CHARACTERISATION OF WASTEWATER FROM LOW-INCOME/HIGH-DENSITY RESIDENTIAL AREAS

EVN Musvoto • MC Ramphao

WRC Report No. 1449/1/07

Water Research Commission

CHARACTERISATION OF WASTEWATER FROM LOW-INCOME/HIGH-DENSITY RESIDENTIAL AREAS

Report to the
WATER RESEARCH COMMISSION

by

Dr EVN Musvoto and MC Ramphao
Ninham Shand (Pty) Ltd

WRC Report No 1449/1/07
ISBN No 978-1-77005-534-6

FEBRUARY 2007

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EXECUTIVE SUMMARY

Wastewater characterization (fractions) is an essential requirement in the design of a suspended medium biological wastewater treatment process. It has a major influence on the quality of the final effluent. Characterizations of the organic and inorganic constituents of municipal wastewaters are important for design of activated sludge systems. These constituents are defined qualitatively and quantitatively in terms of COD, TKN, FSA and TP. It is discussed and concluded that while the selection of this wastewater characteristics is simple, it is not trivial. The pitfalls of selecting wastewater characteristics uncritically and without recognition of the factors that influence them are emphasized by looking at the social aspects of people living in low-income high-density (LIHD) residential areas. The activated sludge system design will be as good as the selected wastewater of that particular wastewater.

Recent designs done for wastewater treatment works for areas with a relatively high percentage of LIHD developments indicated that these areas should have different wastewater characteristics. This observation lead to this study which is an attempt to define the characteristics of these wastewaters more closely.

Two LIHD areas near Cape Town with full water-borne sewer reticulation were surveyed in an attempt to do the characterisation.

The results of the study indicated that, although on the upper end, the characteristics of the wastewater surveyed were similar to that which was assumed thus far for domestic wastewater. The depth of the study was not sufficient to draw any relationship between social parameters and wastewater characteristics.

The study recommend that further, wider investigations be done to confirm the findings and makes proposals on the approach to be followed in any further studies in this regard.

ACKNOWLEDGEMENTS

The writers wish to express their gratitude to the members of the Steering Committee who guided the research work:

Prof C Buckley	University of KwaZulu-Natal
Mr N McNab	Umgeni water
Mr D Malan	Drakenstein Municipality
Dr T Pitman	Johannesburg Water
Mr M Ramphao	Ninham Shand
Mr K Sampson	City of Cape town
Mr G Steenveld	Water Research Commission (Chairman)
Prof M Wentzel	University of Cape Town
Mr K Wilken	ERWAT

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LIST OF ABBREVIATIONS

BEPR	Biological Excess Phosphorus Removal
BNR	Biological Nutrient Removal
COD	Chemical Oxygen Demand
FSA	Free and Saline Ammonia
IAWPRC	International Association for Water Pollution Research and Control
LIHD	Low-Income High-Density
MLSS	Mixed Liquor Suspended Solids
RBCOD	Readily Biodegradable COD
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
VFA	Volatile Fatty Acid
WRC	Water Research Commission
WWTP	Wastewater Treatment Plant

CHARACTERISATION OF WASTEWATER FROM LOW-INCOME/HIGH-DENSITY RESIDENTIAL AREAS

1 INTRODUCTION

1.1 Background to the Study

Cash strapped local authorities need to have economically, socially and environmentally optimal solutions for the treatment of wastewater. In order to provide these optimal solutions accurate characterisation of wastewater is required for the design of new wastewater treatment plants (WWTP) or extensions to existing plants. In South Africa, research has been carried out on the characterisation of municipal wastewater from catchments with full waterborne sewerage (WRC, 1984; Wentzel *et al.*, 1999). However, the wastewater that has been characterised under this research is mostly from catchments with industrial and middle to high-income residential areas. Historically, low-income households were mostly not connected to waterborne sewerage systems and thus did not contribute to this data. With the advent of democracy in 1994 and the implementation of national housing projects, a number of low-income residential areas have been provided with waterborne sewer reticulation which discharges to municipal wastewater treatment plants. Research and data from other countries have shown that the strength of wastewater varies between catchments, even those with similar characteristics (Bagg 1998). The variation was found not to depend only on the type of residential area, but also on other factors such as cost and availability of potable water, population densities, climate, and catchment composition and the presence of any industrial effluent streams.

The characteristics of wastewater from low-income housing schemes in South Africa are, expected to differ from those from middle and high-income residential areas. There might also be a variation in characteristics between catchments with low-income housing schemes due to the factors observed by Bagg (1998). In order to fully assess the impact of discharging wastewater from catchments with low-income-high-density housing schemes onto existing

WWTP in South Africa, the wastewater from these catchments needs to be characterised to the same extent as for catchments with middle to high-income developments which historically had full waterborne sewerage.

1.2 Project Objectives

The objectives of the project are to:

i. Provide new knowledge on characteristics of wastewater from South African low-income high-density housing schemes with full water-borne sewer reticulation and the social aspects that affect the characteristics of these wastewaters;

ii. Enhance the knowledge on wastewater characteristics in South Africa by including low-income high-density housing schemes which were historically not part of catchments with full water-borne sewerage.

1.3 Project Aims

i. Measure the quality of wastewater from low-income high-density residential areas;

ii. Measure the quantity of wastewater discharged from low-income high-density residential areas;

iii. Assess population density, potable water use and effect of cost of water on potable water use in low-income high-density residential areas;

iv. Assess other factors such as climate, type of houses, culture etc. which might impact on the quality and quantity of wastewater from low-income high-density residential areas.

1.4 Approach and Methodology

The first step of the project was to identify suitable catchments where the investigation could be conducted. Fisantekraal and DuNoon in the Western Cape were identified as suitable catchments.

Fisantekraal is a low-income high-density area that was first developed in 2000 and is located a few kilometers north of Durbanville. The area currently has approximately 1 500 houses. The whole area is serviced by waterborne sewerage and the collector sewer discharges into a pumpstation from where the wastewater is pumped to the Kraaifontein WWTP.

DuNoon is located about 45 km north of Cape Town in the Table View area. The area consists of approximately 2 500 houses with full waterborne sewerage. The collector sewer from DuNoon via pumpstation drains to the Potsdam WWTP.

The location of the two areas are shown in Figure 1.1

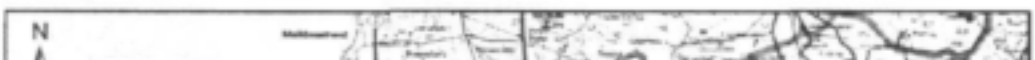

Figure 1.1 : Fisantekraal and DuNoon – Locality Plan

Wastewater characterization involved analyzing the quantity and quality of wastewater discharged from both areas. The characteristics were determined during the wet (June to September 2003) and dry (January to April 2004) seasons. Staff from the City of Cape Town's Scientific Services Department carried out the sampling and analyses. Samples were collected over 24 hour periods using an automatic sampler. The corresponding wastewater flow was also measured during the sampling period. The samples were analyzed for the various parameters including COD, Total Kjeldahl Nitrogen (TKN), Free and Saline Ammonia (FSA), Total Phosphorus, Readily biodegradable COD (RBCOD) and Total Suspended Solids (TSS).

A social scientist assessed the population density, type of houses, water use patterns and cultural practices with regards to water use in these areas. Questionnaires specifically developed for this study were used to capture the data.

Once collected all the data was analyzed with a view to relating the wastewater characteristics and the social and cultural practices in the area.

The report is divided into three sections namely:

i Literature review

ii Wastewater characterization and

iii Social aspects

A literature review was carried out to assess whether similar research had been carried out elsewhere. The data from other researches will then serve as a comparison to this project.

2 LITERATURE REVIEW

2.1 BACKGROUND

With the advent of democracy in South Africa in 1994, the government embarked on provision of housing, water and sanitation to previously disadvantaged communities. The provision of housing in urban areas has largely been done through the Reconstruction and Development Programme (RDP). The houses provided through this programme are aimed at the low-income earners and typically consists of four roomed houses fully serviced with a piped water system and water-borne sewerage.

2.2 IMPACT OF RDP HOUSING SCHEME ON WASTEWATER TREATMENT

The RDP housing schemes have been provided in almost all urban centres in South Africa since 1994 and have often been an extension of the existing urban residential area. Water and wastewater treatment have therefore been provided at existing water and wastewater treatment works. In most cases this has necessitated the construction of additional works or extension of existing works to cater for the additional load.

Significant research has been carried out in South Africa on the characterization of municipal wastewater from catchments with full water-borne sewerage (WRC, 1984; Wentzel *et al.*, 1999). The wastewater that has been characterized by this research is mostly from catchments with industrial and middle- to high-income residential areas. Historically, low-income households were mostly not connected to water-borne sewerage systems and thus did not contribute to this data. However, with the implementation of the national housing projects under the RDP a number of low-income residential areas have full water-borne sewerage which discharges to municipal wastewater treatment plants. In order to provide these optimal solutions accurate characterization of wastewater is required for design of new wastewater plants or extensions of existing plants.

2.3 DATA ON WASTEWATER CHARACTERIZATION – LITERATURE REVIEW

A literature review was carried out to determine whether any investigations had been carried out on the characterization of wastewater from low-income high-density areas.

Apart from the study by Bagg (1998) the data available in the literature is a characterization of wastewater from middle to high-income residential areas. In South Africa significant data has been collected on characteristics of wastewater from middle to high-income areas (WRC, 1984; Wentzel *et al.*, 1999). No information has however been gathered on low-income high-density residential areas with water-borne sewerage.

Bagg (1998) collected data on wastewater characteristics from 7 high-density urban catchments in Zimbabwe. Comparison of the data from the different catchments showed a wide variation in the various parameters such as COD, TKN and Total Phosphate, even where the demographics of the contributing catchments were similar, factors which appear to have an impact on wastewater strength were reviewed and the following was found (Bagg, 1998).

2.3.1 Cost and availability of potable water

At the current pricing the cost and availability of potable water did not have a significant impact on quantity and quality of wastewater.

2.3.2 Climate

Climate was found to have some effect in that catchments with higher temperatures seemed to have lower strengths because of increased sewage volumes.

2.3.3 *Population density*

Population density was found to have a major impact on wastewater strength with catchments with a higher population density tending to have higher sewage strengths.

2.3.4 *Catchments composition*

The catchment composition was found to have a significant impact on wastewater characteristics. Catchments with wet industries had different strengths to those without. Using the data collected, Bagg proposed an empirical model for the calculation of probable raw sewage characteristics generated by a new catchment.

2.4 SCOPE OF THE INVESTIGATION

Apart from the investigation done by Bagg (1998), it is evident from the literature survey that there is a paucity of data on characteristics of wastewater from low-income high-density areas.

Research and data from other countries has shown that the strength of wastewater varies between catchments, even those with similar characteristics (Bagg, 1998). The variation was found not to only depend on the type of residential area, but also on other factors such as cost and availability of water, population densities, climate, catchment composition and the presence any contributing industrial streams.

The characteristics of wastewater from low-income housing schemes in South Africa are, therefore, expected to differ from those from middle to high-income residential area. There might also be a variation in characteristics between catchments with low-income housing schemes due to the factors observed by Bagg (1998). Therefore, to fully assess the impact of discharging wastewater from catchments with low-income high-density housing schemes into existing WWTW in South Africa, the wastewater from these catchments needs to be characterized to the same extent as for catchments which have historically had full water-borne sewage. The characterization also has to be done for a number of catchments in order to identify the main factors that affect the wastewater composition and concentration. With sufficient data a simple method of predicting wastewater strength can then be developed.

At present there is insufficient data on wastewater characteristics from low-income high-density housing (LIHD) schemes in South Africa for designers to predict with confidence, the design parameters for catchments with these housing schemes.

3 SOCIAL ASPECTS

3.1 INTRODUCTION

A Social Scientist assessed the population density, type of houses, water usage patterns and culture in these areas. One of the objectives of the project is to assess the social aspects which might impact on the wastewater characteristics in Fisantekraal and DuNoon.

The approach and methodology for the study included:

- Quantitative analyses (questionnaire surveys and field measurements)
- Qualitative analyses (informal interviews)

A questionnaire was drawn up to obtain information on:

- Population figures
- Housing
- Water usage and disposal patterns
- Cost of potable water
- Dietary and other cultural factors

The questionnaire was administered and tested in both areas during a pilot survey conducted in September 2003. Subsequent to the pilot survey, the questionnaire was reviewed and amended in light of comments received. Although the questionnaires were in English, the questions were explained to the respondents in their language of preference, i.e. either Afrikaans, Xhosa or English. In order to maximise the quality and quantity of information, the questionnaires were personally distributed and completed by the study team together with the informants. This proved to be of value as the questions and the purpose of the study could be explained to informants on a one to one basis. Respondents were generally keen to provide information.

In addition to the questionnaire survey, informal discussions were held with community leaders and members of the community. Discussions were also held with officials from both Tygerberg and Blaauwberg Administrations in an attempt to obtain relevant information (i.e. population densities, water use patterns, water charges, water metering and water consumption).

Both the study areas are bordered by informal settlements. Only the formal RDP type houses were sampled and surveyed. In both areas a sample of 100 houses each were representatively sampled and surveyed. Observations formed a key component to the field survey, not only as a means to validate the information received from respondents, but also to add value to the process. Such observational evidence is clearly qualitative with the only active aspect being the direct questioning of the respondent by the researcher, which may guide the content of the material recorded. It is important to acknowledge that the qualitative data were mainly observational associations that were likely to be influenced by personality, attitude and diligence of the observer and other subjective factors.

It is important to note that the figures presented in this report are based purely on the information collected during a social survey as mentioned earlier in the report.

3.2 PHYSICAL DESCRIPTION

The Fisantekraal LIHD area is situated a few kilometres north of the affluent Cape Town suburb of Durbanville.

Officials from both Tygerberg and Blaauwberg Administrations alluded that approximately 1 500 RDP units were built in this area during the year 2000. The community of approximately 9 000 consists mainly of people who have moved to the area from surrounding rural areas and the Eastern Cape. The people have come to the city looking for employment opportunities and a better quality of life. Initially they were living in informal housing but have been steadily moving into formal RDP houses built for them by the authorities in the area. This has been happening in a well-planned and orderly manner. Unemployment is however, a big problem in the area. This is exacerbated by the fact that a large number of the residents in urban high-density areas are uneducated and unskilled thus rendering them basically unemployable.

DuNoon is located in the Table View area, about 45 km north-west of Cape Town. The area consists of approximately 2500 RDP houses and various small structures used mainly for the provision of services to the community, i.e. hairdressers, shops, shebeens, etc. The population is estimated to be approximately 12 500 people.

3.2.1 Climate

Cape Town has a Mediterranean climate, where the summers are generally warm and dry with daily average temperatures of 25°C. Temperatures often rise to a high of 30°C and the average minimum temperature is 16°C. It seldom rains in summer, and only briefly when it does. The winters are cool and wet, with an average minimum temperature of about 7°C. Most of the rainfall occurs in winter, but due to the topography the rainfall varies quite dramatically from one area to the other. The rainfall varies between 500 mm and 1700 mm in the Cape Peninsula, to between 500 mm and 800 mm in the Cape Flats, and ranging from 800 to over 2600 mm in the mountains to the east of the Cape Metropolitan Area. Cape Town International Airport situated on the Cape Flats receives an average rainfall of 554 mm per annum (South African Weather Bureau, 1998). Cape Town is also well known for its strong south-easterly winds in summer.

3.3 SOCIO-ECONOMIC DESCRIPTION

3.3.1 Demography

The initial proposal was to compare the data gathered during the social survey with census figures, data available from the City of Cape Town's Housing Department and other Government Departments. This was however found not possible due to the fact that the census data are only available for enumerator districts and not for specific suburbs per se. The social survey involved collecting information from a sample in both Fisantekraal and DuNoon on number and type of dwellings as well as the number of occupants in the dwellings.

Both communities consist mainly of Afrikaans and Xhosa speaking people. However, it was evident that the Fisantekraal community has approximately 60% Afrikaans speaking and 30% Xhosa speaking people. On the other hand, the DuNoon community consist of approximately 70% Xhosa speaking and 20% Afrikaans speaking with an additional 10% of the population being immigrants from neighbouring African countries. The majority of the people have migrated from the surrounding squatter camps and other informal areas to Fisantekraal and DuNoon.

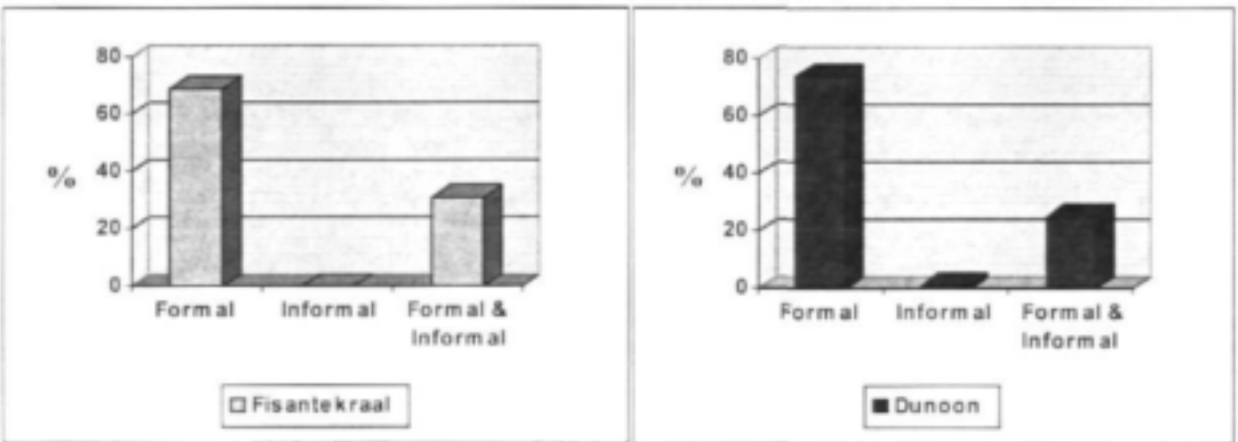

Figure 3.1 : Type of accommodation structures in Fisantekraal and DuNoon

Figure 3.1 shows the type of accommodation structures for the sample interviewed in both Fisantekraal and DuNoon. The majority of the sample interviewed lives in formal housing, only 1% of the interviewees live in informal structures (shacks). However, approximately 31% of the Fisantekraal and 25% of the DuNoon community have extended their houses with the addition of informal structures. It was noted that where people have extended their houses, more people occupy that residence compared to a normal sized RDP house.

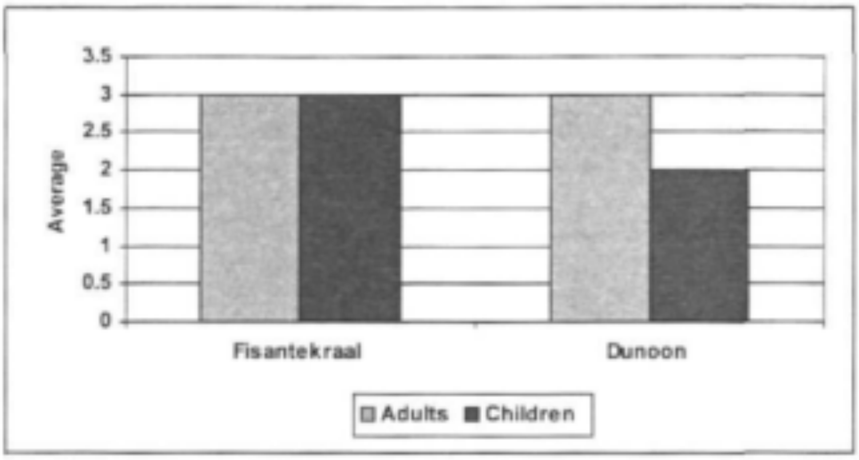

Figure 3.2 : Average number of adults and children per household

Figure 3.2 indicates the average number of adults and children per household. Fisantekraal has the same average number of adults and children per household, namely 3. In DuNoon the average number of adults is 3 and that of children is 2. Despite the differences in terms of cultural composition, the average number of adults is the same in both areas. The difference in composition can possibly be attributed to the fact that the immigrants from the neighbouring African countries, currently living in DuNoon, are generally single adults with no children.

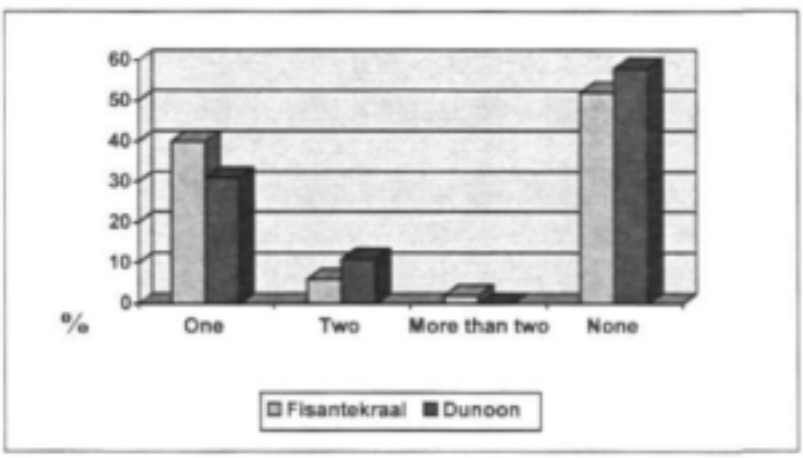

Figure 3.3 : Percentage of informal structures (shacks and wendy houses) added to formal RDP property

Figure 3.3 shows the number of informal accommodation units which have been added to the normal RDP housing property by the residents. Approximately 40% of the Fisantekraal and 31% of the DuNoon respondents have one separate informal accommodation unit on their property. A small percentage of respondents have more than one shack and/or Wendy house on their property. This obviously increases the average number of people per household in the area. Household sizes therefore range from 1 to 16 people. The households consist mainly of extended families that have either moved into the main house or erected a Wendy house type structure in the backyard. Often the occupants of the informal structure are required to pay rent thus providing an additional source of income for the homeowner. The average number of people per household in Fisantekraal is 6 and in DuNoon the average is 5. The average in this survey was calculated as the number of people on an erf, taking into account the extended families living in the outer buildings. It was decided to include everyone living on the erf into the study as they all are deemed to use the water supplies and toilet facilities in the main house.

Based on the information collected during the social survey, the population figure for Fisantekraal is estimated at 9 000 and for DuNoon at 12 500. These figures were derived from the number of houses in the area and the average number of people per household.

3.3.2 Economic Situation

Although no specific questions regarding the economic situation in the study areas were addressed in the questionnaire, the following were deduced from observations and informal discussions with the residents.

- It appears that there is a strong correlation between level of education and standard of living of people in these areas.
- Poverty and unemployment are closely correlated. Unemployment is a significant contributor to poverty.

- Unemployment rates tend to be highest among blacks, women, the youth, and among those with no previous work experience.
- In general high levels of poverty prevail in these areas.

From the informal discussions it can be concluded that the average wages are well below the minimum living level, educational qualifications are low, the residents have few other resources and they demonstrate little mobility on the labour market.

3.4 POTABLE WATER SUPPLY, USAGE

3.4.1 Background

The questionnaire also addressed the availability of household connections (i.e. taps, showers, baths and flush toilets). The purpose was to estimate the portion of water being discharged into the sewers as a percentage of the total consumption. As a result of the information obtained, it is possible to assume that, although various problems are experienced in LIHD areas with the actual recovery of cost of water supply, the supply of water to these areas is not a prohibiting factor. Respondents indicated that the main uses of water is for domestic purposes, i.e. washing and cooking.

3.4.2 Household connections

Approximately 91% of the sampled houses in Fisantekraal and 99% in DuNoon have a potable water household connection via a sink supplied in the kitchen. During the survey the residents indicated that having a tap inside the house makes the usage of water easier and more convenient, because water is readily available. In a number of houses it was observed that the tap at the kitchen sink was constantly dripping, which obviously leads to an increase in water usage. The households, who do not have a tap inside the house, collect water from a tap outside the house.

There were approximately 16% of the residents in Fisantekraal and approximately 17% in DuNoon who indicated that they have either a bath or a shower connected to the sewer. However, the respondents noted that they prefer to use a plastic bucket/basin instead of a bath and/or shower in order to minimise their water usage. Observations indicated that even though some residents have baths and/or showers they still use a plastic bucket to bathe. It was also noticed that a number of these baths and/or showers were not connected to the sewer, and therefore people could not use them. Further, the residents also indicated that it takes significantly longer to boil enough water to fill a bath rather than a bucket. Using a bath is thus more time consuming and uses more electricity than using a bucket. Lack of financial resources was given as the reason why most respondents cannot afford a bath and/or shower. In most instances, even though these facilities are available, they are often not in use due to lack of financial resources.

3.4.3 Water used for personal purposes

The respondents in both Fisantekraal and DuNoon indicated that they do not have an idea of the amount of water they use per day, since the water meters in the areas were either not working, not properly connected or were not read by the Local Authorities. In an attempt to estimate the water usage in these areas, the questionnaire addressed questions on the size and type of baths/buckets people use and also the number of times they wash per day. Based on the results of this survey and the assumption that each person uses a minimum of 20 litres of water every time they wash (i.e. twice per day), it was estimated that an average of 120 litres and 100 litres of water are used per household in Fisantekraal and DuNoon respectively on a daily basis for washing (ablution) purposes only. The higher estimated usage in Fisantekraal is due to the higher occupancy per household. Based on the information collected and observations during the survey it can be concluded that the bulk of the water consumed in these LIHD areas is for washing (i.e. clothes, dishes and ablution). It should also be noted that the people living in the informal squatter areas also collect water from the taps at the formal (RDP) houses.

These additional water consumption figures are not accounted for in this report.

3.4.4 Sanitation Systems

Approximately 99% of the respondents in both Fisantekraal and DuNoon have flush toilets in their homes. The remaining 1% who do not have flush toilets use the toilet facilities at their neighbours. The questionnaire also asked the respondents to give an indication of how often the toilet was flushed in a day. Figure 3.4 gives an indication of the toilet flushing frequency in the two areas. In Fisantekraal the majority of the sampled respondents (51%) flush their toilet approximately 6-10 times per day, whereas 55% of the DuNoon respondents flush their toilets between 1-5 times per day. Assuming that approximately 11 litres of water is used per flush and using the highest range of 10 times per day, it was assumed that approximately 110 litres of water gets flushed per household per day in Fisantekraal. For DuNoon taking the highest range of 5 times per day, it was estimated that approximately 55 litres of water gets flushed per household per day in DuNoon. This difference in usage can possibly be attributed to the difference in population density per erf, potential difference in education levels, the difference in unemployment rates (i.e. people at home throughout the day) and the awareness of water saving.

Various attempts were made to obtain information regarding the cost of water to these LIHD areas. However, no information could be obtained from the various municipal administrations. The questionnaire also attempted to get an idea of how many people pay and how much is paid for water supply per month. In Fisantekraal approximately 20% of the respondents indicated that they currently do not pay for their water supply. In DuNoon approximately 79% of the respondents noted that they do not pay for their water supply. However, the information obtained and the results from the survey indicate that approximately 99% of the sample in Fisantekraal and 98% in DuNoon have water meters and the municipalities maintain that everyone is being invoiced on a monthly basis. The respondents in Fisantekraal indicated that the water meters were not regularly read and some were not even aware that they had a water meter on the property. Observations during the survey confirmed these discussions as many of the water meters were covered with paving blocks.

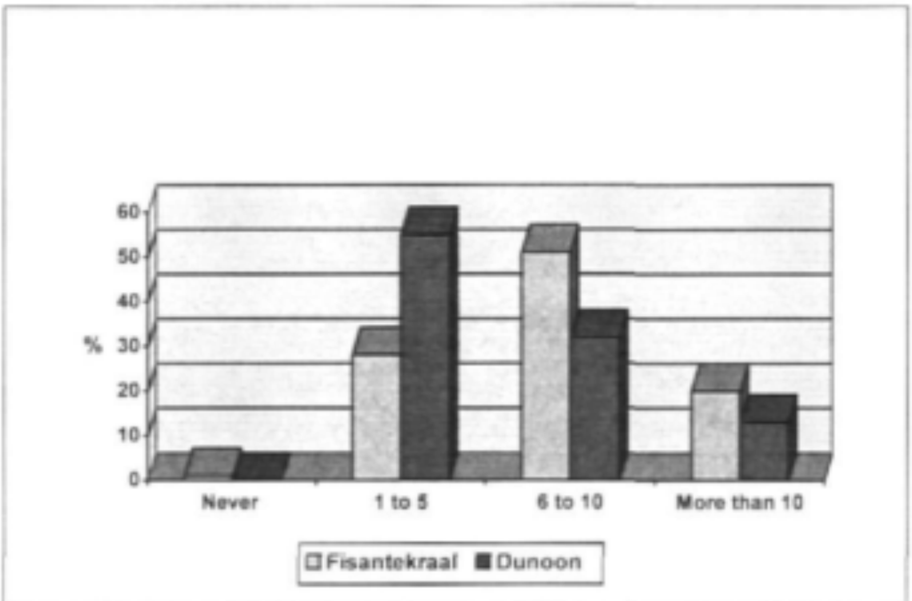

Figure 3.4 : Frequency of toilet flushing per day, cost and availability of water

Participants also indicated immense unhappiness with the current billing system, which according to them is a mere estimate from the municipalities. Similar responses were received from the DuNoon respondents who indicated that the community as a group decided not to pay for the water supply due to the lack of a reliable water billing system. Respondents also noted that other community members threatened to use water from their taps if they decide to oppose the decision and continue to pay for their water supply. During follow-up discussions with municipal officials, it was noted that due to various reasons the municipality is not able to read the water meters as required. Officials indicated that most of the residents are not charged for their water supply, because the majority of people use less than the free 6 kℓ per household per month. A major problem experienced in these areas is the inability of people to pay for services, whether it be water supply, electricity supply or refuse removal. The high level of poverty in these areas makes it impossible for people to afford payment for these services.

From looking at some of the invoices, it is believed that the people from Fisantekraal and DuNoon are being charged a minimal amount for their water usage, because they use less or slightly more than the free 6 kℓ per household per month. It is important to note that respondents indicated that they were under the impression that they were being charged between R10–R100 for water usage, merely because they do not know how to read their invoices.

3.5 WATER DISCHARGE PATTERNS

3.5.1 Disposal of wastewater

This section of the questionnaire aimed to provide some clarity on the wastewater discharge patterns. The information deemed from this section of the questionnaire is indicated in Figure 3.5. Approximately 79% and 70% of the Fisantekraal and DuNoon respondents respectively indicated that they only use their water once and then dispose of it through the sewer. The potential of re-using greywater is unexploited. Fifty-one percent of the Fisantekraal and 69% of the DuNoon respondents indicated that they dispose of greywater via the sewer, i.e. via the kitchen sink, toilet, bath and/or shower. The rest of the greywater is discharged into the stormwater system, in the garden or the veld.

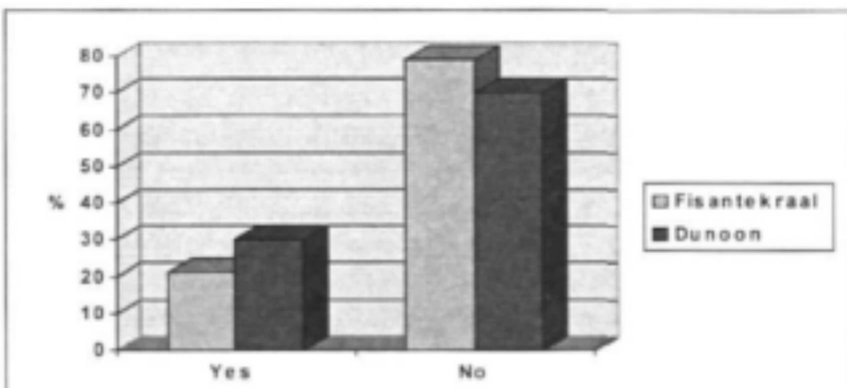

Figure 3.5 : Re-use of greywater

3.5.2 Water used for washing clothes

Due to the lack of real data this report aims to estimate the amount of greywater being discharged from these LIHD areas on a daily basis. The figures that are illustrated below (Table 3.1) are an estimate of the consumption figures based on the assumption that 1 bucket represents 5 liters of water. The data represented below is a direct result of information obtained from the questionnaire.

Table 3.1: Estimate of consumption figures

Buckets	Litres	Fisantekraal	Dunoon
1 - 2 buckets	5 – 10 litres	8%	7%
2 - 4 buckets	10 – 20 litres	25%	26%
4 - 6 buckets	20 – 30 litres	38%	38%
6 - 8 buckets	30- 40 litres	16%	22%
8 - 10 buckets	40- 50 litres	9%	6%
More than 10 buckets	More than 50 litres	4%	1%

These figures could be an over- or underestimate of the real usage. Further, it is important to note that the water usage for washing clothing was not assessed as part of this survey. However, respondents indicated that they dispose approximately double their normal usage on the days when they do their washing. It was noted that respondents do their washing at least once a week in either the municipal black dustbins or 25 litre drums. Further it was indicated that respondents change their wash water at least two times, but only uses one drum of water for rinsing. It is therefore estimated that each household uses at least 70 litres of water for washing clothing per week.

Approximately 21% of informants in Fisantekraal and 30% in DuNoon indicated that they re-use greywater as a means to saving water. It was noted that the greywater from washing is being disposed off either into the stormwater drains or on the gardens.

3.6 SUMMARY OF RESULTS FROM SOCIAL SURVEY

The results from the social survey pertinent to this research can be summarised as follows:

3.6.1 Population density

There are 1 500 and 2 500 RDP erven in Fisantekraal and DuNoon respectively. The population of Fisantekraal is estimated to be 9 000 and that for DuNoon is 12 500. No data from the local authority or the census was available to serve as a comparison. The above estimates were based on an average number of residents per erf of 6 for Fisantekraal and 5 for DuNoon as determined in the survey. This takes into account the occupants of informal structures erected on the erfs.

3.6.2 Potable water consumption

It is estimated that the residents in Fisantekraal use about 300 ℓ/household (total from Sections 3.4.3, 3.4.4 and 3.5.2), which is an average of about 50 ℓ/capita/d (i.e. 9 kℓ/month). The residents in DuNoon use about 225 ℓ/household/d (total from Sections 3.4.3, 3.4.4 and 3.5.2), which is about 45 ℓ/capita/d (i.e. 6,75 kℓ/month) . The average water consumption in these areas although low, is within the range of 40-100 ℓ/capita/d expected in tropical developing countries (Mara, 1976). Since the reading of the water meters and the billing of the residents were not regularly done by the local authorities, no water consumption figures were available from any other source to serve as a comparison. However, the indications by local authorities that the majority of households do not exceed the free basic water consumption of 6 kℓ/month seem to be incorrect according to consumption patterns in both Fisantekraal and DuNoon.

3.6.3 Wastewater disposal patterns

The majority of the residents do not re-use the greywater. Most of the greywater is therefore discharged into the sewer. It can therefore be assumed that most of the potable water used by the households is discharged into the sewer.

4 WASTEWATER CHARACTERIZATION

4.1 INTRODUCTION

In accordance with the objectives outlined in Chapter 1, samples were collected from the Fisantekraal and DuNoon developments in order to characterize the wastewater. This is because characterization of municipal wastewaters form an important design component of biological treatment plants as will be explained later in Chapter 5.

4.2 METHODS AND PROCEDURES

4.2.1 Sampling and analysis

The samples for DuNoon (near Killarney Gardens) were collected from the outfall sewer that discharges to the Potsdam WWTW, samples were collected from the 1st manhole adjacent to the SATI container depot feeding the DuNoon pumpstation (off Sati Road). The location of the manhole as measured by a GPS instrument (Garmin strex) is approximately 33.81°S and 18.52°E.

Samples for Fisantekraal were collected from the second last manhole on the outfall sewer from Fisantekraal to the Fisantekraal pumpstation. The wastewater is pumped from Fisantekraal pumpstation to the Kraaifontein WWTW. The location of the manhole as measured by a GPS instrument is 33.79°S and 18.71°E.

4.2.2 Sampling Procedure

An automatic wastewater sampler (Aquatic Aqua Cell) was placed adjacent to the manhole and set up with the inlet hose inserted well into the U-channel of the sewer. The inlet of the hose was weighted using a steel tip to prevent it from floating to the surface of the channel during high flow periods. The inlet also had several suction holes (inlets) to minimize blockages that may be caused by rags in the sewers, which is more characteristic of sewage from low-income areas.

One-litre samples were taken each hour over a 24-hour period. Each litre sample was the composite of three 250mℓ aliquots taken 20 minutes apart during the same hour period.

4.2.3 Flow Metering

An ultrasonic flow meter was set up in each manhole to measure the height of the surface in the U-channel from the sensor positioned directly above. The instrument was calibrated using a velocity meter, which takes into account the width of the channel, the gradient of the channel and the type of material of which the sewer is made.

The height/level data was stored on a data logger and the information downloaded on a PC using the Flopac 2000 software supplied with the instrument. The battery life of the data loggers ranged from about 7 to 12 days, after which they were re-charged. Once the data was downloaded it was converted using Microsoft Excel to flow readings in Mℓ/d. The hourly flows corresponding to the sample times were then established.

4.2.4 Analysis Procedure

Once the autosampler was brought back to the laboratory, samples over a two-hour period were combined and decanted into a 300 mℓ container. The remainders of the samples were put into a 20 ℓ bucket to form a 24 hour composite sample. The 300 mℓ containers were marked according to the time the sample was taken. In certain instances, during periods of low or zero flow (as was the case with Fisantekraal), there was no sample for that particular time period.

The contents of each of the 300 mℓ containers were homogenized and analyzed for:

- Total suspended solids (TSS)
- Volatile suspended solids (VSS)
- Chemical oxygen demand (COD)
- Total kjeldahl nitrogen (TKN)
- Ammonia (free and saline) (FSA)
- Total phosphorus (Total P)
- Ortho-phosphate (Ortho P)
- pH
- Chloride, and
- Alkalinity.

The test procedures given in Standard Methods (1985) were used in measuring the various parameters.

The composite sample was also analyzed for the above (see Appendix B). A portion of the composite sample (approximately 2.5 ℓ) was flocculated using alum (20 mℓ of 50 g/ℓ solution), filtered through 0.45 µm filter paper and stored in the refrigerator for use in the measurement of the slowly biodegradable and unbiodegradable particulate COD fractions.

5 RESULTS

5.1 GENERAL

As mentioned in Chapter 1, the characteristics of wastewater from low-income housing schemes in South Africa are not well known. This is because many research focused on the characterization of municipal wastewater from catchments with full waterborne sewerage (WRC, 1984; Wentzel *et al.*, 1999). In order to provide optimal solutions accurate characterization of wastewater is required for the design of new wastewater treatment plants (WWTP) or extensions to the existing plants in low-income residential areas. This is because the design of biological treatment plants will be as good as the selected wastewater characteristics.

In this section, the experimental results (mainly wastewater characteristics) from both Fisantekraal and DuNoon, which are low-income high-density residential areas will be presented and discussed in more details.

The methods described by Wentzel *et al.* (1995, 1999) were used for the characterization of the raw sewage into the various fractions, i.e. readily biodegradable COD (RBCOD), slowly biodegradable (SBCOD), unbiodegradable soluble COD (USCOD) and unbiodegradable particulate COD (UPCOD).

Section 1.3 indicate the months which were regarded as representative of dry and wet weather flow periods respectively. In considering the results of the survey it is necessary that not only the long-term rainfall trends during these months be observed, but in specific also the rainfall during the period for which the survey was conducted. Table 5.1 summarises this information. Koeberg and Altydgedacht are the closest rainfall stations to DuNoon and Fisantekraal respectively for which long-term rainfall records are available.

The observed rainfall at Altydgedacht and Cape Town Weather Office were used to give an indication of rainfall during the study period.

Table 5.1 : Rainfall Statistics from 1920 to 1989 (from Weather Bureau, SA)

Month	1920 to 1989		2003 to 2004	
	Altydgedacht Rainfall (mm)	Koeberg Rainfall (mm)	Altydgedacht Rainfall (mm)	Cape Town WO Rainfall (mm)
January	**15.3**	**10.9**	**7.0**	**2.4**
February	**17.8**	**12.4**	**1.0**	**0.2**
March	**19.5**	**14.9**	**8.8**	**9.2**
April	**49.0**	**37.2**	**16.1**	**11.9**
May	79.0	63.6	12.5	3.8
June	**98.8**	**79.2**	**28.1**	**25.0**
July	**91.1**	**72.8**	**59.2**	**33.4**
August	**82.3**	**65.4**	**91.2**	**100.3**
September	**50.8**	**38.7**	**28.2**	**25.1**
October	36.6	26.4	41.2	19.2
November	21.9	15.6	2.8	3.4
December	16.7	12.1	6.1	9.2
MAP	**579**	**450**	**302**	**243**

NB: Bold values represent the months identified to represent the dry and wet periods respectively.

Figure 5.1 gives a graphical representation of the average monthly long-term rainfall for the Altydgedacht and Koeberg rainfall stations as well as the average monthly rainfall for the Altydgedacht and Cape Town Weather Office rainfall stations for 2003/2004. These graphs clearly indicate the below average rainfall experienced during the study period.

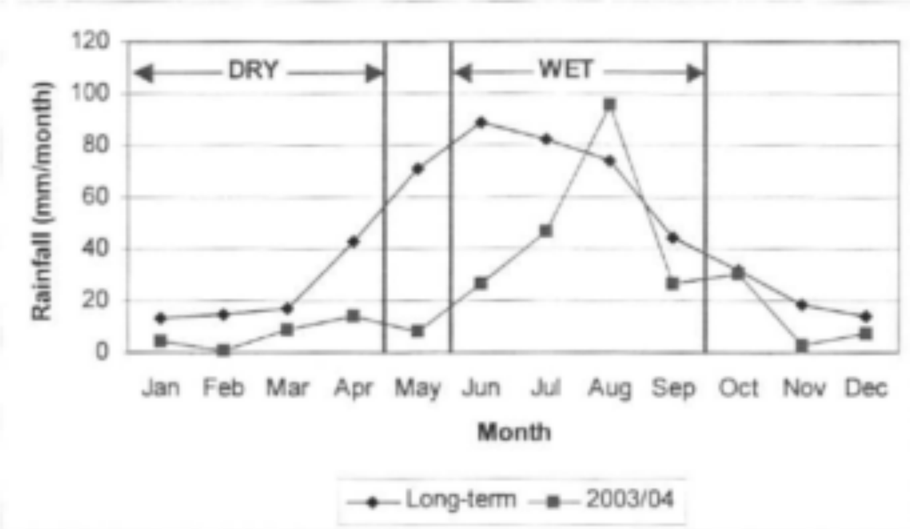

Figure 5.1 : Rainfall distribution

5.2 RESULTS FOR THE FISANTEKRAAL CATCHMENT

5.2.1 General

The average flows during the dry and wet season were the same. Average concentrations for most of the parameters, except for the TSS and VSS, were slightly lower during the dry season than during the wet season (see Table 5.2).

An increase in average flow during the dry season can possibly be attributed to the use of more water during the hot summer months, e.g. for bathing. The lower flows during the winter can be ascribed to the fact that this is fairly new area with closed connections; hence infiltration is not expected to be a problem. In addition, the low flows during the winter season clearly suggest that there was not much rainfall during the time of sampling. This is evident from Table 5.1 which shows the 79 year rainfall period for catchments within the vicinity of Fisantekraal residential area. From Table 5.1 it is clear that there was low rainfall (measured in mm) received during the time the sampling was undertaken, as the averages are below the averages observed over a period of 79 years (i.e. 1920 to 1989).

Table 5.2 : Results for Fisantekraal

Parameter	Unit	Dry Season	Wet Season
		Average	Average
Flow	kℓ/d	238	238
COD	mg/ℓ	1002	1165
TSS	mg/ℓ	371	459
VSS	mg/ℓ	320	400
TKN	mgN/ℓ	125	156
FSA	mgN/ℓ	93.4	108
Total P	mgP/ℓ	15.4	17.2
Ortho P	mgP/ℓ	11.5	12.3
VSS/TSS		0.86	0.87
RB COD/ COD	%	16	15.3
FSA/TKN		0.75	0.69
TKN/COD		0.124	0.134
Total P/COD		0.015	0.015
Ortho P/Total P		0.75	0.72

5.2.2 WASTEWATER FRACTIONS

5.2.2.1 Unbiodegradable Soluble COD Fraction ($f_{s,us}$)

The Unbiodegradable Soluble COD Fraction ($f_{s,us}$) of the influent wastewater with respect to the total influent COD was determined from the method of Ekama *et al.*, 1986.

The daily average $f_{s,us}$ data for both dry and wet weather conditions were plotted in a linearised probability graph (for details on this see Muller *et al.*, 2003) to check for normality as shown in Appendix A.1.

Fig A.1.1a data fit relatively close to the true normal line, indicating that the data are uniformly distributed, and give a mean $f_{s,us}$ = 0.059 and a sample standard deviation (SSD) of 0.005. For Fig A.1.1b, although no outliers were identified, the data do exhibit deviation from the true normal line for a range of values, which suggests that the data are not uniformly distributed. However, the data gave a mean $f_{s,us}$ = 0.059 and SSD = 0.012 regardless of this deviation. Thus both the dry and wet weather conditions gave an overall mean of $fs_{,us}$ = 0.059. This mean value corresponds reasonably well with the range of typical values expected from domestic wastewaters (middle to high-income residential areas) in South Africa (0.04 to 0.10, WRC, 1984), and it is significantly lower than values found by other researchers who used wastewater from industrial and middle to high income residential areas (Mitchells Plain WWTP raw wastewater): Cronje *et al.* (2000), $fs_{,us}$ = 0.085; Ubisi *et al.* (1997a,b), $fs_{,us}$ = 0.090; Mbewe *et al.* (1995), $fs_{,us}$ = 0.090 and Muller *et al.* (2003), $fs_{,us}$ = 0.096. However, it must be noted that the latter values were obtained with laboratory-scale conventional systems (with long sludge ages greater than 15 days), which was not the case in this research.

5.2.2.2 Unbiodegradable Particulate COD Fraction ($fs_{,up}$)

The unbiodegradable particulate COD fraction ($fs_{,up}$) calculated using the methods described by Wentzel *et al.*, 1995, 1999 gave mean values higher than 35% on average which is not a true reflection of the particulate fraction in the wastewater. This is because to accurately estimate $fs_{,up}$ values a long sludge age (>15 days) laboratory-scale system is required which was not done in this case. As a result of this, $fs_{,up}$ values could not be estimated (see Chapter 6, Section 6.2).

5.2.2.3 Readily Biodegradable COD with respect to total COD ($f_{ts,S}$)

From Fig A.1.2a and A.1.2b, no outliers were identified although the data in Fig A.1.2b do exhibit some deviation from the true normal distribution line. The analysis gave a mean $f_{ts,S}$ = 0.160 with SSD = 0.024 and $f_{ts,S}$ = 0.153 with SSD = 0.038 for dry and wet weather seasons respectively. The overall average of $f_{ts,S}$ = 0.157 compares reasonably well with the square wave (SQW) of $f_{ts,S}$ = 0.160 obtained by Marais and Ekama (1978), $f_{ts,S}$ = 0.140 obtained by Muller *et al.* (2003), $f_{ts,S}$ = 0.145 found by Ramphao *et al.* (2004), but it is significantly lower than the SQW $f_{ts,S}$ = 0.190 (SSD within the same range) obtained by Mbewe *et al.* (1995) all using domestic wastewaters from Mitchells Plain WWTP in Cape Town.

5.2.2.4 *VSS/TSS Ratio (f_i)*

From Fig A.1.3a and A.1.3b, the VSS concentrations track TSS concentrations fairly closely, being lower by an apparent constant value. The average daily VSS/TSS ratio (f_i) for the mixed liquor was calculated (see Appendix A.1) and is shown plotted in Fig A.1.4a and A.1.4b. Fig A.1.4a shows that the data are normally distributed, and in Fig A.1.4b the data do not lie closely to the true normal distribution line and can therefore be classified as non-normally distributed data. This means that only Fig A.1.4a (dry weather season) results need to be analyzed. Fig A.1.4a data are normally distributed over a relatively narrow range, from 0.845 to 0.884 mgVSS/mgTSS giving a mean value of f_i = 0.862 mgVSS/mgTSS and a sample standard deviation of 0.014.

5.2.2.5 *Ammonia Fraction of the Influent TKN (f_{na})*

From Fig A.1.5a and A.1.5b, the data lie close to the true normal distribution line, thus indicating that the data are normally distributed and give mean values of f_{na} = 0.745 with SSD = 0.026 and f_{na} = 0.692 with SSD = 0.043 for the dry and wet weather seasons respectively. This gives an overall average of f_{na} = 0.719 which falls within the typical values expected for domestic wastewaters (middle to high income with an industrial component) in South Africa (0.60 to 0.80, WRC, 1984).

5.2.2.6 *TKN/COD Ratio*

The data in Fig A.1.6a *and* A.1.6b *exhibits little deviation from the true normal* line, indicating that the data are normally distributed, i.e. it is accepted that the data were small and random, with no single factor exerting a dominating influence. The experimental TKN/COD ratios were 0.124 with SSD = 0.009 and 0.134 with SSD = 0.006 for the dry and wet weather seasons respectively. The overall mean is approximately 0.129 which falls outside the range of typical values expected from domestic wastewaters in South Africa (0.07 – 0.10, WRC, 1984).

5.3 RESULTS FOR THE DUNOON CATCHMENT

5.3.1 GENERAL

The results for DuNoon (Table 5.3) show that the average flow during the dry season is higher than during the wet season. Consequently most of the parameters are slightly lower during the dry season than during the wet season. As mentioned previously, it would therefore appear that infiltration is not a problem during the wet season. It should however be noted that the rain received during the year 2003/2004 was low (Table 5.2) and not typical of wet seasons in the Western Cape.

Table 5.1 : Results for DuNoon

Parameter	Unit	Dry Season	Wet Season
		Average	Average
Flow	kℓ/d	1011	939
COD	mg/ℓ	896	1059
TSS	mg/ℓ	400	481
VSS	mg/ℓ	360	404
TKN	mgN/ℓ	92.9	104.5
FSA	mgN/ℓ	62.7	73.1
Total P	mgP/ℓ	12.3	13.2
Ortho P	mgP/ℓ	8.9	9.3
VSS/TSS		0.900	0.838
RB COD fraction		0.137	0.122
TKN/COD		0.099	0.100
FSA/TKN		0.68	0.70
Total P/COD		0.014	0.012

5.3.2 WASTEWATER FRACTIONS

5.3.2.1 Unbiodegradable Soluble COD Fraction ($fs_{,us}$)

Fig A.2.1a data fit relatively close to the true normal line, indicating that the data are uniformly distributed, and give a mean $fs_{,us}$ = 0.044 and a sample standard deviation (SSD) of 0.012. For Fig A.2.1b, the data lie close to the true normal line and gives a mean $fs_{,us}$ = 0.052 and SSD = 0.011. Thus both the dry and wet weather conditions gave an overall mean of $fs_{,us}$ = 0.048. This mean value corresponds reasonably well with the range of typical values expected from domestic wastewaters (middle to high-income residential areas) in South Africa (0.04 to 0.10, WRC, 1984), and it is significantly lower than values found by other researchers who used wastewater from industrial and middle to high income residential areas (Mitchells Plain WWTP raw wastewater): Cronje *et al.* (2000), $fs_{,us}$ = 0.085; Ubisi *et al.* (1997a,b), $fs_{,us}$ = 0.090; Mbewe *et al.* (1995), $fs_{,us}$ = 0.090 and Muller *et al.* (2003), $fs_{,us}$ = 0.096.

5.3.2.2 Unbiodegradable Particulate COD Fraction ($fs_{,up}$)

The unbiodegradable particulate COD fraction ($fs_{,up}$) calculated using the methods described by Wentzel *et al.*, 1995, 1999 could not be accurately estimated (see Chapter 6, Section 6.2 for a detailed explanation).

5.3.2.3 Readily Biodegradable COD with respect to total COD ($f_{ts,S}$)

From Fig A.2.2a and A.2.2b, no outliers were identified although the data in Fig A.2.2b do exhibit some deviation from the true normal distribution line. The analysis gave a mean $f_{ts,S}$ = 0.137 with SSD = 0.021 and $f_{ts,S}$ = 0.122 with SSD = 0.018 for dry and wet weather seasons respectively. The overall average of $f_{ts,S}$ = 0.130 compares reasonably well with the square wave (SQW) of $f_{ts,S}$ = 0.160 obtained by Marais and Ekama (1978), $f_{ts,S}$ = 0.140 obtained by Muller *et al.* (2003), $f_{ts,S}$ = 0.145 found by Ramphao *et al.* (2004), but it is significantly lower than the SQW $f_{ts,S}$ = 0.190 obtained by Mbewe *et al.* (1995) all using domestic wastewaters from Mitchells Plain WWTP in Cape Town.

5.3.2.4 VSS/TSS Ratio (f_i)

The VSS concentrations track TSS concentrations (Fig A.2.3a and A.2.3b) fairly closely, being lower by an apparent constant value, and this is evident from the VSS/TSS ratios (f_i) shown plotted in a linearised probability graph (Figs A.2.4a), which show that the data are uniformly distributed because there are deviations from the true normal distribution line. This gives an overall mean value of 0.848.

5.3.2.5 Ammonia Fraction of the Influent TKN (f_{na})

From Fig A.2.5a and A.2.5b, the data lie close to the true normal distribution line, thus indicating that the data are normally distributed and give mean values of f_{na} = 0.684 with SSD = 0.077 and f_{na} = 0.701 with SSD = 0.041 for the dry and wet weather seasons respectively. This gives an overall average of f_{na} = 0.692 which falls within the typical values expected for domestic wastewaters (middle to high income with an industrial component) in South Africa (0.60 to 0.80, WRC, 1984).

5.3.2.6 TKN/COD Ratio

The TKN/COD ratio in Fig A.2.6a shows slight deviation from the true normal line even though no outliers were observed. However, in Fig A.2.6b the data lie close to the true normal distribution line indicating that the data set are uniformly distributed, and give a mean TKN/COD ratio of approximately 0.100 with SSD = 0.011. The overall mean values found for DuNoon wastewater fall at the extreme end of typical values expected from raw domestic wastewaters (i.e. middle to high-income areas) in South Africa (0.07 to 0.10, WRC, 1984).

5.4 COMPARISON BETWEEN THE DRY WEATHER RESULTS FOR FISANTEKRAAL AND DUNOON CATCHMENTS

The dry weather characteristics are generally applied in design. This section compares the average dry weather characteristics for the two areas.

Table 5.4 : Dry weather characteristics for Fisantekraal and DuNoon

Mass Parameter Concentrations	Unit	Fisantekraal	DuNoon
COD	mg/ℓ	1002	896
TSS	mg/ℓ	371	400
VSS	mg/ℓ	320	360
TKN	mgN/ℓ	125	92.9
FSA	mgN/ℓ	93.4	62.7
Total P	mgP/ℓ	15.4	12.3
Ortho P	mgP/ℓ	11.5	8.9
Wastewater fraction			
TKN/COD		0.124	0.099
FSA/TKN	f_{na}	0.75	0.68
Total P/COD		0.015	0.014
RBCOD	$f_{bs,S}$	0.16	0.137
USCOD	$f_{S,us}$	0.059	0.053
VSS/TSS	f_i	0.864	0.858

The following is noted for the two areas:

- There is no significant difference between most of the parameter concentrations (also see Appendix B).
- The TKN, FSA, Total P and Ortho P concentrations for Fisantekraal are slightly higher than for DuNoon. Consequently the TKN/COD, FSA/TKN, Total P/COD fractions are also slightly higher.
- The TSS and VSS concentrations for DuNoon are slightly higher than for Fisantekraal.
- DuNoon has a slightly lower RBCOD fraction with respect to total COD (14%) than Fisantekraal (16%). However, the USCOD (6%) fraction for Fisantekraal are higher than for DuNoon ($f_{S,us}$ = 4%).

6 DISCUSSION OF WASTEWATER CHARACTERISTICS

6.1 INTRODUCTION

Before biological removal process design models can be used, it is necessary to determine the various fractions of the influent COD. These fractions are needed to accurately describe the behaviour of the biological removal process. Figure 6.1 shows the subdivisions as presented by Ekama *et al.* (1984). Although the terminology varies, these are the same fractions used in the IAWPRC Activated Sludge Model 1 (Henze *et al.*, 1987).

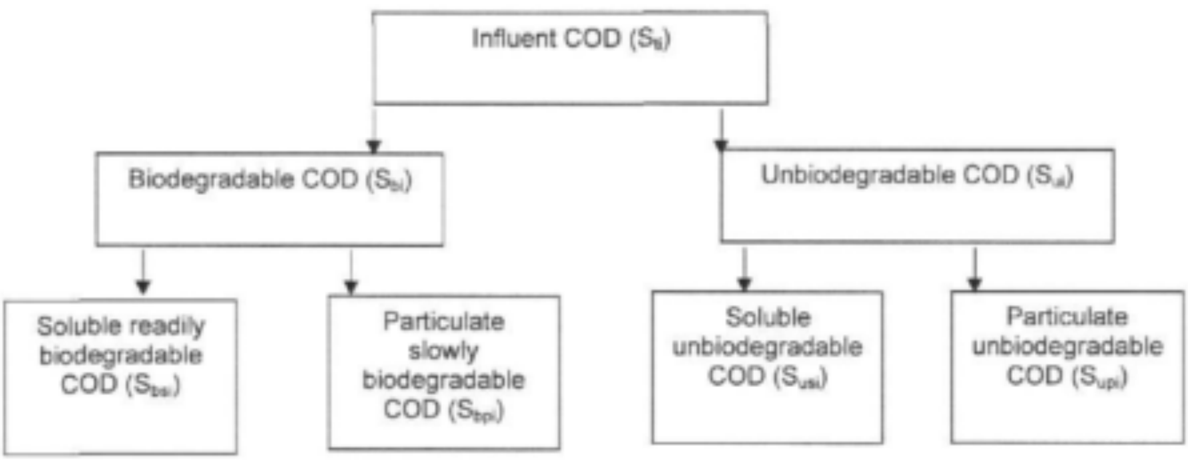

Figure 6.1 : Division of the total influent COD in municipal wastewater into its various constituent fractions.

6.2 DESIGN PARAMETERS

The first major subdivision of the total influent COD (S_{ti}) is into biodegradable (S_{bi}) and unbiodegradable (S_{ui}) fractions. Each of these is further subdivided. The unbiodegradable COD (S_{ui}) consists of two fractions: unbiodegradable soluble COD (S_{usi}) and unbiodegradable particulate COD (S_{upi}).

S_{usi} will pass through the treatment process and be discharged with the effluent. S_{upi} is enmeshed in the activated sludge. The mass of S_{upi} entering the system will equal the mass leaving the system via activated sludge wasting. Thus, S_{upi} has the principal effect of increasing the mixed liquor suspended solid (MLSS) concentration.

The reasonableness of the S_{upi} estimate is checked by running a laboratory scale unit at a long sludge age, say, 15 days or longer, calculating the total volatile solids concentration using the biodegradable COD (S_{bi}) and particulate unbiodegradable COD (S_{upi}) against the volatile mass observed. A long sludge age (>15 days) is selected because the total volatile mass of the sludge becomes more sensitive to influent volatile solids concentration as the sludge age increases.

The biodegradable COD fraction (S_{bi}) is divided into readily biodegradable soluble COD (S_{bsi}) and slowly biodegradable particulate COD (S_{bpi}). S_{bsi} is taken up by activated sludge in a matter of minutes and metabolized, giving rise to a high unit rate of oxygen demand for synthesis. S_{bpi} must first be absorbed onto the microorganisms, and broken down to simple chemical units by extracellular enzymes before finally being metabolized by the microorganisms. The soluble readily biodegradable fraction, S_{bsi}, plays an important role in biological phosphorus removal because phosphorus-removing microorganisms sequester volatile fatty acids (VFAs) in the S_{bsi} fraction, using the energy obtained from cleavage of a phosphate bond of the polyphosphates stored within the biomass.

In order to fully estimate wastewater characteristics, a steady state aerobic activated sludge needs to be operated at long sludge ages (>15 days). This will ensure that the S_{upi} can be accurately estimated. Once the S_{upi} is known, the particulate fraction of the COD ($f_{S,up}$) could be estimated, hence the fraction of the readily biodegradable COD with respect to biodegradable COD ($f_{S,bs}$). As this could not be done on this research due to financial constraints (i.e. not enough budget), then S_{upi}, S_{bi}, and $f_{S,bs}$ could not be estimated.

The Readily Biodegradable Soluble COD (S_{bsi}) is an important fraction especially in the anaerobic zone of a BPR process, where only the readily biodegradable soluble COD (S_{bsi}) component is susceptible to fermentation to form VFAs within the short detention time (1 - 2 hours).

Early evidence of the need for readily biodegradable substrate in phosphorus removal processes was provided by Fuhs and Chen (1975). They proposed that the enrichment of activated sludge with the phosphate accumulating bacteria, *Acinetobacter*, would ensure efficient biological phosphorus removal. The growth of *Acinetobacter* could be ensured by supplying readily biodegradable short carbon chain substrates such as ethanol, acetate, and succinate to an anaerobic zone in the process. Such a carbon source could also be provided by bleeding in fermented primary effluent or anaerobic digester supernatant liquor.

Further evidence of the need for VFAs in biological phosphorus removal was provided by Venter et al. (1978) and Osborn and Nicholls (1978). These experiments indicated that S_{bsi} is mostly utilized in the anaerobic reactor. This concept was also postulated by Nicholls and Osborn (1979) when they stated that S_{bsi} was taken up into the cell under anaerobic conditions and stored as poly-ß-hydroxybutyrate.

In seeking an explanation for the behavior of different phosphorus release patterns, Ekama et al. (1984) found that phosphorus release increased as the readily biodegradable soluble COD (S_{bsi}) increased. Ekama et al. (1984) concluded that a prerequisite for phosphorus release in the anaerobic zone is that the concentration of readily biodegradable soluble COD (S_{bsi}) surrounding the microorganisms in the anaerobic zone must exceed approximately 25 mg/ℓ. Therefore, S_{bsi} is thought to be a very important wastewater characteristic in the process of biological phosphorus removal.

7 CONCLUSIONS AND RECOMMENDATIONS

The principle aim of this research was to evaluate the wastewater characteristics from low-income high-density residential area. To address this objective, daily samples from the two (Fisantekraal and DuNoon) low-income areas were taken during the dry and wet weather seasons.

From the investigation, the following general conclusions can be drawn:

- An assessment was made of the social circumstances and behaviour of the residents of the areas investigated. Although this survey did give some indication of the nature of the area surveyed, the extent of the study was not sufficient to determine any relationship between social circumstances and wastewater characteristics. It can only be stated that the characteristics determined are typical of the type of areas investigated.

- This short-term study has demonstrated that the wastewater compositions and characteristics from low-income high-density residential areas gave wastewater characteristics that fall within the range of typical domestic wastewaters (middle to high-income areas) in South Africa ($f_{S,us}$ = 0.04 – 0.10; $f_{bs,S}$ = 0.08 – 0.25; f_{na} = 0.60 – 0.80 and TKN/COD ratio = 0.07 – 0.10, WRC, 1984).

- The unbiodegradable particulate COD fraction ($f_{S,up}$) could not be accurately estimated. This is because the reasonableness of $f_{S,up}$ estimate is checked by running a laboratory-scale unit at a long sludge age, say, 15 days or longer, calculating the total volatile solids concentration and checking this value against the volatile mass observed. A long sludge age is selected because the total volatile mass of the sludge becomes more sensitive to influent volatile solids concentration as the sludge age increases. The future work in determining $f_{S,up}$ should be contracted to an academic institution for in-depth analysis.

- The knowledge on characteristics of wastewater from South African low-income high-density housing schemes with full water-borne sewer reticulation and the social aspects that affect the characteristics of these wastewaters could not be accurately estimated because of the way the research was carried out, i.e. the methodology that was chosen to characterize the wastewater. In future proper laboratory scale should be operated for a reasonable longer time so that steady state could be achieved for accurate estimation of wastewater fractions.

- The work in this research is of a nature that is not sufficient to serve as a national guideline on the wastewater characteristics in low-income high-density residential areas, and similar researches, most probably in different areas, should be done.

8 LESSON LEARNT

The following lessons were learnt from this study and can benefit future studies in this regard:

- If an attempt is to be made to determine a relationship between specific social parameters and wastewater characteristics, a study will have to be conducted over a much higher number of different study areas. The social parameters which will be related to wastewater characteristics will have to be defined upfront to align the social survey correctly.

- Attempts should be made to identify study areas for which reliable data on parameters such as water consumption and population is readily available or for which it can be recorded over an extended study period.

- In the case of this study, doubts have been raised as to the reliability of the sampling method as it was felt that the samples possibly did not take account of solid organic matter which will still be broken up or dissolved in the water before the treatment works. This concern was raised with the samplers. It was mentioned that in the case of the Fisantekraal catchment the samples were taken after a pumping station and in the case of the DuNoon catchment it was taken quite a distance down the sewer where most of the solids could already have broken-up or dissolved. Despite the assurances obtained regarding this study, this is a legitimate concern and it is recommended that steps should be taken in any further studies that this uncertainty does not exist.

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APPENDIX A1

TRANSFORMED RANKED PROBIT GRAPHS FOR THE FISANTEKRAAL CATCHMENT

List of figures

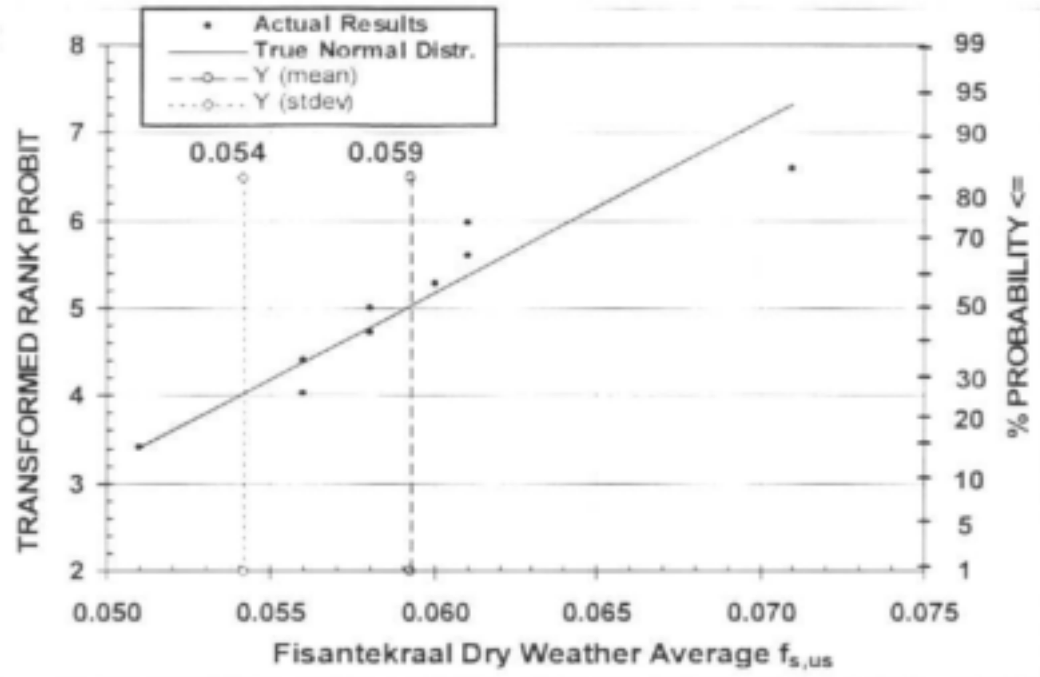


Figure A1.1a : Statistical plot of average dry weather unbiodegradable COD fraction ($fs_{,us}$) in the influent.

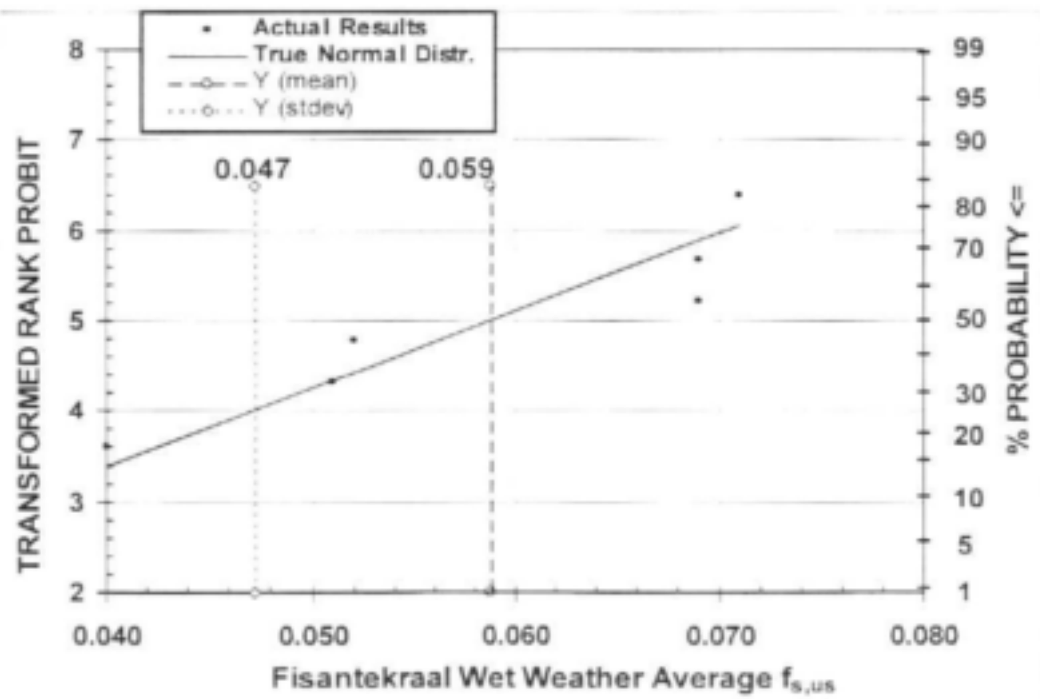


Figure A1.1b : Statistical plot of average wet weather unbiodegradable COD fraction ($fs_{,us}$) in the influent

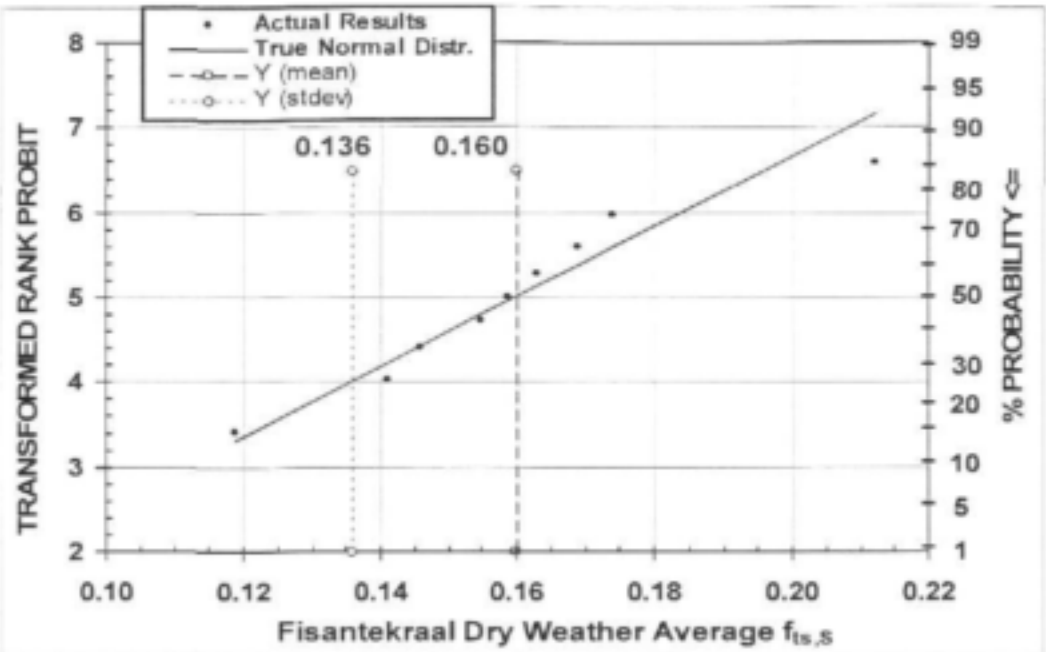


Figure A1.2a : Statistical plot of average dry weather readily biodegradable COD fraction with respect to biodegradable COD ($f_{ts,S}$) in the influent

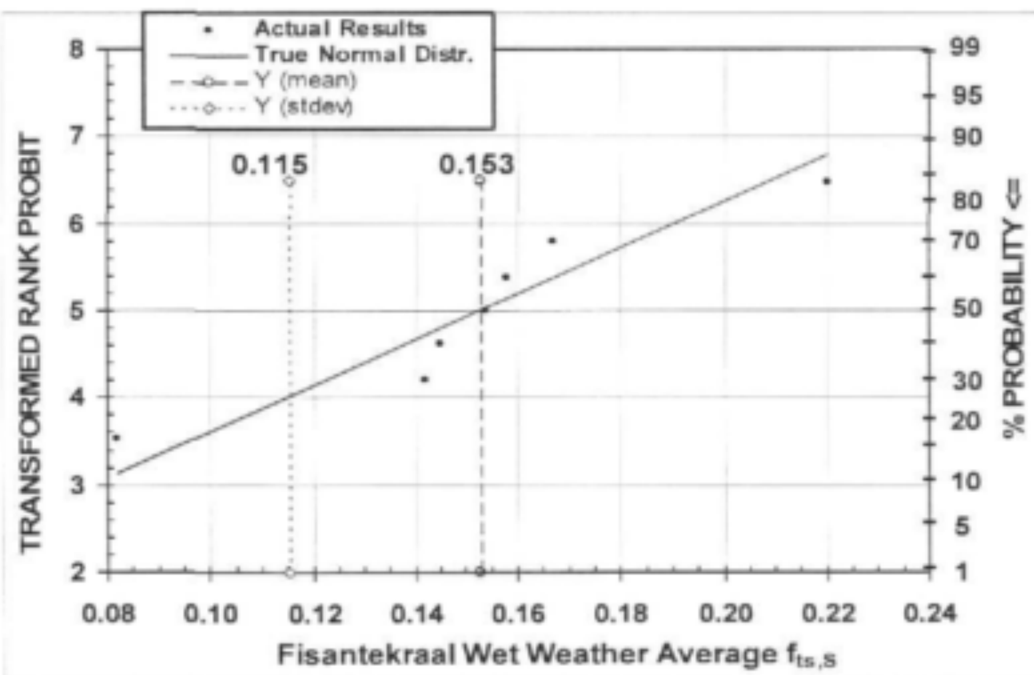


Figure A1.2b : Statistical plot of average wet weather readily biodegradable COD fraction with respect to biodegradable COD ($f_{ts,S}$) in the influent

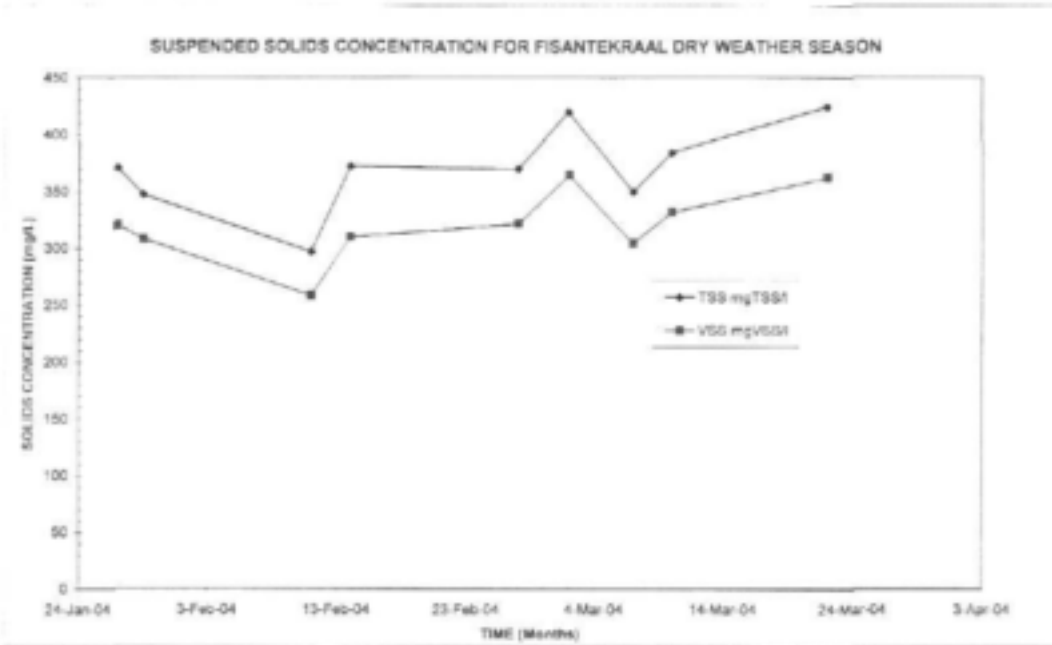


Figure A1.3a : Dry weather mixed liquor total suspended solids (TSS) and volatile suspended solids (VSS) concentrations

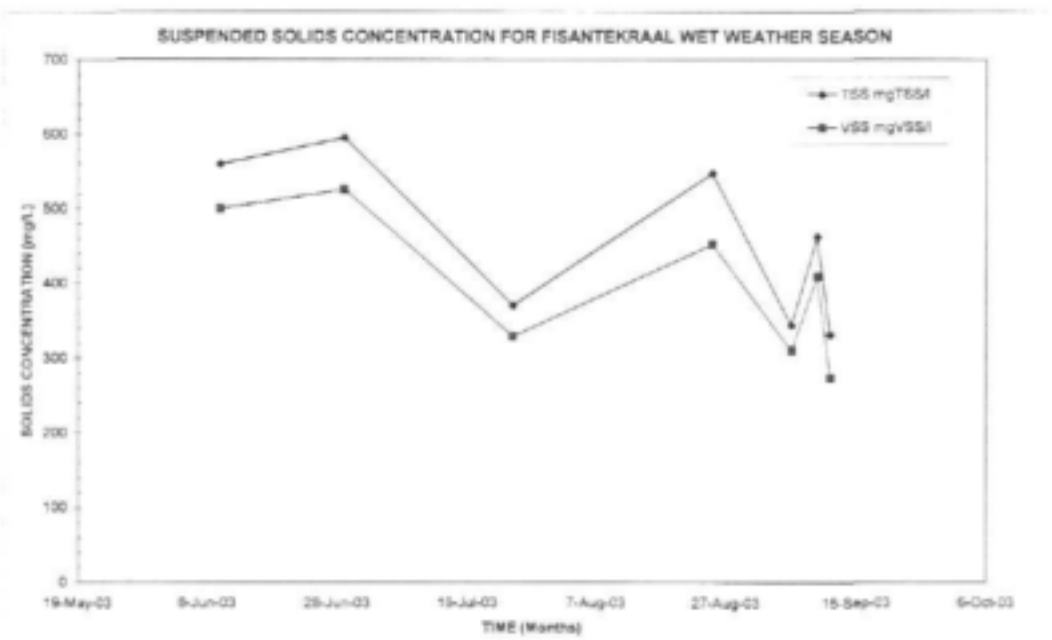


Figure A1.3b : Wet weather mixed liquor total suspended solids (TSS) and volatile suspended solids (VSS) concentrations

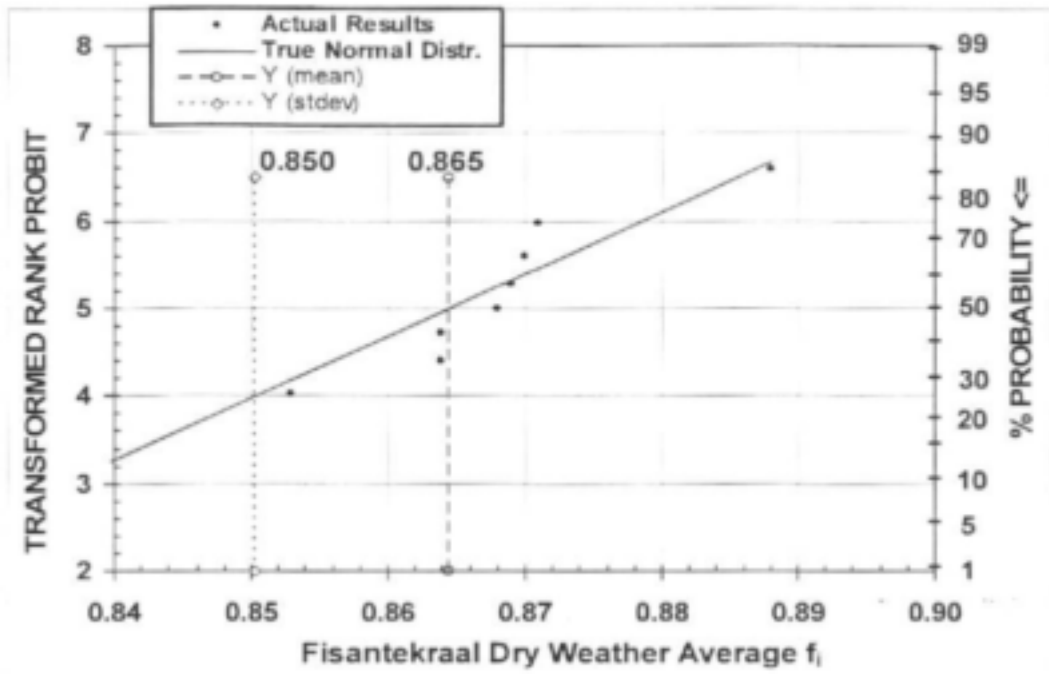
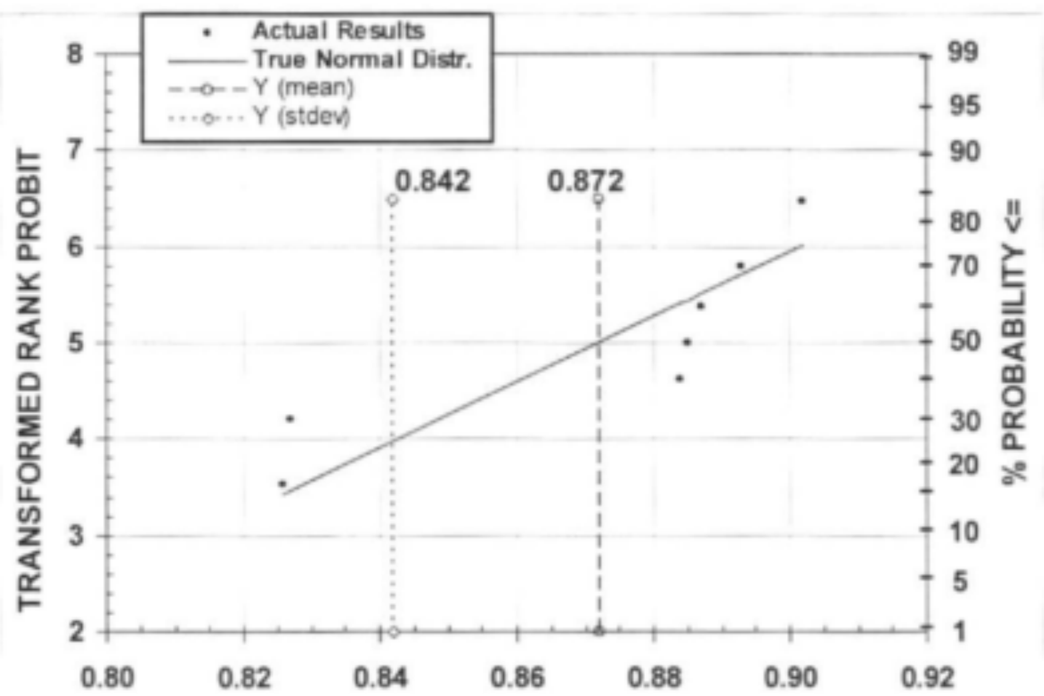


Figure A1.4a : Statistical plot of average dry weather VSS/TSS ratio (f_i)



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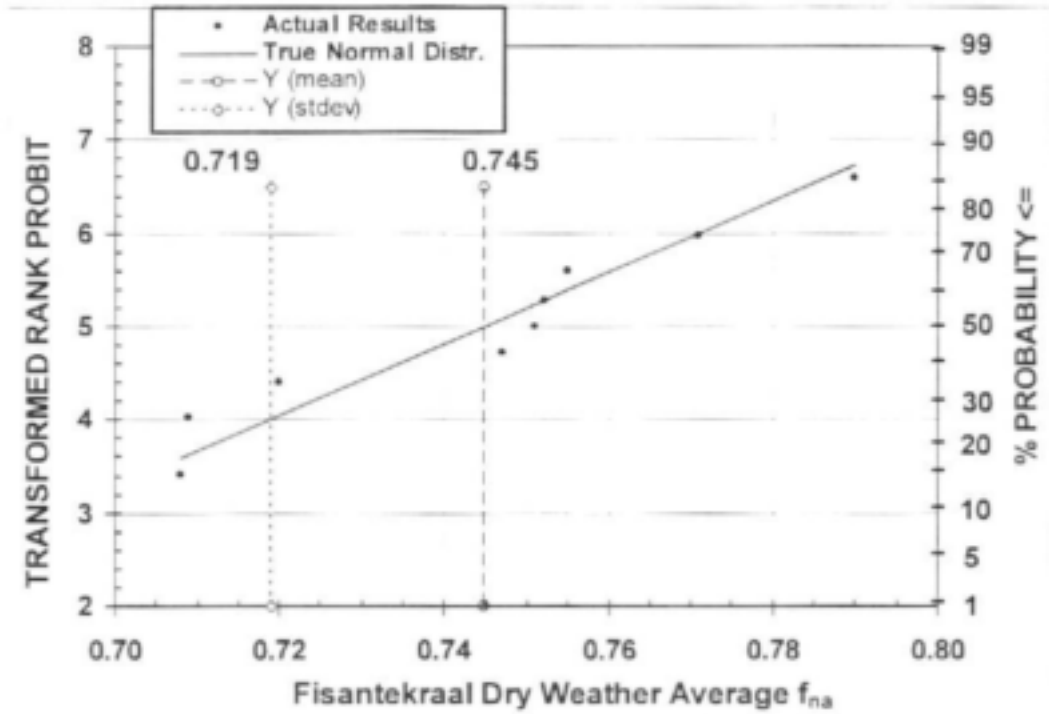
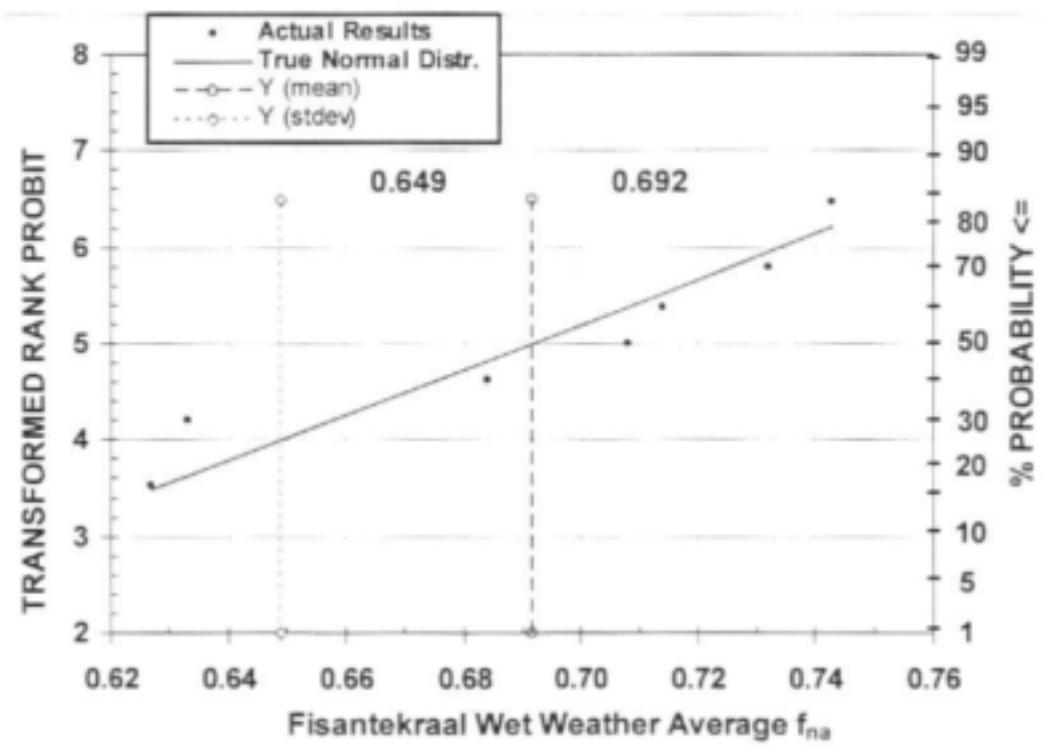


Figure A1.5a : Statistical plot of average dry weather ammonia fraction of the influent TKN (f_{na})



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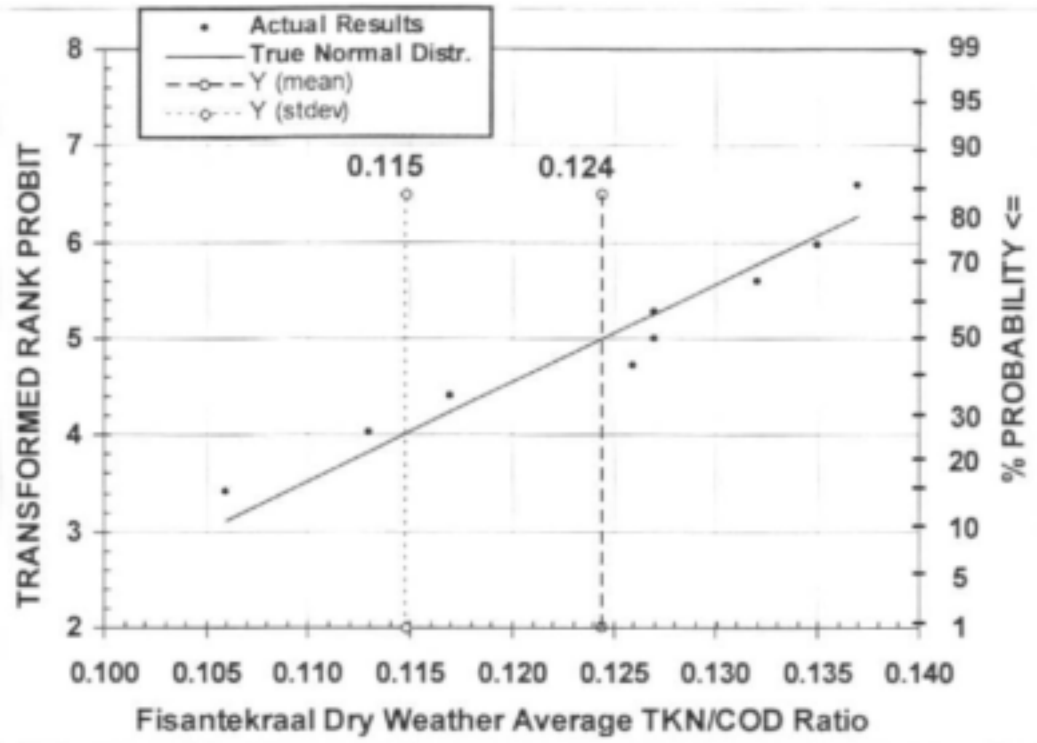

Figure A1.6a : Statistical plot of average dry weather TKN/COD ratio

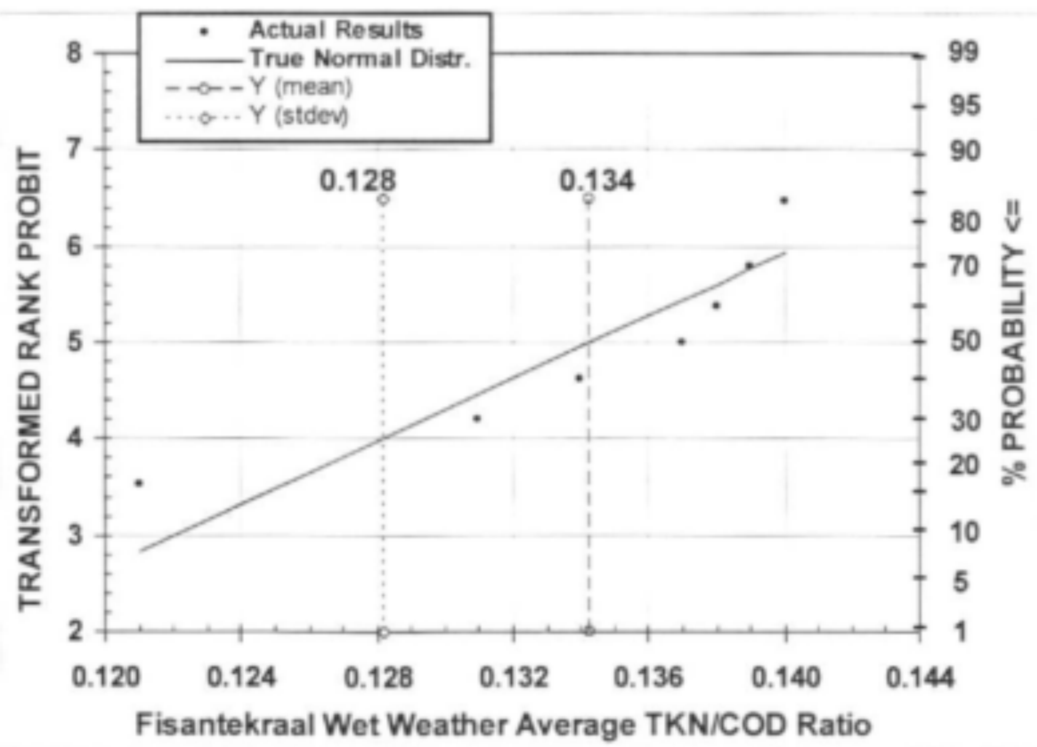

Figure A1.6b: Statistical plot of average wet weather TKN/COD ratio

APPENDIX A2

TRANSFORMED RANKED PROBIT GRAPHS FOR THE DUNOON CATCHMENT

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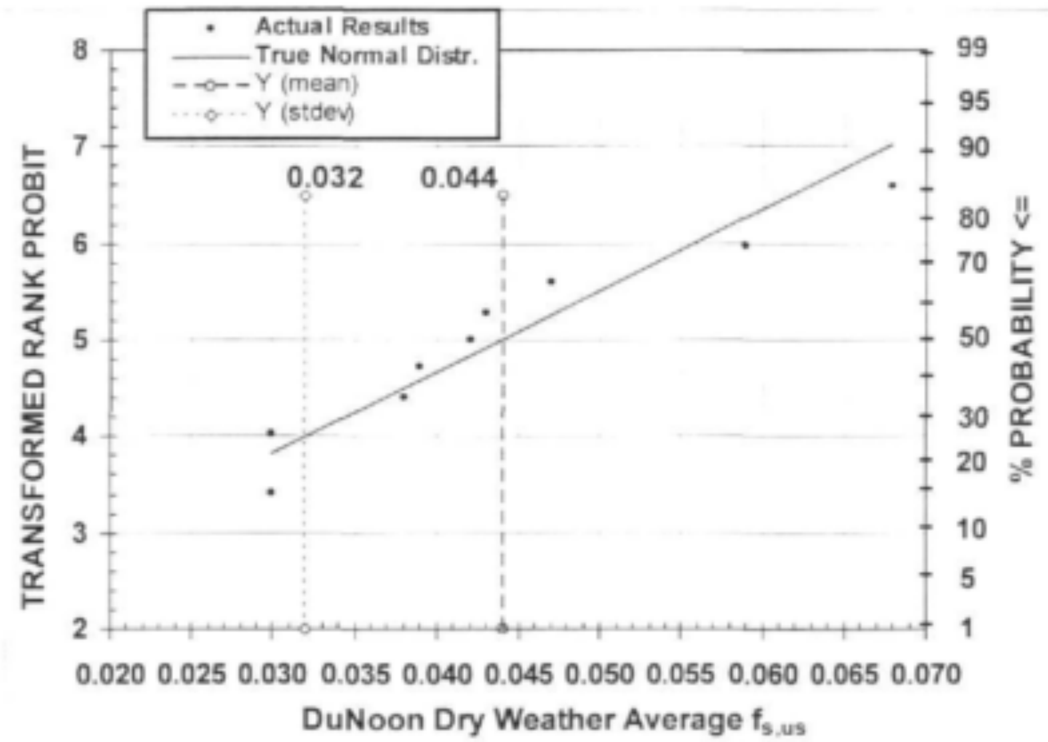


Figure A2.1a : Statistical plot of average dry weather unbiodegradable COD fraction ($fs_{,us}$) in the influent

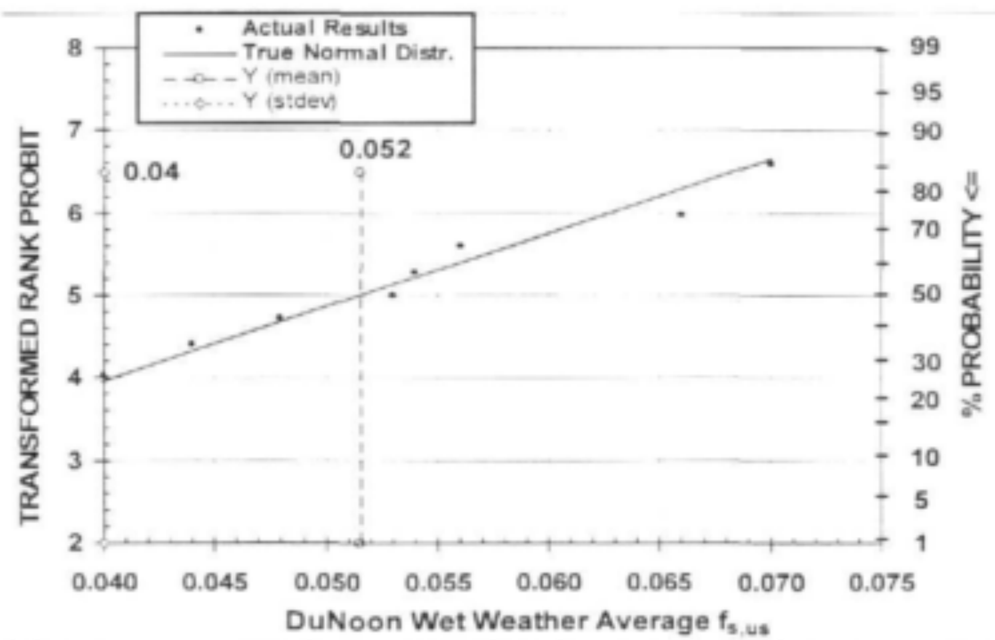


Figure A2.1b : Statistical plot of average wet weather unbiodegradable COD fraction ($fs_{,us}$) in the influent

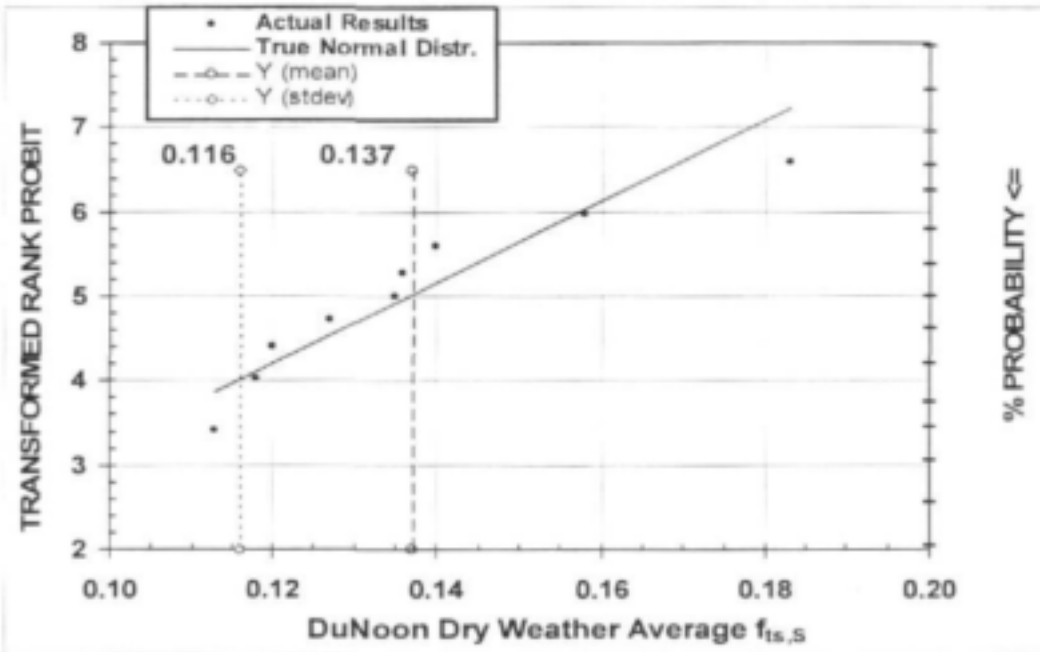


Figure A2.2a : Statistical plot of average dry weather readily biodegradable COD fraction with respect to biodegradable COD ($f_{ts,S}$) in the influent

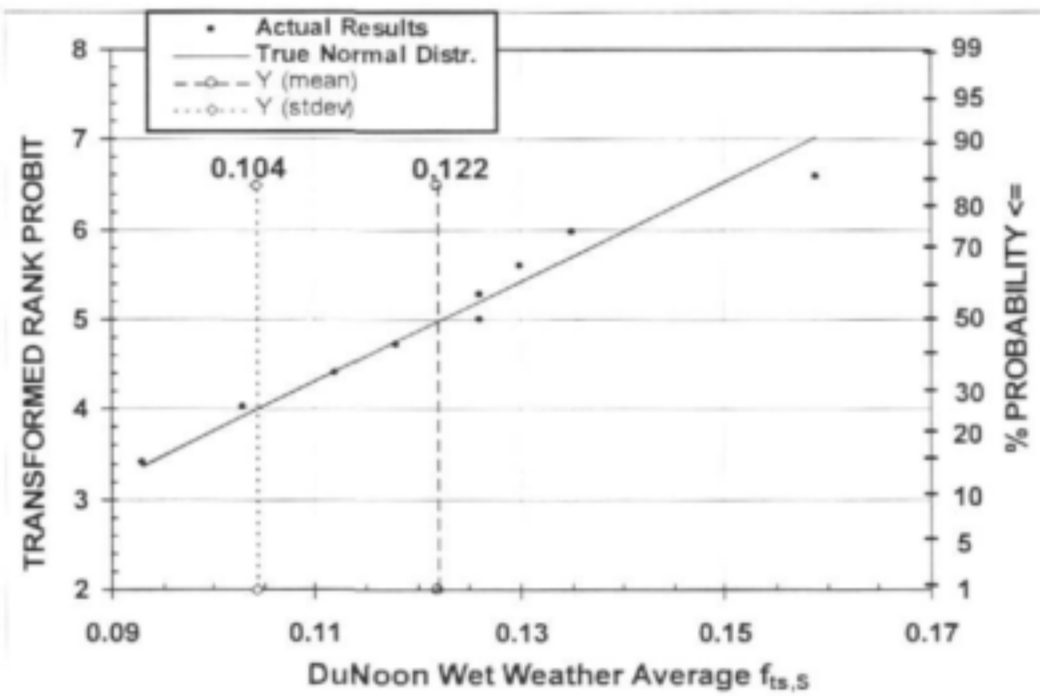
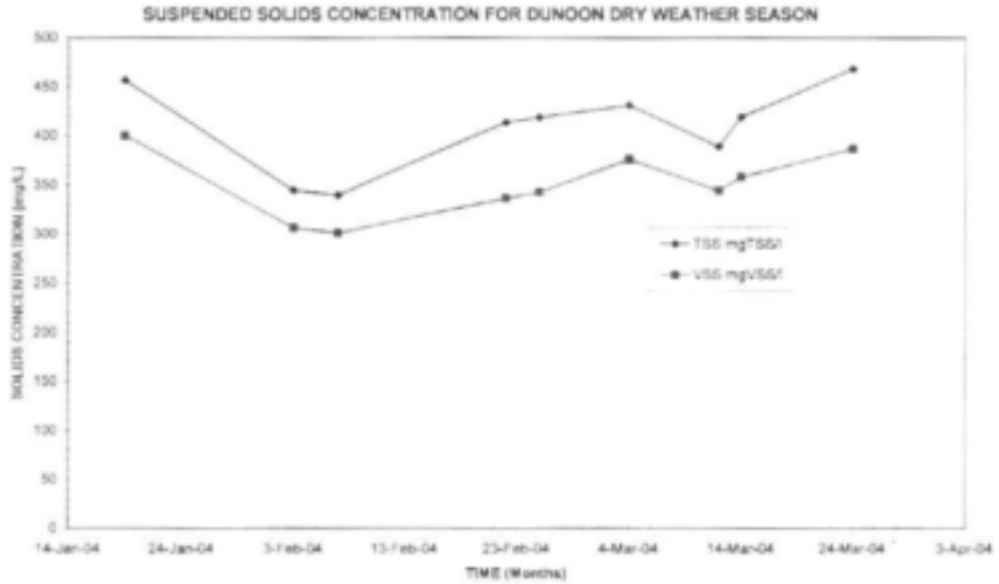


Figure A2.2b : Statistical plot of average wet weather readily biodegradable COD fraction with respect to biodegradable COD ($f_{ts,S}$) in the influent



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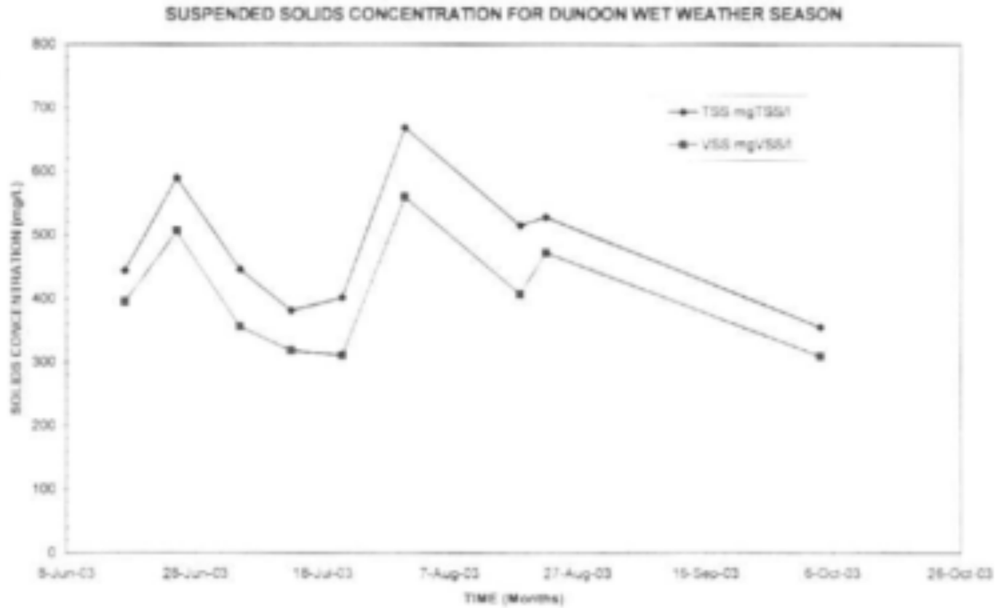

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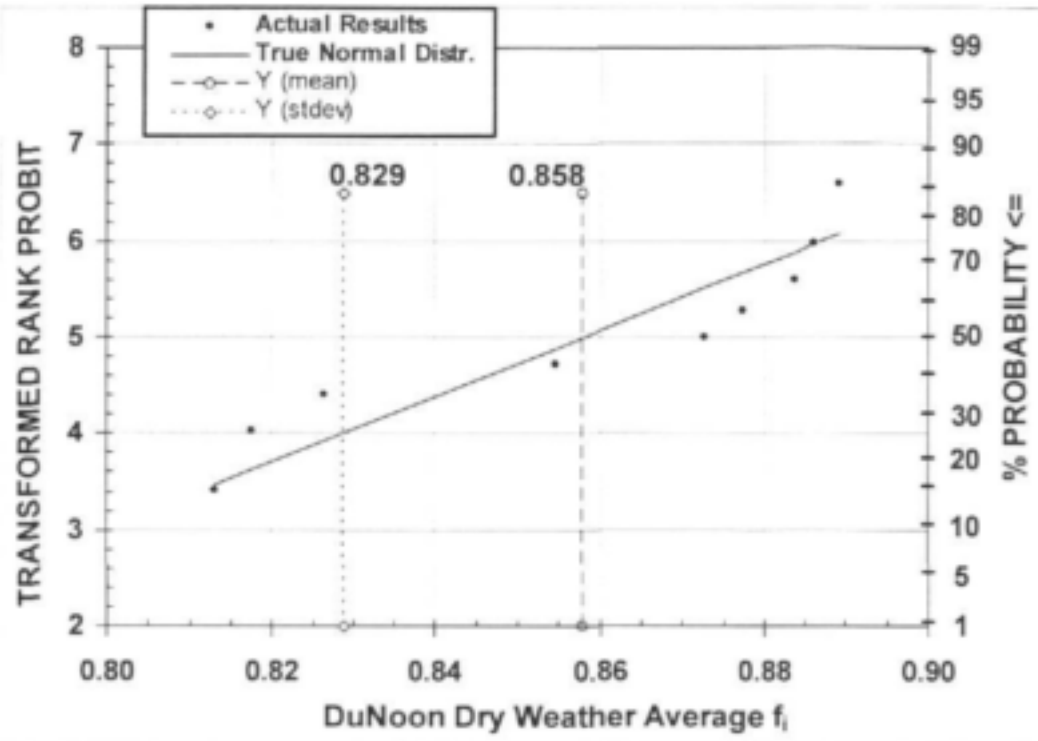


Figure A2.4a : Statistical plot of average dry weather VSS/TSS ratio (f_i)

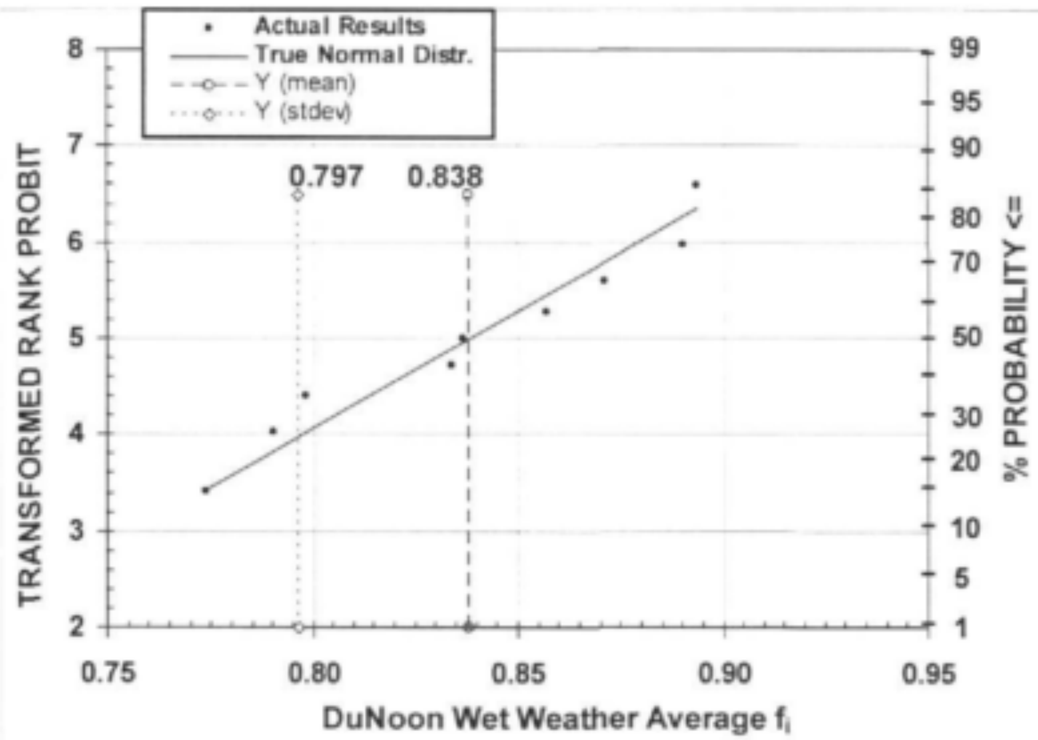
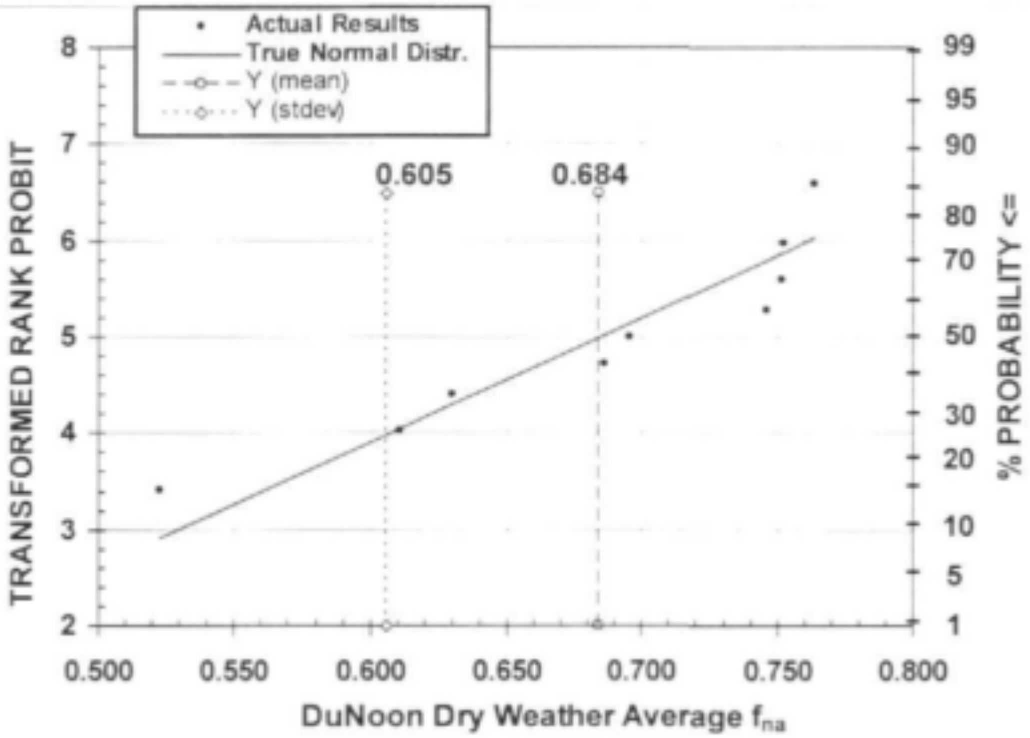


Figure A2.4b : Statistical plot of average wet weather VSS/TSS ratio (f_i)



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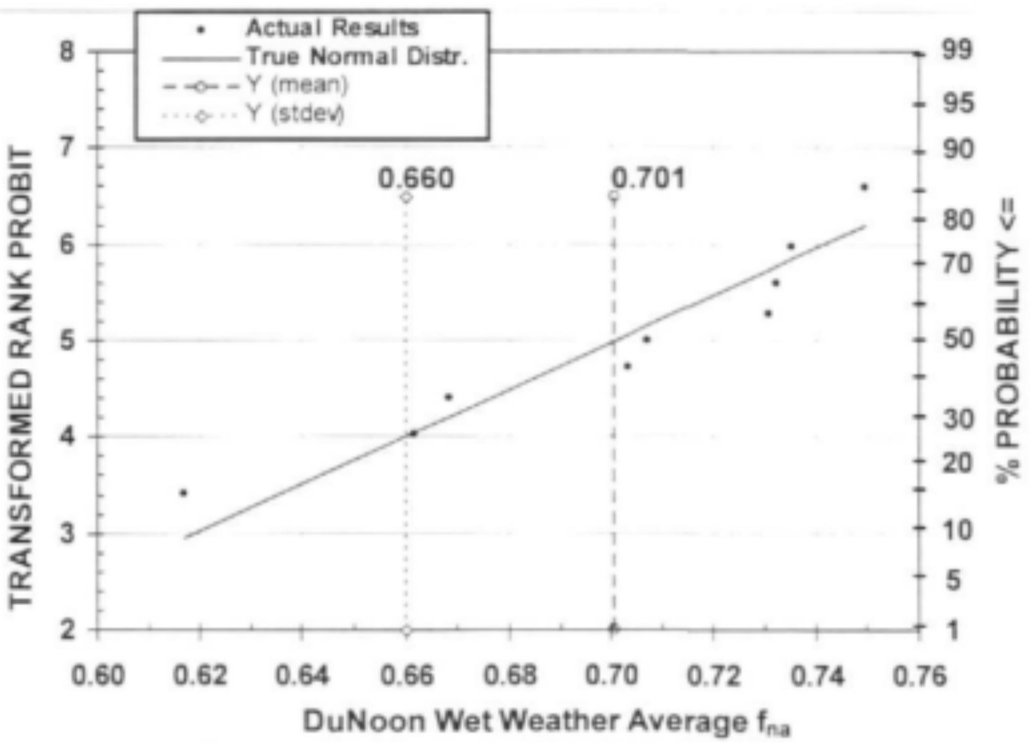

Figure A2.5b : Statistical plot of average wet weather ammonia fraction of the influent TKN (f_{na})

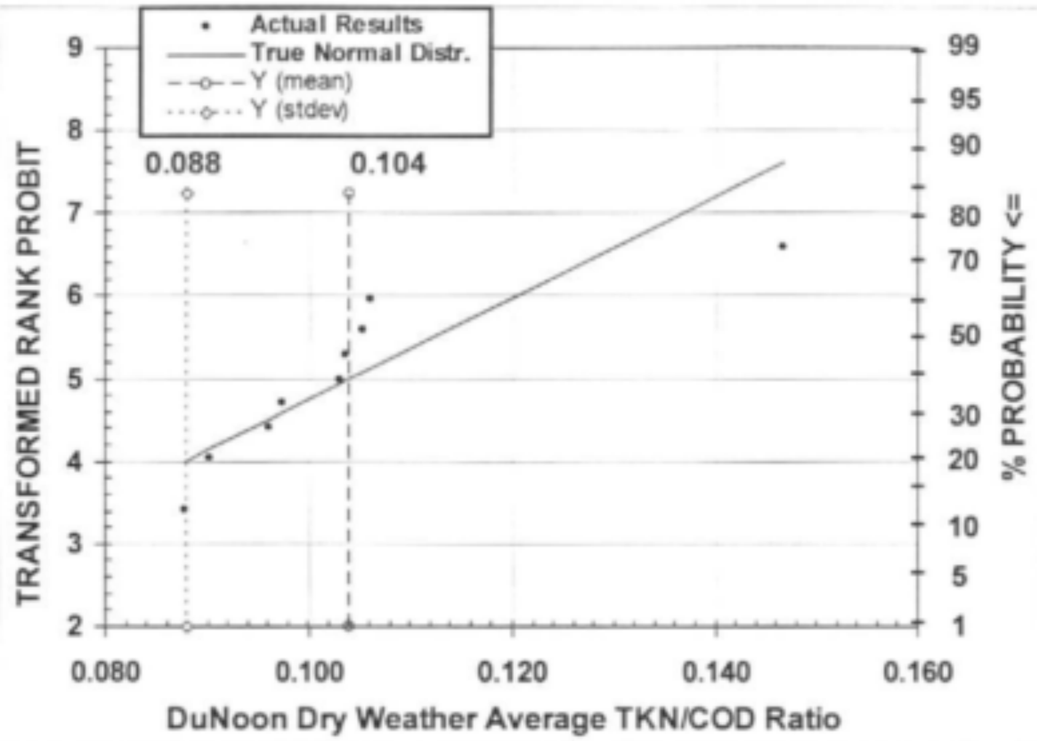

Figure A.2.6a : Statistical plot of average dry weather TKN/COD ratio

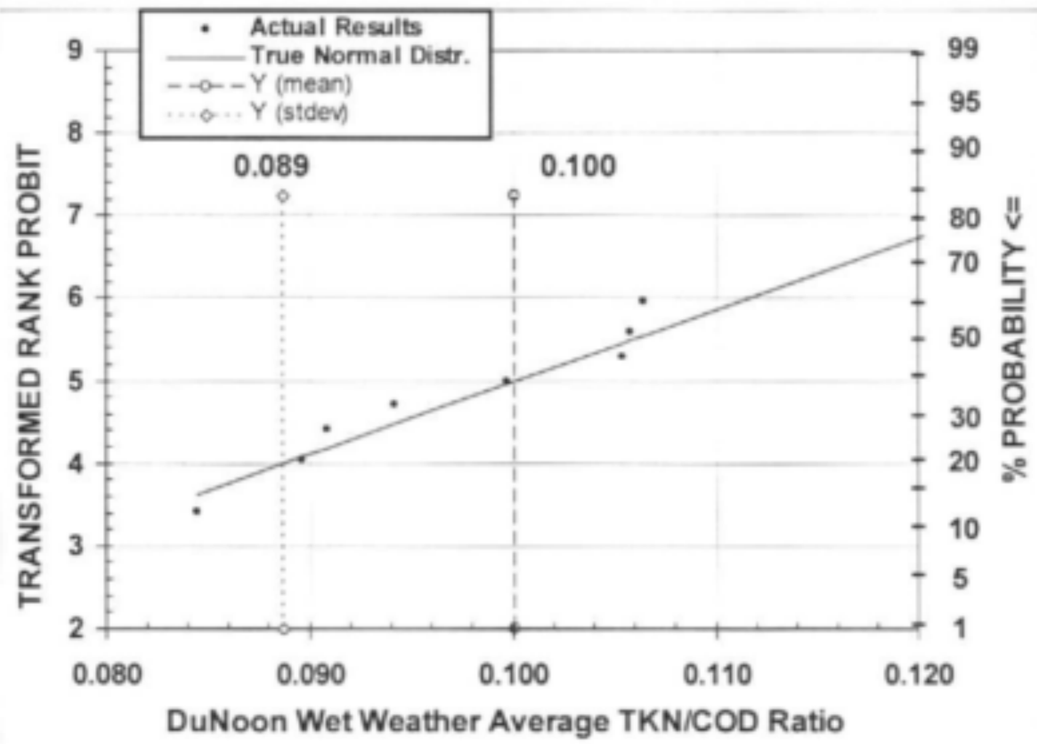

Figure A.2.6b : Statistical plot of average wet weather TKN/COD ratio

APPENDIX B1

RAW DATA FOR THE FISANTEKRAAL CATCHMENT DURING DRY SEASON

Date	Flow	COD	COD Load	TKN	TKN Load	FSA	FSA Load	Ortho-P	Ortho-P Load	Total P	Total P Load	FSA/TKN	fus
	kl/d	mgCOD/l	kgCOD/d	mgN/l	kgN/d	mgN/l	kgN/d	mgP/l	kgP/d	mgP/l	kgP/d	mgN/mgN	
27-Jan-04	320.4	909	291.37	106.0	33.96	75.1	24.06	9.7	3.11	12.8	4.10	0.708	0.071
29-Jan-04	322.9	914	295.07	96.8	31.26	68.6	22.15	9.4	3.04	12.5	4.04	0.709	0.056
11-Feb-04	303.9	829	251.93	105.2	31.97	79.1	24.04	9.8	2.98	13.2	4.01	0.752	0.060
14-Feb-04	285.1	999	284.81	134.8	38.43	97.0	27.65	11.9	3.39	16.3	4.65	0.720	0.058
27-Feb-04	153.0	979	149.83	129.5	19.81	99.9	15.28	12.0	1.84	16.1	2.46	0.771	0.061
02-Mar-04	155.6	1106	172.09	139.3	21.68	104.6	16.28	13.4	2.09	17.3	2.69	0.751	0.058
07-Mar-04	204.1	1017	207.47	139.4	28.45	105.2	21.47	12.6	2.57	16.7	3.41	0.755	0.061
10-Mar-04	136.5	1015	138.52	114.8	15.67	92.2	12.59	11.3	1.54	15.0	2.05	0.803	0.051
22-Mar-04	255.7	1248	319.16	159.0	40.66	118.8	30.38	13.8	3.53	18.8	4.81	0.747	0.056
AVERAGE	**237.5**	**1001.8**	**234.5**	**125.0**	**29.1**	**93.4**	**21.5**	**11.5**	**2.7**	**15.4**	**3.6**	**0.75**	**0.059**

Date	TSS	TSS Load	VSS	VSS Load	pH	Chloride	Chloride Load	Alkalinity	Alkalinity Load	TKN/COD	TP/COD	VSS/TSS	Fts
	mgTSS/ℓ	kgTSS/d	mgVSS/ℓ	kgVSS/d	-	mg/ℓ	kg/d	mgCaCO3/ℓ	kgCaCO3/d	N/COD	P/COD	VSS/TSS	
27-Jan-04	370.9	118.8	320.6	102.7	7.4	87.0	27.9	321.4	103.0	0.117	0.014	0.864	0.141
29-Jan-04	347.3	112.1	308.4	99.6	7.6	73.4	23.7	219.8	71.0	0.106	0.014	0.888	0.119
11-Feb-04	296.8	90.2	258.5	78.6	7.6	96.8	29.4	345.6	105.0	0.127	0.016	0.871	0.146
14-Feb-04	372.1	106.1	309.9	88.4	7.9	103.2	29.4	414.2	118.1	0.135	0.016	0.833	0.174
27-Feb-04	370.1	56.6	321.7	49.2	7.7	100.5	15.4	431.3	66.0	0.132	0.016	0.869	0.163
2-Mar-04	420.0	65.4	364.5	56.7	7.7	115.3	17.9	455.5	70.9	0.126	0.016	0.868	0.169
7-Mar-04	349.8	71.4	304.5	62.1	7.9	100.2	20.5	434.3	88.6	0.137	0.016	0.870	0.155
10-Mar-04	384.2	52.4	331.8	45.3	7.8	111.5	15.2	390.1	53.2	0.113	0.015	0.864	0.159
22-Mar-04	424.6	108.6	362.2	92.6	7.5	117.2	30.0	468.8	119.9	0.127	0.015	0.853	0.212
AVERAGE	**370.6**	**84.1**	**320.2**	**72.8**	**7.7**	**100.6**	**22.4**	**386.8**	**84.5**	**0.124**	**0.015**	**0.864**	**0.160**

APPENDIX B2

RAW DATA FOR THE FISANTEKRAAL CATCHMENT DURING WET SEASON

Date	Flow	COD	COD Load	TKN	TKN Load	FSA	FSA Load	Ortho-P	Ortho-P Load	Total P	Total P Load	FSA/TKN	Fus
	kl/d	mgCOD/l	kgCOD/d	mgN/l	kgN/d	mgN/l	kgN/d	mgP/l	kgP/d	mgP/l	kgP/d	mgN/mgN	
10-Jun-03	313.9	1340	420.63	175.2	55.00	109.8	34.47	13.7	4.30	19.2	6.03	0.627	0.069
29-Jun-03	389.5	1549	603.28	215.1	83.78	159.8	62.24	17.4	6.78	22.7	8.84	0.743	0.071
25-Jul-03	156.3	1102	172.29	151.0	23.60	106.9	16.71	11.8	1.84	17.0	2.66	0.708	0.051
25-Aug-03	135.2	1058	143.00	145.8	19.71	92.3	12.48	9.4	1.27	14.4	1.95	0.633	0.113
06-Sep-03	221.4	971	214.98	129.7	28.72	88.7	19.64	11.1	2.46	15.4	3.41	0.684	0.052
10-Sep-03	220.2	1203	264.94	145.3	32.00	103.7	22.83	11.7	2.58	16.6	3.66	0.714	0.040
12-Sep-03	231.4	933	215.85	130.8	30.27	95.8	22.17	10.7	2.48	15.4	3.56	0.732	0.069
AVERAGE	**238.3**	**1165.1**	**290.7**	**156.1**	**39.0**	**108.1**	**27.2**	**12.3**	**3.1**	**17.2**	**4.3**	**0.69**	**0.066**

Date	TSS	TSS Load	VSS	VSS Load	pH	Chloride	Chloride Load	Alkalinity	Alkalinity Load	TKN/COD	TP/COD	VSS/TSS	Fts
	mgTSS/l	kgTSS/d	mgVSS/ℓ	kgVSS/d	-	mg/ℓ	kg/d	mgCaCO3/ℓ	kgCaCO3/d	N/COD	P/COD		
10-Jun-03	560.0	175.8	500.0	157.0	8.4	121.0	38.0	448.0	140.6	0.131	0.014	0.893	0.158
29-Jun-03	595.3	231.9	526.0	204.9	8.3	151.8	59.1	618.1	240.7	0.139	0.015	0.884	0.220
25-Jul-03	370.8	58.0	329.0	51.4	8.5	114.6	17.9	424.9	66.4	0.137	0.015	0.887	0.154
25-Aug-03	547.5	74.0	452.6	61.2	8.2	136.4	18.4	417.5	56.4	0.138	0.014	0.827	0.142
6-Sep-03	344.5	76.3	310.6	68.8	8.0	101.1	22.4	370.9	82.1	0.134	0.016	0.902	0.145
10-Sep-03	462.8	101.9	409.6	90.2	8.1	124.9	27.5	439.4	96.8	0.121	0.014	0.885	0.082
12-Sep-03	331.8	76.8	274.2	63.4	8.2	105.2	24.3	395.9	91.6	0.140	0.017	0.826	0.167
AVERAGE	**459.0**	**113.5**	**400.3**	**99.6**	**8.2**	**122.1**	**29.7**	**445.0**	**110.7**	**0.134**	**0.015**	**0.872**	**0.153**

APPENDIX B3

RAW DATA FOR THE DUNOON CATCHMENT DURING DRY SEASON

Date	Flow	COD	COD Load	TKN	TKN Load	FSA	FSA Load	Ortho-P	Ortho-P Load	Total P	Total P Load	FSA/TKN	Fus
	kl/d	mgCOD/l	kgCOD/d	mgN/l	kgN/d	mgN/l	kgN/d	mgP/l	kgP/d	mgP/l	kgP/d	mgN/mgN	
19-Jan-04	1426.8	1003	1431.22	88.1	125.70	55.5	79.19	8.7	12.41	12.6	17.98	0.630	0.046
03-Feb-04	1071.2	889	952.19	85.4	91.48	63.7	68.24	8.9	9.53	11.8	12.64	0.746	0.062
07-Feb-04	885.2	867	767.03	84.5	74.80	63.6	56.30	9.6	8.50	12.5	11.07	0.753	0.058
22-Feb-04	942.7	819	772.07	85.0	80.13	64.9	61.18	9.1	8.58	11.9	11.22	0.764	0.055
25-Feb-04	903.5	861	778.18	77.7	70.20	58.4	52.76	8.2	7.41	11.6	10.48	0.752	0.053
04-Mar-04	846.1	944	798.38	99.5	84.19	60.8	51.44	8.1	6.85	12.4	10.49	0.611	0.045
12-Mar-04	1047.3	936	979.96	96.5	101.06	66.2	69.33	8.9	9.32	12.6	13.20	0.686	0.049
14-Mar-04	1158.7	908	1052.33	96.5	111.81	67.1	77.75	10.1	11.70	13.3	15.41	0.695	0.050
24-Mar-04	814.0	839	683.19	123.2	100.28	64.4	52.42	8.7	7.08	12.3	10.01	0.523	0.056
AVERAGE	**1010.6**	**896.2**	**912.7**	**92.9**	**93.3**	**62.7**	**63.2**	**8.9**	**9.0**	**12.3**	**12.5**	**0.68**	**0.053**

Date	TSS	TSS Load	VSS	VSS Load	pH	Chloride	Chloride Load	Alkalinity	Alkalinity Load	TKN/COD	TP/COD	VSS/TSS	Fts
	mgTSS/l	kgTSS/d	mgVSS/l	kgVSS/d	-	mg/l	kg/d	mgCaCO3/l	kgCaCO3/d	mgN/mgCOD	mgP/mgCOD	mgVSS/mgTSS	
19-Jan-04	456.8	651.8	400.8	571.9	7.0	86.2	123.0	263.6	376.1	0.088	0.013	0.877	0.118
3-Feb-04	344.8	369.3	306.6	328.4	7.0	94.3	101.0	299.2	320.5	0.096	0.013	0.889	0.158
7-Feb-04	340.1	301.1	301.4	266.8	7.1	93.2	82.5	306.4	271.2	0.098	0.014	0.886	0.135
22-Feb-04	414.0	390.3	336.6	317.3	7.3	92.2	86.9	300.8	283.6	0.104	0.015	0.813	0.136
25-Feb-04	419.3	378.8	342.8	309.7	7.4	94.9	85.7	290.0	262.0	0.090	0.013	0.818	0.120
4-Mar-04	431.4	365.0	376.5	318.6	7.4	97.8	82.7	283.0	239.4	0.105	0.013	0.873	0.113
12-Mar-04	389.5	407.9	344.2	360.5	7.3	95.5	100.0	301.4	315.7	0.103	0.013	0.884	0.183
14-Mar-04	419.5	486.1	358.5	415.4	7.3	90.5	104.9	304.8	353.2	0.106	0.015	0.855	0.140
24-Mar-04	468.4	381.3	387.1	315.1	7.5	86.6	70.5	294.0	239.3	0.147	0.015	0.826	0.127
AVERAGE	**409.3**	**418.8**	**350.5**	**361.1**	**7.3**	**92.4**	**95.8**	**293.7**	**302.7**	**0.099**	**0.014**	**0.858**	**0.137**

APPENDIX B4

RAW DATA FOR THE DUNOON CATCHMENT DURING WET SEASON

Date	Flow	COD	COD Load	TKN	TKN Load	FSA	FSA Load	Ortho-P	Ortho-P Load	Total P	Total P Load	FSA/TKN	Fus
	kl/d	mgCOD/l	kgCOD/d	mgN/l	kgN/d	mgN/l	kgN/d	mgP/l	kgP/d	mgP/l	kgP/d	mgN/mgN	
17-Jun-03	802.40	1009	809.94	101	80.80	73.60	59.06	8.8	7.06	12.2	9.79	0.731	0.047
25-Jun-03	687.40	1269	872.59	120	82.21	73.80	50.73	9.7	6.67	14.8	10.17	0.617	0.030
5-Jul-03	1107.90	1032	1143.69	110	121.76	77.70	86.08	9.5	10.53	12.7	14.07	0.707	0.039
13-Jul-03	863.70	905	781.99	113	97.51	79.40	68.58	10.2	8.81	13.8	11.92	0.703	0.038
21-Jul-03	615.70	1142	703.31	104	63.91	76.00	46.79	10.1	6.22	14.6	8.99	0.732	0.043
31-Jul-03	496.20	1356	672.80	115	56.81	85.80	42.57	10.4	5.16	15.2	7.54	0.749	0.030
18-Aug-03	1253.90	875	1096.66	93	115.99	61.20	76.74	7.0	8.78	10.2	12.79	0.662	0.042
22-Aug-03	1214.60	1123	1363.75	101	122.31	67.30	81.74	9.1	11.05	13.4	16.28	0.668	0.059
4-Oct-03	1412.00	817	1153.89	86	121.57	63.30	89.38	8.6	12.14	11.9	16.80	0.735	0.068
AVERAGE	**939.3**	**1058.8**	**955.4**	**104.5**	**95.9**	**73.1**	**66.9**	**9.3**	**8.5**	**13.2**	**12.0**	**0.70**	**0.044**

Date	TSS	TSS Load	VSS	VSS Load	pH	Chloride	Chloride Load	Alkalinity	Alkalinity Load	TKN/COD	TP/COD	VSS/TSS	Fts
	mgTSS/l	kgTSS/d	mgVSS/l	kgVSS/d	-	mg/l	kg/d	mgCaCO3/l	kgCaCO3/d	mgN/mgCOD	mgP/mgCOD	mgVSS/mgTSS	
17-Jun-03	444.2	356.4	395.6	317.4	7.4	140.6	112.8	253.0	203.0	0.100	0.012	0.891	0.130
25-Jun-03	590.5	405.9	506.1	347.9	7.4	115.7	79.5	316.1	217.3	0.094	0.012	0.857	0.112
5-Jul-03	445.8	493.9	355.9	394.3	7.7	122.0	135.2	301.9	334.5	0.106	0.012	0.798	0.159
13-Jul-03	381.3	329.3	318.1	274.7	7.6	112.4	97.1	324.1	279.9	0.125	0.015	0.834	0.135
21-Jul-03	401.6	247.3	310.8	191.4	7.6	118.9	73.2	318.8	196.3	0.091	0.013	0.774	0.103
31-Jul-03	669.0	332.0	559.7	277.7	7.6			351.3	174.3	0.084	0.011	0.837	0.126
18-Aug-03	514.9	645.6	406.9	510.2	7.5	107.8	135.2	279.8	350.8	0.106	0.012	0.790	0.093
22-Aug-03	528.4	641.8	472.3	573.7	7.5	127.0	154.3	304.2	369.5	0.090	0.012	0.894	0.118
4-Oct-03	354.7	500.8	309.0	436.3	7.4	116.8	164.9	303.2	428.1	0.105	0.015	0.871	0.126
AVERAGE	**481.2**	**439.2**	**403.8**	**369.3**	**7.5**	**120.2**	**119.0**	**305.8**	**283.7**	**0.100**	**0.013**	**0.838**	**0.122**

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Water Research Commission
Private Bag X03, Gezina, 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za

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