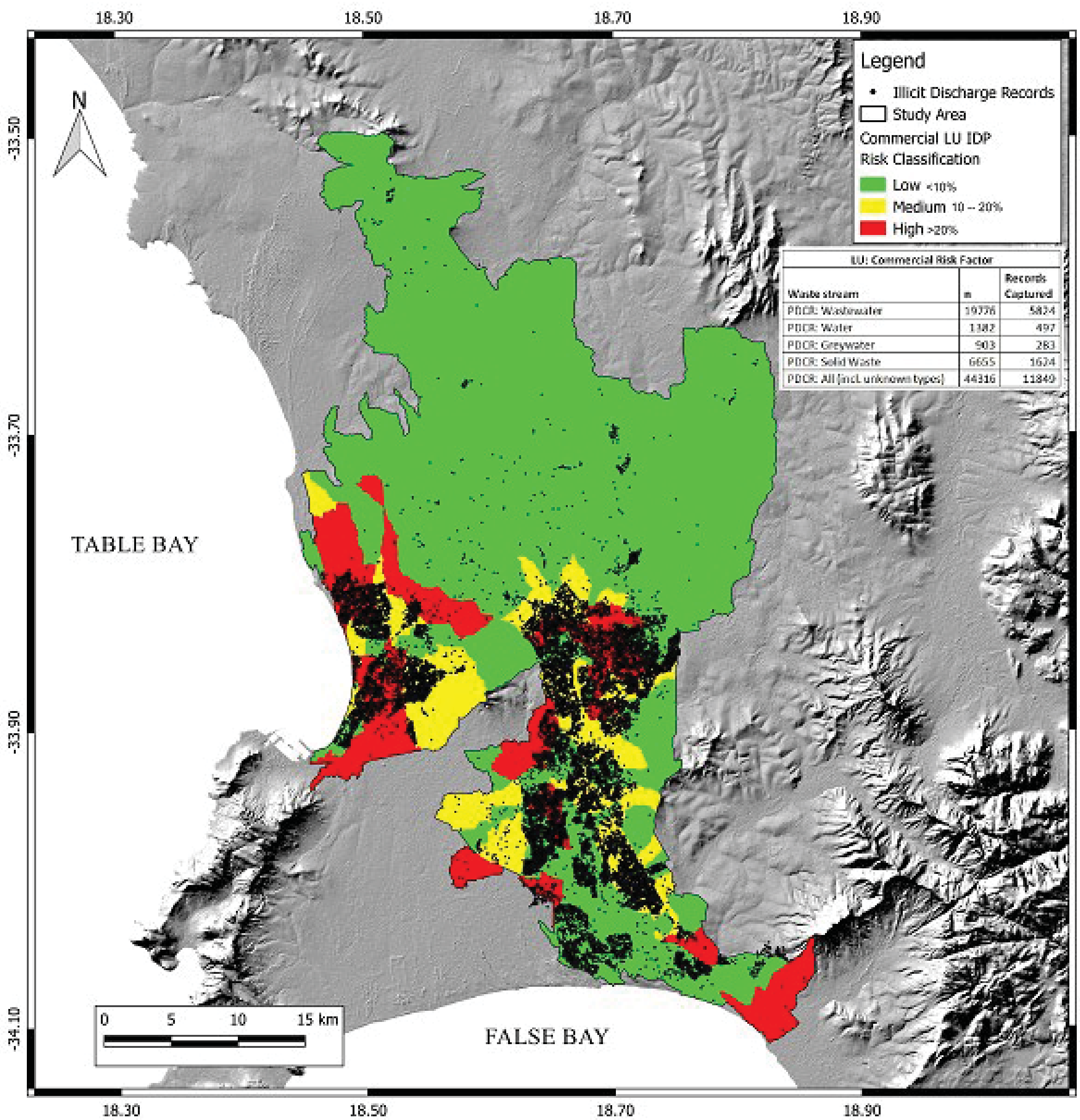
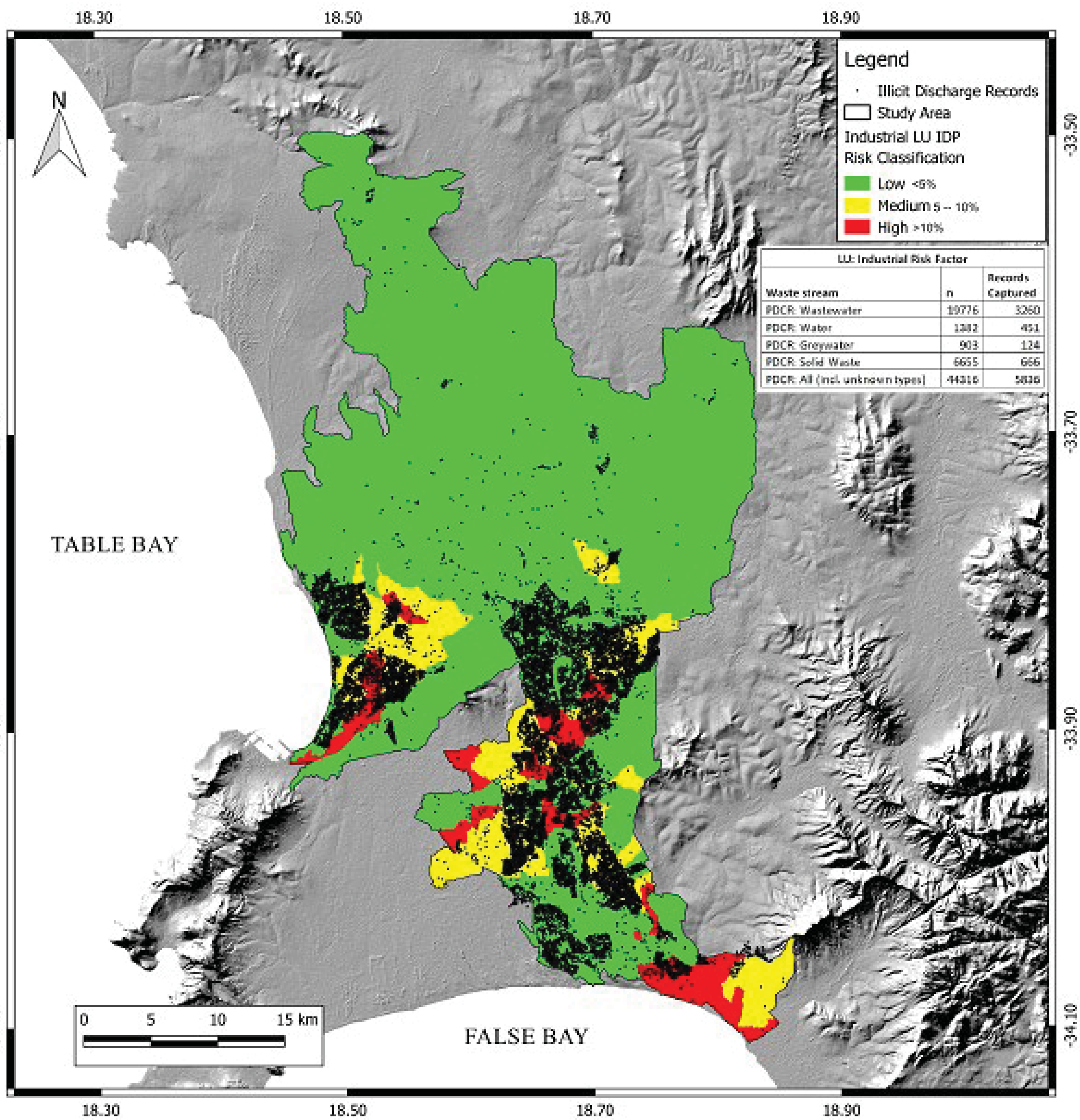



**Figure C2.2: Spatial overlay for commercial land use risk factor**




| LU: Industrial Risk Factor | | |
|---|---|---|
| Waste stream | n | Records Captured |
| PDCR: Wastewater | 10776 | 3260 |
| PDCR: Water | 1382 | 451 |
| PDCR: Greywater | 903 | 124 |
| PDCR: Solid Waste | 6655 | 666 |
| PDCR: All (incl. unknown types) | 44316 | 5836 |

**Figure C2.3: Spatial overlay for industrial land use risk factor**

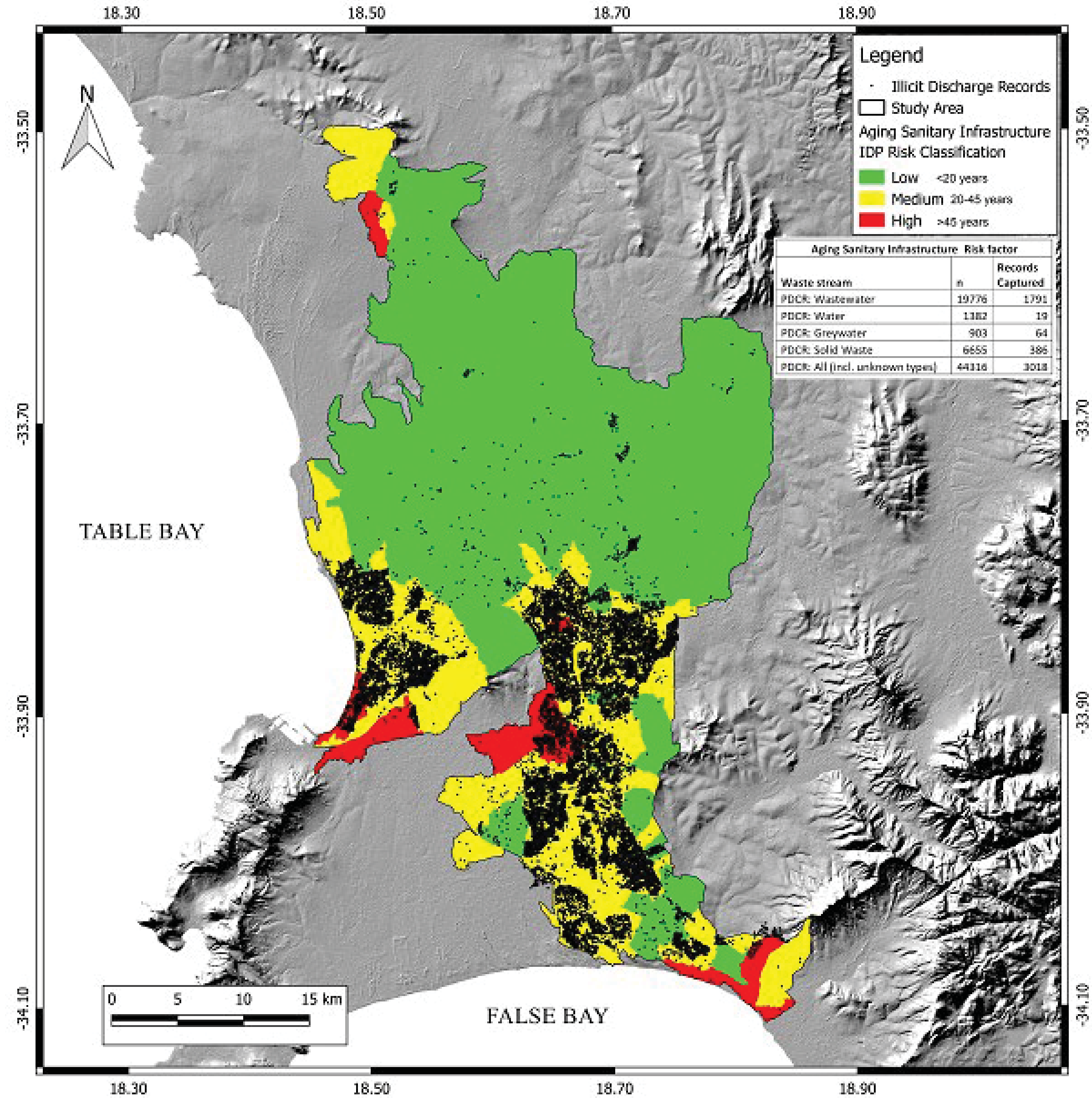



**Figure C2.4: Spatial overlay for aging sanitary infrastructure risk factor**

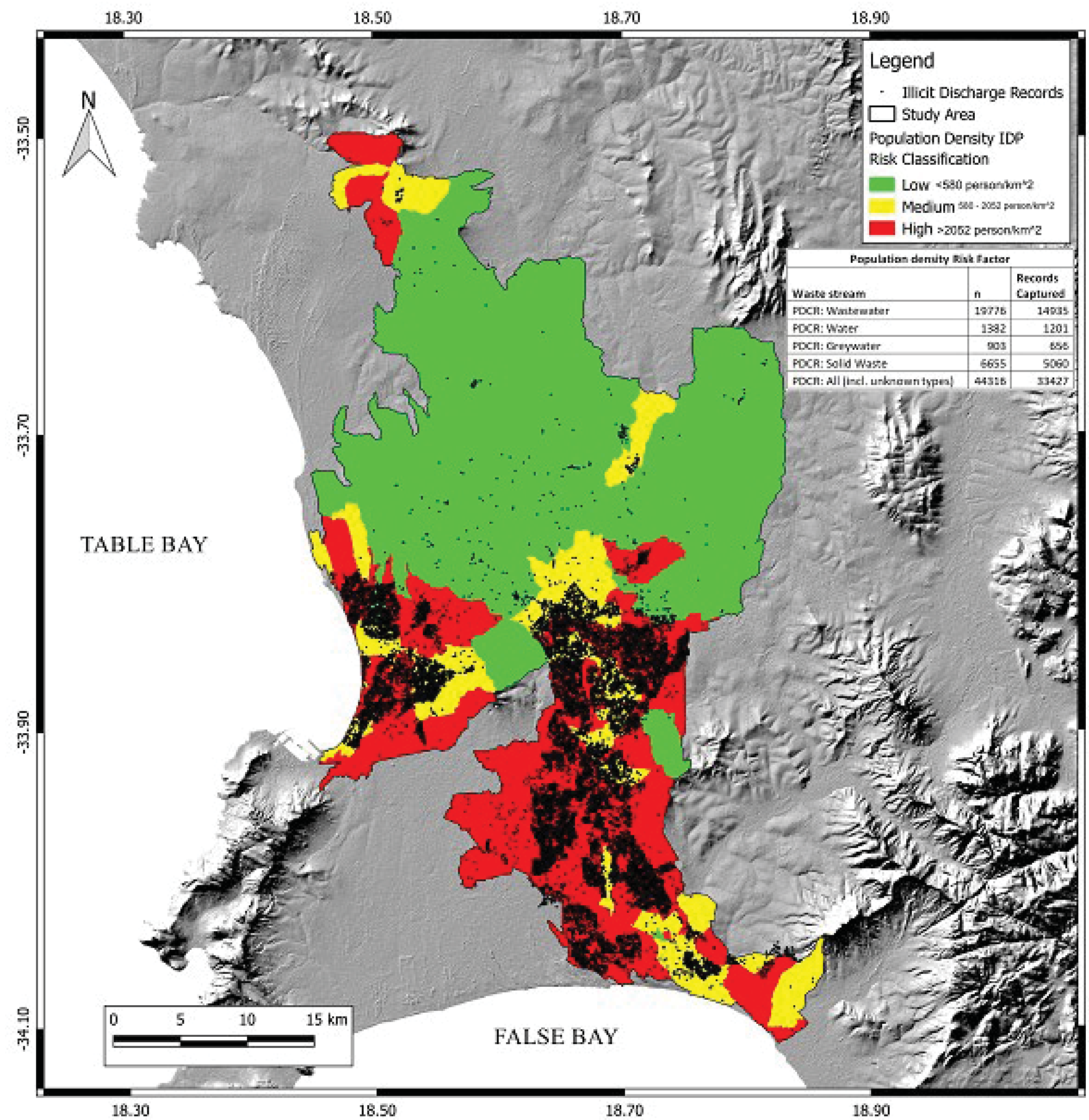
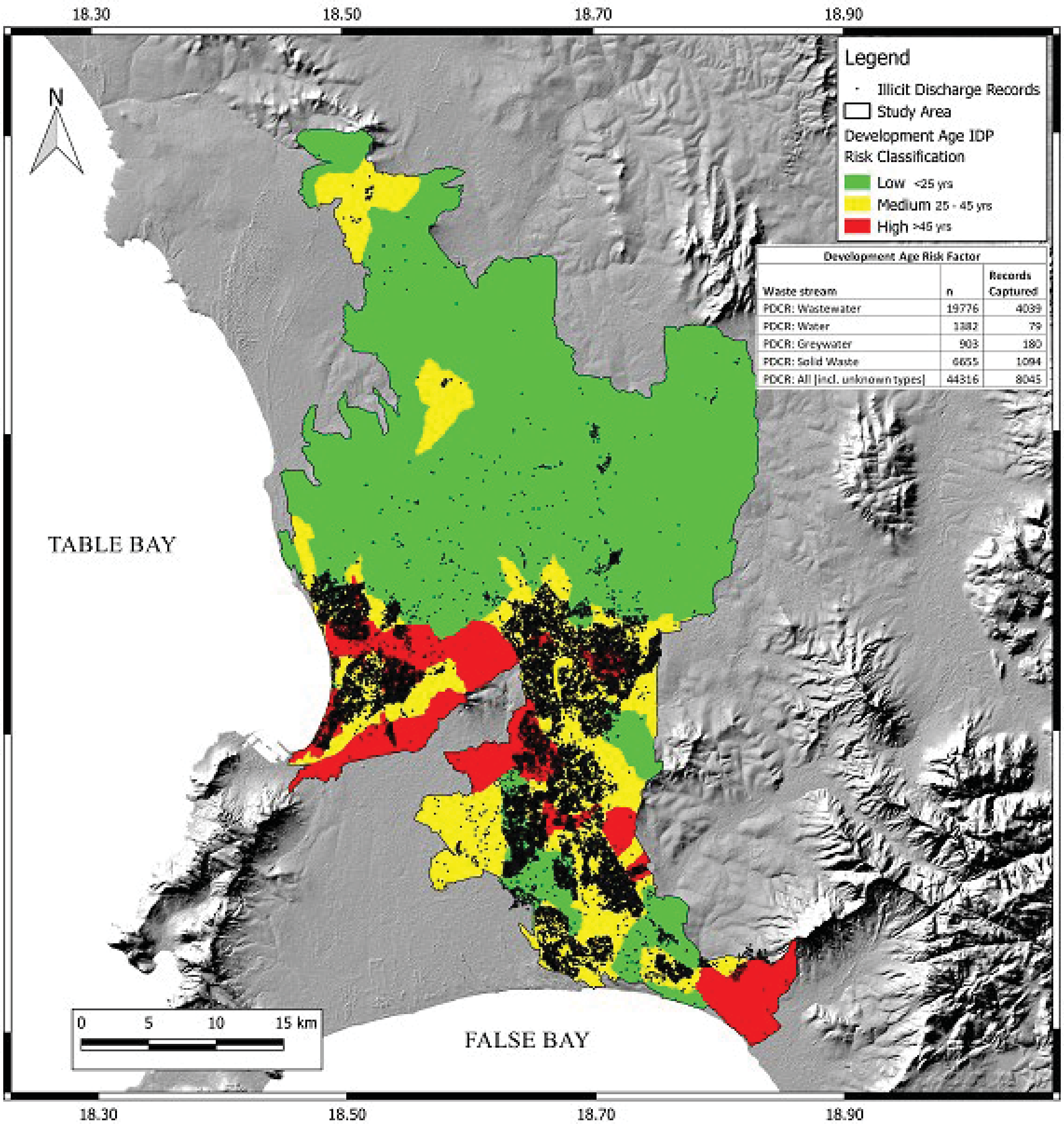



**Figure C2.5: Spatial overlay for population density risk factor**




| Development Age Risk Factor | | |
|---|---|---|
| Waste stream | n | Records Captured |
| PDCR: Wastewater | 19776 | 4039 |
| PDCR: Water | 1382 | 79 |
| PDCR: Greywater | 903 | 180 |
| PDCR: Solid Waste | 6655 | 1094 |
| PDCR: All [incl. unknown types] | 44316 | 8045 |

**Figure C2.6: Spatial overlay for development age risk factor**

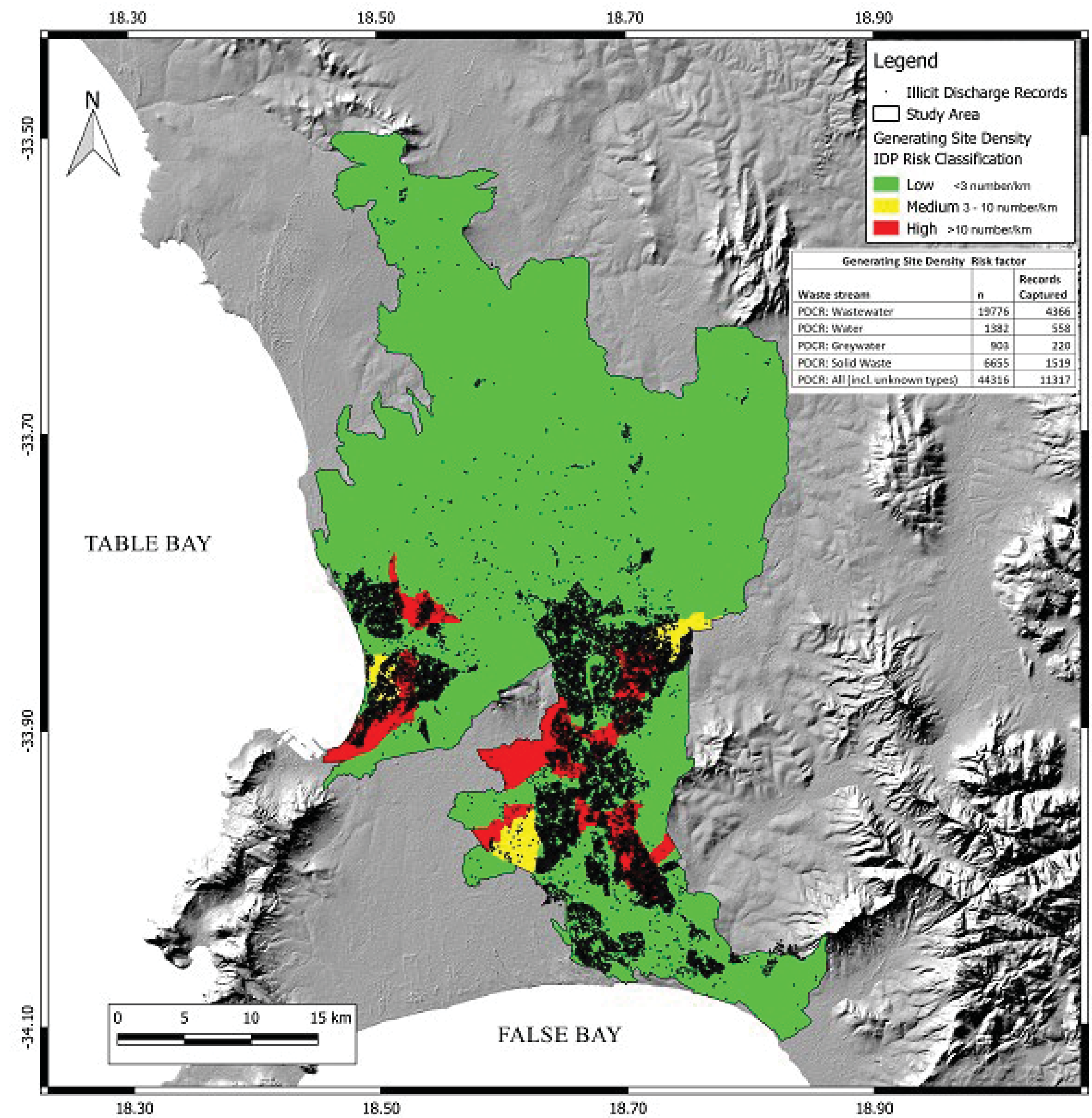
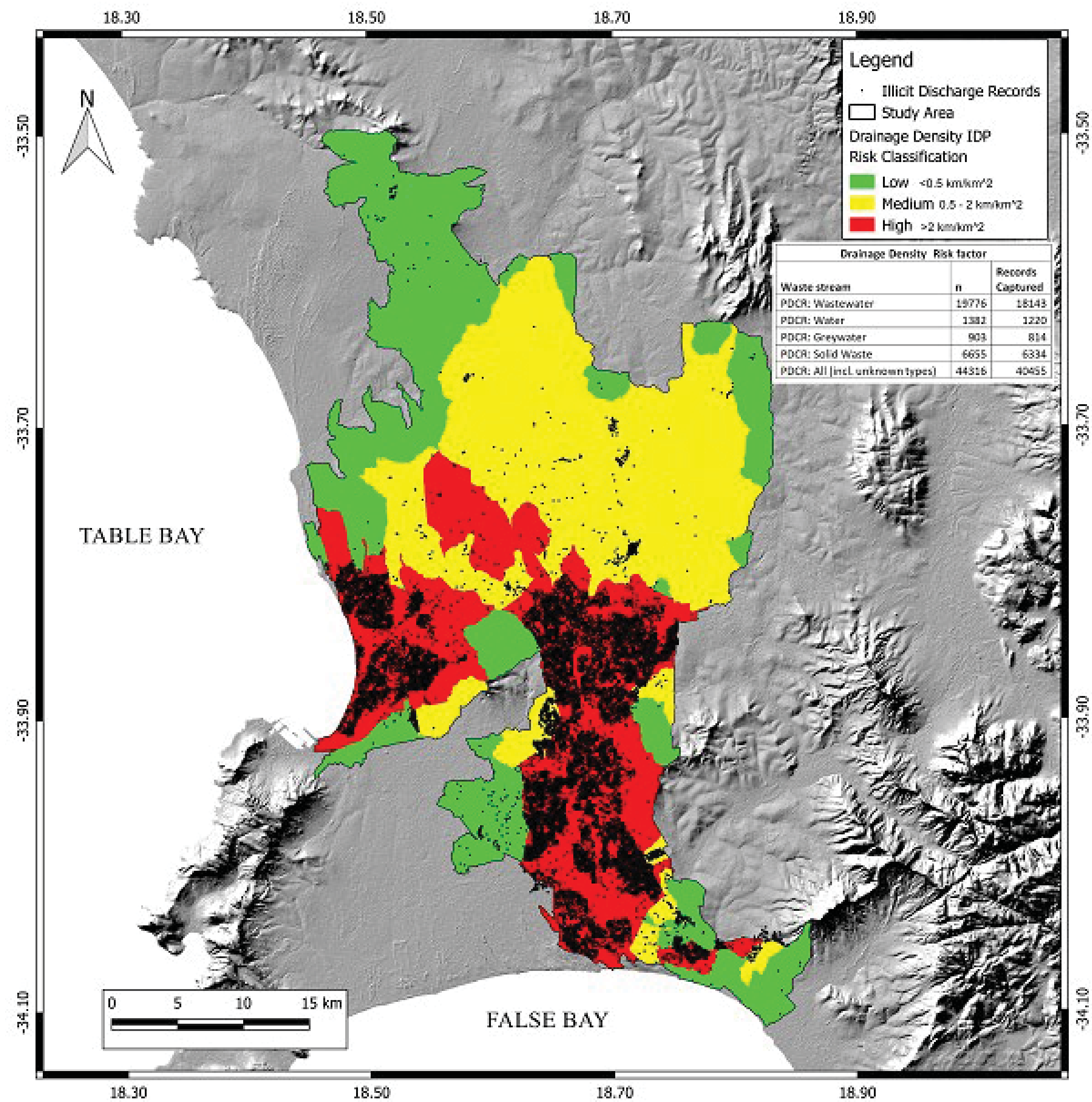



**Figure C2.7: Spatial overlay for generating site density risk factor**




| Drainage Density Risk factor | | |
|---|---|---|
| Waste stream | n | Records Captured |
| PDCR: Wastewater | 19776 | 18143 |
| PDCR: Water | 1382 | 1220 |
| PDCR: Greywater | 903 | 814 |
| PDCR: Solid Waste | 6655 | 6334 |
| PDCR: All (incl. unknown types) | 44316 | 40455 |

**Figure C2.8: Spatial overlay for drainage density risk factor**

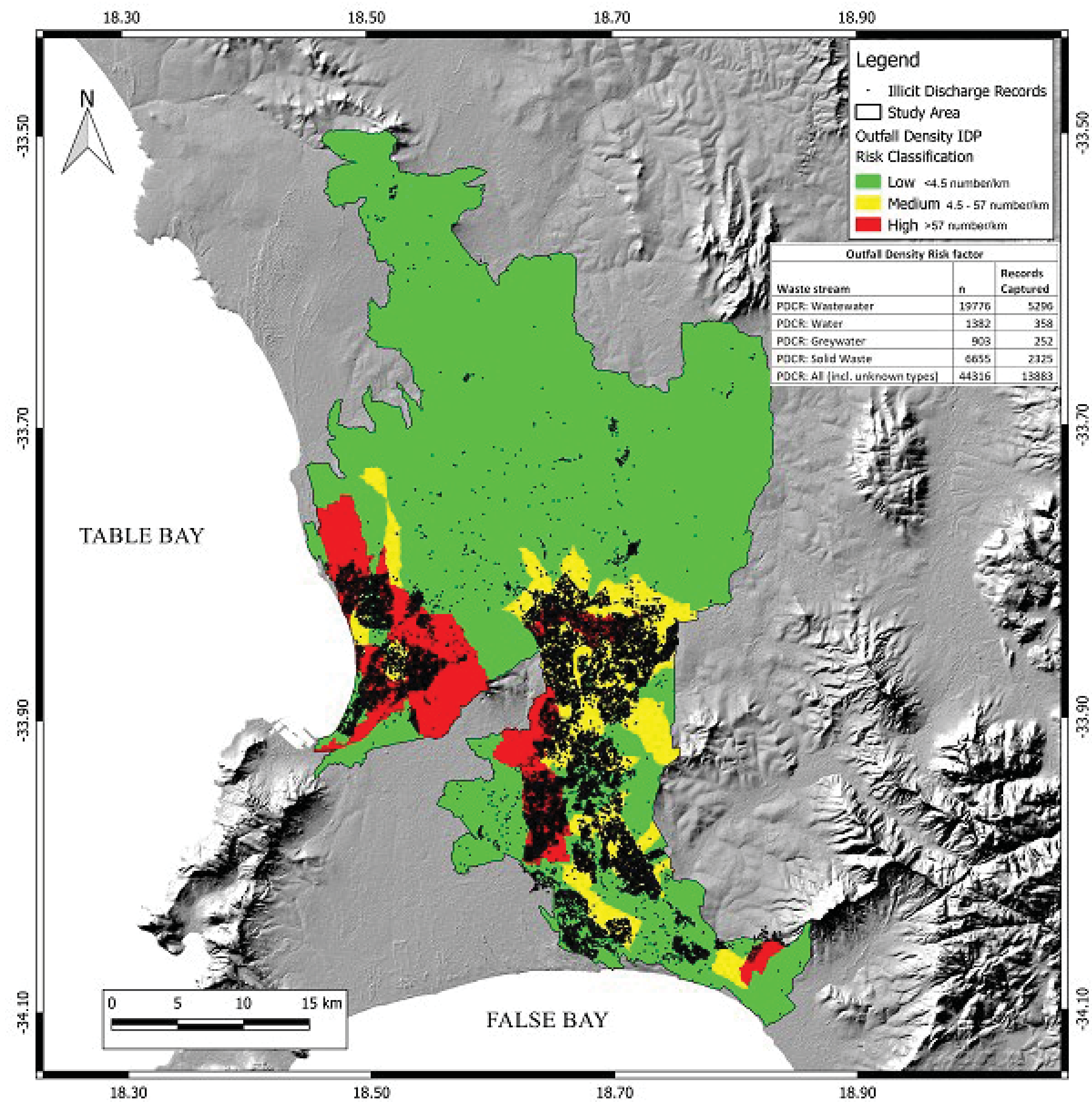
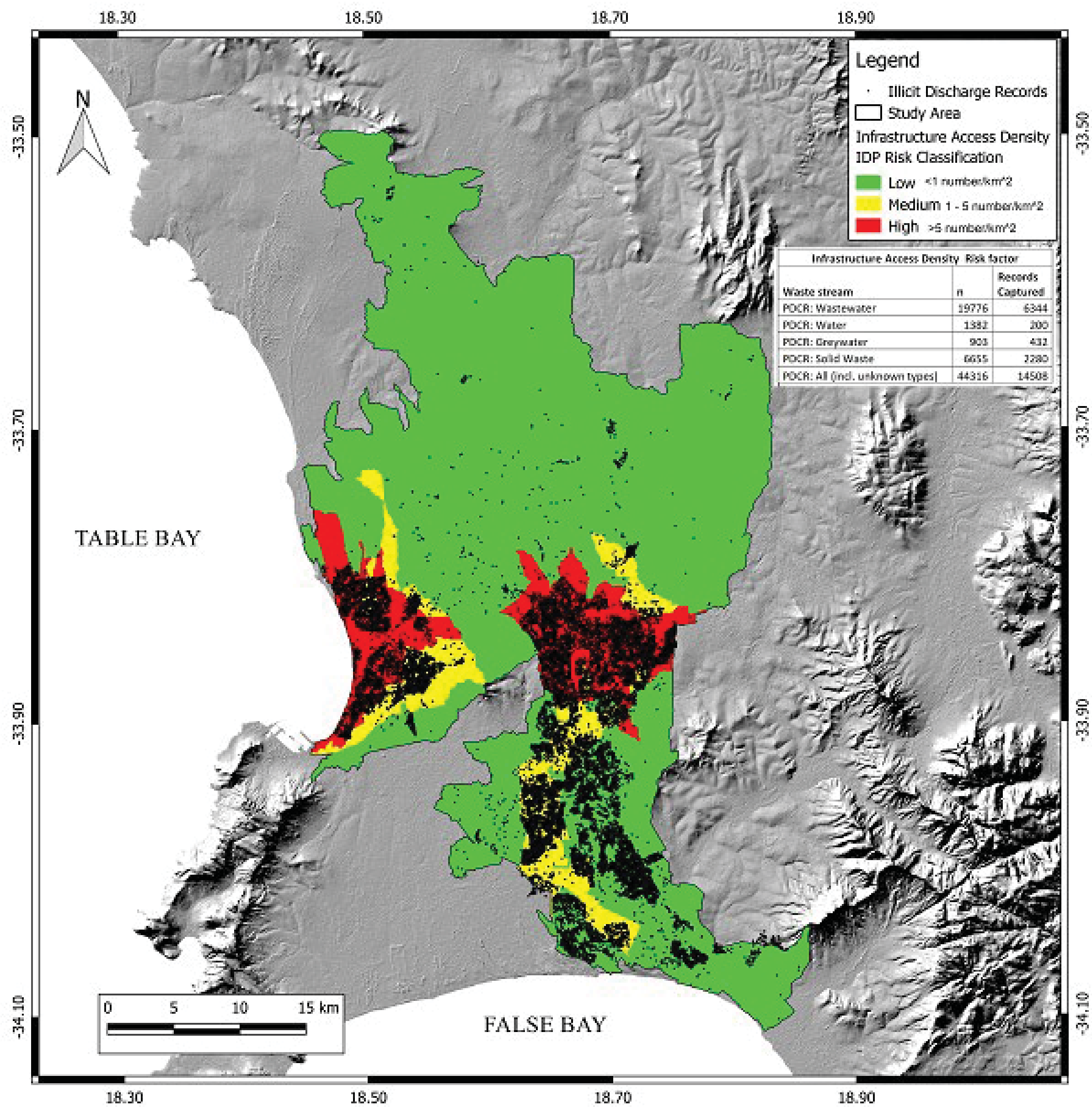



**Figure C2.9: Spatial overlay for outfall density risk factor**




| Infrastructure Access Density Risk factor | | |
|---|---|---|
| Waste stream | n | Records Captured |
| POCR: Wastewater | 19776 | 6344 |
| POCR: Water | 1382 | 200 |
| POCR: Greywater | 903 | 432 |
| POCR: Solid Waste | 6655 | 2280 |
| POCR: All (incl. unknown types) | 44316 | 14508 |

**Figure C2.10: Spatial overlay for infrastructure access density risk factor**

## Table C2.1: Discharges captured by individual risk factors during the spatial overlay process

| RISK FACTORS | Group total captured by high-risk factor | | | | |
|---|---|---|---|---|---|
| | PDCR: Wastewater | PDCR: Water | PDCR: Greywater | PDCR: Solid Waste | PDCR: All |
| ***Records in Cluster*** | ***19776*** | ***1382*** | ***903*** | ***6655*** | ***44316*** |
| LU: Residential | 2924 | 36 | 213 | 955 | 6382 |
| LU: Commercial | 5824 | 497 | 283 | 1624 | 11849 |
| LU: Industrial | 3260 | 451 | 124 | 666 | 5836 |
| Population Density | 14935 | 1201 | 656 | 5060 | 33427 |
| Development Age | 4039 | 79 | 180 | 1094 | 8045 |
| Outfall Density | 5296 | 358 | 252 | 2325 | 13883 |
| Aging Sanitary Infrastructure | 1791 | 19 | 64 | 386 | 3018 |
| Drainage Density | 18143 | 1220 | 814 | 6334 | 40455 |
| Generating Site Density | 4366 | 558 | 220 | 1519 | 11317 |
| Infrastructure Access Density | 6344 | 200 | 432 | 2280 | 14508 |

## Table C2.2: Example of 2x2 contingency table. Data taken from wastewater pathway group

| Risk Factor | Proportion captured | Proportion not captured |
|---|---|---|
| Development Age | **4039** | **15737** |
| Outfall density | **5296** | **14480** |

## Table C2.3: Chi-square test output showing p-values for wastewater pathway group

| | LU: Residential | LU: Commercial | LU: Industrial | Population Density | Development Age | Outfall Density | Aging Sanitary Infrastructure | Drainage Density | Generating Site Density | Infrastructure Access Density |
|---|---|---|---|---|---|---|---|---|---|---|
| LU: Residential | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| LU: Commercial | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| LU: Industrial | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Population density | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Development Age | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.000058 | <0.00001 |
| Outfall Density | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Aging Sanitary Infrastructure | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 |
| Drainage Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 |
| Generating Site Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 |
| Infrastructure Access Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

## Table C2.4: Chi-square test output showing p-values for water pathway group

| | LU: Residential | LU: Commercial | LU: Industrial | Population Density | Development Age | Outfall Density | Aging Sanitary Infrastructure | Drainage Density | Generating Site Density | Infrastructure Access Density |
|---|---|---|---|---|---|---|---|---|---|---|
| LU: Residential | N/A | <0.00001 | <0.00001 | <0.00001 | <0.000042 | <0.00001 | <0.020589 | <0.00001 | <0.00001 | <0.00001 |
| LU: Commercial | N/A | N/A | <0.065305 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.016923 | <0.00001 |
| LU: Industrial | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.000101 | <0.00001 | <0.00001 | <0.000024 | <0.00001 |
| Population density | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.273004 | <0.00001 | <0.00001 |
| Development Age | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Outfall Density | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Aging Sanitary Infrastructure | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 |
| Drainage Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 |
| Generating Site Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 |
| Infrastructure Access Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

**Table C2.5: Chi-square test output showing p-values for greywater pathway group.**

| | LU: Residential | LU: Commercial | LU: Industrial | Population Density | Development Age | Outfall Density | Aging Sanitary Infrastructure | Drainage Density | Generating Site Density | Infrastructure Access Density |
|---|---|---|---|---|---|---|---|---|---|---|
| LU: Residential | N/A | <0.000224 | <0.00001 | <0.00001 | <0.059844 | <0.03583 | <0.00001 | <0.00001 | <0.699635 | <0.00001 |
| LU: Commercial | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.11013 | <0.00001 | <0.00001 | <0.000943 | <0.00001 |
| LU: Industrial | N/A | N/A | N/A | <0.00001 | <0.000428 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Population density | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Development Age | N/A | N/A | N/A | N/A | N/A | <0.000071 | <0.00001 | <0.00001 | <0.023408 | <0.00001 |
| Outfall Density | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.086566 | <0.00001 |
| Aging Sanitary Infrastructure | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 |
| Drainage Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 |
| Generating Site Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 |
| Infrastructure Access Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

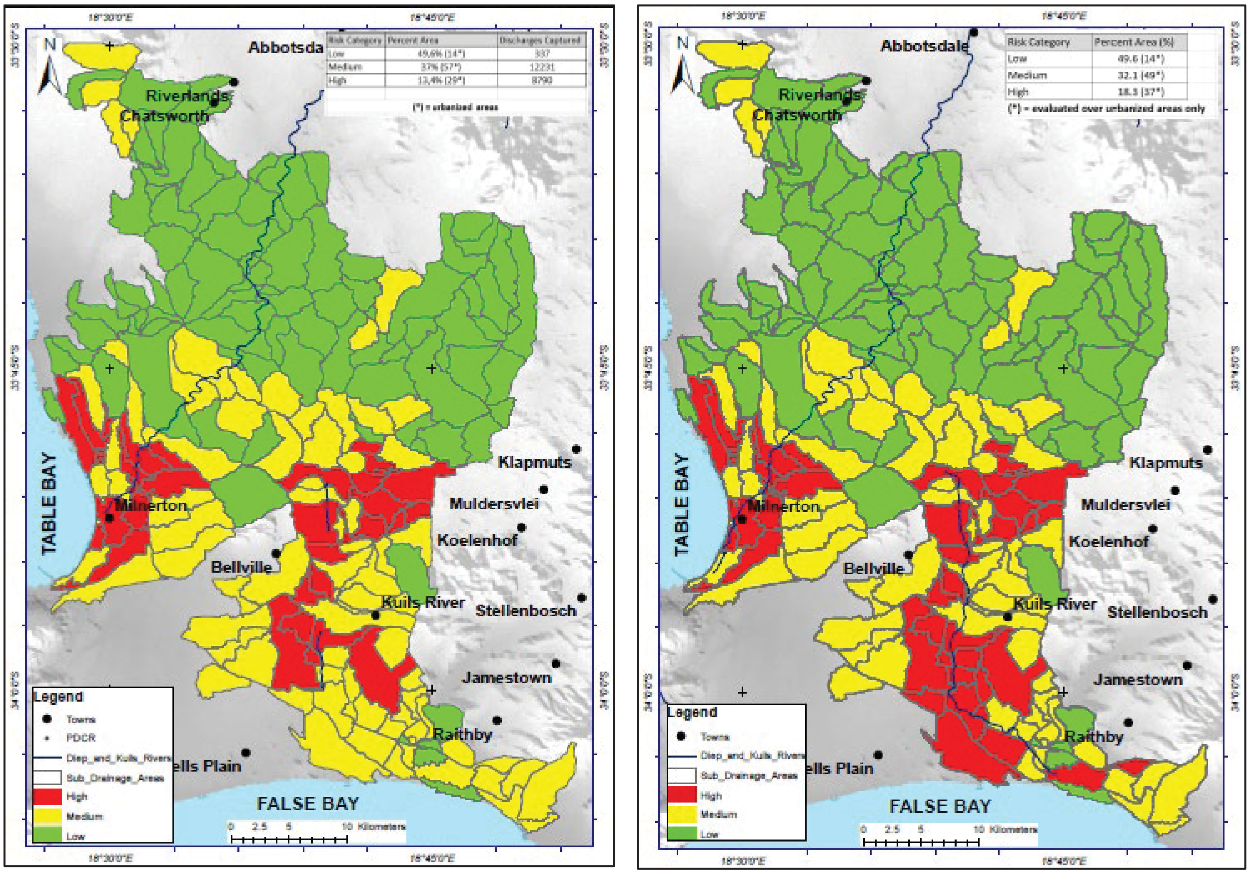
## Table C2.6: Chi-square test output showing p-values for solid waste pathway group

| | LU: Residential | LU: Commercial | LU: Industrial | Population Density | Development Age | Outfall Density | Aging Sanitary Infrastructure | Drainage Density | Generating Site Density | Infrastructure Access Density |
|---|---|---|---|---|---|---|---|---|---|---|
| LU: Residential | N/A | <0.00001 | <0.00001 | <0.00001 | <0.000842 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| LU: Commercial | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.032118 | <0.00001 |
| LU: Industrial | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Population Density | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Development Age | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.00001 | <0.00001 |
| Outfall density | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 | <0.412229 |
| Aging Sanitary Infrastructure | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 | <0.00001 |
| Drainage density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 | <0.00001 |
| Generating Site Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.00001 |
| Infrastructure Access Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

## Table C2.7: Chi-square test output showing p-values for all (combined) pathways group

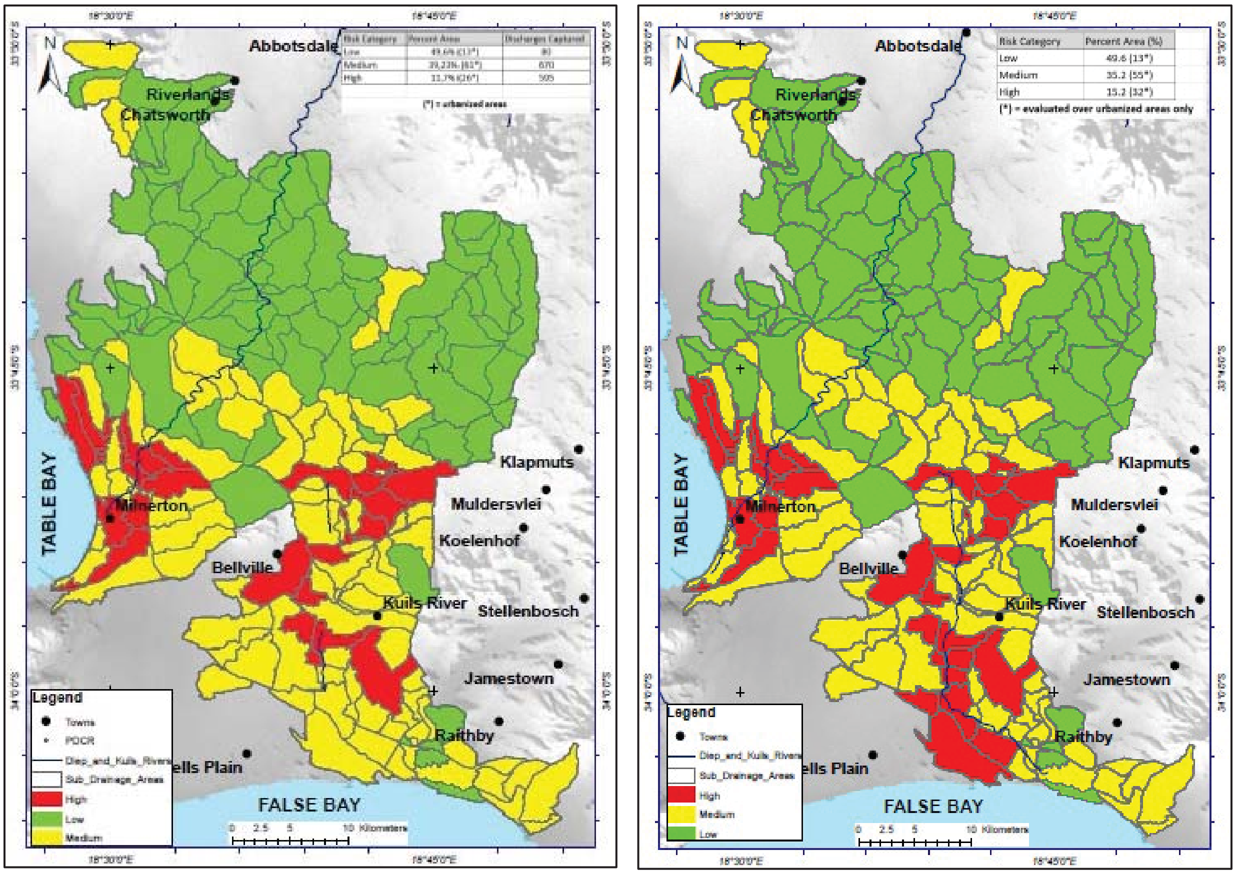
| | LU: Residential | LU: Commercial | LU: Industrial | Population Density | Development Age | Outfall Density | Aging Sanitary Infrastructure | Drainage Density | Generating Site Density | Infrastructure Access Density |
|---|---|---|---|---|---|---|---|---|---|---|
| LU: Residential | N/A | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| LU: Commercial | N/A | N/A | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| LU: Industrial | N/A | N/A | N/A | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Population Density | N/A | N/A | N/A | N/A | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Development Age | N/A | N/A | N/A | N/A | N/A | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Outfall Density | N/A | N/A | N/A | N/A | N/A | N/A | <0.001 | <0.001 | <0.001 | <0.001 |
| Aging Sanitary Infrastructure | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.001 | <0.001 | <0.001 |
| Drainage Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.001 | <0.001 |
| Generating Site Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | <0.001 |
| Infrastructure Access Density | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

# APPENDIX C3 – Composite maps



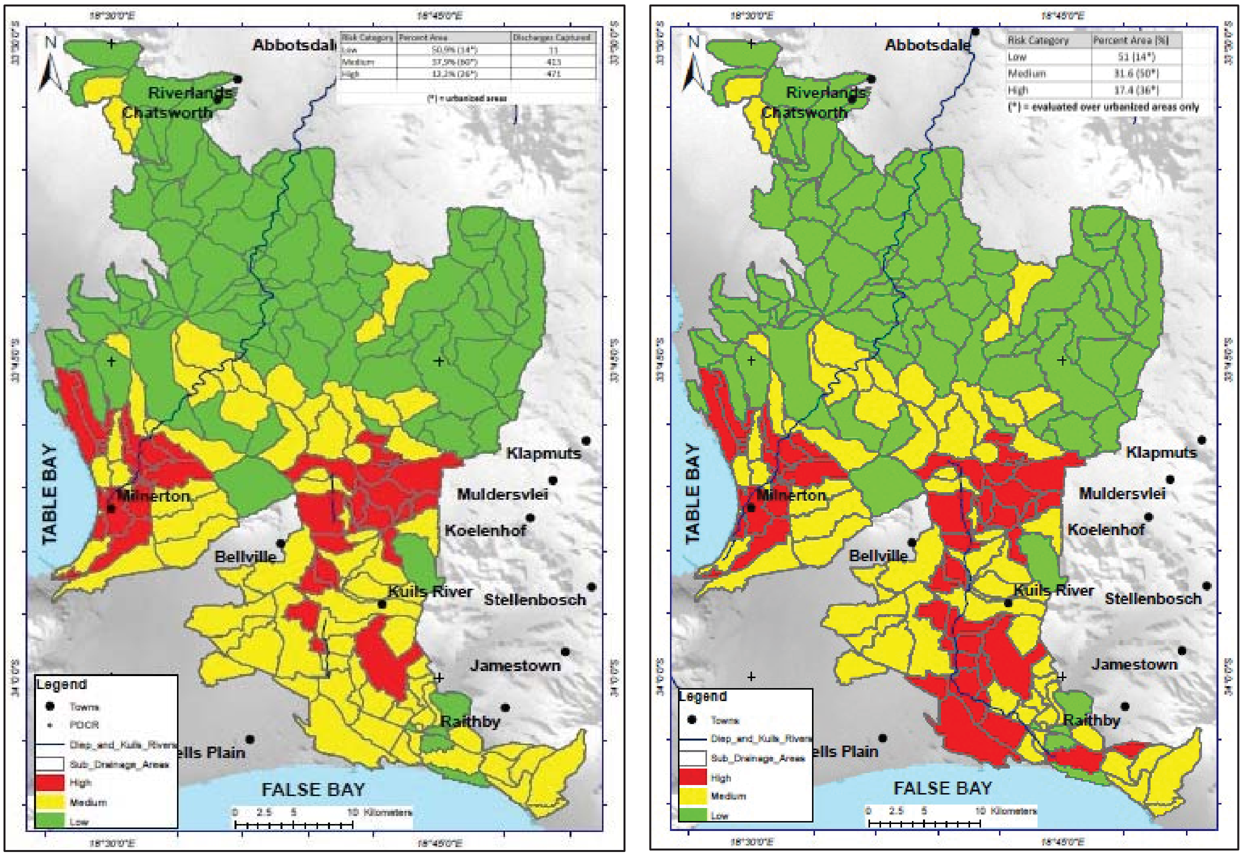

**(a)** **(b)**

**Figure C3.1: Composite risk map for wastewater discharge records. (a) all sub-catchments were evaluated with all 10 risk factors; (b) Informal settlements sub-catchments were evaluated with 4 risk factors; all else with 10.**



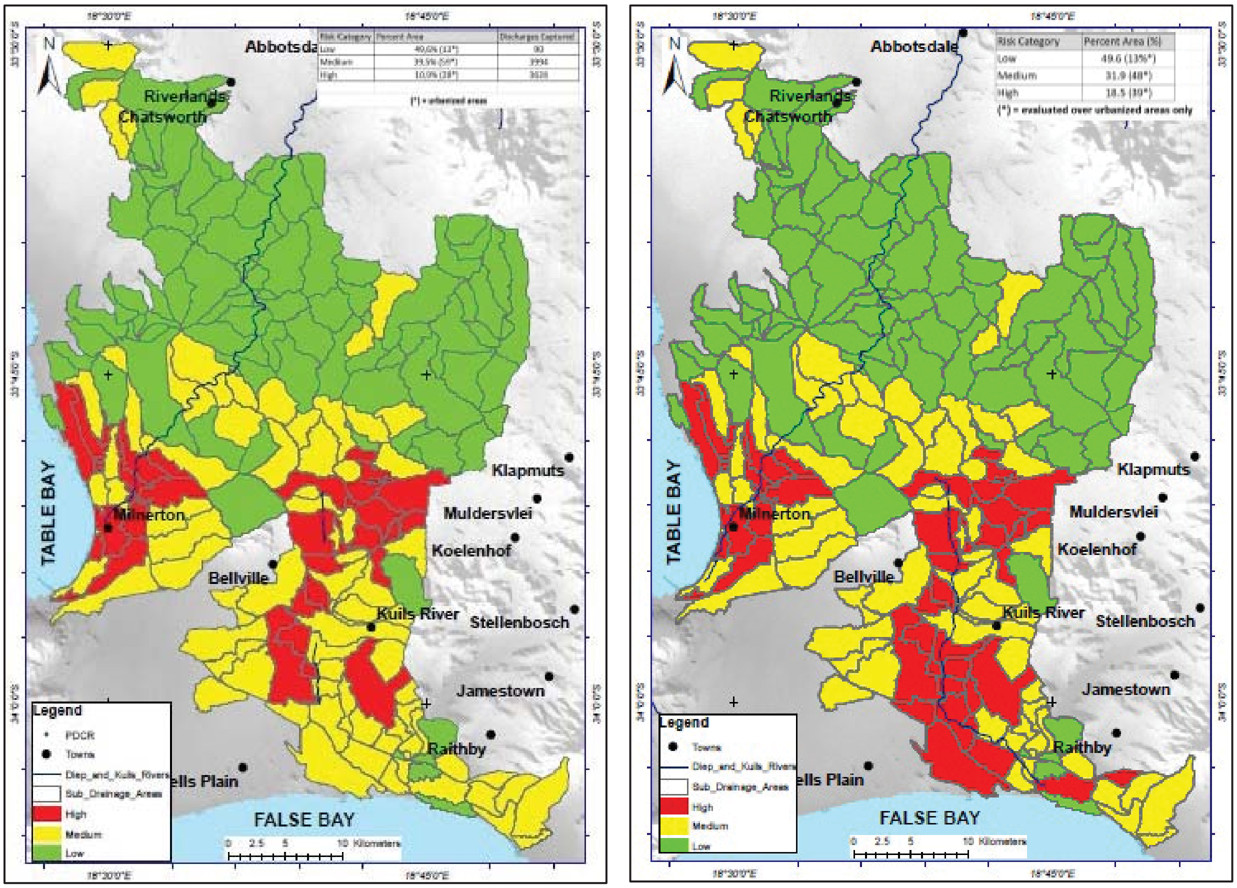

**(a)** **(b)**

**Figure C3.2: Composite risk map for water discharge records. (a) all sub-catchments were evaluated with all 10 risk factors; (b) Informal settlements sub-catchments were evaluated with 4 risk factors; all else with 10.**




**(a)** **(b)**

**Figure C3.3: Composite risk map for greywater discharge records. (a) all sub-catchments were evaluated with all 10 risk factors; (b) Informal settlements sub-catchments were evaluated with 4 risk factors; all else with 10.**




**(a)** **(b)**

**Figure C3.4: Composite risk map for solid waste discharge records. (a) all sub-catchments were evaluated with all 10 risk factors; (b) Informal settlements sub-catchments were evaluated with 4 risk factors; all else with 10.**

# APPENDIX D: Illegal discharge field investigation information

# APPENDIX D1: Incident Report & Response Form; Outfall Inspection and Instruction Form

## INCIDENT REPORT & RESPONSE FORM

**I. Incident Report** Incident Number:_________
Date/Time: ___________________ Received By: ______________________________
Location:_________________________________________
Initial Report of Conditions:
_________________________________________________________________
______________________________________________________________________
Reported By: ____________________________Phone:_________________________

**II. Investigation**
Date: _________________ By: _____________________
Location Description/Storm Drain ID/Outfall:
___________________________________________________
Discharge Entered Storm Drain System/Receiving Waters? ___Yes ___No
Material Type

- ☐ Hazardous
- ☐ Sediment/solids
- ☐ Wastewater
- ☐ Oil/Grease
- ☐ Other______________
- ☐ Unknown

Est. Quantity: _________________________
Additional Information:
_____________________________________________________________________
Sample(s) Collected: ____ Yes _____No Photo(s) Taken: ____ Yes _____No
Observed Land Use

- ☐ Residential
- ☐ Commercial/Industrial Stormwater Permit ___Yes ___No ___Unknown
- ☐ Public

Direct/Constructed Connections Found? ___ Yes ___ No
Source Description: _______________________________________________
Source/Responsible Party: ___________________________________________

**III. Action and Closure**
Referred To: ______________________________ Date: __________________________
Action Taken:____________________________________________________________
_________________________________________________________________________

Date Closed: _____________________

# OUTFALL INSPECTION FORM

## Section 1: Background Data

| | | | |
|---|---|---|---|
| Sub-drainage area: | | Outfall ID: | |
| Today's date: | | Time (Military): | |
| Investigators name: | | Form completed by: | |
| Temperature (°C): | Rainfall (mm): Last 24 hours: | Last 48 hours: | |
| Latitude: | Longitude: | GPS Unit: | GPS LMK #: |
| Camera: | | Photo #s: | |

Land Use in Drainage Area (Check all that apply):

- ☐ Industrial
- ☐ Ultra-Urban Residential
- ☐ Suburban Residential
- ☐ Commercial
- ☐ Open Space
- ☐ Institutional
- Other: ____________________
- Known Industries: ____________________

Notes (e.g., origin of outfall, if known):

## Section 2: Outfall Description

| LOCATION | MATERIAL | SHAPE | | DIMENSIONS (mm) | SUBMERGED |
|---|---|---|---|---|---|
| ☐ **Closed Pipe** | ☐ RCP ☐ CMP<br>☐ PVC ☐ HDPE<br>☐ Steel ☐ Other: _____<br>__________ | ☐ Circular<br>☐ Eliptical<br>☐ Box<br>☐ Other: _____ | ☐ Single<br>☐ Double<br>☐ Triple<br>☐ Other: _____ | Diameter/Dimensions:<br>__________ | In Water: ☐ No ☐ Partially ☐ Fully<br>With Sediment: ☐ No ☐ Partially ☐ Fully |
| ☐ **Open drainage** | ☐ Concrete<br>☐ Earthen<br>☐ rip-rap<br>☐ Other: _____ | ☐ Trapezoid<br>☐ Parabolic<br>☐ Other: _____ | | Depth: _____<br>Top Width: _____<br>Bottom Width: _____ | |
| ☐ **In-Stream** | **(applicable when collecting samples)** | | | | |
| **Flow Present?** | ☐ Yes | ☐ No | ***If No, Skip to Section 5*** | | |
| **Flow Description (If present)** | ☐ Trickle | ☐ Moderate | ☐ Substantial | | |

## Section 3: Quantitative Characterisation

| FIELD DATA FOR FLOWING OUTFALLS | | | | | |
|---|---|---|---|---|---|
| **PARAMETER** | **RESULT** | **UNITS** | **PARAMETER** | **RESULT** | **UNITS** |
| Chlorine | __ . __ | mg/L | Nitrate | __ . __ | mg/L |
| Fluoride | __ . __ | --mg/L | Nitrite | __ . ____ | mg/L |
| Ammonia | ____. __ | mg/L | Conductivity | __ . __ | mS/m |
| Detergents | __ . ____ | mg/L | pH | ____ . ____ | pH Units |
| Phosphorus | __ . ____ | mg/L | Temperature | ________ . _______ | °C |
| Sample collected from: | | | ☐ Flow | ☐ Pool | |

Flow Depth (mm): _____ Flow Width (mm): _____ Flow Velocity (m/s):_____ Volume (L): _____ Time to fill (sec): _____ **Flow Rate s (L/s.):**______

**Section 4: Physical Indicators for Flowing Outfalls Only**

Are Any Physical Indicators Present in the flow? ☐ Yes ☐ No *(If No, Skip to Section 5)*

| INDICATOR | CHECK if Present | DESCRIPTION | RELATIVE SEVERITY INDEX (1-3) | | |
|---|---|---|---|---|---|
| Odor | ☐ | ☐ Sewage ☐ Rancid/sour ☐ Petroleum/gas<br>☐ Sulfide ☐ Other: | ☐ 1 – Faint | ☐ 2 – Easily detected | ☐ 3 – Noticeable from a distance |
| Color | ☐ | ☐ Clear ☐ Brown ☐ Grey ☐ Yellow<br>☐ Green ☐ Orange ☐ Red ☐Other: | ☐ 1 – Faint colors in sample bottle | ☐ 2 – Clearly visible in sample bottle | ☐ 3 – Clearly visible in outfall flow |
| Turbidity | ☐ | See severity | ☐ 1 – Slight cloudiness | ☐ 2 – Cloudy | ☐ 3 – Opaque |
| Floatables<br>-Does Not Include Trash!! | ☐ | ☐ Sewage (Toilet Paper, etc.) ☐ Suds<br>☐ Petroleum (oil sheen) ☐ Other: | ☐ 1 – Few/slight; origin not obvious | ☐ 2 – Some; indications of origin (e.g. possible suds or oil sheen) | ☐ 3 - Some; origin clear (e.g. obvious oil sheen, suds, or floating sanitary materials) |

**Section 5: Physical Indicators for Both Flowing and Non-Flowing Outfalls**

Are physical indicators that are not related to flow present? ☐ Yes ☐ No *(If No, Skip to Section 6)*

| INDICATOR | CHECK if Present | DESCRIPTION | COMMENTS |
|---|---|---|---|
| Outfall Damage | ☐ | ☐ Spalling, Cracking or Chipping ☐ Peeling Paint<br>☐ Corrosion | |
| Deposits/Stains | ☐ | ☐ Oily ☐ Flow Line ☐ Paint ☐ Other: | |
| Abnormal Vegetation | ☐ | ☐ Excessive ☐ Inhibited | |
| Poor pool quality | ☐ | ☐ Odors ☐ Colors ☐ Floatables ☐ Oil Sheen<br>☐ Suds ☐ Excessive Algae ☐ Other: | |
| Pipe benthic growth | ☐ | ☐ Brown ☐ Orange ☐ Green ☐ Other: | |
| Trash | ☐ | ☐ Aluminium ☐ Glass bottles ☐ Plastic bottles☐ Paper<br>☐ Styrofoam ☐ Other: | |

**Section 6: Overall Outfall Characterisation**

☐ Unlikely ☐ Potential (presence of ≥2 Section 5 indicators) ☐ Suspect ( ≥1 Section 4 indicator with a severity of 3)
☐ Obvious (≥1 WQ indicator in Section 3)

**Section 7: Any Non-Illegal Discharge Concerns (e.g. dumping or needed infrastructure repairs)?**

(Form adapted from Brown et al. 2004)

# Instructions and necessary information on outfall inspection form

**NOTE: This information is to accompany the Outfall Inspection Form.**

The outfall inspection form consists of six sections (and must be completed in full), described and summarised as follows:

g) ***Section 1– Background Data:*** Record current date, physical location, GPS location, investigators name, and other background data.

h) ***Section 2– Outfall Description:*** Enter information describing the outfall, including outfall ID, whether closed pipe or open channel, physical dimensions, shape, and material type. Indicate if water is flowing from the outfall (with yes or no) and describe (e.g. trickle, moderate, substantial).

i) ***Section 3– Quantitative Characterisation:*** If flowing water is observed, measure flow rate and take water sample for lab testing. Measure also physical water quality parameters (pH, conductivity, and temperature).

j) ***Section 4– Physical Indicators for Flowing Outfalls Only:*** Collect information on physical features of flowing outfalls (e.g. odour, colour, turbidity, floating materials) and indicate their relative severity.

k) ***Section 5– Physical Indicators for Flowing and Dry Outfalls:*** Collect and enter information on physical features of both flowing and dry outfalls. Examine outfall for presence and type of algae, abnormal vegetation, damage, stains, trash, and condition of plunge pool (if any). Structural problems (*e.g.* cracking, holes in corrugated metal pipes, dissolved concrete) should also be noted.

l) ***Section 6 – Overall outfall characterisation:*** Information from sections 1 to 5 is used to characterise the severity of illegal discharge at the outfall as: unlikely, potential, suspect and obvious according to the following criteria:

- ***Unlikely:*** non-flowing outfalls with no physical indicators of illegal discharge.
- ***Potential:*** presence of two or more indicators in Section 5 only
- ***Suspect:*** presence of one or more indicator(s) in Section 4 with a severity index of 3.
- ***Obvious:*** presence of one or more water quality indicator in Section 3 exceeding recommended limit.

***Odour –*** Most strong odours, especially gasoline, oils, and solvents are likely associated with high responses on the toxicity screening test.

*Stale sanitary wastewater:* sewage

*Detergent, perfume:* Laundromat or household laundry

*Sulphur ("rotten eggs"):* industries that discharge sulphide compounds or organics (meat packers, canneries, dairies)

*Oil and gas:* facilities associated with vehicle maintenance or petroleum product storage (gas stations) or petroleum refineries

*Rancid-sour:* food preparation facilities (restaurants, hotels)

| Relative ranking | Description |
|---|---|
| 1 | Odour is faint or the crew cannot agree on its presence or origin |
| 2 | Indicates a moderate odour. |
| 3 | Odour is so strong that crew smells it from a considerable distance away from the outfall. |

***Colour –*** Important indicator of inappropriate industrial sources. Dark colours, such as brown, grey, or black are the most common.

*Yellow:* chemical plants, textile, and tanning plants

*Brown:* meat packers, printing plants, metal works, stone and concrete, fertilizers, and petroleum refining facilities [note: can be from natural organic acids if a wetland is upstream]

*Green:* chemical plants, textile facilities

*Red:* meat packers [note: can be from organic acids if a wetland is upstream]

*Grey:* dairies

| Relative ranking | Description |
|---|---|
| 1 | Flow is primarily clear, faint colours may be present |
| 2 | Clearly visible, moderately intense |
| 3 | Flow is intensely coloured |

***Turbidity –*** The cloudy appearance of water caused by the presence of suspended or colloidal matter. In dry weather, high turbidity is often a characteristic of undiluted industrial discharges.

*Cloudy:* sanitary wastewater, concrete or stone operations, fertilizer facilities, automotive dealers
*Opaque:* food processors, lumber mills, metal operations, pigment plants

| Relative ranking | Description |
|---|---|
| 1 | Slight cloudiness to the water |
| 2 | Cloudy, more difficult to see through the water |
| 3 | Water is opaque; cannot be seen through |

***Floatable matter* –** a contaminated flow may contain floating solids or liquids directly related to industrial or sanitary wastewater pollution. Floatables of industrial origin may include animal fats, spoiled food, oils, solvents, sawdust, foams, packing materials, or fuel.
*Oil sheen:* petroleum refiners or storage facilities and vehicle service facilities. [note: there is a type of bacteria that looks like an oil sheen. If you take a stick and swirl around the sheen, it will break up into blocky pieces if it is the bacteria. True oil sheen will quickly re-form and not look blocky.]
*Toilet paper bits, faecal bits, food particles*: sanitary wastewater
*Soap suds*: if white or a clear sheen, laundry discharge (check odour) [note: can also occur from natural surfactants; usually off-white or tan with an earthy-fishy odour.]

| Relative ranking | Description |
|---|---|
| 1 | Oil sheen & soap suds – small thickness and coverage |
| 2 | Oil sheen & soap suds – medium thickness and coverage |
| 3 | All sanitary wastewater floatables; Oil sheen & soap suds – thick and large coverage |

***Deposits and Stains* –** Any type of coating near the outfall, usually a dark colour. Deposits and stains will often contain fragments of floatable substances.
*Lots of sediment:* construction site erosion, sand and gravel pits, winter road applications
*Oil stain:* petroleum storage, vehicle service facilities, petroleum refineries
*Rusty:* precipitates from iron-rich water (natural or industrial) [note: if slimy and clumpy, it could be iron bacteria]
*Greyish-black deposits and hair:* leather tanneries
*White crystalline powder:* nitrogenous fertilizer waste

***Vegetation* –** Vegetation surrounding an outfall may show the effects of industrial pollutants. Decaying organic materials coming from various food product wastes would cause an increase in plant life, while the discharge of chemical dyes and inorganic pigments from textile mills could noticeably decrease vegetation. It is important not to confuse the adverse effects on high storm water flows on vegetation with highly toxic dry-weather intermittent flows.
*Excessive growth:* food product facilities, fertilizer runoff (lawns, golf courses, and farms)
*Inhibited growth:* high storm water flows, beverage facilities, printing plants, metal product facilities, drug manufacturing, petroleum facilities, vehicle service facilities, and automobile dealers.

***Damage to Outfall Structures* –** Outfall damage can be caused by severely contaminated discharges that are very acidic or basic in nature. Primary metal industries have a strong potential to cause outfall structure damage because their batch dumps are highly acidic. Poor construction, hydraulic scour, and old age can also negatively affect the condition of al outfall structure.
*Concrete or spalling (breaking off into chips or layers):* industrial flows
*Peeling paint*: industrial flows
*Metal corrosion*: industrial flows.
This sheet was modified after (Brown et al., 2004)

## References

Brown, E. Caraco, D. and Pitt, R. (2004). Illicit Discharge Detection and Elimination: a guidance manual for program development and technical assessments. Center for Watershed Protection and University of Alabama. EPA X-82907801-0.U.S. EPA Office of Wastewater Management, Washington, D.C.

# APPENDIX D2: Outfall Inspection Standard Operating Procedure (Modified after: CWP, 2017)

**1.0 Purpose**

1.1 To guide project leaders and technicians (field crews) to conduct inspection, inventory and monitoring at storm drain outfalls and at other discharge sources.

**2.0 Scope**

2.1 This procedure is appropriate to individuals undertaking stormwater drainage system outfall inspection and monitoring to detect illegal discharges.

**3.0 Responsibility**

3.1 The Project leader is responsible for:

- o Ensuring the proper approved forms are used;
- o Facilitating training for all staff;
- o Making sure that all information is appropriately maintained, controlled and disseminated.

3.2 Project field crews or technicians are responsible for:

- o Reading, understanding and following this SOP
- o Conducting field activities and data collection
- o Completing appropriate forms
- o Completing and submitting weekly illegal discharge/illegal connection detection report to the Project leader.

**4.0 Definitions**

4.1 *Stormwater:*

4.2 *Stormwater drainage system*:

4.3 *Outfall*:

4.4 *Illegal Connection*:

4.5 *Illegal Discharge:*

**5.0 Procedures**

*5.1 Field Procedures*

5.1.1 Inspect outfalls only if it's safe to do so and accessible.

5.1.2 Mark each outfall with a spray paint

5.1.3 Take a photo of each outfall.

5.1.4 With handheld GPS unit take the coordinates of each outfall and complete the Outfall Inspection Form. Measure water quality characteristics with suitable field equipment whenever flow is present and capture all information on the Outfall Inspection Form.

5.1.5 If flow is suspected to be illegal, take samples to the laboratory to analyse requisite tracer indicators. If possible, deal with major problems straightaway. Notify Project leader of obvious illegal discharges as soon as possible.

*5.2 Post Field Activity/Data Management Procedure*

5.2.1 Each day after field activities, deliver samples to laboratory.

5.2.2 At least for every two days, transfer all data collected including GPS unto municipality's GIS system and submit for authentication.
5.2.3 Field photos must be downloaded into appropriate outfall inspection subfolder at least every two days.
5.2.4 Completed Outfall Inspection Forms should be scanned and saved in appropriate outfall inspection subfolder at least once per week.
5.2.4 Capture all information on completed Outfall Inspection Form, including photographs onto municipal stormwater drainage system database, at least once per week.
5.2.5 Write and submit illegal discharge and illegal connection discovery report to the Project leader. Report must contain the following: photos, maps showing locations and characteristics of all potential, suspect and obvious illegal discharge and illegal connections discovered during the week's field activities.

*5.3 Task-Specific Requirements*

5.3.1 Training in IDDE program components and storm drains outfalls inspection procedures.
5.3.2 Acquaintance with protocols for water quality monitoring and sampling.
5.3.3 Ability to traverse and work in a coarse environment and in different outdoor conditions.

*5.4 Safety*

5.4.1 Avoid entering fast-flowing water that is more than about 300 mm deep
5.4.2 Avoid and guard against poison ivy (if available), spiders, ticks, dogs, snakes as well as off-leash pets.
5.4.3 Beware when crossing slippery surfaces such as wet rocks, concrete or wood.
5.4.4 Have an Emergency Number (and set to speed dial) on your mobile phone, if possible.
5.4.5 Waterproof waders or rubber boots must always be worn before entering into water-bodies.
5.4.6 Beware of criminals and homeless people living along urban watercourses.
5.4.7 Avoid confined spaces if appropriate training and necessary equipment are not received.
5.4.8 Ensure the number of field crew is at least two or more each time.

*5.5 Equipment and Supplies*

5.5.1 Field Equipment:

- Waterproof waders or rubber boots
- Disposable hand gloves
- Hand sanitiser
- High visibility safety vests
- Safety glasses
- First aid kit
- Mobile phone
- Stormwater drainage system map
- Outfall Inspection Forms
- Field notebook

- Handheld GPS unit
- pH and Conductivity meters
- Detergents test kit and optical brightener fluorometer
- Sterile *E. coli* sample bottles
- Cooler box with frozen ice packs
- Digital camera (with spare batteries)
- Clipboard, pencils, pens, permanent and dry erase markers
- Flashlight (with spare batteries)
- Mirror
- Tape measure
- Stopwatch
- Calculator
- Spray paint
- Machete
- Spray paint

5.5.2 Color printer

5.5.3 Computer with ArcGIS Desktop, Microsoft Office and internet access

**6.0 Related Documents**

6.1 Outfall Inspection Form

6.2 Water Sampling Standard Operation Procedures:

SANS 5667-1, Water Quality – Sampling – Part 1: Guidance on the design of sampling programmes and sampling techniques.

SANS 5667-3, Water Quality – Sampling – Part 3: Guidance on the preservation and handling of water samples.

SANS 5667-5, Water Quality – Sampling – Part 5: Guidance on sampling of rivers and streams.

SANS 5667-10, Water Quality – Sampling – Part 10: Guidance on sampling waste waters.

SANS 5667-11, Water Quality – Sampling – Part 11: Guidance on the sampling of groundwaters.

SANS 5667-14, Water Quality – Sampling – Part 14: Guidance on quality assurance and quality control of environmental water sampling and handling.

**References**

Center for Watershed Protection (CWP). (2017). Illicit Discharge Detection and Elimination field guide for the coastal plain: How to identify and quickly report pollution problems. Hampton Roads Planning District Commission MS4 Communities.

# APPENDIX D3: Selected Indicator parameters and analytical procedures

# SELECTED INDICATOR PARAMETERS

(Source: Brown et al., 2004).

### *Ammonia*

Ammonia occurs as a breakdown product of nitrogenous material in natural waters. It is also found in domestic effluents and certain industrial waste waters. Ammonia is a good indicator of sanitary wastewater; since its concentration is much higher there than in groundwater or tap water. High ammonia concentrations may also indicate liquid wastes from some industrial sites. Ammonia is relatively simple and safe to analyse. Generation of ammonia from non-human sources, such as pets or wildlife poses a challenge in its utility as an indicator of sanitary wastewater.

### *Boron*

Boron is an abundant natural element. It usually occurs in the form of calcium or sodium borate. Borates are widely used in the industrial processes and boron can occur in effluent discharges. Boron is an element present in the compound borax, which is often found in detergent and soap formulations. Consequently, boron is a good potential indicator for car and laundry wash waters and sewage. Research from the US (Pitts, 1993; Pitts, 2001, etc.) supports this contention. Boron may not be a useful indicator everywhere since it may be found at elevated levels in groundwater in some areas and is a common ingredient in water softeners products. Data on boron concentrations in local tap water and groundwater sources may indicate whether it will be an effective indicator of illegal discharges.

### *Chlorine*

Chlorine can be present in water as free available chlorine and as combined available chlorine (usually as chloramines). Both types can exist in the same water and be determined together as the total available chlorine. Chlorine and chlorine release compounds are widely used for the disinfection of water. Chlorine concentrations in tap water tend to be significantly higher than most other discharge types. Unfortunately, chlorine is extremely volatile and even moderate levels of organic materials can cause chlorine levels to drop below detection levels. Because chlorine is non-conservative, it is not a reliable indicator, although if very high chlorine levels are measured, it is a strong indication of a water line break, swimming pool discharge, or industrial discharge from a chlorine bleaching process.

### *Conductivity*

Conductivity is a measure of how easily electricity can flow through a water sample. Conductivity is often strongly correlated with the total amount of dissolved material in water, known as Total Dissolved Solids. The utility of conductivity as an indicator depends on whether concentrations are elevated in natural or clean waters. In particular, conductivity is a poor indicator of illegal discharge in estuarine waters. Previous studies (Pitt, 1993; Pitt, 2001, etc.) suggest that conductivity has limited value to detect sewage or wash water. Conductivity has some value in detecting industrial discharges that can exhibit extremely high conductivity readings. Conductivity is extremely easy to measure with field probes, so it has the potential to be a useful supplemental indicator in sub-catchments that are dominated by industrial land uses.

### *Detergents*

Most illegal discharges have elevated concentration of detergents. Sewage and washwater discharges contain detergents used to clean clothes or dishes, whereas liquid wastes contain detergents from industrial or commercial cleansers. The nearly universal presence of detergents in illegal discharges, combined with their absence in natural waters or tap water, makes them an excellent indicator. Research has revealed three indicator parameters that measure the level of detergent or its components-- surfactants, fluorescence and surface tension (Pitt, 1993; Pitt, 2001, Brown et al., 2004, etc.). Surfactants have been the most widely applied and transferable of the three indicators. Fluorescence and surface tension show promise, but only limited field testing has been performed on them.

### *E. coli (or Enterococci or Total Coliform)*

Each of these bacteria is found at very high concentrations in sewage compared to other flow types and is a good indicator of sewage or septage discharges, unless pet or wildlife sources exist in the sub-catchment. Overall, bacteria are good supplemental indicators and can be used to find “problem” streams or outfalls that exceed public health standards. Relatively simple analytical methods are now available to test for bacteria indicators, although they still suffer from two monitoring constraints. The first is the relatively long analysis time (18-24 hours) to get results and the second is that the waste produced by the tests may be classified as a biohazard and require special disposal techniques.

### *Fluorescence (optical brighteners)*

Laundry detergents are highly fluorescent because optical brighteners are added to the formula to produce brighter whites. Optical brighteners are primarily added to laundry soaps, detergents and cleaning agents for the purpose of brightening fabrics and/or surfaces. Optical brighteners are dyes that are added to essentially all laundry detergents. These brighteners are adsorbed by fabric and brighten clothing. Laundry wastewater is the largest contributor of optical brighteners to wastewater systems because it retains a large portion of dissolved optical brighteners. Laundry effluent is predominantly associated with sanitary wastewater. Toilet papers contain fluorescent whitening agents. As toilet paper breaks down, fluorescent whitening agents are released into water. Since optical brighteners decompose relatively slowly except through photo-decay, they serve as ideal indicators (surrogates) of illicit discharges in storm drains, leaking pipes from community wastewater treatment systems and/or failing septic tanks.

Using optical brighteners or fluorescence as indicators (surrogates) for detecting wastewater has several advantages. Detection is nearly instantaneous, the equipment used is relatively inexpensive, no formal training is needed and large numbers of samples can be analysed in a short period of time. It is even possible to conduct “laboratory” operations “in the field”. Where faecal contamination is known or is suspected to occur, the detection of optical brighteners can assist in pollution screening and source identification. Since no chemicals are needed for testing, fluorometers have minimal safety and waste disposal concerns. Some technical concerns do limit the utility of fluorescence as an indicator of illegal discharges. The concerns include the considerable variation of fluorescence between different detergent brands and the lack of a readily standard or benchmark concentration for optical brighteners. For example, Pitt (1993) measured fluorescence in mg/L of Tide™ brand detergent and found the degree of fluorescence varied regionally, temporally and between specific detergent formulations. A good calibration of the fluorometer unit is critical.

### *Fluoride*

Fluoride concentration should be a reliable indicator of potable water where fluoride levels in the water supply are adjusted to consistent levels and where groundwater has low to non-measurable natural fluoride levels. Fluoride measurements have often been used to distinguish treated waters from natural waters. Fluoride is added to drinking water supplies in most communities to improve dental health and normally found at a concentration of 2 mg/l in tap water. Consequently, fluoride is an excellent conservative indicator of tap water discharges or leaks from water supply pipes that end up in the storm drain. Fluoride is obviously not a good indicator in communities that do not fluoridate drinking water.

### *Hardness*

Hardness may also be useful in distinguishing between natural and treated waters (like fluoride), as well as between clean treated waters and waters that have been subjected to domestic use. The hardness of waters varies considerably from place to place, with groundwater generally being harder than surface waters. Water hardness is caused by the presence of calcium and magnesium salts. Hardness may be applicable in communities where hardness levels are elevated in groundwater due to karst or limestone terrain. In these regions, hardness can help distinguish natural groundwater flows present in outfalls from tap water and other flow types.

### *pH*

Most discharge flow types are neutral, having a pH value around 7, although groundwater concentrations can be somewhat variable. pH is a reasonably good indicator for liquid wastes from industries, which can have very high or low pH (ranging from 3 to 12). The pH of residential wash water tends to be rather basic (pH of 8 or 9). The pH of a discharge is very simple to monitor in the field with low cost test strips or probes. Although pH data is often not conclusive by itself, it can identify problem outfalls that merit follow-up investigations using more effective indicators.

### *Potassium*

Potassium is an abundant natural element. However, in fresh water potassium levels are normally low. Higher levels can be observed in brackish waters. Potassium is found at relatively high concentrations in sewage and extremely high concentrations in many industrial process waters. Studies such as Evans (1968), Verbanck et al. (1990) and

Hypes et al. (1975) have shown increased potassium concentrations following domestic water usage and this suggest potential of potassium as an indicator parameter. Consequently, potassium can act as a good first screen for industrial wastes and can also be used in combination with ammonia to distinguish wash waters from sanitary wastes.

***Surfactants***

Surfactants are the active ingredient in most commercial detergents and are typically measured as Methyl Blue Active Substances (or MBAS). Anionic surfactants account for approximately two thirds of the total surfactants used. Surfactants are a synthetic replacement for soap, which builds up deposits on clothing over time. Since surfactants are not found in nature, but are always present in detergents, they are excellent indicators of sewage and wash waters. In raw sanitary wastewaters, surfactants generally range from 1 to 20 mg/L, while natural waters usually have surfactant concentrations below 0.1 mg/L. The presence of surfactants in cleansers, emulsifiers and lubricants also makes them an excellent indicator of industrial or commercial liquid wastes. Several analytical methods are available to monitor surfactants. Unfortunately, the reagents used involve toluene, chloroform, or benzene, each of which is considered hazardous waste with a potential human health risk. The most common analysis method uses chloroform as a reagent and is recommended because it is relatively safer when compared to other reagents.

***Turbidity***

Turbidity is a quantitative measure of cloudiness in water and is normally measured with a simple field probe. While turbidity itself cannot always distinguish between contaminated flow types, it is a potentially useful screening indicator to determine if the discharge is contaminated (i.e. not composed of tap water or groundwater).

# ANALYTICAL PROCEDURES

(Analytical Procedures for: Detergents was adapted from www.chemetrics.com (accessed 6 June 2017); Fluorescence was adapted from www.turnerdesigns.com (accessed 6 June 2017) and the rest of the parameters were adapted from www.palintest.com (accessed 6 June 2017))

### “AMMONIA ($NH_3$-N)

Range: 0-1.0 mg/l-N

### Method

Refer to Palintest method for PHOT.4.AUTO for Ammonia. The Palintest Ammonia test is based on an indophenol method. Ammonia reacts with alkaline salicylate in the presence of chlorine to form a green-blue indophenol complex. Catalysts are incorporated to ensure complete and rapid colour development. The reagents are provided in the form of two tablets for maximum convenience. The test is simply carried out by adding one of each tablet to a sample of the water. The intensity of the colour produced in the test is proportional to the ammonia concentration and is measured using a Palintest Photometer.

### Reagents and Equipment

- Palintest Ammonia No 1 Tablets
- Palintest Ammonia No 2 Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

### Test Instructions

1. Fill test tube with sample to the 10 ml mark.
2. Add one Ammonia No 1 tablet and one Ammonia No 2 tablet, crush and mix to dissolve.
3. Stand for ten minutes to allow colour development. (At low temperatures the rate of colour development in the test may be slower. If the sample temperature is below 20°C allow 15 minutes for the colour to develop).
4. Select Phot 4 on Photometer to measure Ammonia mg/l N **or** select Phot 62 on Photometer to measure Ammonium mg/l $NH_4$.
5. Take Photometer reading in usual manner (see Photometer instructions).

### Duration of test for each sample

Because of the duration of this test, samples should be run in batches of about six. From start to finish, each batch of six samples takes about 30 minutes, including the time taken to clean the sample test tubes.

**Hazardous Reagents**

According to good laboratory practice, the contents of each sample cuvette, after the analysis, should be poured into another properly-labelled container for proper disposal.

**Ease of Analysis**

This procedure is time-consuming and should be performed indoors.

**BORON (B)**

Range: 0-2.5 mg/l B

**Method**

Boron in the form of borates, react with azomethine under slightly acidic conditions to form a yellow coloured complex. In the Palintest Boron method two test tablets are used to provide the necessary buffer and indicator reagents. A sequestering agent is incorporated to eliminate any interference from cations. The test is simply carried out by adding one of each tablet to a sample of the water. The intensity of colour produced in the test is proportional to the boron concentration and is measured using a Palintest Photometer.

**Reagents and Equipment**

- Palintest Boron No 1
- Tablets Palintest Boron No 2
- Tablets Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Fill the test tube with sample to the 10 ml mark.
2. Add one Boron No 1 tablet, crush and mix to dissolve.
3. Add one Boron No 2 tablet, crush and mix to dissolve.
4. Stand for exactly 20 minutes to allow full colour development.
5. Select Phot 40 on photometer.
6. Take Photometer reading in usual manner (see Photometer instructions).
7. The result is displayed as mg/l B.

**Duration of test for each sample**

Each batch of six samples takes approximately 40 minutes.

**Hazardous Reagents**

Standard laboratory practice requires that all unwanted chemicals be properly disposed.

**Ease of Analysis**

The procedure is a little time consuming, but several samples can be analysed together.

**COPPER (Cu)**

Range: 0-5 mg/l Cu

**Method**

The Palintest Coppercol method provides a simple means of measuring copper in natural and treated waters over the range 0-5 mg/l. The test is particularly useful since it can be used to measure specifically the concentrations of free and chelated copper present in the water. In the Palintest Coppercol method copper salts are reduced to the cuprous form and then reacted with a 2,2 Biquinoline-4,4-dicarboxylic salt to form a purple coloured complex. This provides a measure of the free copper ions present in the sample. In the second stage of the test, a decomplexing agent is introduced and this induces a further reaction with any chelated copper compounds which might be present. The reagents are provided in tablet form and the test is simply carried out by adding tablets to a sample of the water. The intensity of colour produced in the test is proportional to the copper concentrations and is measured using a Palintest Photometer.

**Reagents and Equipment**

- Palintest Coppercol No 1 Tablets
- Palintest Coppercol No 2 Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Fill test tube with sample to the 10 ml mark.
2. Add one Coppercol No 1 tablet, crush and mix to dissolve.
3. Gently invert the tube to remove any bubbles from the inner walls of the tube.
4. Select Phot 10 on Photometer.
5. Take Photometer reading in usual manner – see Photometer instructions.
6. The result represents the free copper concentration as mg/l Cu. Stop the test at this stage if only free copper determination is required.
7. If it is desired to measure chelated or total copper continue the test on the same test portion. Select the ‘Follow On’ from screen options to continue the test program.
8. Add one Coppercol No 2 tablet, crush and mix to dissolve.
9. Gently invert the tube to remove any bubbles from the inner walls of the tube.
10. Take Photometer reading.
11. The result represents the **Total Copper** concentration as mg/l Cu.
12. The **Chelated Copper** concentration is obtained by subtracting the free copper concentration from the total copper concentration:-

**Duration of test for each sample**

Approximately 6 minutes.

**Hazardous Reagents**

Coppercol No 2 tablet is classified as hazardous. Standard laboratory practice requires that all unwanted chemicals be properly disposed.

**Ease of Analysis**

Simple and fast.

**DETERGENTS (SURFACTANTS)**

Range: 0-3 mg/l MBAS

**Method**

The following procedure comes with the Detergents kit. The Detergents CHEMets® test kit employs the methylene blue extraction method2,3,4. Anionic detergents react with methylene blue to form a blue complex that is extracted into an immiscible organic solvent. The intensity of the blue colour is directly related to the concentration of "methylene blue active substances (MBAS)" in the sample. Anionic detergents are one of the most prominent methylene blue active substances. Test results are expressed in mg/Litre linear alkylbenzene sulfonate (equivalent weight 325).

**Reagents and Equipment**

Detergents (anionic surfactants) kit from *CHEMetrics*. The main components of the *CHEMetrics* detergent test kit are:

- Test tube
- Comparator device
- Snapper
- Double tipped ampoule containing chloroform and other reagents (blue stained)
- CHEMets ampoule (empty vacuum ampoule)

**Test Instructions**

1. Rinse the reaction tube with the sample to be tested and then fill it to the 5 mL mark with the sample.
2. While holding the double-tipped ampoule in a vertical position, snap the upper tip using the tip breaking tool.
3. Invert the ampoule and position the open end over the reaction tube. Snap the upper tip and allow the contents to drain into the reaction tube.
4. Cap the reaction tube and shake it vigorously for **30 seconds**. Allow the tube to stand undisturbed for **1 minute**.
5. Make sure that the flexible tubing is firmly attached to the CHEMet ampoule tip.
6. Insert the CHEMet assembly (tubing first) into the reaction tube making sure that the end of the flexible tubing is at the bottom of the tube. Break the tip of the

CHEMet ampoule by gently pressing it against the side of the reaction tube. The ampoule should draw in fluid only from the organic phase (bottom layer).

7. When filling is complete, remove the CHEMet assembly from the reaction tube.
8. Remove the flexible tubing from the CHEMet ampoule and wipe all liquid from the exterior of the ampoule. Place an ampoule cap firmly onto the tip of the CHEMet ampoule. Invert the ampoule several times, allowing the bubble to travel from end to end.
9. Obtain a test result by placing the ampoule, flat end first, into the comparator. Hold the comparator up toward a source of light and view from the bottom. Rotate the comparator until the best colour match is found.

**Duration of test for each sample**

Approximately 8 minutes per sample.

**Hazardous Reagents**

The main components of the double-tipped ampoule are considered hazardous and possibly carcinogenic (contains chloroform). The used ampoule should be placed back in the test kit box for later disposal at a hazardous waste facility. Use proper safety protection when performing this test: laboratory coat, gloves and safety glasses. It is also strongly recommended that the test be performed under a laboratory fume hood. Wash hands thoroughly after handling the kit.

**Ease of Analysis**

This procedure may be performed outside of a standard laboratory, if well ventilated. Produces hazardous chemicals.

**FLUORESCENCE (F)**

Range: 0-2.5 mg/l B

**Method**

Optical brighteners (also known as OBs or OBAs), or fluorescent whitening agents (FWAs in the detergent industry), are compounds that are excited (activated) by wavelengths of light in the near-ultraviolet (UV) range (360 to 365 nm) and then emit light in the blue range (400 to 440 nm). Electrons in fluorescent molecules are excited into a higher energy state by absorption of light and then emit a small amount of heat plus fluorescence as the electrons return to their ground state. Usually, the fluorescence from the second excited state is measured as this can be accomplished with a variety of different pieces of equipment called fluorometers.

**Reagents and Equipment**

- Sample Bottles
- Foil
- Disposable polymethacrylate cuvettes
- Permanent marker

- Fluorometer (such as Aquaflor) with:
  - UV Lamp (300-400nm excitation & 436nm emission filters; (6W, 365 nm typically used)
- Calibration standard solution:
  - Equipment necessary to prepare a calibration solution
    - OB Agent (Tide 2X Original Scent is suggested. Any type OB Agent can be used provided one knows the OB concentration)
    - Pipette (Piston type)
    - Pipette Tip(s)
    - DI Water
    - 1 litre Erlenmeyer flask & aluminium foil or a 1 litre amber bottle
    - Falcon tube (50 ml) or equivalent
    - Tissue -optic brightener free (This can be checked by placing the tissue under the UV lamp and checking for florescence.)

**Sample Storage:**

**Figure D3.1: Sample wrapped in foil**

The sample must be stored at room temperature and in a lightproof container. An amber bottle or a sample bottle covered with foil can be used (Figure D3.1). *Always protect the sample from light exposure. Optical brighteners photodecay.*

**Positioning the Sample (Labeling and Marking the Curvette):**

The curvette (Figure D3.2) needs to be placed in the sample compartment with the same orientation for each measurement taken. Mark the curvette at the top on one side so that the curvette can be placed into the sample compartment the same way each time (Figure D3.3).


**Fig D3.2: Disposable polymethacrylate cuvette** **Fig D3.3: Cuvette labeled for positioning**

**Sample Handling:**

Use a clean (new) cuvette for each sample. The cuvette must be dry on the outside. If it is not possible to use a new cuvette for each sample, after cleaning the cuvette fill it with a blank solution (DI water) and take a measurement to check for contamination. If the cuvette is contaminated do not use it again.

Do not take a measurement if there are air bubbles in the cuvette. Remove any bubbles present by lightly tapping on the outside of the cuvette wall with your finger, or slightly tilt the cuvette to dissipate the bubbles.

**Calibration:**

Read and follow the instructions for your fluorometer. It is suggested that you use an optical brightener (OB) calibration solution. If this is not available, one can be prepared using a clothes washing detergent such as Tide. If you are using a fluorometer provided on loan by the US Clean Water Team, a preset adjustable secondary standard will be provided which will allow the operator to quickly and easily check the fluorometer's calibration stability. If the meter's reading is more than +/-10% of the secondary standard's value, the fluorometer should be recalibrated. Be sure that the calibration value for the 50 mg/L standard is set to 100 relative fluorescence units (RFU) such as 2 RFU relative to 1 mg/L of calibration solution (Tide 2x or equivalent). For this research study, a Turner Design AquaFluor Handheld Fluorometer was obtained from the Clean Water Team.

**Preparing a 50ppm OB calibration solution using a clothes washing detergent:**

As it can be very difficult to make a 50 mg/L calibration solution directly, because it requires adding 5 ul of detergent (Tide 2X) into 100 ml DI water, it is recommended that a two-step serial dilution process be used.

- Prepare a 1 litre Erlenmeyer flask covered with aluminum foil to make it light-proof or a 1 litre amber bottle with 100 ml of DI water.

- Using a piston style pipette, draw 0.5 ml of OB agent (Tide 2X Original Scent is suggested). Wipe off excess OB agent that might have coated the pipette tip. Dispense the OB agent into the 1 litre vessel of DI water, cap and mix thoroughly. Allow foam to settle before next step. (This solution is 500 mg/L Tide 2X and can be reserved as stock for further use.)
- To then make the actual calibration solution (50.0ppm Tide 2X), add 5.0 ml of the stock solution to 45 ml of DI water in a foil-wrapped Falcon tube. Cap the tube and mix thoroughly. Allow foam to settle before use.
- It may take quite a long time for foam to settle


**Fig D3.4: Fluorometer**

**Fig D3.5: Secondary Standard**

Label 3 disposable polymethacrylate cuvettes per sample (Analyse triplicates for each sample).

Load 3mls of sample into each curvette (protect the sample from light as much as possible during loading). If 3mls of sample is not available be sure that at least 2 ml of sample is used (1/2 of the cuvette is full).

**Assigning a Calibration Standard Value (Aquafluor):**

1. Press the <STD VAL> button.
2. Use the - and + arrow buttons to set the standard value. Holding down either arrow button down will allow you to change the value using fast scrolling.
3. When finished, Press the <ENT> or <ESC> button to accept the value and to return to the Home screen.

**Performing the Calibration (Aquafluor):**

1. Press the <CAL> button.
2. Press <ENT> to start the calibration.

3. Insert your blank sample and press <ENT>. The Aquafluor will average the reading for 10 seconds and set the blanking zero point.
4. Insert the standard sample and press <ENT>. The reading is averaged for 10 seconds and the Standard Calibration value is set.
5. Press <ENT> when the calibration is complete to accept the calibration. If <ENT> is not pressed within 10 seconds, you will be asked if you want to abort the calibration. Aquafluor™ User's Manual 12 Press the ↑ or ↓ arrow button to abort or accept the calibration respectively. If at any time during steps 1-4 you want to stop the calibration, press <ESC>. This will return you to the Home screen and will default the instrument to the previous calibration.

**Sample Preparation:**

- Label 3 disposable polymethacrylate cuvettes per sample (Analyse triplicates for each sample).
- Load 3mls of sample into each cuvette (protect the sample from light as much as possible during loading). If 3mls of sample is not available be sure that at least 2 ml of sample is used (1/2 of the cuvette is full).

**Sample Analysis:**

1. Turn the fluorometer on.
2. Insert the sample.
3. Press the <READ> button.
4. The reading result will appear on the top line of the Home screen.
5. Once the word "WAIT" disappears from the Home screen another reading can be made. During each reading, the sample is warmed.
6. Be sure that you wait for each sample to equilibrate to room temperature before each reading is made.

**Duration of test for each sample**

Once the instrument is calibrated, it takes less than a minute to test a sample.

**Hazardous Reagents**

No hazardous reagents involved.

**Ease of Analysis**

Easy and fast and can be performed in the field.

**FLUORIDE (B)**

Range: 0-1.5 mg/l B

**Method**

Zirconyl Chloride and Eriochrome Cyanine R are reacted in acid solution to form a red coloured complex. This colour is destroyed by fluoride ions to give the pale yellow colour of the Eriochrome Cyanine. Differing amounts of fluoride thus produce a range of colours from red to yellow.

The particular advantage of this method is that it is substantially free from interferences which normally beset chemical methods of fluoride testing. In particular interference from aluminium and iron is eliminated by making the solution alkaline in the first stage of the test procedure. This breaks down any aluminium-fluoride and iron-fluoride complexes which may be present in the water. Interference from calcium should not be significant at the levels normally encountered in natural and drinking waters.

In the Palintest Fluoride test two tablet reagents are used. The test is simply carried out by adding one of each tablet to a sample of the water. The colour produced in the test is indicative of the fluoride concentration and is measured using a Palintest Photometer.

**Reagents and Equipment**

- Palintest Fluoride No 1 Tablets
- Palintest Fluoride No 2 Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Fill test tube with sample to the 10 ml mark.
2. Add one Fluoride No 1 tablet, crush and mix to dissolve.
3. Add one Fluoride No 2 tablet, crush and mix to dissolve.
4. Stand for five minutes to allow full colour development.
5. Select Phot 14 on Photometer.
6. Take Photometer reading in usual manner (see Photometer instructions).
7. The result is displayed as mg/l F.

**Duration of test for each sample**

Each sample takes an average of 8 minutes to test. Time can be reduced if done in batches.

**Hazardous Reagents**

The reagent is hazardous. According to good laboratory practice, the contents of each sample cuvette, after the analysis, should be poured into another properly-labelled container for proper disposal.

**Ease of Analysis**

The procedure is relatively easy and fast and can be performed in the field. However, as for all tests, it is recommended that the analyses be conducted in a laboratory, or at least in a workroom having good lighting and water.

**POTASSIUM (K)**

Range: 0-12.0 mg/l

**Method**

The Palintest Potassium test provides a simple means of testing potassium levels in water over the range 0-12.0 mg/l. The Palintest Potassium test is based on a single tablet reagent containing sodium tetraphenylboron. Potassium salts react with sodium tetraphenyl-boron to form an insoluble white complex. At the potassium levels encountered in the test, this is observed as turbidity in the test sample. The degree of turbidity is proportional to the potassium concentration and is measured using a Palintest Photometer.

**Reagents and Equipment**

- Palintest Potassium K Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Fill test tube with sample to the 10 ml mark.
2. Add one Potassium K tablet, crush and mix to dissolve. A cloudy solution indicates the presence of potassium.
3. Select Phot 30 on Photometer.
4. Take Photometer reading on the display.
5. The result is displayed as mg/l K.

**Duration of test for each sample**

Testing each sample takes approximately 2 minutes.

**Hazardous Reagents**

None

**Ease of Analysis**

Simple and fast. Can be used in the field.

**TOTAL HARDNESS**

Range: 0-12.0 mg/l

**Method**

The Palintest Hardness test provides a simple method of checking water hardness over the range 0-500 mg/l $CaCO_3$. The Palintest Hardicol test is based on a unique colorimetric method. The reagents are provided in tablet form and the test is carried out simply by adding the appropriate tablets to a sample of the water. Under the controlled conditions of the test calcium and magnesium ions react with Hardicol indicator to produce a purple coloration. The intensity of the colour is proportional to the total hardness of the water and is measured using a Palintest Photometer. This test measures total hardness. For the specific measurement of calcium hardness or magnesium hardness refer to the Palintest Calcicol (PHOT.12) and Magnecol (PHOT.21) tests respectively.

**Reagents and Equipment**

- Palintest Hardicol No 1 Tablets
- Palintest Hardicol No 2 Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595) Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Filter sample if necessary to obtain a clear solution.
2. Fill test tube with sample to the 10 ml mark.
3. Add one Hardicol No 1 tablet, crush and mix to dissolve.
4. Add one Hardicol No 2 tablet, crush and mix to dissolve. Ensure all particles are completely dissolved.
5. Stand for two minutes to allow full colour development.
6. Select Phot 15 on the Photometer.
7. Take Photometer reading in the usual manner (see Photometer instructions).
8. The Total Hardness result is displayed as mg/l $CaCO_3$.

**Duration of test for each sample**

Testing each sample takes approximately 5 minutes.

**Hazardous Reagents**

No environmental precaution is required but harmful if inhaled or ingested. According to good laboratory practice, the contents of each sample cuvette, after the analysis, should be poured into another properly-labelled container for proper disposal.

**Ease of Analysis**

Test is simple and fast and can be done in the field.

**TURBIDITY**

Range: 5-400 Turbidity Units

**Method**

The turbidity of the water is determined photoelectrically using the Palintest Photometer. In many samples both colour and turbidity will be present. In order to separate the effect of turbidity and colour, the sample is compared against a filtered portion of the same water.

The Palintest method has been calibrated against the widely recognised formazin turbidity solutions. Turbidity is expressed in terms of Formazin Turbidity Units (FTU). These units are broadly equivalent to Jackson Turbidity Units (JTU) and Nephelometric Turbidity Units (NTU).

**Reagents and Equipment**

- Palintest Colour/Turbidity Set (PM 269)
- Palintest Automatic Wavelength Selection Photometer

**Test Instructions**

1. Filter a portion of the sample through a GF/B filter paper.
2. Fill a test tube with filtered sample and retain for use as the BLANK tube.
3. Fill a test tube with unfiltered sample to the 10 ml mark.
4. Select Phot 48 on photometer.
5. Take photometer reading in usual manner (see photometer instructions) using the filtered sample as the blank.

*Note*

An optional light shield is available for use with the photometer. This shield fits over the test chamber and reduces stray light reaching the photocell. It is not necessary to use the light shield when carrying out this test indoors or under shaded outdoor light. The use of the light shield is however recommended when testing for turbidity under bright or variable lighting conditions.

**Duration of test for each sample**

Approximately 3 minutes.

**Hazardous Reagents**

None.

**Ease of Analysis**

Test is simple and fast and can be done in the field.

**TOTAL CHLORINE ($Cl_2$)**

Range: 0-5.0 mg/l $Cl_2$

**Method**

The Palintest DPD Total Chlorine method provides a simple means of measuring free chlorine and combined chlorines as a single Total Chlorine value. The Palintest Total Chlorine test uses the DPD method. This method is internationally recognised as the standard method of testing for chlorine and other residuals. In the Palintest method the reagents are provided in tablet form for maximum convenience and simplicity of use.

Free chlorine reacts with diethyl-p-phenylene diamine (DPD) in buffered solution to produce a pink coloration. Inclusion of potassium iodide induces further reaction with any combined chlorine present over a period of two minutes. The increase in colour intensity is therefore proportional to the Total Chlorine concentration. The colour intensity is measured using a Palintest Photometer.

**Reagents and Equipment**

- Palintest DPD 4 Tablets
- Palintest Automatic Wavelength Selection Photometer
- Round Test Tubes, 10 ml glass (PT 595)

**Test Instructions**

1. Rinse test tube with sample leaving a few drops in the tube.
2. Add and then crush the DPD 4 tablet in the few drops of the water sample until the tablet is thoroughly crushed.
3. Add the 10 ml test solution, mix and seal the tube with the cap
4. Wait for 2 minutes.
5. Select Phot 8 on photometer.
6. Take photometer reading in usual manner – see photometer instructions.
7. The result represents the Total Chlorine value as mg/l Cl2.

**Duration of test for each sample**

Approximately 4 minutes.

**Hazardous Reagents**

The reagent is hazardous. According to good laboratory practice, the contents of each sample cuvette, after the analysis, should be poured into another properly-labelled container for proper disposal.

**Ease of Analysis**

Test is simple and fast and can be done in the field."

## References

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# APPENDIX D4: Summary of Outfall Inspection Field Data

## Table D4.1: Summary of Qualitative Outfall Inspection field data – Kuils- and Diep River

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K1 | Kuils | commercial | closed pipe | RCP | Circular | 300 | | | _ | | Unlikely |
| K2 | Kuils | commercial | closed pipe | RCP | Circular | 375 | Moderate | orange colour | 1 | SCC damage; Excessive vegetation | Unlikely |
| K3 | Kuils | commercial | closed pipe | RCP | Circular | 525 | Moderate | orange colour | 1 | | Unlikely |
| K4 | Kuils | commercial | closed pipe | RCP | Circular | 675 | Moderate | clear colour | | | Unlikely |
| K5 | Kuils | commercial | closed pipe | RCP | Circular | 375 | | | no | flowline stains; Excessive vegetation; green benthic growth | Unlikely |
| K6 | Kuils | commercial | closed pipe | RCP | Circular | 300 | | | no | flowline stains | Unlikely |
| K7 | Kuils | commercial | closed pipe | RCP | Circular | 525 | Moderate | | no | excessive vegetation; green benthic grow | Unlikely |
| K8 | Kuils | commercial | closed pipe | RCP | Circular | 300 | Trickle | | no | green benthic grow | Unlikely |
| K9 | Kuils | commercial | closed pipe | RCP | Circular | 160 | | | no | flowline stains | Unlikely |
| K10 | Kuils | Suburban Residential | closed pipe | RCP | Circular | 375 | | | no | flowline stains; (dump at outfall) | Unlikely |
| K11 | Kuils | Suburban Residential | closed pipe | RCP | Circular | 375 | Trickle | sewage odour; grey colour | 2; 2 | | Potential |
| K12 | Kuils | Suburban Residential | closed pipe | RCP | Circular | 525 | Trickle | | no | | Unlikely |
| K13 | Kuils | sports field | closed pipe | RCP | Circular | 900 | Trickle | no | no | flowline stains | Unlikely |
| K14 | Kuils | sub-residential | Open-drainage | Concrete | Trapezoid | 350-700-550 | Moderate | clear colour | 1 | excessive vegetation; green benthic growth | Unlikely |
| K15 | Kuils | **sub-residential** | closed pipe | RCP | Circular | 375 | Trickle | clear colour | | | Unlikely |
| K16 | Kuils | ultra-urban resident | closed pipe | RCP | circular | 300 | | no | no | flowline stains | Unlikely |
| K17 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | Trickle | clear colour | | flowline stains | Unlikely |
| K18 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | Trickle | no | no | flowline stains; excessive vegetation | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K19 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | Trickle | Brown colour | | excessive vegetation | Obvious |
| K20 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 375 | Trickle | no | no | excessive vegetation | Unlikely |
| K21 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | | no | no | SCC damage; Flowline stains | Unlikely |
| K22 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 450 | Moderate | rancid odour; reddish brown colour | no | SCC damage; Flowline stains; excessive vegetation; brown benthic growth | Potential |
| K23 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | Trickle | no | no | flowline stains | Unlikely |
| K24 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | flowline stains | Unlikely |
| K25 | Kuils | **sub-residential** | closed pipe | RCP | Circular | 300 | Trickle | no | no | | Unlikely |
| K26 | Kuils | ultra-urban resident | closed pipe | RCP | Circular | 300 | Pool | no | no | flowline stains; excessive vegetation, green benthic growth | Potential |
| K27 | Kuils | ultra-urban resident | closed pipe | PVC | Circular | 200 | Trickle | sewage odour; brown colour; floatables | 2; 2 | flowline stains; excessive vegetation | Potential |
| K28 | Kuils | ultra-urban resident | open drainage | | | | Substantial | sewage odour; grey colour; floatables | 2; 2 | excessive vegetation; odour & algae pool | Potential |
| K29 | Kuils | **sub-residential** | open drainage | | | 420-900-480 | moderate | no | no | no | Unlikely |
| K30 | Kuils | **sub-residential** | closed pipe | RCP | Circular | 300 | Trickle | red colour | 3 | flowline stains; red colour | Suspect |
| K31 | Kuils | **sub-residential** | closed pipe | RCP | Circular | 600 | Moderate | clear colour | 1 | flowline stains | Unlikely |
| K32 | Kuils | sub-residential | closed pipe | RCP | Circular | 750 | moderate | no | no | brown benthic growth | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K33 | Kuils | sub-residential | closed pipe | RCP | Circular | 100 | | no | no | flowline stains | Unlikely |
| K34 | Kuils | sub-residential | closed pipe | RCP | Circular | 100 | | no | no | flowline stains; colour pool | Unlikely |
| K35 | Kuils | sub-residential | closed pipe | RCP | Circular | 450 | | no | no | flowline stains | Unlikely |
| K36 | Kuils | sub-residential | closed pipe | RCP | Circular | 450 | Trickle | no | no | SCC damage; flowline stains | Unlikely |
| K37 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | Trickle | grey | 2 | flowline stains | Unlikely |
| K38 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | Trickle | no | no | flowline stains | Unlikely |
| K39 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | orange flowline stains | Unlikely |
| K40 | Kuils | sub-residential | closed pipe | RCP | Circular | 375 | Trickle | no | no | oily stains; excessive vegetation | |
| K41 | Kuils | sub-residential | open drainage | Other | Gulley | 5m-22m-8m | substantial | no | no | no | Unlikely |
| K42 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | flowline stains; excessive vegetation; floatables | Potential |
| K43 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | flowline stains; excessive vegetation | Unlikely |
| K44 | Kuils | sub-residential | open drainage | Other | Gulley | 6m-10m-4m | Trickle | no | no | no | Obvious |
| K45 | Kuils | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | excessive vegetation | Unlikely |
| K46 | Kuils | sub-residential | closed pipe | RCP | Circular | 525 | | no | no | pool floatables & excessive algae | Unlikely |
| K47 | Kuils | sub-residential | closed pipe | RCP | Circular | 450 | | | | flowline stains; excessive vegetation | Unlikely |
| K48 | Kuils | sub-residential | closed pipe | RCP | Circular | 450 | | no | no | SCC damage; flow line stains; excessive vegetation | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K49 | Kuils | sub-residential | closed pipe | RCP | Circular | 450 | | no | no | flowline stains; green benthic growth | Potential |
| K50 | Kuils | sub-residential | closed pipe | RCP | Circular | 600 | | no | no | pool excessive algae & floatables | Unlikely |
| K51 | Kuils | sub-residential | closed pipe | RCP | Circular | 1050 | | no | no | no | Unlikely |
| K52 | Kuils | sub-residential | closed pipe | RCP | Circular | | moderate | grey colour | 3 | SCC damage; excessive vegetation; pool excessive Algae & Floatables; green benthic growth | Suspect |
| K53 | Kuils | sub-residential | closed pipe | RCP | Circular | 525 | | no | no | flowline stains; | Unlikely |
| K54 | Kuils | sub-residential | closed pipe | RCP | Circular | 1200 | substantial | clear | no | pool floatables | Unlikely |
| K55 | Kuils | sub-residential | closed pipe | RCP | Circular | 900 | | sewage floatables | 2 | pool odour | Potential |
| K56 | Kuils | sub-residential | open drainage | Other | | 40-300 | substantial | grey colour; cloudy turbidity; Solid waste | 2 | excessive vegetation | Potential |
| K57 | Kuils | sub-residential | closed pipe | RCP | Circular | | | | | pool floatables | Potential |
| K58 | Kuils | sub-residential | closed pipe (Overflow manhole) | RCP | Circular | | | no | no | flowline stains | Potential |
| K59 | Kuils | sub-residential | closed pipe | RCP | Circular | 825 | substantial | clear colour | no | no | Unlikely |
| K60 | Kuils | sub-residential | closed pipe | RCP | Circular | 525 | | no | no | flowline stains | Unlikely |
| K61 | Kuils | sub-residential | open drainage | | | 160-200-100 | Pool | no | no | inhibited vegetation; pool oil sheen | Potential |
| K62 | Kuils | sub-residential | open drainage | Concrete | Trapezoid | 3000-6000-4500- | moderate | no | no | excessive vegetation | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K63 | Kuils | sub-residential | closed pipe | fibre cement | Circular | 300 | | no | no | no | Unlikely |
| K64 | Kuils | sub-residential | open drainage | | | 500-1000-600 | trickle | no | no | oily/flow line / inhibited | Potential |
| K65 | Kuils | sub-residential | closed pipe | RCP | Circular | 600 | substantial | clear colour | no | corrosion damage; green benthic growth | Unlikely |
| K66 | Kuils | sub-residential | closed pipe | RCP | circular | 900 | substantial | clear colour | no | pool floatables | Unlikely |
| K67 | Kuils | sub-residential | closed pipe | RCP | Circular | 225 | | no | no | flow line stains; inhibited vegetation; pool floatable | Potential |
| K68 | Kuils | sub-residential | closed pipe | RCP | Circular | 525 | moderate | clear colour | | Inhibited vegetation; pool floatables; solid wastes | Unlikely |
| K69 | Kuils | sub-residential | closed pipe | RCP | Circular | 1050 | Trickle | no | no | green benthic growth | Potential |
| K70 | Kuils | sub-residential | closed pipe | RCP | Circular | 600 | | no | no | | Unlikely |
| K71 | Kuils | Industrial | closed pipe | RCP | Circular | 450 | | no | no | excessive vegetation | Unlikely |
| K72 | Kuils | Industrial | closed pipe | RCP | Circular | 1350 | substantial | clear colour; turbid | 2; 2 | brown benthic growth | Obvious |
| K73 | Kuils | Industrial | closed pipe | Steel | Circular | 450 | moderate | Brown colour | 1 | flow line/floatables (solid-waste) | Potential |
| K74 | Kuils | Industrial | closed pipe | RCP | Circular | 1200 | substantial | Petroleum odour | 2 | oily stains; inhibited vegetation, pool odour & oil sheen | Potential |
| K75 | Kuils | Industrial | closed pipe | RCP | Circular | 600 | | no | no | flow line stains | Unlikely |
| K76 | Kuils | Industrial | closed pipe | RCP | Circular | 600 | | no | no | SCC damage; flow line stains | Unlikely |
| K77 | Kuils | Industrial | closed pipe | RCP | Circular | 825 | moderate | sewage odour; brown colour | 1; 2 | pool colours & excessive vegetation | Potential |
| K78 | Kuils | Industrial | closed pipe | RCP | Circular | 525 | trickle | no | no | no | Unlikely |
| K79 | Kuils | Industrial | closed pipe | RCP | Circular | 300 | Trickle | no | no | green benthic growth | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K80 | Kuils | Industrial | closed pipe | RCP | Circular | 525 | Moderate | no | no | no | Unlikely |
| K81 | Kuils | Industrial | Open-drainage (Box Culvert) | RCP | Box | 740-2000-2000 | Moderate | sewage odour; grey colour; petroleum floatables | 3; 2; 3 | Oily stains; pool Floatables | Suspect |
| K82 | Kuils | Industrial | Open-drainage | Other | Trapezoid | 700-1500-700 | Substantial | Brown colour; (solid wastes) | 2; 2 | Excessive vegetation | Suspect |
| K83 | Kuils | Industrial | Closed Pipe | RCP | Box | H920,W2100 | Substantial | sewage odour; grey colour; (solid waste) | 1; 2; 1 | benthic growth (green) | suspect |
| K84 | Kuils | sub-residential | Closed pipe | RCP | Circular | 750 | Moderate | solid wastes | | pool floatables & excessive Algae; green benthic growth | suspect |
| K85 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 600 | | | | Flow Line stains; inhibited vegetation | Potential |
| K86 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 750 | | no | no | flow line stains; inhibited vegetation; pool floatable | Potential |
| K87 | Kuils | sub-residential | Closed Pipe | RCP | 2Circular | 370/370 | | no | no | Flow-Line stains; Inhibited vegetation; pool floatables | Potential |
| K88 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 600 | | no | no | Flow-Line/Inhibited/floatables | Potential |
| K89 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-Line stains; green Benthic growth | Potential |
| K90 | Kuils | sub-residential | Closed pipe | RCP | Circular | 300 | | no | no | Flow-Line stains; green Benthic growth | Potential |
| K91 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-Line stains; green Benthic growth | Potential |
| K92 | Kuils | sub-residential | Closed pipe | RCP | Circular | 300 | | | | Flow-Line stains; Excessive vegetation | Potential |
| K93 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-Line stains | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K94 | Kuils | Industrial | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-Line stains; Excessive vegetation; pool colours &floatables; green benthic growth | Potential |
| K95 | Kuils | Industrial (Garage BP) | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-line stains; green Benthic growth | Potential |
| K96 | Kuils | Industrial | Closed Pipe | RCP | Circular | 450 | | no | no | excessive Vegetation | Unlikely |
| K97 | Kuils | Industrial | Closed Pipe | RCP | Circular | 600 | | no | no | Flow-Line stains; green benthic growth | Potential |
| K98 | Kuils | sub-residential | Closed pipe | RCP | Circular | 300 | | no | no | Flow-Line stains | Unlikely |
| K99 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 900 | | no | no | Flow-Line stains | Unlikely |
| K100 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-Line stains | Unlikely |
| K101 | Kuils | Commercial | Closed Pipe | RCP | Circular | 375 | Trikle | Sewage odour; Grey colour; opaque turbidity; sewage floatables | 3; 3; 3; 3 | pool Odour & Colour | Obvious |
| K102 | Kuils | Industrial | Open-drainage | Concrete | Trapezoid | 280-3500 | Substantial | Solid-waste | 2 | Inhibited vegetation; pool floatables; green benthic growth | potential |
| K103 | Kuils | Sub/Indus | Closed Pipe | RCP | Circular | 450 | Moderate | Sewage odour; Grey colour; sewage floatables | 2; 3; 3; 3 | Pool odours & floatables | Obvious |
| K104 | Kuils | sub-residential | Closed pipe | PVC&CMP | Circular/Double | 450 & 120 | | no | no | Flow-Line stains; Green Benthic growth | Potential |
| K105 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-Line stains; Green Benthic growth | Unlikely |
| K106 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-Line stains; Green Benthic growth | Potential |
| K107 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-Line stains | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K108 | Kuils | sub-residential | Open-drainage | Concrete | Rectangular | 740-2400 | Substantial | Clear/sewage | | Pool Floatables | Potential |
| K109 | Kuils | sub-residential | Open-drainage | | Trapezoid | 2000-1000-4000 | Moderate | grey/Algae | | Inhibited vegetation; Pool floatables & excessive algae | Potential |
| K110 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 525 | | no | no | Flow Line stains | Unlikely |
| K111 | Kuils | Ult-Ur-Res | Closed Pipe | RCP | Circular | 525 | | no | no | Flow Line stains | Unlikely |
| K112 | Kuils | Ult-Ur-Res | Closed Pipe | RCP | Circular | 450 | | no | no | Flowline stains; excessive vegetation; Solid-waste | Unlikely |
| K113 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 600 | Trickle | Clear | no | Flow-Line stains | Unlikely |
| K114 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Sediments & solid waste | Unlikely |
| K115 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flowline stains; Pool colours & Floatables; Solid-waste | Potential |
| K116 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 600 | Moderate | Clear | no | | Unlikely |
| K117 | Kuils | sub-residential | Closed pipe | RCP | Circular | 300 | | no | no | no | Unlikely |
| K118 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 375 | | no | no | no | Unlikely |
| K119 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | Flow cannot be measured due to solid wastes on the top | Grey colour; cloudy turbidity; Solid-Waste | 2; 2; 2 | Excessive vegetation; Pool colours & floatables | Obvious |
| K120 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | Trickle | Clear colour; Trash | 1 | Pool Excessive Algae & floatables | Potential |
| K121 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | | no | no | Dark Flow Line stains | Potential |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K122 | Kuils | sub-residential | open-drainage | | Box | 650-1300-1300 | Substantial | Clear colour | no | Excessive vegetation; Green benthic growth | Potential |
| K123 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-Line stains | Unlikely |
| K124 | Kuils | sub-residential | Closed Pipe | RCP | Box | 1400-560 | substantial | Clear colour; Solid-waste | 1 | Green benthic growth | Potential |
| K125 | Kuils | sub-residential | Cl0sed Pipe | RCP | Circular | 375 | | Solid-waste | no | Flow-Line stains | Unlikely |
| K126 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 375 | | Solid-waste | no | no | Unlikely |
| K127 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow Line stains; inhibited vegetation; solid wastes | Unlikely |
| K128 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 375 | | Solid-waste | no | no | Unlikely |
| K129 | Kuils | sub-residential | Open-drainage | | Pool | | | no | no | Excessive vegetation; Pool floatables, Colours & Odor | Unlikely |
| K130 | Kuils | sub-residential | Closed Pipe | RCP | Box | 450-1200 | Substantial | Sewage odour; Grey colour; Opaque turbid; Suds floatables | 3; 3; 3; 2 | Pool Odour | Obvious |
| K131 | Kuils | sub-residential | Closed Pipe | RCP | Box | 630-1200 | | no | | Flow-Line stains; Pool floatables; Green benthic growth | Potential |
| K132 | Kuils | sub-residential | Closed pipe | RCP | Circular | 300 | | no | no | Flow-Line stains | Unlikely |
| K133 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 300 | | no | no | Flow-line stains; inhibited vegetation | Unlikely |
| K134 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 375 | Trickle | no | no | Flow-Line stains; Inhibited vegetation; Pool odours & excessive algae; brown benthic growth | Obvious |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K135 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 450 | | no | no | Flow-Line stains; Excessive vegetation | Unlikely |
| K136 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 600 | substantial | Sewage odour; Brown colour | 3; 2 | Pool odours & floatable | Obvious |
| K137 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Substantial | Green colour; turbid | 1; 1 | Flow-line stains; Excessive vegetation; Pool excessive algae & floatables; Green benthic growth | Potential |
| K138 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 1800 | Substantial | Rancid odour; turbid; Solid-waste | 1; 1; 1 | Flow line stains; Excessive vegetation; Pool Excessive Algae | Suspect |
| K139 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Moderate | Sewage odour; Clear colour | 1; 1 | Flow Line stains; Pool odors, & floatable; Green benthic growth | Potential |
| K140 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Moderate | Rancid & Sewage odour | 3 | excessive vegetation; Pool odors, colors, Suds, Floatables & Excessive Algae | Suspect |
| K141 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Moderate | Rancid & Sewage odour | 3 | Pool odors, Colors, Suds, Floatables; (Debris) | Suspect |
| K142 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Moderate | Sewage odour; grey colour | 3 | Pool odors, colors, excessive algae, suds, Oil sheen, floatables | Suspect |
| K143 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 675 | Moderate | Sewage odour; Brown colour; turbid; Sewage & Suds floatables | 3; 3; 3; 3 | Pool excessive algae, suds, floatables, odors, oil sheens | Suspect |
| K144 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 900 | Moderate | Sewage & Rancid odour; Grey colour; Opaque turbid; Suds floatables | 3; 3; 3; 3 | SCC damage; Excessive vegetation; Pool odours, colors, floatables, excessive algae | Suspect |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K145 | Kuils | sub-residential | Closed Pipe | RCP | Box | 1450-2140 | substantial | sewage odour; Dark colour; turbid | 3; 3; 3 | Excessive vegetation; Pool dark colours, odours; Green benthic growth | Suspect |
| K146 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 525 | Trickle | Petroleum odour; clear colour; solid-wastes | 2; 1; 1 | SCC damage; Inhibited vegetation; Pool floatables | Potential |
| K147 | Kuils | sub-residential | Closed Pipe | RCP | Box | 320-1300 | Trickle | Sewage odour; clear colour; turbid; Solid waste | 2; 2; 1; 3 | Inhibited vegetation; Pool floatables, odors, excessive algae; Sediments and Solid-wastes | Suspect |
| K148 | Kuils | sub-residential | Closed Pipe | RCP | Box | 55-1200 | substantial | sewage odour; Green colour; Suds floatables; solid wastes | 3; 3; 2; 3 | Green benthic growth | Obvious |
| K149 | Kuils | Ult-Ur-Res | Closed Pipe | RCP | Circular | 1200 | Trickle | Sewage odour; Brown colour; turbid; Solid waste | 3; 2; 3; 3 | Pool colours, floatables, odours; Green benthic growth | Suspect |
| K150 | Kuils | Industrial | Closed Pipe | RCP | Circular | 1500 | Substantial | Sewage odour; Grey colour | 3; 2; 3; 3 | Pool floatables, colours, odours, suds; Green benthic growth | Obvious |
| K151 | Kuils | sub-residential | Closed Pipe | RCP | Circular | 100 | Trickle | Clear colour; solid-waste | Clearly visible | Pool floatables; Green benthic growth; Solid waste | Suspect |
| K152 | Kuils | sub-residential | Closed Pipe | RCP | Circular (Double) | 1200 & 1200 | Substantial | sewage odour; Brown colour; Suds floatables | 2; 3; 3 | Pool odours, suds, colours, floatables | Obvious |
| | | | | | | | | | | | |
| D1 | Diep | Ind/Ult/C | Closed Pipe | RCP | Circular | 600 | Trickle | Rancid odour; Brown colour; turbid; solid waste | 3; 2; 2; 3 | pool odours, colours, excessive algae, floatables | Suspect |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D1A | Diep | Industrial | Open-drainage | Other | Box | 700-2400 | Seepage | Petroleum floatables | 3 | Flowline stains | Suspect |
| D2 | Diep | Industrial/commercial | Open-drainage | Other | Trapezoid | 500-4300-2000 | Substantial | Sewage odour; Grey colour; floatables | 3; 2; 3 | Excessive vegetation; Pool excessive algae, colour, floatables | Obvious |
| D3 | Diep | Ind/UltraUrb. | Open-drainage | Other | Surface flow. | top Width;2500 | Moderate | Sewage odour; Grey colour; turbid | 3; 2; 3 | Pool odours, floatables, colours, excessive algae | Obvious |
| D4 | Diep | Ind/UltraUrb. | Open-drainage | Other | Trapezoid | 1000-2000-500 | Substantial | Sewage odour; Grey colour; Suds floatables | 3; 2; 3 | Excessive vegetation | Obvious |
| D5 | Diep | Ind/UltraUrb. | Closed Pipe | RCP | Circular | 1200 | Substantial | Sewage odour; Grey colour; opaque turbid; sewage floatables | 3; 3; 3; 3 | Paint stains; Pool floatables | Obvious |
| D6 | Diep | Ind/UltraUrb. | Closed pipe | RCP | Circular | | Substantial | Sewage odour; Grey colour; opaque turbid; sewage floatables | 3; 3; 3; 3 | Pool odours, colours, floatables, Oil Sheen | Obvious |
| D7 | Diep | Industrial | Closed Pipe | PVC | Circular | 100 | | no | no | paint stains | Potential |
| D8 | Diep | Industrial | Open-drainage. Natural | | Surface flow. | 400-1600 | Moderate | Rancid odour; Brown colour; turbid; | 3; 1; 3 | Pool odours, colours, suds, oil sheen | Obvious |
| D9 | Diep | Industrial | | | Pool | 300 | | Sewage odour; Grey colour; turbid; solid waste | 3; 1; 3; 3 | Inhibited vegetation; Pool odours, colours | Obvious |
| D10 | Diep | Industrial | Open-drainage Earthen | Other | Trapezoid | 60-700-500 | Substantial | Brown colour; opaque turbidity; Solid-waste | 1; 3; 3 | | Obvious |
| D11 | Diep | Industrial | Closed Pipe | RCP | Circular | 1200 | Substantial | Rancid odour; whitish colour; opaque turbidity; | 3; 3; 3; 3 | Excessive vegetation; Pool odours, Oil sheen | Obvious |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Suds floatables; Solid Waste | | | |
| D12 | Diep | Industrial | Open-drainage | Other | | | | Sewage odour; Grey colour; opaque turbidity; sheen floatables | 3; 3; 3; 3 | Flow line stains; Excessive vegetation; Pool odours, colours, floatables, suds | Obvious |
| D13 | Diep | Industrial | closed Pipe | RCP | Circular | 1200 | Substantial. | Sewage odour; Grey colour; turbid; solid waste | 3; 2; 2; 3 | Excessive vegetation; Pool odours, colours, suds | Obvious |
| D14 | Diep | sub-residential | Closed pipe | RCP | Circular | 450 | | Sewage odour | 2 | Flow line stains; Excessive vegetation | Potential |
| D15 | Diep | sub-residential | Closed pipe | RCP | Circular | 450 | Trickle | Sewage odour; Green colour; turbid | 2; 2; 1 | Excessive vegetation; Pool odours, colours, floatables | Obvious |
| D16 | Diep | sub-residential | Closed Pipe | RCP | Circular | 375 | | no | no | no | Unlikely |
| D17 | Diep | sub-residential | Closed Pipe | | | 450 | | no | no | no | Unlikely |
| D18 | Diep | Industrial | Closed Pipe | RCP | Circular | 450 | | Brown colour | 1 | Excessive vegetation | Potential |
| D19 | Diep | Commercial | Closed pipe | RCP | Box | L=1500;B=1300 | Moderate. | Clear colour; turbid; solid-waste | 1; 1; 3 | Inhibited vegetation; Green benthic growth | Obvious |
| D20 | Diep | Commercial | open Drainage | Concrete | Trapezoid | 6m-10m-8m | substantial | Rancid odour; Grey colour; turbid; floatables | 2 ; 2; 2; 3 | Green benthic growth | Obvious |
| D21 | Diep | Sub-Resid | closed Pipe | RCP | Circular | 1050 | substantial | Brown colour; turbid; Suds floatables | 2; 2; 2 | Excessive vegetation; Green benthic growth | Suspect |
| D22 | Diep | sub-residential | closed pipe | RCP | Circular | 900 | | Brown colour; turbid | 2; 2 | Excessive vegetation; Green benthic growth | Suspect |
| D23 | Diep | sub-residential | closed pipe | RCP | Circular | 300 | | no | no | flowline stains | Unlikely |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characteris ation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D24 | Diep | sub-residential | closed pipe | RCP | Circular | 600 | | no | no | flowline stains; Excessive vegetation | Unlikely |
| D25 | Diep | Commercial | closed Pipe | RCP | Circular | 375 | | solid waste | 1 | Flowline stains | Unlikely |
| D26 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | | no | no | Flowline stains | Unlikely |
| D27 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | | no | no | Flowline stains | Unlikely |
| D28 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | | solid waste | 1 | Flowline stains | Unlikely |
| D29 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | | solid waste | no | Flowline stains | Unlikely |
| D30 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | trickle | Clear colour; turbid; solid waste | 1; 1; 1 | Excessive vegetation; Pool excessive algae; Green benthic growth | Potential |
| D31 | Diep | sub-residential | closed Pipe | PVC | Circular | 160 | | no | | flowline stains; Excessive growth | Potential |
| D32 | Diep | sub-residential | closed Pipe | RCP | Circular | 675 | | no | no | flowline stains; Excessive growth | Suspect |
| D33 | Diep | commercial | open drainage | Concrete | Trapezoid | 2m-8m-4m | Substantial | clear colour; turbid; floatable (solid waste) | 2; 2; 2 | Brown benthic growth | Suspect |
| D34 | Diep | commercial | closed pipe | PVC | Circular | 250 | | no | no | flowline stains | Unlikely |
| D35 | Diep | sub-residential | closed Pipe | RCP | Circular | 600 | trickle | sewage odour; brown colour; turbid | 2; 2; 2 | Pool colours, odours, floatables | Obvious |
| D36 | Diep | sub-residential | closed Pipe | RCP | Circular | 600 | | Solid-waste | | flowline stains | Unlikely |
| D37 | Diep | sub-residential | closed pipe | RCP | Circular | 600 | trickle | no | no | flowline stains; excessive vegetation | Potential |
| D38 | Diep | sub-residential | closed Pipe | RCP | Circular | 600 | substantial | sewage odour; grey colour; turbid; suds floatables | 3; 3; 3; 3 | excessive vegetation; Pool floatables & excessive algae | Obvious |

| Outfall ID | River Name | Landuse drainage area | Location | Outfall Material | Outfall Shape | Outfall Dimension (mm) | Flow Description | Description Physical Indicators Flowing Outfalls Only | Severity Physical Indicators Flowing Outfalls Only (1, 2, 3) | Description Physical Indicators Flowing and Non-Flowing Outfalls | Overall Outfall Characterisation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D39 | Diep | sub-residential | closed Pipe | RCP | Circular | 825 | | Solid-waste | 1 | flowline stains; excessive vegetation | Potential |
| D40 | Diep | sub-residential | closed Pipe | RCP | Circular | 600 | substantial | sewage odour; grey colour; suds floatables | 3; 3; 3 | Excessive vegetation; Pool odours, suds | Suspect |
| D41 | Diep | sub-residential | closed Pipe | RCP | Circular | 375 | substantial | sewage odour; brown colour; suds floatables | 3; 3; 3 | excessive vegetation; Pool odours & suds | Suspect |
| D42 | Diep | sub-residential | closed Pipe | RCP | Circular | 300 | substantial | sewage odour; brown colour; suds floatables | 3; 3; 3 | excessive vegetation; Pool odours, floatables & excessive algae | Obvious |
| D43 | Diep | sub-residential | closed Pipe | RCP | Circular | 300 | substantial | sewage odour; brown colour; suds floatables | 3; 3; 3 | Pool odours & colours; Brown benthic growth | Obvious |
| D44 | Diep | sub-residential | closed Pipe | RCP | Circular | 750 | substantial | sewage odour; grey colour; suds & petroleum floatables | 3; 3; 3 | excessive vegetation; Pool odours, floatables, suds | Obvious |
| D45 | Diep | Commercial | closed Pipe | RCP | Circular/double | 525 | substantial | sewage odour; grey colour; suds & petroleum floatables | 3; 3; 3 | Pool odours, colours, floatables, suds | Obvious |
| D46 | Diep | sub-residential | closed Pipe | RCP | Circular | 525 | substantial | sewage odour; brown colour; suds floatables; solid waste | 3; 3; 3 | excessive vegetation; Pool odours & floatables | Obvious |
| D47 | Diep | | | | | | substantial | no | no | none | Suspect |

## Table D4.2: Summary of Quantitative Outfall Inventory field data – Kuils- and Diep River

| Out-fall ID | River Name | Flow rate (l/s) | Temp | pH | Conduc-tivity (mS/m) | $NH_3$ mg/l | Turbi-dity (NTU) | $NO_2$ mg/l | $NO_3$ mg/l | $PO_4$ mg/l | K mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K3 | Kuils | 0.7 | 17.3 | 7.15 | 0.1079 | < | 0.02 | | | | |
| K4 | Kuils | 0.45 | 18.2 | 7.12 | 1.149 | 0.1 | 2.24 | | | | |
| K7 | Kuils | 0.8 | 19 | 7.03 | 0.973 | < | 0 | | | | |
| K12 | Kuils | | 15.8 | 7.51 | 1.59 | 0.03 | 0.58 | | | | |
| K13 | Kuils | | 15.8 | 7.06 | 0.7375 | | | | | | |
| K14 | Kuils | 0.5 | 15.8 | 7.57 | 2.422 | 0.07 | 2.17 | | | | |
| K15 | Kuils | | 16.7 | 6.84 | 0.9121 | < | 7.02 | | | | |
| K17 | Kuils | 0.2 | 17.1 | | 0.702 | < | 3.72 | | | | |
| K18 | Kuils | 0.3 | 17 | | 1.812 | 0.01 | | | | | |
| K19 | Kuils | | 17.2 | | 3.098 | 0.27 | 47.9 | | | | |
| K22 | Kuils | 1.5 | 17.5 | | 1.355 | < | 4.7 | | | | |
| K23 | Kuils | 0.2 | 17.9 | | 2.791 | | 0.62 | | | | |
| K25 | Kuils | 0.1 | | | | | | | | | |
| K27 | Kuils | 0.1 | 18.5 | | 0.5935 | | 85.5 | | | | |
| K29 | Kuils | 0.5 | 18.5 | | 2.881 | 0.13 | 6.04 | | | | |
| K31 | Kuils | 0.5 | 19.4 | | 1.99 | 0.05 | 2.1 | | | | |
| K32 | Kuils | 1 | 16 | | 1.578 | < | 0.7 | | | | |
| K37 | Kuils | 0.1 | 16.7 | | 1.299 | 0.13 | 4.26 | | | | |
| K40 | Kuils | 0.1 | | | | | | | | | |
| K41 | Kuils | 5 | 16.2 | 7.12 | 1.126 | 0.18 | 1.63 | | | | |
| K44 | Kuils | | 13.6 | 7.18 | 1.985 | 0.72 | 1.02 | | | | |
| K54 | Kuils | 7.5 | 14.6 | 7.25 | 0.1089 | 0.19 | 0.79 | | | | |
| K56 | Kuils | | 15.8 | 6.96 | 1.245 | 0.15 | 12.2 | | | | |
| K59 | Kuils | 6 | 17.2 | 8.03 | 1.555 | 0.14 | 2.59 | | | | |
| K61 | Kuils | | 16 | 6.61 | 0.5299 | 0.09 | 2.89 | | | | |
| K62 | Kuils | 2.7 | 18.1 | 6.87 | 0.504 | 0.1 | 0.5 | | | | |
| K64 | Kuils | 0.1 | 16.8 | 6.87 | 0.8842 | 0 | 9.08 | | | | |
| K65 | Kuils | 14.4 | 16.9 | 8.07 | 1.112 | 0.11 | 1.24 | | | | |
| K66 | Kuils | 9 | 16.9 | 7.9 | 1.167 | 0.14 | 3.24 | | | | |
| K68 | Kuils | 3.9 | 17.8 | 7.17 | 2.591 | 0 | 24.1 | | | | |
| K72 | Kuils | 296 | 21.5 | 9.04 | 2.011 | 0.18 | 5.12 | | | | |
| K73 | Kuils | 4.6 | 17 | 7.87 | 0.83 | 0.1 | 11.75 | | | | |
| K74 | Kuils | 7.6 | 17.5 | 7.54 | 0.5713 | 0.1 | 10.65 | | | | |
| K77 | Kuils | 1 | 14.8 | 6.9 | 0.7014 | 0.1 | 65.8 | | | | |
| K78 | Kuils | 0.2 | 16.2 | 7.87 | 0.6472 | < | 0.84 | | | | |
| K79 | Kuils | | 15.8 | 7.91 | 0.6088 | < | 17.73 | | | | |
| K80 | Kuils | 2 | 15.1 | 9.27 | 0.1144 | 0.15 | 2.89 | | | | |
| K81 | Kuils | 3 | 16.5 | 7.47 | 1.293 | 0.17 | 13.96 | | | | |
| K82 | Kuils | 10.5 | 16.8 | 7.31 | 0.49 | 0.17 | 105 | | | | |

| Out-fall ID | River Name | Flow rate (l/s) | Temp | pH | Conduc-tivity (mS/m) | $NH_3$ mg/l | Turbi-dity (NTU) | $NO_2$ mg/l | $NO_3$ mg/l | $PO_4$ mg/l | K mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| K83 | Kuils | 12.6 | 19 | 7.25 | 0.8116 | 0.16 | 2.43 | | | | |
| K84 | Kuils | 1 | 17.8 | 8.04 | 1.273 | 0.1 | 1.36 | | | | |
| K101 | Kuils | | 24.2 | 5.92 | 3.397 | 1.5 | 902 | | | | |
| K102 | Kuils | 11 | 18.6 | 5.08 | 1.362 | 0.13 | 7.88 | | | | |
| K103 | Kuils | | 16.5 | 7.66 | 0.278 | 0.26 | 66.5 | | | | |
| K108 | Kuils | | 20.7 | 7.64 | 1.041 | 0.17 | 5.63 | | | | |
| K109 | Kuils | 8 | 18 | 7.14 | 1.03 | 0.12 | 4.25 | | | | |
| K113 | Kuils | 0.2 | 18.4 | 7.73 | 0.858 | < | 1.72 | | | | |
| K116 | Kuils | 2.4 | 19.5 | 7.9 | 1.16 | 0.12 | 4.6 | | | | |
| K119 | Kuils | | 19 | 7.16 | 2.718 | 0.39 | 42.9 | | | | |
| K120 | Kuils | 0.1 | 19 | 7.75 | 0.913 | < | 9.15 | | | | |
| K122 | Kuils | 8 | 18.7 | 8.59 | 2.1 | 0.18 | 0.25 | | | | |
| K124 | Kuils | 6.4 | 20.6 | 7.97 | 0.604 | 0.13 | 8.05 | | | | |
| K129 | Kuils | | 18.7 | 8.22 | 0.101 | < | 4.66 | | | | |
| K130 | Kuils | 14.4 | 21.2 | 8.09 | 1.274 | 0.26 | 195 | | | | |
| K131 | Kuils | | 19.3 | 7.66 | 1.674 | | | | | | |
| K134 | Kuils | 0.1 | 19.7 | 7.82 | 2.406 | 1 | 69.8 | | | | |
| K136 | Kuils | 8 | 21.4 | 7.54 | 1.887 | 0.25 | 158 | | | | |
| K137 | Kuils | | 21.2 | 8.7 | 1.084 | 0.16 | 4.94 | | | | |
| K138 | Kuils | 313 | 18.2 | 7.49 | 0.705 | 2.9 | 0.87 | 0.32 | 2.92 | 1.1 | 12 |
| K139 | Kuils | | 19.4 | 7.61 | 0.943 | 0.1 | 4.56 | | | | |
| K140 | Kuils | | 26 | 7.89 | 0.99 | 5.4 | 2.14 | 0.033 | 0.8 | 1.55 | 20 |
| K141 | Kuils | | 21.7 | 7.44 | 0.6439 | 0.13 | 0.97 | 0.2 | 6.2 | 0.14 | 7.7 |
| K142 | Kuils | | 22.4 | 7.61 | 1.022 | 2.6 | 1.67 | 0.105 | 3.82 | 0.51 | 0 |
| K143 | Kuils | 0.1 | 20.8 | 7.65 | 0.927 | 0.66 | 1.07 | 1.35 | 12.6 | 0.42 | 8 |
| K144 | Kuils | | 21.1 | 7.85 | 0.865 | 0.32 | 1.51 | 0.95 | 14.56 | 1.12 | 8.6 |
| K145 | Kuils | 14.5 | 20.7 | 8.44 | 1.309 | 0.3 | 0.5 | 0.033 | | 0.68 | 6.6 |
| K146 | Kuils | 0.1 | 15.7 | 8.22 | 1.788 | 0.01 | 3.39 | | | | |
| K147 | Kuils | | 20.7 | 7.98 | 1.743 | 0.73 | 7.05 | 0.91 | 10.71 | 2.8 | 8 |
| K148 | Kuils | 19 | 19.4 | 7.9 | 1.487 | 8.1 | 4.35 | 1.47 | 4.48 | 2.6 | 42 |
| K149 | Kuils | | 17.6 | 7.58 | 1.015 | < | | | | | 12 |
| K150 | Kuils | 194 | 20.1 | 7.64 | 1.154 | 24.24 | 17.87 | 0.007 | 0.024 | | 10.1 |
| K151 | Kuils | | 23.5 | 7.58 | 1.141 | 0.69 | 33.5 | 0.11 | 3.78 | 11.2 | 84 |
| K152 | Kuils | 32 | 21.4 | 7.35 | 0.965 | 10.08 | 12.08 | 0.005 | 0.3 | 1.4 | 8.4 |
| | | | | | | | | | | | |
| D1 | Diep | | 22.1 | 7.91 | 2.115 | 0.18 | 13.32 | | | | |
| D2 | Diep | | 20.5 | 6.66 | 1.844 | | | | | | |
| D3 | Diep | 10 | 23.4 | 6.78 | 1.797 | 0.17 | 93.7 | | | | |
| D3A | Diep | 0.4 | 25.2 | 7.88 | 4.61 | 10.74 | 375 | | | | |
| D4 | Diep | 12.7 | 24.2 | 7.51 | 3.017 | 96.36 | 632 | | | | |
| D5 | Diep | 25 | 20.6 | 8.06 | 1.951 | 70.07 | 477 | | | | |

| Out-fall ID | River Name | Flow rate (l/s) | Temp | pH | Conduc-tivity (mS/m) | $NH_3$ mg/l | Turbi-dity (NTU) | $NO_2$ mg/l | $NO_3$ mg/l | $PO_4$ mg/l | K mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|
| D6 | Diep | 171 | 21 | 7.71 | 1.597 | 72.8 | 300 | | | | |
| D8 | Diep | 3.1 | 24.6 | 7.77 | 3.88 | 0.36 | 39 | | | | |
| D9 | Diep | | 18.8 | 6.72 | 0.336 | 0.5 | 497 | | | | |
| D10 | Diep | 3 | 19.6 | 7.4 | 8.529 | 0.79 | | 0.12 | 5.34 | 1.15 | 23.4 |
| D11 | Diep | | 21.6 | 6.64 | 1.845 | 0.42 | | 0.15 | 1.6 | 9.6 | 4.7 |
| D13 | Diep | | 29.2 | 7.07 | 2.519 | 0.8 | | 0.52 | 0.22 | 44 | 210 |
| D15 | Diep | | 18.9 | 7.2 | 1.872 | 0.1 | | 0.03 | 0.83 | 1.3 | 4.7 |
| D16 | Diep | | 20.3 | 6.98 | 1.644 | 0.15 | | 0.07 | 1.67 | 1.25 | 57 |
| D18 | Diep | | 18 | 7.68 | 2.135 | 0.09 | | 0.04 | 1.03 | | 69 |
| D19 | Diep | | 18.1 | 7.49 | 1.796 | 0.24 | | 0.3 | 14.49 | 0.35 | 10 |
| D20 | Diep | | 19.3 | 6.83 | 3.022 | 0.07 | | 0.057 | 0.865 | 1.8 | 10 |
| D21 | Diep | | 18.7 | 6.92 | 1.446 | | | 0.029 | 0.835 | 12 | 31.2 |
| D22 | Diep | | 21 | 6.9 | 1.966 | 0.04 | | 0.046 | 0.825 | 11.1 | 30.6 |
| D30 | | | 16.2 | 6.22 | 0.1215 | 0.03 | | 0.028 | 0.232 | 0.23 | 1.6 |
| D32 | Diep | | 16.5 | 6.84 | 3.099 | 0.01 | | 0.015 | 0.26 | 0.57 | 7.2 |
| D33 | Diep | | 21.6 | 8.12 | 6.324 | 0.17 | | 0.026 | 0.7 | 0.26 | 11 |
| D35 | Diep | | 17.5 | 7.36 | 13.08 | 0.48 | | 0.03 | 14.4 | 0.91 | 55 |
| D38 | Diep | | 19 | 6.84 | 3.672 | 0.07 | | 0.04 | 2.4 | 0.71 | 44 |
| D40 | Diep | | 17.8 | 6.75 | 3.168 | 0.09 | | 0.05 | 4.5 | 1.45 | 12 |
| D41 | Diep | | 19.7 | 7.01 | 4.348 | 0.12 | | 0.3 | 3.9 | 0.78 | 56.4 |
| D42 | Diep | | 21.12 | 7.46 | 5.918 | 0.23 | | 0.18 | 24 | 1.4 | 49.2 |
| D43 | Diep | | 21.8 | 7.34 | 6.512 | 0.37 | | 0.12 | 23.4 | 2.4 | 48 |
| D44 | Diep | | 20.5 | 6.76 | 7.428 | 0.43 | | 0.18 | 6.24 | 5.76 | 44.4 |
| D45 | Diep | | 21.3 | 6.86 | 9.451 | 0.39 | | 0.12 | 2.04 | 9.6 | 64.9 |
| D46 | Diep | | 21.2 | 7.31 | 13.37 | 0.43 | | 0.1 | 3.84 | 2.76 | 78.1 |
| D47 | Diep | | 22.4 | 7.21 | 1.087 | | | | | | |

## Table D4.3: Summary of outfall flow description in Diep- and Kuils River

| Outfall characterisation | Number of outfalls | Outfall ID |
|---|---|---|
| | | **Diep River** |
| Trickle | 5 | D1, D15, D30, D35, D37 |
| Moderate | 4 | D3, D8, D10, D19 |
| Substantial | 18 | D2, D4, D5, D6, D11, D13, D20, D21, D33, D38, D40, D41, D42, D43, D44, D45, D46, D47 |
| | | **Kuils River** |
| Trickle | 31 | K2, K8, K12, K13, K15, K17, K18, K19, K20, K23, K25, K27, K30, K36, K37, K40, K38, K40, K44, K64, K69, K78, K79, K101, K113, K120, K134, K146, K147, K149, K151. |
| Moderate | 26 | K3, K4, K7, K14, K22, K29, K32, K31, K32, K52, K62, K68, K73, K77, K80, K81, K84, K103, K109, K116, K139, K140, K141, K142, K143, K144. |

| | | |
|---|---|---|
| Substantial | 23 | K28, K41, K54, K56, K59, K65, K66, K72, K74, K82, K83, K102, K108, K122, K124, K30, K136, K137, K138, K145, K148, K150, K152 |

**Table D4.4: Statistics of flow rates measured on Diep- and Kuils River**

| **Statistical parameter** | **Flow rate (L/s)** |
|---|---|
| Sample size | 58 |
| Min | 0.1 |
| Max | 313 |
| Mean | 22 |
| COV | 2.88 |
| 10th Percentile | 0.1 |
| 25th Percentile | 0.45 |
| 50th Percentile | 3 |
| 75th Percentile | 10 |
| 90th Percentile | 21.4 |

**Table D4.5: Statistical summary of chemical analysis results of flowing outfalls of Diep- and Kuils River (Aug-Oct 2017)**

| | Temp (°C) | pH | Conductivity (mS/m) | Ammonia (mg/l-N) | Turbidity (NTU) | Nitrite (mg/l-N) | Nitrate (mg/l-N) | Phosphate (mg/l-P) | Potassium (mg/l) |
|---|---|---|---|---|---|---|---|---|---|
| Sample size (N) | 103 | 93 | 103 | 99 | 75 | 34 | 33 | 32 | 35 |
| Min | 13.60 | 5.08 | 0.10 | 0.00 | 0.00 | 0.01 | 0.02 | 0.14 | 0.00 |
| Max | 29.20 | 9.27 | 13.37 | 96.36 | 902.00 | 1.47 | 24.00 | 44.00 | 210.00 |
| Mean | 19.10 | 7.44 | 2.08 | 3.83 | 59.58 | 0.24 | 5.27 | 4.15 | 32.85 |
| COV | 0.14 | 0.08 | 1.10 | 3.95 | 2.58 | 1.55 | 1.21 | 1.92 | 1.18 |
| 10th Percentile | 16.00 | 6.79 | 0.58 | 0.06 | 0.74 | 0.03 | 0.27 | 0.36 | 5.46 |
| 25th Percentile | 17.05 | 7.03 | 0.91 | 0.10 | 1.70 | 0.03 | 0.83 | 0.70 | 8.20 |
| 50th Percentile | 18.80 | 7.49 | 1.36 | 0.17 | 4.70 | 0.10 | 2.92 | 1.35 | 12.00 |
| 75th Percentile | 20.90 | 7.87 | 2.13 | 0.43 | 20.99 | 0.20 | 6.20 | 2.77 | 48.60 |
| 90th Percentile | 22.04 | 8.07 | 3.84 | 2.81 | 136.80 | 0.79 | 14.47 | 10.95 | 67.36 |

### Table D4.6: Ecosystem Health Criteria: Categories (adapted from Nel et al., 2015:24)

| Variable | Units | Natural | Good | Fair | Poor | Unaccept-able | Comments |
|---|---|---|---|---|---|---|---|
| Temperature*# | °C | Depends on background (Upper boundary = 90th percentile; Lower boundary = 10th percentile); Good ±2°C; Fair ±4°C; Poor ± >4°C | | | | | Need to determine typical background water quality - not essential for prioritisation exercise |
| Conductivity (EC)#* | mS/m | Depends on background (not more than 15% different from normal cycles) | | | | | Need to determine typical background water quality - not essential for prioritisation exercise |
| pH * | units | 8-6.5 | 9-8 or 6.5-5.75 | 10-9 or 5.75-5 | >10; <5 | | Need to determine typical background water quality - not essential for prioritisation exercise |
| $PO_4$* | mg/l | <0.005 | 0.005 - 0.025 | 0.025-0.125 | 0.125-0.250 | >0.250 | Ranges as recommended in the latest water quality benchmarks for the Ecological Reserve (DWAF, 2005) |
| Total Inorganic Nitrogen* | mg/l | <0.25 | 0.25-1 | 1-4 | 4-10 | >10 | |
| Ammonia (NH3-N)* | mg/l | <0.015 | 0.015-0.058 | 0.058-0.1 | 0.1-0.2 | >0.2 | No unacceptable range is given but if one selects equal bands then 0.2 mg/l is the next logical band and applies to assessing the actual data |

# South African Water Quality Guidelines (DWAF, 1996b)
* Ecological reserve water quality benchmarks (Jooste & Rossouw, 2002)

### Table D4.7: Summary of outfall characterisation in Diep- and Kuils River

| Outfall characterisation | Number of outfalls | Outfall names |
|---|---|---|
| **Diep River** | | |
| Potential | 7 | D7, D14, D18, D30, D31, D37, D39 |
| Suspect | 9 | D1, D1A, D21, D22, D32, D33, D40, D41, D47 |
| Obvious | 21 | D2, D3, D4, D5, D6, D8, D9, D10, D11, D12, D13, D15, D19, D20, D35, D38, D42, D43, D44, D45, D46 |
| **Kuils River** | | |
| Potential | 43 | K11, K22, K26, K27, K28, K42, K49, K55, K56, K57 K58, K60, K64, K67, K69, K73, K74, K77, K85, K86, K87, K88, K89, K90, K91, K92, K94, K95, K97, K102, K104, K106, K108, K109, K115, K120, K121, K122, K124, K131, K137, K139, K146 |
| Suspect | 16 | K30, K52, K81, K82, K83, K84, K138, K140, K141, K142, K143, K144, K145, K147, K149, K151 |
| Obvious | 12 | K19, K44, K72, K101, K103, K119, K130, K134, K136, K148, K150, K152 |

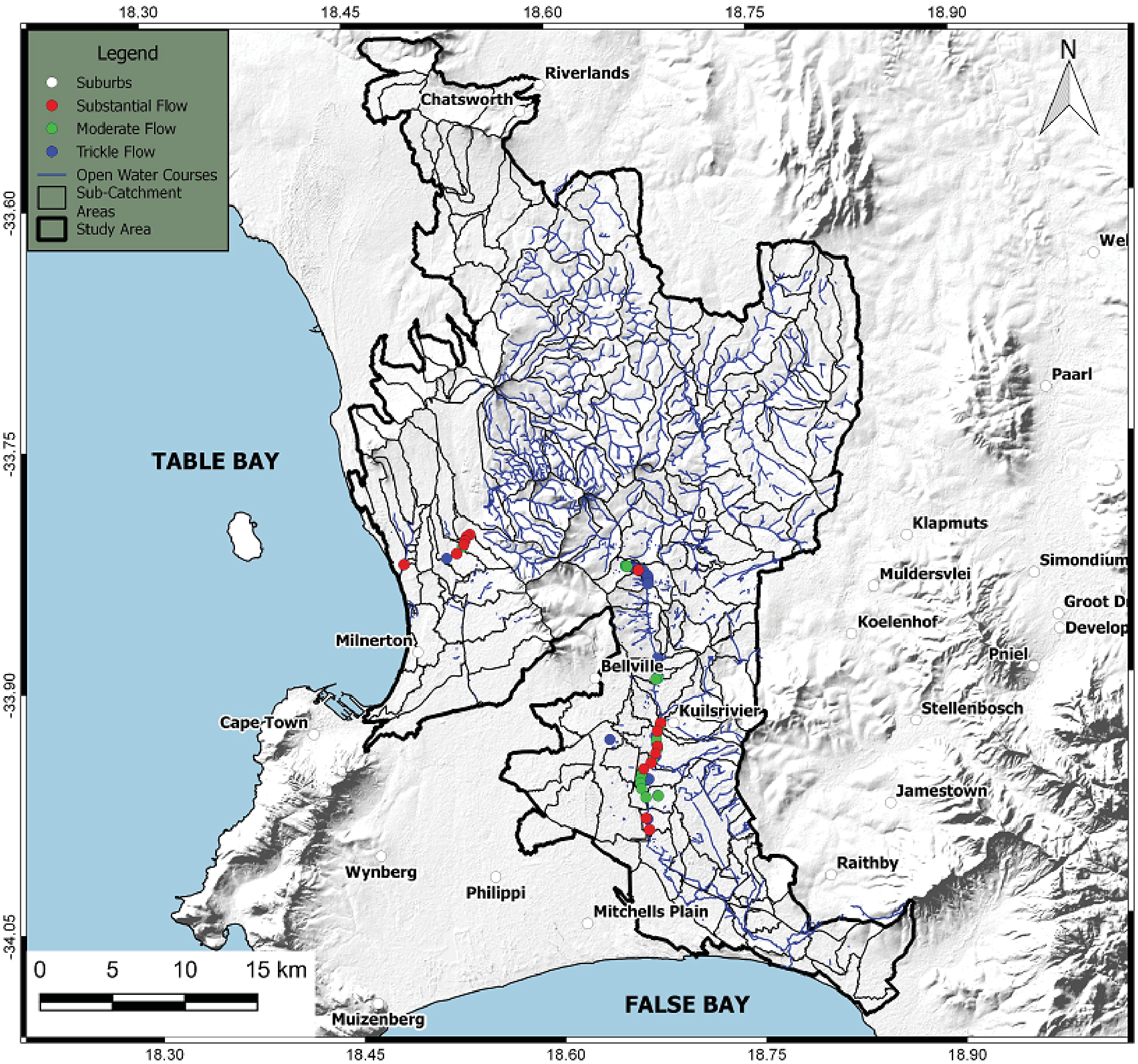


**Figure D4.1: Outfalls with non-storm flows in Diep- and Kuils River (Aug-Oct 2017)**

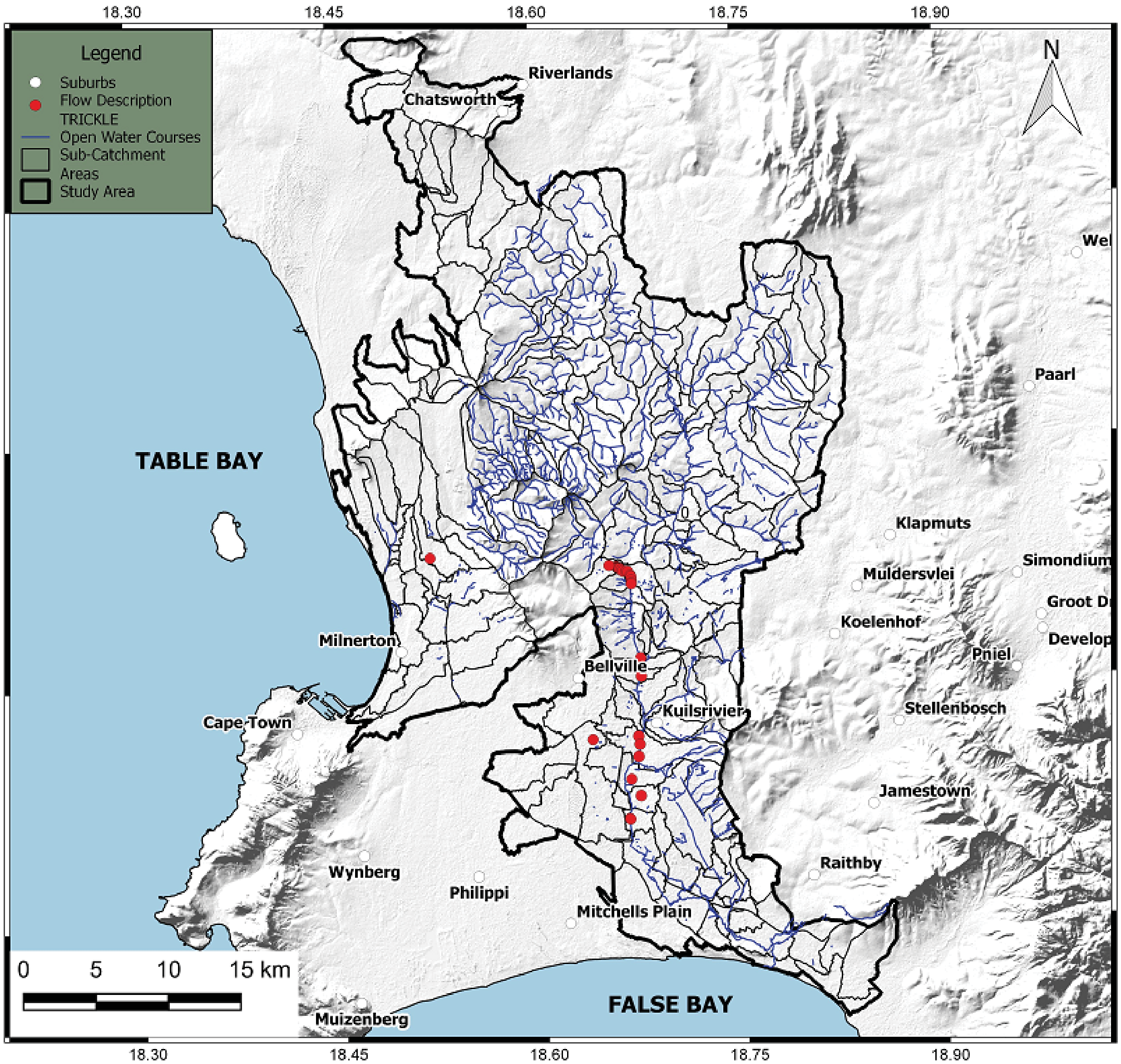


**Figure D4.2: Outfalls with trickle non-storm flows in Diep- and Kuils River (Aug-Oct 2017)**

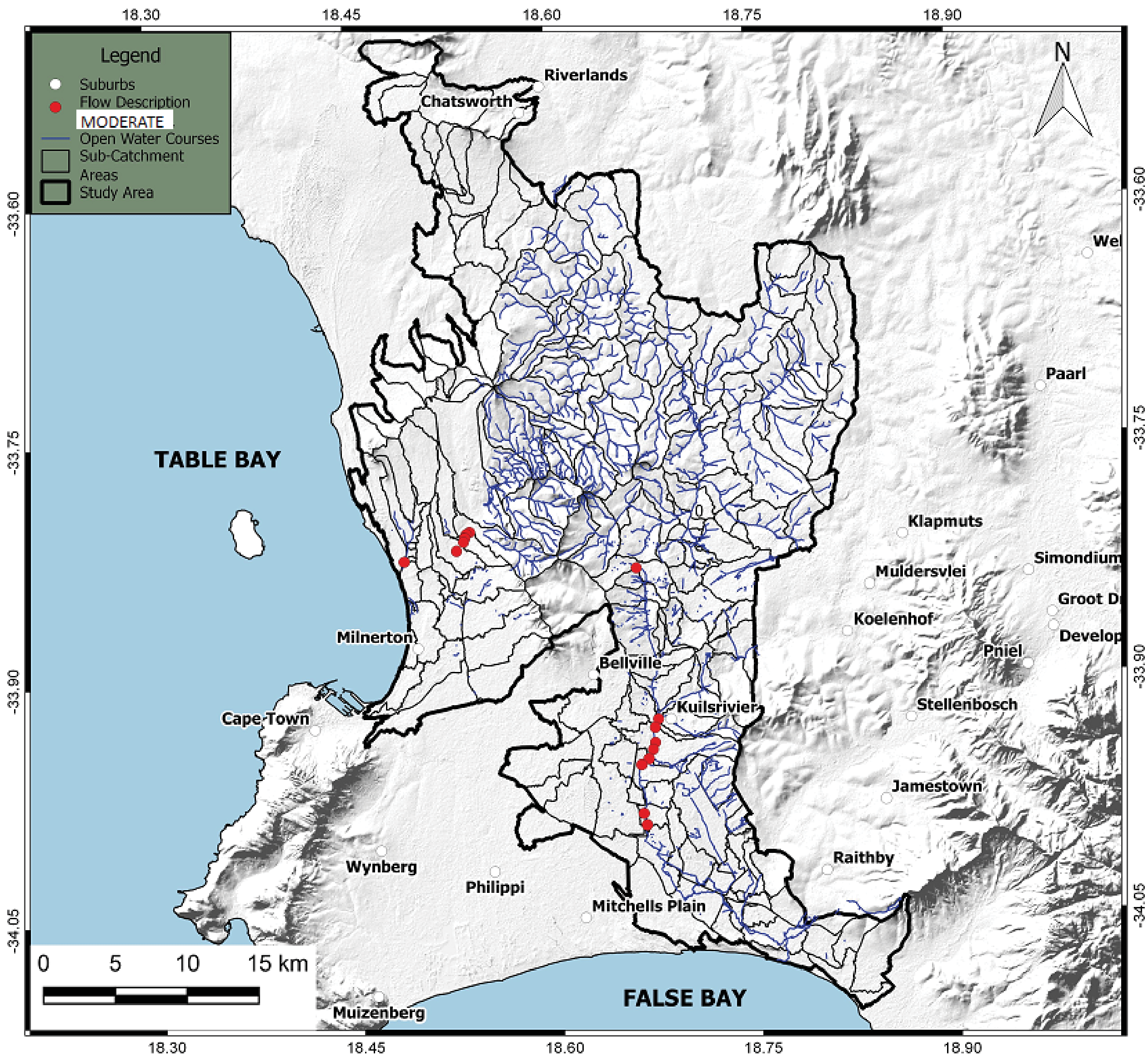


**Figure D4.3: Outfalls with moderate non-storm flows in Diep- and Kuils River (Aug-Oct 2017)**

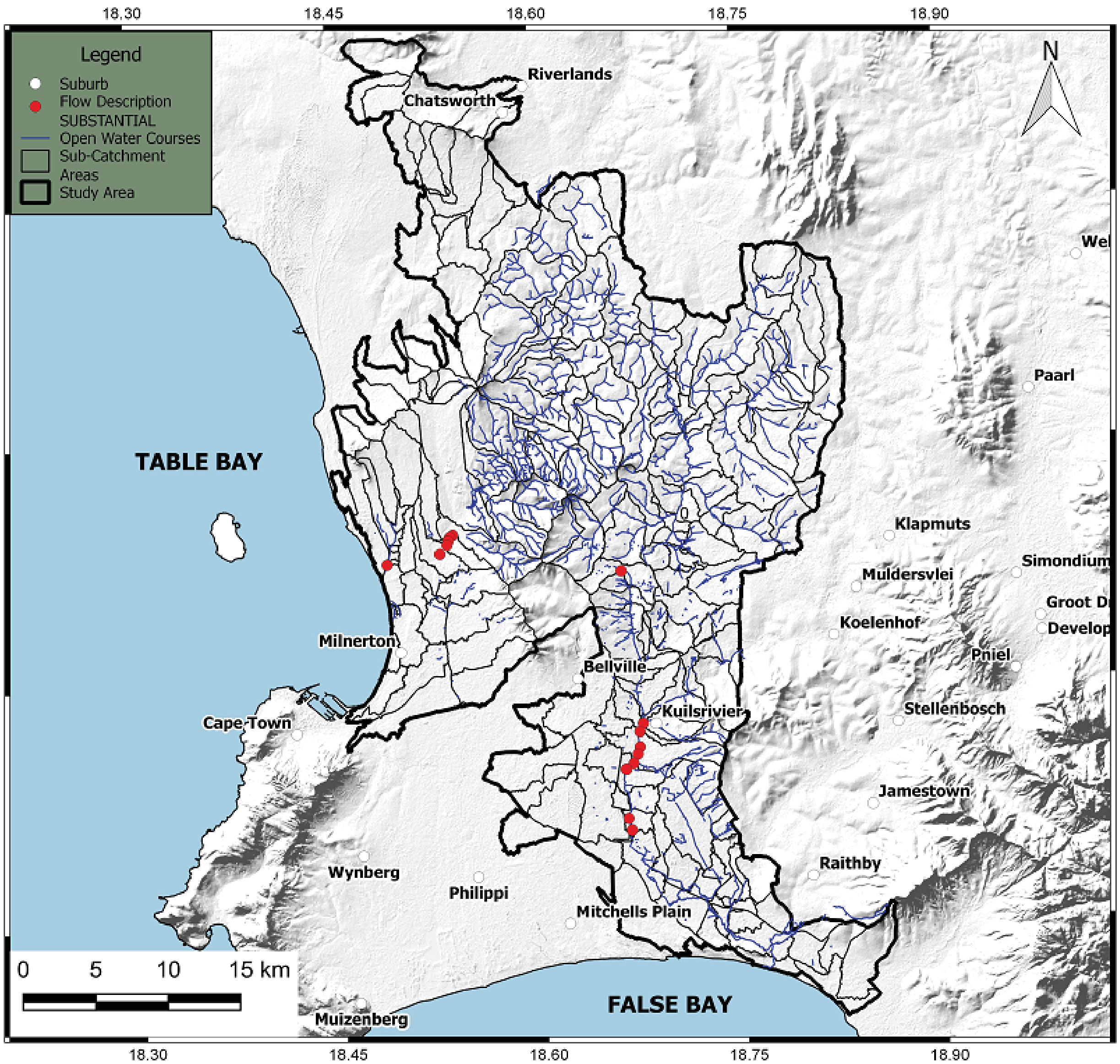


**Figure D4.4: Outfalls with substantial non-storm flows in Diep- and Kuils River (Aug-Oct 2017)**

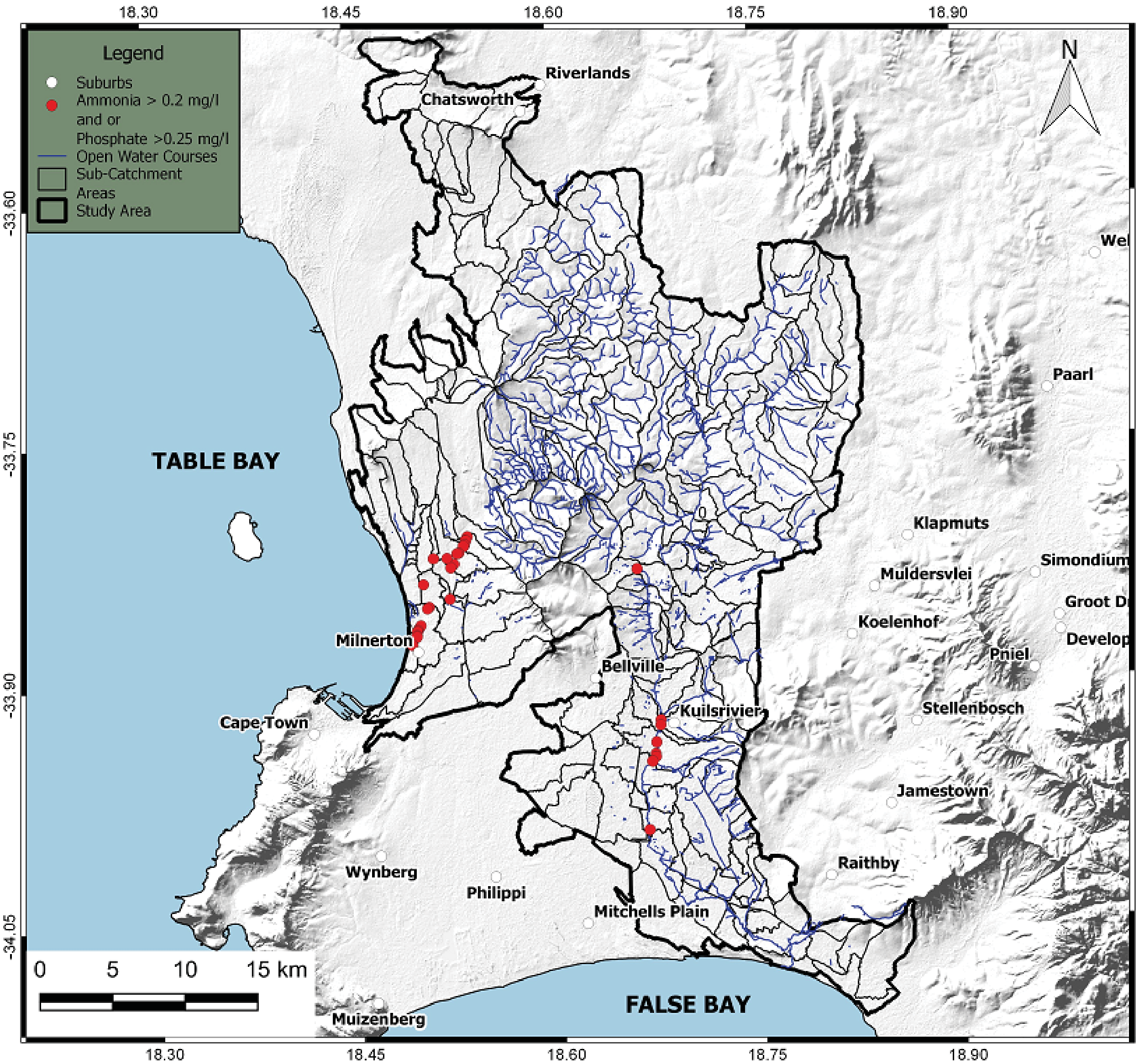


**Figure D4.5: Outfalls where nutrients exceed ecosystem health in Diep- and Kuils River (Aug-Oct 2017)**

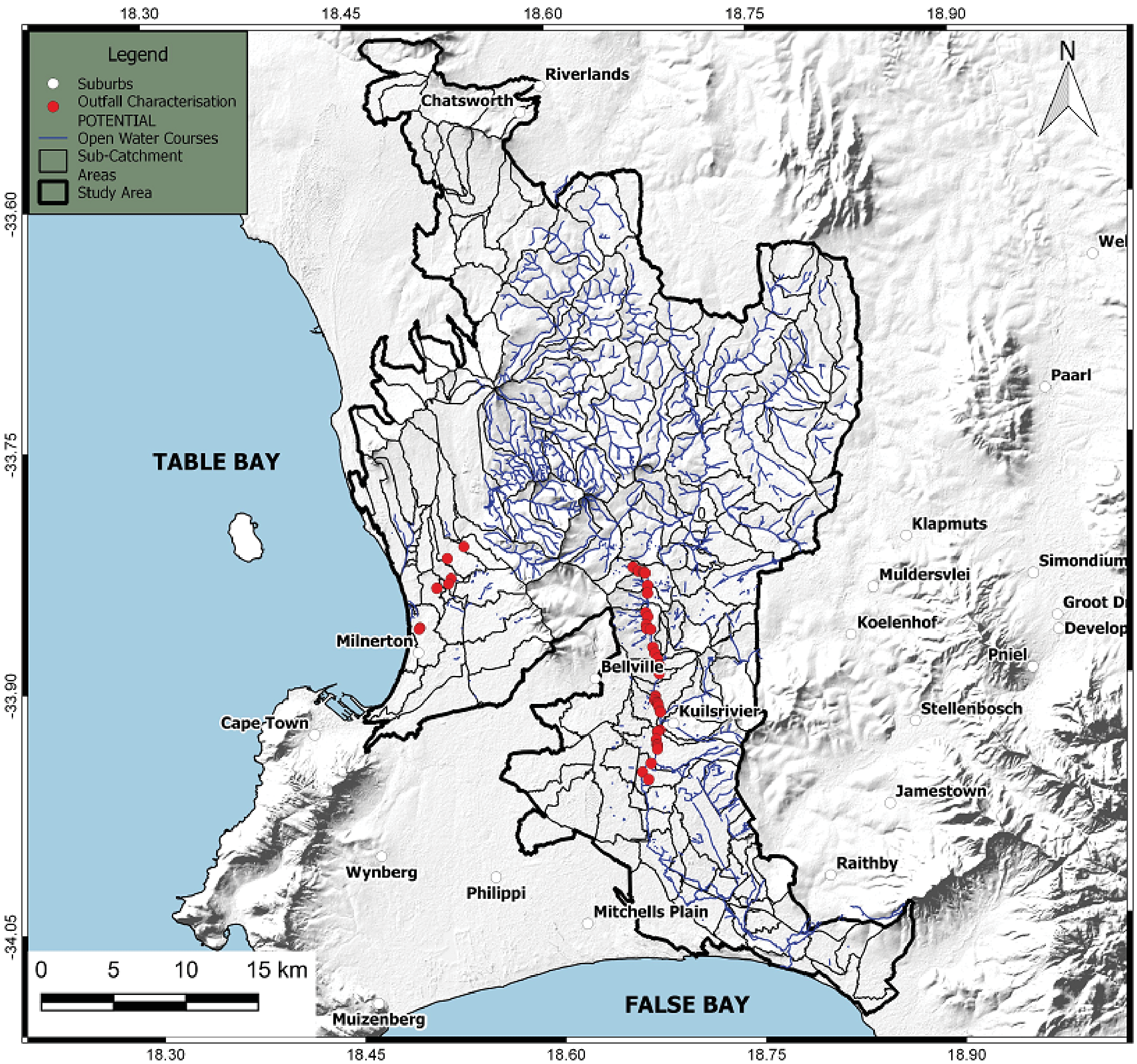


**Figure D4.6: Outfalls characterised as Potential for illegal discharges in Diep- and Kuils River (Aug-Oct 2017)**

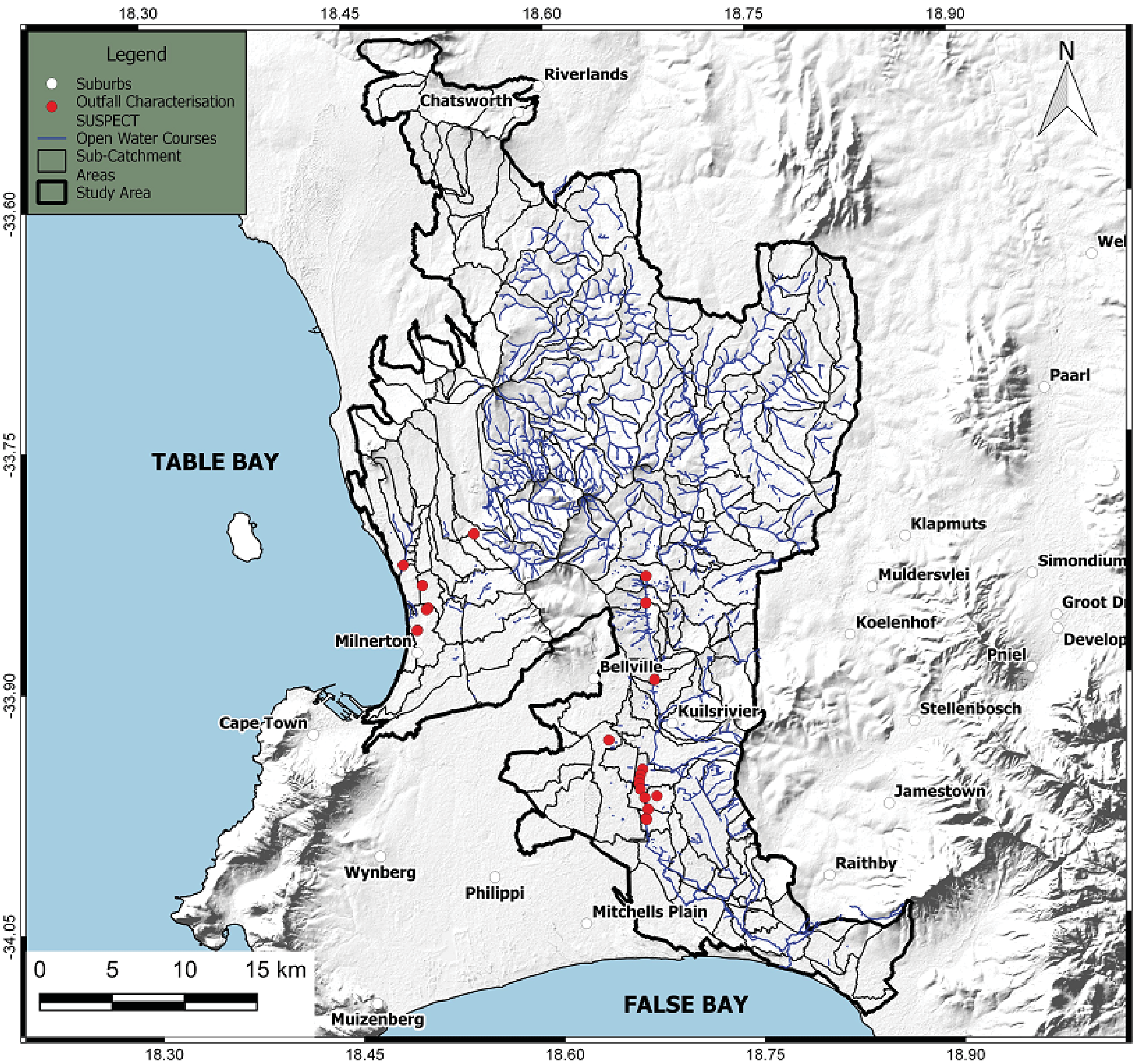


**Figure D4.7: Outfalls characterised as Suspect for illegal discharges in Diep- and Kuils River (Aug-Oct 2017)**

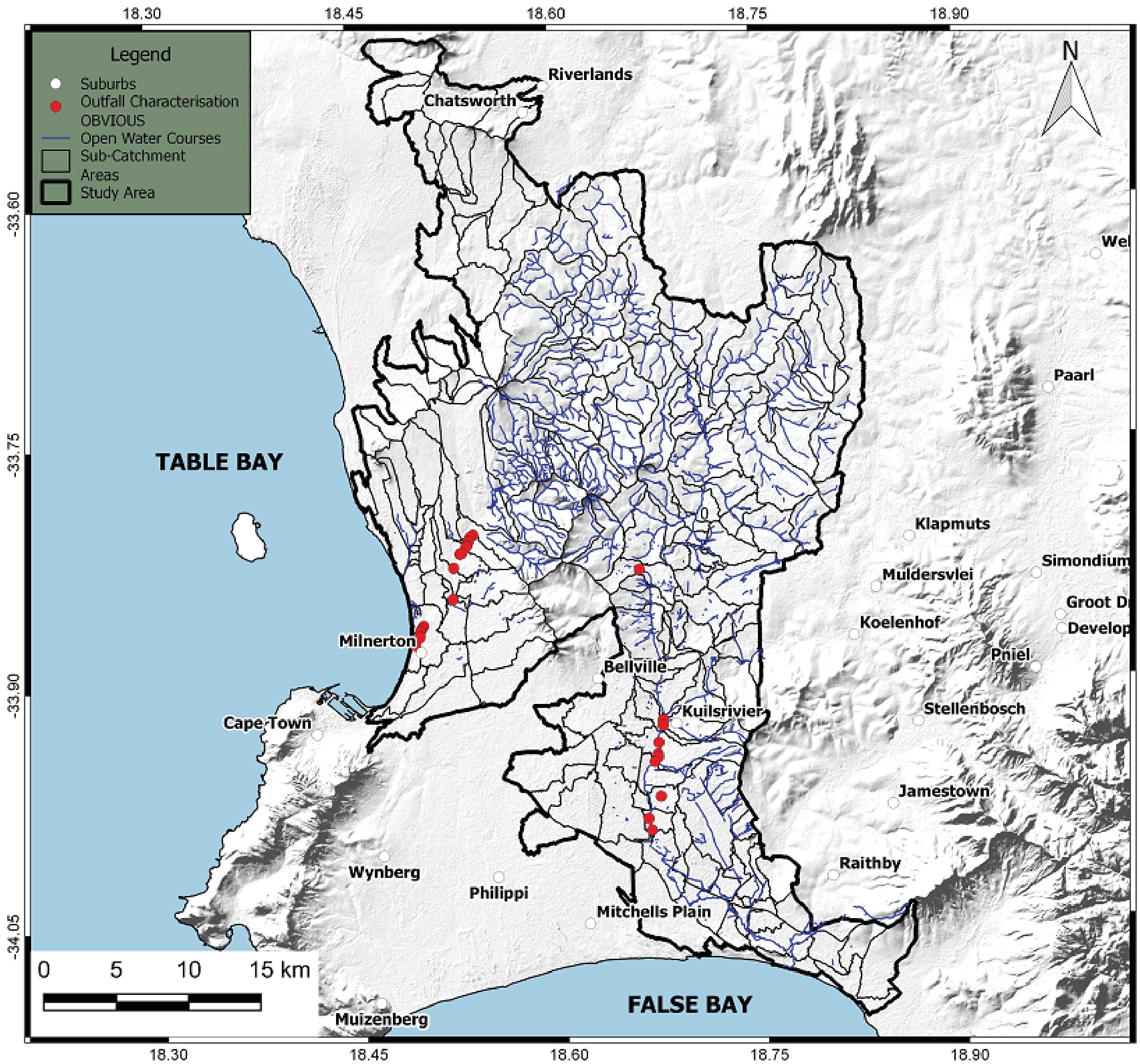


**Figure D4.8: Outfalls characterised as Obvious for illegal discharges in Diep- and Kuils River (Aug-Oct 2017)**

## APPENDIX D5: Flow type monitoring results – “fingerprint library”

## Table D5.1: Tap Water Reference ("Library") Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3$/K (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | Tableview | 06/12/2017 | 8.57 | 1.40 | 19.50 | <0.01 | <0.05 | 0.40 | 0.03 | 0.00 | 0.09 | 40.00 | 0.05 | 0.06 | N/A | 5.45 | N/A |
| T2 | Tableview | 07/12/2017 | 6.68 | 1.32 | 23.80 | <0.01 | <0.05 | 0.40 | 0.03 | 0.00 | 0.08 | 35.00 | <0.01 | < | N/A | 5.57 | N/A |
| T3 | Plattkloof Village | 07/12/2017 | 7.07 | 1.33 | 25.90 | 0.09 | <0.05 | 0.80 | 0.11 | 0.52 | 0.11 | 30.00 | 0.04 | < | N/A | 5.70 | N/A |
| T4 | Harare (Khayelitsha) | 07/12/2017 | 7.37 | 1.61 | 25.70 | <0.01 | <0.05 | 1.20 | 0.01 | 0.13 | 0.11 | 45.00 | 0.09 | 0.04 | N/A | 4.28 | N/A |
| T5 | Site C (Khayelitsha) | 07/12/2017 | 7.84 | 1.56 | 25.40 | 0.01 | <0.05 | 0.20 | 0.05 | 0.40 | 0.13 | 45.00 | 0.18 | 0.02 | N/A | 4.71 | N/A |
| T6 | CPUT(Bellville) | 07/12/2017 | 8.12 | 1.18 | 26.10 | 0.03 | <0.05 | 0.60 | 0.05 | 0.07 | 0.05 | 30.00 | < | 0.06 | N/A | 5.20 | N/A |
| T7 | Tableview | 08/12/2017 | 9.18 | 1.44 | 27.90 | <0.01 | <0.05 | 0.10 | 0.10 | 0.56 | 0.05 | 35.00 | 0.06 | < | N/A | 4.92 | N/A |
| T8 | Plattkloof Village | 08/12/2017 | 8.70 | 1.32 | 26.90 | 0.08 | <0.05 | 0.50 | 0.16 | 0.12 | 0.10 | 30.00 | 0.06 | < | N/A | 4.96 | N/A |
| T9 | Harare (Khayelitsha) | 08/12/2017 | 8.40 | 1.51 | 25.90 | 0.02 | <0.05 | 0.50 | 0.04 | 0.30 | 0.23 | 45.00 | 0.14 | < | N/A | 4.92 | N/A |
| T10 | Site C (Khayelitsha) | 08/12/2017 | 8.44 | 1.48 | 25.90 | <0.01 | <0.05 | 0.40 | 0.03 | 0.14 | 0.03 | 35.00 | 0.62 | < | N/A | 3.93 | N/A |
| **Mean** | | | 8.04 | 1.42 | 25.30 | 0.05 | N/A | 0.51 | 0.06 | 0.22 | 0.10 | 37.00 | 0.16 | 0.05 | N/A | 4.96 | N/A |
| **Standard Deviation** | | | 0.79 | 0.13 | 2.29 | 0.04 | N/A | 0.31 | 0.05 | 0.21 | 0.06 | 6.32 | 0.19 | 0.02 | N/A | 0.56 | N/A |
| **95% Confidence Limits (mean +/-)** | | | 0.45 | 0.07 | 1.29 | 0.02 | N/A | 0.18 | 0.03 | 0.12 | 0.03 | 3.58 | 0.11 | 0.01 | N/A | 0.32 | N/A |
| **Median** | | | 8.26 | 1.42 | 25.90 | 0.03 | N/A | 0.45 | 0.05 | 0.14 | 0.10 | 35.00 | 0.08 | 0.05 | N/A | 4.94 | N/A |
| **Coefficiant of Variability (COV)** | | | 0.098 | 0.092 | 0.090 | 0.793 | N/A | 0.609 | 0.816 | 0.927 | 0.573 | 0.171 | 1.252 | 0.426 | N/A | 0.113 | N/A |
| **Anderson-Darling P-value (Normal)** | | | 0.353 | 0.883 | 0.002 | 0.240 | N/A | 0.030 | 0.022 | 0.161 | 0.139 | 0.067 | <0.0005 | 0.255 | N/A | 0.895 | N/A |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.835 | 0.002 | 0.294 | N/A | 0.584 | 0.746 | 0.339 | 0.657 | 0.085 | 0.567 | 0.184 | N/A | 0.814 | N/A |

## Table D5.2: Spring Water Reference ("Library") Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3$/K (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BG00271 | CBD, Bellevue | 13/11/2017 | 6.59 | 0.23 | 20.30 | 0.09 | 0.10 | 0.67 | 0.13 | 0.38 | 0.32 | 40.00 | 0.42 | 0.02 | 0.20 | 2.72 | <1 |
| BG00233 | Newlands, SCA | 13/11/2017 | 6.00 | 0.14 | 16.80 | < | 0.10 | 0.40 | < | 0.15 | < | <0.1 | 0.10 | 0.06 | 0.10 | 3.40 | <1 |
| NS1 | Newlands, | 13/11/2017 | 5.55 | 0.13 | 17.30 | 0.02 | 0.06 | 0.56 | 0.04 | < | < | 20.00 | 0.10 | 0.02 | < | < | <1 |
| BG00242 | CBD, Molteno | 26/10/2017 | 5.19 | 0.16 | 20.20 | < | 0.25 | 0.20 | < | 0.16 | 0.08 | 25.00 | 0.13 | 0.02 | < | 2.89 | <1 |
| BG00233 | Newlands, SCA | 17/12/2017 | 5.49 | 0.14 | 18.00 | 0.70 | 0.35 | 2.35 | < | 0.53 | < | 20.00 | 0.01 | 0.03 | 0.10 | 3.40 | <1 |
| BG00242 | CBD, Molteno | 17/12/2017 | 5.48 | 0.16 | 21.00 | < | 0.20 | 1.10 | < | 0.77 | 0.13 | 35.00 | 0.05 | 0.04 | 0.10 | 1.51 | <1 |
| BG00287 | Durbanville | 17/12/2017 | 6.37 | 0.27 | 20.00 | 0.02 | 0.95 | 3.70 | 0.01 | 0.76 | 0.25 | 44.00 | 0.02 | 0.02 | 0.25 | 3.35 | <1 |
| NS2 | Newlands, | 17/12/2017 | 5.40 | 0.13 | 18.00 | 0.20 | < | 3.55 | < | 0.34 | < | 20.00 | 0.05 | 0.04 | < | < | <1 |
| BG00271 | CBD, Bellevue | 17/12/2017 | 6.87 | 0.17 | 21.00 | 0.44 | 0.07 | 0.68 | 0.65 | 0.25 | 0.10 | 10.00 | 0.00 | 0.00 | 0.20 | 2.80 | <1 |
| BG00253 | Newlands, | 05/10/2017 | 5.79 | 0.15 | 18.70 | < | 0.35 | 2.40 | < | 0.48 | 0.14 | 20.00 | 0.01 | 0.20 | < | 2.87 | 45 |
| **Mean** | | | 5.87 | 0.17 | 19.13 | 0.25 | 0.27 | 1.56 | 0.21 | 0.42 | 0.17 | 26.00 | 0.09 | 0.05 | 0.16 | 2.87 | |
| **Standard Deviation** | | | 0.57 | 0.04 | 1.56 | 0.27 | 0.28 | 1.33 | 0.30 | 0.23 | 0.09 | 11.19 | 0.12 | 0.06 | 0.07 | 0.62 | |
| **95% Confidence Limits (mean +/-)** | | | 0.35 | 0.03 | 0.96 | 0.17 | 0.17 | 0.82 | 0.19 | 0.14 | 0.06 | 6.94 | 0.08 | 0.04 | 0.04 | 0.38 | |
| **Median** | | | 5.67 | 0.16 | 19.35 | 0.15 | 0.20 | 0.89 | 0.09 | 0.38 | 0.14 | 20.00 | 0.05 | 0.03 | 0.15 | 2.88 | |
| **Coefficiant of Variability (COV)** | | | 0.096 | 0.264 | 0.081 | 1.114 | 1.033 | 0.850 | 1.456 | 0.547 | 0.554 | 0.430 | 1.400 | 1.263 | 0.420 | 0.215 | |
| **Anderson-Darling P-value (Normal)** | | | 0.246 | 0.017 | 0.274 | 0.386 | 0.010 | 0.052 | 0.524 | 0.522 | 0.219 | 0.113 | 0.002 | <0.0005 | 0.061 | 0.012 | |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.088 | 0.269 | 0.191 | 0.564 | 0.476 | 0.763 | 0.646 | 0.593 | 0.174 | 0.691 | 0.032 | 0.038 | 0.064 | |

## Table D5.3: Landscape Irrigation Water Reference ("Library") Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3$/K (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RG1A/B | Bellvile | 28/11/2017 | 7.01 | 1.24 | 9.30 | 0.24 | 1.50 | 26.00 | 0.01 | 7.95 | 0.10 | 211.00 | 0.30 | 0.01 | 0.55 | 93.42 | 7.11E+02 |
| CPUT - 1 | Bellvile | 23/11/2017 | 7.14 | 0.73 | 20.00 | 0.25 | 0.10 | 7.10 | 0.04 | 2.24 | 0.62 | 136.00 | 0.01 | < | 0.25 | 45.00 | 2.00E+03 |
| CPUT - 2 | Bellvile | 23/11/2017 | 7.23 | 0.73 | 22.00 | 0.43 | 0.15 | 7.00 | 0.06 | 1.63 | 0.83 | 123.00 | 0.05 | < | 0.25 | 55.00 | 2.58E+03 |
| RG4A/B | Bellvile | 29/11/2017 | 7.00 | 0.95 | 23.00 | 0.30 | 0.45 | 34.00 | 0.01 | 202.00 | 2.00 | 150.00 | 0.64 | 0.72 | 0.75 | 61.00 | 1.34E+02 |
| RG5A/B | Bellvile | 30/11/2017 | 7.30 | 1.02 | 21.00 | 0.08 | 0.10 | 12.00 | 0.01 | 3.46 | 0.57 | 170.00 | 0.08 | 0.06 | 0.60 | 91.98 | 4.10E+03 |
| RG6A/B | Bellvile | 01/12/2017 | 7.20 | 1.22 | 22.40 | 0.08 | 0.20 | 12.00 | 0.01 | 0.46 | 0.24 | 180.00 | 0.05 | < | 0.50 | 80.74 | 1.05E+02 |
| RG7A/B | Bellvile | 02/12/2017 | 7.80 | 1.39 | 27.00 | 0.21 | 0.30 | 95.00 | 0.00 | 4.24 | 0.82 | 175.00 | 0.00 | < | 1.00 | 93.33 | 2.00E+03 |
| RG8A/B | Bellvile | 05/12/2017 | 7.55 | 1.20 | 20.00 | 0.27 | 0.15 | 120.00 | 0.00 | 3.31 | 0.61 | 155.00 | 0.00 | < | 0.50 | 67.00 | 1.46E+03 |
| RG9A/B | Bellvile | 06/12/2017 | 7.60 | 1.20 | 23.00 | 0.22 | 0.25 | 12.00 | 0.02 | 5.10 | 0.54 | 165.00 | 0.01 | < | 0.75 | 79.13 | 1.73E+02 |
| RG10A/B | Bellvile | 07/12/2017 | 7.31 | 1.25 | 25.40 | 0.42 | 0.35 | 12.00 | 0.04 | 14.14 | 0.81 | 160.00 | 0.03 | < | 0.57 | 78.43 | 2.00E+03 |
| **Mean** | | | 7.31 | 1.09 | 21.31 | 0.25 | 0.36 | 33.71 | 0.02 | 24.45 | 0.71 | 162.50 | 0.12 | 0.26 | 0.57 | 74.50 | 1.53E+03 |
| **Standard Deviation** | | | 0.26 | 0.23 | 4.76 | 0.12 | 0.42 | 40.23 | 0.02 | 62.51 | 0.51 | 24.40 | 0.20 | 0.40 | 0.23 | 16.94 | 1.29E+03 |
| **95% Confidence Limits (mean +/-)** | | | 0.16 | 0.14 | 2.95 | 0.07 | 0.26 | 24.94 | 0.01 | 38.74 | 0.32 | 15.12 | 0.13 | 0.25 | 0.14 | 10.50 | 7.97E+02 |
| **Median** | | | 7.27 | 1.20 | 22.20 | 0.25 | 0.23 | 12.00 | 0.01 | 3.85 | 0.62 | 162.50 | 0.04 | 0.06 | 0.56 | 78.78 | 1.73E+03 |
| **Coefficiant of Variability (COV)** | | | 0.036 | 0.207 | 0.224 | 0.471 | 1.177 | 1.194 | 1.043 | 2.556 | 0.717 | 0.150 | 1.745 | 1.505 | 0.398 | 0.227 | 0.842 |
| **Anderson-Darling P-value (Normal)** | | | 0.476 | 0.076 | 0.022 | 0.356 | <0.0005 | <0.0005 | 0.392 | <0.0005 | 0.017 | 0.880 | <0.0005 | 0.099 | 0.466 | 0.438 | |
| **Anderson-Darling P-value (Log-normal** | | | | 0.031 | 0.001 | 0.050 | 0.398 | 0.055 | 0.526 | 0.145 | 0.062 | 0.895 | 0.328 | 0.586 | 0.356 | 0.287 | |

## Table D5.4: Car Wash Reference ("Library") Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3$/K (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CW1A/B | Parklands | 02/11/2017 | 7.240 | 1.12 | 20.80 | 5.10 | 0.26 | 16.20 | 0.31 | 74.00 | 0.90 | 126.00 | 1.96 | 0.80 | 200.00 | 50.23 | 2.00E+00 |
| CW2A/B | Parklands | 02/11/2017 | 9.250 | 0.80 | 20.80 | 0.10 | 0.20 | 2.50 | 0.04 | 30.00 | 0.50 | 41.00 | 1.00 | 0.10 | 50.25 | 184.30 | 2.76E+02 |
| CW3A/B | Bellville | 06/11/2017 | 6.730 | 4.21 | 18.40 | 0.40 | 0.10 | 12.00 | 0.03 | 41.10 | 0.31 | 90.00 | 1.10 | 0.41 | 150.75 | 31.94 | 1.94E+02 |
| CW4A/B | Kuilsriver | 06/11/2017 | 6.210 | 0.36 | 20.60 | 2.95 | 0.10 | 4.00 | 0.74 | 34.30 | 1.50 | 85.50 | 0.90 | 0.10 | 80.40 | 24.53 | 1.16E+02 |
| CW5A/B | Kuilsriver | 06/11/2017 | 7.180 | 0.93 | 22.00 | 0.39 | 0.06 | 25.20 | 0.02 | 3.43 | 0.50 | 210.00 | 0.50 | 0.01 | 10.05 | 61.52 | 8.66E+02 |
| CW6A/B | Kuilsriver | 06/11/2017 | 6.830 | 0.50 | 20.00 | 0.66 | 0.10 | 2.20 | 0.30 | 186.00 | 0.85 | 85.00 | 1.80 | 0.70 | 291.45 | 38.65 | 1.30E+03 |
| CW7A/B | Kuilsriver | 06/11/2017 | 6.770 | 0.42 | 21.70 | 6.57 | 0.10 | 7.20 | 0.91 | 64.00 | 0.66 | 70.00 | 0.70 | 0.10 | 100.50 | 33.19 | 1.99E+03 |
| CW8A/B | Bellville | 06/11/2017 | 9.440 | 1.14 | 21.80 | 4.90 | 0.25 | 9.50 | 0.52 | 178.00 | 0.86 | 165.80 | 2.20 | 0.10 | 201.00 | 118.00 | 3.00E+03 |
| CW9A/B | Epping 2 | 17/12/2017 | 8.610 | 1.99 | 22.00 | 5.31 | 0.15 | 13.05 | 0.41 | 196.00 | 0.42 | 190.00 | 0.36 | 1.13 | 1100.00 | 96.10 | 2.17E+03 |
| CW10A/B | Bellville | 17/12/2017 | 9.830 | 2.20 | 27.00 | 2.79 | 0.20 | 9.90 | 0.28 | 174.00 | 0.78 | 155.00 | 0.54 | 0.38 | 600.00 | 219.00 | 3.02E+03 |
| **Mean** | | | 7.809 | 1.37 | 21.51 | 2.92 | 0.15 | 10.18 | 0.36 | 98.08 | 0.73 | 121.83 | 1.11 | 0.38 | 278.44 | 85.75 | 1.29E+03 |
| **Standard Deviation** | | | 1.331 | 1.17 | 2.22 | 2.44 | 0.07 | 7.02 | 0.30 | 76.10 | 0.34 | 56.16 | 0.66 | 0.38 | 333.66 | 68.38 | 1.18E+03 |
| **95% Confidence Limits (mean +/-)** | | | 0.825 | 0.73 | 1.38 | 1.51 | 0.04 | 4.35 | 0.19 | 47.17 | 0.21 | 34.81 | 0.41 | 0.23 | 206.80 | 42.38 | 7.33E+02 |
| **Median** | | | 7.210 | 1.02 | 21.25 | 2.87 | 0.13 | 9.70 | 0.31 | 69.00 | 0.72 | 108.00 | 0.95 | 0.24 | 175.38 | 55.88 | 1.08E+03 |
| **Coefficiant of Variability (COV)** | | | 0.170 | 0.860 | 0.103 | 0.836 | 0.466 | 0.690 | 0.845 | 0.776 | 0.467 | 0.461 | 0.593 | 0.989 | 1.198 | 0.798 | 0.916 |
| **Anderson-Darling P-value (Normal)** | | | 0.071 | 0.030 | 0.023 | 0.134 | 0.104 | 0.523 | 0.399 | 0.037 | 0.246 | 0.514 | 0.183 | 0.057 | 0.005 | 0.044 | |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.840 | 0.051 | 0.068 | 0.162 | 0.455 | 0.046 | 0.094 | 0.699 | 0.565 | 0.760 | 0.146 | 0.806 | 0.515 | |

## Table D5.5: Laundry Reference (“Library”) Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3/K$ (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LW1A/B | Parklands | 02/11/2017 | 10.730 | 6.01 | 23.90 | 2.26 | 0.10 | 41.00 | 0.06 | 184.00 | 0.06 | 101.00 | 3.30 | 0.10 | 40.20 | 322.10 | 0 |
| LW2A/B | Parklands | 02/11/2017 | 10.740 | 1.18 | 21.60 | 1.39 | 0.10 | 4.89 | 0.28 | 63.22 | 0.04 | 26.00 | 1.40 | 0.03 | 50.25 | 184.30 | 0 |
| LW3A/B | Tableview | 02/12/2017 | 10.720 | 8.47 | 23.00 | 0.81 | 0.20 | 1.80 | 0.45 | 583.00 | 1.33 | 80.00 | 0.55 | 0.02 | 1200.00 | 3142.00 | 7.50E+00 |
| LW4A/B | Tableview | 03/12/2017 | 10.630 | 3.14 | 26.00 | 0.29 | 0.16 | 3.80 | 0.08 | 250.00 | 0.86 | 68.00 | 0.47 | 0.15 | 400.00 | 3064.00 | 1.05E+03 |
| LW5A/B | Kuilsriver | 12/12/2017 | 11.430 | 9.65 | 25.70 | 0.01 | <0.08 | 3.10 | 0.00 | 9.77 | 0.61 | 25.00 | 0.07 | 0.18 | 30.15 | 1140.00 | 1.19E+03 |
| LW6A/B | Bellville | 12/12/2017 | 10.450 | 1.02 | 24.80 | 0.11 | <0.08 | 16.00 | 0.01 | 99.50 | 0.85 | 50.00 | 4.50 | 0.10 | 120.60 | 1006.00 | 6.08E+03 |
| LW7A/B | Bellville | 12/12/2017 | 9.090 | 3.49 | 22.40 | 3.40 | <0.08 | 6.00 | 0.57 | 145.00 | 0.72 | 69.50 | < | < | 100.50 | 2282.00 | 9.20E+02 |
| LW8A/B | Bellville | 12/12/2017 | 10.270 | 7.60 | 24.00 | 0.95 | 0.16 | 6.00 | 0.16 | 133.00 | 0.81 | 45.00 | 0.02 | 0.08 | 100.50 | 1570.00 | 2.26E+03 |
| LW9A/B | Bellville | 12/12/2017 | 10.390 | 8.28 | 24.20 | 0.90 | 0.14 | 19.00 | 0.05 | 33.00 | 0.90 | 100.00 | 0.40 | 0.40 | 301.50 | 4189.00 | 2.14E+03 |
| LW10A/B | Bellville | 12/12/2017 | 7.830 | 6.49 | 11.00 | 7.00 | <0.08 | 24.00 | 0.29 | 319.00 | 0.68 | 100.00 | 0.50 | 0.11 | 5012.50 | 8314.00 | 0 |
| **Mean** | | | 10.228 | 5.53 | 22.66 | 1.71 | 0.14 | 12.56 | 0.19 | 181.95 | 0.69 | 66.45 | 1.25 | 0.13 | 735.62 | 2521.34 | 1.71E+03 |
| **Standard Deviation** | | | 1.027 | 3.12 | 4.32 | 2.13 | 0.04 | 12.56 | 0.20 | 170.21 | 0.39 | 29.30 | 1.58 | 0.11 | 1543.61 | 2414.79 | 1.95E+03 |
| **95% Confidence Limits (mean +/-)** | | | 0.607 | 1.84 | 2.55 | 1.26 | 0.02 | 7.42 | 0.12 | 100.59 | 0.23 | 17.31 | 0.94 | 0.07 | 912.20 | 1427.02 | 1.16E+03 |
| **Median** | | | 10.540 | 6.25 | 23.95 | 0.93 | 0.15 | 6.00 | 0.12 | 139.00 | 0.77 | 68.75 | 0.50 | 0.10 | 110.55 | 1926.00 | 1.12E+03 |
| **Coefficiant of Variability (COV)** | | | 0.100 | 0.564 | 0.191 | 1.243 | 0.273 | 1.000 | 1.016 | 0.935 | 0.564 | 0.441 | 1.272 | 0.871 | 2.098 | 0.958 | 1.146 |
| **Anderson-Darling P-value (Normal)** | | | 0.034 | 0.390 | <0.0005 | 0.010 | 0.515 | 0.021 | 0.138 | 0.060 | 0.073 | 0.159 | <0.0005 | 0.043 | <0.0005 | 0.098 | |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.078 | 0.001 | 0.247 | 0.422 | 0.418 | 0.185 | 0.728 | <0.0005 | 0.062 | 0.428 | 0.437 | 0.171 | 0.588 | |

## Table D5.6: Selected Industries Reference (“Library”) Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3/K$ (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GT1A/B | Bellvile | 28/11/2017 | 7.14 | 1.48 | 26.70 | 1.60 | 0.20 | 32.80 | 0.05 | 800.00 | 0.22 | 1105.00 | 6.90 | 0.01 | 50.20 | 440.70 | N/A |
| SAB1A/B | Newlands | 28/11/2017 | 7.11 | 2.92 | 31.00 | 59.66 | 0.20 | 52.00 | 1.15 | 195.00 | 0.24 | 21.00 | 4.40 | 0.02 | 40.20 | 90.35 | N/A |
| MF1A/B | Goodwood | 28/11/2017 | 10.18 | 2.66 | 33.00 | 1.10 | 0.10 | 18.80 | 0.06 | 85.30 | 1.20 | 41.90 | 1.21 | 0.01 | 50.25 | 86.14 | N/A |
| FB1A/B | killarney | 28/11/2017 | 6.76 | 3.80 | 28.00 | 1.80 | 0.10 | 24.00 | 0.08 | 152.00 | 0.12 | 125.86 | 13.33 | 0.02 | 100.50 | 156.08 | N/A |
| GT2A/B | Bellvile | 28/11/2017 | 7.23 | 1.49 | 26.00 | 3.75 | 9.00 | 40.00 | 0.09 | 800.00 | 0.19 | 750.00 | 3.00 | 0.01 | 42.21 | 609.20 | N/A |
| MF2A/B | Goodwood | 28/11/2017 | 10.65 | 11.40 | 38.00 | 3.10 | 1.50 | 16.00 | 0.19 | 70.80 | 0.12 | 100.00 | 0.20 | 0.01 | 60.00 | 163.20 | N/A |
| GT3A/B | Bellvile | 29/11/2017 | 7.41 | 1.45 | 28.00 | 0.15 | 13.00 | 32.00 | 0.00 | 800.00 | 0.13 | 1300.00 | 0.30 | 5.80 | 44.22 | 625.80 | N/A |
| MF3A/B | Goodwood | 29/11/2017 | 11.42 | 5.08 | 36.00 | 1.70 | 1.50 | 40.00 | 0.04 | 52.80 | 0.35 | 150.00 | 3.35 | 0.01 | 58.00 | 77.80 | N/A |
| RB2A/B | killarney | 29/11/2017 | 6.91 | 4.26 | 29.00 | 5.70 | 3.50 | 35.00 | 0.16 | 457.00 | 0.70 | 50.00 | 0.10 | 0.40 | 80.40 | 84.95 | N/A |
| RG3A/B | Bellvile | 29/11/2017 | 11.32 | 1.73 | 26.00 | 6.70 | 0.50 | 25.00 | 0.27 | 565.00 | 0.12 | 150.00 | 0.70 | 0.01 | 60.30 | 176.50 | N/A |
| **Mean** | | | 8.61 | 3.63 | 30.17 | 8.53 | 2.96 | 31.56 | 0.21 | 397.79 | 0.34 | 379.38 | 3.35 | 0.63 | 58.63 | 251.07 | N/A |
| **Standard Deviation** | | | 2.00 | 3.02 | 4.24 | 18.08 | 4.47 | 10.95 | 0.34 | 323.51 | 0.35 | 484.17 | 4.15 | 1.82 | 18.83 | 220.50 | N/A |
| **95% Confidence Limits (mean +/-)** | | | 1.24 | 1.87 | 2.63 | 11.21 | 2.77 | 6.79 | 0.21 | 200.51 | 0.22 | 300.09 | 2.57 | 1.13 | 11.67 | 136.67 | N/A |
| **Median** | | | 7.32 | 2.79 | 28.50 | 2.45 | 1.00 | 32.40 | 0.08 | 326.00 | 0.20 | 137.93 | 2.11 | 0.01 | 54.13 | 159.64 | N/A |
| **Coefficiant of Variability (COV)** | | | 0.232 | 0.832 | 0.140 | 2.121 | 1.509 | 0.347 | 1.619 | 0.813 | 1.036 | 1.276 | 1.238 | 2.890 | 0.321 | 0.878 | N/A |
| **Anderson-Darling P-value (Normal)** | | | 0.005 | 0.007 | 0.165 | <0.0005 | 0.001 | 0.864 | <0.0005 | 0.050 | 0.001 | 0.001 | 0.025 | <0.0005 | 0.095 | 0.003 | N/A |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.340 | 0.259 | 0.268 | 0.432 | 0.764 | 0.459 | 0.145 | 0.102 | 0.332 | 0.715 | <0.0005 | 0.432 | 0.063 | N/A |

## Table D5.7: Sewage or Sanitary Wastewater Reference ("Library") Samples

| Sample number | Sample Location | Sample Date | pH | Conductivity (mS/m) | Temp. (°C) | Ammonia (mg/L as N) | Boron (mg/L) | Potassium (mg/L) | $NH_3$/K (ratio) | Turbidity (NTU) | Fluoride (mg/L) | Total Hardness (mg/l CaCO3) | Total Chlorine (mg/l) | Copper (mg/l) | Detergent (mg/L as MBAS) | Fluorescence (RFU) | E-Coli (MPN/100 mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A5A/B | Bellville WWTW | 27/10/2017 | 7.62 | 1.41 | 20.80 | 48.27 | 0.39 | 40.60 | 1.19 | 104.00 | 0.10 | 460.69 | 2.21 | <0.02 | 15.00 | 168.00 | 2.51E+06 |
| P6A/B | Potsdam WWTW | 27/10/2017 | 7.32 | 1.81 | 20.60 | 41.62 | 0.63 | 37.30 | 1.12 | 160.00 | 0.20 | 448.60 | 2.79 | 0.02 | 12.00 | 127.70 | 1.88E+07 |
| Z6A/B | Zandvleit WWTW | 27/10/2017 | 7.55 | 1.37 | 19.80 | 48.91 | 0.30 | 27.40 | 1.79 | 240.00 | 0.10 | 295.30 | 2.50 | <0.02 | 10.40 | 135.80 | 2.14E+06 |
| B4A/B | Athlone WWTW | 27/10/2017 | 7.45 | 1.91 | 20.60 | 38.28 | 0.55 | 18.10 | 2.11 | 144.00 | 0.30 | 271.53 | 2.09 | 0.03 | 12.00 | 137.00 | 1.44E+06 |
| P5A/B | Potsdam WWTW | 26/10/2017 | 7.29 | 1.59 | 21.30 | 60.39 | 0.32 | 32.40 | 1.86 | 107.00 | 0.30 | 165.90 | 2.83 | <0.02 | 17.00 | 157.70 | 2.81E+07 |
| Z5A/B | Zandvleit WWTW | 26/10/2017 | 7.71 | 1.29 | 19.20 | 90.52 | 0.27 | 29.40 | 3.08 | 340.00 | 0.02 | 110.03 | 5.15 | <0.02 | 8.50 | 127.80 | 1.46E+07 |
| B3A/B | Bellville WWTW | 26/10/2017 | 7.31 | 1.28 | 21.20 | 68.88 | 0.26 | 32.20 | 2.14 | 242.00 | 0.20 | 153.28 | 3.99 | <0.02 | 12.00 | 164.60 | 2.22E+06 |
| A4A/B | Athlone WWTW | 26/10/2017 | 7.30 | 1.40 | 20.80 | 57.98 | 0.21 | 28.80 | 2.01 | 193.00 | 0.30 | 91.88 | 3.32 | 0.18 | 18.00 | 149.60 | 2.09E+05 |
| P4A/B | Potsdam WWTW | 26/10/2017 | 7.20 | 1.51 | 20.80 | 59.36 | 0.39 | 35.00 | 1.70 | 112.00 | 0.33 | 162.36 | 2.45 | <0.02 | 20.00 | 155.20 | 5.25E+05 |
| P7A/B | Potsdam WWTW | 16/12/2016 | 7.44 | 1.60 | 25.30 | 87.87 | 0.50 | 43.00 | 2.04 | 130.00 | 0.20 | 97.50 | 0.09 | 0.55 | 17.50 | 214.00 | 3.83E+06 |
| **Mean** | | | 7.42 | 1.52 | 21.04 | 60.21 | 0.38 | 32.42 | 1.90 | 177.20 | 0.21 | 225.71 | 2.74 | 0.20 | 14.24 | 153.74 | 7.44E+06 |
| **Standard Deviation** | | | 0.16 | 0.21 | 1.62 | 17.83 | 0.14 | 7.16 | 0.55 | 76.78 | 0.10 | 138.41 | 1.32 | 0.25 | 3.78 | 25.69 | 9.64E+06 |
| **95% Confidence Limits (mean +/-)** | | | 0.10 | 0.13 | 1.01 | 11.05 | 0.09 | 4.44 | 0.34 | 47.59 | 0.07 | 85.78 | 0.82 | 0.15 | 2.35 | 15.92 | 5.97E+06 |
| **Median** | | | 7.38 | 1.46 | 20.80 | 58.67 | 0.36 | 32.30 | 1.94 | 152.00 | 0.20 | 164.13 | 2.65 | 0.11 | 13.50 | 152.40 | 2.37E+06 |
| **Coefficiant of Variability (COV)** | | | 0.022 | 0.141 | 0.077 | 0.296 | 0.361 | 0.221 | 0.288 | 0.433 | 0.512 | 0.613 | 0.480 | 1.270 | 0.266 | 0.167 | 1.296 |
| **Anderson-Darling P-value (Normal)** | | | 0.358 | 0.340 | 0.002 | 0.319 | 0.435 | 0.846 | 0.197 | 0.166 | 0.185 | 0.064 | 0.280 | 0.140 | 0.414 | 0.163 | |
| **Anderson-Darling P-value (Log-normal)** | | | | 0.512 | 0.004 | 0.715 | 0.840 | 0.370 | 0.170 | 0.513 | 0.011 | 0.391 | <0.0005 | 0.465 | 0.423 | 0.379 | |

## Table D5.8: Statistical descriptions of parameter concentrations in Cape Town

| Parameter | Tap water | Spring water | Irrigation | Car wash | Laundry | Industries | Sewage |
|---|---|---|---|---|---|---|---|
| **Ammonia:** | | | | | | | |
| Mean= | 0.055 | 0.245 | 0.250 | 2.917 | 1.712 | 8.526 | 60.208 |
| Median= | 0.055 | 0.145 | 0.245 | 2.870 | 0.925 | 2.450 | 58.670 |
| St Dev= | 0.035 | 0.273 | 0.118 | 2.439 | 2.128 | 18.084 | 17.831 |
| COV= | 0.639 | 1.114 | 0.471 | 0.836 | 1.243 | 2.121 | 0.296 |
| **Boron:** | | | | | | | |
| Mean= | N/A | 0.270 | 0.355 | 0.152 | 0.142 | 2.960 | 0.382 |
| Median= | N/A | 0.200 | 0.225 | 0.125 | 0.146 | 1.000 | 0.355 |
| St Dev= | N/A | 0.279 | 0.418 | 0.071 | 0.039 | 4.466 | 0.138 |
| COV= | N/A | 1.033 | 1.177 | 0.466 | 0.273 | 1.509 | 0.361 |
| **Potassium:** | | | | | | | |
| Mean= | 0.510 | 1.561 | 33.710 | 10.175 | 12.559 | 31.560 | 32.420 |
| Median= | 0.450 | 0.890 | 12.000 | 9.700 | 6.000 | 32.400 | 32.300 |
| St Dev= | 0.311 | 1.327 | 40.234 | 7.021 | 12.561 | 10.949 | 7.164 |
| COV= | 0.609 | 0.850 | 1.194 | 0.690 | 1.000 | 0.347 | 0.221 |
| **NH3/K:** | | | | | | | |
| Mean= | 0.060 | 0.206 | 0.019 | 0.356 | 0.194 | 0.210 | 1.904 |
| Median= | 0.045 | 0.085 | 0.009 | 0.307 | 0.117 | 0.084 | 1.939 |
| St Dev= | 0.049 | 0.299 | 0.019 | 0.301 | 0.197 | 0.339 | 0.548 |
| COV= | 0.816 | 1.456 | 1.043 | 0.845 | 1.016 | 1.619 | 0.288 |
| **Turbidity:** | | | | | | | |
| Mean= | 0.224 | 0.424 | 24.453 | 98.083 | 181.949 | 397.790 | 177.200 |
| Median= | 0.135 | 0.380 | 3.850 | 69.000 | 139.000 | 326.000 | 152.000 |
| St Dev= | 0.208 | 0.232 | 62.506 | 76.098 | 170.211 | 323.507 | 76.782 |
| COV= | 0.927 | 0.547 | 2.556 | 0.776 | 0.935 | 0.813 | 0.433 |
| **Fluoride:** | | | | | | | |
| Mean= | 0.098 | 0.170 | 0.714 | 0.728 | 0.686 | 0.339 | 0.205 |
| Median= | 0.095 | 0.135 | 0.615 | 0.720 | 0.765 | 0.205 | 0.200 |
| St Dev= | 0.056 | 0.094 | 0.512 | 0.340 | 0.387 | 0.351 | 0.105 |
| COV= | 0.573 | 0.554 | 0.717 | 0.467 | 0.564 | 1.036 | 0.512 |
| **Tot Hardness:** | | | | | | | |
| Mean= | 37.000 | 26.000 | 162.500 | 121.830 | 66.450 | 379.376 | 225.707 |
| Median= | 35.000 | 20.000 | 162.500 | 108.000 | 68.750 | 137.930 | 164.130 |
| St Dev= | 6.325 | 11.192 | 24.401 | 56.156 | 29.298 | 484.172 | 138.405 |
| COV= | 0.171 | 0.430 | 0.150 | 0.461 | 0.441 | 1.276 | 0.613 |
| **Total chlorine:** | | | | | | | |
| Mean= | 0.155 | 0.089 | 0.117 | 1.106 | 1.121 | 3.349 | 2.742 |
| Median= | 0.075 | 0.050 | 0.040 | 0.950 | 0.485 | 2.105 | 2.645 |
| St Dev= | 0.194 | 0.125 | 0.204 | 0.656 | 1.545 | 4.148 | 1.316 |
| COV= | 1.252 | 1.400 | 1.745 | 0.593 | 1.378 | 1.238 | 0.480 |
| **Copper:** | | | | | | | |
| Mean= | 0.045 | 0.045 | 0.263 | 0.383 | 0.130 | 0.630 | 0.195 |
| Median= | 0.050 | 0.025 | 0.060 | 0.240 | 0.100 | 0.010 | 0.105 |
| St Dev= | 0.019 | 0.057 | 0.396 | 0.379 | 0.113 | 1.821 | 0.248 |
| COV= | 0.426 | 1.263 | 1.505 | 0.989 | 0.871 | 2.890 | 1.270 |
| **Fluorescence:** | | | | | | | |
| Mean= | 4.963 | 2.869 | 74.503 | 85.746 | 2521.340 | 251.072 | 153.740 |
| Median= | 4.939 | 2.880 | 78.780 | 55.875 | 1926.000 | 159.640 | 152.400 |
| St Dev= | 0.559 | 0.617 | 16.941 | 68.385 | 2414.788 | 220.503 | 25.692 |
| COV= | 0.113 | 0.215 | 0.227 | 0.798 | 0.958 | 0.878 | 0.167 |
| **Detergent:** | | | | | | | |
| Mean= | N/A | 0.158 | 0.572 | 278.440 | 735.620 | 58.628 | 14.240 |
| Median= | N/A | 0.150 | 0.560 | 175.375 | 110.550 | 54.125 | 13.500 |
| St Dev= | N/A | 0.066 | 0.227 | 333.662 | 1543.606 | 18.828 | 3.784 |
| COV= | N/A | 0.420 | 0.398 | 1.198 | 2.098 | 0.321 | 0.266 |
| ***E. coli*:** | | | | | | | |
| Mean= | N/A | N/A | 1.53E+03 | 1.29E+03 | 1.71E+03 | N/A | 7.44E+06 |
| Median= | N/A | N/A | 1.73E+03 | 1.08E+03 | 1.12E+03 | N/A | 2.37E+06 |
| St Dev= | N/A | N/A | 1.29E+03 | 1.18E+03 | 1.95E+03 | N/A | 964E+06 |
| COV= | N/A | N/A | 0.842 | 0.913 | 1.146 | N/A | 1.296 |

**Table D5.9: Results of monitoring at Dunoon outfalls and pollutants load estimates**

| Out-fall No | Sample Date (Year 2018) | Monitored Data | | | | | | | | Load Estimates | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Daily Discharge Volume (kL) | $NH_3$ (mg/L) | $PO_4$ (mg/L) | K (mg/L) | Deter-gents (mg/L) | TSS (mg/L) | COD (mg/L) | **E. coli* (MPN/100 mL) | $NH_3$ (kg/d) | $PO_4$ (kg/d) | TSS (kg/d) | COD (kg/d) | **E. coli* (MPN/d) |
| D6 | 08 Sep | 2958 | 83 | 21 | 29.6 | 6.3 | 601 | 1446 | 1.09E+06 | 246 | 62 | 1778 | 4277 | 3.2E+13 |
| D6 | 09 Sep | 2666 | 91 | 18.5 | 32.6 | 9.6 | 633 | 1378 | 3.15E+06 | 243 | 49 | 1688 | 3674 | 8.4E+13 |
| D6 | 10 Sep | 3315 | 96 | 30 | 35 | 10.2 | 585 | 1520 | 1.27E+07 | 318 | 99 | 1940 | 5039 | 4.2E+14 |
| D6 | 11 Sep | 3424 | 77 | 11 | 28 | 8.7 | 410 | 1220 | 1.70E+06 | 264 | 38 | 1404 | 4177 | 5.8E+13 |
| D6 | 12 Sep | 3674 | 86 | 13 | 30 | 13.5 | 522 | 1156 | 2.06E+05 | 316 | 48 | 1918 | 4248 | 7.6E+12 |
| D6 | 13 Sep | 2951 | 72.1 | 5.7 | 22.2 | | 300 | 846 | 2.11E+05 | 213 | 17 | 885 | 2496 | 6.2E+12 |
| D6 | 16 Sep | 2539 | 85 | 6.3 | 18 | | 384 | 620 | 1.17E+06 | 216 | 16 | 975 | 1574 | 3.0E+13 |
| D5 | 16 Sep | 1821 | 120 | 9.6 | 22 | | 898 | 1353 | 1.99E+08 | 219 | 17 | 1635 | 2464 | 3.6E+15 |
| **Number monitored** | | 8 | 8 | 8 | 8 | 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Minimum | | 1821 | 72.1 | 5.7 | 18 | 6.3 | 300 | 620 | 2.06E+05 | 213 | 16 | 885 | 1574 | 6.2E+12 |
| Maximum | | 3674 | 120 | 30 | 35 | 13.5 | 898 | 1520 | 1.99E+08 | 318 | 99 | 1940 | 5039 | 3.6E+15 |
| Median | | 2954 | 85.5 | 12 | 28.8 | 9.6 | 553.5 | 1286.5 | 1.43E+06 | 244 | 43 | 1662 | 3926 | 4.5E+13 |
| Mean | | 2919 | 88.8 | 14.4 | 27.2 | 9.7 | 541.6 | 1192.4 | 2.74E+07 | 254 | 43 | 1528 | 3494 | 5.3E+14 |
| St. dev | | 585 | 15 | 8 | 6 | 3 | 186 | 312 | 6.96E+07 | 43 | 29 | 406 | 1184 | 1.3E+15 |

***Grap sample**

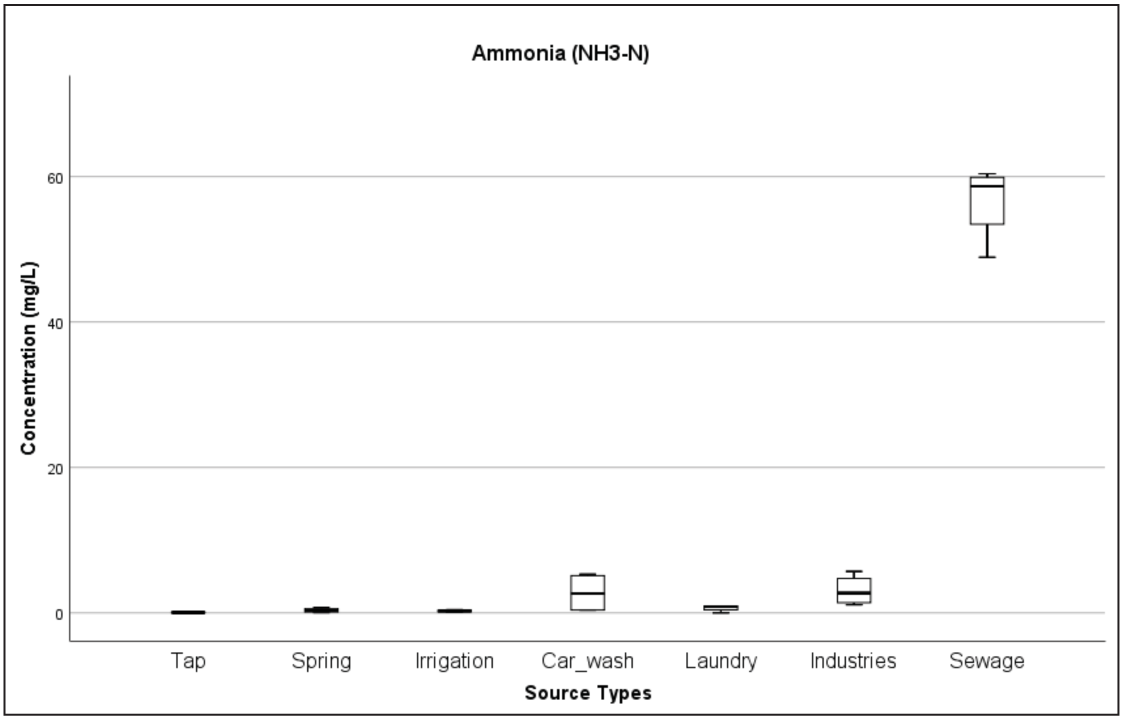


**Figure D5.1: Ammonia comparison for different source types**

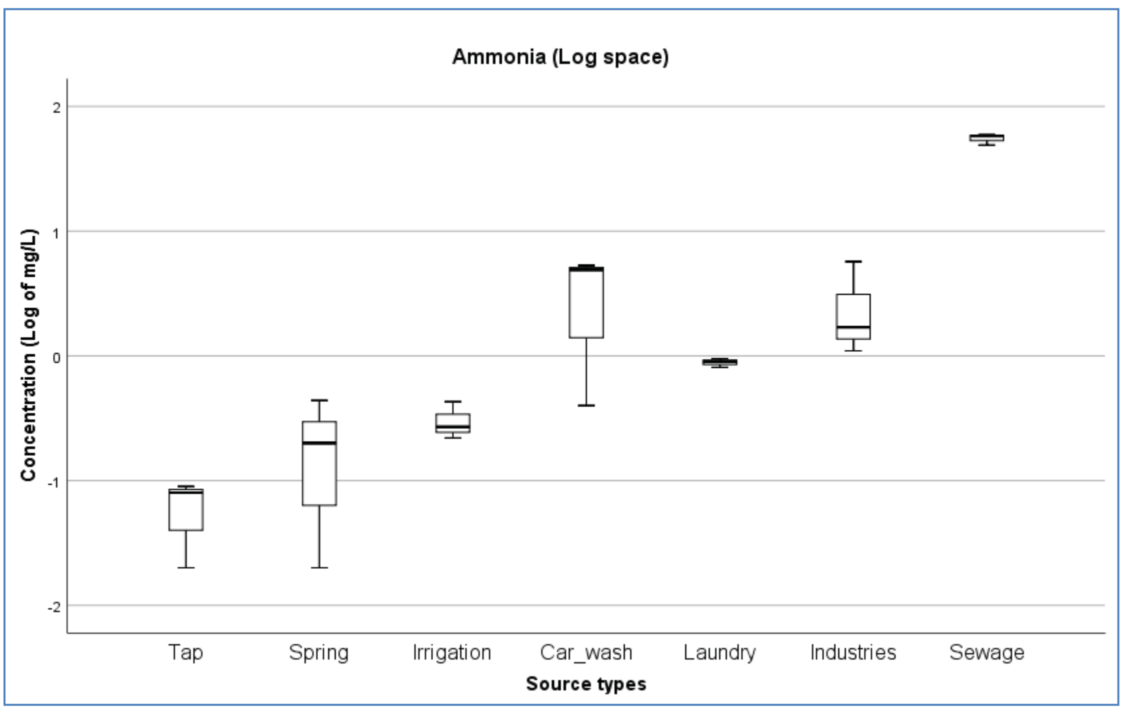


**Figure D5.2: Ammonia comparison for different source types in Log space**

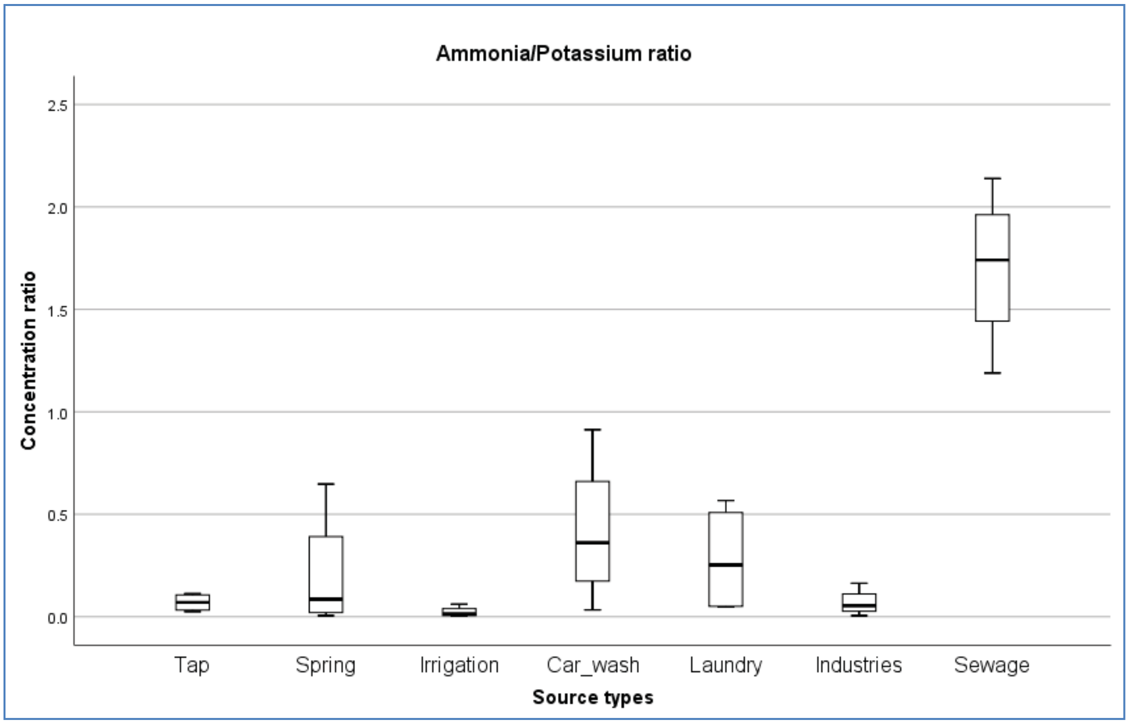


**Figure D5.3: Ammonia/Potassium ratio comparison for different source types**

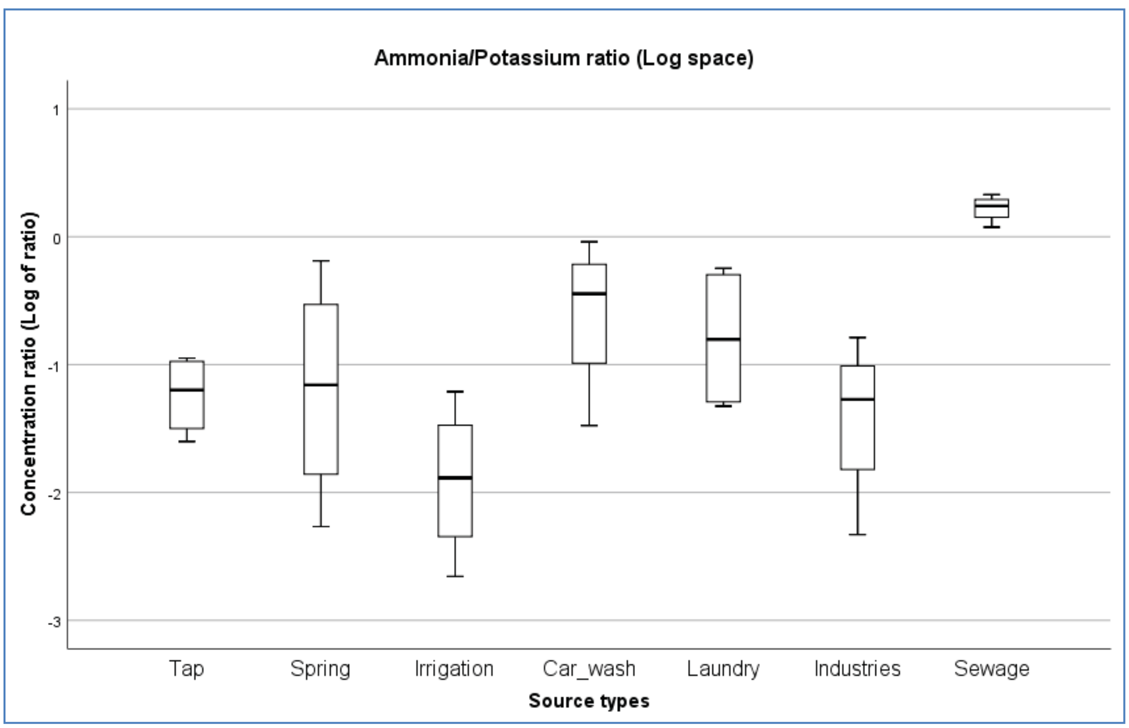


**Figure D5.4: Ammonia/Potassium ratio comparison for different source types in Log space**

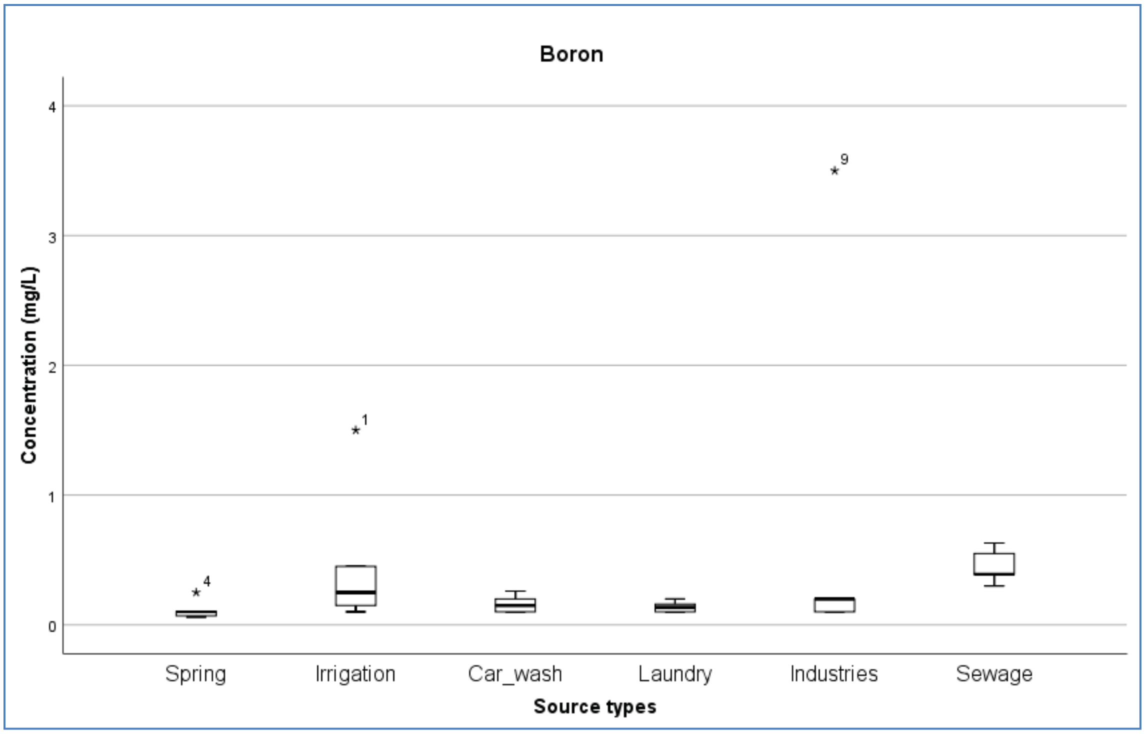


Figure D5.5: Boron comparison for different source types

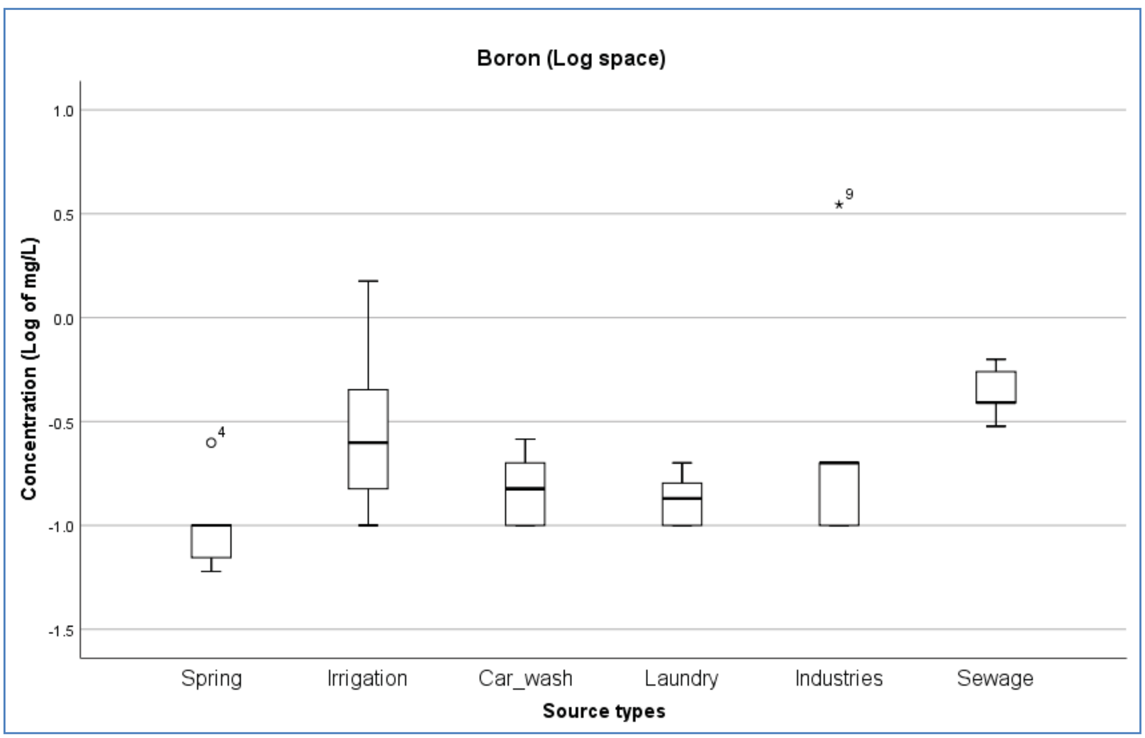


Figure D5.6: Boron comparison for different source types in Log space

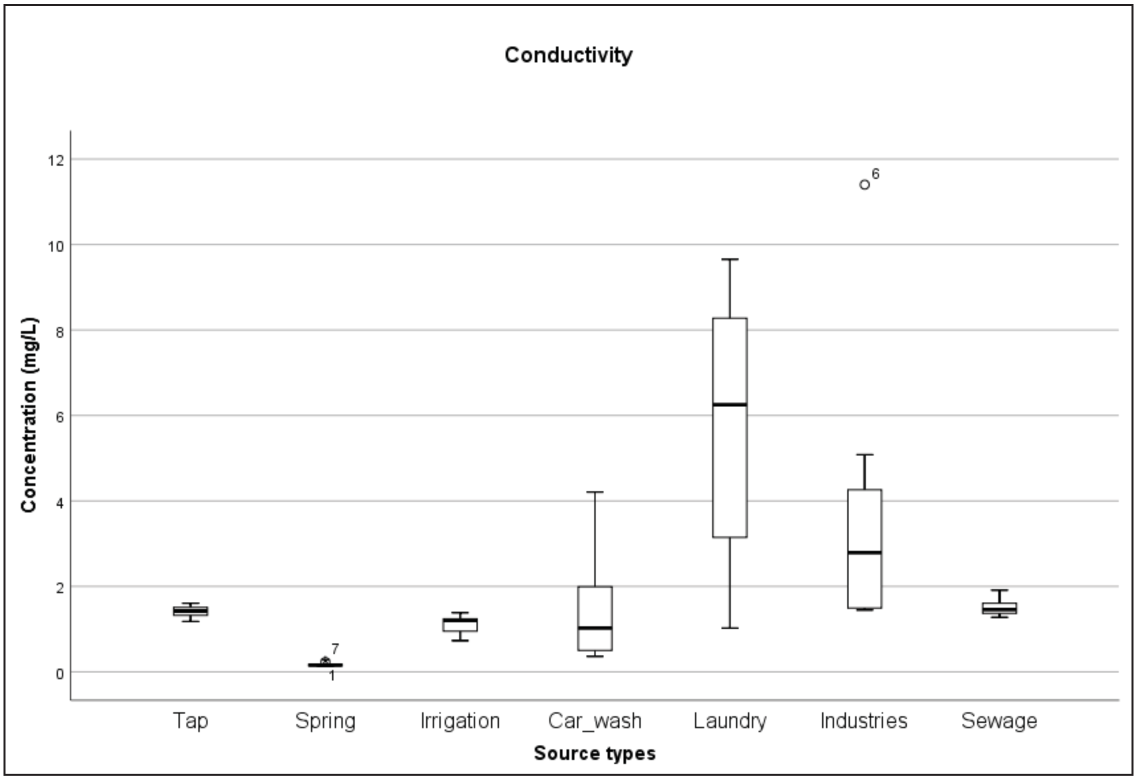


**Figure D5.7: Conductivity comparison for different source types**

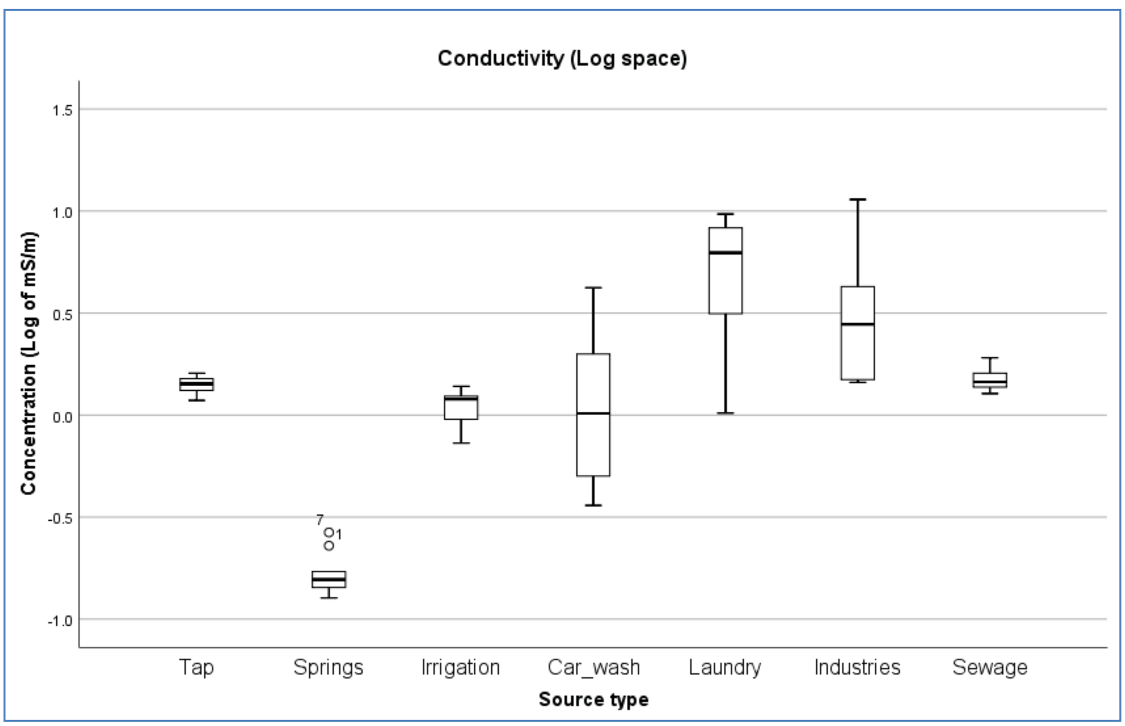


**Figure D5.8: Conductivity comparison for different source types in Log space**

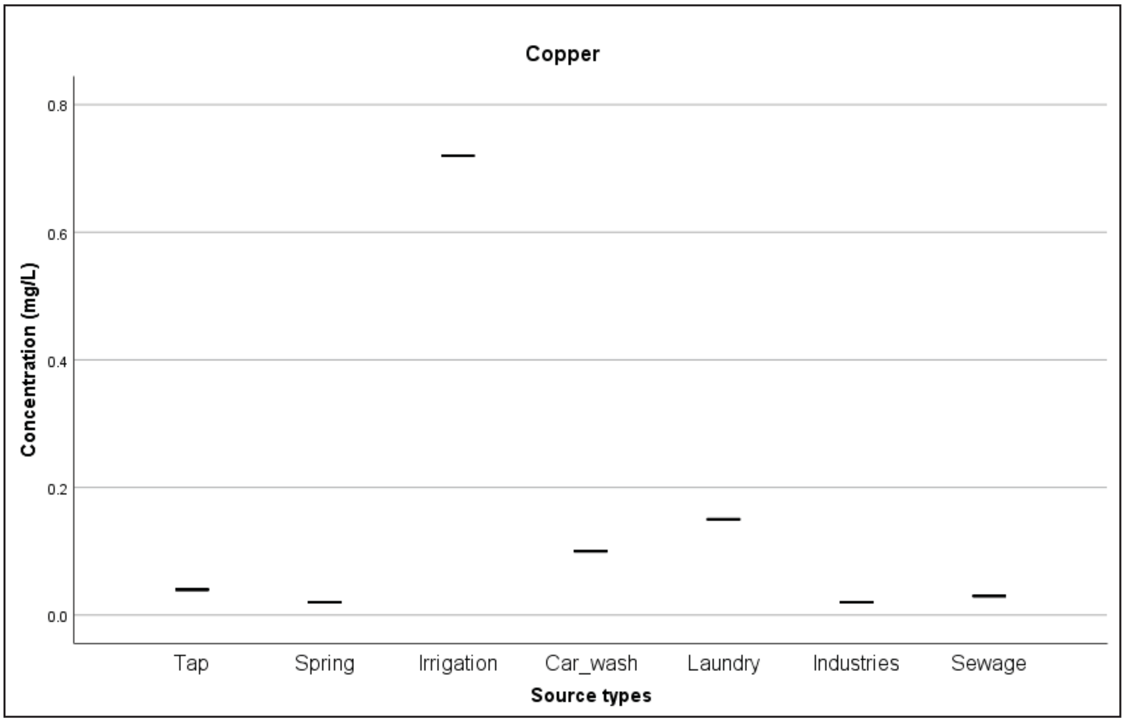


**Figure D5.9: Copper comparison for different source types**

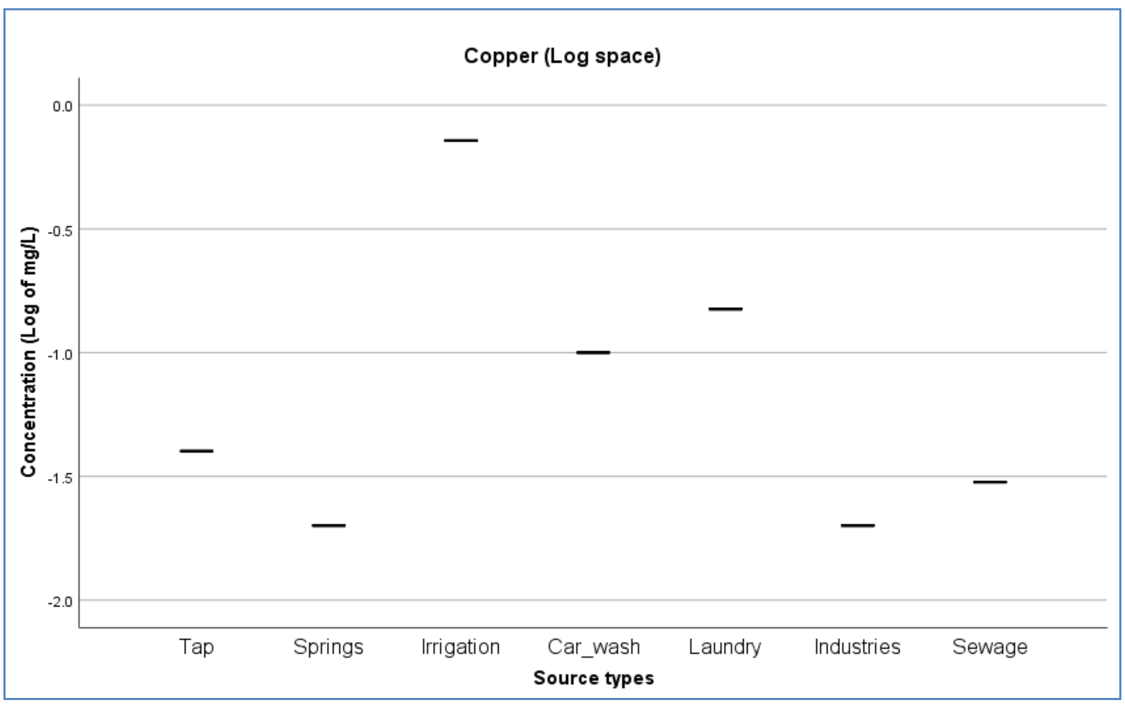


**Figure D5.10: Copper comparison for different source types in Log space**

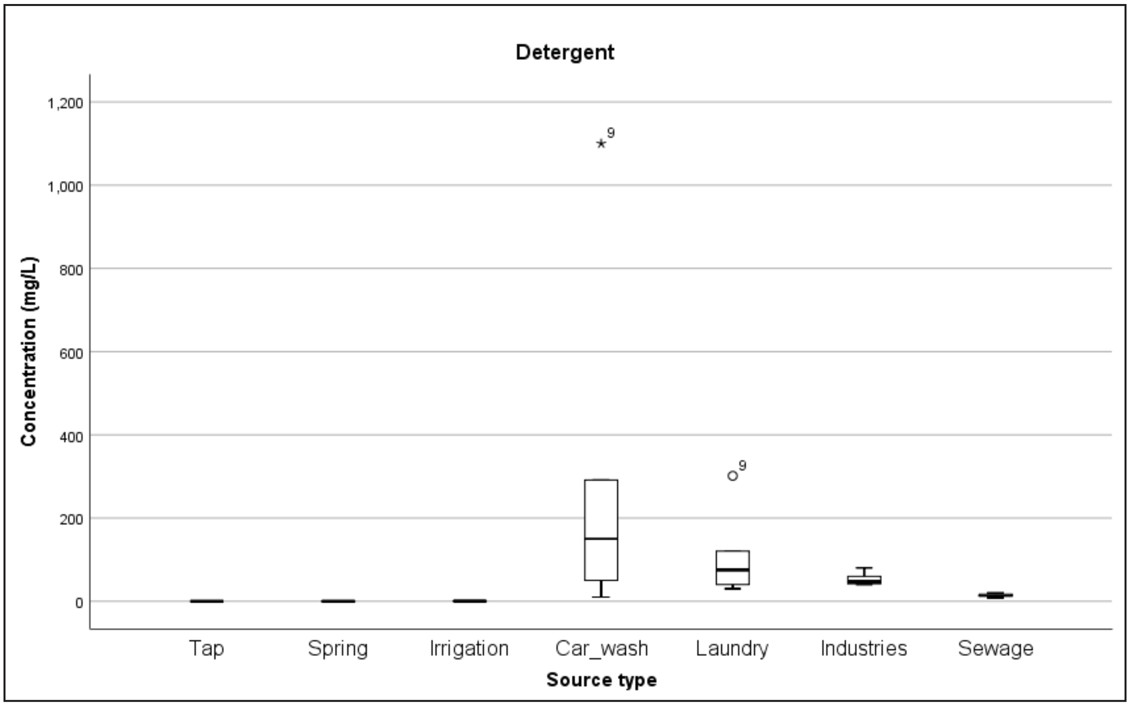


**Figure D5.11: Detergent comparison for different source types**

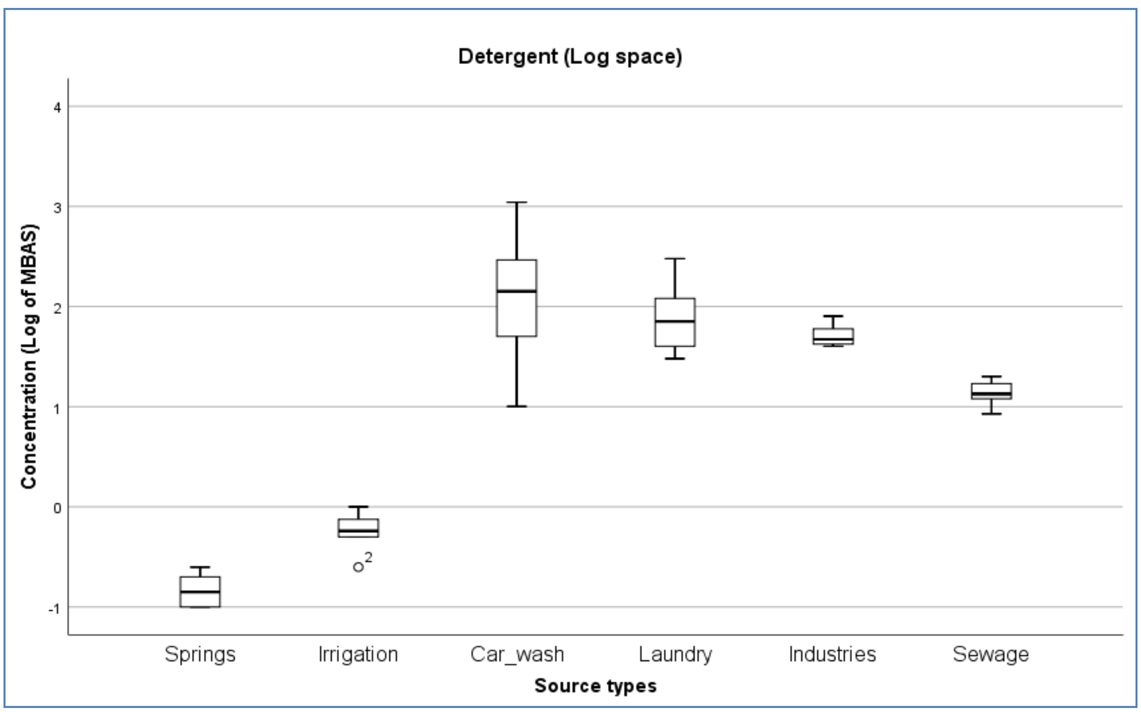


**Figure D5.12: Detergent comparison for different source types in Log space**

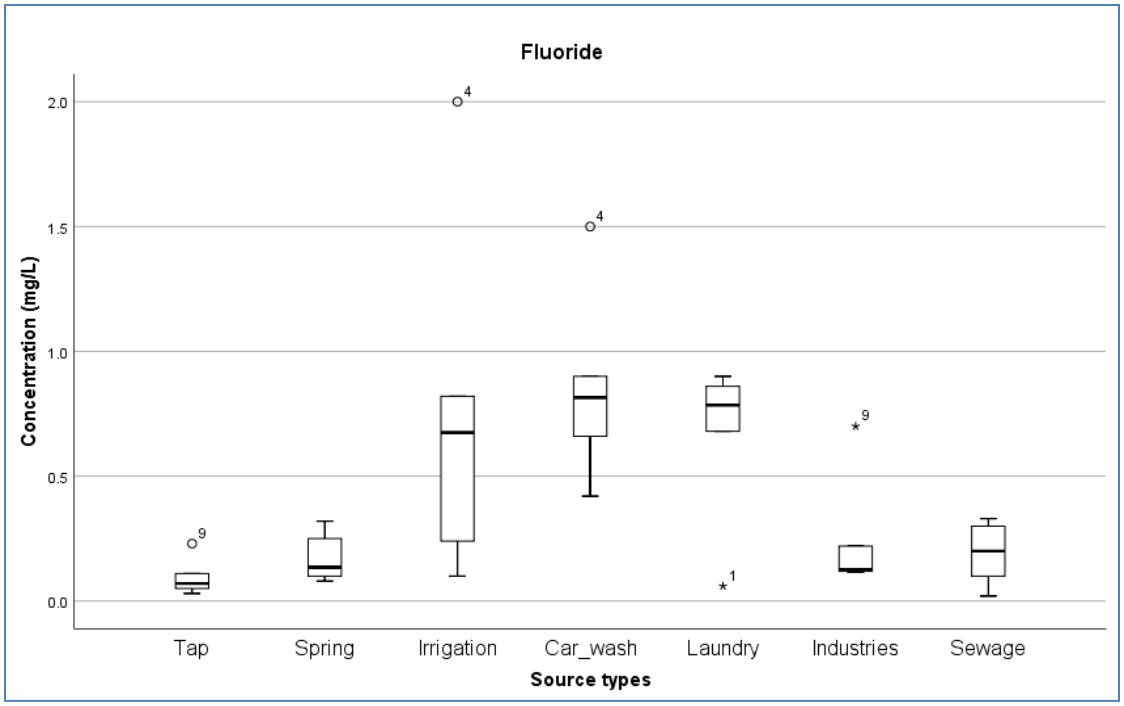


Figure D5.13: Fluoride comparison for different source types

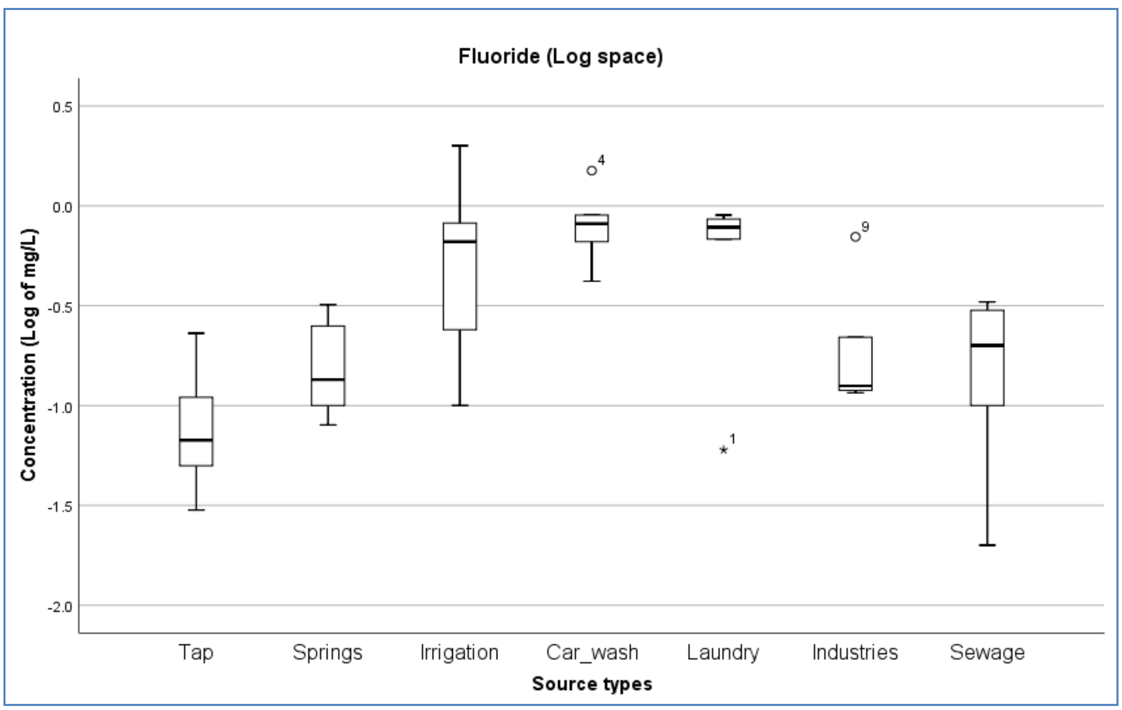


Figure D5.14: Fluoride comparison for different source types in Log space

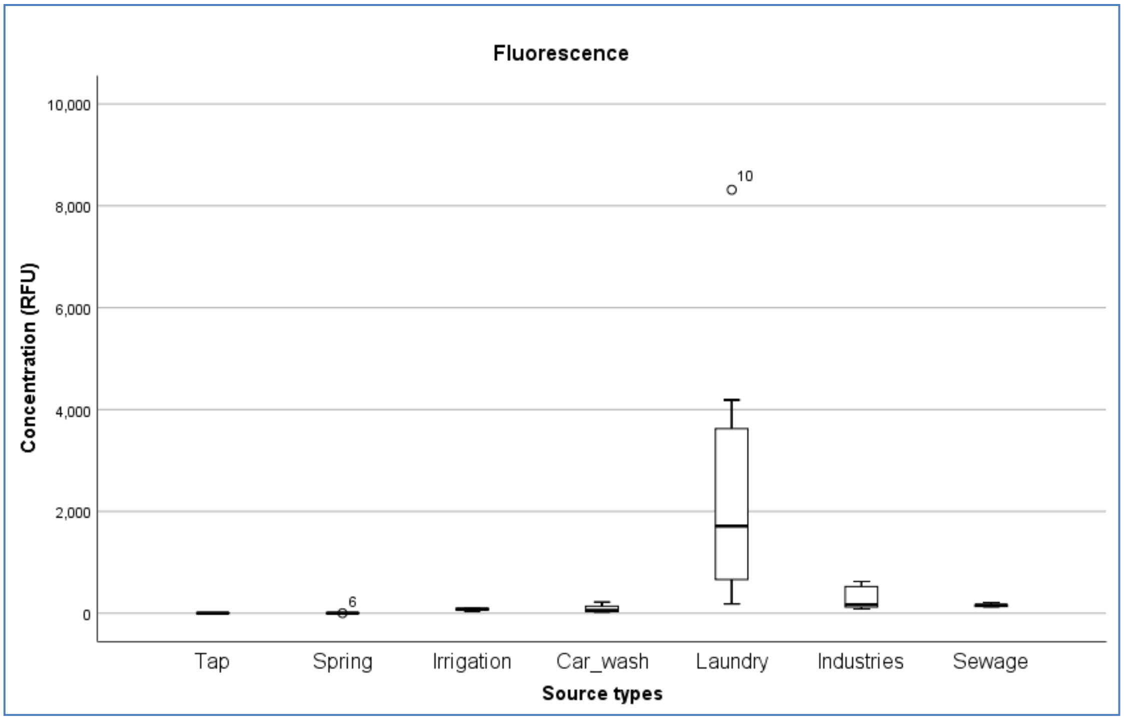


**Figure D5.15: Fluorescence comparison for different source types**

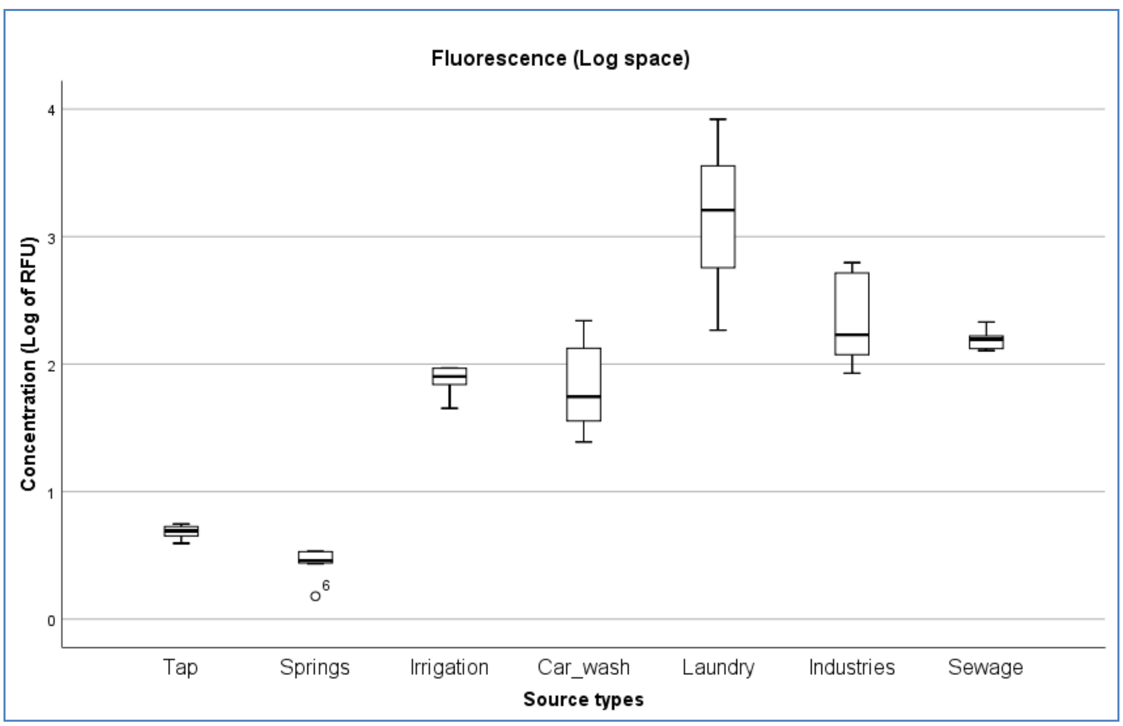


**Figure D5.16: Fluorescence comparison for different source types in Log space**

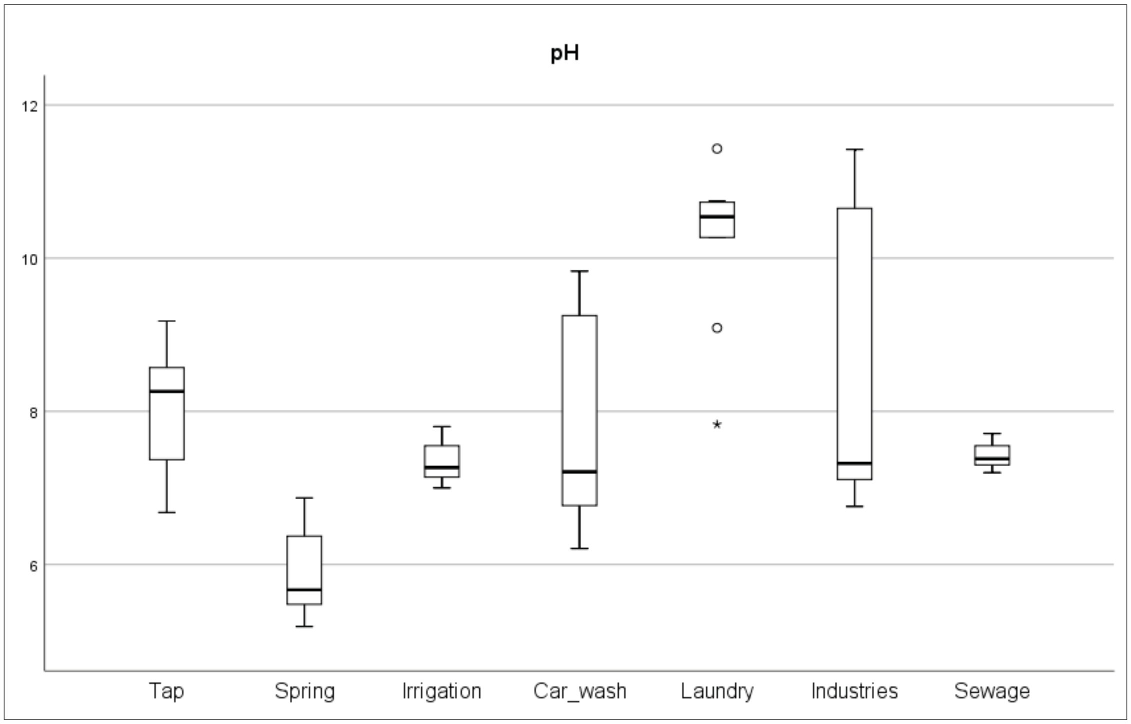


**Figure D5.17: pH comparison for different source types**

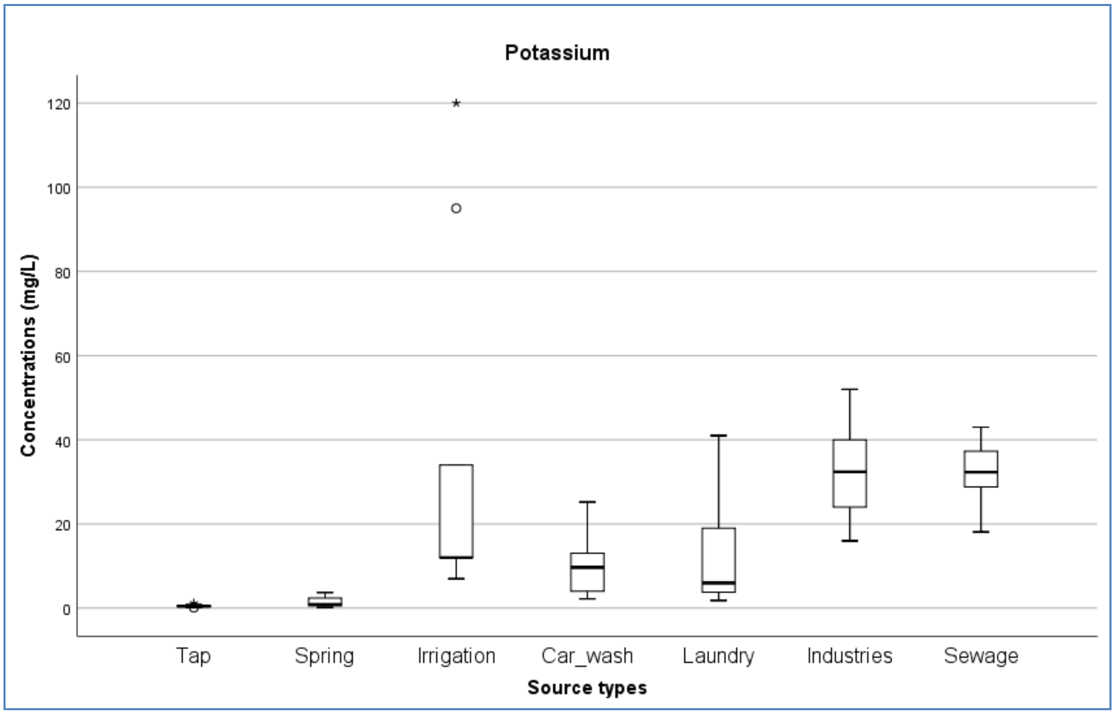


**Figure D5.18: Potassium comparison for different source types**

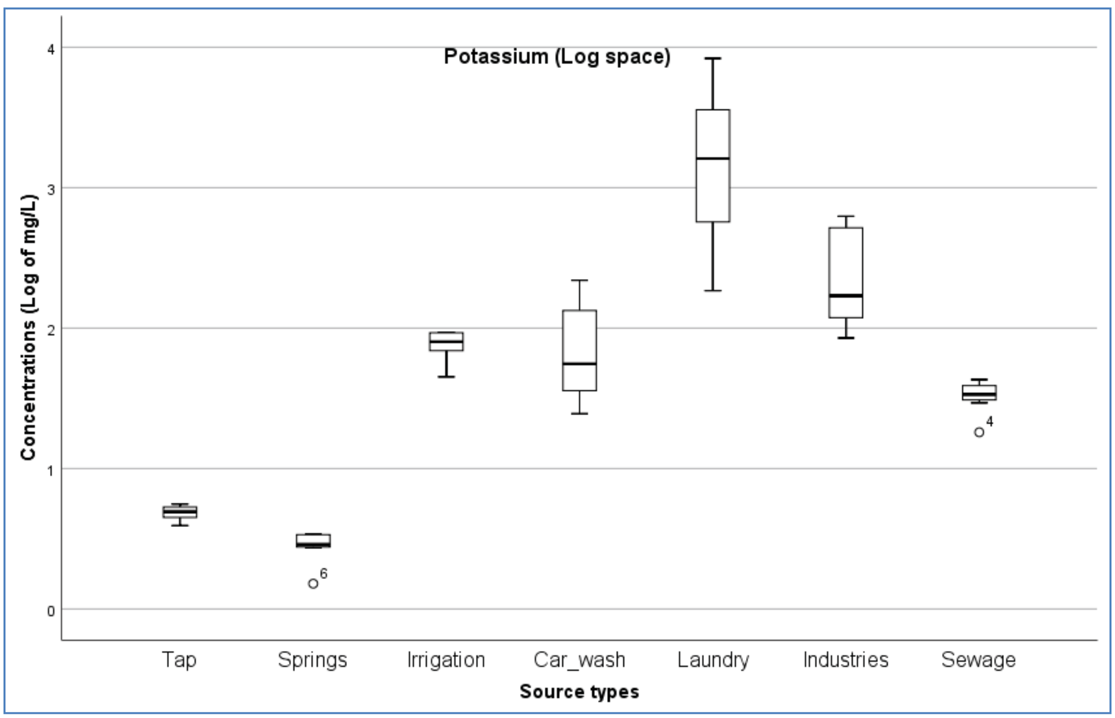


**Figure D5.19: Potassium comparison for different source types in Log space**

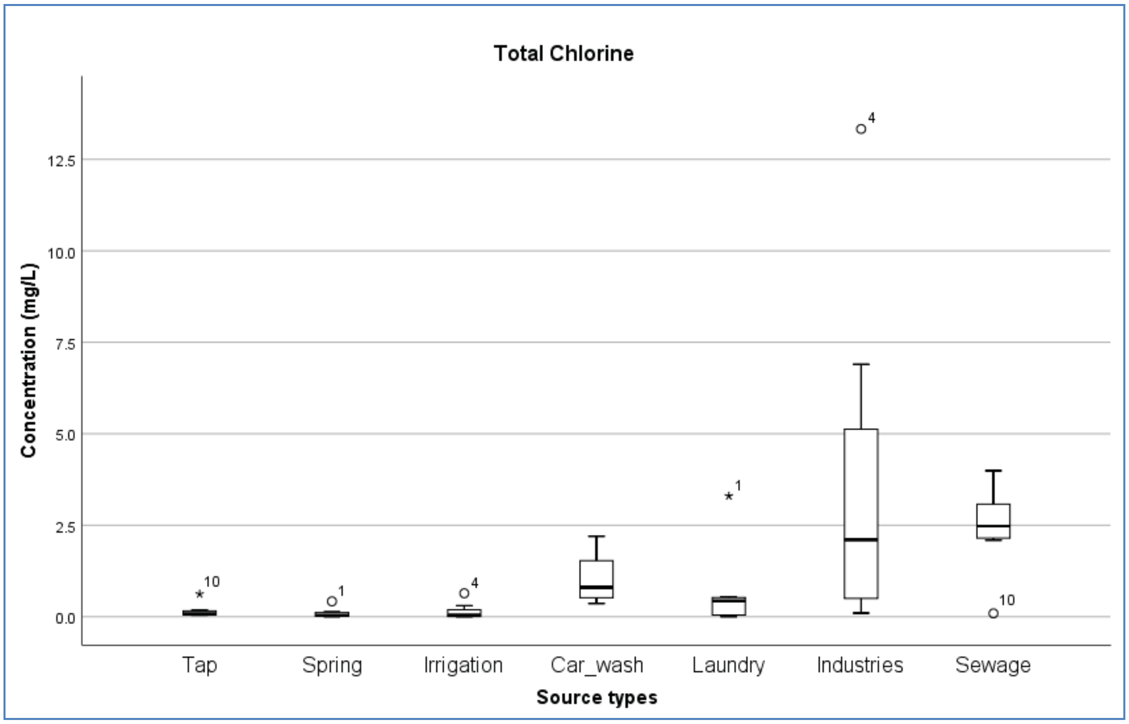


**Figure D5.20: Total Chlorine comparison for different source types**

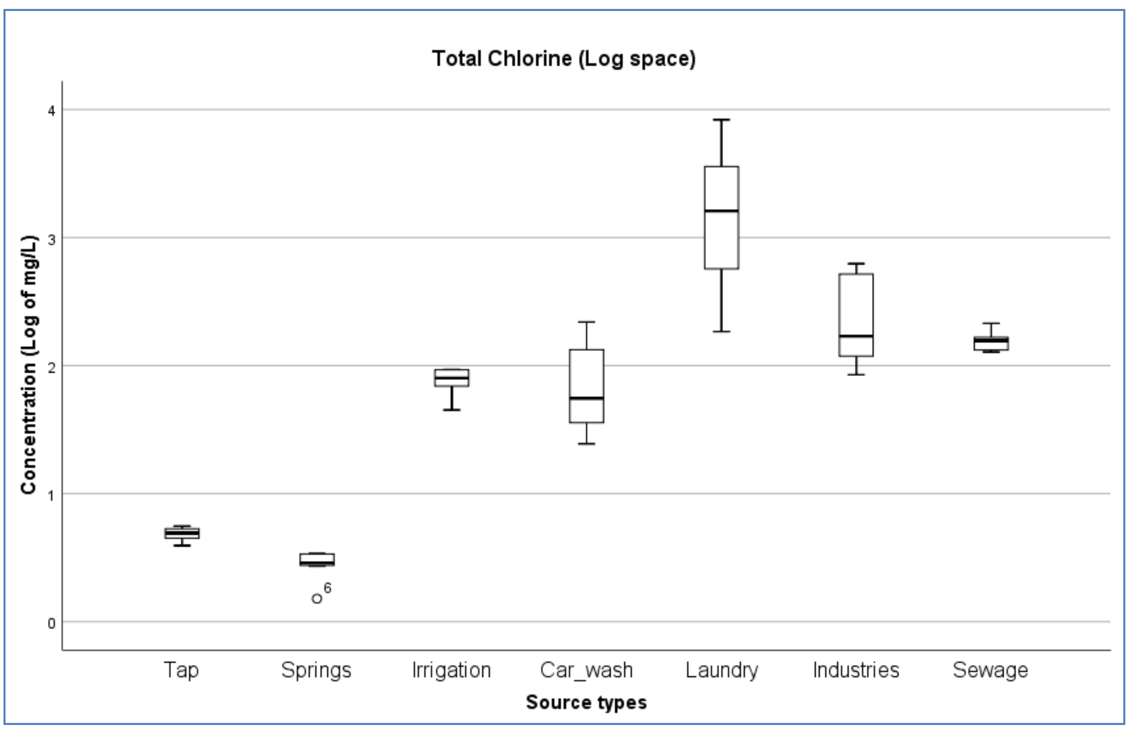


**Figure D5.21: Total Chlorine comparison for different source types in Log space**

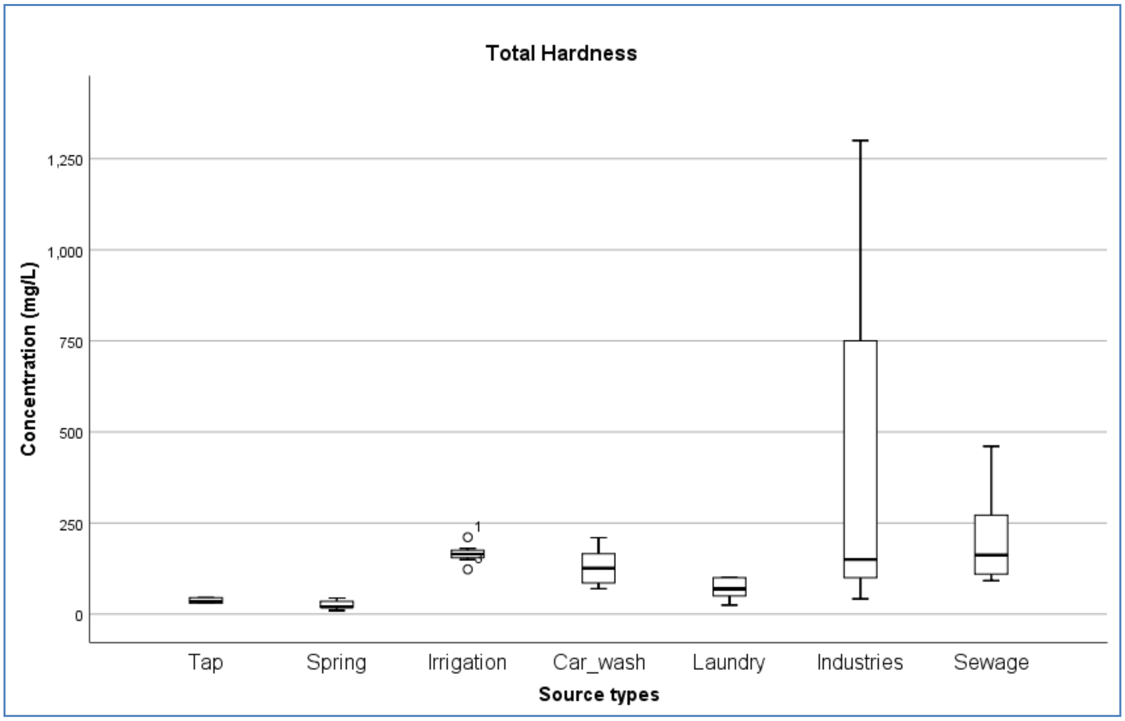


**Figure D5.22: Total Hardness comparison for different source types**

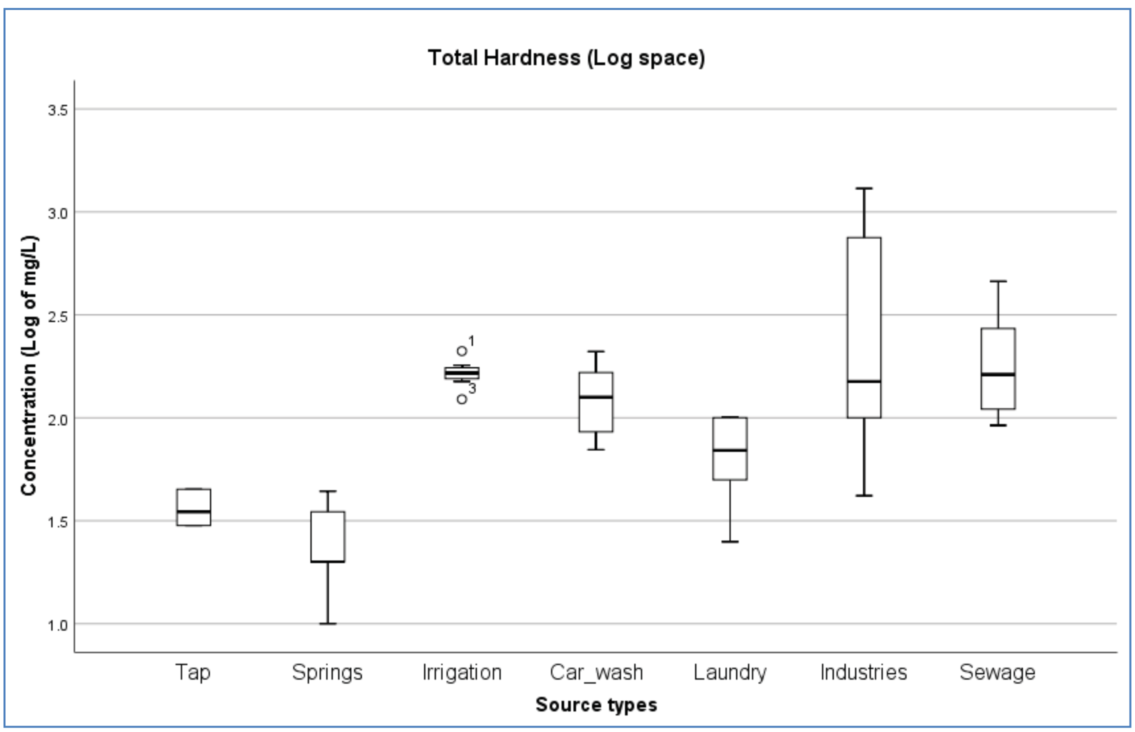


**Figure D5.23: Total Hardness comparison for different source types in Log space**

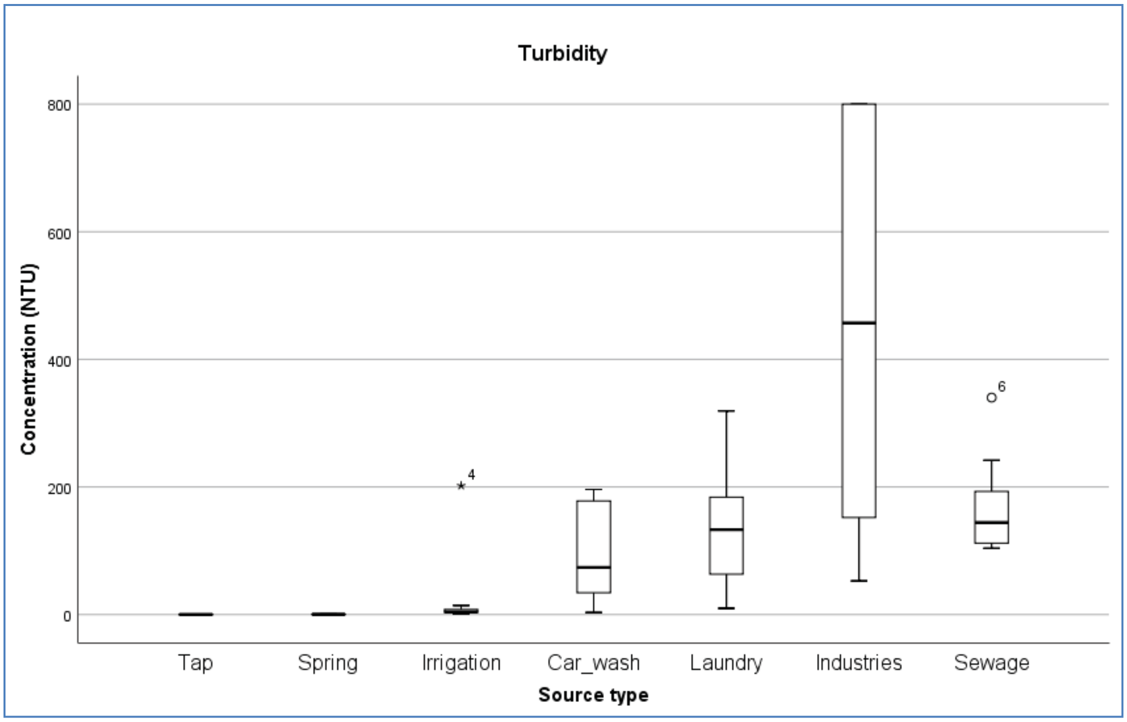


**Figure D5.24: Turbidity comparison for different source types**

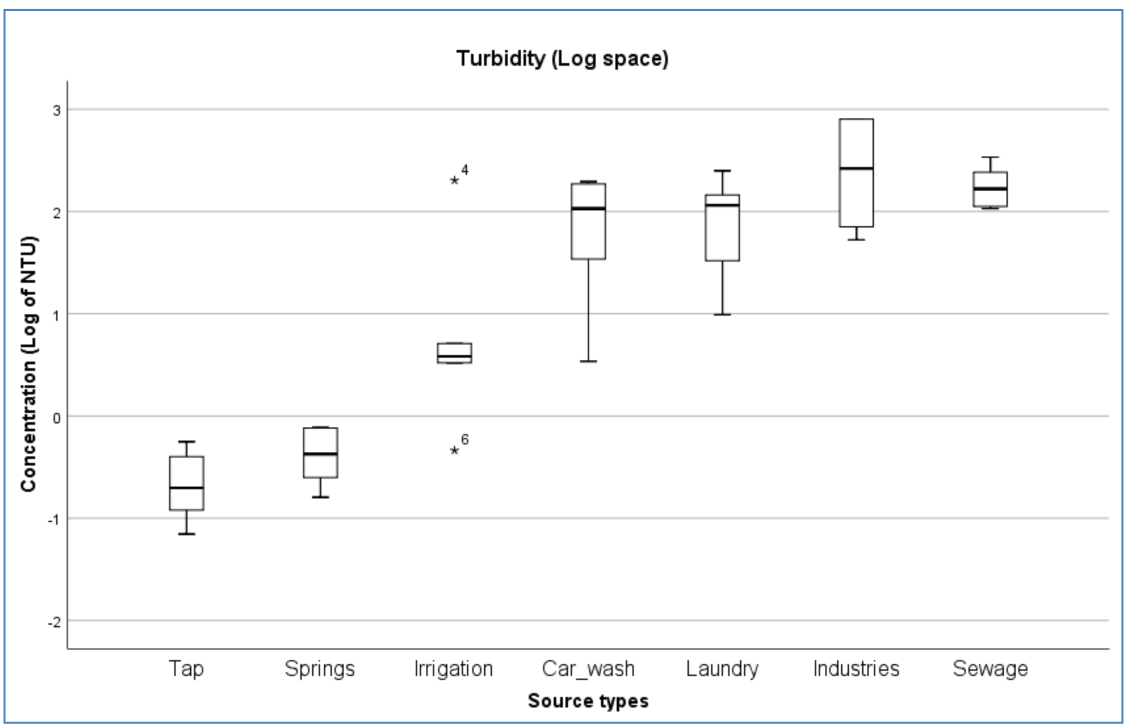


**Figure D5.25: Turbidity comparison for different source types in Log space**

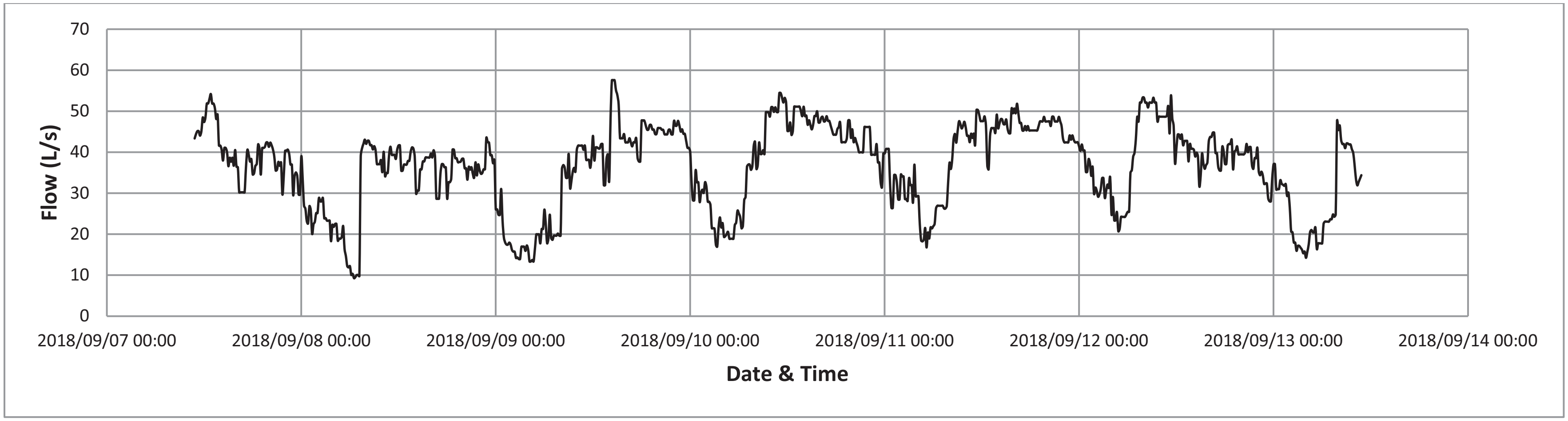


**Figure D5.26: Six-days dry weather flow hydrograph at Du Noon, Outfall D6 (07-13 Sep 2018)**

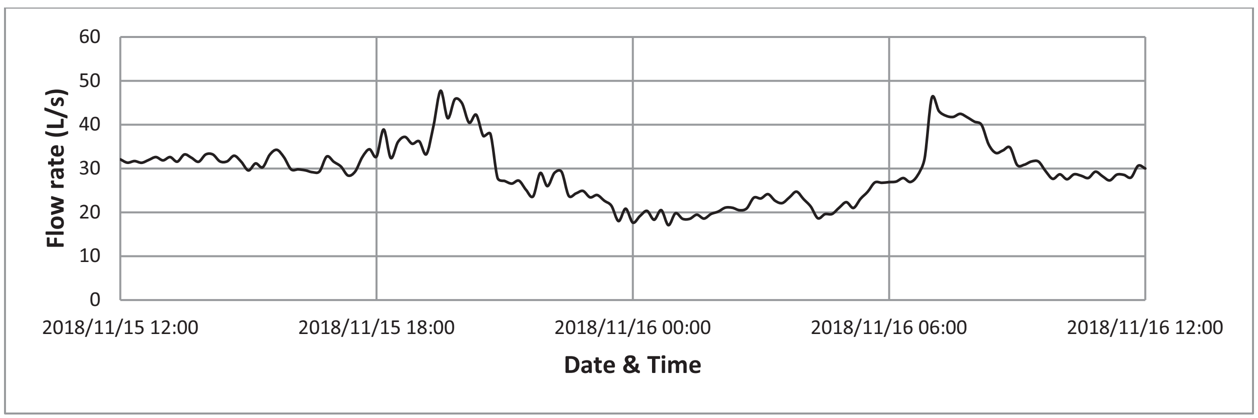


**Figure D5.27: One-day Hydrograph at Du Noon, Outfall D6 (15-16 Nov 2018)**

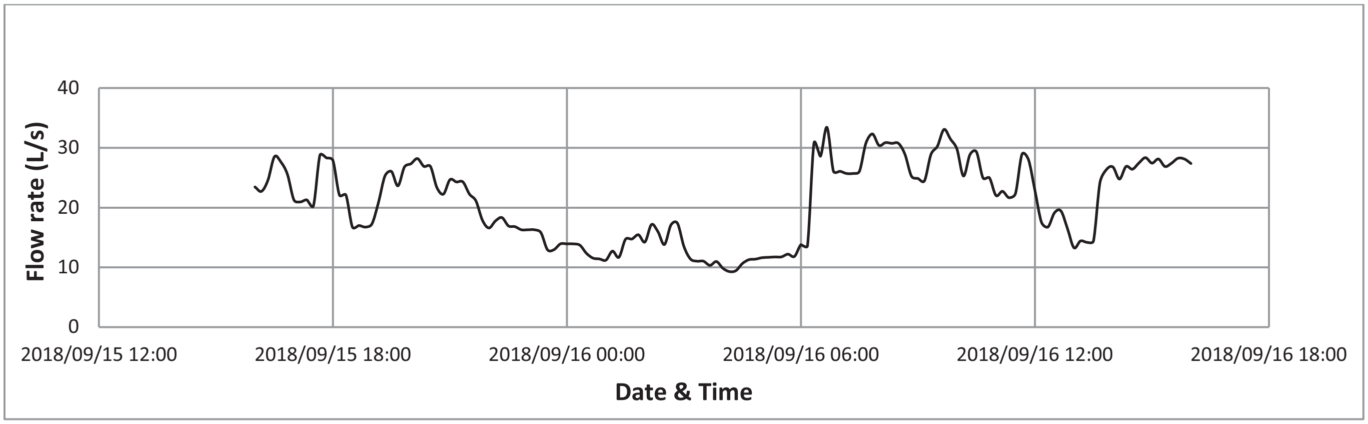


**Figure D5.28: One-day hydrograph at Du Noon, Outfall D5 (15-16 Nov 2018)**

# APPENDIX D6: Illegal Discharge Source Tracking Form

## ILLEGAL DISCHARGE SOURCE TRACKING FORM

STORM DRAIN NETWORK OR DRAINAGE AREA INVESTIGATION

| BACKGROUND DATA | | |
|---|---|---|
| **Inspectors' Names:** | | |
| **Date:** | **Time:** | |
| **Site Address:** | | |
| **Manhole ID:** | **Sample ID:** | |
| **Longitude:** | | **Latitude:** |
| **Rainfall (mm)** | **Last 24 hours:** | **Last 48 hours:** |

| OBSERVATIONS |
|---|
| **Is water standing in manhole?** ☐Yes ☐No |
| **Colour of water:** ☐Clear ☐Cloudy ☐suspended solids ☐Other |
| **Flow in manhole:** Velocity: ☐Slow ☐Medium ☐Fast |
| **Flow in manhole:** Velocity (m/s)______ Flow depth (cm)_______ Flow rate (l/s)___ |
| **Blockages:** ☐Yes ☐No |
| **Sediment in manhole:** ☐Yes ☐No; If yes Percent filled_______ % |
| **Floatables:** ☐None ☐Sewage ☐Oily sheen ☐Foam ☐Other______ |
| **Odour:** ☐None ☐Sewage ☐Petroleum/gas ☐Rancid/sour ☐Sulphide ☐Other_____ |
| **Comments:** |

| FIELD TESTING | | |
|---|---|---|
| pH____ | Temp.____ºC | Conductivity_______mS/m |
| Surfactants____ mg/l(MBAS) | Ammonia_____ mg/l | Potassium________ mg/l |
| Fluorescence________ RFU | Phenols______ mg/l | |
| **Comments:** | | |

| CONTAMINATION |
|---|
| Contamination found during inspection**:** ☐Yes ☐No |
| If Yes, check one**:** ☐by observation ☐by field testing results |
| If No, was sandbag placed?**:** ☐No ☐Yes Date (if yes):_______________ |

| |
|---|
| Sandbag check date____________________; Was flow captured?: ☐Yes ☐No |
| **Comments:** |

# APPENDIX D7: Results of source tracking investigation

## Table D7.1: Summary of Qualitative Illegal Discharge Tracking Field Data

| BACKGROUND INFORMATION | | | | | PHYSICAL OBSERVATION | | | | | | | CONTAMI-NATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Address | Sample ID | Inspection Date | Latitude | Longitude | Standing water | Colour | Flow speed | Block-ages | Sediment in manhole | Float-ables | Odour | Yes | No |
| SATI RD, Killarney | D11 | 15/05/2018 | | | Yes | Cloudy | Slow | Yes | Yes | Sewage | Sewage | | |
| SATI RD, Killarney | D11-M1A | 15/05/2018 | 33$^{0}$49.166' | 018$^{0}$31.762' | Yes | Clear | Slow | No | No | None | None | | |
| SATI RD, Killarney | D11M1 | 15/05/2018 | 33$^{0}$49.166' | 018$^{0}$31.762' | No | Clear | Medium | No | No | None | None | | |
| SATI RD, Killarney | D11M1B | 17/05/2018 | | | No | Whitish /Milky | Medium | | No | None | None | | |
| SATI RD, Killarney | D11M1 | 05/06/2018 | 33$^{0}$49.161' | 18$^{0}$31.762' | | Cloudy | Slow | No | No | Foam | | | |
| Killarney Racecourse | D12B (overflow) | 05/06/2018 | | | | | | | | | | | |
| Killarney Racecourse | D12 | 05/06/2018 | 33$^{0}$49.528' | 18$^{0}$31.458' | | Sewage Overflow | | | | | Sewage | x | |
| 21 Winning Way, Dunoon | D6M2 | 06/06/2018 | | | | Cloudy | Fast | No | No | None | Rancid | | |
| TMSC, Milnerton | D20A | 04/07/2018 | 33$^{0}$50.784' | 18$^{0}$30.975' | | | | | | | | | |
| TMSC, Milnerton | D20B | 09/07/2018 | 33$^{0}$49.163' | 18$^{0}$31.763' | | | | | | | | | |
| TMSC, Milnerton | D20 | 09/07/2018 | 33$^{0}$50.990' | 18$^{0}$31.147' | | Cloudy | Medium | | | Oily sheen & Foam | None | X | |
| Fair Cape Dairy, Killarney | FC2 | 10/07/2018 | 33$^{0}$49.328' | 18$^{0}$32.11' | No | Cloudy | Medium | No | No | None | None | | |
| Horse boarding stable, Killarney | D13M2 | 10/07/2018 | 33$^{0}$49.726' | 18$^{0}$31.587' | No | Clear | Medium | No | No | None | None | | |
| Afrimat, Killarney | Afrimat | 10/07/2018 | 33$^{0}$49.302' | 18$^{0}$32.122' | No | Clear | Slow | No | No | None | None | | X |
| SATI RD, Killarney | D11M2 | 10/07/2018 | | | No | Whitish | Medium | No | No | None | None | | |

| BACKGROUND INFORMATION | | | | | PHYSICAL OBSERVATION | | | | | | | CONTAMI-NATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site Address** | **Sample ID** | **Inspection Date** | **Latitude** | **Longitude** | **Standing water** | **Colour** | **Flow speed** | **Block-ages** | **Sediment in manhole** | **Float-ables** | **Odour** | **Yes** | **No** |
| Fair Cape Dairy, Killarney | FC1 | 10/07/2018 | $33^{0}$49.341' | $18^{0}$32.015' | No | Cloudy | Fast | No | No | Papers | None | | |
| Esso Rd, Montague | Esso 1 | 16/07/2018 | $33^{0}$51.775' | $18^{0}$29.924' | Yes | Clear | slow | No | No | None | None | | |
| Esso Rd, Montague | Esso 2 | 16/07/2018 | $33^{0}$51.775' | $18^{0}$29.924' | Yes | Brownish suspensio ns | slow | No | No | colloids | None | | |
| Esso, Montague | Esso 3 | 17/07/2018 | $33^{0}$51.439' | $18^{0}$31.287' | | | | | | | | | |
| Stella Rd, Montague | Stella 1 | 17/07/2018 | $33^{0}$51.075' | $18^{0}$31.203' | No | Brownish | Medium | No | | Oily sheen | Petroleu m | | |
| Stella Rd, Montague | Lamark | 17/07/2018 | $33^{0}$51.201' | $18^{0}$31.118' | No | Cloudy | slow | No | No | Sewage | | | |
| Stella Rd, Montague | Dirt Rider | 17/07/2018 | $33^{0}$51.123' | $18^{0}$31.170' | | | | | | | | | |
| Stella Cove, Montague | Stella 27 | 18/07/2018 | $33^{0}$51.056' | $18^{0}$31.198' | Yes | Cloudy | slow | No | No | None | None | X | |
| Dawn, Montague | Dawn 23 | 18/07/2018 | $33^{0}$51.063' | $18^{0}$31.207' | No | Clear | Slow | No | No | None | None | | X |
| Dawn Rd, Montague | 12-14 Dawn | 18/07/2018 | $33^{0}$51.223' | $18^{0}$31.208' | | | | | | | | | |
| Dawn, Montague | 15 Dawn | 18/07/2018 | $33^{0}$51.154' | $18^{0}$31.247' | No | Brownish red | Slow | No | No | None | None | | |
| Marconi Rd | Montigo | 18/07/2018 | $33^{0}$51.399' | $18^{0}$31.051' | No | Clear | Medium | No | No | None | None | | |
| Second Str, Montague | 2nd Str | 18/07/2018 | $33^{0}$51.413' | $18^{0}$31.096' | No | Clear | slow | No | No | None | None | | |
| First Str , Montague | 4 First | 23/07/2018 | $33^{0}$51.411' | $18^{0}$31.080' | No | Clear | Slow | No | No | None | None | | |
| Cnr Montague & First Str | 19 Montague | 23/07/2018 | $33^{0}$51.268' | $18^{0}$31.274' | No | Cloudy | Medium | No | No | Foam | None | X | |
| Fourth Str, Montague | 4 Fourth | 23/07/2018 | $33^{0}$51.481' | $18^{0}$31.046' | No | Cloudy | Medium | No | No | None | None | X | |
| Fourth Str, Montague | 18A Fourth | 23/07/2018 | $33^{0}$51.538' | $18^{0}$31.125' | No | | | No | No | Oily sheen | Petroleu m | | |
| Marconi Cres, Montague | Macroni Cres | 23/07/2018 | $33^{0}$51.890' | $18^{0}$30.977' | Yes | Clear | Medium | Yes | Yes | | | | |

| BACKGROUND INFORMATION | | | | | PHYSICAL OBSERVATION | | | | | | | CONTAMI-NATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Address | Sample ID | Inspection Date | Latitude | Longitude | Standing water | Colour | Flow speed | Block-ages | Sediment in manhole | Float-ables | Odour | Yes | No |
| Marconi Rd, Montague | 36 Macroni | 23/07/2018 | $33^{0}51.795'$ | $18^{0}31.031'$ | Yes | Cloudy | | | | Oily sheen | | | |
| Long claw, Montague | 1 Long claw | 24/07/2018 | $33^{0}51.893'$ | $18^{0}30.699'$ | No | Clear | Medium | No | No | None | None | | X |
| Rainbow , Montague | 1 Rainbow | 24/07/2018 | $33^{0}51.881'$ | $18^{0}30.877'$ | No | Cloudy | Medium | No | No | Trash | None | | |
| Kunene, Montague | 1 Kunene | 24/07/2018 | $33^{0}51.794'$ | $18^{0}30.802'$ | No | Cloudy | Fast | No | No | None | None | | |
| Omuramba Rd, Montague | OM 1 | 24/07/2018 | $33^{0}51.799'$ | $18^{0}31.023'$ | No | Clear | Slow | No | No | | None | | |
| Sixth, Montague | 3 Sixth | 27/07/2018 | $33^{0}51.526'$ | $18^{0}31.059'$ | No | Clear | slow | No | No | None | None | | |
| Fourth STR, Montague | 10 Fourth | 27/07/2018 | $33^{0}51.499'$ | $18^{0}31.080'$ | No | Clear | Slow | No | No | None | None | | X |
| Marconi Cres, Montague | 2 Macroni Cres | 27/07/2018 | $33^{0}51.671'$ | $18^{0}30.942'$ | Yes | Clear | Slow | No | No | None | None | | X |
| Bolt Ave, Montague | 2 Bolt | 30/07/2018 | $33^{0}52.136'$ | $18^{0}31.182'$ | No | clear | slow | No | No | None | None | | X |
| Chain Ave, Montague | 17 Chain | 30/07/2018 | $33^{0}52.284'$ | $18^{0}31.165'$ | | Clear | Medium | | | | | | |
| Chain Ave, Montague | 1 Chain | 30/07/2018 | $33^{0}51.261'$ | $18^{0}31.207'$ | | | | | | | | | |
| Chain Ave, Montague | 5 Chain | 30/07/2018 | $33^{0}52.231'$ | $18^{0}31.253'$ | Yes | Cloudy | slow | No | No | Oily sheen | None | Possible | |
| Drill Ave, Montague | 1 Drill | 30/07/2018 | $33^{0}52.444'$ | $18^{0}31.207'$ | No | Cloudy | | No | No | Oily sheen | None | | |
| Drill Ave, Montague | 1A Drill | 30/07/2018 | $33^{0}52.444'$ | $18^{0}31.207'$ | No | clear | slow | No | No | None | None | | X |
| Drill Ave, Montague | 2 Drill | 30/07/2018 | $33^{0}52.430'$ | $18^{0}31.256'$ | No | Cloudy | Slow | No | No | None | None | X | |
| Alternator Ave, Montague | 11 Alternator | 03/08/2018 | $33^{0}51.703'$ | $18^{0}31.390'$ | No | Cloudy | Fast | No | No | None | None | x | |
| Alternator Ave, Montague | 7 Alternator | 03/08/2018 | $33^{0}51.775'$ | $18^{0}31.388'$ | No | Clear | Medium | No | No | Foam | None | X | |
| Link Rd , Montague | 1 Link | 03/08/2018 | $33^{0}51.662'$ | $18^{0}31.324'$ | Yes | Clear | No flow | | Yes | None | None | | X |

| BACKGROUND INFORMATION | | | | | PHYSICAL OBSERVATION | | | | | | | CONTAMI-NATION | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site Address | Sample ID | Inspection Date | Latitude | Longitude | Standing water | Colour | Flow speed | Block-ages | Sediment in manhole | Float-ables | Odour | Yes | No |
| Ferrule Ave , Montague | 5 Ferrule | 03/08/2018 | $33^{0}52.207'$ | $18^{0}31.492'$ | No | Clear | slow | No | Yes | None | None | | X |
| Engine Ave, Montague | 15 Engine | 03/08/2018 | $33^{0}52.370'$ | $18^{0}31.452'$ | No | Clear | slow | No | No | None | None | | X |
| BP Ave, Montague | 1BP | 10/08/2018 | $33^{0}51.771'$ | $18^{0}31.631'$ | No | Clear | slow | No | No | None | None | | |
| BP Ave, Montague | 2BP | 10/08/2018 | $33^{0}51.556'$ | $18^{0}31.400'$ | No | clear | Fast | No | No | None | None | X | |
| Link Rd, Montague | 10Link | 10/08/2018 | $33^{0}51.585'$ | $18^{0}31.590'$ | Yes | Dark Maroon | slow | No | No | None | Rancid | x | |
| Cnr Killarney & Laguna RD | 6Killerney | 04/09/2018 | | | No | clear | slow | No | No | None | None | | X |
| Cnr Killarney & Laguna RD | 7Laguna RD | 04/09/2018 | | | No | Cloudy | Medium | No | No | None | None | | |
| Hoist Ave, Montague | 20 Hoist | 11/09/2018 | $33^{0}51.588'$ | $18^{0}31.593'$ | No | Clear | Slow | No | No | None | None | | x |
| Bolt Ave, Montague | 23 Bolt | 11/09/2018 | $33^{0}51.863'$ | $18^{0}31.408'$ | Yes | clear | slow | No | No | None | None | | X |
| Railway Rd, Montague | 4Railway | 11/09/2018 | $33^{0}51.878'$ | $18^{0}31.623'$ | No | clear | slow | No | No | None | None | | X |
| Railway Rd, Montague | 5Railway | 11/09/2018 | $33^{0}51.871'$ | $18^{0}31.622'$ | No | clear | Fast | No | No | None | None | | |
| Rainbow Close, Montague | 1RC | 21/09/2018 | $33^{0}51.870'$ | $18^{0}31.622'$ | No | clear | slow | No | No | None | None | | X |
| Rainbow Close, Montague | 2Rc | 21/09/2018 | $33^{0}52.034'$ | $18^{0}30.945'$ | Yes | Clear | Medium | No | No | None | None | | x |
| Rainbow Close, Montague | 3RC | 21/09/2018 | $33^{0}51.999'$ | $18^{0}30.942'$ | Yes | Clear | Medium | No | No | None | None | | |
| Kunene Rd, Montague | 4RC | 21/09/2018 | $33^{0}51.672'$ | $18^{0}30.773'$ | No | Clear | Slow | No | No | None | None | | x |

## Table D7.2: Summary of Quantitative Illegal Discharge Tracking Field Data Results

| BACKGROUND INFORMATION | | | | | QUANTITATIVE (PHYSICO-CHEMICAL) DATA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Latitude | Longitude | Sample ID | Sample Date | pH | EC mS/m | Temp °C | Flow rate L/s | $NH_3$ mg/L | $NO_3$ mg/L | $NO_2$ mg/L | $PO_4$ mg/L | K mg/L | COD mg/l | Detergent mg/L as MBAS | Fluore-scence RFU) |
| Killarney | | | D6 | 14/05/18 | 7.69 | 1.74 | 20.20 | | 73.10 | 22.62 | 0.01 | 35.00 | 22.00 | 846 | 13.62 | |
| Killarney | | | D6M2 | 14/05/18 | 7.38 | 1.70 | 19.50 | 21 | 73.00 | 13.80 | 0.11 | 29.00 | 22.00 | | | |
| Killarney | | | D6M3 | 14/05/18 | 7.53 | 1.66 | 19.60 | | 73.40 | 8.80 | 1.05 | 31.00 | 21.00 | 846 | 13.62 | |
| Killarney | | | D11 | 15/05/18 | 6.5 | 4.45 | 20.60 | | 0.76 | 0.15 | 0.08 | 0.06 | 6.50 | | | |
| Killarney | 33°49.166' | 018°31.762' | D11M1A | 15/05/18 | 4.45 | 8.77 | 18.30 | 2 | 0.80 | 0.28 | 0.01 | 0.96 | 12.00 | | | |
| Killarney | | | D11M1B | 17/05/18 | 6.82 | 6.12 | 20.20 | 2 | 0.40 | 1.54 | 0.06 | 18.20 | 10.50 | | | |
| Killarney | 33°49.528' | 18°31.458' | D12B | 05/06/18 | 6.93 | 2.31 | 26.00 | >100 | 81.00 | 0.84 | < | 28.40 | 22.00 | | | |
| Killarney | | | D12 | 05/06/18 | 7.35 | 1.67 | 23.50 | | 68.00 | 1.95 | 0.10 | 28.00 | 21.00 | | 18.35 | 267 |
| Killarney | 33°49.163' | 18°31.763' | D20B | 09/07/18 | 7 | 2.92 | 18.20 | 86 | 0.39 | 3.83 | 0.25 | 0.57 | 8.80 | | | 64.91 |
| Killarney | 33°50.990' | 018°31.147' | D20 | 09/07/18 | 6.77 | 2.84 | 19.00 | | 0,31 | 5.00 | 0.18 | 0.63 | 8.60 | 464 | 10.23 | 79.76 |
| Killarney | | | D11M2 | 10/07/18 | 7.52 | 5.92 | 17.40 | 6 | 0.74 | 1.01 | 0.06 | 0.98 | 3.90 | | | |
| Killarney | 33°50.784' | 18°30.975' | D20A | 10/07/18 | 6.54 | 2.05 | 15.90 | | 0.24 | 5.25 | 0.33 | 2.70 | 28.00 | | | 79.80 |
| Killarney | 33°49.726' | 18°31.587' | D13M2 | 10/07/18 | 7.57 | 4.19 | 18.30 | 3 | 0.92 | 3.39 | 1.20 | 0.51 | 6.00 | | 8.86 | 64.34 |
| Killarney | 33°49.341' | 18°32.015' | FC1 | 10/07/18 | 6.4 | 2.64 | 30.40 | | 0.01 | 1.79 | 0.05 | 3.70 | 5.10 | | | 32.84 |
| Killarney | | | D35 | 11/07/18 | 7.45 | 7.66 | 20.90 | | 0.98 | 3.37 | 0.01 | 0.55 | 32.00 | | | 86.06 |
| Killarney | | | D39 | 11/07/18 | 7.39 | 2.60 | 17.70 | | 0.05 | 4.25 | 0.04 | 0.21 | 10.00 | | | 74.72 |
| Killarney | 33°49.328' | 18°32.11' | FC2 | 11/07/18 | 7.2 | 0.37 | 20.80 | 4 | | | | | | | | 22.58 |
| Montague | 33°51.075' | 18°31.203' | STELLA 1 | 17/07/18 | 7.16 | 2.55 | 18.70 | 5 | 0.72 | 3.32 | 0.02 | 3.50 | 32.00 | | 35.00 | 168.60 |

| BACKGROUND INFORMATION | | | | | QUANTITATIVE (PHYSICO-CHEMICAL) DATA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Latitude | Longitude | Sample ID | Sample Date | pH | EC mS/m | Temp °C | Flow rate L/s | $NH_3$ mg/L | $NO_3$ mg/L | $NO_2$ mg/L | $PO_4$ mg/L | K mg/L | COD mg/l | Detergent mg/L as MBAS | Fluore- scence RFU) |
| Montague | 33°51.056' | 18°31.198' | STELLA 27 | 18/07/18 | 9.02 | 0.66 | 15.20 | | 0.01 | 2,28 | 3.10 | 1.20 | 15.00 | | 109 | 104.4 |
| Montague | 33°51.154' | 18°31.247' | DAWN 15 | 18/07/18 | 6.68 | 1.22 | 20.10 | 2 | 0.08 | | | 0.00 | 12.00 | | | |
| Montague | 33°51.063' | 18°31.207' | DAWN 23 | 18/07/18 | 6.5 | 1.02 | 20.10 | 2 | 0.56 | | | 0.00 | | | | 57.8 |
| Montague | 33°51.439' | 18°31.287' | ESSO3 | 18/07/18 | 6.67 | 1.17 | 19.50 | | | | | | | | | 76.34 |
| Montague | 33°51.413' | 18°31.096' | SECOND ST | 18/07/18 | 7.07 | 0.45 | 18.60 | 0.3 | < | | | | 5.30 | | | 37.45 |
| Montague | 33°51.399' | 18°31.051' | MONTIGO | 18/07/18 | 7.3 | 0.98 | 18.10 | 4 | 0.11 | 6.50 | 0.44 | 0.34 | 9.50 | | | 46.46 |
| Montague | 33°51.795' | 18°31.031' | 36 MARCONI | 23/07/18 | 7.39 | 1.27 | 19.20 | | | | | | | | | 97.06 |
| Montague | 33°51.890' | 18°30.977' | MARCONI CRES | 23/07/18 | 8.6 | 0.09 | 16.30 | | < | | | 0.17 | 0.50 | | | 8.49 |
| Montague | 33°51.671' | 18°30.942' | 2 MARCONI CRES | 23/07/18 | 7.44 | 1.28 | 18.40 | | 0.91 | | | 1.55 | 13.00 | | | |
| Montague | 33°51.499' | 18°31.080' | 1O FOURTH | 23/07/18 | 7.33 | 0.55 | 18.80 | 1 | < | 4.43 | 0.02 | 0.08 | 6.60 | 30 | | 0.20 |
| Montague | 33°51.481' | 18°31.046' | 4 FOURTH | 23/07/18 | 9.1 | 0.84 | 19.20 | 4 | 4.90 | 0.77 | 0.43 | 27.00 | 12.00 | >2000 | 31.5 | 164.32 |
| Montague | 33°51.411' | 18°31.080' | 4 FIRST | 23/07/18 | 7.01 | 1.20 | 21.30 | 1 | < | | | 5.20 | 24.00 | | | 40.82 |
| Montague | 33°51.268' | 18°31.274' | 19 M0NTAGUE | 23/07/18 | 7.4 | 6.93 | 19.80 | 4 | | | | | | | 136.17 | 68.80 |
| Montague | 33°51.893' | 18°30.699' | 1 LONG CLAW | 24/07/18 | 7.47 | 1.38 | 9.40 | 3 | 0.08 | 3.14 | 0.01 | 0.52 | 4.50 | | | 47.18 |
| Montague | 33°51.881' | 18°30.877' | 1 RAINBOW | 24/07/18 | 7.69 | 1.91 | 18.90 | | 0.43 | | | 0.33 | 3.50 | 370 | 1.26 | 51.62 |
| Montague | 33°51.794' | 18°30.802' | 1 KUNENE | 24/07/18 | 7.36 | 2.15 | 19.40 | | 0.49 | 4.35 | 0.00 | 2.30 | 39.00 | 180 | 0.77 | 55.27 |
| Montague | 33°51.799' | 18°31.023' | OM1 | 24/07/18 | 7.47 | 1.24 | 19.00 | 0.5 | 0.07 | | | | | | | |
| Montague | 33°52.444' | 18°31.207' | 1 DRILL | 30/07/18 | 7.49 | 1.04 | 18.00 | trickling | 0.86 | 8.80 | 0.84 | 0.69 | 30.00 | | | |
| Montague | 33°52.430' | 18°31.256' | 2 DRILL | 30/07/18 | 6.99 | 1.08 | 18.90 | 1 | 0.22 | 4.16 | | 1.80 | 38.00 | >2000 | 3.49 | 140 |

| BACKGROUND INFORMATION | | | | | QUANTITATIVE (PHYSICO-CHEMICAL) DATA | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample Location** | **Latitude** | **Longitude** | **Sample ID** | **Sample Date** | **pH** | **EC mS/m** | **Temp °C** | **Flow rate L/s** | **$NH_3$ mg/L** | **$NO_3$ mg/L** | **$NO_2$ mg/L** | **$PO_4$ mg/L** | **K mg/L** | **COD mg/l** | **Detergent mg/L as MBAS** | **Fluore-scence RFU)** |
| Montague | 33°52.444' | 18°31.207' | 1A DRILL | 30/07/8 | 7.62 | 0.70 | 18.40 | 0.7 | | | | | | | | |
| Montague | 33°52.231' | 18°31.253' | 5 CHAIN | 30/07/18 | 7.57 | 1.11 | 17.90 | 1.2 | 0.10 | 0.68 | 0.02 | 0.12 | 8.80 | 65 | 0.16 | 44.06 |
| Montague | 33°51.261' | 18°31.207' | 1 CHAIN | 30/07/18 | 7.18 | 1.36 | 18.10 | | 0.46 | 7.85 | 4.40 | 1.50 | 7.20 | | | 45.06 |
| Montague | 33°52.284' | 18°31.165' | 17 CHAIN | 30/07/18 | 7.23 | 7.10 | 19.10 | 1.6 | 0.32 | 0.92 | 0.00 | 2.10 | 6.20 | 470 | 0.09 | 44.45 |
| Montague | 33°52.136' | 18°31.182' | 2 BOLT | 30/07/18 | 7.89 | 2.74 | 19.30 | 2.5 | 0.27 | | | | 7.70 | | | |
| Montague | 33°51.703' | 18°31.390' | 11 ALTERNATOR | 03/08/18 | 6.88 | 2.44 | 18.30 | 10 | 0.20 | 9.93 | 0.01 | 191.10 | 42.00 | >2000 | 3.49 | 61.54 |
| Montague | 33°51.775' | 18°31.388' | 7 ALTERNATOR | 03/08/18 | 7.89 | 13.34 | 16.20 | 2.5 | 1.30 | 11.01 | 0.05 | 10.00 | 12.00 | >2000 | 3.49 | 57.42 |
| Montague | 33°51.662' | 18°31.324' | 1 LINK RD | 03/08/18 | 7.53 | 0.35 | 17.20 | | | | | | | | | |
| Montague | 33°52.207' | 18°31.492' | 5 FERULE | 03/08/18 | 7.53 | 4.87 | 18.20 | 2.5 | | | | | | | | 58.83 |
| Montague | 33°52.370' | 18°31.452' | 15 ENGINE | 03/08/18 | 8.05 | 4.87 | 18.50 | 1 | 0.37 | | | | | | | |
| Montague | 33°51.771' | 18°31.631' | 1BP | 10/08/18 | 7,38 | 0.20 | 16.50 | 2 | | 0.98 | | 2.70 | | | | 45.37 |
| Montague | 33°51.556' | 18°31.400' | 2 BP | 10/08/18 | 7,56 | 3,37 | 17.80 | | 0,46 | 0.58 | 0.02 | 0,05 | | 15 | 1.36 | 66.47 |
| Montague | 33°51.585' | 18°31.590' | 10 LINK | 10/08/18 | 4.23 | 85.45 | 16.10 | | 0,07 | 1.90 | 0,006 | 19.19 | 4.30 | | 0.65 | 4.54 |
| Montague | | | 6 Killarney | 04/09/18 | 6.92 | 2.95 | 17.90 | 1 | 0.19 | 5.05 | | 0.24 | | 1040 | 3.38 | 115 |
| Montague | | | 7 Laguna rd | 04/09/18 | 6.87 | 1.89 | 18.20 | 2 | 0.18 | 0.57 | 0.02 | 2.20 | | | 0.99 | 105.90 |
| Montague | 33°51.588' | 18°31.593' | 20 hoist | 11/09/18 | 7 | 3.48 | 17.40 | 2.5 | 0.32 | 10.40 | 0.28 | 0.10 | | 380 | 1.18 | 53.47 |
| Montague | 33°51.863' | 18°31.408' | 23 bolt | 11/09/18 | 7.15 | 1.77 | 18.30 | trickling | 0.15 | 0.27 | 0.01 | 0.23 | | 45 | 0.47 | 78.14 |
| Montague | 33°51.878' | 18°31.623' | 4 railway | 11/09/18 | 6.86 | 0.94 | 19.10 | 1 | 0.01 | 11.55 | 0.43 | 0.77 | | 85 | 2.68 | 45.73 |
| Montague | 33°51.871' | 18°31.622' | 5 railway | 11/09/18 | 7.81 | 3.00 | 18.10 | 8 | 0.30 | 8.45 | 0.03 | 0.19 | | 55 | 0.39 | 58.26 |

| BACKGROUND INFORMATION | | | | | QUANTITATIVE (PHYSICO-CHEMICAL) DATA | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Latitude | Longitude | Sample ID | Sample Date | pH | EC mS/m | Temp °C | Flow rate L/s | $NH_3$ mg/L | $NO_3$ mg/L | $NO_2$ mg/L | $PO_4$ mg/L | K mg/L | COD mg/l | Detergent mg/L as MBAS | Fluore-scence RFU) |
| Montague | 33°51.870' | 18°31.622' | 1RC | 21/09/18 | 5.42 | 1.45 | 19.00 | 1.5 | 0.11 | 4.97 | 2.90 | 0.31 | 6.00 | 30 | 0.74 | 70 |
| Montague | 33°52.034' | 18°30.945' | 2RC | 21/09/18 | 7.3 | 1.63 | 19.20 | 5 | 0.76 | 6.35 | 0.53 | 0.24 | 6.40 | 60 | 0.71 | 67.85 |
| Montague | 33°51.999' | 18°30.942' | 3RC | 21/09/18 | 7.09 | 1.53 | 18.30 | 5 | 0.54 | 3.55 | 0.72 | 0.15 | 6.00 | 45 | 0.58 | 61.75 |
| Montague | 33°51.672' | 18°30.773' | 4RC | 21/09/18 | 7.17 | 1.63 | 18.50 | 1 | 0.20 | 3.05 | 0.07 | 0.10 | 12.00 | 35 | 0.77 | 69.39 |