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P RSA C000/00/2305/2

Development of an Integrated Water Quality Management Plan for the Vaal River System

Task 3

Salinity Balance

September 2009

ZITHOLELE CONSULTING

WRP

DMM

Golder Associates

Development of an Integrated Water Quality Management Plan for the Vaal River System

TASK 3:

SALINITY BALANCE OF THE VAAL RIVER SYSTEM

FINAL REPORT

Directorate National Water Resource Planning
Department of Water Affairs and Forestry

September 2009

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EXECUTIVE SUMMARY

Introduction

The WQT salinity model has been set up for the Vaal River system as part of the Vaal River System Analysis Update Study (VRSAU) (DWAF, 1998). The process of setting up the water quality model involved calibrating the WQT model and the calibrated WQT model input parameters being input into the WRPM. The WRPM is used for the strategy development, planning and operational management of the Vaal River System. The process of calibration involved the collection of point source discharge volumes and Total Dissolved Solid (TDS) concentrations, land use information, in-stream flows and qualities at river and dam monitoring points for use in calibrating the model. The WQT model uses the monthly naturalised hydrology as input. The WQT and the hydrological models have been calibrated up until September 1995.

The hydrological model and WQT have not been calibrated since the VRSAU Study. The water quality situation in the Vaal River has changed since September 1995 with changes in the discharge volumes and qualities from gold mines such as Petrex (formerly Grootvlei mine) and the wastewater treatment works (WWTW). A recalibration of the water quality model will require a substantial amount of work including the calibration or extension of the hydrology. This additional work may be largely unnecessary for the broad level planning being undertaken in this study. A simpler approach has therefore been proposed to check if the water quality component of the WRPM is still valid. An annual salinity balance was developed for the hydrological years from October 1995 to September 2004. This is aimed at determining the relative contributions of pollution sources and identifying any significant divergence from the assumptions that drove the VRSAU study calibrations.

Study Approach

The study approach involved the following steps:-

- The Vaal River catchment was divided into the Grootdraai Dam, Frankfort, Vaal Dam Incremental, Vaal Barrage, Mooi and Bloemhof Dam Incremental catchments. The selection was made on the basis of the availability of a flow and water quality station at the catchment outlet to measure the mass of salt leaving the catchment.

- The water and salt balance for a catchment can be represented by the equation:-Start storage+mine dewatering+catchment washoff+return flows+upstream+transfers in-transfers out-outflows-abstractions-losses-net irrigation=End storage. The volumes and salt masses associated with all the terms except the catchment washoff are measured.

- The equation was used to calculate the catchment uashoff volume and TDS mass by collecting the measured volumes and TDS concentrations for the measured terms of the balance equation for the period October 1995 to September 2004. The WRPM was run for a 100 sequences of length 10 years. The annual average TDS concentrations and runoff volumes for each of the catchments were represented as box plots for comparison to the results of the water and salinity balance. In this way the validity of the calibrations of the salt wash off components of the WQT model can be checked.

Results of the salinity balance

The results of the annual salinity balance can be summarised by showing the salt load contribution from the different sources in each of the sub-catchments. The results are given in **Table E1** and the values are the average annual TDS loads over the calculation period of 1995 to 2004. The results show that the effluent and mine contributions to the salinity load is significant. The contribution from upstream increases downstream with the largest contribution from the Vaal Barrage into the Bloemhof Dam catchment.

Table E1: Average annual TDS loads (tonne/a) contributed from different sources in each of the sub-catchments

Sub-catchment	Transfers	Upstream	Effluent	Mines	Catchment	Total load
Grootdraai Dam	4171	0	4580	0	105680	114431
Frankfort	33764	0	2624	0	172511	208899
Vaal Dam Inc	0	284109	14065	0	127349	425523
Vaal Barrage	0	264127	201306	128361	367396	961190
Mooi	0	0	18549	23887	139414	181850
Bloemhof Dam	0	424288	13567	9419	126907	574181

The sources of TDS load and the volume of water contributed by the sources down to Bloemhof Dam are shown in **Table E2**. The mine discharges have the highest average TDS concentration and are therefore the source where the largest load can be removed per m^3 of water. The effluent volume contribution is significant and will therefore influence the TDS concentrations in the Vaal Barrage and downstream. The volume of water transferred into the Vaal catchment is significant and will grow in the future. The TDS concentration of this water is currently good. Deterioration in the TDS concentration of the transferred water will therefore impact on the TDS concentration in the system in particular Vaal Dam which receives the Lesotho and Thukela water.

The comparisons of the box plots of the simulated TDS concentrations and volumes for the catchments and the results of the salinity balance are shown in **Figure 28** to **Figure 38.**

Table E2: Summary of volume (million m^3/a) and TDS load (tonne/a) from sources for catchment down to Bloemhof Dam

	Transferred	Effluent	Mines	Catchment
Volume (million m^3/a)	479	492	91	4235
Load (tonne/a)	37935	254691	161667	1039257
Ave TDS Conc (mg/l)	79	518	1777	245

Conclusions and Recommendations

The following conclusions and recommendations can be made as a result of this study :-

- The salinity balance shows that the mine discharges and sewage effluent contribute significantly to the salt and volume water balance.
- There were two wet years in the salinity balance analysis period viz in 1995/96 and 1999/2000. The water balance period can be considered to be a wet period.
- The salinity balance shows that the salt washoff modules associated with the Grootdraai Dam, Frankfort, Vaal Dam Incremental, Mooi and Vaal Barrage are producing adequate results. The salinity balance for the Bloemhof Dam catchment is not accurate and no firm conclusions can be drawn from the balance. There were issues with the water balance for the Bloemhof Dam catchment. A balance would not be achieved.
- The salinity balance suggests that the recharge rates for the Vaal Barrage washoff modules should be increased.
- The WRPM system network needs updating to reflect the latest layout.
- Irrigation modules need to be added for the Upper and Middle Vaal catchment areas to model the salt and water balances.
- The irrigation modules in the Lower Vaal and Rietspruit catchment need to be reviewed.
- The return flows from the Midvaal Water demand centre need to be reviewed.

DOCUMENT INDEX

Reports as part of this project:

Bold type indicates this report.

REPORT INDEX	REPORT NUMBER	REPORT TITLE
1		Inception Report
2	P RSA C000/00/2305/1	Water Quality Status Assessment
3	**P RSA C000/00/2305/2**	**Salinity Balance**
4	P RSA C000/00/2305/3	Integration of Resource Water Quality Objectives
5	P RSA C000/00/2305/4	Water Quality Economic Impact Modelling
6	P RSA C000/00/2305/5	Evaluation of Water Quality Management Scenarios
7	P RSA C000/00/2305/6	Monitoring Programme
8	P RSA C000/00/2305/7	Water Quality Management Strategy

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LIST OF ACCRONYMS AND ABBREVIATIONS

Al	Aluminium
BID	Background Information Document
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EIS	Ecological Importance and Sensitivity
ERWAT	East Rand Water Care Company
GDP	Gross Domestic Product
ICM	Integrated Catchment Management
ISP	Internal Strategic Perspective
IWQMP	Integrated Water Quality Management Plan
IWRM	Integrated Water Resource Management
KOSH	Klerksdorp-Orkney-Stilfontein-Hartbeesfontein
LBWSRS	Large Bulk Water Supply Reconciliation Strategies
NWA	National Water Act
NWRS	National Water Resource Strategy
PES	Present Ecological State
PWV	Pretoria-Witwatersrand-Vereeniging
RDM	Resource Directed Measures
RQOs	Resource Quality Objectives
RO	Regional Office
RWQO	Resource Water Quality Objectives
SAWQGs	South African Water Quality Guidelines
TDS	Total Dissolved Salts
TOR	Terms of Reference
TWQR	Target Water Quality Range
VRSAU	Vaal River System Analysis Update
WCWDM	Water Conservation Water Demand Management
WDCS	Waste Discharge Charge System

WMA	Water Management Area
WMIs	Water Management Institutions
WMS	Water Management System
WRC	Water Research Commission
WUA	Water User Association
WWTP	Wastewater Treatment Plants
WQT	TDS Water Quality Model
WRPM	Water Resources Planning Model

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The water resources of the Vaal River System are an important asset to the country and its people, supporting major economic activities and a population of about 12 million people. The Vaal River System comprises the C primary drainage region within the water management basins of South Africa and spans four water management areas (WMAs), *viz.* the Upper, Middle, part of Lower Vaal and part of the Upper Orange (Modder Riet catchment) WMAs. Due to the cascading orientation and associated inter-dependency of these WMAs, it is vital that the water resources of this river system are managed in an integrated manner to achieve a balance between meeting specific water user and use requirements in each WMA as well as in fulfilling the transfer obligations between these WMAs, and the donating and receiving WMAs that form part of the larger integrated system (Figure 1). The Vaal River serves as a conduit to transfer water among the three Vaal WMAs and significant transfers out of the Upper Vaal WMA occur through the distribution system of Rand Water to the Crocodile West and Marico WMA. The Vaal River System has extensive water resource infrastructure and is linked to other water resource systems (Thukela, Usutu, Lesotho) through substantial transfers between them (shown in **Figure 1**).

The Upper Vaal is highly altered by catchment development, with the Middle Vaal having a few major development centres and agriculture and mining being the main activities. The Lower Vaal WMA is less developed with agriculture being the predominant land use. The Modder Riet catchment is dominated by agricultural activities with a few urban centres. The significant development within the system includes both formal and informal urbanisation, industrial growth, agricultural activities and widespread mining activities. This development has led to deterioration in the water quality of the water resources in the system, requiring that management interventions are needed to ensure that water of acceptable quality is available to all users in the system, especially as land use activities continue to grow and intensify. Salinisation and eutrophication of the water resources in the Vaal River System appear to be the two major water quality problems being experienced. If the system is going to sustain the envisaged growth and development, sound strategies and actions are needed to ensure that the water resources of the Vaal River System are managed to meet the needs of all water users while at the same time affording an adequate level of protection of instream resource quality.

The challenge is to develop a detailed understanding of the current water quality situation of the water resources within the system and the processes that drive the impact and associated pollution such that the resulting water quality management plan identifies optimum, sustainable solutions that not only serve to alleviate the water quality issues but also accommodate for the interdependency of the linked resource systems.

One of the basic principles of management is that "*you can only manage what you measure*". This principle applies to any human endeavour and to the world that surrounds us, with the domain of water resource management being no different.

Thus, in order that the water resources in the Vaal River System are effectively managed into the future and sound strategies for water quality management are developed, relevant information about water related conditions, issues and developments in the WMAs is needed to appropriately address the threats and problems that currently prevail. This “measurement” process of collating, processing and interpreting such information either takes the form of situation analyses, basin studies or in this case a salinity balance. Thus the purpose of the salinity balance is to better understand the existing water quality situation within the Vaal River System, which will subsequently support the development of the integrated water quality management plan.

2 STRUCTURE OF REPORT

The report has been structured into 8 sections. The contents of the sections are summarised below :-

- **Section 1** gives the background to the study as well as the objective of this report and the methodology used in the study.
- **Section 2** describes the system layout and the selection of the key monitoring stations used in the analysis of the salt balance
- **Section 3** describes the assembly of data related to the pollution sources, abstractions, water transfers and effluent discharges needed for the salinity balance
- **Section 4** gives the annual salinity and water balances for the Grootdraai Dam, Frankfort, Vaal Dam Incremental, Vaal Barrage, Mooi and Bloemhof catchments.
- **Section 5** compares the results of the Water Resource Planning Model (WRPM) to the annual salinity balance.
- **Section 6** presents the conclusions and recommendations resulting from the study.

2.1.1 Objectives

The WQT salinity model has been set up for the Vaal River system as part of the Vaal River System Analysis Update Study (VRSAU) (DWAF, 1998). The process of setting up the water quality model involved calibrating the WQT model and the calibrated WQT model input parameters being input into the WRPM. The WRPM is used for the strategy development, planning and operational management of the Vaal River System. The process of calibration involved the collection of point source discharge volumes and Total Dissolved Solid (TDS) concentrations, land use information, instream flows and qualities at river and dam monitoring points for use in calibrating the model. The WQT model uses the monthly naturalised hydrology as input. The WQT and the hydrological models have been calibrated up until September 1995.

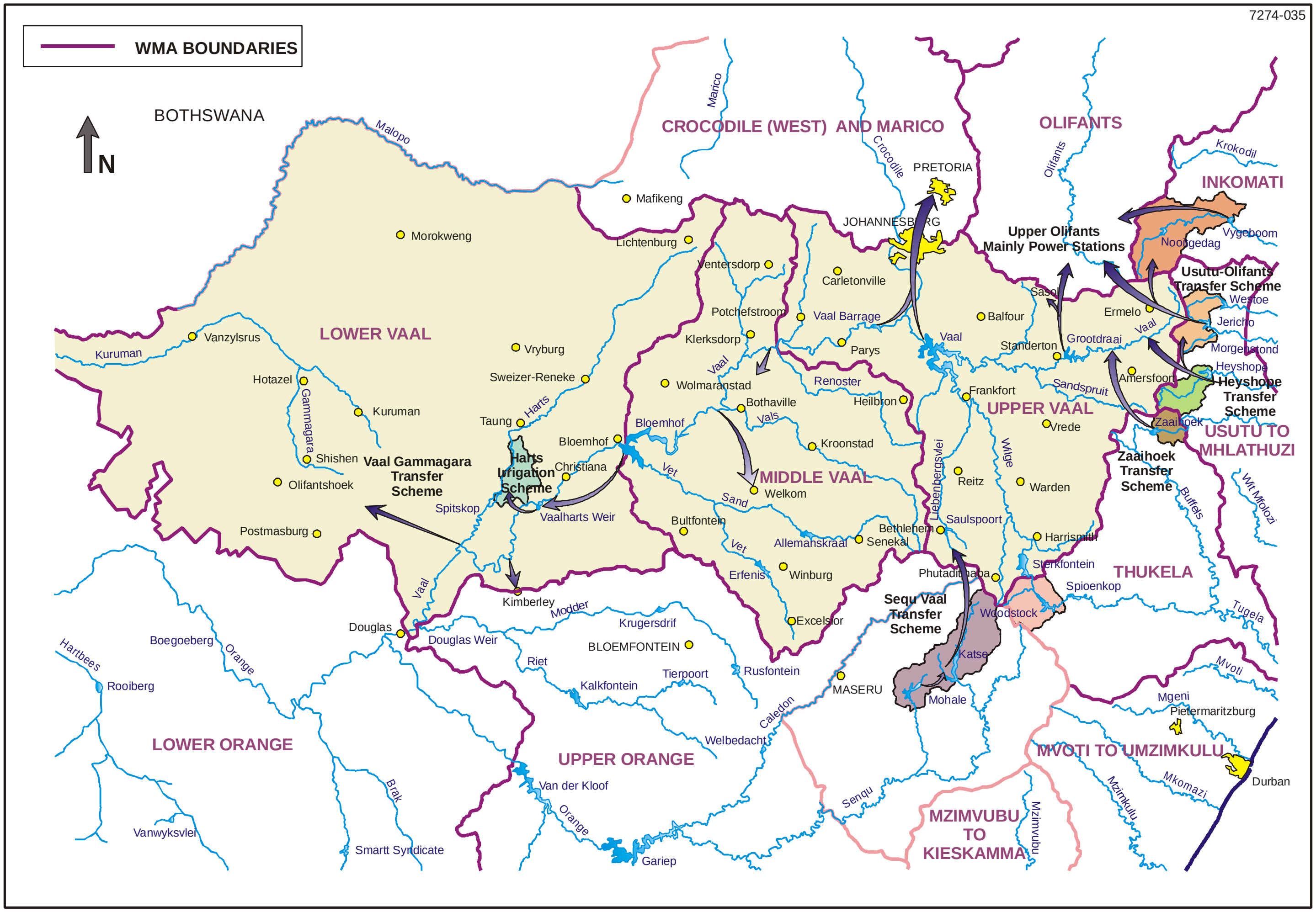

Figure 1: The Vaal River System depicting water resource infrastructure and associated transfers within the integrated system (DWAF, 2005a)

The hydrological model and WQT have not been calibrated since the VRSAU Study. The water quality situation in the Vaal River has changed since September 1995 with changes in the discharge volumes and qualities from gold mines such as Petrex (formerly Grootvlei mine) and the wastewater treatment works (WWTW). A recalibration of the water quality model will require a substantial amount of work including the calibration or extension of the hydrology. This additional work may be largely unnecessary for the broad level planning being undertaken in this study. A simpler approach has therefore been proposed to check if the water quality component of the WRPM is still valid. An annual salinity balance was developed for the hydrological years from October 1995 to September 2004. This is aimed at determining the relative contributions of pollution sources and identifying any significant divergence from the assumptions that drove the VRSAU study calibrations. The sub tasks involved in the process are discussed in section 1.3.

2.2 Study Approach

2.2.1 Introduction

Six sub tasks were identified during the inception phase to develop a salinity balance for the Vaal River. The sub-tasks are described in the sections below.

2.2.2 Task 3a: Select key monitoring stations

Key monitoring points were selected for analysis. These comprised reliable flow gauging stations with good water quality records. The distribution of the stations accounted for significant natural features, such as river junctions, reservoirs, urbanised catchments, major irrigation schemes (such as Vaalharts) and major abstraction and effluent discharge points and the location of reliable monitoring points.

2.2.3 Task 3b: Assemble, patch and aggregate data

The simulated flow and water quality data is available up to the end of September 1995. Calibration and naturalisation was not carried out for the subsequent 9 years. However, in order to support the load balances it was necessary to assemble key data for this period. This includes flow and salinity data at the key stations, abstractions and effluent discharges to the major river systems.

Although the salt balance was carried out at a relatively coarse scale, all the major inputs needed to be collected and patched to complete the salt balance.

2.2.4 Task 3c: Calculate salinity balances

Water and salinity balances were calculated for the period October 1995 to September 2004. While the (terms of reference) called for annual balances, the patching was done at a monthly time step and the balances were calculated at this time step. This will facilitate more detailed checking against model simulations. The primary output was in the form of annual balances, which was presented numerically and graphically.

The split between point and diffuse salt loads to the incremental catchments above key monitoring points were calculated from the continuity equation. The inflows and outflows of water and salt from a typical catchment are shown in **Figure 2**. The routes included in the salinity balance are described below.

- **Upstream** – This is the input via the river system into the catchment of interest from the upstream catchment. This is therefore the output from the upstream catchment.
- **Tranfers in** – This is the water and salt load transferred into the catchment from an adjacent catchment. The water from Heyshope and Zaaihoek Dams pumped into the Grootdraai Dam catchment to support the water users in the catchment are examples of transfers into a catchment.
- **Transfers out** – This is the water and salt transferred out of the catchment to an adjacent catchment. The transfer of water and salt from the Vaal Barrage catchment to the Crocodile West and Marico WMA in the Rand Water network is an example of transfers out of a catchment.
- **Losses -** Losses are the loss of water in a conveyance/river system due to evaporation or infiltration. Evaporative losses are represented as a loss of volume but not a loss of salt. This allows for the concentrating up affect of evaporation on salt concentrations. The other form of loss is the loss of both volume and salt. This would be a loss due to infiltration such as the losses in the Blesbokspruit due to infiltration into the dolomites.
- **Abstractions** – Abstractions remove water and salt from the system. The abstractions can take place from a river or a dam. The abstracted water can be used consumptively and the water volume and salt mass removed from the system or a portion of the water used can be returned to the system as a return flow. The return flow could be via the wastewater treatment plants in the case of urban use or as an industrial effluent for an abstraction for industrial use. In the process of using the water, salt gets added to the water resulting in an increase in the concentration in the effluent.
- **Irrigation** – Abstractions made from the river system or dams for irrigation use. Irrigation abstractions are associated with a return flow which returns water and salts to the river system.
- **Mine dewatering -** Mining results in the ingress of groundwater into the mine workings. This water has to be pumped from the workings to enable mining to continue. Some of the water pumped from the mines is used in the mining process and the balance discharged to the environment. The water quality of the mine discharges varies between mines. The TDS concentrations of the mine water vary from high (3900 mg/l) to values that are typical of the inflowing groundwater. Data was collected on the water quality and the volumes of the mine water discharges.
- **Return/effluent flows** – The return flows or effluent discharges referred to under this category are typically from wastewater treatment plants and industrial complexes. In these cases water is abstracted from the river system and passed through a process which results in the production of a lower volume more saline effluent due to the consumptive use of water and the addition of salt mass to the intake water. The water quality of the effluent stream depends on the water quality of the intake water. Effluent volumes and water quality data were collected during the data gathering process. In the WRPM a demand centre node is used to model this affect with an additional salt

mass added at the node to simulate the affect of the process on the water quality of the effluent stream. The critical percentage return flow volumes and the increase in TDS concentration through use need to be calculated and checked against the current input in the WRPM.

- **Catchment washoff** – The catchment washoff is the term used to describe the salt load contributed from the catchments to the river system. The salt load is contributed from the catchments by means of surface runoff and groundwater flows to the river.
- **Outflows** – The outflow from the catchment is the water volume and salt load that leaves the catchment and passes on downstream. The catchments were selected in such a way that a flow and water quality gauging station was located at the downstream end of the catchment. The recorded flow and TDS concentrations are used to determine the volume and salt mass leaving the catchment.
- **Storage –** The other source and sink of water volume is the storages in the catchment. The difference between the start and end storages over the simulation period should be accounted for in the salinity balance. There are records of volumes and water qualities in the major dams in the system. The smaller farm dams are represented in the model as dummy dams. There are no records of storage in these dams. However their volumes are small when compared to the other volumes and the difference in volume over the simulation period is therefore small and will not significantly affect the water and salt balance

The water and salt balance can be written as follows:-

Start storage+mine dewatering+catchment washoff+return flows+upstream+transfers in-transfers out-outflows-abstractions-losses-net irrigation=End storage

Data on all the elements in the above equation can be collected except for the catchment washoff component. The collected data can therefore be used to back calculate the catchment washoff loads, volumes and average annual TDS concentrations.

During compilation of the balances it was found that conflicts arose between the recorded flows at different gauges. This is an inevitable result of gauging errors and the subtraction of large numbers (for example to obtain the inflow from tributaries during periods of large flow down the Vaal River). Judicious balancing of the gauged flows was undertaken, taking account of the reliability of the gauges and the integrity of the overall catchment balance. The water and salt balance were set up on a spreadsheet to facilitate rapid iteration to achieve a sound balance.

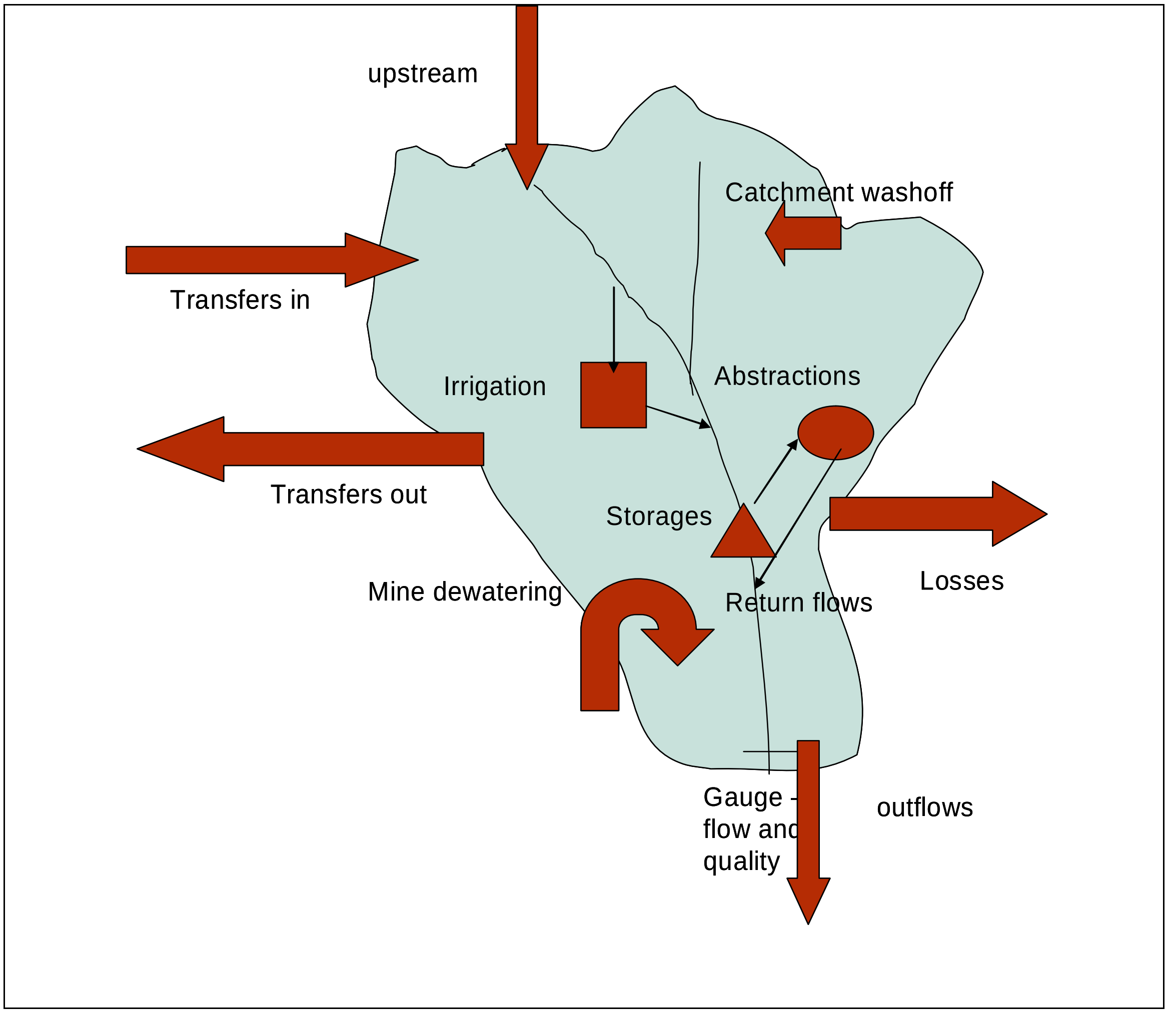

Figure 2: Flow routes for water and salt load for a typical catchment

2.2.5 Task 3d: Evaluate water and salt balances

The system water and salt balances were assessed to gain a clear understanding of the mechanisms driving system salinity. Existing operating rules were evaluated in this light and potential new ameliorative measures identified.

The flow and TDS ratios between water abstracted and returned to the Vaal River and its tributaries are also of critical importance. Demographic trends and changes in the mix of industries could alter the water quality trends in the Vaal River.

2.2.6 Task 3e: Simulate load balances

The WRPM model abstraction and effluent flow data was set to mimic the patched observed values. The beginning of October 1995 salt washoff, reservoir and irrigation module starting salt storages were set equal to those simulated in the VRSAU for the end of September 1995. The model was then run for the period 1995 to 2004 to generate a series of salt concentration scenarios at key monitoring stations.

2.2.7 Task 3f: Identify and correct anomalies

The simulated WRPM results were compared with the calculated values at key points in the system to determine if the observed scenario is within reasonable statistical limits. This initial superficial check was followed by a check of the simulated stochastic scenario that most closely matches the observed hydrology.

3 SELECTION OF KEY MONITORING STATIONS

3.1 System layout

The Vaal River catchment is represented in the WRPM as the following major sub-systems viz Upper Vaal (upstream of Vaal Dam), Vaal Barrage (between Vaal Dam and the Barrage wall), Middle Vaal (Vaal Barrage to Bloemhof Dam), Lower Vaal (Bloemhof Dam to Douglas weir) and the Modder-Riet systems. Each of the major sub-systems is further subdivided based on the main tributaries. The layout of the major sub-systems and their subdivisions as in the WRPM is shown in **Figure 3**.

The areas for the salinity balances were based on the WRPM schematics. A broader sub-division than is shown in **Figure 3** was used for the salinity balance. The selection of the areas was based on land use, transfers and the availability of adequate flow and water quality data to define the catchment outflows. The final selection is shown in **Figure 4**. The areas for which salinity balances were developed are given in **Table 1**.

A finer subdivision of the Vaal Barrage to Bloemhof Dam catchment was initially considered by subdividing the area at the Midvaal and Sedibeng abstraction weirs on the Vaal River. However the accuracy of the flow records was such that a sensible water balance could not be achieved. The balance showed that the catchment runoff had to be negative in order to achieve a balance. This highlights the need for accurate information in carrying out the balances.

3.2 Key stations

The key stations selected to measure the outflows from the catchments for which salinity balances were to be calculated are summarised in **Table 2**. The key stations are the stations that provide the salt load and volumes leaving the salinity balance sub-catchment. These were either flow stations with a daily flow record and a suitable water quality record to calculate the loads leaving the subcatchment. In some cases dam balances were used in conjunction with the downstream flow and water quality measuring station. The dam balance provides the abstractions and storage volumes and salt masses in the storage while the downstream monitoring station provides the TDS concentration information to calculate the salt loads leaving the dam.

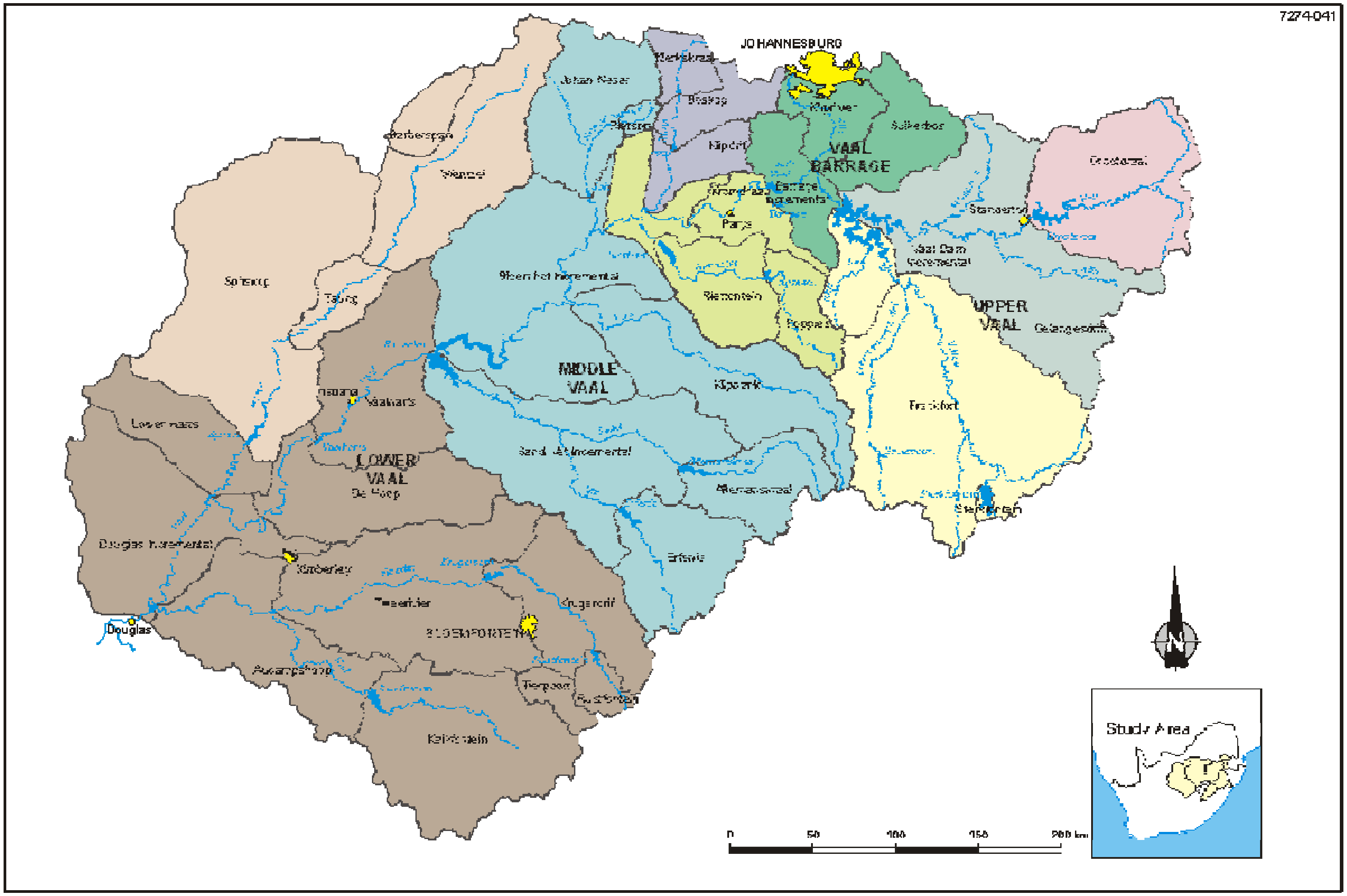

Figure 3: Major sub-systems and their subdivisions used in the WRPM

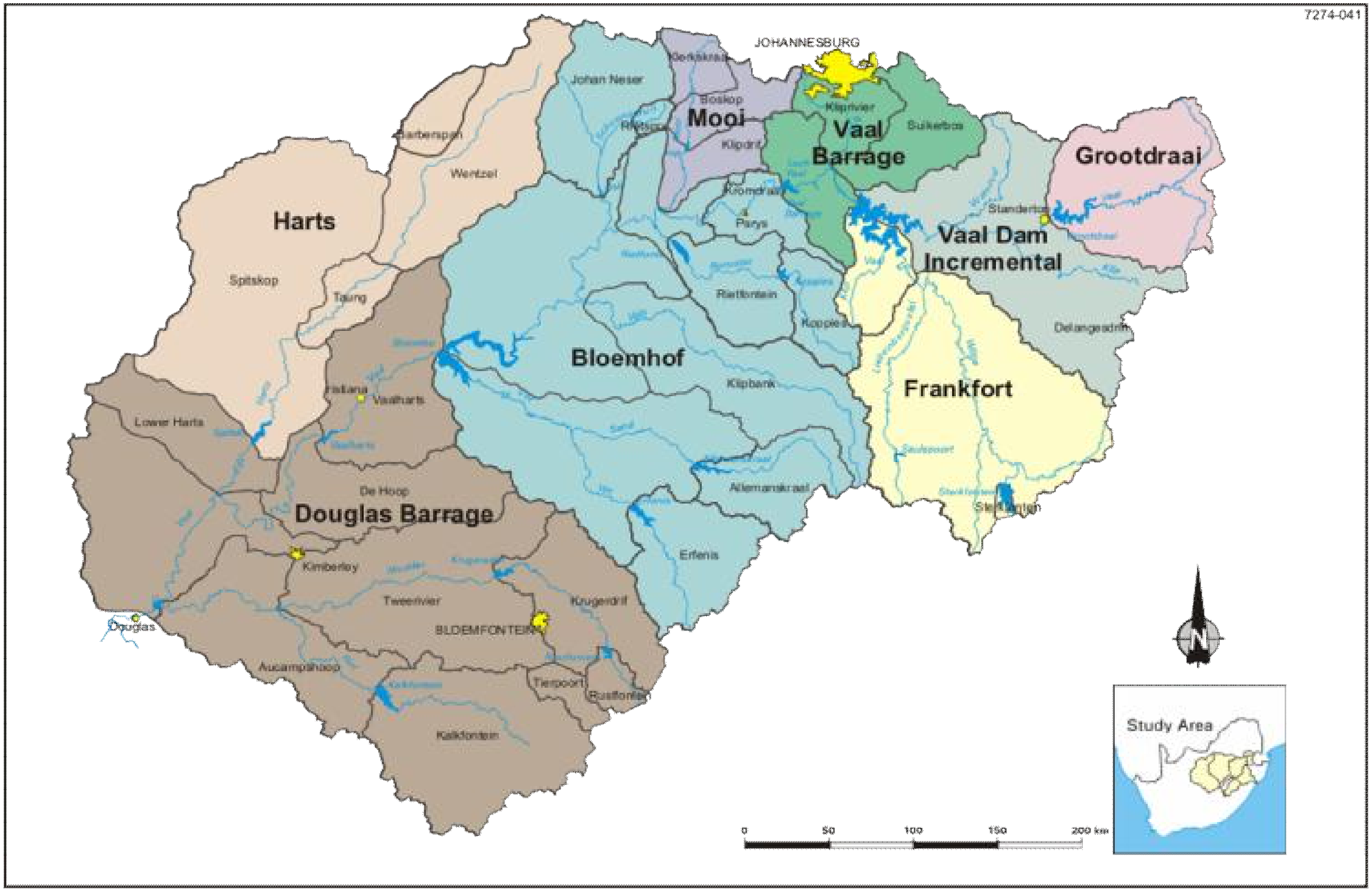

Figure 4: Catchments used to develop the salinity balance

Table 1: Sub-catchments used in the salinity balance

Major subsystem (WRPM)	Salinity balance sub-catchment	Catchment Area (km^2)
Upper Vaal	Grootdraai Dam Frankfort Vaal Dam incremental	7924 15673 14908
Vaal Barrage	Vaal Barrage	8613
Middle Vaal	Mooi Vaal Barrage to Bloemhof Dam	6114 54679
Lower Vaal	Harts at Spitskop Dam	26914

Table 2: Key Stations used in the salinity balance

Salinity Balance sub-catchment	Key Station
Grootdraai Dam	C1R002 – dam balance for Grootdraai Dam C1H019 – Dam outflow quality and quantity
Frankfort	C8H001 – flow and water quality data
Vaal Dam incremental	CR001 – dam balance for Vaal Dam C2H122 – Anniesdrift weir measuring outflow quality and quantity released from Vaal Dam
Vaal Barrage	C2R008 – water quality data daily discharge information from Barrage obtained from Rand Water
Mooi	C2H085 – Flow and water quality data
Vaal Barrage to Bloemhof Dam	C9R002 – Bloemhof Dam balance C9H021 – Flow and water quality of Bloemhof Dam discharge
Harts at Spitskop Dam	C3R002 – Spitskop Dam balance and water quality data C9R001 – Vaal Harts weir abstraction data

4 DATA ASSEMBLY AND AGGREGATION

4.1 Data sources

The study team undertook a data collection exercise to assemble the discharge volumes and water qualities of the point source discharges included in the WRPM and any new discharges not included. The following approaches were used in collecting the data:

- Existing databases of information collected by the study team for various studies such as the Water Research Commission (WRC) fluoridisation study were used.
- Recently completed situation assessments and catchment management strategies for some of the sub-catchments.
- The organisations were approached directly for information by means of a questionnaire and follow up phone calls.
- The Department’s database at the regional offices were also accessed for water quality data for effluent discharges.

- Some of the organisations were visited to clarify issues related to the data.

4.1.1 Mine dewatering

The mine dewatering data was collected as part of the task to assess the re-use potential of effluent in the Vaal River catchment. This task formed part of the Vaal reconciliation study which runs in parallel to this study. This data was difficult to collect and in general no detailed time series of water quality or flow was made available. The exception was Petrex where a detailed record of the discharge volumes and water quality was provided for the Grootvlei mine. The discharge information for the mines cannot be considered as high confidence data.

In general there is uncertainty on the future of the current mining operations and integrated and co-operative plans to manage the water in the gold mine workings in the western, central, eastern and far west basins. The future of the mining is largely dependent on the gold price.

4.1.2 River stations

River flow and TDS monitoring data was obtained primarily from the Department's databases. The flow information was abstracted from the Department's web site, the dam balances were requested from the Department head office and the water quality data was received from the Regional Office and the Institute for Resource Quality Studies. Rand Water, Midvaal Water and Sedibeng Water also provided water quality data. Rand Water provided a daily flow record for the discharges from the Vaal Barrage. Gaps in river flow measurements were patched by making comparisons with adjacent flow gauges. Gaps in TDS records were patched using a moving regression process between daily flow and weekly (or less frequent) TDS records. The patched daily flow and TDS records were used to calculate loads and aggregated into monthly and annual totals. These comprised the basic input to the load balance.

In processing the data, it was found that the period at which the sampling is undertaken to determine the water quality information is becoming longer. The water quality data is becoming sparse and the periods of no record longer. The paucity of data impacts on the accuracy of the patching techniques use to in fill the TDS concentration data records.

4.1.3 Abstractions

For the abstraction data, the information collected for the Large Bulk Water Supply Reconciliation Strategies (LBWRS) study, the water conservation and demand management study and the ongoing operational management of the Vaal River System were used. These studies are running in parallel with the IWQMP for the Vaal River. The data was provided in a spreadsheet and included return flow information from the wastewater treatment plants.

4.1.4 Effluent source

The effluent sources are made up of industrial and discharges from the wastewater treatment plants. The water quality data for the smaller wastewater treatment plants were collected from the Department's databases in the regional offices. The data stored in these databases was generally water quality only with little or no flow information. The data is either stored on the WMS system or on spreadsheets and in some instances in hard copy. The flow information was obtained from the data collected for the annual operating analysis of the Vaal River System.

Data for the major wastewater treatment works run by Johannesburg Water, Erwat and Metsi a Lakoa were collected from the Department's databases as well as from the institutions themselves. Information was also collected on the future plans of these institutions with their wastewater treatment works. The data for the industrial complexes was obtained from the industries and from the Department's databases.

4.1.5 Water Transfers

The water volumes transferred into the Vaal River catchment through the water transfer schemes were obtained from the Department. The water quality of the transferred water was obtained from the Department's water quality database of the source of the water.

4.1.6 Irrigation

The process of the validation/verification of the irrigation water use in the Vaal River catchment is underway. Preliminary results have been produced and are summarised in a report entitled "Irrigation Sector: Demands and economic importance" produced as a task under the LBWRS project. The study revealed that there has been growth in the irrigation water use with much of the growth being unlawful. The extent of the unlawful use is still being determined. The water use values given in the report for 1998 and 2005 were used as the basis for the irrigation use in the salinity balance.

In calculating the return flow volume and salt load, the assumption was made that 10% of the irrigation abstraction was returned to the river as a return flow with 40% of the abstracted load to give an estimate of the return flow TDS concentration. Based on these assumptions, a net irrigation demand and salt load abstraction was determined for the irrigation areas.

4.2 Patching

The discharge information and the flow records at the river stations required patching to produce the monthly flow weighted TDS concentrations needed for the salinity balance. The MOVE moving regression software was used to patch the river station data. This process uses a regression between the available grab sample TDS concentration information and the daily flow record at the river station to in fill the TDS concentration for each day. The daily flow record and the in-filled TDS concentration time series are then used to produce the monthly flow records and the monthly flow weighted average TDS concentrations needed for the salinity balance.

For the point source discharge information the software AVEMON3 and TDSPAT were used to detect the seasonality in the point source discharge quality and patch the data so as to preserve the observed seasonality.

The application of the MOVE regression techniques requires a good set of daily flow data and a maximum of 2 weekly sampling interval between TDS concentrations to achieve an in-filled TDS concentration time series of adequate accuracy which can be used with confidence in the salinity balance. In many cases the set of TDS concentrations was insufficient to support accurate patching.

5 WATER AND SALT BALANCE

5.1 Annual salt balances

5.1.1 Grootdraai Dam sub-catchment

Description of sub-catchment

The Grootdraai Dam catchment is developed with coal mines in the Ermelo area of the catchment and in the Leeuspruit catchment. There also a number of defunct and abandoned collieries in the catchment, many of which are decanting. Eskom has the coal fired Majuba and Tutuka power stations currently operating in the catchment. The previously moth balled Camden power station is being refurbished to bring it back on line to help meet the growing electricity demand in the country. The Usutu Colliery is being reopened and new sections developed to supply the coal to the power station.

The Grootdraai Dam supplies the Sasol Secunda complex and the Tutuka power station with water. The dam is supported by transfers into the catchment from the Zaaihoek Dam on the Slang River in the Thukela WMA and from the Heyshope Dam in the Usutu-Mhlatuze WMA.

Mine dewatering

There is no active mine dewatering in the catchment. There are however decants from abandoned mines and seepages into the river system from mine workings and waste disposal facilities. These seepages and decants have been taken into account in the calibration of the WQT by calculating the TDS load needed to achieve calibration at the observation point. These have been included in the WQT and transferred into the WRPM as seep files. These files are a record of flows and TDS concentrations. There are three seep files in the WQT which have been aggregated into a single seep file in the WRPM. There are seep files for the Leeuspruit, Blesbokspruit and along the Vaal main stem. These seep files cannot be recalculated unless the WQT model and the hydrological models are recalibrated. The average flow and TDS concentration of the existing seep records were used in the salinity balance. In the Grootdraai Dam catchment this may be inaccurate as there has been substantial rehabilitation efforts undertaken on the coal mines in the catchment.

River stations

The Grootdraai Dam and downstream weir were used to determine the outflow from the Grootdraai Dam sub-catchment into the Vaal incremental sub-catchment. The records were patched using the MOVE model and the time series of discharge volumes and TDS concentrations are shown in **Figure 5**.

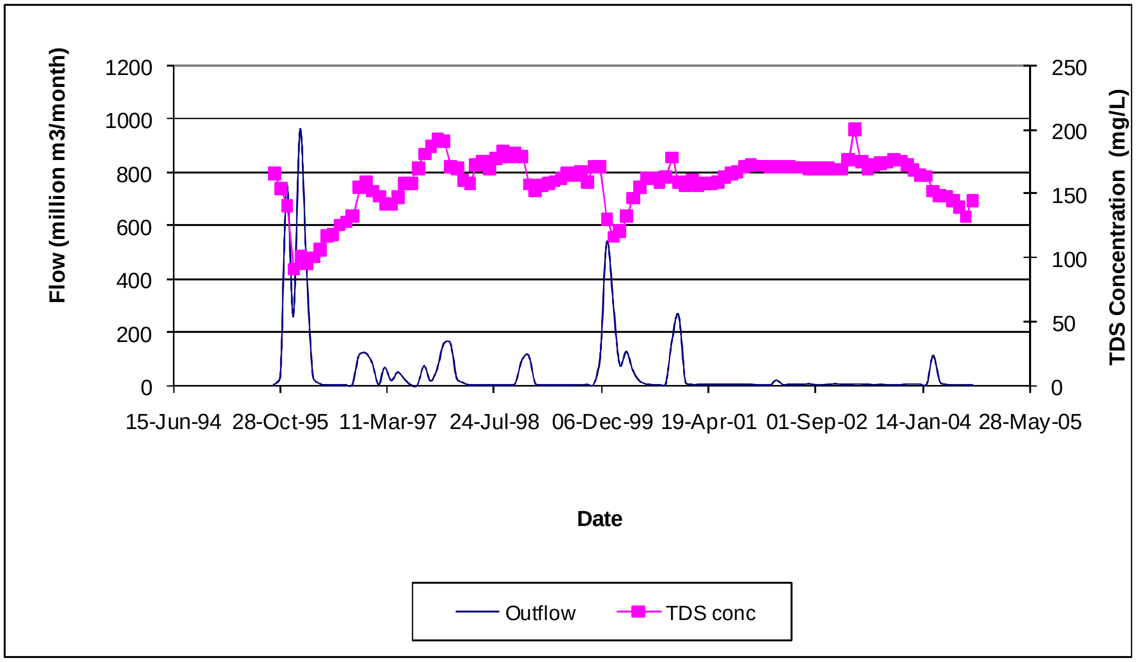

Figure 5 : Plot of discharge volumes and TDS concentrations of discharge from Grootdraai Dam

The plot in **Figure 5** shows that there have been large outflows from Grootdraai Dam in 1995/96 and again in 1999/2000. The period for which the salinity balance is being undertaken is a wet period. The TDS concentrations in the dam also responded to the flood events by reducing due to the addition of the low concentration flood waters. The TDS concentration in the dam varies around a concentration of 170 mg/L.

Effluent

The only effluent discharges in this catchment are the wastewater treatment plant discharges. The effluent discharges from the wastewater treatment plants are aggregated into a single file in the WRPM called GRurban.TDS. The wastewater treatment plant discharges included in the catchment are listed in **Table 3**. The seepage volumes and loads described in the section on mine dewatering are also included as an effluent in the salinity balance for the catchment.

Table 3: Effluent discharges in the Grootdraai Dam sub-catchment

Discharge	Type	River	Average monthly volume (million m^3)
Tutuka Power Station	Wastewater treatment plant	Leeuspruit	0.04
Bethal	Wastewater treatment plant	Blesbokspruit	0.27
Ermelo	Wastewater treatment plant	Willem Brummerspruit	0.24
Seep	Diffuse sources	Leeuspruit, Blesbokspruit and the Vaal river mainstem	0.03

Irrigation

The irrigation demand in the Grootdraai Dam sub-catchment was varied from 17.91 million m^3 in 1998 and 29.54 million m^3 in 2005.

Abstraction

The major abstractions from Grootdraai Dam are for the Tutuka Power Station and Sasol Secunda. Water is also abstracted from the river system to meet the water requirements of small towns such as Amersfoort. These have been included in the abstraction information.

Water transfers

Water is transferred into the Grootdraai dam catchment as support for the Vaal River System. The water is transferred from the Zaaihoek and Heyshope Dams. The water transferred from Zaaihoek Dam is also used to supply the Majuba Power Station. The transfer volumes into Grootdraai Dam were obtained from the Department. In the case of the Zaaihoek transfer the supply to Majuba Power Station has already been accounted for. The total volume and the volume transferred into the catchment from Heyshope Dam and Zaaihoek Dam are shown plotted **Figure 6**. The plot shows that the transferred volume is sporadic. The volumes transferred are determined as part of the annual operating runs for the Vaal River System.

The volumes of water are substantial and the water quality in Grootdraai Dam will be affected by the water quality of the transferred water. A plot of the TDS concentration in the Zaaihoek Dam and in the Heyshope Dam are shown plotted in **Figure 7**. The concentration in Heyshope Dam showed an increasing trend in TDS concentration from 1990 to 1995. The influx of clean water during the floods of 1995 reduced the concentration in the Heyshope Dam. Since 1995 the concentration has remained between 80 mg/L and 100 mg/L. The monitoring at the dam stopped in 2000. The TDS concentration in the Zaaihoek Dam has remained between 80 mg/L and 100 mg/L over the monitoring period.

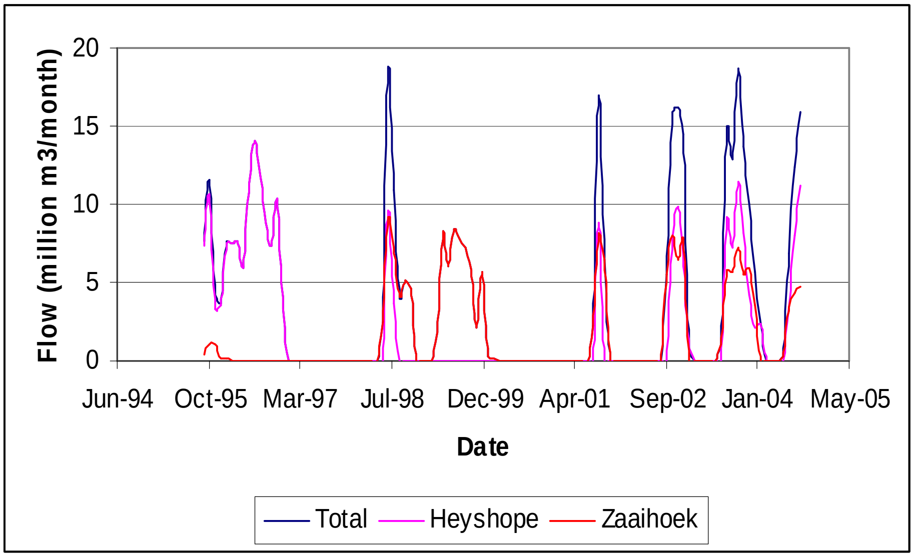

Figure 6: Plot of volume transferred into Grootdraai Dam sub-catchment from Heyshope and Zaaihoek Dams

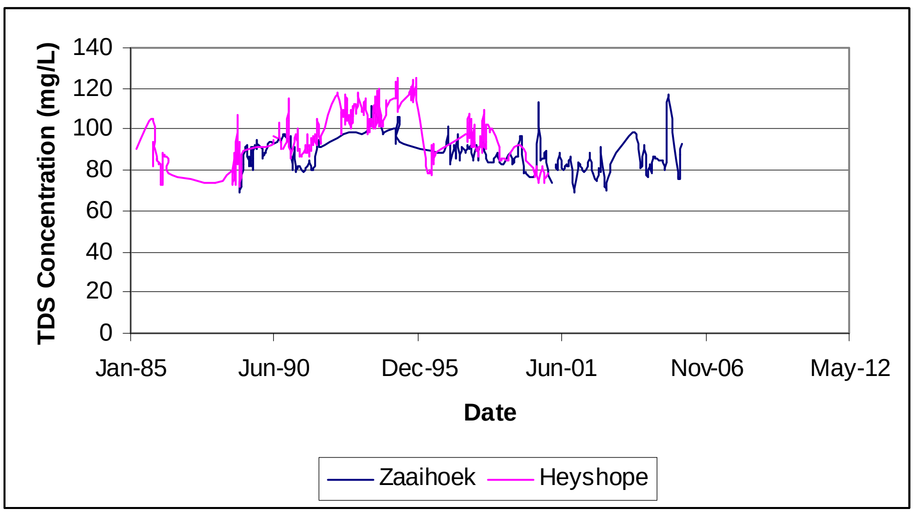

Figure 7: Plot of TDS concentration in the Zaaihoek and Heyshope Dams

<u>Salinity balance results</u>

The results of the salinity balance are presented as a pie chart showing the sources of TDS load. The pie chart is shown in **Figure 8** and the values are listed in **Table 4**. The figures given in the table and used to generate the percentage contributions given in the pie chart are averages over the 9 year analysis period.

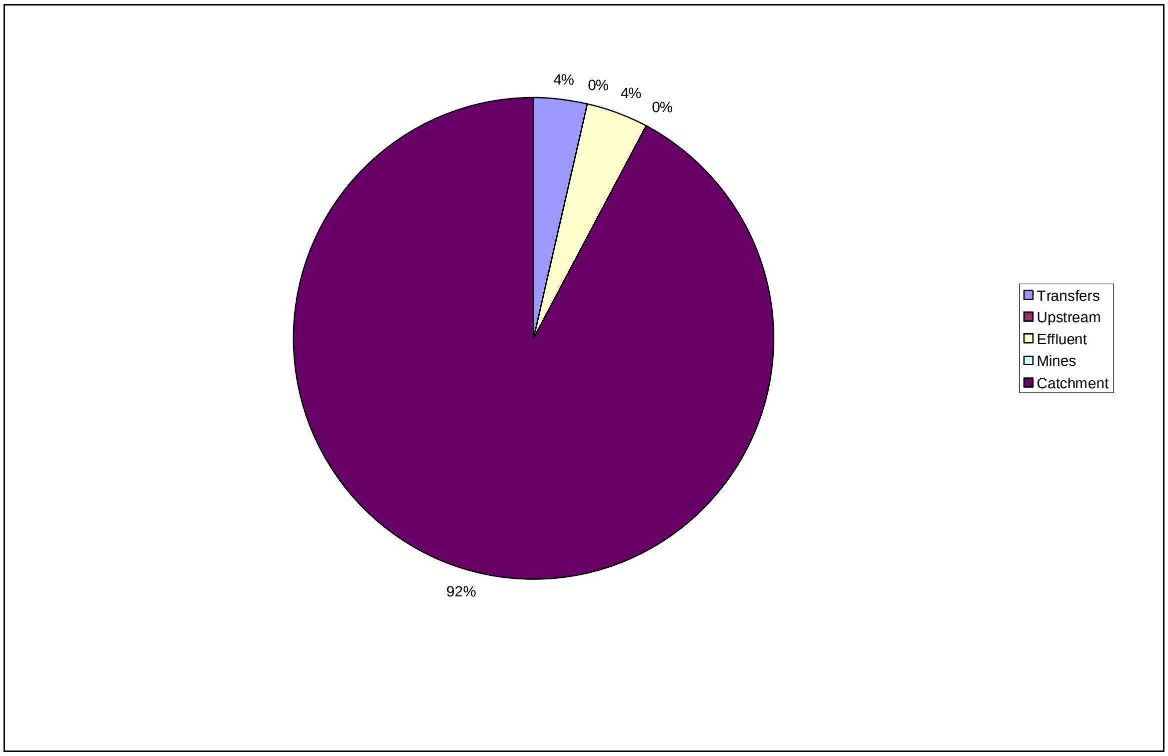

Figure 8: Pie chart showing contribution of TDS load from sources in Grootdraai Dam sub-catchment

Table 4: Volumes and loads from sources of TDS load for Grootdraai Dam sub-catchment

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	46.14	4171	90
Upstream	0	0	-
Effluent	6.25	4580	732
Mines	0	0	-
Catchment	766 (97 mm/a)	105680	138

The results given in **Figure 8** and **Table 4** show that the largest contribution to the salt load is made by the catchment washoff. The calculation of the average TDS concentration of the washoff is 138 mg/L and the unit runoff is 97 mm/a.

5.1.2 Frankfort sub-catchment

Description of sub-catchment

The Frankfort sub-catchment is largely rural in nature with agriculture being the major activity. The major towns in the sub-catchment include Harrismith, Bethlehem, Frankfort and QwaQwa. The Wilge River which drains the sub-catchment directly into the Vaal Dam. The flow and water quality in the sub-catchment is dominated by the water transferred into the sub-catchment from Lesotho and from the Thukela River. The discharge from the Lesotho Highlands Project is released into the Liebenbergsvlei, a tributary of the Wilge River. The water transferred from the Thukela WMA is stored in Sterkfontein Dam from where water can be released into the Nuwejaarspruit, a tributary of the Wilge River. The major dams in the catchment are the Sterkfontein Dam and Saulspoort Dam.

Mine dewatering

There are no mines in the sub-catchment so there is no mine dewatering.

River stations

The weir C8H001 at Frankfort on the Wilge River was used as the river station to calculate the outflow from the sub-catchment. The TDS concentration record was patched using the MOVE model. The time series of discharge volumes and TDS concentrations are shown in **Figure 9**.

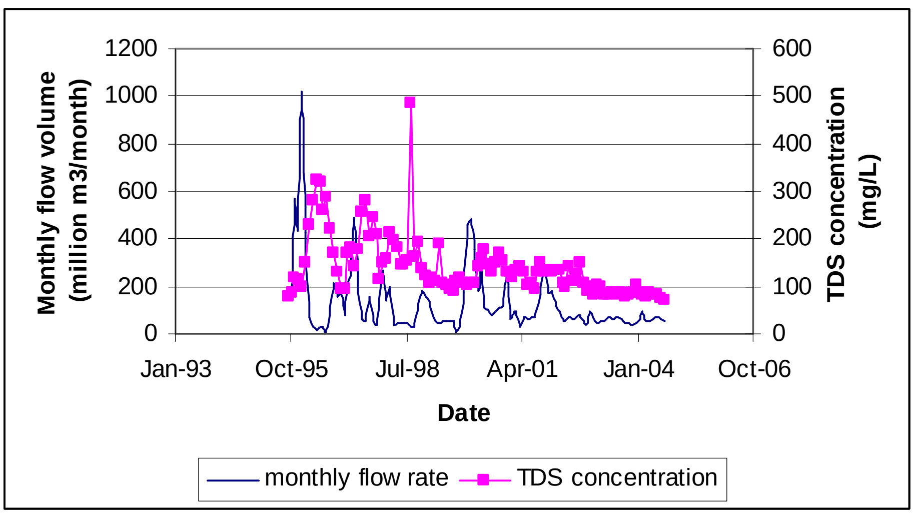

Figure 9: Plot of discharge volumes and TDS concentrations at outflow from Frankfort sub-catchment (C8H001)

The plot in **Figure 9** shows the two flood events in 1995 and 2000. The downward trend in the TDS concentration shown in **Figure 9** is due to the low TDS concentration water being discharged from Lesotho.

Effluent

The only effluent discharges in this catchment are the wastewater treatment plant discharges.. The wastewater treatment plant discharges included in the catchment are listed in **Table 5**.

Table 5: Effluent discharges in the Frankfort sub-catchment

Discharge	Type	River	Average monthly volume (million m^3)
Harrismith	Wastewater treatment plant	Wilge River	0.14
Bethlehem	Wastewater treatment plant	Liebenbergsvlei	0.28
QwaQwa	Wastewater treatment plant	Wilge River	0.35

Irrigation

The irrigation demand in the Frankfort catchment varied from 54.99 million m^3 in 1998 to 145.26 million m^3 in 2005. The growth in irrigation has been substantial in this catchment with much of the irrigation unlawful. The eradication of the unlawful use in this area is one of the immediate reconciliation strategies to be implemented by the Department.

Abstraction

The major abstractions in the catchment are the supplies to the towns in the sub-catchment. The abstractions included in the balance are the supplies to Bethlehem, Frankfort, Warden, QwaQwa and Harrismith.

Water transfers

Water is transferred into the Frankfort sub-catchment from the Thukela WMA and from Lesotho. The flow measuring weir located downstream of Sterkfontein Dam was used to determine the volumes supplied to the catchment from the Thukela. The weir records showed that no releases have taken place over the analysis period.

The supply from the Lesotho Highlands Project started in 1998. The plot of the monthly volumes discharged into the Liebenbergsvlei is shown in **Figure 10**. The current volumes are about 70 million m^3/month. A TDS concentration of 78 mg/L was used to determine the salt load transferred into the sub-catchment from Lesotho.

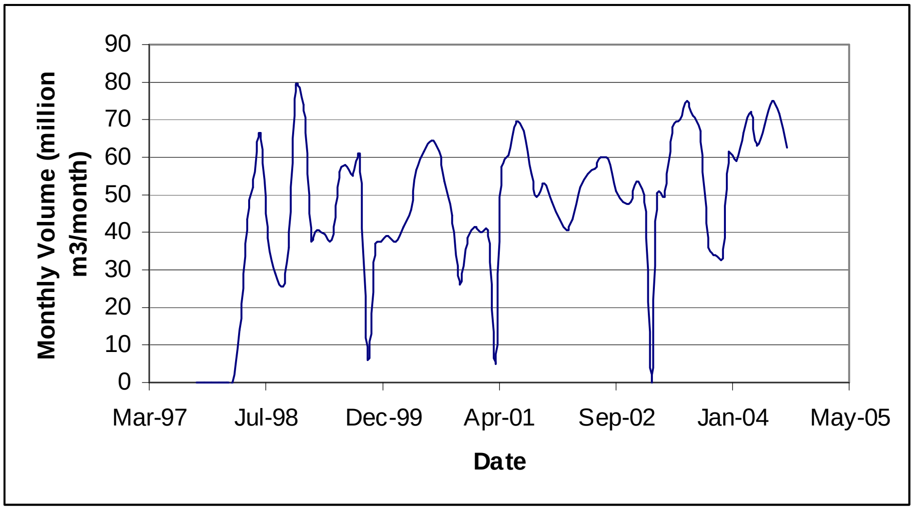

Figure 10: Plot of volume transferred into Frankfort sub-catchment from Lesotho

Salinity balance results

The results of the salinity balance are presented as a pie chart showing the sources of TDS load. The pie chart is shown in **Figure 11** and the values are listed in **Table 6**. The figures given in the table and used to generate the percentage contributions given in the pie chart are averages over the 9 year analysis period.

The salinity balance shows that the transfer volume from Lesotho is a substantial volume when compared to the catchment contribution. The current fraction is 32% of the runoff volume during a period with high runoff the large transfer volume also contributes 16% of the salt load to the catchment and therefore influences the water quality in the catchment significantly. This is shown in the decreasing TDS concentration at C8H001 observed since 1998 (See **Figure 9**).

The salt and water balance gives the unit runoff for the sub-catchment of 76 mm/a and the average TDS concentration of 148 mg/L.

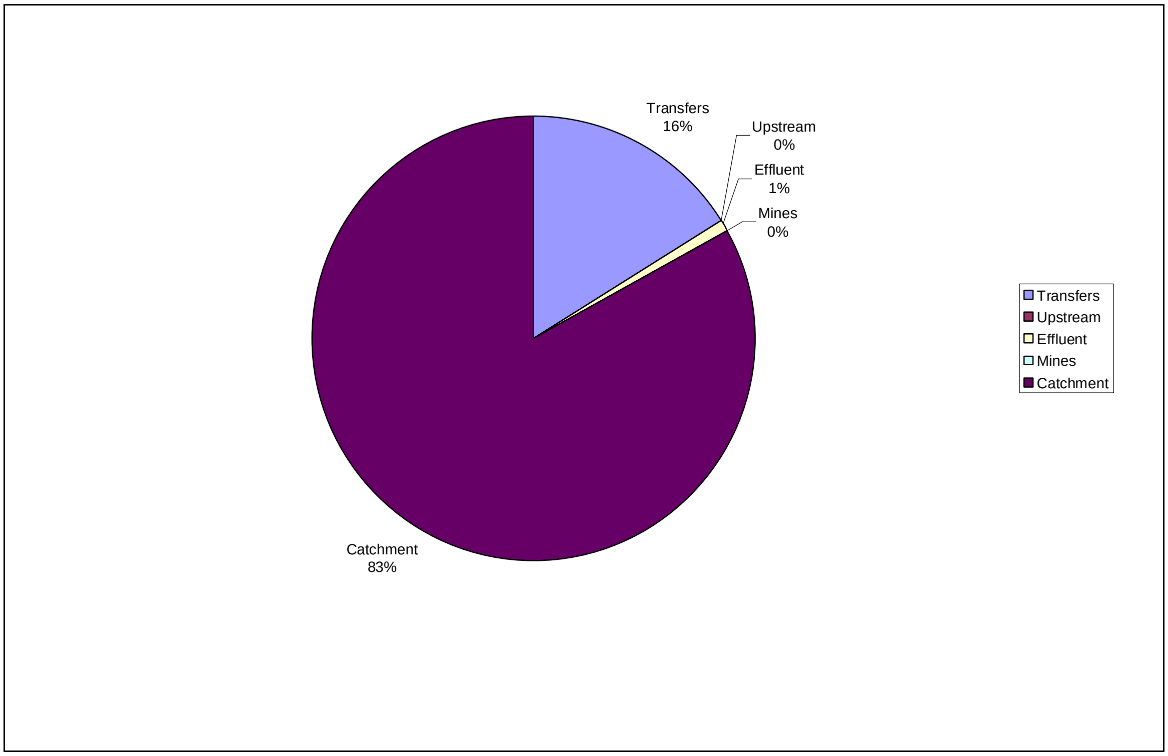

Figure 11: Pie chart showing contribution of TDS load from sources for the Frankfort sub-catchment

Table 6: Volumes and loads from sources of TDS load for Frankfort sub-catchment

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	432.9	33764	78
Upstream	0	0	-
Effluent	9.24	2624	284
Mines	0	0	-
Catchment	1167 (76 mm/a)	172511	148

5.1.3 Vaal Dam Incremental sub-catchment

Description of sub-catchment

The Vaal Dam incremental sub-catchment is the area between Grootdraai Dam, C8H001 on the Wilge River and Vaal Dam. Vaal Dam itself is included in the sub-catchment. The major land-use is agriculture except for the upper reaches of the Waterval catchment where the Sasol Synfuels plant, Sasol coal mining and Evander gold mines are active. The towns of Secunda, Evander and Embalenhle are also located in the upper reaches of the Waterval catchment. There are a number of industrial and wastewater treatment plant discharges located in the Waterval catchment. As a result of these activities the Waterval River has elevated TDS concentrations and nutrients which flow into the

Vaal River upstream of Vaal Dam. The Waterval impacts on the stretch of the Vaal River from the confluence of the Waterval and Vaal Rivers to Vaal Dam.

There are no transfers into the sub-catchment from adjacent WMA's. The upstream inputs into the sub-catchment are the outflows from the Grootdraai Dam and Frankfort sub-catchments.

Mine dewatering

Although there are mines in the sub-catchment, there is no mine dewatering being discharged into the river system.

River stations

The Vaal Dam C1R001 and the downstream weir C2H122 were used as the station to calculate the outflow from the sub-catchment. The time series of discharge volumes and TDS concentrations are shown in **Figure 12**.

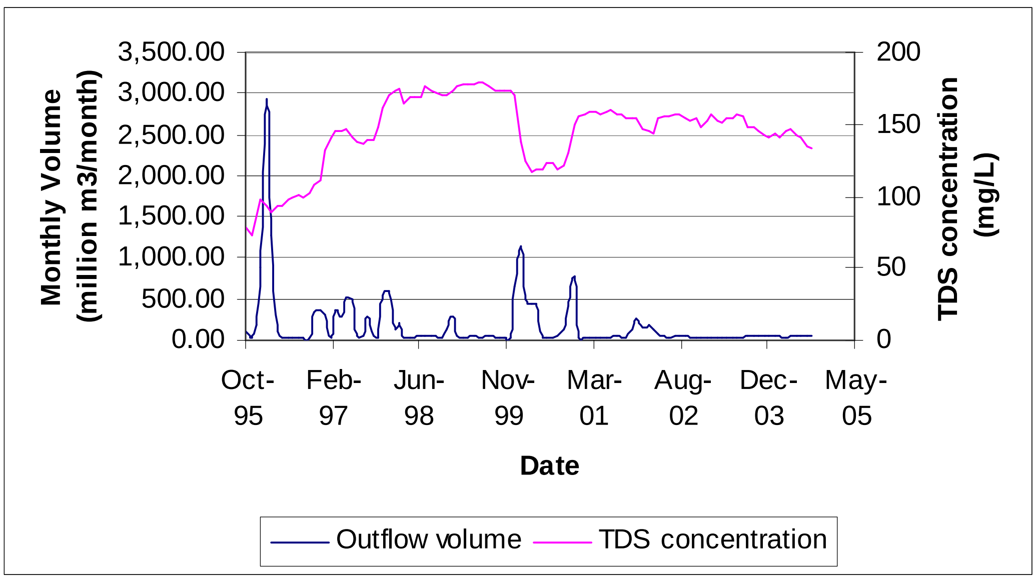

Figure 12: Plot of discharge volumes and TDS concentrations at outflow from Vaal Dam Incremental sub-catchment

The plot in **Figure 12** shows the reduction in the TDS concentration caused by the two flood events in 1995 and 2000. After 2001, there has a downward trend in the TDS concentration caused by the low TDS concentration water discharged from Lesotho.

Effluent

The effluent discharges in the Vaal Incremental sub-catchment are the wastewater treatment plants, industrial discharges from Sasol Synfuels and seepages. The discharges included in the catchment are listed in **Table 7** together with the average monthly discharge volume.

Table 7: Effluent discharges in the Vaal Dam incremental sub-catchment

Discharge	Type	River	Average monthly volume (million m^3)
Evander	Wastewater treatment plant	Waterval	0.15
Twisdraai	Wastewater treatment plant	Bossiesspruit	0.004
Embalenhle	Wastewater treatment plant	Waterval	0.36
Leslie	Wastewater treatment plant	Waterval	0.03
Brakfontein/Nthorwane	Wastewater treatment plant	Waterval	0.02
Secunda	Wastewater treatment plant	Waterval	0.19
Sasol effluent	Industrial effluent – blow down unit 205 and 05	Bossiesspruit	0.36
Standerton	Wastewater treatment plant	Vaal River	0.31
Seepage in Waterval catchment		Waterval	0.01
Seepage in Vaal upstream of Waterval confluence		Vaal River	0.01

A water quality modelling exercise was carried out as part of the project to develop a catchment management strategy for the Waterval Catchment. The modelling showed that the water quality in the Waterval catchment during the dry season is governed by the discharges and seepages. The seepage in the sub-catchment is a major contributor to the pollution load. Sasol is planning to treat and recycle the blow down. If the blow down is removed from the system then the TDS concentration in the Waterval River in fact increases. A strategy is being developed to address the seepage source with plans to reduce the seepage load by up to 50%.

Irrigation

The irrigation demand in the Vaal Dam Incremental catchment varied from 59.8 million m^3 in 1998 to 92.8 million m^3 in 2005. Similar to the Frankfort area, the validation/verification study has shown that there has been an increase in unlawful irrigation in this area.

Abstraction

The major abstraction in the sub-catchment is the abstraction from Vaal Dam by Rand Water. Rand Water has the option of abstracting water from the Vaal Barrage and blending with water drawn directly from Vaal Dam to achieve a TDS concentration of 300 mg/L. Rand Water however has not practised the blending operating rule since 1998 due to the poor quality water in the Vaal Barrage. The algae and microbiological quality in the Barrage is at levels that the Rand Water water treatment plants cannot safely treat.

The abstractions from the other large water users such as Sasol, Mittal and Eskom's Lethabo Power Station are made from the Vaal River downstream of the dam. These abstractions are included in the water and salinity balance for the Vaal Barrage as the release volumes are included in the flow measurements at the weir downstream of Vaal Dam.

Water transfers

There are no water transfers into the Vaal Dam Incremental sub-catchment from adjacent WMA.

Salinity balance results

The results of the salinity balance are presented as pie charts showing the sources of TDS load. Two pie charts have been produced. The pie chart shown in **Figure 13** and the values listed in **Table 8** are for the Vaal Dam Incremental sub-catchment including the contribution from upstream. The pie chart given in **Figure 14** is for the case excluding the contribution from upstream. The figures given in the table and used to generate the percentage contributions given in the pie charts are averages over the 9 year analysis period.

The pie charts show that the salt load contribution from upstream is the largest contributor with the Vaal Dam Incremental catchment contributing 30%. The upstream volume contribution is also the highest which implies that the water quality from upstream is good quality water as is reflected in the average TDS concentration of 133 mg/L. The effluent contribution is 3% if the upstream contribution is included in the balance. The effluent contribution increases to 10% if the upstream contribution is excluded. The source of the effluent salt load in the Vaal Dam Incremental sub-catchment is largely from the Waterval River.

The salt and water balance gives the unit runoff for the sub-catchment of 67 mm/a and the average TDS concentration of 128 mg/L.

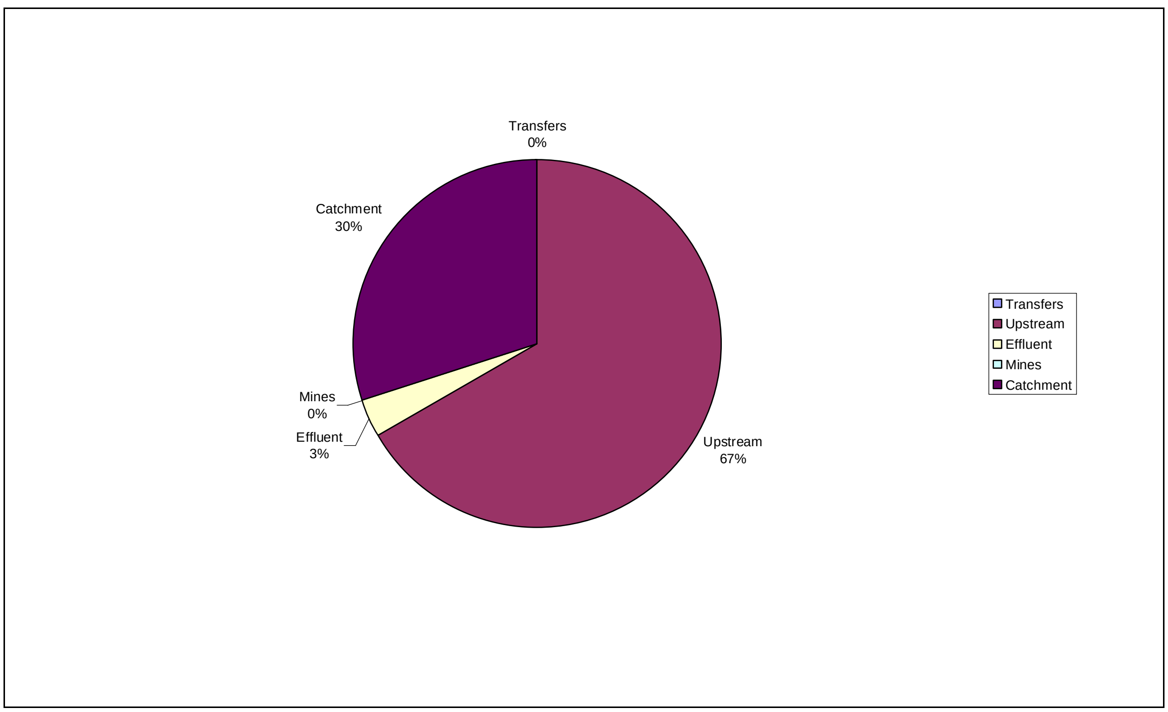

Figure 13: Pie chart showing contribution of TDS load from sources for the Vaal Dam incremental sub-catchment including upstream contributions

Table 8: Volumes and loads from sources of TDS load for Vaal Dam incremental sub-catchment including upstream contributions

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	0	0	-
Upstream	2144	284109	133
Effluent	19	14065	735
Mines	0	0	-
Catchment	995 (67 mm/a)	127349	128

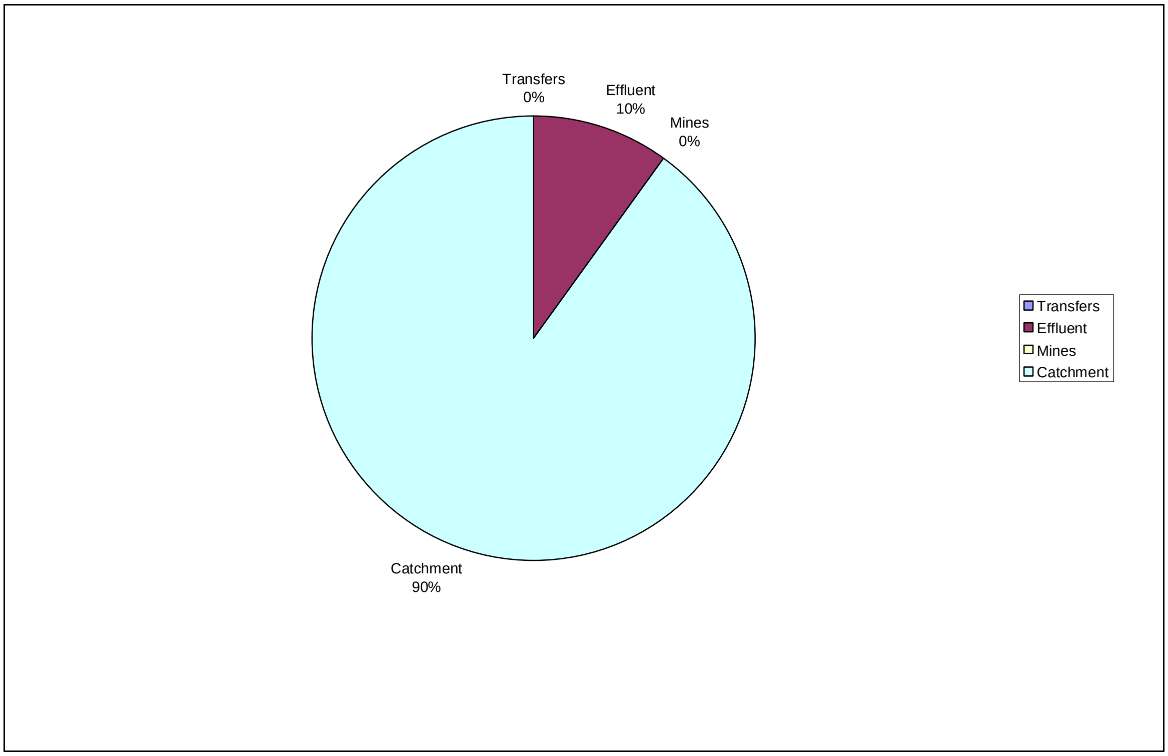

Figure 14: Pie chart showing contribution of TDS load from sources for the Vaal Dam incremental sub-catchment excluding upstream contributions

5.1.4 Vaal Barrage sub-catchment

Description of sub-catchment

The Vaal Barrage sub-catchment is a highly impacted catchment. The flows and water quality in the river system are dominated by return flows from the numerous wastewater treatment plants, mine dewatering discharges and industrial discharges. The area is developed with extensive urban areas and some agriculture. The Lethabo Power Station, Mittal and the Sasol industrial complex at Sasolburg are located in the Vaal Barrage catchment. There are also coal mining activities located along the banks of the Vaal River.

The main tributaries draining into the Barrage are the Klip River (Gauteng), Suikerbosrand, Rietspruit and the Taaibosspruit.

Mine dewatering

The gold mines are dewatering the mine workings and discharging water in the river system. The gold mines have been divided into 4 geohydrological basins viz the Far West rand, Western, Central and Eastern basins. A project is currently being funded by the WRC to investigate management options and uses of the water for these basins. The data presented in the sections below is drawn from a progress report to the WRC for the project. Each of the basins are discussed below.

Far West Rand Basin includes Simmer and Jack's Ezulwini Mine (Previously Randfontein no 4 shaft), South Deep Mine and Harmony's Cooke 3 Shaft. This basin is located on the far west rand in the vicinity of Westonaria and Libanon. The Far West Rand basin includes the Gemsbokfontein West Dolomitic groundwater compartment. This compartment is bounded by the Panvlakte Dyke to the north with the Gemsbokfontein and Magazine dykes forming the western and eastern boundaries. The basin falls in the Wonderfonteinspruit (Mooi sub-catchment) and the Rietspruit catchment. The Ezulwini Shaft has partially dewatered the Gemsbokfontein West compartment and it is only in this mine that significant ingress of groundwater occurs. The groundwater inflow sources to the Far West Rand Basin are the rainfall recharge, recharge of surface water into the mine workings through sinkholes and fractures and inflow from adjacent compartments. The volumes are summarised in **Table 9**. The groundwater from this basin is of good quality as about 30 ML/d is collected close to the source in the upper levels of the mine. The water collected in the lower levels in the mine workings is treated with lime and settling before mixing with the good quality water and discharging to the Kleinwes Rietspruit. The current discharge from the basin is 75 ML/d which is expected to reduce to 48 ML/d once the aquifer has been dewatered.

The following conclusions can be made regarding closure:

- Once the mine void is flooded, the contamination will remain in the mine void ie the water will be of reasonably good quality.
- The basin will decant out of the Wonderfonteinspruit eye into the Wonderfonteinsspruit. The flow at the eye will increase from 4 ML/d to 17 ML/d as the mine fills.
- The mine void will flood and the dolomitic aquifer will recover over a 9 year period once mining ceases.

West Rand Basin includes the defunct Randfontein Estates (Harmony), Luipaardsvlei and Durban Roodepoort Deep mines. The Western basin is located on the water shed between the Vaal River and Crocodile West catchments. The section of the basin falling in the Vaal River catchment is located in the upper Wonderfonteinspruit catchment in the vicinity of Krugersdorp. During the mining operations water was pumped from the mines at a rate of approximately 40 ML/d. When mining was discontinued, the defunct workings started to fill and started to decant in September 2002 at a rate of 15.5ML/d. The basin is currently decanting towards the Crocodile West catchment. The sources of inflow to the basin are groundwater recharge, ingress through reef outcrop, ingress from opencast mines, ingress of surface runoff and ingress from sand dumps and tailings dams. The volumes associated with the different sources are summarised in **Table 9**. The water decanting from the workings is acid and has a TDS concentration of 5410 mg/L. The water is neutralised before discharge.

Central Rand Basin extends from the defunct Durban Roodepoort Deep mine in the west to the only operating mine in the basin East Rand Propriety Mine (ERPM) in the east. The central basin was dewatered until 1974 at which time most of the mines in the central portion of the basin stopped working. The water levels in the basin are being maintained by the pumping from ERPM. The volume of the central basin void is 280 million m^3. The central basin is divided into three sub-basins viz the central, DRD and ERPM sub-basins. These basins are all connected but they currently act independently due to mining pillars and the installation of plugs. The pumping data from this basin is limited and only cover short periods of time. This makes predictions of filling times for the basin difficult. The water balance for the central basin are summarised in **Table 9**. ERPM is currently pumping at 37 ML/d which is discharged to the Klip River after treatment.

East Rand Basin covers an area of 75 km^2 and includes the towns of Boksburg, Brakpan, Springs and Nigel. The only operating gold mine is Petrex's Grootvlei Mine. The mining basin consists of three sub-basins namely the Sallies, East and Brakpan Basins. The water levels in the East Rand basin are being managed by the pumping from the Grootvlei No. 3 shaft where water is treated before discharge to the Blesbokspruit, a tributary of the Suikerbosrand. The current pumping rate is 70 ML/d. The volume of the underground void was estimated to be 327 million m^3. The water balance is summarised in **Table 9**.

The Petrex Gold Mine has prepared a master plan to manage the water on the mine. The water management strategy depends on the feasibility of dewatering the workings to enable the mining of the Sallies section. The current operational mine water management was to implement the 10 ML/d Biosure partial desalination plant and the reduction of surface water ingress to the workings. The Biosure plant has been implemented and the treated water is discharged through the Erwat Ancor wastewater treatment plant. If the mining of Sallies is found to be viable then there will be a 5 to 6 year period at which water will be pumped at 150 ML/d. The plan is to continue to discharge 75 ML/d but to construct a 75 ML/d potable water desalination plant to supply Rand Water with water. After the first 5 to 6 years, the rate of dewatering will reduce to 75 ML/d which will then be treated in the desalination plant and the discharge will be stopped. If the Sallies project is not viable then the mine will close and the water levels in the mine workings will be managed by pumping 50 ML/d from the workings, 40 ML/d will be treated to potable standard for supply to Springs while the remaining 10 ML/d will be treated in the Biosure process and used for agriculture or discharged.

Table 9: Summary of water volumes entering the geohydrological basins

Far West Rand Basin		
Source	**% of total inflow volume**	**Inflow Volume (ML/d)**
Surface water recharge Simunye and Westonaria	4	3
Surface Water recharge Leeuspruit	11	7.5
Surface Water recharge Kleinwes Rietspruit	7	5
Rainfall Recharge	51	36
Total	**100**	**67**
Western Basin		
Source	**% of total inflow volume**	**Inflow Volume (ML/d)**
Groundwater recharge	47	7.23
Reef outcrop	6	0.85
Opencast mines	22	3.47
Surface water ingress	6	0.86
Tailings dams	19	3.07
Total	**100**	**15.48**
Central Basin		
Source	**% of total inflow volume**	**Inflow Volume (ML/d)**
Outcrop	15.3	12.06
Perched aquifer	44.3	35.01
Surface streams	40.4	32.01
Total	**100**	**79.08**
Eastern Basin		
Source	**% of total inflow volume**	**Inflow Volume (ML/d)**
Catchment recharge	27	24.5
Recharge via outcrop	1.3	1.2
Shallow undermining	27	24.29
Recharge through geological structures	11.6	10.38
Recharge through dolomite aquifers	33.1	29.34
Total	**100**	**89.71**

River stations

The daily discharge record and TDS concentration record at the Vaal Barrage outlet was used to determine the outflow volumes and loads from the Vaal Barrage sub-catchment. The daily flow record was provided by Rand Water and the TDS concentration record was a combination of the Rand Water data and the Department's record at C2R008. On examining the flow record at the Barrage outlet provided by Rand Water, it was found that there were unusually high flow peaks on some days during the low flow winter period. A plot of the daily flow record over such a period is shown in **Figure 15**. Included in **Figure 15** is the flow rate measured at C2H122 (releases from Vaal Dam) and at C2H018 downstream of the Vaal Barrage. The plot shows that over the period October 1995 to March 1999 there are flow peaks in the daily record during the dry periods. The high flow peaks at the Barrage outlet are not supported by the record of releases from Vaal Dam as measured at C2H122 or flow measured downstream of the Barrage at weir C2H018. The daily flow record at the Barrage outlet was revised based on the flow record downstream of the Vaal Barrage. The revised record was used in the salinity balances.

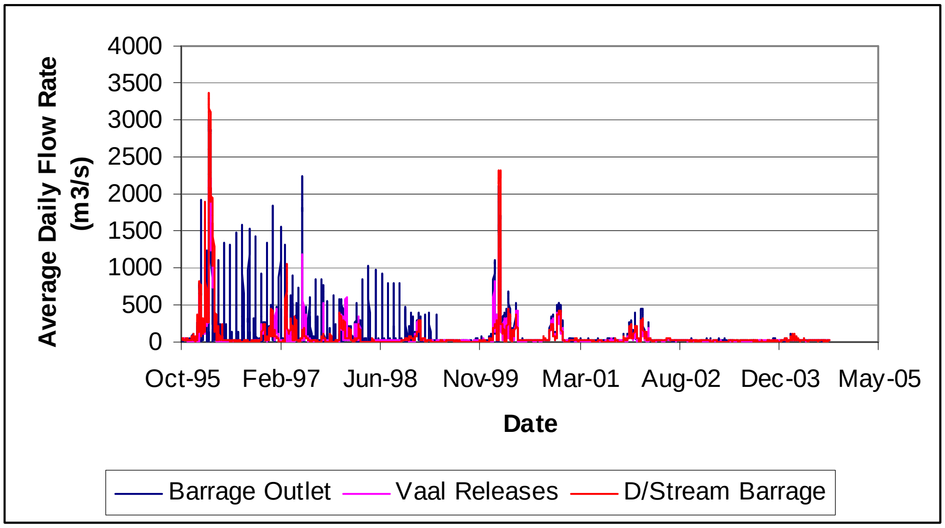

Figure 15 : Plot of daily flow record measured at the Barrage outlet, releases from Vaal Dam (C2H122) and at C2H018 downstream of the Barrage

A plot of the monthly flow record and patched monthly average TDS concentration is given in **Figure 16**. The plot in **Figure 16** shows the increases in flow through the Barrage during the 1995 and 2000 floods. During these periods the TDS concentrations dropped. The TDS concentration rarely exceeds 600 mg/L in the Barrage. This is due to the dilution rule practised in the Barrage where releases are made from Vaal Dam to maintain the TDS concentration at 600 mg/L.

In compiling the monthly average TDS concentrations, it was found that the record of TDS concentrations became sparse for periods during the record. The gaps were partially filled by data acquired from Rand Water. Given the steady high flow rates that discharge from the Barrage, an error in the TDS concentration or the flow rate equates to a large error in the loads which not only affects the salinity balance for the Barrage but also the balances for the downstream catchments.

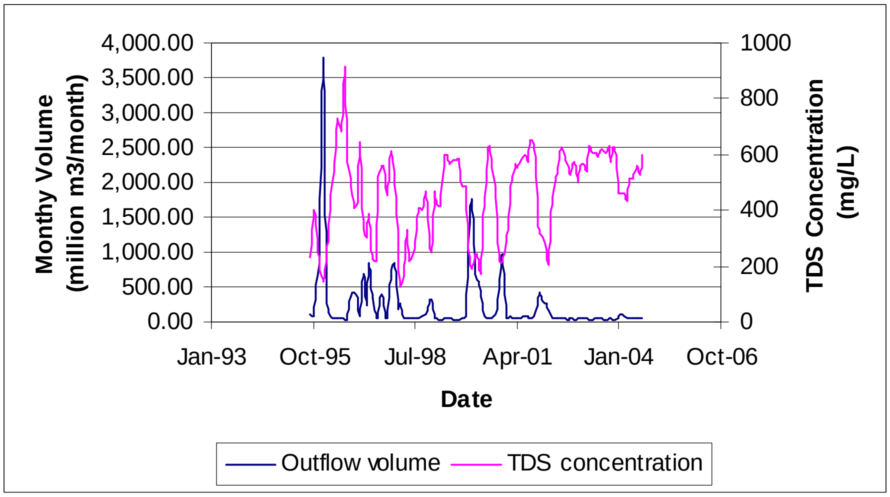

Figure 16: Plot of discharge volumes and TDS concentrations at outflow from Vaal Barrage sub-catchment

<u>Effluent</u>

There are both industrial and wastewater treatment plant discharges in the Vaal Barrage sub-catchment. These major wastewater treatment plants in the sub-catchment are managed by Erwat, Johannesburg Water and Metsi-a-Lekoa. The Johannesburg Water plants that affect the Vaal are located in the Klip River and the Rietspruit. Erwat's plants that affect the Vaal River are located in the Klip River and the Suikerbosrand while Metsi-a-Lekoa's plants are in the Rietspruit catchment. The industrial discharges that are discharged directly to the river and not into a sewer system include Sasol and Sappi. The major effluent discharges are discussed below.

Erwat wastewater treatment plants are located in Ekurhuleni. There are a total of 17 wastewater treatment plants in the Vaal River catchment. Currently 16 of the plants are operational with the McComb plant closing in 2002. Of the 16 operational plants, four are located in the Klip River catchment and the remaining 12 are located in the Suikerbosrand catchment. The Erwat discharges are listed in **Table 10** together with the average monthly discharge volume. The discharge volumes and TDS concentrations of the Erwat plants discharging to the Suikerbosrand River are shown plotted in **Figure 17**. The Erwat plants discharging to the Klip River are included with the Johannesburg Water plants to give a total for the Klip River. The resulting discharge volumes and average monthly TDS concentrations are shown plotted in **Figure 18.**

Johannesburg Water has 4 wastewater treatment plants in the Vaal River catchment. Three of the large plants viz Olifantsvlei, Bushkoppies and Goudkoppies are located in the Klip River catchment with the fourth plant Ennerdale in the Rietspruit catchment. The treated effluent from the Olifantsvlei and Goudkoppies plants was used for irrigation. The irrigation of 20 ML/d of treated effluent from the Olifantsvlei plant was stopped in 2002 while the irrigation of 10 ML/d from the Goudkoppies Plant stopped in 1995. In calculating the discharge back to the river the effluent volumes were corrected for the irrigation. The Wastewater Treatment Plant discharges in the Klip River were added to the discharges of the plants belonging to Erwat to give a total discharge and average monthly TDS concentrations discharged from wastewater treatment plants to the Klip River. The plot is shown in **Figure 18**. The Johannesburg Water discharges are listed in **Table 10** together with the average monthly discharge volume.

The future plans at that the Bushkoppies and Goudkoppies plants may be expanded with an additional 50 ML/d module. The development in the area draining to the Goudkoppies plant is stationary so further expansion of the plant is not likely. Johannesburg Water is considering handing over the Ennerdale plant to Metsi-a-Lekoa when the plant may be closed and the sewage treated at the Sebokeng Wastewater Treatment Plant.

Emfuleni/Metsi-a-Lekoa. There are three wastewater treatment plants run by Metsi-a-Lekoa which discharge to the Rietspruit. The three plants are Sebokeng, Leeukuil and Rietspruit. These plants have experienced problems in the passed and have under performed. In particular the Rietspruit plant is operating over capacity. The data on the effluent discharges, in particular the effluent discharge volumes were also sparse for sections of the record. Plans are in the process of being implemented to improve the capacity of the staff working at the plants and to upgrade the plants. A management contract has been awarded to a consultant to improve the performance of the works and to start developing wastewater master plans. The volumes of water discharged to the Riespruit catchment and the average monthly TDS concentrations of the discharge are shown in **Figure 19**. The discharges are listed in **Table 10** together with the average monthly discharge volume.

Sasol: Sasol has two effluent discharge streams. The effluent from the Sasol Midlands plant is discharged to the Taainbosspruit which discharges into the Vaal Barrage. The effluent stream from the Sasol Chemical Industries plant is discharged by pipeline into the Vaal River downstream of the Vaal Barrage. Sasol also treats effluent received from other industries in the Sasolburg area as well as the sewage from Sasolburg. The volume of sewage effluent treated in the Sasol bioworks is 14 Ml/d with some of the treated effluent being used in the Sasol process. Sasol receives mine dewatering water from the Mooikraal and Sigma Collieries for use at Sasol. The effluent volumes discharged are given in **Table 10**.

Mittal Steel: According to the questionnaire filled in by Mittal Steel, the Mittal plant at van der Bijl Park does not discharge effluent. The complex does however have a saline stormwater stream which leaves the complex discharging into the Rietspruit. Data was provided by Mittal on the water quality and the volumes of storm water leaving the complex. The storm water volumes discharged are given in **Table 10**.

Other discharges: The other wastewater treatment plants in the sub-catchment are the van der Bijl Park, Meyerton and Vereeniging plants. The Vereeniging works discharges to the Barrage while the effluent from the Van der Bijl plant is discharged below the Vaal Barrage.

Johannesburg Water and Metsi-a-Lekoa reported infiltration into their sewer networks. This is due to poorly maintained pipe system and the theft of manhole covers. In addition pump station breakages also results in overflows of untreated sewage reporting to the river systems.

Table 10: Effluent discharges in the Vaal Barrage sub-catchment

Discharge	Type	Barrage Tributary	Average monthly volume (million m^3)
Daveyton	Wastewater treatment plant	Suikerbosrand	0.53
Jan Smuts	Wastewater treatment plant	Suikerbosrand	0.27
Benoni	Wastewater treatment plant	Suikerbosrand	0.30
Rynfield	Wastewater treatment plant	Suikerbosrand	0.28
J P Marais	Wastewater treatment plant	Suikerbosrand	0.61
McComb	Wastewater treatment plant	Suikerbosrand	0.39
Ancor	Wastewater treatment plant	Suikerbosrand	0.88
Tsakane	Wastewater treatment plant	Suikerbosrand	0.34
Grundling	Wastewater treatment plant	Suikerbosrand	0.08
Welgedacht	Wastewater treatment plant	Suikerbosrand	0.35
H Bickely	Wastewater treatment plant	Suikerbosrand	0.24
Heidelberg	Wastewater treatment plant	Suikerbosrand	0.20
Ratanda	Wastewater treatment plant	Suikerbosrand	0.04
Bushkoppies	Wastewater treatment plant	Klip	5.53
Olifantsvlei	Wastewater treatment plant	Klip	4.66
Goudkoppies	Wastewater treatment plant	Klip	3.45
Waterval	Wastewater treatment plant	Klip	3.15
Dekema	Wastewater treatment plant	Klip	0.78
Rondebult	Wastewater treatment plant	Klip	0.52
Vlakplaats	Wastewater treatment plant	Klip	2.84
Meyerton	Wastewater treatment plant	Klip	0.17
Sebokeng	Wastewater treatment plant	Rietspruit	1.63
van der Bijl Park	Wastewater treatment plant	Vaal	0.22
Leeuwkuil	Wastewater treatment plant	Rietspruit	0.40
Ennerdale	Wastewater treatment plant	Rietspruit	0.10
Rietspruit	Wastewater treatment plant	Rietspruit	0.90
Vereeniging	Wastewater treatment plant	Vaal (downstream Barrage)	-
Sasol Midlands	Industrial effluent	Taaibosspruit	0.17
Sasol Chemical Industries	Industrial effluent	Vaal River downstream of Vaal Barrage	1.1
Mittal Steel	Stormwater	Rietspruit	0.89

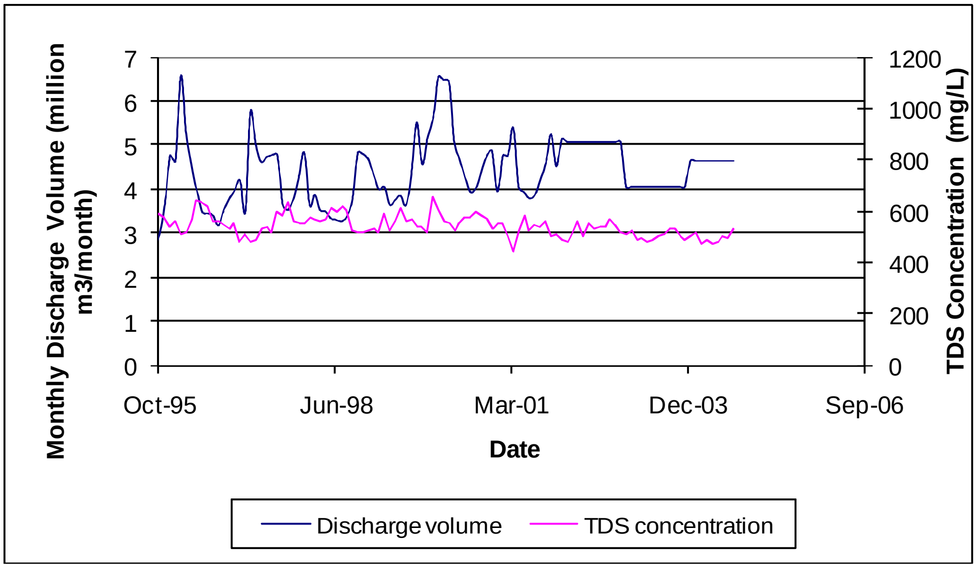

Figure 17: Plot of discharge volumes and TDS concentrations of wastewater treatment plants discharging to the Suikerbosrand River

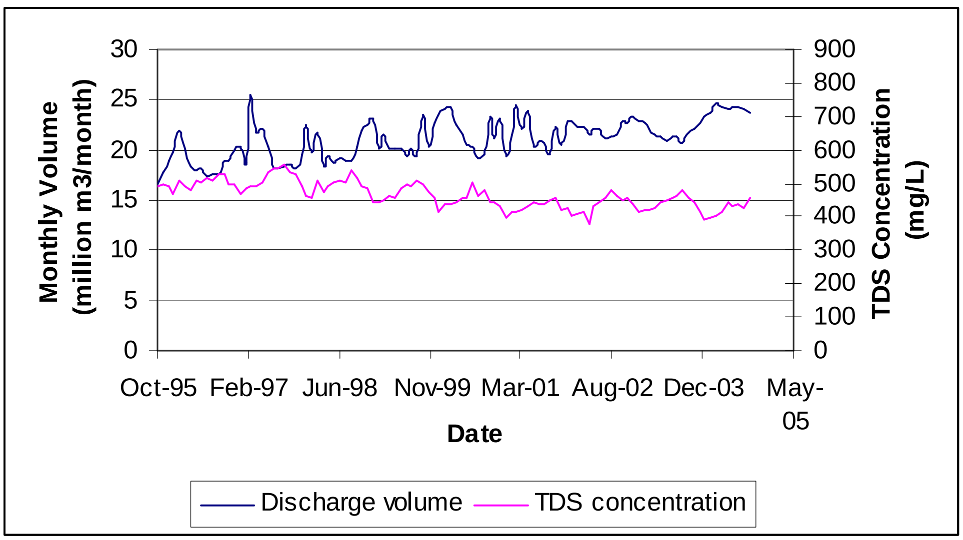

Figure 18: Plot of discharge volumes and TDS concentrations of wastewater treatment plants discharging to the Klip River

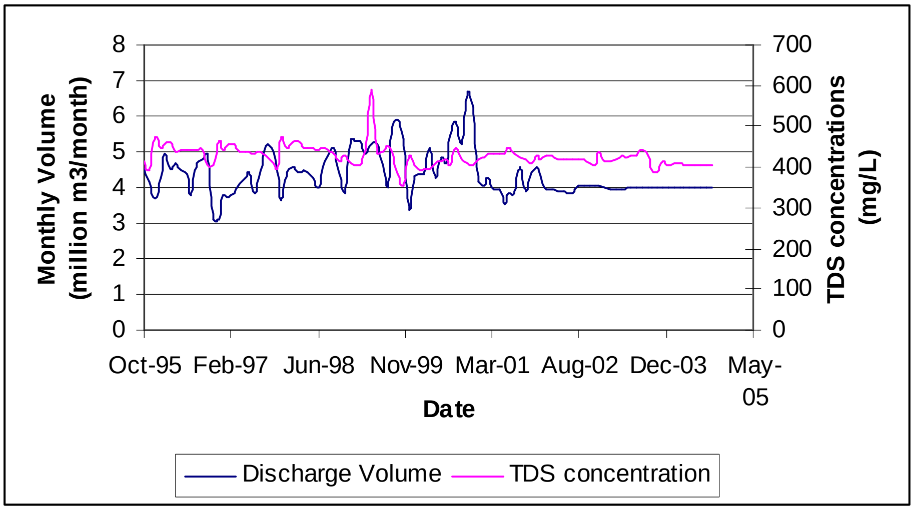

Figure 19: Plot of discharge volumes and TDS concentrations of wastewater treatment plants discharging to the Rietspruit River

Discussion of wastewater treatment plant discharges : The plots shown in **Figure 17**, **Figure 18** and **Figure 19** show an increasing discharge volume over the analysis period and a decreasing TDS concentration. The drop in TDS concentration is between 80 mg/L and 100 mg/L. The total wastewater treatment plant discharge volume and flow weighted TDS concentration is given in **Figure 20**. The TDS concentration in the Vaal Dam is included as it is representative of the TDS concentration of the water treated and distributed by Rand Water which is ultimately discharged through the wastewater treatment plants. The change in concentration across the works is represented as a delta TDS concentration by subtracting the effluent concentration from the Vaal Dam concentration. A plot of the delta concentration is shown in **Figure 21**. The plot shows a downward trend in the delta TDS concentration. The reduction in the delta TDS concentration over the period October 1995 to November 1999 is due to the effluent concentration being largely steady and the Vaal Dam TDS concentration deteriorating over the period October 1995 to November 1999. After 1999, the average delta TDS concentration is steadier at about 275 mg/L. The delta TDS concentration shows a seasonal variation with the delta concentration increasing over the dry season and reducing over the wet season. This is due to infiltration of storm water into the sewer systems during the rainy season. This increase of stormwater and shallow groundwater into the sewer systems also contributes to the downward trend seen in the TDS concentrations.

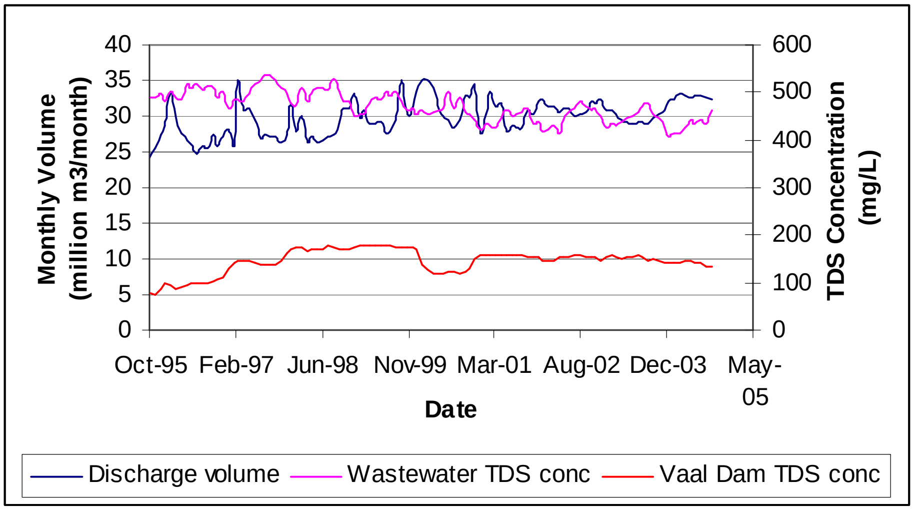

Figure 20: Plot of total wastewater treatment plant discharge volume and TDS concentrations discharging to the Vaal Barrage

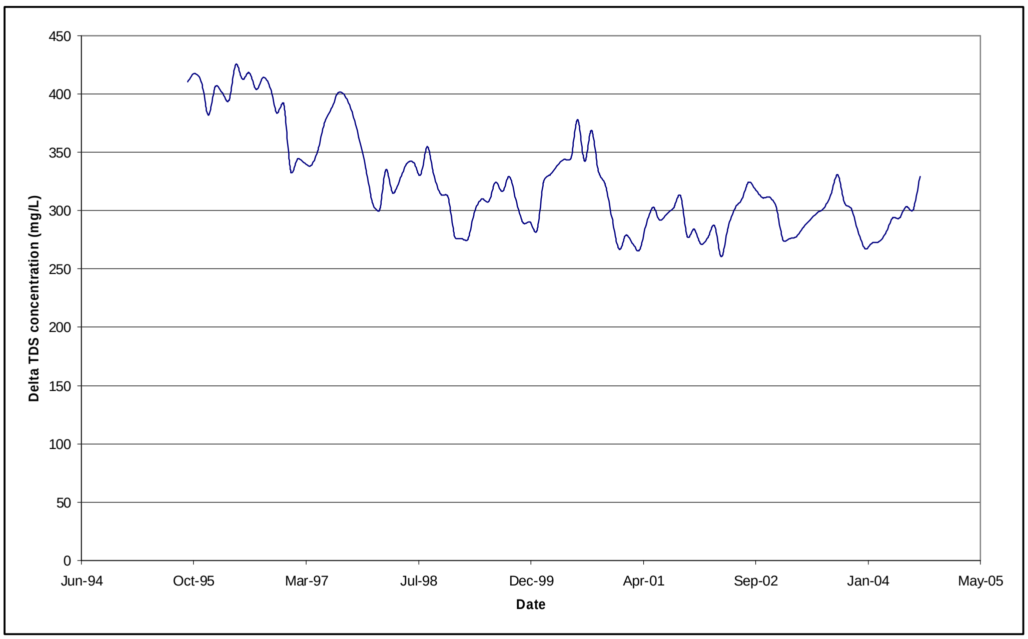

Figure 21: Plot of the change in TDS concentration between the intake water and the wastewater treatment plants

<u>Irrigation</u>

The irrigation demand in the Vaal Barrage catchment varied from 42.6 million m^3/a in 1998 to 71.34 million m^3/a in 2005. Similar to the Frankfort area, the validation/verification study has shown that there has been an increase in unlawful irrigation in this area.

Abstractions

The major abstraction in the sub-catchment is the abstraction from the Vaal Barrage from the Lethabo weir for the Lethabo Power Station. Sasol has two abstraction points one at the Lethabo weir and the other from the Vaal Barrage downstream of the weir. The two abstraction points allow for Sasol to blend water. Sasol however rarely users the lower abstraction point as the water quality has adverse affects on the Sasol treatment processes. Similarly Rand Water can also blend water between Vaal Dam water and Vaal Barrage water but this practise has not been used over the analysis period.

Water transfers

There are no water transfers into the Vaal Barrage catchment from adjacent WMA.

Salinity balance results

The results of the salinity balance are presented as a pie chart showing the sources of TDS load. The pie chart is shown in **Figure 22** and the volumes are summarised in **Table 11**. The figures given in the table and used to generate the percentage contributions given in the pie charts are averages over the 9 year analysis period.

The pie charts show that the salt load contribution from the Vaal Barrage catchment is the largest contributor at 39% with the contribution from the Vaal Dam releases contributing 27%. The mine dewatering and the effluent contributions contribute a significant TDS load to the Vaal Barrage.

The salt and water balance gives the unit runoff for the sub-catchment of 67 mm/a and the average TDS concentration of 636 mg/L. The unit runoff is similar to the unit runoffs calculated for the other sub-catchments. One would expect the unit runoff to be higher given the impervious area associated with the large urban areas in the sub-catchment. The similar unit runoff could be due to the correction of the Barrage outlet flow record.

5.1.5 Mooi sub-catchment

Description of sub-catchment

The Mooi sub-catchment is a highly impacted catchment. The flows and water quality in the river system are dominated by return flows from wastewater treatment plants and mine dewatering discharges. The area is also developed with urban areas such as Westonaria, Potchefstroom, Carletonville and parts of Krugersdorp. There is also extensive agriculture practised in the sub-catchment. The Wonderfonteinspruit in the Mooi sub-catchment has a hydrology dominated by dolomitic compartments. Many of the dolomitic compartments used to discharge through eyes into the Wonderfonteinspruit. However with the gold mining activities many of the dolomitic compartments have been dewatered and the eyes have dried up. As a result sinkholes have developed in the Wonderfonteinspruit catchment. The mines have installed a pipeline which conveys the runoff water from upstream into a canal system which conveys the water over the dewatered dolomitic compartments and discharges the water downstream of the compartments.

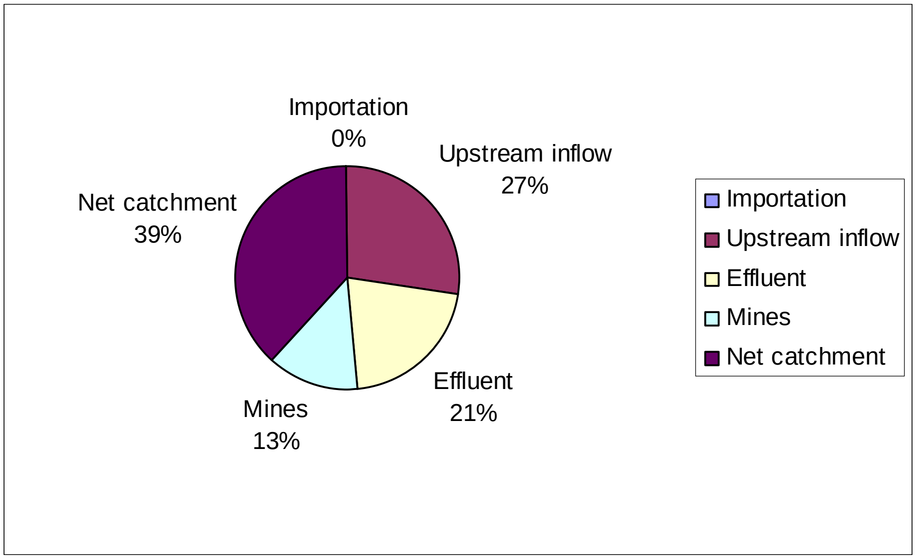

Figure 22: Pie chart showing contribution of TDS load from sources for the Vaal Barrage sub-catchment

Table 11: Volumes and loads from sources of TDS load for Vaal Barrage sub-catchment

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	0	0	-
Upstream	2042.0	264 127	129
Effluent	405.0	201 306	497
Mines	51.3	128 361	2502
Catchment	577 (67 mm/a)	367 396	636

Mine dewatering

The gold mines are dewatering the mine workings and discharging water in the river system. The gold mines in the Mooi sub-catchment fall into a geohydrological basin which forms a part of the Far West Rand basin. This is an additional basin further to the west of the Far West Rand Basin discussed in the section in the Vaal Barrage catchment. Driefontein Gold Mine is discharging 26 ML/d, Kloof Gold Mine 34 ML/d and Blyvooruitzicht 10 ML/d.

River stations

The daily discharge record and TDS concentration record at the Department’s weir C2H085 on the Mooi River was used to determine the outflow volume and TDS load from the sub-catchment. A plot of the monthly flow record and patched monthly average TDS concentration is given in **Figure 23**.

The water balances for the Boskop Dam, Klerkskraal Dam and Klipdrift Dam were also obtained to determine the storages in the sub-catchment.

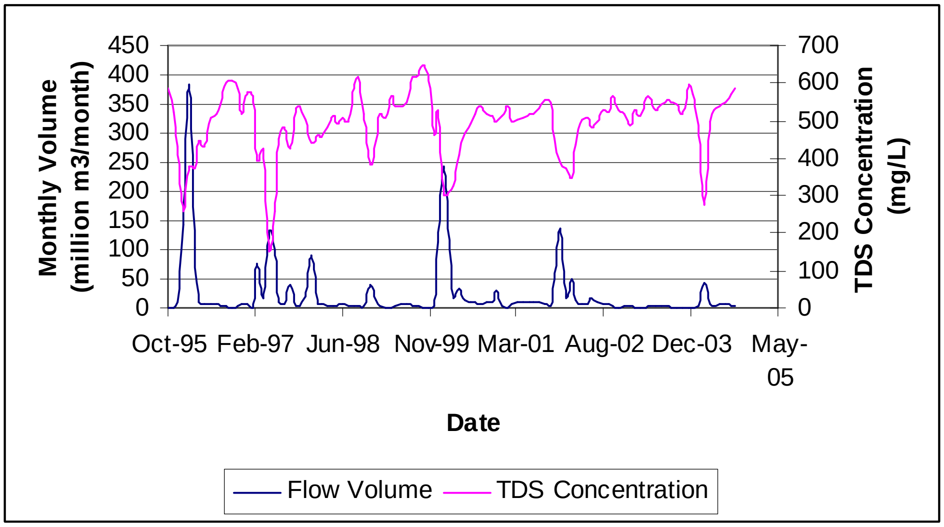

Figure 23: Plot of discharge volumes and TDS concentrations at outflow from Mooi sub-catchment

Effluent

There are no industrial discharges directly into the river system in the Mooi sub-catchment. There are however wastewater treatment plants located in the sub-catchment with the Flip Human plant being the largest. The discharges and the average monthly discharge volume over the analysis period are listed in **Table 12**. There are also a number of small wastewater treatment pants located on some of the mines. The effluent from these works is sometimes used as mine process water with the balance discharged. The volumes are however typically small and have not been included in the balance.

Table 12: Effluent discharges in the Mooi sub-catchment

Discharge	Type	River	Average monthly volume (million m^3)
Flip Human	Wastewater treatment plant	Wonderfonteinspruit	1.40
Khutsong	Wastewater treatment plant	Wonderfonteinspruit	0.07
Oberholzer	Wastewater treatment plant	Wonderfonteinspruit	0.15
Kakosi	Wastewater treatment plant	Loopspruit	-
Potchefstroom	Wastewater treatment plant	Mooi	0.65
Hannes van Niekerk	Wastewater treatment plant	1 m pipeline in Wonderfonteinspruit caatchment	0.33
Welverdiend	Wastewater treatment plant	1 m pipeline in Wonderfonteinspruit caatchment	0.03

Irrigation

The irrigation schemes in the Mooi sub-catchment abstract water from the Klerkskraal, Boskop and Klipdrift Dams. Eye water discharging at Gerhard Minnebron is also utilised for irrigation. The irrigation demand has not changed significantly in the sub-catchment and totals 43.6 million m^3/a.

Abstractions

The major abstraction in the sub-catchment is the supply to Potchefstroom. The remainder of the urban water requirements are supplied by Rand Water. The mine water requirements are met by water supplied from Rand Water and using the mine dewatering water.

Water transfers

There are no water transfers into the Mooi sub-catchment from other WMAs which is discharged directly to a river. There is however a transfer into the Mooi sub-catchment in the form of water supplied via the Rand Water supply network which is discharged as a sewage effluent from the wastewater treatment plants.

Salinity balance results

The results of the salinity balance are shown in **Figure 24** and listed in **Table 13**.

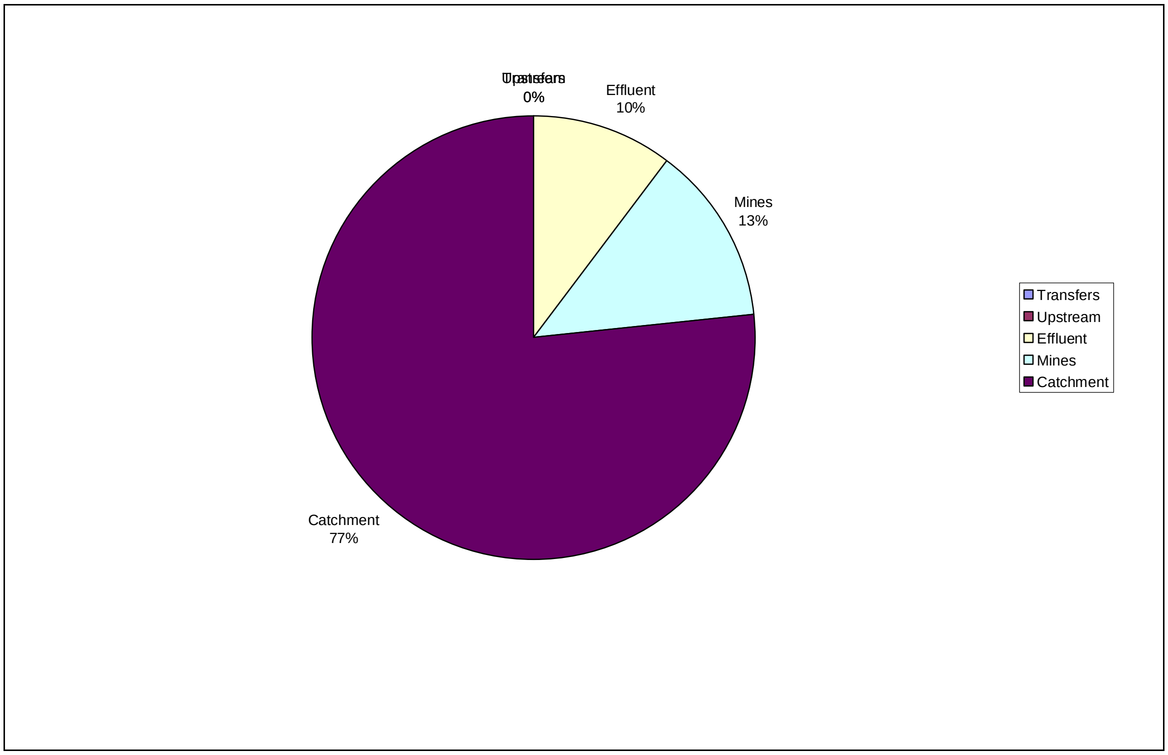

Figure 24: Pie chart showing contribution of TDS load from sources for the Mooi sub-catchment

Table 13: Volumes and loads from sources of TDS load for the Mooi sub-catchment

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	0	0	-
Upstream	0	0	-
Effluent	33.0	18 549	562
Mines	31.8	23 877	754
Catchment	340.0 (56 mm/a)	139 414	410

The catchment contribution is the largest source of salt in the Mooi sub-catchment with the mines and effluent making a significant contribution. The unit runoff from the Mooi sub-catchment in 56 mm/a and the average TDS concentration from the catchment is 410 mg/L.

5.1.6 Bloemhof sub-catchment

Description of sub-catchment

The Bloemhof sub-catchment is largely rural in nature. The main tributaries are the Sand-Vet system, Vals River, Renoster River, Koekemoerspruit and the Schoonspruit. There is significant irrigation taking place in all the major tributaries in the sub-catchment. Dams such as Koppies, Erfenis, Allemanskraal, Rietspruit and Johan Neser have been constructed to supply irrigation water. Bloemhof Dam was also constructed to support the irrigation demands in the Lower Vaal WMA.

There are gold mines located in the Virginia-Welkom and in the Klerksdorp-Orkney-Stilfontein-Hartbeesfontein (KOSH) areas of the sub-catchment. There is a defunct coal mine in the Vierfontein catchment. The gold mines in the KOSH area are dewatering the workings and are discharging to the Koekemoerspruit. The Vierfontein coal mine is decanting into the Vierfontein River.

The Virginia, Welkom, Klerksdorp, Orkney and Stilfontein urban areas have developed as a result of the gold mines in the area. Other urban centres include Kroonstad and Parys. The urban water supply in the sub-catchment is managed by the Midvaal and Sedibeng Water. Midvaal Water supplies the KOSH area while Sedibeng Water the Virginia and Welkom areas.

The upstream inflow into the sub-catchment is the outflow from the Mooi and Vaal Barrage sub-catchments. Also included in the upstream inflow is the effluent from Sasol discharged below the Vaal Barrage and the sewage effluent from van der Bijl Park.

Mine dewatering

The gold mines in the KOSH area are dewatering the mine workings and discharging water to the Koekemoerspruit. The pumping is taking place at the Stilfontein Gold mine and currently 37 ML/d are being discharged to the Koekemoerspruit. The Koekemoerspruit joins the Vaal River upstream of

Midvaal Water's abstraction point. There are no discharges from the mines in the Virginia-Welkom area. The mine contributions are represented as a seep in the WRPM.

River stations

The daily discharge record and TDS concentration record at the Department's weir C9H021 on the Vaal River downstream of Bloemhof Dam together with the dam balance and TDS concentration record in Bloemhof Dam were used to determine the outflow volume and TDS load from the sub-catchment. A plot of the monthly flow record and patched monthly average TDS concentration at the weir C9H021 are given in **Figure 25**. The water balances for the other major dams were also used to determine the storage changes in the sub-catchment. There were no balances available for Johan Neser, Serfontein and Rietspruit Dams.

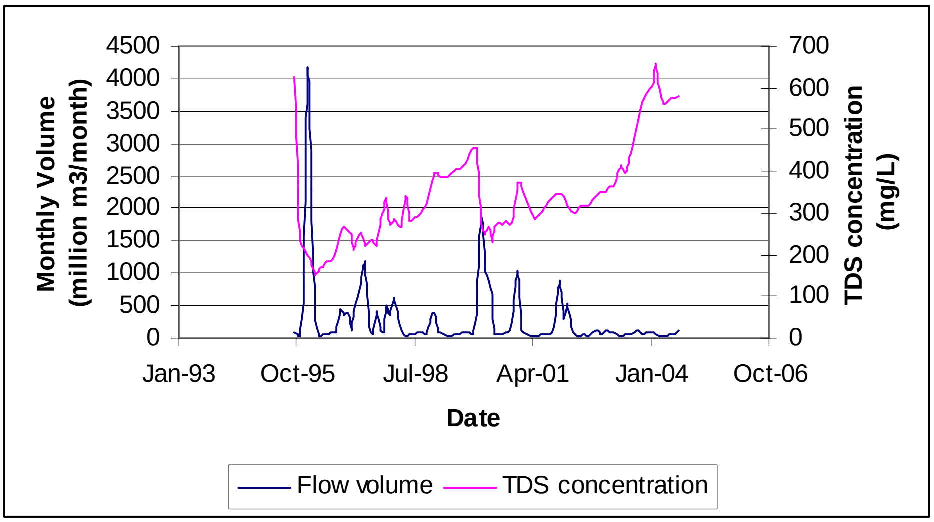

Figure 25: Plot of outflow volumes and monthly average TDS concentrations measured at C9H021 downstream of Bloemhof Dam.

There were missing periods of daily flow records at C9H021. The flow record ended in July 2004 and January and February 1998 were missing. The average monthly volumes were used to patch the missing values.

Effluent

There are no industrial discharges directly into the river system in the Bloemhof sub-catchment. There are however wastewater treatment plants associated with the urban areas located in the sub-catchment. The discharges and the average monthly discharge volume over the analysis period are listed in **Table 14**. In the WRPM the wastewater treatment plants receiving water supplied by Midvaal Water have been lumped together. The wastewater treatment plants at Kroonstad and Welkom have been included separately in the WRPM. The return flows from the urban centres supplied by Sedibeng Water have been included in the net abstraction by Sedibeng Water and the water discharged as tail water from the irrigation canals into which Virginia discharges its sewage effluent.

The mine impacts are represented as seeps in the WRPM. The seep volume included in the WRPM is also listed in **Table 14**. There are two additional effluent discharges into the Vaal River from the Vaal Barrage catchment. These are the effluent discharges from Sasol at Sasolburg and some of the wastewater treatment plant discharges in the Vereeniging area.

Table 14: Effluent discharges in the Bloemhof sub-catchment

Discharge	Type	River	Average monthly volume (million m^3)
Kroonstad	Wastewater treatment plant	Vals	0.5
Hartbeesfontein	Wastewater treatment plant	Jagspruit	0.12
Ventersdorp	Wastewater treatment plant	Schoonspruit	0.24
Klerksdorp	Wastewater treatment plant	Schoonspruit	0.56
Orkney	Wastewater treatment plant	Schoonspruit	0.43
Stilfontein	Wastewater treatment plant	Koekemoerspruit	0.19
Buffels	Wastewater treatment plant	Koekemoerspruit	-
Welkom	Wastewater treatment plant	Sand River	0.12
Sedibeng Water (Virginia etc)	Wastewater treatment plant	Sand-Vet	1.07
Seep	Seepage from mines	Sand-Vet	0.15

Irrigation

There are a number of irrigation schemes in the Bloemhof sub-catchment. The major schemes are located in the Schoonspruit, Renoster, Vals and Sand-Vet. The irrigation demand has not changed significantly in the sub-catchment and totals 161.52 million m^3/a.

Abstractions

The major abstractions in the sub-catchment are the abstraction by Sedibeng and Midvaal Water for urban and industrial supply. The remainder of the urban water requirements are abstractions to supply the smaller towns. These are made from the Vaal River or dams located on the tributaries. The largest of these towns are Kroonstad and Virginia. Kroonstad draws its water from the Serfontein Dam on the Vals River while Virginia draws part of its water requirements from Allemanskraal dam.

Water transfers

There are no water transfers into the Bloemhof sub-catchment from other WMAs.

Losses

There are losses along the Vaal River due to evaporation. The losses used in the WRPM were included in the salinity balance. The total bed loss used was 4.86 million m^3/month

Salinity balance results

The salinity balance for this sub-catchment gave negative salt loads being generated from the catchment washoff for some years in order to achieve a salt balance. The negative washoff contribution occurred when the inflow from upstream is high and the salt load therefore high. The high inflow load exceeded the load in the outflow from the sub-catchment, storage, losses and abstractions resulting in the negative loads. The magnitude of the negative loads was such that the average load for the period was negative resulting in a negative TDS concentration. The most likely reasons for the negative values could be due to inaccurate flow measurement and the dearth of TDS concentration information for the Vaal Barrage which is the major contributor of load during high flood conditions.

To get an indication of the runoff and average TDS concentrations the years with large negative loads were not included in the balance. The results of the salinity balance are shown in **Figure 26** and listed in **Table 15**.

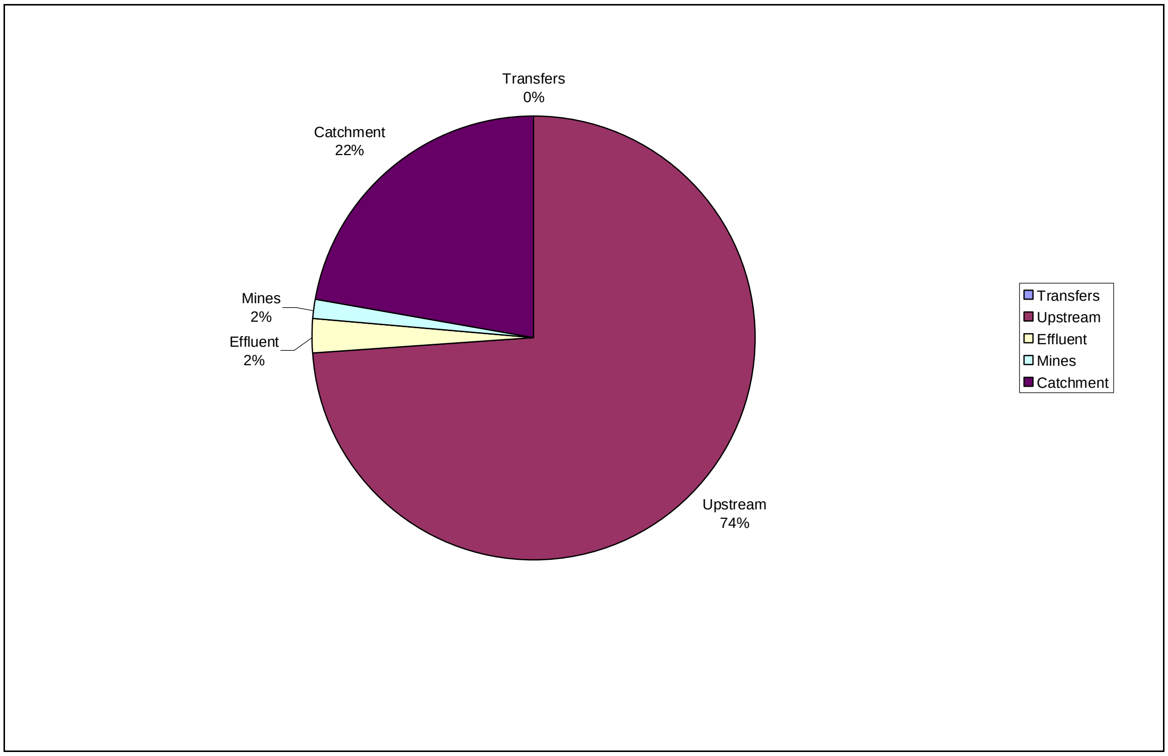

Figure 26: Pie chart showing contribution of TDS load from sources for the Bloemhof sub-catchment

Table 15: Volumes and loads from sources of TDS load for the Bloemhof sub-catchment

Source	Volume (Million m^3/a)	Load (Tonne/a)	Average TDS concentration (mg/L)
Transfers	0	0	-
Upstream	1293	424 288	328
Effluent	19.3	13 567	704
Mines	7.58	9 419	1243
Catchment	390 (7.1 mm/a)	126 907	325

The upstream contribution is the largest source of salt and water in the Bloemhof sub-catchment with the Bloemhof sub-catchment making the next highest contribution at 22%. The mines and effluent discharges have a similar contribution at 2%. The unit runoff from the Bloemhof sub-catchment is 7.1 mm/a and the average TDS concentration from the catchment is 333 mg/L.

5.2 Summary of annual salinity balance

The results of the annual salinity balance can be summarised by showing the salt load contribution from the different sources in each of the sub-catchments. The results are given in **Table 16** and the values are the annual average TDS loads over the calculation period of 1995 to 2004. The results show that the effluent and mine contributions to the salinity load is significant. The contribution from upstream increases downstream with the largest contribution from the Vaal Barrage into the Bloemhof Dam catchment.

The contributions from the individual sub-catchments of mines, effluent, transfers and catchment are shown in **Figure 27**. The pies are scaled in proportion to the total load. The Figure clearly shows the large contribution from the Vaal Barrage sub-catchment.

Table 16 : Average annual TDS loads (tonne/a) contributed from different sources in each of the sub-catchments

Sub-catchment	Transfers	Upstream	Effluent	Mines	Catchment	Total load
Grootdraai Dam	4171	0	4580	0	105680	114431
Frankfort	33764	0	2624	0	172511	208899
Vaal Dam Inc	0	284109	14065	0	127349	425523
Vaal Barrage	0	264127	201306	128361	367396	961190
Mooi	0	0	18549	23887	139414	181850
Bloemhof Dam	0	424288	13567	9419	126907	574181

The sources of TDS load and the volume of water contributed by the sources down to Bloemhof Dam are shown in **Table 17**. The mine discharges have the highest average TDS concentration and are therefore the source where the largest load can be removed per m^3 of water. The effluent volume contribution is significant and will therefore influence the TDS concentrations in the Vaal Barrage and downstream. The volume of water transferred into the Vaal catchment is significant and will grow in the future. The TDS concentration of this water is currently good. Deterioration in the TDS concentration of the transferred water will therefore impact on the TDS concentration in the system in particular Vaal Dam which receives the Lesotho and Thukela water.

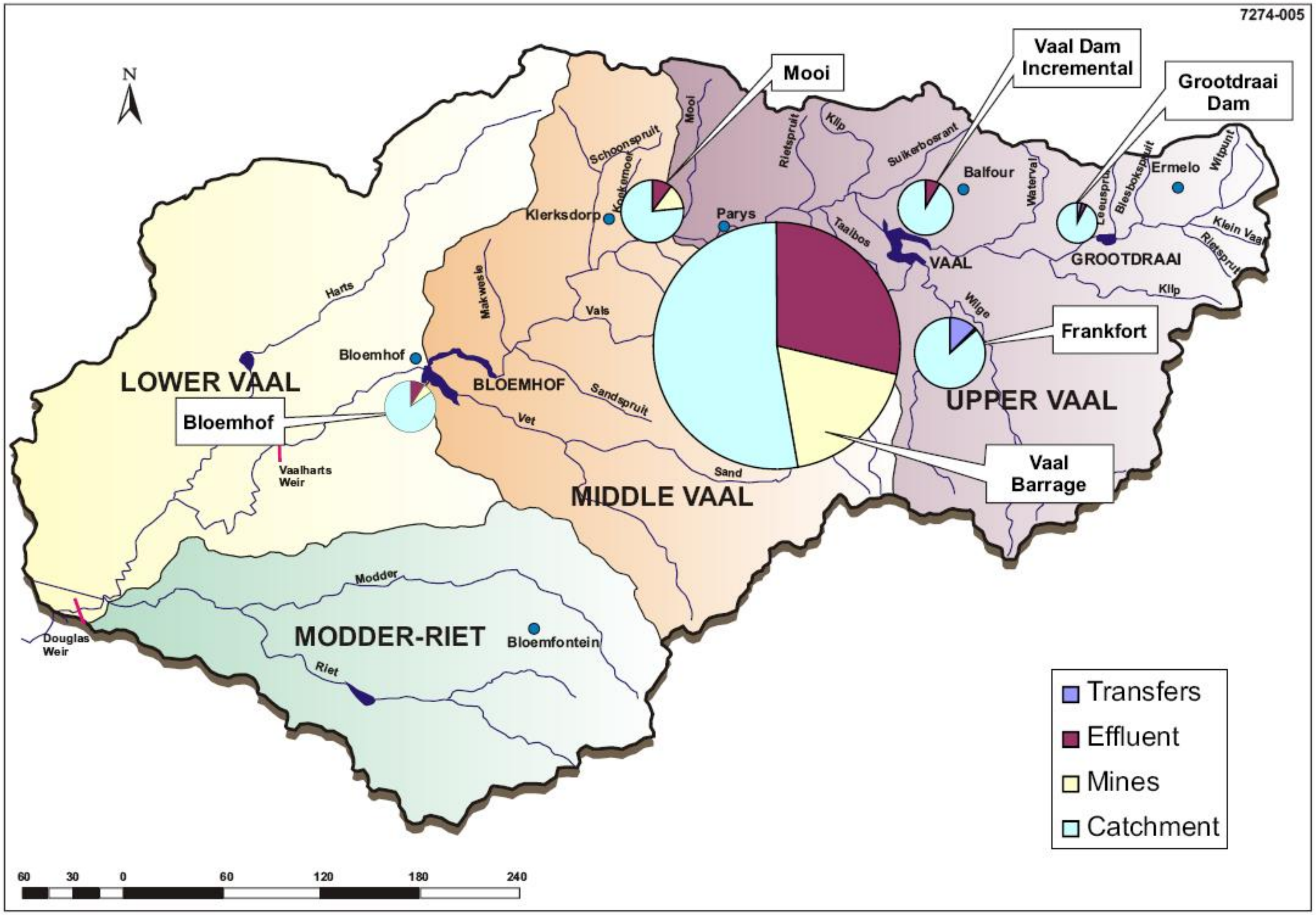

Figure 27 : Contribution from effluent, mines, transfers and catchment in each of the sub-catchments

Table 17 : Summary of volume (million m^3/a) and TDS load (tonne/a) from sources for catchment down to Bloemhof Dam

	Transferred	Effluent	Mines	Catchment
Volume (million m^3/a)	479	492	91	4235
Load (tonne/a)	37935	254691	161667	1039257
Ave TDS Conc (mg/l)	79	518	1777	245

6 SIMULATE LOAD BALANCES

6.1 Water resources planning model

The water resources planning model (WRPM) has been set up for the Vaal River system and is used for planning and operating the system. The schematics of the system network were assessed to determine if the current layout represents the current water quality situation in the system. In addition to checking the schematics, the runoff volumes and TDS concentrations produced by the salt washoff modules in the WRPM in each of the sub-catchments were checked against the annual salinity balance results. The WRPM was run for 100 sequences of 10 year length. The time series of TDS concentrations and runoff volumes were analysed and box plots produced of the annual TDS concentrations and runoff volumes. The salinity balance results were then plotted on the box and whisker plot to check if the TDS concentrations lay within the range predicted by the WRPM.

The results of the assessment of the schematic and the salt washoff module assessment are given in the sections below.

6.2 System network

The following points can be made regarding the system network :

- The mine discharges from the Far West, Central, Eastern and West Rand basins are discharged directly into the Vaal Barrage. In reality the discharges are made into tributaries of the Vaal River. Tributaries such as the Blesbokspruit have bed losses into dolomites and some of the mine discharge volume will be removed from the system as a bed loss. Similarly the Far West Rand mines discharge into the Mooi River which discharges below the Vaal Barrage.

- Sappi’s effluent discharge should be added to the network.

- The schematic shows the Mooi and Schoonspruit rivers enter the Vaal River at the incorrect points. The Mooi River is shown entering below the Renoster River and the node representing the Midvaal offtake. The Mooi River discharge is available to meet the Midvaal demands and will affect the water quality at the Midvaal offtake. The schematic shows the Schoonspruit coming in below the Sedibeng offtake from the Vaal River. The Schoonspruit joins the Vaal River upstream of the offtake and therefore influences the water quality at the Sedibeng offtake.

- Irrigation modules in the Upper and Middle Vaal areas are not used to model the water and salt balance for the irrigation areas. The current irrigation nodes in these areas should be replaced with the irrigation module.

- The data collected on the sewage discharges in the Middle Vaal showed that the return flows are about 40% of the water abstracted to meet the water requirements supplied by Midvaal Water. The Midvaal Water abstraction is represented as a demand centre in the WRPM and a return of 2.4% is used to calculate the return flow volume. Initial discussions indicate that the return flows had to be reduced to achieve a water balance in the middle Vaal area.

- The irrigation modules in the Lower Vaal WMA and the Modder-Riet are producing high TDS concentrations which result in the TDS concentrations in the Lower Harts, Rietspruit and in the Douglas weir which exceed the current TDS concentrations measured at these points.

6.3 Salt washoff module comparison

The salt washoff module annual average TDS concentrations and runoff volumes simulated using the WRPM are compared to the catchment washoff TDS concentrations and annual runoff volume totals calculated using the salinity balance approach. There are a number of salt washoff modules in each of the sub-catchments used in the salinity balance. The washoff module channel numbers in each of the sub-catchments are listed in **Table 18**. A program called WQSUM was used to add the flow and loads from the different washoff modules making up the salinity balance sub-catchments. The loads and flows were used to calculate a flow weighted TDS concentration representative of the sub-catchment.

The end of September 1995 salt load stored on the catchment surfaces as modelled in the WQT was input into the WRPM as the start conditions for the simulations using the WRPM. The WRPM was run for 100 sequences of length 9 years. The annual average TDS concentrations and the annual runoff volumes were extracted from the data sets. These were then represented as box and whisker plots for each year of the 9 year simulation period. The TDS concentrations and the annual volumes as calculated in the salinity balance were then plotted on the box and whisker plots. This enables the sub-catchments salinity balance calculations to be compared to the WRPM results.

The box and whisker plots used to represent the WRPM results are non-exceedance probabilities ie the 75 percentile means that 75 percent of the values are less than or equal to the percentile value. The box and whiskers show the 1, 25, 75 and 99 percentile values.

Table 18: Salt washoff modules in each of the salinity balance sub-catchments

Salinity balance sub-catchments	WRPM washoff module channel numbers
Grootdraai Dam	203, 512
Frankfort	204, 520, 513
Vaal Dam incremental	560, 521, 769
Vaal Barrage	604, 246, 835, 837, 608, 607, 855, 605, 245, 847
Mooi	567, 791, 788, 230, 231, 600, 566, 595, 792, 232
Bloemhof	563, 593, 591, 562, 784, 228, 779, 229, 242, 869, 871, 818, 819, 564, 594, 820, 233, 603, 243, 234, 565, 609, 235, 244, 569, 601, 236, 507, 568, 570, 602, 237

6.3.1 Grootdraai Dam sub-catchment

The results of the analysis are shown in **Figure 28** and **Figure 29** for the TDS concentrations and annual runoff volumes respectively. The comparison of the annual runoff volumes shows the two large runoff events in 1995/96 (year 1) and in 1999/2000 (year 5). The annual runoff volumes for the salinity balance simulation period exceed the 75 percentile for the first 6 years. The last three years of the salinity analysis period are drier with the annual runoff volumes falling below the 25 percentile values.

The TDS concentrations calculated in the salinity balance are below the 25 percentile for the first 6 years as would be expected given the higher runoff volumes experienced over this period. The TDS concentrations increase over the 3 dry years at the end of the salinity balance analysis period as would be expected with the lower annual flows.

The conclusion that can be drawn from the analysis given the uncertainties in the inputs into the salinity balance is that the salt washoff modules in the WRPM predict the range of TDS concentrations that spans the TDS concentrations predicted by the salinity balance. The indications are that the water quality of the runoff from the Grootdraai Dam sub-catchment may have improved. However the improvement indicated by the salinity balance is not significant enough to warrant a recalibration of the water quality model.

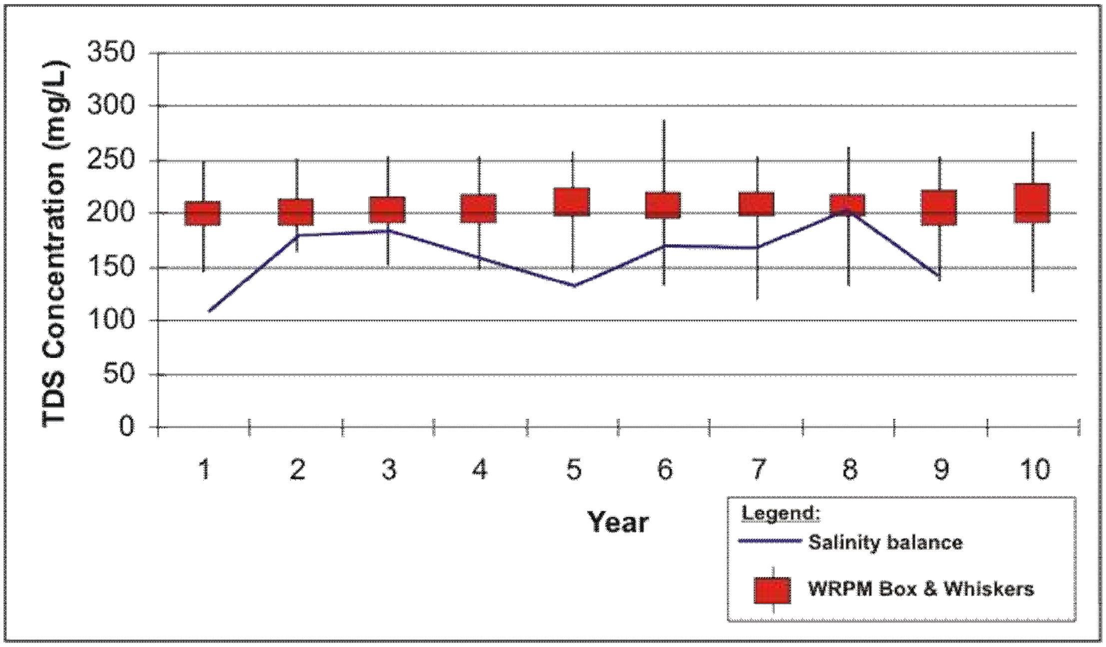

Figure 28: Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Grootdraai Dam sub-catchment

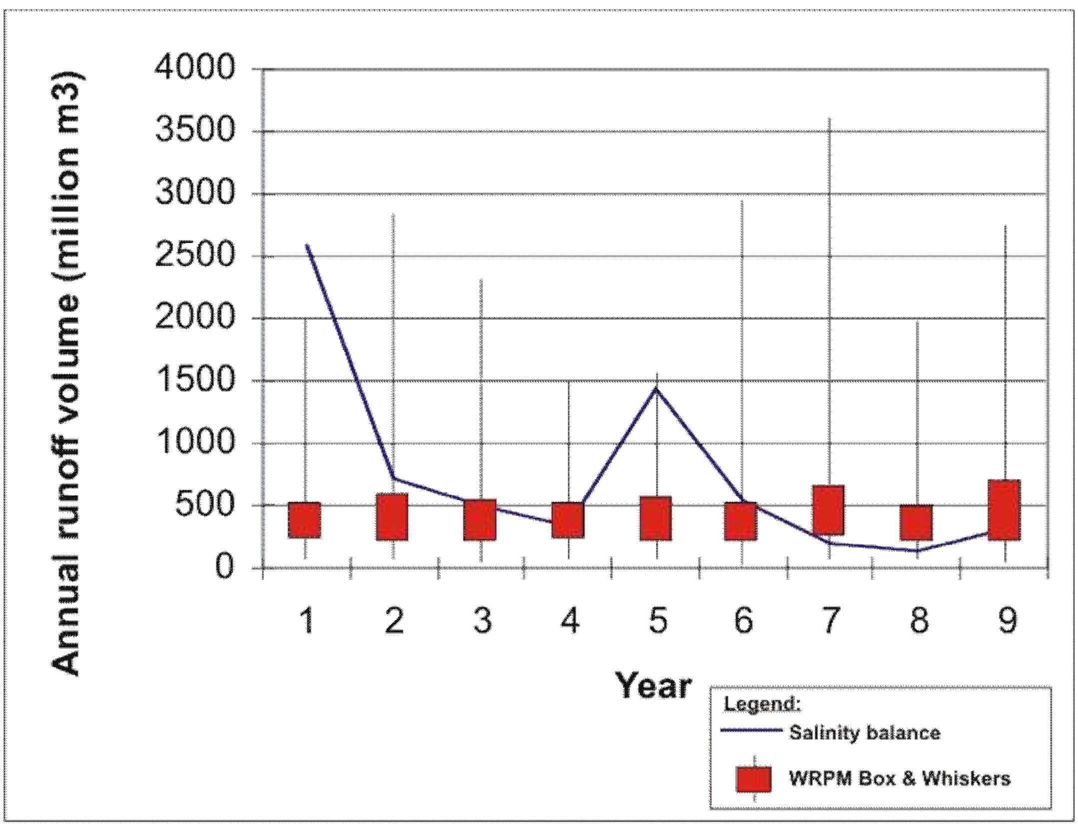

Figure 29: Comparison of WRPM annual runoff volume box and whisker plots and the salinity balance calculations for the Grootdraai Dam sub-catchment

6.3.2 Frankfort sub-catchment

The results of the comparison analysis for the Frankfort sub-catchment are given in **Figure 30** and **Figure 31** for the TDS concentrations and annual runoff volumes respectively. The salinity balance TDS concentrations fit within the range modelled by the WRPM. However the runoff volumes from the catchment for the wet years exceed the 99 percentile volumes modelled using the WRPM. For the low flow years 8 and 9, the WRPM predicts volumes that are higher than those calculated using the salinity balance.

The variation in the annual TDS concentration shows the typical responses that are expected ie the lower concentrations associated with the higher runoff years and the higher concentrations with the lower flow years.

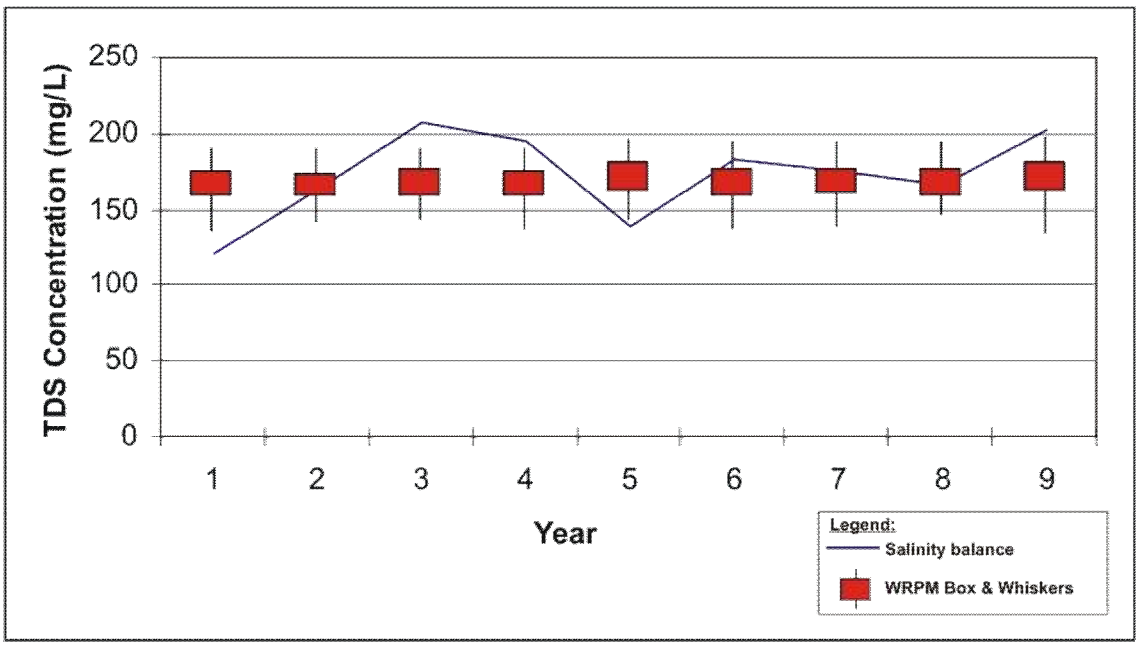

Figure 30: Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Frankfort sub-catchment

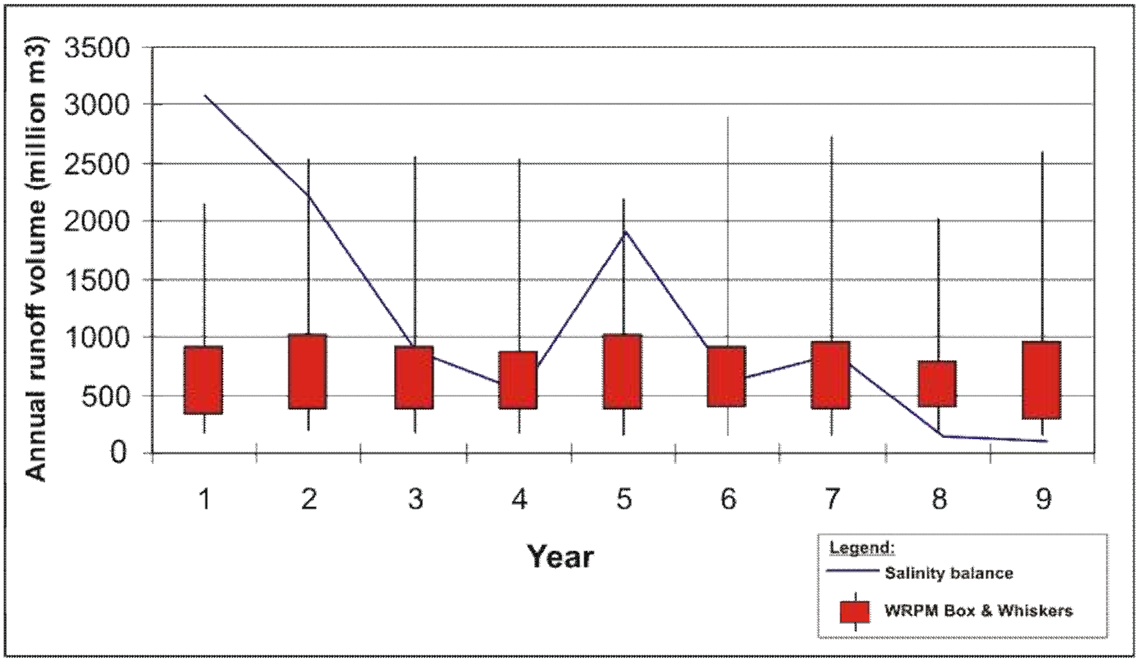

Figure 31: Comparison of WRPM annual runoff volume box and whisker plots and the salinity balance calculations for the Frankfort sub-catchment

6.3.3 Vaal Dam Incremental sub-catchment

The results of the comparison analysis for the Vaal Dam Incremental sub-catchment are given in **Figure 32** and **Figure 33** for the TDS concentrations and annual runoff volumes respectively. The salinity balance TDS concentrations fit within the range modelled by the WRPM. However the runoff volumes from the catchment for the wet years exceed the 99 percentile volumes modelled using the WRPM. For the low flow years 8 and 9, the WRPM predicts volumes that are within the range of the salinity balance.

The variation in the annual TDS concentration shows the typical responses that are expected ie the lower concentrations associated with the higher runoff years and the higher concentrations with the lower flow years.

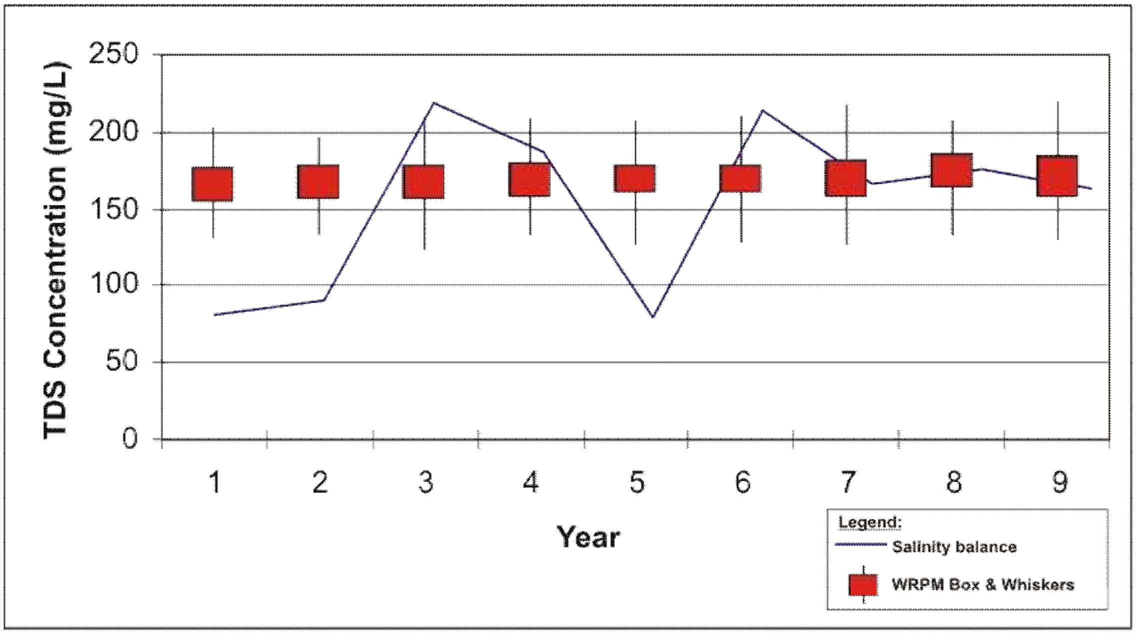

Figure 32 : Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Vaal Dam Incremental sub-catchment

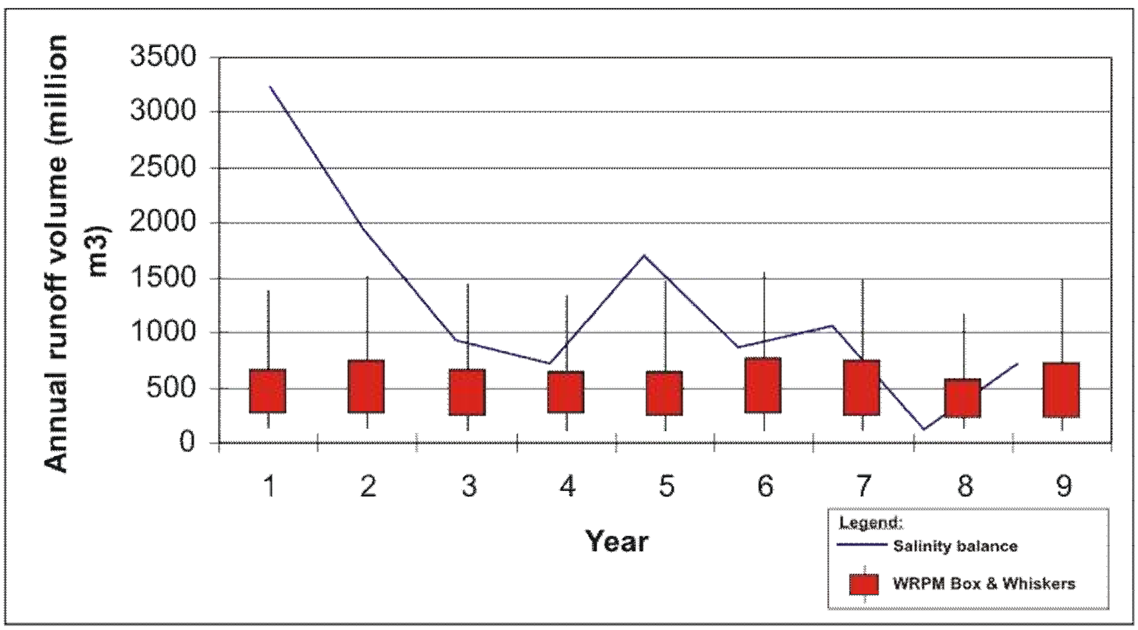

Figure 33 : Comparison of WRPM annual runoff volume box and whisker plots and the salinity balance calculations for the Vaal Dam Incremental sub-catchment

6.3.4 Vaal Barrage sub-catchment

The results of the comparison analysis for the Vaal Barrage sub-catchment are given in **Figure 34** and **Figure 35** for the TDS concentrations and annual runoff volumes respectively. The salinity balance estimates high TDS concentrations for the first three years. The runoff volumes are also high over this period. The accuracy of the measured flow volumes into and out of the Vaal Barrage are in question particularly the outflow from the Barrage. The catchment volume and load contribution is sensitive to the volumes and the TDS concentrations. The first three years data are not considered accurate.

The important point that the TDS concentrations calculated using the salinity balance show is that the concentrations are predicted to increase over time. An increasing salt recharge rate has been included in the WRPM as can be seen in the increasing trend in the box plots. The rate of increase in the TDS concentration calculated using the salinity balance is higher than the box plots. Consideration will have to be given to increasing the recharge rate used in the WRPM.

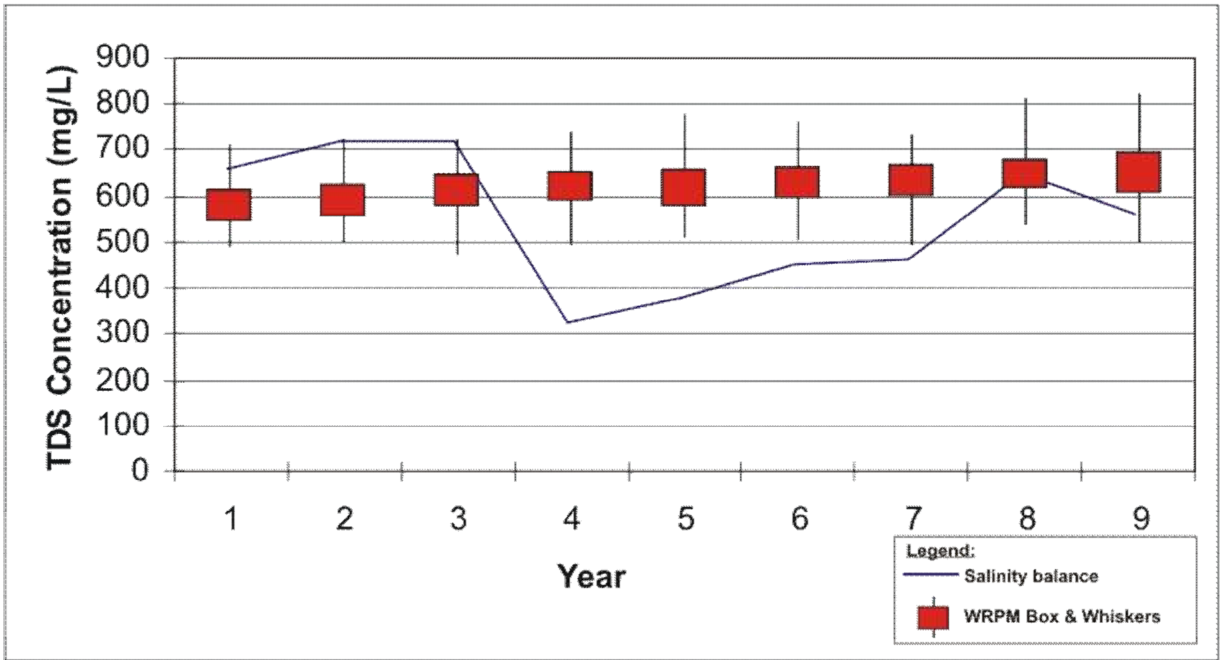

Figure 34 : Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Vaal Barrage sub-catchment

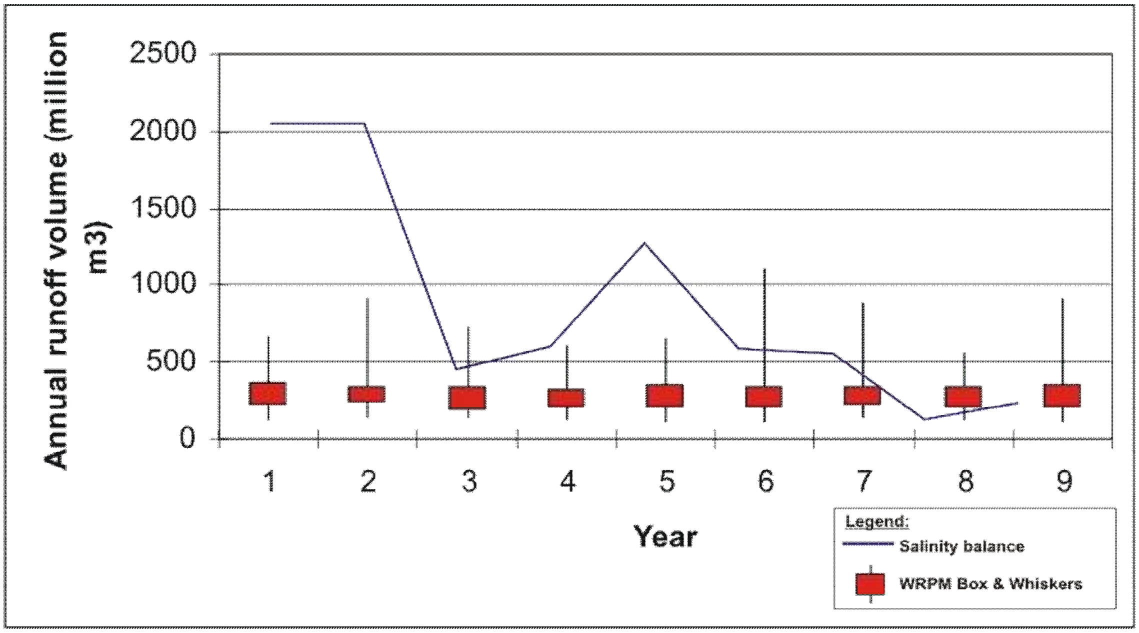

Figure 35 : Comparison of WRPM annual runoff volume box and whisker plots and the salinity balance calculations for the Vaal Barrage sub-catchment

6.3.5 Mooi sub-catchment

The results of the comparison analysis for the Mooi sub-catchment are given in **Figure 36** for the TDS concentrations. The salinity balance estimates TDS concentrations which fit into the range simulated using the WRPM.

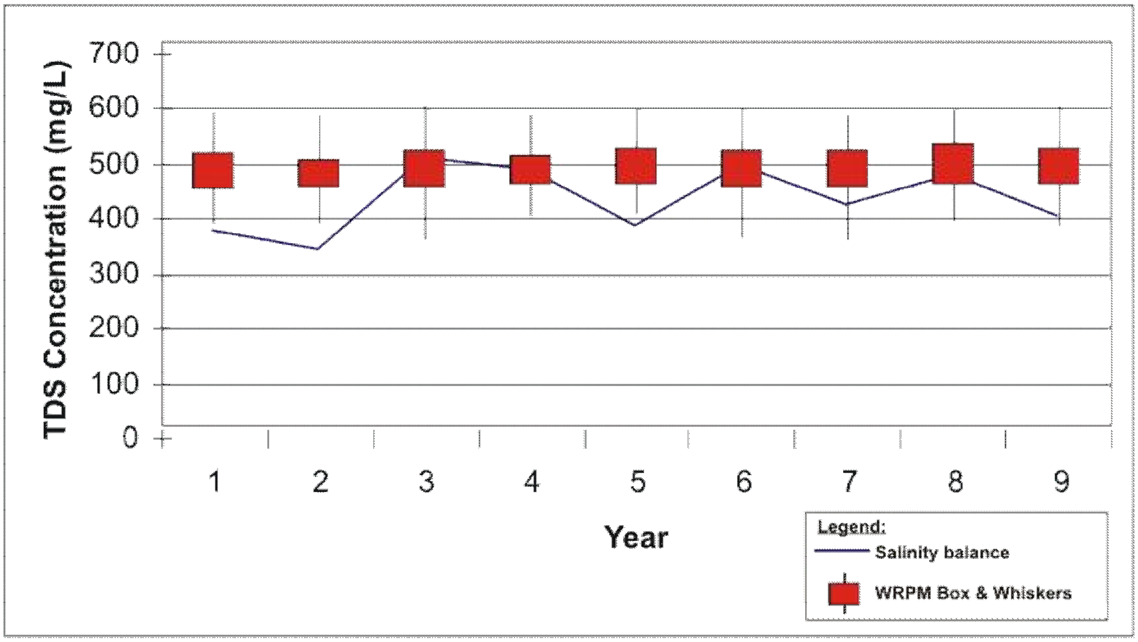

Figure 36 : Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Mooi sub-catchment

6.3.6 Bloemhof Dam sub-catchment

The results of the comparison analysis for the Bloemhof Dam sub-catchment are given in **Figure 37** and **Figure 38** for the TDS concentrations and annual runoff volumes respectively. The salinity balance in this catchment presented enormous problems with the balance producing both negative runoff volumes and salinity loads from the catchments. The negative values are shown as zero in the Figures. The salinity balance volumes that are not negative fit in the range predicted by the WRPM except for year 1 where the volume is exceeded. Similarly the TDS concentrations fit in the WRPM range where TDS concentration could be predicted using the salinity balance.

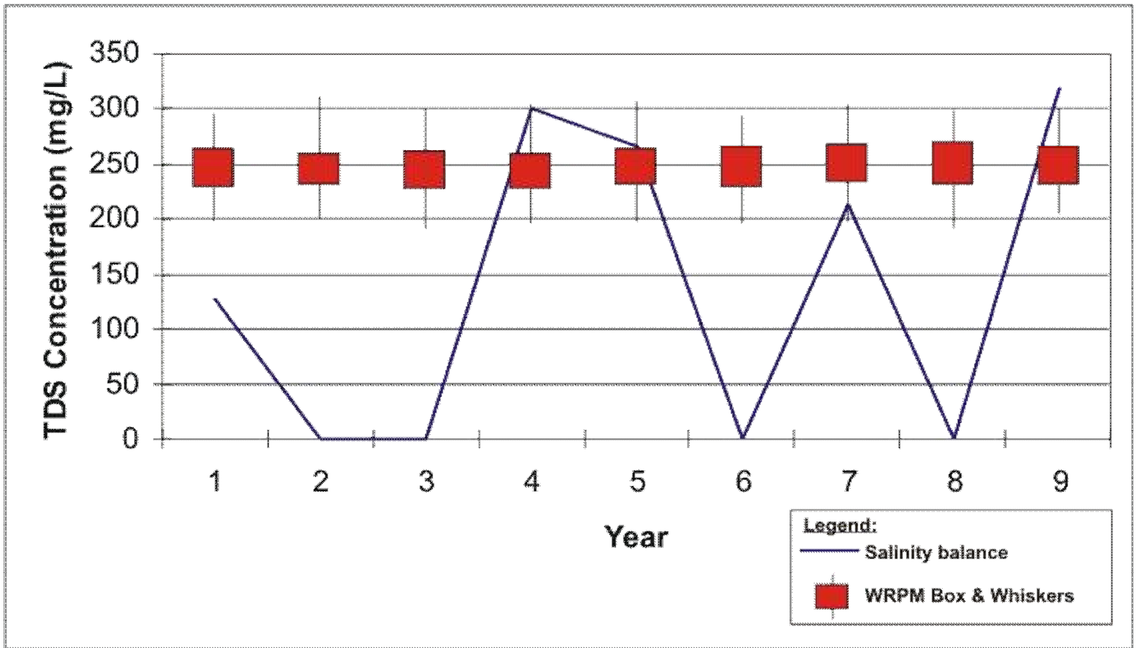

Figure 37 : Comparison of WRPM TDS concentration box and whisker plots and the salinity balance calculations for the Bloemhof Dam sub-catchment

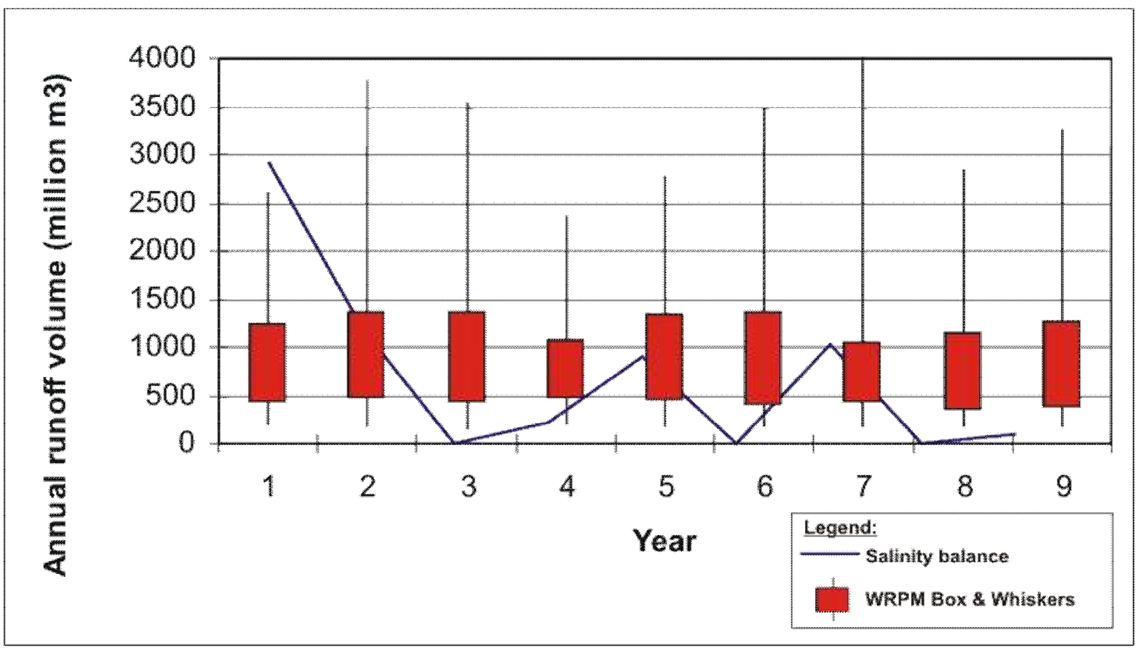

Figure 38 : Comparison of WRPM annual runoff volume box and whisker plots and the salinity balance calculations for the Bloemhof Dam sub-catchment

7 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made as a result of this study :-

- The salinity balance shows that the mine discharges and sewage effluent contribute significantly to the salt and volume water balance.
- There were two wet years in the salinity balance analysis period viz in 1995/96 and 1999/2000. The water balance period can be considered to be a wet period.
- The salinity balance shows that the salt washoff modules associated with the Grootdraai Dam, Frankfort, Vaal Dam Incremental, Mooi and Vaal Barrage are producing adequate results. The salinity balance for the Bloemhof Dam catchment is not accurate and no firm conclusions can be drawn from the balance.
- The salinity balance suggests that the recharge rates for the Vaal Barrage washoff modules should be increased.
- The system network needs updating to reflect the latest layout.
- Irrigation modules need to be added for the Upper and Middle Vaal catchment areas to model the salt and water balances.
- The irrigation modules in the Lower Vaal and Rietspruit catchment need to be reviewed.
- The return flows from the Midvaal Water demand centre need to be reviewed.

8 REFERENCES

DWAF, 1998: Directorate of Project Planning *Vaal River system Analysis Update : Hydro-salinity model calibration : Upper Vaal Catchment – PC000/00/18096, December 1998.*