Lower Vet River Water Quality Situation Analysis with Special Reference to the OFS Goldfields

CE Herold • WV Pitman • AK Bailey • I Taviv

Report to the Water Research Commission
by
Stewart Scott Incorporated

WRC Report No 523/1/96

LOWER VET RIVER WATER QUALITY SITUATION ANALYSIS WITH SPECIAL REFERENCE TO THE OFS GOLDFIELDS

FINAL REPORT

to the

WATER RESEARCH COMMISSION

by

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The Steering Committee responsible for this project, consisted of the following persons:

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EXECUTIVE SUMMARY

AIM

The main aim of the study is to evaluate the surface water salinity status of the Lower Vet River catchment and identify the main factors affecting the status.

MOTIVATION

The major water quality management goal of the Department of Water Affairs and Forestry (DWA&F) is to maintain *fitness for use* of the country's water resources on a sustained basis. Attainment of this management goal requires the setting of source water quality objectives. The water quality situation analysis is the first step in the process of setting these objectives.

The DWA&F is in the process of setting water quality objectives for water sources on a prioritised basis. Owing to the water quality problems being experienced, the Lower Vet catchment was given a high priority and selected as one of the first sources for the setting of water quality objectives.

TERMS OF REFERENCE

Scope

The Vet River catchment is shown in Fig. 1. The main focus of the study was on that portion of the catchment influenced by pollution sources in the OFS Goldfields mining area. The water quality situation analysis was confined to the study of Total Dissolved Salts (TDS) and its main inorganic constituents in the surface water.

Only data available up to the end of September 1992 was included in the analysis. Hence subsequent changes in the water quality status will not be reflected.

Specific tasks

The specific tasks included in the study are summarised as follows:

- determine water quality requirements for recognised users;
- document sources of pollution;
- assess existing water quality monitoring systems;
- patch and naturalise hydrological records;
- estimate diffuse source salt loads; and
- evaluate the present water quality status of the catchment.

The main findings of the study are discussed under the report chapter headings in the following sections.

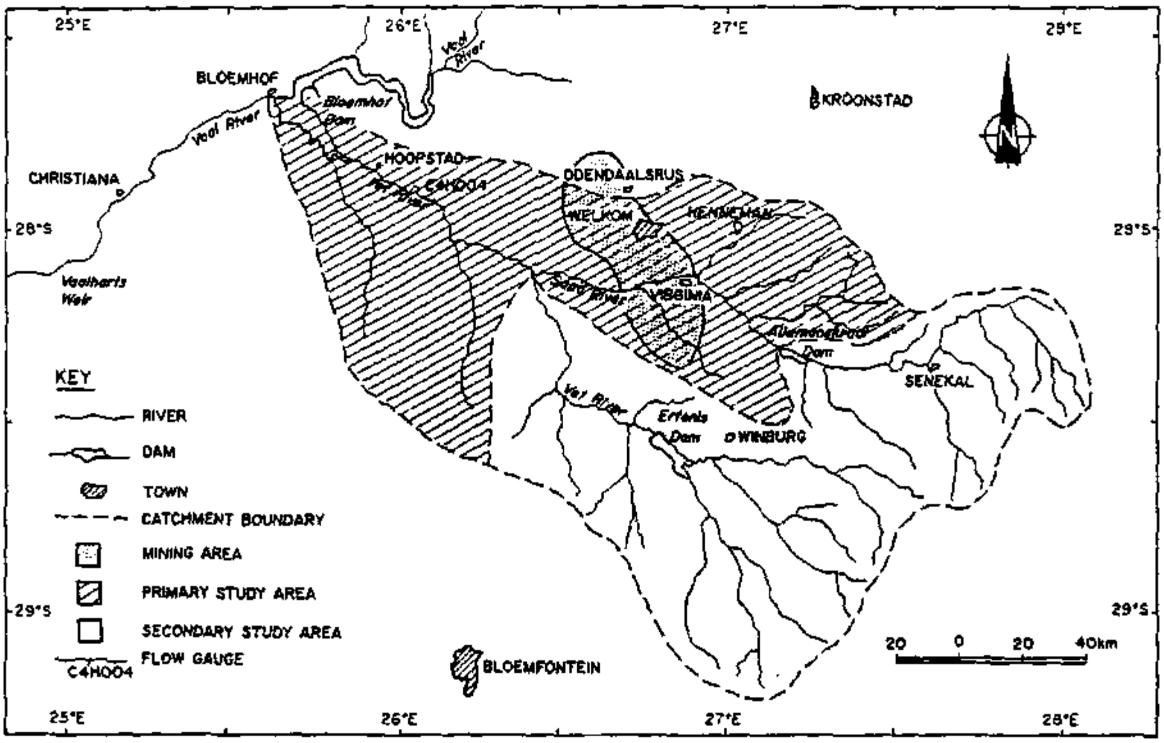

Fig. 1 : Map of Vet River catchment

WATER USE (Chapter 2)

There is a high degree of inter-dependence between the different water users in the OFS Goldfields region. The following is an overview of water use and water balances in the study area.

Water supply

The main suppliers of water are the Sand-Vet Government Water Scheme (GWS), which draws water from Allemanskraal and Erfenis Dams, and Goldfields Water, which draws most of its raw water from the Vaal River. A number of towns abstract water from local water sources.

The Sand-Vet GWS provides water mostly for irrigation use, part of which is supplied direct from the canals and part from the lower Vet River. It is only the latter part that could be affected by pollution emanating from the OFS Goldfields area.

Of the towns supplied from the Sand-Vet river system, only Hoopstad, adjacent to the lower Vet River, is likely to be affected by pollution sources in the OFS Goldfields region.

The main crops irrigated from the Sand-Vet system are wheat, maize, fodder crops, potatoes, other vegetables, ground-nuts and sunflowers.

Several contradictions and deficiencies were found in the water use data for the Sand-Vet GWS. The most serious of these is the apparent large under-estimation of the actual irrigation supply from the canals.

Effluent discharge

Most of the purified sewage effluent generated in the study area is re-used by local mines and to irrigate parks, gardens and sports fields. Until recently most of the remainder was disposed of in natural pans by Welkom Municipality (Witpan and Flamingopan). At present only Joel, Beatrix and Oryx mines and Welkom's new Thabong STW make significant direct contributions to the runoff from the OFS Goldfields study area.

Water balances

The water balance for the main water users in the OFS Goldfields region is very complex (see Appendix C of the main report), with water being transferred between several mines, municipalities and storage facilities. Unfortunately the water balance data provided by the different organisations is often contradictory. The water balances for individual pans and evaporation ponds are generally deficient.

PROVISIONAL WATER QUALITY USER REQUIREMENTS (Chapter 3)

The main findings with regard to water quality user requirements are as follows:

- Those water users most likely to be affected by activities taking place in the OFS Goldfields mining area are the town of Hoopstad, riparian irrigation farmers along the lower Vet River and farmers using water from polluted local rivers for livestock watering.

- Water quality user requirements for different broad categories of use have been based on the new S.A. Water Quality Guidelines, taking account of information obtained regarding local conditions and specific water uses within each category.

- The S.A. Water Quality Guidelines for nature conservation have not yet been released. Nor were the OFS Nature Conservation able to come up with any water quality user requirements. As an interim measure the S.A. Water Quality Guidelines for aquaculture were used to approximate the needs of fish life. Other literature sources were also drawn upon to provide interim user requirements for the natural environment.

- The provisional water quality user requirements for the lower Sand and Vet Rivers and the OFS Goldfields area are summarised in Table 3.10 of the main report.

- In view of the absence of adequate information regarding the water quality requirements for the natural environment, the water quality user requirements for each river reach must be regarded as provisional. The DWA&F intends to undertake a biological survey to fill this information gap, after which the overall user requirements will be revised.

POLLUTION SOURCES (Chapter 4)

- **Ground-water pollution:** Pollution sources in the OFS Goldfields region have led to salinisation of the ground-water over a large area.

- **Surface water pollution:** A number of natural rivers and streams, pans and wetlands in the region have suffered severe salinisation. Affected rivers include:

Sand River, Mahemspruit, Doring River, Theronspruit, Bosluisspruit, probably the Rietspruit and possibly the Merriespruit (the water quality data is too sparse to make definite statements about the latter two streams). The following pans are also salinised: Dankbaar, Riet, Wolwe, Stuurmans, Doring, Blesbok, Toronto, Flamingo, Wit, Swart.

- **Nature of pollution:** The most dominant ions present in the polluted river water are chloride, sodium and sulphate.

- **Salinisation of Sand River:** In the case of the Sand River the median electrical conductivity (EC) was found to increase seven-fold, from 30 mS/m to 216 mS/m, from east to west across the mining area. Median chloride concentrations increased twenty-fold, from 18 to 390 mg/l.

- **Mining pollution:** Gold mining in the OFS Goldfields area was identified as the main cause of the salinisation of the ground-water, pans and rivers. The most likely mining causes of the salinisation of the surface water, and in particular the Sand River and its tributaries, include:

  - President Brand and President Steyn mines discharge to the Sand River Canal, and hence to the Sand River.

  - Harmony Mine (Virginia Section) to Sand River east of Virginia.

  - Harmony Mine (Harmony Section) and/or President Brand and President Steyn mines in vicinity of De Kroon to Sand River.

  - Harmony Mine (Harmony Section) in vicinity of Harmony to Rietspruit.

  - Harmony Mine (*Merriespruit Section*) in vicinity of Convent Dam to Sand River.

  - Beatrix Mine to Theronspruit and Doring River.

  - Oryx Mine to Bosluisspruit.

  - General diffuse seepage over a wide area.

In addition the Western Holdings and Freestate Geduld mines affect the Mahemspruit, which discharges to an area with internal drainage that does not appear to have any outlet to any major surface water drainage system. St. Helena Gold Mine discharges to the Wolwepan/Rietpan system, which also does not have any obvious outlet. However, the presence of an ancient palaeodrainage system might hold the potential for eventual seepage towards the Sand River. The mines located further to the north fall outside the Sand/Vet River catchment.

In all of these instances the main mode of entry of the contaminated water to the river system is via seepage. Intermittent spillage events also sometimes occur.

Saline water is also disposed of in a number of natural pans and wetland systems.

- **Industrial pollution:** The wetland system near Blesbokpan was seriously polluted by yeast effluent from the NCP factory, which has recently closed.

- **Municipal pollution:** Other than that disposed of in Witpan and discharged to the Sand River Canal from the new Theronia STW, there is little sewage effluent that is not re-used within the OFS Goldfields area. Witpan also suffers occasional pollution episodes due to contaminated storm water.

- **Effect of irrigation:** Irrigation from the Sand-Vet GWS appears to add little to the salinisation of the river system. On the contrary, it plays an important beneficial role in diluting the pollution in the lower Sand and Vet rivers.

- **Solid waste sites:** Municipal solid waste sites do not appear to be significantly affecting surface water quality. Ground-water contamination also seems to be confined to areas close to the sites.

- **Nutrients:** Nitrate, ammonia and phosphate concentrations in the Sand River are elevated throughout the area affected by mining and urbanisation. This holds the potential for eutrophication of slow moving portions of the river, such as in the pool backed up by Virginia weir. It is difficult to identify any one source of the nutrients, since they can originate from municipal, industrial and agricultural activities, all of which are closely inter-twined in the study area.

ASSESSMENT OF MONITORING SYSTEMS (Chapter 5)

The catchment monitoring system was found to be deficient in a number of respects:

- **Insufficient coverage of catchment:** Portions of the catchment, such as the Rietspruit and the Bosluisspruit are not regularly monitored.

- **Lack of flow gauging:** There is a total lack of flow gauging at all water quality sampling points in the most polluted portion of the catchment (i.e. the OFS Goldfields area).

- **Lack of water balance monitoring:** A lack of storage state, inflow and outflow data for most polluted water storage facilities makes it almost impossible to evaluate either the overall water balance for the mining area or the balances for individual facilities.

- **Sampling frequencies:** At most regular monitoring stations within the study area, the current monthly sampling frequency is inadequate for estimating pollution loads or even detecting all pollution events.

- **Choice of water quality variables:** In some instances important water quality variables (such as sodium) are not measured in surface water courses.

- **Site identification:** In many instances the identification of monitoring sites was ambiguous or inconsistent.

- **Consistency of water quality data:**

    - External consistency problems: Large discrepancies were sometimes found between observed water quality data collected by different organisations at the same (or nearby) points. Since the sampling frequency is so low, it could not be ascertained if these discrepancies arose from data errors or changes in flow regime between sampling dates.

    - Internal consistency problems: The mines data in particular showed large internal inconsistencies. For example, contradictions between EC and TDS values resulting in impossible TDS/EC ratios of 20 or more were common. Large imbalances between anions and cations were also often found. This implies poor laboratory control.

- **Data access and processing:**

    Available data was generally made available to the study. However, long delays (up to half a year) were commonly experienced in obtaining data from some mining houses. Moreover, very little data appears to have been computerised.

- **Co-ordination of monitoring programs:** Duplication of effort at various monitoring points and no sampling at all in other areas indicates a lack of co-ordination between the different monitoring programmes.

NATURALISATION OF STREAMFLOW (Chapter 6)

- **Natural mean annual runoff (MAR):** The natural MAR of the Vet River catchment (at gauge C4H004) is estimated to be 404 x 10^6m^3 (based on 1920 to 1991 hydrology). This is about 10% of the MAR of the entire Vaal River catchment.

- **Present day (1992) MAR:** Under present-day conditions the MAR of the catchment has decreased to about 271 x 10^6m^3. The difference in MAR is accounted for as follows:

Naturalised MAR (10^6m^3)		404
-	Abstractions from Allemanskraal Dam	38
-	Evaporation from Allemanskraal Dam	17
-	Abstractions from Erfenis Dam	46
-	Evaporation from Erfenis Dam	25
-	Sand-Vet GWS irrigation from Vet River	4
-	Private irrigation (plus evap. from minor dams)	22
+	Discharges from Allemanskraal (Sand) canal	2
+	Discharges from Erfenis (Vet) canal	9
+	Return flows from Sand-Vet GWS	8
Net MAR (1992 conditions)		271

HYDRO-SALINITY MODEL CALIBRATION (Chapter 7)

Comparisons of modelled and observed monthly flows, TDS concentrations and TDS loads are given in Appendix F of the main report.

- **Allemanskraal Dam and Erfenis Dam catchments:** The model calibration results for these two dams are satisfactory.

- **Sand River in OFS Goldfields area:** Although far from ideal, the calibration results for the Sand River between Allemanskraal and Blaaudrift bridge are good enough to provide a reasonable first order representation of the system.

- **Lower Vet River:** The fit between modelled and observed results at station C4H004 in the lower Vet River is poor. The poor fit between modelled and observed data at C4H004 is attributable to the following factors:

    - For the entire region between Allemanskraal Dam, Erfenis Dam and station C4H004 on the lower Vet River there was no streamflow data to calibrate against. This made calibration particularly difficult in the Sand River sub-system, when the balance between normal river flow and seepage flow has a profound effect on water quality.

    - Data received from the mines was scarce and often inaccurate and/or incomplete. Only Harmony Mine provided a reasonable monitoring system. Conflicting estimates of return flows to river systems were received from different sources.

    - Reliable data pertaining to irrigation water use, actual irrigation areas and irrigation return flows was incomplete. This made calibration of the irrigation sub-model extremely difficult.

    - The accuracy of observed TDS concentrations in the mining areas was in doubt. In some instances there were large discrepancies between the water quality data collected by different organisations.

    - The water quality sampling frequency in rivers (generally monthly) is too low to arrive at a reliable estimate of the average TDS during the monthly time step at which the model operates. The observed values that the model was calibrated against are therefore not necessarily a true reflection of the monthly averages.

    - The important role played by irrigation return flows in diluting the polluted runoff from the Sand River could not be modelled accurately due to lack of information regarding irrigation water use and return flows.

- **Overall evaluation of salinity modelling:** Despite the above limitations, the model calibration for the two dams and the Sand River to Blaaudrift bridge provides a reasonable representation of the salinity regime.

ESTIMATION OF TDS LOADS (Chapter 8)

- **OFS Goldfields TDS load contribution**

  - During the last fifteen years pollution sources in the OFS Goldfields region are estimated to have added about 16 000 t p.a. to the TDS washoff from the Vet River catchment. This represents an increase in the Vet River catchment TDS export of about 35%.

  - During wet years the contribution of the OFS Goldfields region is significantly higher. For example, during the 1987/88 and 1988/89 hydrological years the pollution increased the Vet River TDS export by 40% and 68% respectively.

- **Net TDS export to Lower Vaal System**

  - During dry weather there appears to be a net retention of salt in the Vet River system. Under these conditions there should be little runoff entering Bloemhof Dam and consequently little effect on downstream water quality.

  - The retention of salt in irrigated lands appears to have reduced the mean annual net TDS export from the Vet River to the Vaal River system by about 13 800 t p.a. This had the effect of reducing the increase in the mean annual net TDS export (relative to virgin conditions) to only about 2200 t (compared to a total average annual TDS input to Bloemhof Dam from the Vaal and Vet Rivers of the order of 600 000 t).

  - During wet conditions the increase in the net TDS export from the Vet River (relative to natural conditions) is estimated to have increased the TDS load entering Bloemhof Dam by up to about 9%.

- **Impact on downstream water users:** The impact of increased TDS load export from the Vet River on users in the Lower Vaal System is dependent on the relative magnitude of the monthly runoff and TDS inputs to Bloemhof Dam from the Vet and Vaal Rivers. Modelling of the Vaal River System will be required to assess these impacts.

- ***Data deficiencies:*** *The* absence of flow gauging stations and the low water quality sampling frequency prevented reliable estimation of pollutant loads anywhere within the most polluted portion of the catchment, or even immediately downstream of it.

EVALUATION OF SALINITY STATUS (Chapter 9)

Salinity trends

- The only points in the system where *significant salinity* trends were detected over the last two decades are in Harmony Mine's "Waste Dump Stream" and "Donga Dump Stream", east of Virginia, and in the Sand River immediately downstream of these two streams. In more recent years the salinity regime at these stations appears to have reached some sort of a plateau.

- At all other stations there was no significant trend in EC or any of the major ions comprising the TDS. This is consistent with the predominance of older long-established gold mines in the OFS Goldfields region. However, as some of the new gold mines to the south of the Sand River come into full production, it is possible that further deterioration in water quality will occur.

Surface water quality status for salinity

Figs. 2 and 3 summarise the salinity status for the Sand-Vet river system. The following conclusions have been drawn regarding the overall surface water quality status, with particular emphasis on the salinity status:

- **Background surface water quality status:** Based on the data from the two dams, Allemanskraal and Erfenis, the background water quality is excellent and fully complies with the user requirements for salinity related variables.

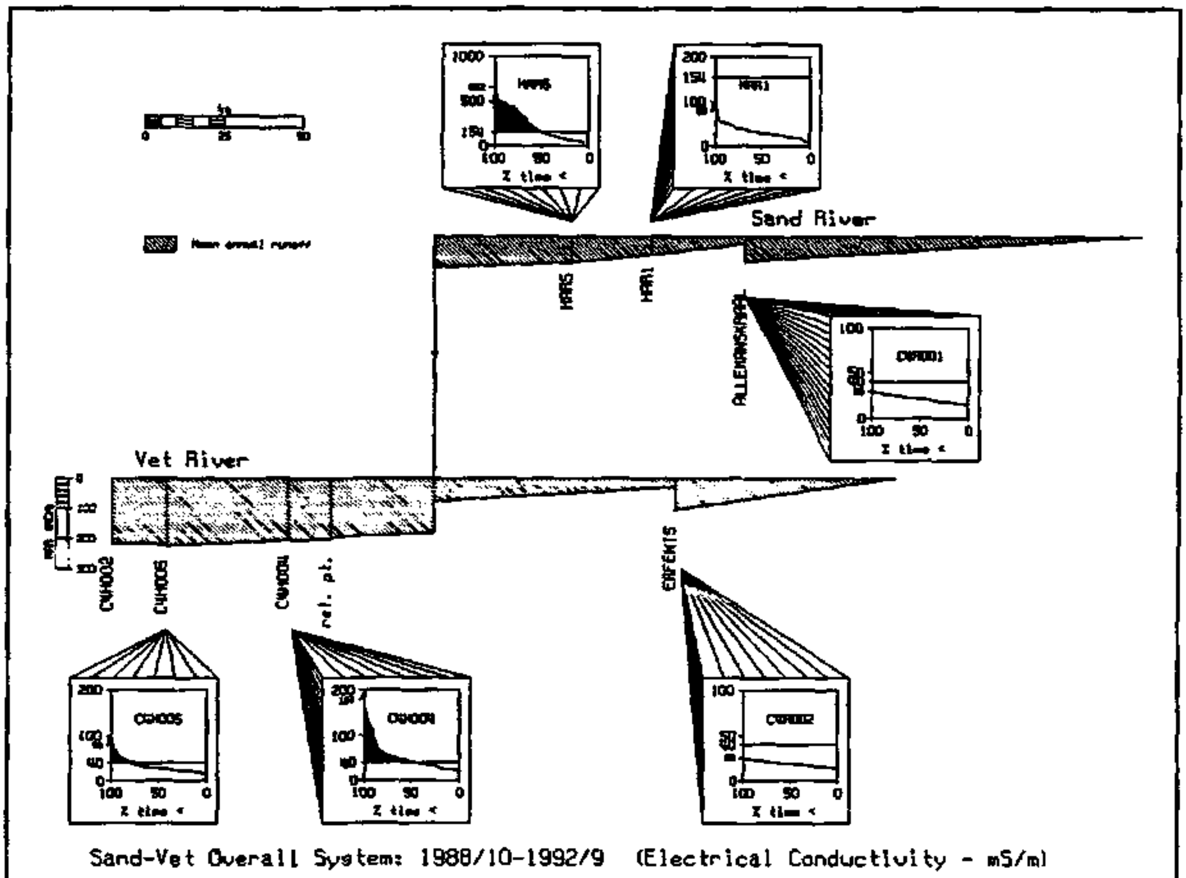

Fig. 2 : Comparison of duration curves of EC at different stations with user requirements

- **Lower Sand and Vet Rivers:** From excellent background salinity conditions in Allemanskraal Dam, the EC levels in the Sand River at station HAR1 (DWA2), on the eastern fringe of the OFS Goldfields area, deteriorated significantly, but not sufficiently to exceed the user requirement limit for livestock watering. The chloride and sulphate ions showed the largest increases at this station, however, the user requirement limits were not exceeded.

A sharp deterioration in the mineral water quality of the Sand River was observed at stations HAR2 and HAR3, in the vicinity of Harmony Mine's "Waste Dump Stream" and "Donga Dump Stream". The water quality user requiements for a number of salinity related variables were exceeded at these stations.

From station HAR1 all the way to Blaaudrift bridge (station DWA7), which is downstream of the western fringe of the OFS Goldfields region, the mineral water quality showed further deterioration, with the user requirement limits often being exceeded by very wide margins and for large percentages of the time.

In some portions of the Sand River the deterioration is serious enough to present a very real acute health threat to potential rural or informal users who might use it for domestic purposes. The reach of the Sand River of most concern in this regard is between the Sand River Canal and Blaaudrift bridge (station DWA7). It is not known for how far downstream these dangerous salinity levels prevail, since DWA7 is the last water quality monitoring point before station C4H004 in the lower Vet River.

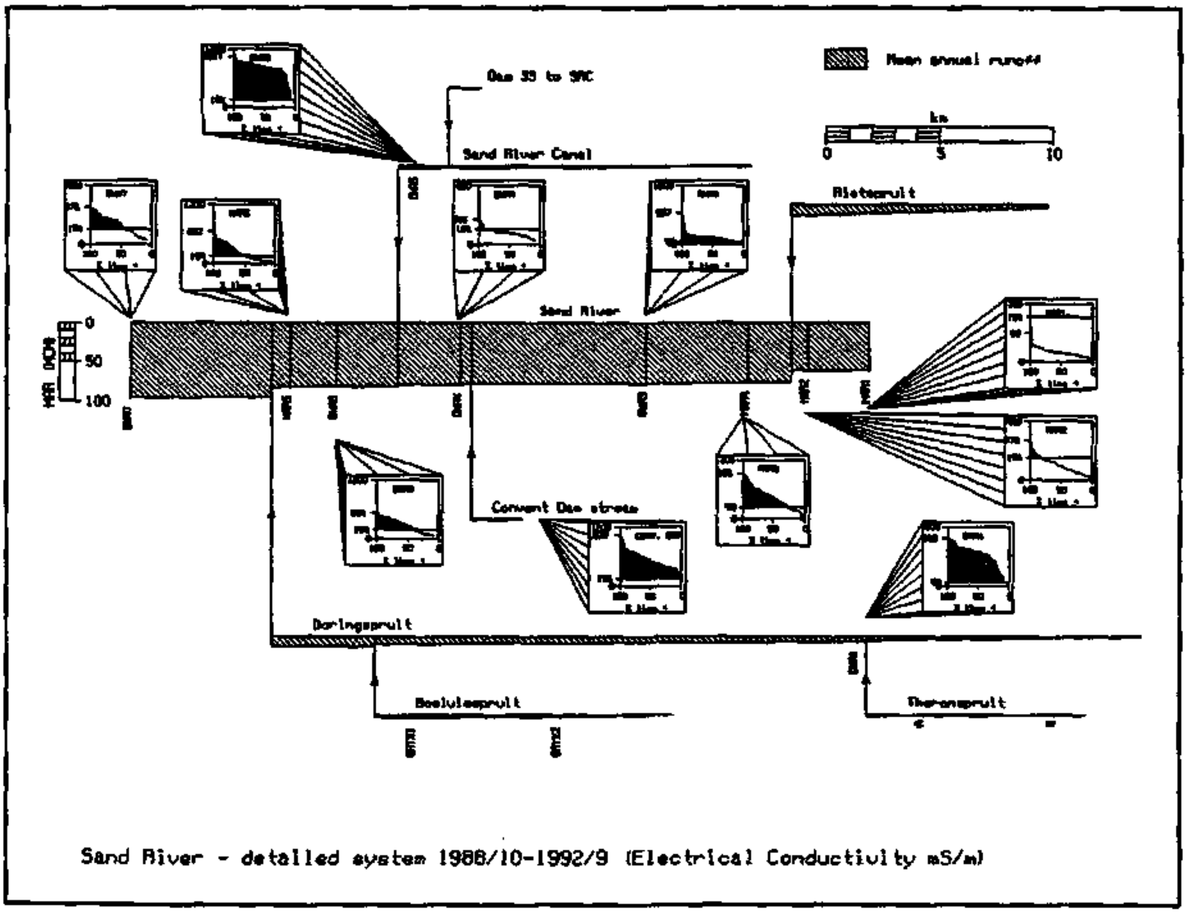

Fig. 3 : Comparison of duration curves of EC at different stations with user requirements

Dilution of the lower Vet River due to low TDS water released from the Sand-Vet GWS canals resulted in considerable improvement in the salinity status at station C4H004. However, although the salinity levels at this point no longer present a serious threat to public health, the interim user requirement limits for EC, chloride, sodium and the sodium absorption ratio (SAR) were all exceeded. In the case of

EC the user requirement limit of 40 mS/m was exceeded for 40% of the time, with peaks reaching 163 mS/m. This could be detrimental to irrigation use in the lower Vet River. The observed exceedence of the user requirement limit for SAR in the lower Vet River are likely to necessitate the surface application of gypsum to prevent surface crusting when rainfall occurs on irrigated lands, since the soils in this area are particularly susceptible to sodicity problems.

- **Rietspruit:** There are no water quality monitoring stations in the Rietspruit. However, the moderate improvement in the mineral water quality between stations HAR3 and HAR4 suggests that the Rietspruit is contributing little to the pollution of the Sand River. However, given the very poor water quality in the Sand River, this does not preclude the possibility of local salinisation problems in the Rietspruit.

- **Sand River Canal:** Aside from calcium and magnesium, all of the salinity-related water quality user requirement limits were exceeded in the Sand River Canal by extremely wide margins (usually several-fold) for most of the time. This water is unacceptable for domestic, irrigation, livestock watering or the natural environment. It also presents a serious potential acute health threat, even for casual short term ingestion.

  While the canal itself was built as a stormwater drain, and as such is not intended for public use, portions of the canal follow a natural water course. A farmer's dam is also situated in the highly polluted stream into which the canal discharges. The possibility of this water being accidentally used for purposes for which it is totally unfit therefore cannot be precluded.

- **Doring River and Theronspruit:** As with the Sand River Canal, several of the mineral water quality user requirement limits were exceeded for high durations and by wide margins. The EC level above which chronic health problems can be expected was exceeded for 68% of the time and the acute health threat limit was exceeded for nearly 10% of the time at station DWA1 in the Doring River downstream of the Theronspruit confluence. By implication the salinity levels in the Theronspruit are likely to be as bad, if not worse. From the scant information available, the Bosluisspruit also appears to be salinised.

  Hence the Doring River is not only unsuitable for irrigation, it could also present serious problems for domestic water use by local riparian farmers and their labourers.

- **Surface water quality status for other water quality variables**

  Aside from salinity-related variables, which form part of the brief of the study, the water quality status for a few other water quality variables that came to hand were also dealt with. These are discussed below:

  - **Ammonia:** In the case of ammonia (which is not a salinity related variable), the user requirement limit for aquaculture (used to represent the natural environment) was exceeded to some extent at all points in the system. In the cases of Allemanskraal Dam, Erfenis Dam and the lower Vet River only isolated events exceeded the user requirement limits for short durations. More frequent and severe exceedences occurred in the

Sand River and its tributaries in the vicinity of the OFS Goldfields area, indicating the possibility of faecal or other biological pollution. However, the 1 mg/l limit for domestic use was not exceeded at any monitoring stations.

- **Nitrate:** The target water quality user requirement limits for nitrates were generally met at all points in the Sand and Vet Rivers, with the exception of a short duration marginal exceedence at one point (station DWA4).

  The nitrate limit was exceeded for 7% and 5% of the time in the Sand River Canal and in the Doring River respectively.

- **Fluoride:** The recorded fluoride levels in Allemanskraal Dam, Erfenis Dam and in the lower Vet River at station C4H004 are all well within the user requirement limit.

- **Phosphate:** No firm phosphate user requirement limit was derived, since this would require a detailed eutrophication study. However, exceedence of 1 mg/l at a number of points indicates the possibility of eutrophication problems in slow moving river reaches.

- **pH:** The observed pH at all surface water monitoring stations appears to be within acceptable limits for domestic water use. Despite not always being ideal for irrigation use, pH does not appear to present any serious problems in the study area.

- **Cyanide:** The recorded cyanide levels for those stations examined appear to be within the user requirement limit.

RECOMMENDATIONS

The recommendations arising from the Water Quality Situation Analysis are too numerous to deal with in an executive summary. Hence only a few of the main recommendations have been highlighted. Chapter 11 deals with the recommendations in greater detail.

- **Formulation of catchment water management plan:** There is an urgent need to prepare a comprehensive water management plan to address the salinisation problems experienced in the OFS Goldfields region and the downstream portions of the Sand-Vet River System.

- **Improvement of monitoring systems:** Several problems were encountered with regard to the flow (virtually non-existent) and water quality monitoring system in the OFS Goldfields area. The problems include lack of flow data, poor spatial and water quality constituent coverage, low sampling frequencies, data conflicts, poor identification of sites, extremely poor access of data and inadequate checking and reporting procedures. A number of recommendations have been made to improve the monitoring system.

- **Water quality requirements of users:** Further information regarding the soils of irrigated riparian lands along the lower Vet River is required to refine the water quality requirements for irrigation use and agricultural water management options. The requirements of the natural environment also need further investigation.

- **Water and salt balances:** Regular procedures need to be set in place to obtain complete and reliable water and salt balances for all surface water storage facilities in the OFS Goldfields area.

- **Water use data:** A more accurate and efficient system for keeping records of irrigation water use, irrigation areas and crop distribution in the Sand-Vet GWS is required.

- **Water quality modelling:** As more data becomes available the hydro-salinity model developed during this study needs to be expanded to cover the gold mining areas in greater detail. The use of a daily time step model is recommended to make better use of the existing data to quantify pollution inputs.

- **Investigation of salt balance of irrigated lands:** A research project aimed at improving the current irrigation sub-model and investigating the apparent retention of salts in the irrigated lands along the lower Sand and Vet Rivers is recommended.

- **Investigation of impact on downstream river system:** An evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream river system is recommended.

- **Development of water quality data patching package:** The development of a user-friendly expert system for selecting water quality data patching methods and accessing the appropriate software is recommended. This would place a valuable tool for estimating pollutant loads from deficient data in the hands of researchers and other water quality practitioners. Innovative methods and software developed during earlier studies and applied in the current situation analysis could provide a starting point for the development of such an expert system.

CHAPTER 1

INTRODUCTION

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1. INTRODUCTION

1.1 Aim

The main aim of the Lower Vet River Water Quality Situation Analysis is to evaluate the water quality status of the Lower Vet River and identify the main factors affecting the status.

1.2 Motivation

As custodian of the limited water resources of the Republic of South Africa, the Department of Water Affairs and Forestry (DWA&F) has to ensure the equitable provision of adequate quantities of water to all competing users at an acceptable degree of risk and cost under changing conditions.

The Department has long recognised the need to ensure that the water made available to users is of an acceptable quality. In this regard ***sustained fitness for use*** is the Department's major water quality management goal. Attainment of this management goal requires the setting of source water quality objectives. The water quality situation analysis is the first step in the process of setting these objectives.

The DWA&F is in the process of setting water quality objectives for water sources on a prioritised basis. Due to the water quality problems being experienced, the Lower Vet catchment was given a high priority and selected as one of the first sources for the setting of water quality objectives.

1.3 Scope of work

The geographical limits of the study area are shown in Fig. 1.1 . With regard to the ground-water and surface water, the greatest emphasis will be placed on Total Dissolved Solids (TDS) and its main inorganic constituents.

Only data available up to the end of September 1992 was included in the analysis. Hence subsequent changes in the water quality status will not be reflected.

1.4 Specific tasks

A full description of the specific tasks included in the study is given in the Terms of Reference (see Appendix B). These tasks are summarised below:

(a) Determine water quality requirements of recognised users

Determine the desirable water quality limits for each river reach, taking cognisance of present and potential beneficial water uses.

(b) Document sources of pollution

Document both point and diffuse sources of those pollutants identified as being problematic to users.

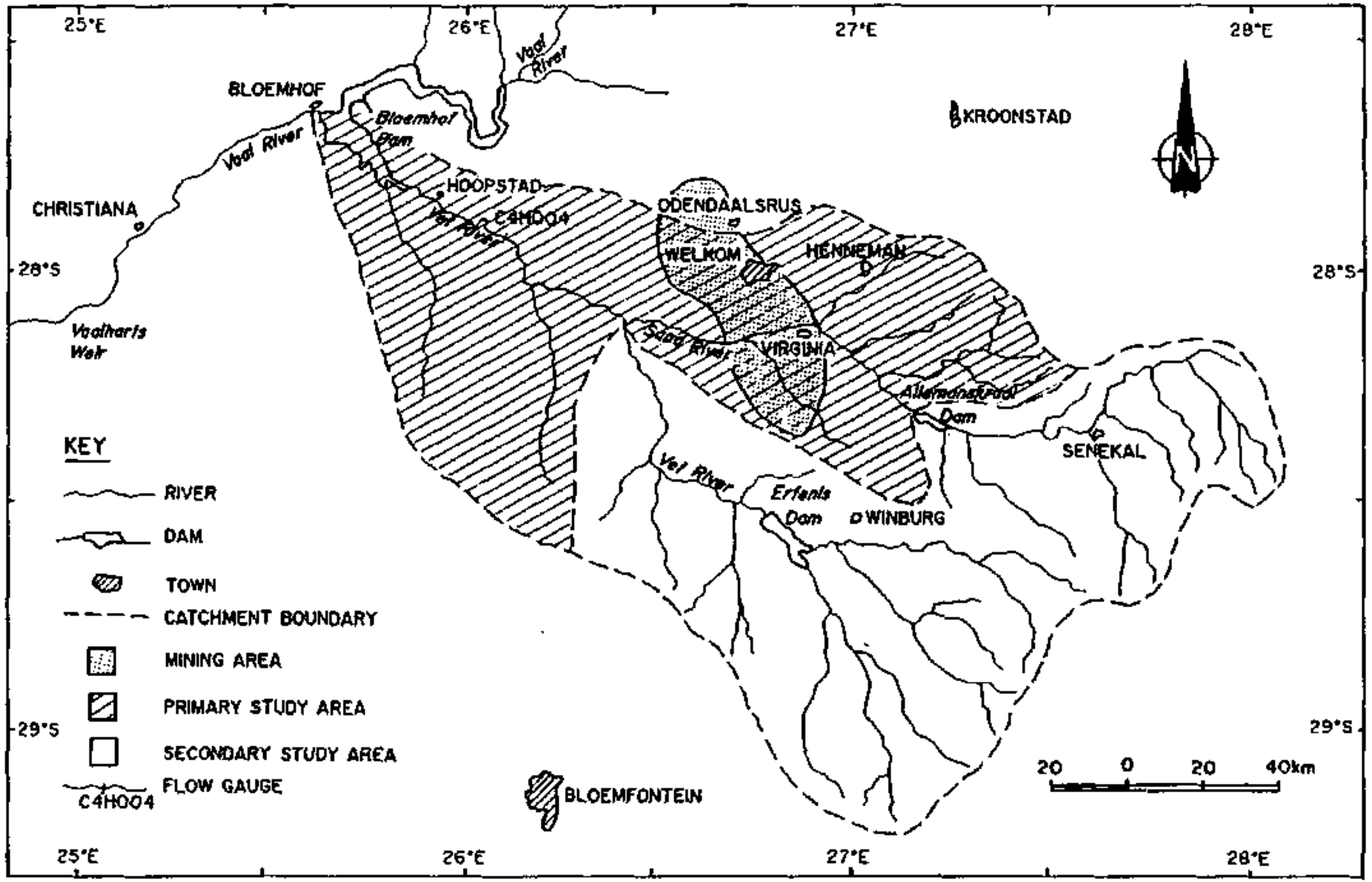

Figure 1.1 : Map of study area

(c) **Assess present water quality monitoring systems**

Identify and evaluate all existing water quality monitoring systems. This is required to determine the reliability of the data used in the water quality analyses.

(d) **Patch and naturalise hydrological records**

This is required to estimate the mean annual runoff (MAR) and the statistical properties of the runoff from key sub-catchments. It is also an essential step in estimating diffuse source pollutant loads.

(e) **Quantify natural and developed catchment water and TDS balances.**

(f) **Estimate diffuse source loads for the main inorganic constituents of the TDS**

Estimate the pollutant loads of those of the main inorganic constituents of the TDS identified as posing a threat to beneficial water use.

(g) **Evaluate the present water quality status of the catchment**

Examine historical water quality trends and compare with the water quality guidelines.

(h) **Draw appropriate conclusions**

1.5 Modular report structure

An attempt has been made to accommodate the reader whose time is limited and who may be interested in only certain aspects of the report. Such a reader may wish to gain a quick insight into the chapter contents before deciding whether or not to read the details. The layout of each chapter of the report has been designed with this requirement in mind. Each chapter therefore commences with a brief overview of the main contents.

1.6 Notation

Regarding notation, the Department of Water Affairs and Forestry has been abbreviated to DWA&F throughout. The decimal comma has been replaced by a decimal point throughout due to inconsistencies arising from including computerised data.

CHAPTER 2

OVERVIEW OF WATER USE

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2. OVERVIEW OF WATER USE

This chapter contains an overview of water use in the study area. Although the main emphasis is on water supply, basic information regarding the re-use of effluent has been included since this is widely exploited as a water source. Effluent sources are dealt with in greater detail in Chapter 4, in the context of pollution sources.

2.1 Introduction

There are two main suppliers of water in the study area, viz.

- the Sand-Vet Government Water Scheme and
- Goldfields Water

In addition to these two main water suppliers, a number of towns abstract water from local water sources.

The Sand-Vet Government Water Scheme (GWS) supplies water mainly for irrigation via a system of canals fed by Allemanskraal Dam on the Sand River and by Erfenis Dam on the Vet River (see Fig. A.1). Water is also discharged to the lower Vet River for downstream riparian use.

Goldfields Water obtains most of its water supply from the Vaal River. However, a small proportion is abstracted from Allemanskraal canal, which is part of the Sand-Vet GWS.

The main usage of water in the region is for irrigation (mostly supplied by the Sand-Vet GWS) and mining (mostly supplied by Goldfields Water). The municipalities of greatest importance with respect to water use are Welkom, Virginia and Thabong.

2.2 Sand-Vet Government Water Scheme

The DWAF Sand-Vet GWS office was approached for data on the Sand-Vet GWS. It was found that much of the requested information was not readily available and had to be extracted by hand. This resulted in long delays.

The total scheduled irrigation area in the Sand-Vet GWS is 10 101 ha, of which 4997 ha is along the Sand River, supplied from Allemanskraal Dam, and 5104 ha is along the Vet River, supplied from Erfenis Dam. The annual water allocation is 7200 m^3/ha, which is supplied from canals up to the Sand-Vet confluence and direct from the Vet River downstream of the confluence. Water is released from the Sand and Vet canals for riparian irrigation downstream of the Sand-Vet confluence. There are five points of discharge, all to the Vet River.

The main crops that are irrigated comprise wheat (58%), fodder crops (16%), potatoes (15%) and maize (10%). Vegetables (other than potatoes) and ground-nuts make up the remainder. A more detailed discussion of crop types is given in Chapter 3, which deals with water quality user requirements.

In addition to irrigation use, provision has been made for the supply of water from the Sand-Vet GWS for Goldfields Water's Virginia purification works and various towns, mines and other organisations. The water allocations from the Sand-Vet GWS are summarised in Table 2.1.

TABLE 2.1
Water allocations from the Sand-Vet GWS

USER	ANNUAL ALLOCATION ($10^6 m^3$/year)
SUPPLY FROM ALLEMANSKRAAL DAM	
Goldfields Water	12.800
Harmony Mine	1.200
Beisa/Oryx Mine	2.400
Agricultural Technical Services	0.321
Willem Pretorius	0.365
Department of Correctional Services	0.321
Irrigation	35.980
SUPPLY FROM ERFENIS DAM	
Brandfort*	1.818
Theunissen	0.546
Bultfontein	1.818
Hoopstad	0.312
Irrigation	36.750

NOTES: * Brandfort is located outside the study area (see Fig. A.1).

Historical water use from the canals from Allemanskraal Dam and Erfenis Dam since 1984 is summarised in Table 2.2. Most of the information given in Table 2.2 was provided by the Sand-Vet GWS offices. This information was supplemented with data obtained from Goldfields Water, since the Sand-Vet GWS office could provide abstraction data for Goldfields Water only for 1992.

In most instances the actual water use given in Table 2.2 is considerably less than the allocations given in Table 2.1. This is especially so in the case of Goldfields Water. We understand that the under-utilisation of the capacity of the Virginia water purification works is attributable to the yield of Allemanskraal Dam being too small to meet both the irrigation and urban demands. Since the irrigation has a prior right to the available water, Goldfields Water cannot abstract sufficient water for the Virginia purification works.

The calculated differences between the annual discharges to the canals and water use given in Table 2.2 vary between 24% and 66%, with an average of 38%. This difference is much too large to represent the losses from lined canals. This was confirmed later by the DWA&F OFS Regional Office who estimated the canal loss to be between 9% and 16% (personal communication). Under estimation of the irrigation abstractions appears to be the main cause of the apparently high losses reflected in Table 2.2. Based on a total scheduled area of 10 101 ha and a water allocation of 7200 m^3 p.a., the annual water use could be as high as $72.7x10^6m^3$. The mean irrigation use given in Table 2.2 of $32.71x10^6m^3$ is only 45% of the total allocation. This low utilisation of the water allocation, combined with the inordinately high calculated canal losses, points to the logical conclusion that the irrigation abstractions that were provided have been under estimated. The Sand-Vet GWS office was unable to verify this conclusion.

TABLE 2.2
Annual water use from the Sand-Vet GWS canals (10^6m^3)

DESCRIPTION	1984	1985	1986	1987	1988	1989	1990	1991	1992	AVE
ALLEMANSKRAAL DAM CANALS										
Supply from Allemanskraal Dam[1]	46.91	31.41	20.45	28.24	24.15	36.95	41.44	31.95	48.92	34.49
Irrigation abstractions[2]	10.36	11.92	13.44	8.95	13.10	8.55	15.53	25.12	30.23	15.24
Goldfields Water abstraction[3]	6.16	5.98	1.25	3.16	1.05	0.00	0.00	0.00	3.49	2.34
Harmony Mine abstraction[2]	0.60	0.07	0.25						1.56	0.62
Beisa/Oryx Mine abstraction[2]		0.08	0.07	0.05					0.40	0.15
Agricultural Technical Services[2]									0.28	0.28
Department of Correctional Services[2]									0.29	0.29
Tailwater and release to Sand River[2]	1.12	1.25	1.72	2.11	2.38	1.94	1.36	1.24	2.11	1.69
Difference between supply and use[4]	28.68	12.11	3.72	13.97	7.62	26.46	24.55	5.59	10.56	13.88
ERFENIS DAM CANALS										
Supply from Erfenis Dam[1]	43.72	34.31	40.74	37.67	33.32	37.49	48.13	37.67	62.11	42.24
Irrigation abstraction[5]	25.45	15.84	15.97	18.28	15.30	9.83	8.10	19.21	29.18	17.46
Tailwater and release to Vet River[5]	12.96	10.73	11.78	10.18	5.37	4.53	5.48	7.12	13.82	9.11
Difference between supply and use[4]	5.31	7.74	12.99	9.21	12.65	23.13	34.52	11.34	19.11	15.67
TOTAL WATER USE										
Supply from dams	95.63	65.72	61.19	65.91	57.47	74.44	89.54	69.62	111.03	76.73
Irrigation abstraction	35.80	27.76	29.41	27.23	28.40	18.38	23.63	44.33	59.41	32.71
Other abstractions	6.76	6.13	1.57	3.21	1.05	0.00	0.00	0.00	6.02	3.68
Tailwater and release to rivers	14.08	11.98	13.50	12.29	7.75	6.47	6.84	8.36	15.93	10.80
Difference between supply and use[4]	38.99	19.85	16.71	23.18	20.27	49.59	59.07	16.93	29.67	29.54

NOTES:
1 From DWA&F, Directorate: Hydrology's monthly reservoir water balance sheets.
2 Information provided by DWA&F, Sand-Vet GWS office.
3 Information provided by Goldfields Water.
4 Calculated from dam supply to canals less abstractions and releases. This should represent the canal losses (i.e. and average loss of 38%). However, according to the DWA&F OFS Regional Office the canal losses vary between 9% and 16%. The reservoir records for Allemanskraal Dam and Erfenis Dam appear to be correct. This implies that the canal water use data that was provided by the Sand-Vet GWS office must be incomplete.
5 The scheduled irrigation area supplied from the Erfenis Dam canals is 4997 ha. A further 1297 ha of riparian irrigation along the lower Vet River is supported by releases from the canals. Another 151 ha is irrigated using water abstracted direct from the dam reservoir.

The Sand-Vet GWS office was not able to provide any information regarding the areas actually under irrigation. However, estimates of actual irrigated area and water actually used were obtained from a report by Ninham Shand (1985) for two years. This information is given in Table 2.3.

TABLE 2.3
Actual irrigated area and water use for Sand-Vet GWS (Ninham Shand,1985)

Year	Actual irrigated area (ha)	Annual water use (10^6m^3)
1970/71	9 425	37.8
1980/81	11 576	61.2

2.3 Goldfields Water

At present, Goldfields Water provides water to the towns of Welkom, Henneman, Ventersburg, Winburg, Virginia, Theunissen, Wesselsbron, Thabong, Kutlwanong and Meloding. (Odendaalsrus and Allanridge are also supplied by Goldfields Water, but fall outside the study area).

Goldfields Water obtains its raw water from two sources, namely: The Vaal River at Balkfontein and the Sand River (via the canal from Allemanskraal Dam) at the Virginia purification works. In 1992, $3.392x10^6m^3$ was supplied from the Sand River and $83.534x10^6m^3$ from the Vaal River. From Table 2.2 it can be seen that the production of purified water at the Virginia works has remained low and even ceased entirely during the three year period from 1989 to 1991. Hence most of the water supplied by Goldfields Water originates from the Vaal River.

In the past water quality problems have been encountered with regard to the raw water abstracted from the Vaal River. Water purification costs have been affected by eutrophication, while salinisation of the Vaal River has led to high peak TDS concentrations (reaching 1000 mg/l) in the urban water supply. The DWA&F's Directorate: Project Planning has evaluated a number of options for improving the mineral quality of the raw water supplied to Goldfields Water. These options include the construction of a new dam on the lower Vals River to provide low TDS water for blending with Vaal River water, releases of water from Vaal Dam to dilute the Vaal River, construction of a pipeline from Vaal Dam, buying out the irrigation rights downstream of Allemanskraal Dam to allow utilisation of more Sand River water and the importation of low TDS water into the upper reaches of the Sand River from adjacent catchments (Stewart Scott, 1993).

About 75% of the water supplied by Goldfields Water is used within the study catchment. Table 2.4 gives 1992 water supply figures for mines and municipalities in the study area, provided by Goldfields Water.

TABLE 2.4
Goldfields Water supply to study area for 1992 calendar year

User	Water supply (10^6m^3)
MINES	
Free State Geduld	5.117
President Brand	7.377
President Steyn	5.309
Western Holdings	4.826
Saaiplaas	2.601
Erfdeel	1.242
St. Helena	2.103
Unisel	.987
Beatrix	1.521
Harmony	6.115
Ster Diamante	.061
Joel	.870
Oryx	.970
Samada	.244
SUB-TOTAL (MINES)	39.343
MUNICIPALITIES	
Virginia	4.062
Welkom	13.831
Meloding	1.034
Thabong	5.852
Henneman	0.779
Ventersburg	0.192
SUB-TOTAL (MUNICIPALITIES)	25.749
TOTAL	65.092

2.4 Use of water by municipalities

2.4.1 Welkom Municipality

Welkom municipality is supplied with water by Goldfields Water. Table 2.5 shows the annual water supply since 1986.

TABLE 2.5
Water bought by Welkom from Goldfields Water

Year	Water bought from Goldfields Water ($10^6 m^3$)
1986	9.5
1987	9.7
1988	10.4
1989	10.4
1990	13.3
1991	11.8
1992	14.3

Thabong, which is near Welkom and in the past has had its sewage effluent treated by Welkom Municipality received $5.852 x 10^6 m^3$ of water from Goldfields Water in 1992.

There are two sewage treatment plants in Welkom, namely the Witpan works near Witpan and the Theronia works near Torontopan. The new Thabong works was commissioned in February 1993 and is expected to discharge purified sewage effluent into the head of the Sand River canal, from where it will flow into the Sand River. However, other disposal options, such as discharge to pans or sale to other users are under consideration since a constant flow down the canal may cause saline seepage water from mine waste water disposal sites, which is presently caught in pools in the canal during dry weather, to spill to the Sand River. This may adversely affect the low flow water quality in the Sand River. Conversely, the sewage discharge could have the beneficial effect of diluting the seepage that is already finding its way to the Sand River from various disposal areas. These options will be addressed during the development of the catchment Water Quality Management Plan, which will follow on from the present study.

During 1992 $15.7 x 10^6 m^3$ of purified effluent was produced by the Theronia and Witpan sewage treatment works. Most of this was disposed of by sales to mines and other users. The breakdown of use is as follows: Freegold 40%, Gencor 12% and local parks etc. 48%.

A complex inter-relationship exists between the discharge of sewage to and from mines and the disposal of redundant water in pans. A water balance for Welkom is shown in Fig. 2.1.

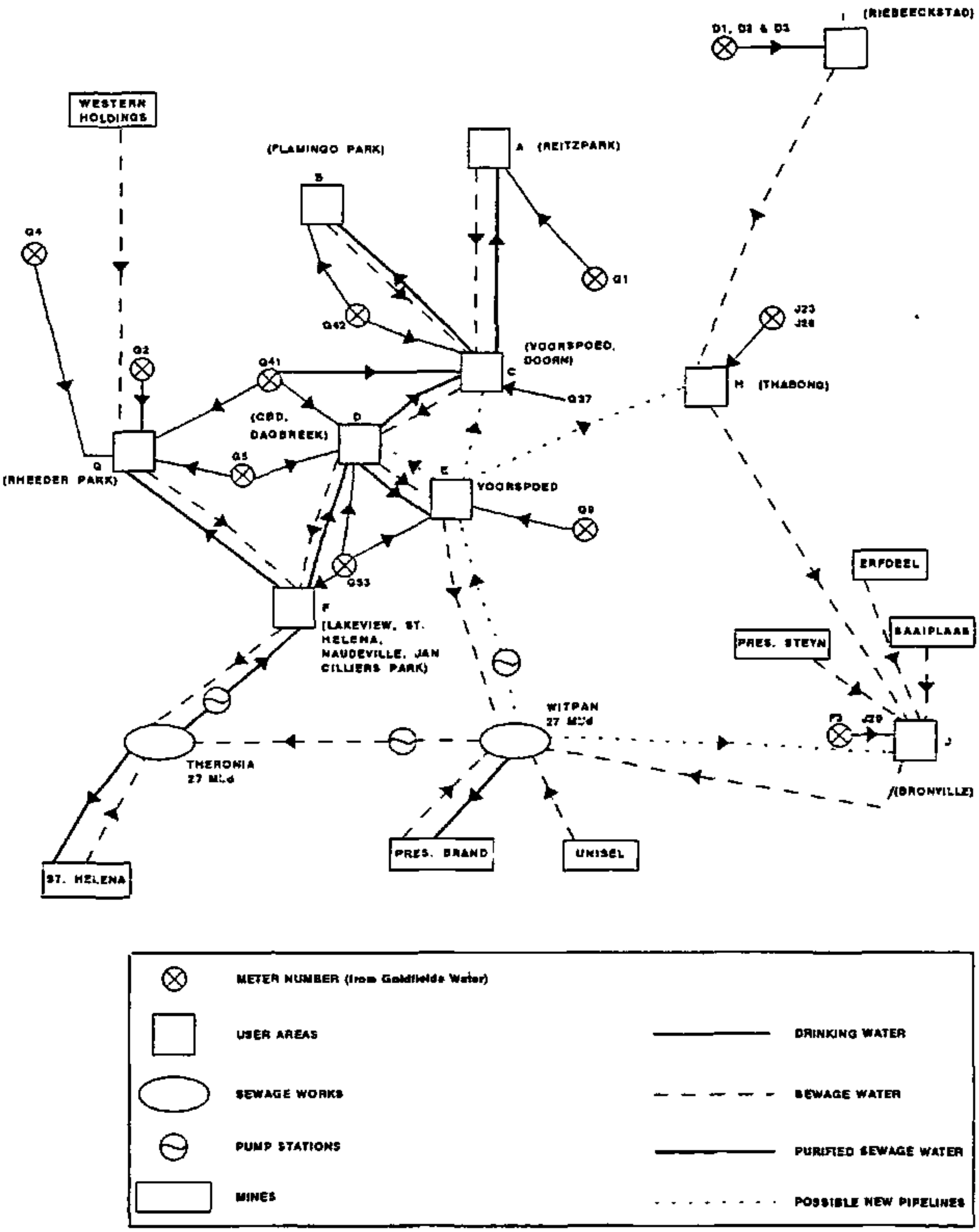

Fig. 2.1 : Welkom Water Plan

The Welkom water balance diagram was obtained from the DWA&F OFS Regional Office and was supplemented with the latest water use information provided by Welkom Municipality.

Purified sewage effluent is discharged to Flamingopan. Torontopan receives urban stormwater runoff from Welkom. Other pans used are:

a) Dankbaarpan, which evaporates poor quality mine process water from Freegold;

b) Doringpan, which disposes of underground water from Freegold;

and

c) Rietpan, where provision has been made for overspills from Wolwepan.

2.4.2 Virginia Municipality

Virginia obtains water from the OFS Goldfields. During 1992 $4.1 \times 10^6 m^3$ was supplied from this source. Virginia sewage works produces an abnormally large amount of purified effluent of $4.7 \times 10^6 m^3$ p.a. This is attributable to the fact that Virginia also treats Harmony Mine's raw sewage. Sewage from Meloding, which is located adjacent to Virginia, is also handled. (In 1992 Meloding was supplied with $1.0 \times 10^6 m^3$ of water by Goldfields Water). Virginia discharges purified effluent to the mines and parks. Excess water is discharged to the Sand River, mainly during wet weather.

2.4.3 Senekal Municipality

Senekal is located near the confluence of the Sand River and the Laerspruit, upstream of Allemanskraal Dam. Senekal has two sources of water, namely: the Sandspruit (De Put Buiteloop storage dam) and the Sand River (Cyferfontein dam). Historical annual water use from 1989 to 1992 is given in Table 2.6.

TABLE 2.6
Senekal Municipality annual water supply

CALENDAR YEAR	ANNUAL WATER USE (m^3)		
	Sandspruit	Sand River	Total
1989	407 871	527 415	935 286
1990	549 083	523 950	1 073 033
1991	279 056	653 314	932 370
1992	448 941	696 890	1 145 831

Senekal produces $0.036 \times 10^6 m^3$ of purified sewage effluent per year, all of which is discharged to parks and golf courses.

2.4.4 Bultfontein Municipality

Bultfontein Municipality is located in the western portion of the Vet River catchment (see Fig. A.1). It has an annual water allocation from the Sand-Vet GWS of $1.818 \times 10^6 m^3$ (see Table 2.1). Data regarding the actual water usage could not be obtained. However, Bultfontein is located about 30 km from the Vet River in a semi-arid area characterised by flat topography and ineffective runoff areas. It follows that little, if any, return flow from this town will reach the Vet River. Therefore the effect on the flow and water quality regime of the lower Vet River should be small.

2.4.5 Henneman Municipality

Henneman is situated due east of Welkom and north-east of Virginia near to the Rietspruit (see Fig. A.1). The entire water supply is obtained from Goldfields Water. Between October 1990 and April 1993, the average annual water supply was $0.74 \times 10^6 m^3$. During 1992 $0.097 \times 10^6 m^3$ of purified sewage effluent was produced by Henneman. Part of Henneman's purified sewage effluent is used for parks and irrigation, the remainder being discharged to the Rietspruit. During 1992 $0.064 \times 10^6 m^3$ was discharged to the Rietspruit (see Chapter 4). Even if some of this effluent is discharged to the Rietspruit, the quantities involved are small and the effect on the hydrology of the Sand River catchment should be negligible. The annual TDS input is also relatively small (69 t for 1992, see Chapter 4).

2.4.6 Hoopstad Municipality

Hoopstad is a small town located adjacent to the lower Vet River just upstream of the Vet River limb of the lake backed up by Bloemhof Dam (see Fig. A.1). It obtains its water supply from the Vet River and has a water allocation from the Sand-Vet GWS of only $0.312 \times 10^6 m^3$. However, water abstraction data provided by Hoopstad indicates that the actual 1992 water use was nearly twice as high (see Table 2.7). Even at $0.714 \times 10^6 m^3$, Hoopstad's water use remains relatively small and has only a small effect on the overall hydrology of the Vet River system. However, Hoopstad is of particular interest for the present study since it represents the only significant urban water use that is likely to be affected by pollution of the Sand River in the OFS Goldfields region.

Hoopstad's water purification works was upgraded in 1992. Hoopstad's projected use is given in Table 2.8.

TABLE 2.7
Annual abstractions from Vet River by Hoopstad Municipality

HYDROLOGICAL YEAR	ANNUAL ABSTRACTION (10^6m^3)
1984	0.401
1985	0.476
1986	0.583
1987	0.556
1988	0.559
1989	0.557
1990	0.555
1991	0.714

TABLE 2.8
Projected water use for Hoopstad

Year	ANNUAL WATER USE (10^6m^3)
1995	0.699
2000	0.749
2005	0.802
2010	0.861
2015	0.926

2.4.7 Theunissen Municipality

Theunissen is located north-west of Erfenis Dam (see Fig. A.1). Little information concerning water use in Theunissen could be obtained, except that it has an annual water allocation of $0.546x10^6m^3$ from Erfenis Dam (see Table 2.1). Sewage is treated in oxidation ponds and no effluent is discharged to the Vet River system.

2.4.8 Winburg Municipality

Winburg Municipality is located upstream of Erfenis Dam (see Fig. A.1). No flow or water quality records could be obtained for Winburg, however, the town is thought to generate only about $0.009x10^6m^3$ of effluent per month. It follows that the effect on the flow and water quality regime of the system should be negligible.

2.4.9 Other towns

The remaining smaller towns of Willem Pretorius and Ventersburg have relatively small water demands. As such they are not expected to significantly affect either runoff or water quality in the Vet River system. Nor is the quality of their water supply affected by the urban and mining activities in the OFS Goldfields region.

2.5 Use of water by mines

Requests for data were sent to the mines in the study area. Thse mines are listed in Table 2.9.

TABLE 2.9
Mines in the study area

MINING GROUP	MINE	AREA (ha)
Anglo American (Freegold North)	Free State Geduld Western Holdings	* 31 625
Anglo American (Freegold South)	Free State Saaiplaas President Brand President Steyn Erfdeel	
Gencor	St. Helena Unisel Beatrix Oryx (previously Beisa)	4 904 450 2 219 4 774
Rand Mines	Harmony: Harmony Virginia Merriespruit	9 917
J.C.I	Joel	1 301

NOTE: * This includes Freddies Mine, which is outside the study area.

2.5.1 Permits to use water

Information regarding permits issued for the use of water at mines obtained from the DWA&F OFS Regional Office is summarised below:

a) St. Helena Mine

Permit 718N for water use from the following sources:

Goldfields Water	7 295 m^3/day
Welkom Municipality (purified effluent)	141 m^3/day
Total	7 436 m^3/day

b) Unisel Gold Mine

Permit 478N for water use from the following sources:

Goldfields Water	6 828 m^3/day
Boreholes on property & underground water	4 960 m^3/day
Total	11 788 m^3/day

c) Harmony Gold Mine

Permit 575N for water use from the following sources:

Sand-Vet Government Water Scheme	3 288 m^3/day
Goldfields Water	53 650 m^3/day
Virginia Municipality	6 600 m^3/day
Surplus water found underground	17 000 m^3/day
Boreholes on property	980 m^3/day
Total	81 518 m^3/day

d) Free State Consolidated Gold Mine (Freegold)

Permit 1214N for water use from the following sources:

Goldfields Water	100 645 m^3/day
Welkom Municipality (potable)	600 m^3/day
(purified effluent)	38 546 m^3/day
Odendaalsrus municipality purified effluent	2 500 m^3/day
Surplus water found underground	14 630 m^3/day
Boreholes on property	3 065 m^3/day
Catchment dams (rainfall)	13 162 m^3/day
Beatrix Mine	10 000 m^3/day
Total	183 200 m^3/day

e) H J Joel Gold Mine

Permit 1339N for water use from the following sources:

Goldfields Water	3 343 m^3/day
Surplus water found underground	410 m^3/day
Total	3 753 m^3/day

f) Beatrix Mine

Permit 776N for water use from the following sources:

Goldfields Water	6 828 m^3/day
Surplus water found underground	4 960 m^3/day
Total	11 788 m^3/day

g) Oryx Mine

Permit 1433N for water use from the following sources:

OFS Goldfields Water Board	4 340 m^3/day
Surplus water found underground	2 503 m^3/day
Total	6 843 m^3/day

2.5.2 Water use by mines

Table 2.10 gives statistics of pans and dams receiving effluent water. This table is based primarily on Table 6.3 of Cogho *et. al.* (1992), with storage capacity data obtained from the DWA&F OFS Regional Office.

Since the information in Table 2.10 is already somewhat dated and some of the areas and capacities given in it do not correlate very well with those derived from other sources, an attempt was made to quantify the overall OFS Goldfields water balance using the latest available data obtained from mines and municipalities in the OFS Goldfields region. The resulting detailed flow balance diagram for the year ending 31 March 1992 is given in Appendix C.

TABLE 2.10
Statistics of pans, dams and rivers receiving effluent water (as per Cogho *et. al.*, 1992)

MINE OR SEWAGE WORKS	TYPE OF WATER*	TOTAL EFFLUENT (m^3/day)	PAN, DAM OR STREAM	SURFACE AREA (ha)	CAPACITY@ (10^6m^3)	EFFLUENT REMAINING IN SYSTEM& (10^6m^3/year)	EFFLUENT RECYCLED
Beatrix Mine Beatrix STW	RW+UG SW+PSE	1 100 1 000	Evap. dam Theronspruit	429	2.668	0.40	
St. Helena	RW+UG+PSE	13 000	Wolwepan and Rietpan system	699	11.170	4.75	
Freegold FS Geduld STW	RW+UG+SW " " " " " " " UG+RW RW+UG+PSE	103 700 (Freegold total) 4 000	12A Dam 12B Dam 12C Dam 13 Dam RWD Dam D Dam N vlei Dankbaarpan Doringpan D Dam	76 18 45 137 36 35 53 300 220 35	0.751 0.178 0.310 1.605 0.777 0.271 1.881 40.000 60.000	&37.87 1.46	
Harmony:	RW+UG	30 000	Evap. Dams	+1 100		10.95	
Oryx Oryx STW	RW+UG SW+PSE	16 000 1 000	Evap. dams Boeluisspruit	816		5.84	
Joel Joel STW	RW+UG SW+PSE	 1 000	Evap. dams Doring River	111	0.832	0	
NCP Yeast$		200	Farm Blesbokpan	24		0.07	
Virginia STW	SW+PSE	18 500	Sand River			0	6.76 (Most re-used by mines and municipalities. Occasional spillage to Sand River.)
Theronia STW (Welkom)	SW+PSE PSE	19 000	Toroniopan Flamingopan	292 131	5.000 2.660	#2.01	4.93 (Winter: 8000 m^3/d re-used by municipalities, remainder into pans. Summer: All re-used.)
Witpan STW (Welkom)	SW+PSE	23 000	Witpan	293	11.028	4.02	4.38 (12 000 m^3/d re-used by municipalities, remainder to Witpan.)
TOTALS:	-	231 500	-	4 850	139.13	67.37	16.07

NOTES:
- * Key to type of water: PSE = Purified sewage effluent
  - RW = Reduction works water
  - UG = Underground water
  - SW = Storm water.
- @ Storage capacity estimates as per DWA&F OFS Regional Office.
- & Most of the values in this column were re-calculated from the average daily flow data since the annual figures given by Cogho *et. al.* appear to have been incorrectly calculated.
- \+ Corrected from map information. Cogho *et. al.* (1992) give a surface area of 11 000 ha.
- \# Annual figure calculated from an average flow rate of 11 000 m^3/day (i.e. 19 000 - 8 000 for ½ year).
- $ The NCP yeast factory has recently closed.

Details of sources and volumes of water used by the mines during 1992 (see also Appendix C) are given in Table 2.11.

TABLE 2.11
Average daily water supply for mines for the year ending 31 March 1992*

MINE		AVERAGE DAILY SUPPLY (m^3)					
		Goldfields Water	Purified sewage	Underground water	Other sources		Total
Freegold North		25 373	958	585	818 4 159 962	Welkom Freegold South Storage dams - rain	32 855
Freegold South:	Saaiplaas	6 319	0	520	3 524 1 293	President Steyn Dam 13 Erfdeel	11 656
	President Brand	15 253	30 782	2 922	4 462 3 439 322 7 442 2 143 836 394	Storage Dams Welkom President Steyn Beatrix Joel Jurgenshof Dam Stuurmanspan	66 995
	President Steyn	15 525	0	675	3 270 6 886 1 440 8 295 2 706	President Brand slimes President Brand 12C dam Storage dams Harmony Witpan	38 797
	Erfdeel	3 563	0	557	0		4 120
St. Helena		4 436	620	5 533	2 200 (7000)& 256 6	Beatrix - 7000 Unisel Rainfall	13 051
Unisel		2 788		1 214	788 (1000)&	Beatrix	4 790
Beatrix		4 822		24 285	0		29 107
Oryx		4 340		12 925	0	Sand-Vet GWS	17 265
Harmony (Harmony section)		9 701	0	15 010	0		24 711
Harmony (Virginia section)		5 047	3 481	15 541	1 150	Harmony - Merriespruit	25 219
Harmony (Merriespruit section)		6 236	10 200	15 080	0	Sand-Vet GWS	31 516
Joel		2 592	0	1 468	6	Reagents	4 066
Total		105 995	46 041	96 315	61 163		304 148

NOTE: * Water balances for the nearest reporting period were used in instances where mine water balances were unavailable for the year ending 31 March 1992.

& Figures given in brackets are differing flow values provided by the specified donor mines (in some instances for different periods).

Water pumped out of mines decreases in quality towards the south. The Total Dissolved Salts (TDS) vary from 1000 mg/l to 4500 mg/l with the main components being sodium and chloride. The water is unsuitable for urban and irrigation use. Consequently discharge of this water into natural streams is undesirable and the mines have made use of evaporation areas to dispose of this water. The large volumes of saline water pumped to evaporation areas is a matter of great concern.

Details of the outflow of water from mines during the year ending 31 March 1992 are given in Table 2.12.

TABLE 2.12

Average daily discharge of water from mines for year ending 31 March 1992+

MINE		AVERAGE DAILY DISCHARGE (m^3)					
		Evaporation areas	To natural pans	To sewage works	Irrigation of gardens, etc.	Other	Total
Freegold North		24 088	681 (Dankbaar)	1 000 Odendaalsrus 3 774 Welkom	4 571	389 Western H. and Freddies	34 503
Freegold South	Saaiplaas	8 666	0	2 506 Virginia	484	0	11 656
	President Brand	44 327	0	5 645 Welkom	2 071	4 159 Freegold North 10 156 Pres. Steyn Dam 13 2 706 President Steyn Plant	69 064
	President Steyn	30 386	0	7 452 Welkom	1 016	3 524 Saaiplaas Dam 3 322 President Brand	42 700
	Erfdeel	818	344	1 525 Welkom	250	1 293 Saaiplaas Gold Plant	4 230
St. Helena		12 041		1 399 Welkom Theronia		0	13 440
Unisel		2 746		1 000 Welkom Theronia		256 St. Helena	4 002
Beatrix		9 786	4 014 (Wolwe)		1 137	7 000 (2 200)& St. Helena 1 000 (788) Unisel 6 000 President Brand 170 Theronspruit	29 107
Oryx		15 332			*1 933	0	17 265
Harmony	Harmony Section	15 757	0		855	8 100 Harmony - Merriespruit	24 712
	Virginia Section	20 174	0	2 945 Virginia		2 100 Harmony - Merriespruit	25 219
	Merrie-spruit	9 131	0	3 988 Virginia		1 150 Harmony - Virginia 17 248 Harmony - Virginia & Harmony	31 517
Joel		3 483			583	2 143 President Brand	6 209
TOTAL		196 735	5 039	31 234	12 900	67 716	313 624

NOTES:
+ Water balances for the period April 1991 to March 1992 inclusive have been used to compile this table. Some mines did not have a water balance for this period, in which case the closest period was used.
& *Figures given in brackets are differing flow values provided by the specified recipient mines (in some instances for different periods).*
* There may be some spillage to the Bosluisspruit during peak periods.

The total average daily discharge from the mines given in Table 2.12 is 9476 m^3 (3%) larger than the water supply given in Table 2.11. The contradiction between the discharge from Beatrix Mine to St. Helena and Unisel mines reported by Beatrix Mine and the two recipient mines accounts for 53% of the difference between the water supply and effluent discharge data. (The flow balance diagrams provided by these three mines did not all coincide with the twelve month period ending 31 March 1992 reflected in Tables 2.11 and 2.12) The remaining difference could be attributable to changes in storage in evaporation ponds, flow gauging errors and possibly stormwater runoff.

Table 2.12 shows that during 1992, $73,7x10^6m^3$ (i.e. 201 774 m^3/day) of saline underground mine water was disposed of in various evaporation areas. The electrical conductivity (EC) of this water is in excess of 500 mS/m. About 5170 ha of land in the OFS Goldfields area is used for the evaporation of effluent and mine water. The total storage capacity of these evaporation areas is in excess of $145x10^6m^3$. Some water is also retained and evaporated from a further 5100 ha of slimes dams.

The conditions of the exemptions granted to mining houses require them to provide the OFS Regional Office with water balance diagrams at six monthly intervals. However, with the exception of Harmony Mine (for which a total of 24 water balance diagrams were received for three mines), only one or two water balance diagrams per mine were obtained from the OFS Regional Office records. Hence, given that most of the mines in question have been operating for a number of years, a large proportion of the water balance diagrams are missing. In some instances those that could be found were years old and were full of inconsistencies. Considerable difficulty was experienced in obtaining the missing essential data from certain of the mining houses concerned.

The problems encountered in obtaining the requisite data led to considerable delay in the project. When the data was finally obtained it was all too often found to contain obvious errors and omissions that had to be followed up. Despite numerous enquiries some inconsistencies in the data were never resolved. Some of these inconsistencies are reflected in the water balance given in Appendix C. For example, Welkom Municipality provided data indicating that it had delivered an average of only 1 747 m^3/day from their Theronia sewage treatment works to Freegold South, whereas Freegold provided data indicating that 4 802 m^3/day was received. In some instances the inconsistencies are attributable to the fact that various mines have not yet (after more than six months) been able to provide us with water balances for the year ending 31 March 1992. Instead the water balance for the nearest reported periods had to be used. In other cases the contradictions occur for data provided for the same reporting period. Numerous examples of irreconcilable gross differences between flow values given in the water balance diagrams and the monthly flow data contained in the data sheets routinely sent to the Regional Office could also be cited.

Based on the information that has been made available it appears that the sum of all of the waste water storage and evaporation facilities, together with the slimes dams operated by the mines in the OFS Goldfields area, should have sufficient surface area to evaporate all of the in-coming waste water. However, in the absence of more comprehensive data regarding pipeline capacities, monthly storage states, inflows and abstractions for each storage facility it is not possible to determine if any individual dams or pans are prone to spill, or have spilled in the past. Even if there is sufficient evaporative surface area and storage capacity to prevent spillage, it can be expected that part of the water retained in evaporation dams will not evaporate but will penetrate the underlying strata and reach the ground water table. In the vicinity of a river, a slope towards the river generally exists. If an evaporation dam is located near a river, the slope will result in this water entering the river course. Evidence of this type of occurrence is provided by the presence of contaminated ground-water (Cogho *et. al.*, 1992) and seepage zones (SRK, 1993) that have been identified in various parts of the study area.

2.6 Conclusions and recommendations

2.6.1 Sand-Vet GWS water use data

The data provided by the Sand-Vet GWS office appears to grossly underestimate the irrigation usage from the canals. Information regarding actual irrigated areas is missing. The establishment of a more accurate and efficient system of irrigation records is recommended to overcome these problems.

2.6.2 Mines water use data

The water use data routinely provided by the mines in the OFS Goldfields region is generally incomplete and contains several inconsistencies. In particular, data regarding storage states and flows between different facilities needs to be collected. Since this information is vital for water quality management in the Sand-Vet river system it is considered essential that the data reporting and checking procedures be improved. More efficient data storage and retrieval systems, both in the mining houses and at the OFS Regional Office are recommended.

2.6.3 Water balance

At face value the available data indicates that the existing surface storage and evaporation facilities provide enough overall evaporative area to dispose of all of the redundant mining waste water. However, the records are not detailed or complete enough to carry out proper evaluations of the water balances of individual storage elements. Improved record keeping to enable such water balances to be made are required. It is something of a misnomer to call the flow diagrams provided by the mines "water balance diagrams". In reality they are no such thing, since they provide data for only the first two of the three terms in the continuity equation:

$$QIN - QOUT = dS \qquad (2.1)$$

where:

QIN = inflow
QOUT = outflow
dS = change in storage.

Without regular monitoring of the storage state in *every* storage facility the water balance is incomplete and it is not possible to check on the adequacy of the water quality management practised by the mines. This points to the need to revise the exemption requirements to ensure that complete water balance information is obtained. This should be done not only for the mines in the study area, but for all exemptions issued by the DWA&F. It is understood that it is the intention of the DWA&F OFS Regional Office to address this in the mine's EMPRs.

2.7 References

Ninham Shand (1985) "*Report on a situation study of irrigation return flow quantity and quality in river basins with extensive irrigation development in South Africa*", Report to the Water Research Commission, No. 943/4061.

Cogho VE, van Niekerk LJ, Pretorius HPJ and Hodgson FDI (1992) "*The development of techniques for the effective management of surface and groundwater contamination in the Orange Free State Golfdields*", WRC Report No. 224/1/92, Institute for Ground Water Studies, University of the Orange Free State.

SRK (1993) "*Preliminary study of pollution of the Sand River*", Report to President Brand Gold Mine, No. 192062/2.

Stewart Scott (1993) "*Summary of work done from January 1981 to December 1992*", Vaal River Salinity Study, Report P C000/00/10892, Directorate of Project Planning, Department of Water Affairs & Forestry, Pretoria.

CHAPTER 3

PROVISIONAL WATER QUALITY USER REQUIREMENTS

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3. PROVISIONAL WATER QUALITY USER REQUIREMENTS

3.1 Introduction

The overall water quality management goal of the DWA&F is the maintenance of the fitness for use of South Africa's water resources on a sustained basis (DWA&F, 1993). In order to attain this goal it is necessary to determine the water quality requirements for the particular water resource being managed. The water quality requirement for the water resource is in turn determined by that of the users. In this regard the DWA&F (1993) has identified five broad categories of users whose water quality requirements need to be taken into account:

- domestic
- recreational
- industrial
- agricultural
- natural environment.

The DWA&F are in the process of publishing a set of manuals giving general water quality guidelines for each of the above categories of water use. Volumes 1, 2, 3 and 4 (dealing with domestic, recreational, industrial and agricultural water use) were made available for use in the OFS Goldfields Water Quality Situation Analysis study. Where appropriate these general water quality guidelines have been adapted to take account of specific water use in the study area.

The target guideline ranges given in the South African Water Quality Guidelines represent the situation with negligible effect on water use. However, the effect on water use is not a step function, with the water suddenly becoming unfit for use once the target guideline range is violated. For most water quality variables much higher levels than the upper limit of the target range can be tolerated, with only a gradual degradation of fitness for use. This must be kept in mind when interpreting the significance of violations of the water quality user requirements derived in this chapter.

The South African Water Quality Guidelines published by the DWA&F (1993) present tables showing the effects on users for different concentrations or levels of each water quality variable of concern. Guidelines have been published for domestic, agricultural and recreational use. The South African Water Quality Guidelines for the natural environment have not yet been published. The South African Water Quality Guidelines for each water quality variable include a target guideline range, within which no significant adverse effects on water use can be expected for each main category of water use.

The general target water quality guidelines serve as a departure point for identifying the user requirements. In some instances these have to be adjusted to take account of local factors.

It must be stressed that the water quality user requirements given in Table 3.10 are provisional. This is because the Hydrological Research Institute (HRI) of the DWA&F have not yet been able to carry out a field survey to identify the specific water quality requirements for the natural environment for key river reaches. The provisional user requirements will be subject to review during the preparation of the catchment Water Quality Management Plan. In accordance with the terms of reference for the study, only those variables related to TDS and its main inorganic constituents have been addressed in detail.

Provisional water quality user requirements have been prepared for each identifiable body of water from Allemanskraal Dam to the point at which the Vet River enters the lake of Bloemhof Dam. Water quality user requirements for the remainder of the Vet River catchment have not been examined since they fall outside the main area of interest, i.e. that portion of the catchment affected by mining activities in the OFS Goldfields area.

A brief overview of the structure of the remainder of the chapter is given below:

- Section 3.2 identifies the water quality variables that are most likely to be affected by the developments taking place within the catchment.

- Sections 3.3 to 3.7 outline the rationale behind the target guideline ranges for each of the five main categories of water use. The target guideline ranges for the most relevant water quality variables are summarised for each water use in Section 3.8.

- The determination of provisional water quality user requirements for specific river reaches is covered in section 3.9.

3.2 Water quality variables of concern

The purpose of this section is to identify the water quality variables that are of most relevance to the study. In this context it should be observed that the terms of reference of the study specifically confined the situation analysis to the study of TDS and its main inorganic constituents. This emphasis arose from the findings of previous studies that gold mining in the OFS Goldfields region has the greatest impact on water quality in the Sand and lower Vet Rivers and that salinity is the most significant water quality problem associated with gold mining. The conclusions of this report confirm these findings. Hence the first objective of this chapter must be to identify the water quality variables that are directly related to salinity (i.e. the main inorganic constituents of the TDS and combinations thereof). In keeping with the terms of reference the evaluation of the water quality status given in Chapter 9 deals mainly with salinity-related water quality variables. These include the following:

electrical conductivity (EC)
total dissolved salts (TDS)
calcium (Ca)
magnesium (Mg)
sodium (Na)
potassium (K)
chloride (Cl)
sulphate (SO_4)
fluoride (F)
sodium adsorption ratio (SAR)
total hardness (as $CaCO_3$)

Aside from salinity, mining activities can also affect pH. The use of cyanide in reduction processes means that this potential contaminant also needs to be taken into account. Residues of from ammonium nitrate based explosives can sometimes lead to high levels of ammonia and nitrate in water spilling or seeping from surface water storage sites. The list of directly salinity related water quality variables has therefore been expanded to include:

pH
ammonia (NH_3)
nitrate (NO_3)
cyanide (CN)

Mining activities also have the potential to cause problems with regard to trace metals. These have not been included in the provisional water quality user requirements since they are beyond the scope of the study. Although the range of pH values observed in the surface water resources do not appear to hold much potential for the mobilisation of metals, it would be prudent to carry out a synoptic survey to identify possible trace elements that might require further attention. These can then be included in the final water quality user requirements. The fact that the old Beisa mine used to mine uranium implies that problems related to radionuclides might also occur. Therefore a survey of radionuclides might also be warranted. Again, such a survey is beyond the scope of the present study.

Mining is not the only activity that can affect water quality in the study catchment. Conventional purified sewage effluent and washoff from formal and informal urban settlements can lead to eutrophication and biological contamination of the water resources. None of these variables have been included in the evaluation of the water quality status (see chapter 9) since they are beyond the scope of the study. However, since these land uses are known to exist in the study area it essential that the water quality variables associated with urban pollution are taken into account in preparing the Water Quality Management Plan for the catchment. For this reason they have been included in the provisional water quality user requirements given in this chapter, although they are not dealt with in any depth elsewhere in the report.

Agricultural land use holds the potential for pollution of water resources with pesticides, A survey is desirable to determine which pesticides are in use and to measure their concentrations in the surface water resources. Those that are found to be problematic should then be included in the final water quality user requirements that will eventually form the basis for the catchment Water Quality Management Plan. This falls outside the scope of the present study.

The following sections deal with the selection of appropriate provisional water quality user requirements for the variables that are relevant to the study for different categories of water use. Overall water quality user requirements for individual river reaches, based on the identified water uses, are given in section 3.9.

3.3 Domestic use

3.3.1 General considerations

Domestic water use includes the following:

- drinking
- food and beverage preparation
- hot water systems
- bathing and personal hygiene
- washing and laundry
- gardening
- recreational (eg in swimming pools).

The impacts of water quality on domestic use fall into three categories:

- health impacts, both acute and chronic

- aesthetic impacts (taste, odour, colour, staining of laundry and fixtures)

- economic impacts (treatment costs, scaling, corrosion and sedimentation in distribution systems, and the scaling and corrosion of household pipes, fittings and appliances and increased use of soap, detergents and softeners).

With regard to domestic water use certain water quality variables have definite limits beyond which prolonged use can lead to chronic health complications, and other limits beyond which acute toxic or metabolic effects can be expected even from short term use.

3.3.2 Communities dependent on affected surface water resources

Most of the domestic users in the study area derive their water supply from Goldfields Water. Goldfields Water in turn obtains its raw water supply mostly from the Vaal River, supplemented by smaller amounts of water abstracted from Allemanskraal Dam via the irrigation canal. The majority of the remaining domestic users obtain their water supply from local rivers and streams that are remote from the OFS Goldfields region. In both instances the quality of their raw water supply is independent of any pollution sources in the OFS Goldfields region.

Notable exceptions to this general rule are the following groupings of users:

(i) Hoopstad Municipality - Located next to the Lower Vet River, downstream of the Sand-Vet confluence and any pollution sources in the OFS Goldfields region;

and

(ii) farmers, rural communities and informal settlements located adjacent to polluted tributaries within the OFS Goldfields region and in the riparian zones surrounding the lower Sand and Vet Rivers.

An important consideration with regard to domestic use is the level of water treatment that is applied. In larger urban centres sufficient water treatment is applied to render the water fit for use (or, at least fit for safe human consumption). However, in rural areas, water is commonly drawn from water courses for domestic use with little or no treatment. This is particularly relevant to riparian farming communities located in, or downstream of, the OFS Goldfields area that do not have access to irrigation canals fed from Erfenis Dam and Allemanskraal Dam. The Vet River downstream of the Sand River confluence is a case in point.

Domestic users in Hoopstad enjoy a measure of protection by virtue of the fact that their raw water is purified and occasionally tested. However, in the case of small rural communities and informal settlements there are few such controls.

The residents of informal settlements adjacent to townships, such as Meloding, and the labourers employed by riparian farmers in the Sand River catchment use the Sand River and its tributaries for domestic use. However, according to officials of the DWA&F OFS Regional Office this use is limited to the washing of laundry, since alternative water supplies are generally available for drinking, cooking and other household purposes. Many of the water quality guidelines for domestic use are not as applicable to these river reaches.

The lack of access to alternative water sources, such as irrigation canals or municipal supply, means that a number of farming and rural communities along the lower Vet River are largely dependent on the Vet River as their main source of water for domestic use. In some instances borehole water serves as the water supply for domestic use.

3.3.3 Water quality user requirements

A summary of the target guideline ranges for each water quality variable that is relevant to the study is given in Section 3.8. These are based on the South African Water Quality Guidelines for Domestic use (DWA&F, 1993).

3.4 Recreational use

3.4.1 General considerations

The South African Water Quality Guidelines (DWA&F, 1993) state that the main problems related to recreational use are:

- health and safety of water users in contact with the water (i.e. mainly full contact and intermediate contact water use)
- aesthetic appreciation of water.

3.4.2 Recreational use in the study area

River reaches and water bodies in the lower Sand and Vet River catchments where full contact recreational use is known to occur include:

(i) Allemanskraal and Erfenis Dams (neither of which is affected by pollution sources in the OFS Goldfields area)

(ii) Virginia Park, which comprises a few kilometres of the Sand River backed up by Virginia Dam. Boating, wind surfing and swimming are known to occur in this river reach.

In other reaches intermediate contact recreation is thought to be limited. Hence for river reaches other than those described in (i) and (ii) above, the South African Water Quality Guidelines for non-contact recreation alone have been used in deriving the provisional water quality guidelines.

3.4.3 Water quality user requirements

A summary of the target water quality user requirement ranges for full contact and non-contact recreational use is given in Section 3.8.

3.5 Industrial use

All of the most significant industrial water use is supplied by Goldfields Water, abstracted from the Sand-Vet GWS canals or comprises recycled mining effluent. The quality of the first two water sources is unaffected by pollution sources in the OFS Goldfields region, while the third source (recycled domestic and mining waste water) is generally used for appropriate processes within the mines. These mines have access to alternative water sources (Goldfields Water), and in some instances abstraction from the Sand-Vet canals, for more sensitive industrial uses (such as refrigeration plant and hydraulic machinery). It follows that specific water quality user requirements for industrial water use are not required for the lower Sand and Vet Rivers. Even if minor abstractions from these rivers for industrial use does take place, the water quality user requirements for domestic use and irrigation use will offer a measure of protection for industrial use.

3.6 Agricultural use

The South African Water Quality Guidelines for Agricultural Use (DWA&F, 1993) divide agricultural use into three categories:

- Irrigation
- Livestock watering
- Freshwater aquaculture

Of the three categories, irrigation is the most important agricultural water use in the study area. Each of the above three categories of agricultural use are discussed in Sections 3.6.1 to 3.6.3.

3.6.1 Irrigation

3.6.1.1 General considerations

The South African Water Quality Guidelines for Agricultural Use (DWA&F, 1993) cite the following norms used to categorise the quality of irrigation water:

- crop yield - the effect of irrigation on profitability (i.e. crop yield, crop selection and crop acceptability)
- soil degradation - the degree to which water quality affects soil degradation and sustainable production
- management options - the degree to which different management options need to be employed to alleviate undesirable effects.

General guidelines for irrigation water are provided in the South African Water Quality Guidelines for Agricultural Use (DWA&F, 1993).

3.6.1.2 Irrigation use in the study area

The Sand-Vet GWS accounts for most of the irrigation in the Vet River catchment. The main groupings of irrigation are as follows:

- Direct from major dams and canals of Sand-Vet GWS	10 251 ha
- Private irrigation from streams and farm dams	5 827 ha
- From lower Vet River supported by releases from Sand-Vet GWS canals	1 297 ha

The limited amount of irrigation supplied from ground-water has been excluded.

Irrigation farmers in the Sand-Vet GWS have an annual water allocation of 7200 m^3 per ha. Based on this allocation the potential annual irrigation use in the Sand-Vet GWS could be as high as $83 \times 10^6 m^3$. However, Tables 2.2 and 2.3 (Chapter 2) indicate a lower irrigation use. Based on the last reliable information obtained by Ninham Shand (1985) the 1980/81 water use was $61.2 \times 10^6 m^3$ corresponding to a water allocation at that time of $72.8 \times 10^6 m^3$. This implies that 84% of the water allocation was taken up.

Most of the private irrigation from streams and small farm dams is of interest mainly in terms of its effect on catchment runoff (see Chapter 6). Most of this type of irrigation takes place in relatively undeveloped portions of the catchment that are unaffected by the mining and industrial activities in the OFS Goldfields region. The quality of the irrigation water in these areas is controlled almost entirely by natural catchment processes over which little or no control can be exercised. As such it is of little interest with regard to the current study.

An exception to this general rule is the riparian irrigation adjacent to the Theronspruit in the vicinity of Beatrix and Joel mines (see Map A.6 in Appendix A).

The irrigation that is supplied directly from the 450 km long Sand-Vet GWS canals is also of little interest since the water quality in Allemanskraal Dam and Erfenis Dam is generally good, and is unaffected by pollution sources in the OFS Goldfields region.

Of greatest concern is that portion of the scheduled 1297 ha of irrigation from the lower Vet River that is located downstream of the Sand-Vet confluence. The water quality in this river reach is directly affected by any pollution sources in the OFS Goldfields region. Peak TDS concentrations have in the past reached 1000 mg/l in the lower Vet River at hydrological station C4H004. This is indicative of the potential for impairment of riparian irrigation in this river reach.

Water quality in the lower Vet River is not only vulnerable to pollution inputs from further upstream in the Sand River catchment. It can also be affected by the evaporative concentration of salts in upstream irrigated lands. Upstream of the Sand-Vet confluence this effect is limited by the fact that the supply water is supplied from the canals at relatively low TDS levels. However, downstream of the ends of the canals the cascading re-use of irrigation return seepage can be expected to result in deteriorating water quality in a downstream direction. During periods of low flow this effect could become quite pronounced, especially near the lower end of the river reach as water use begins to reduce the river flow to the point where the return flows begin to dominate.

Local conditions play a major role in determining the effect of water quality on irrigation use. For example, if all of the crops desired to be grown in an area are salt tolerant, then a higher target guideline limit for EC could be accepted without prejudicing irrigation use. Similarly, the soil types could dictate different requirements with regard to the sodicity hazard (i.e. the Sodium Adsorption Ratio). The main characteristics of the irrigation in the Sand-Vet GWS that could affect the choice of water quality user requirements are described in the following sub-sections.

3.6.1.3 Crop types

A report on a situation study of irrigation return flow quantity by Ninham Shand (1985) provided some data regarding the areas of land under different crops during 1983/84. This data for the Sand-Vet GWS is given in Table 3.1.

TABLE 3.1
Actual areas of irrigation in the Sand-Vet GWS (1983/1984)
as per Ninham Shand (1985)

Crop	*MONTHLY CROP FACTORS*												*Allamans-kraal area (ha)*	*Erfenis area (ha)*
	Oct	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*		
Lucerne	*0.7*	*0.8*	*0.8*	*0.8*	*0.8*	*0.7*	*0.5*	*0.4*	*0.3*	*0.3*	*0.4*	*0.5*	*124*	*350*
Wheat	*0.7*								*0.3*	*0.5*	*0.9*	*1.0*	*1600*	*1800*
Maize			*0.3*	*0.65*	*0.97*	*1.0*	*0.67*						*160*	*400*
Potatoes	*0.9*	*1.0*			*0.4*	*0.65*	*0.9*	*1.0*			*0.4*	*0.65*	*350*	*500*
Fodder	*0.7*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.7*	*0.6*	*0.5*	*0.5*	*0.5*	*0.6*	*150*	*400*
Ground-nuts		*0.3*	*0.7*	*0.6*	*0.5*	*0.3*							*15*	*15*
Vegetables	*0.6*	*0.7*	*0.7*	*0.7*	*0.7*	*0.6*	*0.4*	*0.3*	*0.3*	*0.35*	*0.5*	*0.6*	*56*	*22*
Totals													*2455*	*3487*

Since the data contained in Table 3.1 is somewhat old, an attempt was made to obtain more up to date information. The Sand-Vet GWS office was able to give an approximate breakdown of the types of crops grown. This information is summarised in Table 3.2.

TABLE 3.2
Crop types under irrigation in the Sand-Vet GWS
(based on information received from the Sand-Vet GWS office - 1993)

CROP TYPE	*SUMMER (%)*	*WINTER (%)*	*AREA (ha) (1983/84)*
Wheat	-	*80*	*3400*
Maize	*40*	-	*560*
Vegetables (mainly potatoes)	*35*	*10*	*928*
Other	*25*	*10*	*1054*

Comparison of Tables 3.1 and 3.2 reveals that both tables are based on the identical source data, which is somewhat dated. Consequently, questionnaires were sent out to irrigation farmers at the end of April 1993 in an attempt to obtain more recent information. The Sand-Vet GWS office distributed the questionnaires. Only six farmers, who together account for 6,7% of the total irrigation in the Sand-Vet GWS, returned the questionnaires. This survey information is summarised in Table 3.3.

TABLE 3.3
Survey of crop types under irrigation in the Sand-Vet GWS
(based on first survey of farmers - April 1993)

CROP TYPE	AREA UNDER CROP	
	(ha)	(%)
Wheat	289	43
Maize	128	19
Potatoes	67	10
Soyabeans	50	7
Groundnuts	32	5
Peas	20	3
Pumpkin	20	3
Cabbage	20	3
Lucerne	20	3
Digitaria lanusii	14	2
Sunflower	12	2
TOTAL	672	100

Unfortunately the small sample of questionnaires that were returned appears to include only farms receiving their irrigation water direct from the Sand-Vet GWS canals. Specific information for the lower Vet River downstream of the Sand-Vet confluence was not provided. Since this river reach is the only portion of the Sand-Vet GWS that is affected by pollution emanating from the OFS Goldfields region, a decision was reached to carry out a second survey focused entirely on farms downstream of the Sand-Vet confluence. This second survey took place during the period from October to November 1993 and was carried out by the DWA&F OFS Regional Office. Despite the fact that a DWA&F official was assigned to visit each affected farm to collect the completed forms and assist farmers in filling them in, the response was poor. Only nine completed or partially completed forms had been received by 3 December 1993. The sample received represents farms with a combined area of 398 ha under irrigation (i.e. 31% of the total for the lower Vet River). We understand that the OFS Regional Office will continue to attempt to obtain the outstanding returns for use in developing the water quality management plan for the catchment. Details obtained from the second survey regarding the crops irrigated in the lower Vet River are given in Table 3.4.

TABLE 3.4
Survey of crop types under irrigation along the lower Vet River
(based on second survey of farmers - October 1993)

CROP TYPE	AREA UNDER CROP	
	(ha)	(%)
Wheat	90	23
Lucerne	84	21
Maize	70	18
Various grasses (fodder)	66	16
Potatoes	43	11
Cabbage	30	7
Ground nuts	15	4
TOTAL	398	100

Since the survey of the crops under irrigation in the lower Vet River is incomplete, Table 3.4 may have missed some crops that might be particularly sensitive with regard to specific water quality variables. Therefore contact was made with the Glen Agricultural Station to determine if they are aware of any other crops that are irrigated along the lower Vet River. According to Mr K Snyman (personal communication, 1993) sunflower and onions are also grown in this area.

The cultivation of peas (in the case of lands irrigated from the canals) and onions (in the case of the lower Vet River), all of which are classified as sensitive to EC, confirms that the target guideline value for EC of 40 mS/m given in the South African Water Quality Guidelines is applicable to the entire Sand-Vet GWS. Similarly the dominance of wheat (which is sensitive to boron) in both areas confirms the target guideline for boron of 0,2 mg/l. The presence of either beans or onions (both of which are categorised as being sensitive with regard to the root uptake of chloride) in all parts of the Sand-Vet GWS indicates the need to adopt the guideline limit of 105 mg/l given in the South African Water Quality Guidelines. Significant potato production occurs throughout the Sand-Vet GWS. According to Maas (1990), sodium concentrations of more than 5 mmol/l (115 mg/l) in water used for sprinkler irrigation can result in foliar damage of potatoes. However, Ayers (1977) indicates that such problems can begin to occur at concentrations as low as 3 mmol/l (70 mg/l). This implies that the target limit of 70 mg/l given in the South African Water Quality Guidelines (DWAF,1993) is applicable to the entire Sand-Vet GWS.

3.6.1.4 Soil types

The soils data given in Table 3.5 was obtained from the farmers surveys.

TABLE 3.5
Summary of soil descriptions from farmers' survey data

FARM	AREA UNDER IRRIGATION (ha)	SOIL DESCRIPTION	PERCENTAGE CLAY	SOIL DEPTH (m)	SOIL pH	EXCHANGEABLE SODIUM
IRRIGATED DIRECT FROM SAND-VET GWS CANALS						
Doornvlei LV 499	38	Clovelly	7	2.0	6.5 (KCl)	8 mg/Kg
Beginsel/Duikerbos LV 75/76	110	Hutton/Avalon	15	1.5		
Doyton LV 560	210	Sand-loam	10	0.7	6.2	36%
LV 74, Section 10 of Leliefontein 147	52	Sand-loam	15-30	1.5	6.2 (H_2O) 5.2 (Kcl)	
Vredehoek LV 28,29,36 &37	157	Hutton	12	1.2	5.2	
LV 34,35,48,50,51 & 53	105	Sand	17	1.5	6.9	
IRRIGATED FROM LOWER VET RIVER						
Theronshoop 441	120	Sand-loam	12	2.0	38%	?
Abrahamskraal 627	22	Sand-loam	?	2.0	7-8%	?
Vrede	36	?	?	?	?	?
Blydskap 1042	20	Sand-loam	12	3.0	5.6	3,11
Rusplaas 545	84	Avalon/Cloverly	6-12	2.0-2.5	?	?
DeKroon/Rooiwal	60	?	?	?	?	?
Leeuwkraal	46	Avalon	10	1.5	5.5	?
Resida 1149	10	?	?	?	?	?

The limited information obtained from the small sample of farmers surveyed is too sparse and incomplete to provide much information regarding the range and frequency of occurrence of soil types and the potential for sodicity problems in the Sand-Vet GWS. However, Table 3.6 of Section 3.4.2.9 of the South African Water Quality Guidelines provides a footnote quoting Dr A J van der Merwe of the Institute for Soil, Climate and Water who warned that "*some irrigation soils in the Orange Free State are even more sensitive than the criteria used to derive the SAR ranges*". Upon further enquiry, Dr van der Merwe confirmed that the wind blow soils of the Sand-Vet GWS are particularly susceptible to the formation of surface seals that inhibit infiltration rates when low EC rain water falls on lands that are being irrigated with water with an SAR of 1,5 (or even less). Dr van der Merwe indicated that the soils of the lower Vet River were among the most susceptible soils investigated (Dr A J van der Merwe, Institute for Soil, Climate and Water, personal communication, 1993). This confirms the validity of the target sodium adsorption ratio (SAR) guideline limit of 1,5 given in the South African Water Quality Guidelines (DWA&F, 1993).

3.6.1.5 Planting dates

Certain crops, such as potatoes, are particularly vulnerable to salinity during the germination stage (i.e. soon after planting). Other crops are more sensitive during different stages of their life cycle. The planting dates for the crops grown in the study area are therefore of importance when evaluating the water quality situation. The planting dates reported for crops under irrigation in the Sand-Vet GWS (based on both surveys of the farmers) are summarised in Table 3.6.

TABLE 3.6
Planting dates reported for crops under irrigation in Sand-Vet GWS (1993)

CROP TYPE	PLANTING DATES REPORTED*
Maize	October - December
Wheat	May/June/July
Potatoes	August and January
Pumpkin	September
Lucerne	March/April
Cabbage	January - April
Sunflower	December
Groundnuts	November
Soyabeans	December
Peas	July

NOTE: * Based on surveys of farmers carried out in April and October 1993.

In a semi-arid region it can be expected that pollution sources will dominate the river flow during the winter period. Since potatoes (which appear to account for about 10% of the crops grown) are particularly sensitive to salinity during the germination period, the crop planted in August could be particularly vulnerable during pollution episodes. However, it must be recognised that in a mining environment excess water problems often arise during wet weather. Hence it is not inconceivable that spillage of storage facilities could also occur during the January planting season.

3.6.1.6 Method of irrigation

All of the farmers surveyed use sprinkler systems (mainly centre pivot). Only one farmer, who uses water from one of the Sand-Vet GWS canals, reported using flood irrigation.

The dominance of sprinkler irrigation implies that possible foliar damage of crops needs to be taken into consideration when determining target water quality user requirements for chloride and sodium.

The absence of any mention of drip irrigation implies that potential clogging problems in drip irrigation systems need not be taken into consideration.

3.6.1.7 Water quality problems

The following problems were reported by the farmers who replied to the questionnaire:

- weeds in the water
- very high silt content in the water after rains
- signs of increasing nitrates in the water.

3.6.1.8 Water quality user requirements

Water quality user requirements that are appropriate to the study area were derived from the South African Water Quality Guidelines, taking due cognisance of the considerations discussed in the preceding sub-paragraphs. These are summarised in Section 3.8.

3.6.2 Livestock watering

3.6.2.1 General considerations

The following two main factors were taken into consideration in developing the South African Water Quality Guidelines for livestock watering (DWA&F, 1993):

- effects on animal health and performance
- effects on the consumer of animal products (human health).

3.6.2.2 Local climate

An important factor the affects the concentrations of a water quality variable that can be tolerated in the water used for livestock watering is the temperature and the dryness of the grazing, both of which directly affect the intake of water. In this regard the study area is situated in an area characterised by a semi-arid plateau climate, with cool dry winters and hot summers with some rain. These conditions will tend to increase livestock watering requirements.

3.6.2.3 Water use

For livestock watering and poultry production, eight farmers surveyed used borehole water, two used water from a canal and four used water from the lower Vet River. There is some overlap since one farmer used a combination of both canal and borehole water, while another three used both river and borehole water. A further two farmers who reported livestock watering failed to indicate the type of water source. A number of farmers reported herds of beef and dairy cattle and sheep that either use the Vet or Sand Rivers as well as boreholes for livestock watering. The fifteen farmers who completed the questionnaires reported the livestock totals given in Table 3.7.

TABLE 3.7
Livestock watering reported in the Sand-Vet GWS (1993)

LOCATION	NUMBER REPORTED		
	Dairy cattle	Beef cattle	Sheep
Upstream of Sand-Vet confluence	38	510	38
Lower Vet River	190	855	-
Total	228	1365	200

NOTE: Based on a surveys of six farmers resident upstream of the Sand-Vet confluence (carried out in April 1993) and nine farmers resident adjacent to the lower Vet River (carried out in October 1993).

Only three of the farmers surveyed reported poultry production. However, in these three instances the numbers reported of only 40, 20 and 5 chickens represent a negligible production.

The survey sample therefore indicates that livestock watering is mainly for cattle and sheep.

3.6.2.4 Water quality user requirements

A summary of the target water quality guideline ranges for livestock watering is given in Section 3.8.

3.6.3 Freshwater aquaculture

3.6.3.1 General considerations

The two principles governing the selection of the general guidelines for freshwater aquaculture contained in the South Afican Water Quality Guidelines (DWA&F, 1993) are:

- protection of aquatic ecosystems supporting aquaculture
- protection of human consumers of products from aquaculture.

In their present form the South African Water Quality Guidelines for Agricultural Use are aimed at meeting the requirements for freshwater fish species. This is because fish production is presently the most important freshwater aquaculture activity in South Africa.

3.6.3.2 Local factors

No freshwater aquaculture activities could be identified in the study area. The absence of any identified commercial aquaculture in the study area would normally obviate the need to include water quality requirements for freshwater aquaculture.

3.7 Natural environment

The natural environment is always a recognised water user. However, the Department of Nature Conservation could provide no information regarding the site specific water quality needs of the natural environment and the general S.A. Water Quality Guidelines for the natural environment are still in preparation. Without detailed knowledge of the life forms present in the river it was not possible to propose specific water quality user requirements for all variables. The DWA&F's Directorate: Water Quality Management is in the process of organising a biological survey to identify more specific water quality needs in the study area, however, this survey will not be completed until well after the end of the current study. As an *interim measure*, the guidelines for aquaculture given in the South African Water Quality Guidelines for Agricultural Use (DWA&F, 1993) have been adopted to represent the requirements of the natural environment. This approach has been taken since satisfaction of the requirements for aquaculture should be protective of most types of fish life in rivers and dams. (However, it may not necessarily be protective of all other types of aquatic life, or even of some specific fish types that are not usually raised in aquaculture projects. The biological survey to be undertaken by the HRI will more fully address the water quality requirements for the natural environment.)

In addition to the water quality user requirements for aquaculture (to represent the needs of fish life), certain other general requirements are suggested for adoption until such time as more detailed information becomes available. These are discussed below.

3.7.1 Sodium

Sodium is the most dominant cation associated with mining waste water in the OFS Goldfields region. It follows that a guideline for sodium should be specified. McKee and Wolf (1963) reported that sodium was toxic to fish in distilled and soft waters at 500 - 1000 mg/l when sodium chloride or sodium nitrate was tested. Under those conditions, 500 mg/l Na is lethal for sticklebacks. The degree of toxicity depends on the anions associated with the sodium.

Since the surface waters affected by mining activities in the study area tend to be hard rather than soft, the upper end of the range suggested by McKee and Wolf (i.e. 1000 mg/l) has been adopted as an interim guideline value

Suggested interim guideline: Na $<$ 1000 mg/l.

3.7.2 Chloride

As the most dominant anion present in the mining waste water, a guideline for chloride is required. McKee and Wolf (1963) state that it is difficult to generalise on the effect of chloride concentrations on aquatic life. Every combination of chloride with other salts must be evaluated separately. Clearly, this requires a detailed knowledge of the species present in the rivers. Since this will have to await the more detailed surveys that are to be carried out by the DWA&F's Hydrological Research Institute, another literature source for an interim chloride guideline was sought.

The Canadian Water Quality Guidelines (1987) indicate harmful effects to trout at chloride levels in excess of 400 mg/l and to "some fish" at 2000 mg/l. Although the Sand River is unlikely to support trout, a conservative approach has been adopted to afford a measure of protection for organisms other than fish. This guideline should be revised once either Volume 5 of the South African Water Quality Guidelines (dealing with the natural environment), or the results of a field survey that is to be undertaken by the Hydrological Research Institute of the DWA&F, become available.

Suggested interim guideline: Cl < 400 mg/l.

3.7.3 Sulphate

Sulphate is the second most dominant anion in the mining waste water.

McKee and Wolf (1963) reported that in the United States 95% of the waters that supported good game fish contained less than 90 mg/l sulphate. However, good game fish are usually found in mountain streams where most chemical concentrations are low. The relationship may therefore be spurious, especially since other environmental factors are likely to play a much more important role in supporting game fish.

Kempster *et. al.* (1980) reported a sulphate concentration of 1400 mg/l to be protective of aquatic life. However, Faust and Aly (1981), indicate that sulphate can have purgative effects at 1000 mg/l.

Suggested interim guideline: SO_4 < 1000 mg/l.

3.7.4 Heavy metals, cyanide, arsenic

Given the mining activities in the OFS Goldfields region, particular attention should be focused on heavy metals, cyanide and arsenic in the Sand River and its tributaries draining the mining areas (i.e. the Doringspruit, Theronspruit, Bosluisspruit and Rietspruit). Some of the pans used to dispose of mining waste water also support bird life (eg. flamingoes). This information need should be taken into account when the Hydrological Research Institute carry out their survey of heavy metals.

3.7.5 Indicators of eutrophication potential

Given the generally high turbidity of the Sand River water, the absence of large impoundments downstream of the urban areas and the fact that most of the purified sewage effluent is recycled, the potential for eutrophication of the lower Sand River should be low. Nevertheless expert opinion on the most appropriate guideline range for phosphate should be sought to minimise the risk of unexpected eutrophication problems arising.

3.7.6 Pesticides

A survey of pesticide levels present in the lower Sand and Vet Rivers is recommended in view of the high level of riparian agricultural activity.

3.7.7 Water quality user requirements

A summary of the interim water quality user requirements for the natural environment is given in Section 3.8.

3.8 Summary of water quality user requirements for different water uses

The interim water quality user requirements for the main categories of water use discussed in Sections 3.3 to 3.7 are summarised in Table 3.8.

TABLE 3.8

Preliminary target water quality user requirements for main categories of water use in the lower Sand-Vet catchment[+]

VARIABLE	*UNITS*	*TARGET GUIDELINE RANGES*					
		Domestic use	*Recreational*		*Agricultural use*		*Natural environment*
			full contact	*non-contact*	*Irrigation*	*Livestock watering*	
INORGANIC CONSTITUENTS OF TDS AND SALINITY-RELATED VARIABLES							
Conductivity (EC)	mS/m	0 - 70[*]	NS	NS	< 40[*]	0 - 154[*]	NS
Total Dissolved Salts	mg/l	0 - 450[*]	NS	NS	< 260[*]	0 - 1000[*]	NS
Calcium (Ca)	mg/l	< 150[*]	NS	NS	NS	0 - 1000[*]	NS
Magnesium (Mg)	mg/l	< 70[*]	NS	NS	NS	0 - 500[*]	NS
Sodium (Na)	mg/l	< 100[*]	NS	NS	0 - 70[*]	0 - 2000[*]	< 1000[♦]
Potassium (K)	mg/l	< 200[*]	NS	NS	NS	NS	NS
Chloride (Cl)	mg/l	< 250[*]	NS	NS	0 - 105[+]	0 - 1500[*]	< 400[♦]
Sulphate (SO_4)	mg/l	< 200[*]	NS	NS	NS	0 - 1000[*]	< 1000[♦]
Fluoride (F)	mg/l	0 - 1.0[*]	NS	NS	0 - 2.0[*]	0 - 2[*]	NS
Ammonia (NH_3 as N)	mg/l	< 1.0[*]	NS	NS	NS	NS	0.0 - 0.025[x]
Nitrate (NO_3 as N)	mg/l	NS	NS	NS	0 - 5[*]	0 - 10[*]	NS
Nitrite (NO_2 as N)	mg/l	NS	NS	NS	NS	0 - 100[*]	0 - 0.06[x]
Nitrite + Nitrate (NO_2+NO_3 as N)	mg/l	0 - 6[*]	NS	NS	NS	0 - 10	NS
Phosphate (total as P)	mg/l	NS	NS	NS	NS	NS	?[*]
Sodium Adsorption Ratio (SAR)	-	NS	NS	NS	0 - 1.5[*]	NS	NS
Hardness (as $CaCO_3$)	mg/l	< 150[*]	NS	NS	NS	NS	20 - 175[x]
Alkalinity (as $CaCO_3$)	mg/l	NS[#]	NS	NS	NS	NS	20 - 175[x]
pH	-	6.0 - 9.0[*]	6.5 - 8.5[*]	NS	6.5 - 8.4[*]	NS	6 - 9[x]
OTHER RELEVANT INORGANIC AND PHYSICAL VARIABLES							
Boron (B)	mg/l	< 0.5[*]	NS	NS	0 - 0.2[*]	0 - 5[*]	?[*]
Cyanide (CN)	mg/l	< 0.2[*]	NS	NS	NS	NS	?[*]
Carbon dioxide (CO_2)	mg/l	NS	NS	NS	NS	NS	2 - 5[x]
Dissolved Oxygen	mg/l	NS	NS	NS	NS	NS	> 5[x,*]
Hydrogen sulphide	mg/l	NS	NS	NS	NS	NS	0.0 - 0.002[x]
Radionuclides		NS	NS	NS	NS	•	?[*]
Clarity (Secchi disk depth)	m	NS	> 2.75[&]	NS	NS	NS	?[*]
Suspended solids (SS)	mg/l	NS	NS	NS	NS	NS	25 - 80[x]
Turbidity	NTU	0 - 1[*]	NS	NS	NS	NS	NS
Odour	TON	1[*]	NS	NS	NS	NS	NS

VARIABLE	UNITS	TARGET GUIDELINE RANGES					
		Domestic use	Recreational		Agricultural use		Natural environment
			full contact	non-contact	Irrigation	Livestock watering	
BIOLOGICAL AND ORGANIC VARIABLES							
Algae (chlorophyll a)	µg/l	0 - 5*	0-15*	0-20*	NS	$	?*
Coliphages	N/100 ml	< 1*	0 - 20*	NS	NS	NS	NS
Dissolved Organic Carbon (DOC)	mg/l	0 - 5*	NS	NS	NS	NS	NS
E. coli: - 3-month mean - single sample max.	N/100 ml	NS	0 - 126* < 298*	NS	NS	NS	NS
Enteric viruses	$TCID_{50}$/10 l	< 1*	< 1*	NS	NS	NS	NS
Faecal coliforms	N/100 ml	0*	0 - 150*	NS	NS	NS	NS
Pathogens: - faecal coliforms - total bacteria	N/100 ml	0* NS	0 - 150* NS	NS NS	NS NS	< 1000* < 5000*	NS NS
Pesticides	mg/l	NS	NS	NS	NS	@	?*
Protozoan parasites	N/10 l	< 1*	NS	NS	NS	NS	NS
HEAVY METALS AND TRACE ELEMENTS							
The identification of relevant variables to be included under this category will require a synoptic survey of the concentrations of metals and other trace elements present in the surface water resources.							

NOTES:

+ Requirements for industrial use not included, as there is no such use in the Lower Vet catchment.
• Target guideline range as per South African Water Quality Guidelines.
• "Maximum limit for no risk" as per proposed water quality criteria of the Department of National Health and Population Development (Aucamp and Vivier, 1990).
• Target guideline range as per South African Water Quality Guidelines for aquaculture.
"NS" = not specified.
$ Livestock should not be able to drink water with heavy growths of blue-green algae.
@ Refer to p.129 of South African Water Quality Guidelines Volume 4. A survey is recommended to determine the specific pesticides that warrant attention.
• Refer to page 130 of South African Water Quality Guidelines Volume 4 (paragraph 4.4.27).
♦ As per Canadian Water Quality Guidelines (1987).
♠ As per Mckee and Wolf (1963).
○ As per Faust and Aly (1981).
* Water quality user requirements for these variables for the natural environment are still required. The values given in Kempster et. al. (1980) appear to be too stringent for general application and have therefore not been used.
& A Secchi disk depth of 2,75 m may be unrealistic for the Sand River, seeing as it tends to be naturally turbid. Since the guideline for clarity relates mainly to the suitability for swimming, it may imply that the river water would have been less than ideal for swimming even before development of the catchment took place.

The first choice for the selection of the target guideline ranges contained in Table 3.8 was the South African Water Quality Guidelines (DWA&F, 1993). In instances where the South African Water Quality Guidelines did not cover a particular variable, values were taken from Kempster and Smith (1985), in the case of potable water, and from Kempster *et. al.* (1980) for other water uses (the 50% percentile was found to agree most closely with the DWA&F target guideline values). Although they do not form part of the brief for this study, biological parameters have also been included for the sake of completeness.

The water quality user requirements given in Table 3.10 reflect the new thinking within the DWA&F and away from the framing of user requirements in probabilistic terms (P50, P95 and P100 percentile limits).

A number of the water quality user requirements for the natural environment have been left out (denoted by "?" in Table 3.8). This is because the South African Water Quality Guidelines for the natural environment have not yet been completed. Although Kempster *et. al.* (1980) summarises the water quality criteria for the natural environment from a number of literature sources, these values were not used since most of the criteria appear to be far too stringent to be of any practical value. These missing values will be entered when the South African Water Quality Guidelines for the natural environment are finalised. The DWA&F's Directorate: Water Quality Management is in the process of arranging for the Hydrological Research Institute to carry out a field survey to identify the specific water quality requirements for nature conservation in the lower Sand and Vet Rivers (Brown, personal communication).

3.9 Water quality user requirements for specific river reaches

The different river reaches in the study area have been categorised according to water use. Table 3.9 summarises the water uses identified within each river reach.

The river reaches listed in Table 3.9 have been grouped together into five categories according to the combination of water uses that have to be accommodated. These are not recognised categories, but simply a convenient shorthand means of identifying streams that have similar water quality requirements. The reasoning behind the categorisation of each river reach is discussed in the following sections.

3.9.1 Water uses common to all river reaches

The following water uses have been taken as common to all river reaches:

- The natural environment has been included as a user in all river reaches.
- Non-contact recreation must be considered as a water use in all river reaches since either the public or riparian land owners have access to every stream under consideration.
- Livestock watering is also common to all river reaches in the study area since every stream considered has at least some riparian farms adjoining one or both of its banks. Many of these riparian farms carry livestock. Therefore there is a strong likelihood of livestock watering from all of the streams under consideration.

3.9.2 Sand River at Allemanskraal Dam

Since Allemanskraal Dam can be used for water sports and also serves as a source of water for domestic and irrigation use, the water quality must be maintained fit for all categories of water use. For this reason it has been included in water use Category 1 (see Table 3.9).

3.9.3 Sand River from Allemanskraal Dam to Rietspruit confluence

The irrigation canals leading from Allemaskraal Dam provide a secure source of water for domestic and irrigation use on riparian farms. The right bank canal terminates a short distance upstream of the Sand River-Merriespruit confluence. However, according to officials of the DWA&F OFS Regional Office there is no irrigation use on right bank riparian farms between this point and the Rietspruit confluence. Borehole water is reported to be used for domestic use in this area. Although residents of informal settlements are

TABLE 3.9
Categorisation of river reaches according to water use

RIVER REACH/WATER BODY	IDENTIFIED WATER USES IN RIVER REACH[+]					WATER USE CATEGORY
	Domestic[*]	Recreational (full contact)[°]	Agricultural		Natural environment[#]	
			Irrigation	Livestock watering		
Sand River: Allemanskraal Dam	●	●	●	●	●	1
Sand River: Allemanskraal Dam to Rietspruit confluence				●	●	5
Sand River: Rietspruit confluence to Virginia Dam		●	●	●	●	3
Sand River: Virginia Dam to Vet River confluence				●	●	5
Merriespruit				●	●	5
Rietspruit			●	●	●	4
Sand River Canal				●	●	5
Doring River				●	●	5
Theronspruit	●		●	●	●	2
Bosluisspruit				●	●	5
Vet River: Erfenis Dam	●	●	●	●	●	1
Vet River: Erfenis Dam to Sand River confluence	●		●	●	●	2
Vet River: Sand River confluence to Bloemhof Dam	●		●	●	●	2

NOTE: + Shaded areas in the table denoted uses that have been identified to take place in each river reach.

* *Limited domestic use of streams by informal users for washing clothes that occurs in some river reaches has not been denoted since the water quality requirements for this type of water use are far less stringent than for normal domestic use. Such users include the residents of informal settlements in the vicinity of Virginia and farm labourers. These informal users generally have access to alternative sources of drinking water for household use.*

° The user requirements for non-contact recreation apply to all river reaches for which full contact recreation has not been indicated.

\# The user requirements for the natural environment include those for freshwater aquaculture.

known to wash laundry in the vicinity of the Merriespruit confluence, according to officials of the DWA&F OFS Regional Office alternative water supplies are available for drinking water and other domestic uses. Application of all of the water quality user requirements for domestic use would clearly be inappropriate for this limited water use. Moreover, the washing of laundry in public streams is itself a pollution source, and this practice should be discouraged and alternative arrangements made.

Since for much of the time the river level is very low, full or intermediate contact recreation cannot be considered a significant water use. Hence water use Category 5 (comprising non-contact recreation, livestock watering and the natural environment) has been adopted for setting interim user requirements.

3.9.4 Sand River from Rietspruit confluence to Virginia Dam

This river reach differs from that immediately upstream in that the body of water backed up by Virginia Weir is adjoined on the left bank by Virginia Park. This portion of the river is used for full-contact water sports including boating, windsurfing and water skiing. Angling also takes place. On the right bank of the river the potential also exists for irrigation use on a riparian farm, which does not have access to any irrigation canals. This river reach has been allocated a Category 3 water use rating (i.e. all water uses except domestic).

3.9.5 Sand River from Virginia Dam to Vet River confluence

Riparian farms on both banks of this reach of the Sand River have access to irrigation canals leading from Allemanskraal Dam. (An inverted syphon from the left bank canal re-initiates the right bank irrigation canal in the vicinity of the Sand River Canal). These irrigation canals make adequate provision for domestic and irrigation water uses. A few sand quarries operate at various points along this river reach. However, in these operations the river water is used for little more than washing the sand. Quarry labourers also sometimes use the river water for washing their clothes. According to the DWA&F OFS Regional Office water for domestic use is transported to the quarries by road tanker trucks. Hence water use Category 5 should suffice to cover the needs for this river reach.

3.9.6 Merriespruit

The Merriespruit is dry for most of the time. As such it is an unreliable water source that is not used for domestic, irrigation or full or intermediate contact recreational use. It has therefore been included in water use Category 5.

3.9.7 lower Rietspruit

According to the DWA&F OFS Regional Office strong boreholes provide water for domestic use on riparian farms. The low flow in the lower Rietspruit for most of the year appears to preclude full contact recreational use. The presence of farm dams indicates the possibility of irrigation use. This stream has been placed in water use Category 4 (which includes non-contact recreational, irrigation, livestock watering and natural environment water uses).

3.9.8 Sand River Canal

For much of its course the Sand River Canal follows a natural surface drainage course. In fact the canal itself terminates and enters a small natural stream before reaching the Sand River. A farmer has a small dam on this stream. According to the DWA&F OFS Regional Office the farmer, Mr Nel, used water from this dam until upstream mining activities rendered it unfit for use. Since the stream and its catchment area are small, the dam is unlikely to have had a big enough yield to support viable irrigation. Livestock watering therefore appears to be the most likely use for the water (assuming that the water quality can be restored). Even if water from this dam was used for domestic purposes in the past, alternative sources (boreholes) have already been developed for this use. Future domestic use of this stream is therefore improbable. This stream has therefore been assigned to water use Category 5.

3.9.9 lower Doring River

The Doring River downstream of the Theronspruit is dry for most of the year. Livestock watering and the natural environment appear to be the only significant water uses. Therefore this river reach has been placed in water use Category 5.

3.9.10 Theronspruit

In the past the Theronspruit was used for domestic use and a limited amount of irrigation from a small farm dam. However, these uses ceased after seepage from Beatrix Mine rendered the stream unfit for these water uses. According to the DWA&F OFS Regional Office Beatrix Mine has provided the farmer concerned with a water supply from Goldfields Water to compensate for the loss of this water resource. At present the Theronspruit appears to be used only for livestock watering.

It might be argued that since the domestic and irrigation needs of the affected farmer are now being met by Goldfields Water (via Beatrix Mine) there is no longer any need to maintain the water quality in the Theronspruit fit for these uses. While a pragmatic solution like this might eventually be adopted when the Water Quality Management Plan for the catchment is finalised, it is hardly ideal. The use of expensive purified water transferred from a distant river basin for irrigation and domestic use is undesirable and certainly would not have occurred had the Theronspruit not been polluted. Domestic and irrigation use have therefore been taken into account in determining the provisional water quality user requirements for the Theronspruit. Since this stream is unsuitable for full contact recreational use, the Theronspruit has been placed in water use Category 2 (which includes all water uses except full and intermediate contact recreation).

3.9.11 Bosluisspruit

The Bosluisspruit is dry for most of the year. Livestock watering and the natural environment appear to be the only significant water uses. Therefore this river reach has been placed in water use Category 5.

3.9.12 Vet River at Erfenis Dam

Erfenis Dam can be used for water sports and also serves as a source of water for domestic, irrigation and livestock watering use. Therefore the water quality must be maintained fit for all categories of water use. For this reason it has been included in water use Category 1.

3.9.13 Vet River from Erfenis Dam to Sand River confluence

The irrigation canal from Erfenis Dam services only the left bank riparian farms in this river reach. The right bank riparian farms are therefore dependent on the Vet River as their water source of domestic, irrigation and livestock watering use (although in some instances boreholes may be used for domestic and livestock watering use). The frequency of full and intermediate contact recreational use of this river reach is thought to be low. Consequently this portion of the Vet River has been included in water use Category 2.

3.9.14 Vet River downstream of Sand River confluence

The absence of irrigation canals on the right bank and most of the left bank of the lower Vet River means that most riparian farmers are dependent on the Vet River for water for domestic, irrigation and livestock watering use. Moreover, the town of Hoopstad also draws its raw water supply from the Vet River. The lower Vet River has been included in water use Category 2.

Table 3.10 gives the preliminary water quality user requirements for each river reach. These were derived by using Table 3.9 to identify the water uses within each river reach and referring to Table 3.10 to determine the most sensitive water use for each water quality parameter of interest.

It must be stressed that the water quality user requirements given in Table 3.10 are provisional. They will be subject to review during the preparation of the catchment Water Quality Management Plan. In accordance with the terms of reference for the study, only those variables related to TDS and its main inorganic constituents (i.e. the first section of Table 3.10) have been addressed in further chapters of this report.

TABLE 3.10
Preliminary target water quality user requirements for different river categories in the lower Sand-Vet catchment+

VARIABLE	UNITS	TARGET GUIDELINE RANGES FOR EACH RIVER CATEGORY				
		1	2	3	4	5
INORGANIC CONSTITUENTS OF TDS AND SALINITY-RELATED VARIABLES						
Conductivity (EC)	mS/m	< 40	< 40	< 40	< 40	< 154
Total Dissolved Salts	mg/l	< 260	< 260	< 260	< 260	< 1000
Calcium (Ca)	mg/l	< 150	< 150	< 1000	< 1000	< 1000
Magnesium (Mg)	mg/l	< 70	< 70	< 500	< 500	< 500
Sodium (Na)	mg/l	< 70	< 70	< 70	< 70	< 1000
Potassium (K)	mg/l	< 200	< 200	NS	NS	NS
Chloride (Cl)	mg/l	< 105	< 105	< 105	< 105	< 400
Sulphate (SO_4)	mg/l	< 200	< 200	< 1000	< 1000	< 1000
Fluoride (F)	mg/l	< 1.0	< 1.0	< 2.0	< 2.0	< 2.0
Ammonia (NH_3 as N)	mg/l	< 0.025	< 0.025	< 0.025	< 0.025	< 0.025
Nitrate (NO_3 as N)	mg/l	< 5	< 5	< 5	< 5	< 10
Nitrite (NO_2 as N)	mg/l	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Nitrite + Nitrate (NO_2+NO_3 as N)	mg/l	< 6	< 6	< 10	< 10	< 10
Phosphate (total as P)	mg/l	?#	?#	?#	?#	?#
Sodium Adsorption Ratio (SAR)	-	< 1.5	< 1.5	< 1.5	< 1.5	NS
Hardness (as $CaCO_3$)	mg/l	20 - 150	20 - 150	20 - 175	20 - 175	20 - 175
Alkalinity (as $CaCO_3$)	mg/l	20 - 175	20 - 175	20 - 175	20 - 175	20 - 175
pH	-	6.5 - 8.4	6.5 - 8.4	6.5 - 8.4	6.5 - 8.4	6 - 9
OTHER RELEVANT INORGANIC AND PHYSICAL VARIABLES						
Boron (B)	mg/l	< 0.2	< 0.2	< 0.2	< 0.2	< 5
Cyanide (CN)	mg/l	< 0.2	< 0.2	< 0.2*	< 0.2*	< 0.2*
Carbon dioxide (CO_2)	mg/l	2 - 5	2 - 5	2 - 5	2 - 5	2 - 5
Dissolved Oxygen	mg/l	> 5	> 5	> 5	> 5	> 5
Hydrogen sulphide	mg/l	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Radionuclides		?+	?+	?+	?+	?+
Clarity (Secchi disk depth)	m	> 2.75	NS	> 2.75	NS	NS
Suspended solids (SS)	mg/l	25 - 80	25 - 80	25 - 80	25 - 80	25 - 80
Turbidity	NTU	< 1	< 1	NS	NS	NS
Odour	TON	1	1	NS	NS	NS
BIOLOGICAL AND ORGANIC VARIABLES						
Algae (chlorophyll a)	µg/l	< 5	< 5	< 15	< 20	< 20
Coliphages	N/100 ml	< 1	< 1	< 20	NS	NS
Dissolved Organic Carbon (DOC)	mg/l	< 5	< 5	NS	NS	NS
E. coli: - 3-month mean - single sample max.	N/100 ml	< 126 < 298	< 126 < 298	NS NS	NS NS	NS NS
Enteric viruses	$TCID_{50}$/10 l	< 1	< 1	< 1	NS	NS
Pathogens: - faecal coliforms - total bacteria	N/100 ml	0 < 5000	0 < 5000	< 150 < 5000	< 1000 < 5000	< 1000 < 5000
Pesticides	mg/l	?+	?+	?+	?+	?+
Protozoan parasites	N/10 l	< 1	< 1	NS	NS	NS
HEAVY METALS AND TRACE ELEMENTS+						

NOTES:
- \# Although some countries (such as Australia) have produced general phosphate guidelines for rivers and lakes, these cannot merely be adopted since other factors, such as turbidity and detention time, can cause widely varying responses in terms of eutrophication. Specialist studies are required to arrive at specific water quality user requirements for each of the main river reaches.
- \+ Special investigations are required to determine the user requirements for these variables.
- * A proscriptive approach has been adopted with regard to the guideline for cyanide. Consequently the domestic water use guideline has been applied to all river reaches, irrespective of water use category.

3.10 Conclusions and recommendations

3.10.1 Conclusions

a) Riparian irrigation below the confluence of the Sand and Vet Rivers is the largest user of river water that is likely to be affected by the mining and urban development in the OFS Goldfields region.

b) Domestic users likely to be affected include the town of Hoopstad, riparian farmers along the lower Vet River and farmers and (possibly) informal settlements located within the OFS Goldfields region itself.

c) The Sand-Vet GWS office could provide little information regarding the crop distribution and soils in the irrigated lands.

d) Little useful information could be obtained regarding the water quality requirements for the natural environment in the study area.

e) The provisional water quality user requirements for different river reaches in the study area are summarised in Table 3.10.

f) In some instances the water quality user requirements for some variables in a river reach are more stringent than is the case for upstream river reaches. When the catchment Water Quality Management Plan is developed it may be necessary to tighten the water quality user requirements for some river reaches to accommodate the more stringent requirements of downstream river reaches.

3.10.2 Recommendations

a) An investigation to determine the specific water quality needs for irrigation farming in the lower Vet River is recommended. This investigation should focus on the riparian irrigation supplied from the Vet River and should take account of the crops grown, irrigation practices employed and the soils that are being irrigated.

b) An investigation is needed to determine the water quality requirements for the natural environment. This investigation should consider the Sand River from Virginia to the Sand-Vet confluence, the lower Vet River, the Doring River and its tributaries (the Theronspruit and the Bosluisspruit) and the natural pans that are used to dispose of mining and municipal waste water.

c) An investigation is recommended to identify any problematic radionuclides, pesticides, heavy metals and other trace elements.

d) Where appropriate, the provisional water quality user requirements given in Table 3.10 should be revised or enlarged to take account of the findings of the investigations recommended in (a) and (c) above.

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CHAPTER 4

POLLUTION SOURCES

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4. POLLUTION SOURCES

4.1 Introduction

Pollution sources can be divided into two broad categories:

- point sources
- diffuse sources.

4.1.1 Point sources

For the purposes of this study point sources are defined as known pollution streams discharging directly to a water course via a distinct conduit (pipe, canal or furrow).

Typical point source inputs include the following:

- domestic and industrial sewage effluent
- industrial waste water discharges
- de-watering of mines
- discharges from canals
- inter-basin water transfers.

Permits or exemptions are generally required to legally make such discharges. The permit or exemption conditions usually contain stipulations regarding the monitoring of both flow and water quality. If the permit conditions are complied with such inputs can be quantified.

4.1.2 Diffuse sources

Diffuse sources are defined as all other pollution inputs, usually of a diffuse nature over a relatively large area. By this definition "diffuse sources" includes the washoff from large natural or polluted catchments, spillage and washoff from slimes dams, polluted water disposal areas, land fills, urban and industrial areas, and small point inputs that have as yet either not been identified or quantified.

This pragmatic definition of diffuse sources is compatible with the procedure used to estimate the diffuse pollution export from a catchment. This procedure involves estimation by subtracting observed point source loads from those measured in the river at the catchment outlet. It follows that as more information is obtained and more measurements of point inputs are made, part of what is now defined as diffuse source pollution will be re-defined as point source inputs.

Potential diffuse sources of pollution include runoff from the following developments (not necessarily listed in order of importance):

- washoff or seepage from gold mine slimes dams, waste water disposal dams and reduction works
- runoff from urban and industrial areas (including waste disposal sites)

- illegal or unquantified point discharges
- return flows from riparian irrigation schemes
- runoff from dry land farming areas
- deposition and washoff of atmospheric pollution
- natural catchment weathering processes.

4.1.3 Typical pollution sources in mining areas

In the mining context both point and diffuse pollution sources can occur. The following are some of the most common sources of mining pollution problems:

(a) Deep ground-water pumped out by mines.
(b) Outflow or seepage from drainage channels and slimes dams.
(c) Circulation dams (or return water dams).
(d) Storage dams for process water.
(e) Evaporation dams and areas.
(f) Stormwater flowing over mining areas.
(g) Sewage effluent.
(h) Solid waste disposal areas.

4.1.4 Polluted portions of the study area

The following systems in the OFS Goldfields area have been identified by the DWA&F OFS Regional Office (Van der Merwe, 1989) as either already polluted or are in danger of being polluted:

Rivers:

- Sand River
- Doring River
- Theronspruit
- Bosluisspruit
- Mahemspruit
- other smaller streams
- some farm dams

Pans:

- Rietpan
- Dankbaarpan
- Brakpan
- Swartpan
- Torontopan
- Flamingopan
- Witpan
- Doringpan

Aquifers:

Aquifers containing polluted ground-water.

4.2 Historical development of the catchment

Prior to the 1950s development of the Vet River catchment comprised only small rural towns, dry land farming and private irrigation from small farm dams. The effect of these low intensity developments on water quality is thought to have been insignificant.

Mining commenced in this area in the early fifties, resulting in the rapid growth of the major towns of Virginia and Welkom. Associated with these towns are solid waste disposal sites, sewage treatment works and industries. The most significant industry was the NCP yeast factory near Welkom, which has recently closed.

The Sand-Vet GWS irrigation scheme was developed in 1959 after the commissioning of Allemanskraal Dam, on the Sand River, and Erfenis Dam on the Vet River.

Table 4.1 lists the mines, their commissioning dates and the date when pumping of underground water to the surface commenced.

TABLE 4.1
Dates of commissioning of mines and commencement of pumping of underground water to surface

MINE	COMMISSIONING DATE	DATE WHEN PUMPING OF UNDERGROUND WATER TO SURFACE COMMENCED
St. Helena	1946	1943
President Brand	1949	1949
Western Holdings	1949	1949
Saaiplaas	+- 1950	+- 1950
Erfdeel		
Harmony: Merriespruit Harmony Virginia	 1951 1952 1952	
President Steyn	1954	1954
Free State Geduld	1956	1956
Unisel	1977	1974
Oryx	1978 (as Beisa Mine) Oct. 1987	Nov. 1987
Beatrix	Jul. 1983	End 1982
Joel	1988	Feb. 1990

4.3 Identification of polluted water bodies and probable pollution sources

In this section polluted portions of the catchment are identified. The approach adopted was as follows:

(i) Examine available water quality data, starting with the Sand River at Allemanskraal Dam and working towards the Sand-Vet confluence and on downstream to the lower Vet River.

(ii) Similarly the water quality data for each tributary of the Sand River in the OFS Goldfields area was next examined, starting with the most upstream tributary.

(iii) Examine water quality data for natural pans.

(iv) Examine available ground-water data.

(v) Examine reports of pollution incidents.

(vi) Examine available reports regarding pollution sources in the study area.

(vii) Draw logical conclusions regarding the magnitude of the pollution inputs and the most likely pollution sources.

4.3.1 Sand/Vet River from Allemanskraal Dam to Vet River mouth

The Sand River crosses the study area from east to west and is regarded as a major seasonal stream in the region (see Fig. A.1).

Fig. 4.1 gives a comparison of observed EC values in Allemanskraal Dam (C4R001) with those at hydrological station C4H004 (data obtained from the Hydrobank chemical data base still shows it by its old code C4M04).

The median EC value for C4H004 is 10.7 mS/m higher (equivalent to a TDS increase of about 75 mg/l) than that for Allemanskraal Dam. The mean observed TDS concentrations show an even larger increase of 136 mg/l (i.e from 157 mg/l to 293 mg/l). The peak EC values exceeded for less than 5% of the time at C4H004 are more than four times higher than those at Allemanskraal Dam (i.e. an increase from 28 to 124 mS/m.

Discharges from Erfenis Dam cannot be the cause of the increase since Erfenis Dam EC levels are *lower* than those in Allemanskraal Dam. The main catchment developments that could have influenced the EC levels in the lower Vet River are the Sand-Vet irrigation scheme and the OFS Goldfields mining and urban developments. Evaporative concentration in the river could also play a role, although this effect should be limited due to the influence of the water released from the ends of the irrigation canals, which should serve to dilute the lower Vet River and ensure that the evaporation loss rate is small relative to the flow rate.

Fig. 4.2 shows that the median chloride concentration at C4H004 is nearly three times higher than that at Allemanskraal Dam, while the peak concentrations are more than an order of magnitude higher (growing from 12 to 224 mS/m). Similar results were observed for sulphate.

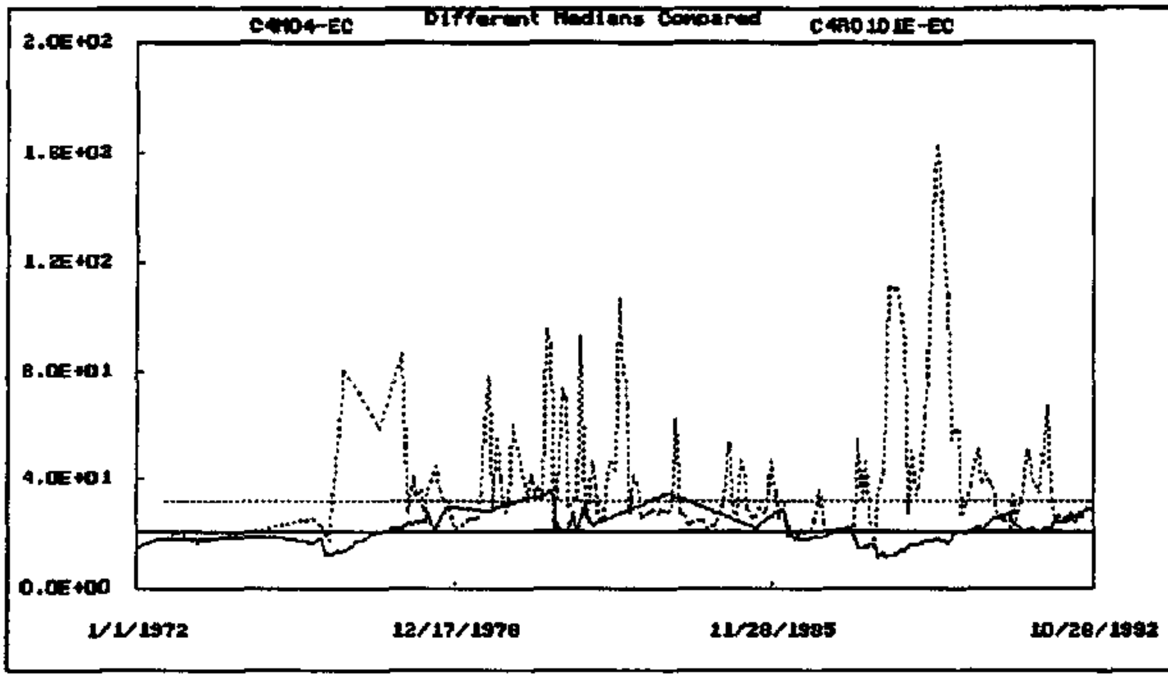

Fig. 4.1 : Comparison of EC values at Allemanskraal Dam (solid line) and C4H004 (dotted line) - Vertical scale in mS/m

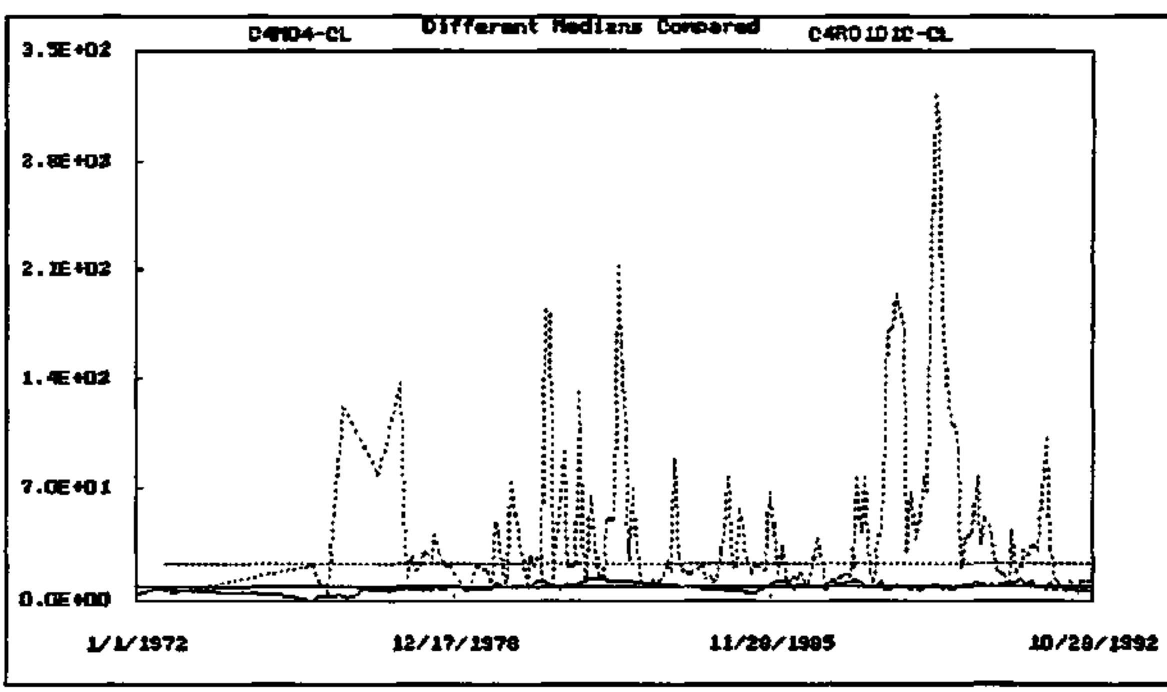

Fig. 4.2 : Comparison of chloride concentrations at Allemanskraal Dam (solid line) and C4H004 (dotted line) - Vertical scale in mg/l

The relatively larger increase in chloride and sulphate concentrations is consistent with the expected influence of mining sources (chloride and sulphate are dominant anions in the underground mine water). This provides indirect but strong evidence that mining activities in the Sand River are playing a dominant role in the deterioration of water quality in the lower Vet River.

Neither C4R0101 nor C4H004 show significant trends in EC or the main constituents of the TDS. This implies that the pollution source discharges have attained a steady state. This would be consistent with the dominance of old mines that have been in operation for a number of years. However, the lack of apparent trends may have been affected by longer term hydrological fluctuations. The effect of some of the newer mines that are still under development may not yet be obvious.

The following sections examine water quality changes along shorter river reaches.

(a) Allemanskraal Dam (C4R001) to station HAR1/DWA2

HAR1 is one of Harmony Mine's water quality monitoring stations in the Sand River at the railway bridge just upstream of the OFS Goldfields area. It is immediately downstream of the confluence with the Merriespruit, which enters the Sand River from a southerly direction to the West of Virginia (see Fig. A.3). The DWA&F OFS Regional Office also has a monitoring station at this site (station DWA2). Observed EC values at Allemanskraal Dam and station HAR1 are compared in Fig. 4.3.

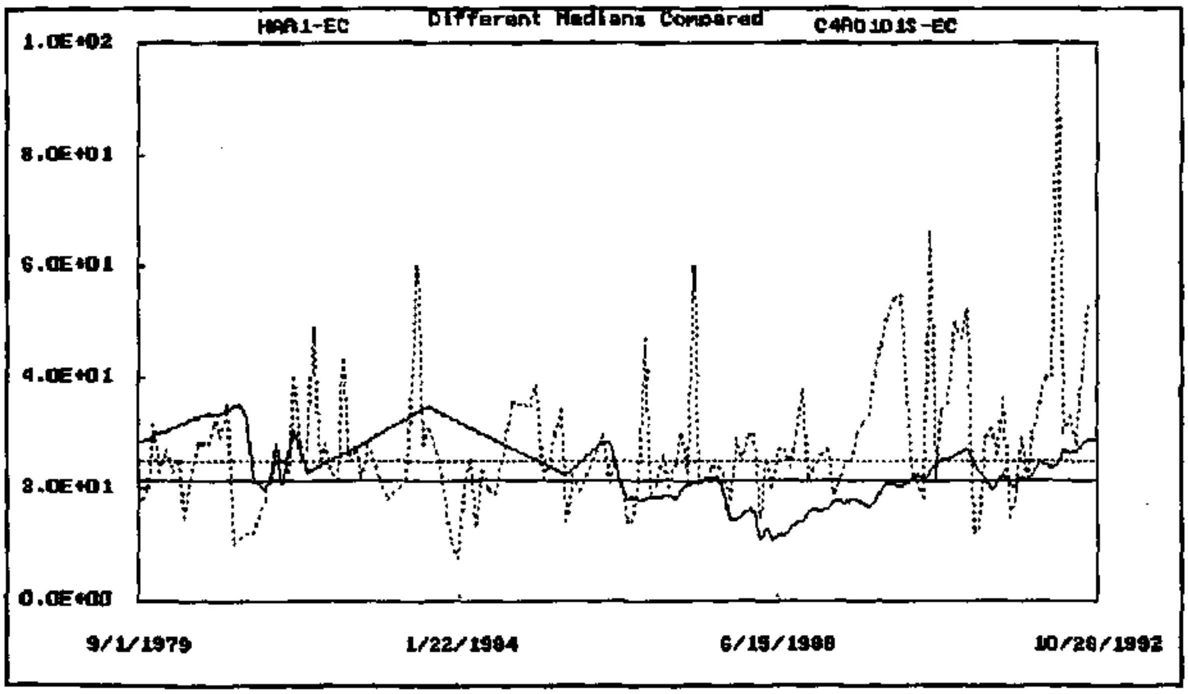

Fig. 4.3 : Comparison of EC values at Allemanskraal Dam (solid line) and station HAR1 in the Sand River at the railway bridge upstream of Virginia (dotted line) - units: mS/m

Fig. 4.3 shows a small but significant increase in the median EC values at station HAR1 (Harmony Mine's station in the Sand River at the railway bridge upstream of Virginia) relative to Allemanskraal Dam of 3,9 mS/m, corresponding to an increase in TDS of about 28 mg/l (or 16%). A somewhat larger increase of 41 mg/l (26%) took place in the average TDS (from 157 to 198 mg/l).

During the recent four-year period ending in September 1992 the P90[1] EC values at station HAR1 reached levels about twice as high as those recorded at Allemanskraal Dam (See Appendix D). Disproportionately larger increases occurred in the P90 sodium (19 to 156 mg/l), sulphate (14 to 103 mg/l) and chloride (11 to 49 mg/l) concentrations. Although the median phosphate concentration at station DWA2 remained well below 0.1 mg/l, the P90 concentration increased sharply from .03 to .84 mg/l, with one peak as high as 7.7 mg/l. Nitrate levels showed little change, and remained well below 5 mg/l. However, the P90 ammonia concentration increased nearly ten-fold (from 0.1 to 0.93 mg/l), with a peak value of 12.5 mg/l.

Irrigation return seepage and the evaporative concentration of salts in the river channel itself are most likely causes of the moderate increase in the mean TDS of the Sand River between Allemanskraal Dam and station HAR1. About half of the irrigation from the canals leading from Allemanskraal Dam occurs upstream of Virginia. However, the disproportionately higher increases in the peak chloride and sulphate concentrations indicate the possibility of some other intermittent pollution source (since irrigation is unlikely to account for the rise in both chloride and sulphate levels). Informal settlements in the vicinity of Meloding, located near to the Merriespruit could have contributed to the change in composition during peak TDS episodes. The increase in ammonia concentrations points to the possibility of faecal pollution. This could also be associated with fertilizer residues in irrigation return flows. The increase in peak phosphate concentrations could have arisen from irrigation or informal settlements. Fig. 4.14 indicates the possibility of contamination of the ground-water from mining sources in the vicinity of the Merriespruit. This might provide an explanation for the disproportionate rise in sulphate and chloride concentrations during episodes of high TDS.

The following conclusions can be drawn from the relatively small magnitude of the increase in TDS between Allemanskaal Dam and station HAR1:

(i) Irrigation return seepage is small and/or well diluted with tailwater spillage from the ends of canals and furrows.

(ii) Disproportionately high sulphate and chloride concentrations in samples taken during peak TDS concentration events provides indirect evidence of the possibility of intermittent pollution inputs from the Merriespruit due to the seepage of ground-water contaminated by mining activities.

(iii) The peak ammonia and phosphate concentrations at station

[1] The "percentile 90" or P90 level is the concentration that is not exceeded for 90% of the time.

HAR1/DWA2 may have arisen from informal domestic use of the river for washing laundry and diffuse washoff from the Meloding area. Irrigation return flows may also have had an effect.

The absence of flow data and sufficient water quality sampling in the Merriespruit and in the Sand River upstream of the Merriespruit infall prevents conclusive identification of the pollution source.

(b) Station HAR1 to HAR3

Fig. 4.4 shows a doubling of the median and an even sharper jump in the peak EC values between stations HAR1 and HAR2 (see Fig. A.3). Station HAR2 is located in the Sand River just downstream of the "waste dump stream". Although Harmony Mine has a small weir on this stream,it overflows into the Sand River during wet weather (OFS Regional Office - personal communication, 1993). A number of Harmony Mine's slimes dams are also located further upstream near to the left bank of the Sand River. These are thought to be the main cause of the sharp rise in salinity in the Sand River between stations HAR1 and HAR3 (OFS Regional Office - personal communication, 1993). The median and P90 chloride and sulphate concentrations show even more pronounced increases (see Appendix D). Sodium analyses are not available at station HAR2 (nor at any of the other Harmony Mine sampling points in the Sand River). Station HAR2 is downstream of the eastern fringe of the area affected by mining activities. Virginia's solid waste disposal site is also located between stations HAR1 and HAR2, adjacent to the right bank of the Sand River. However, Cogho *et. al.* (1992) could not find evidence of seepage to the river from this site.

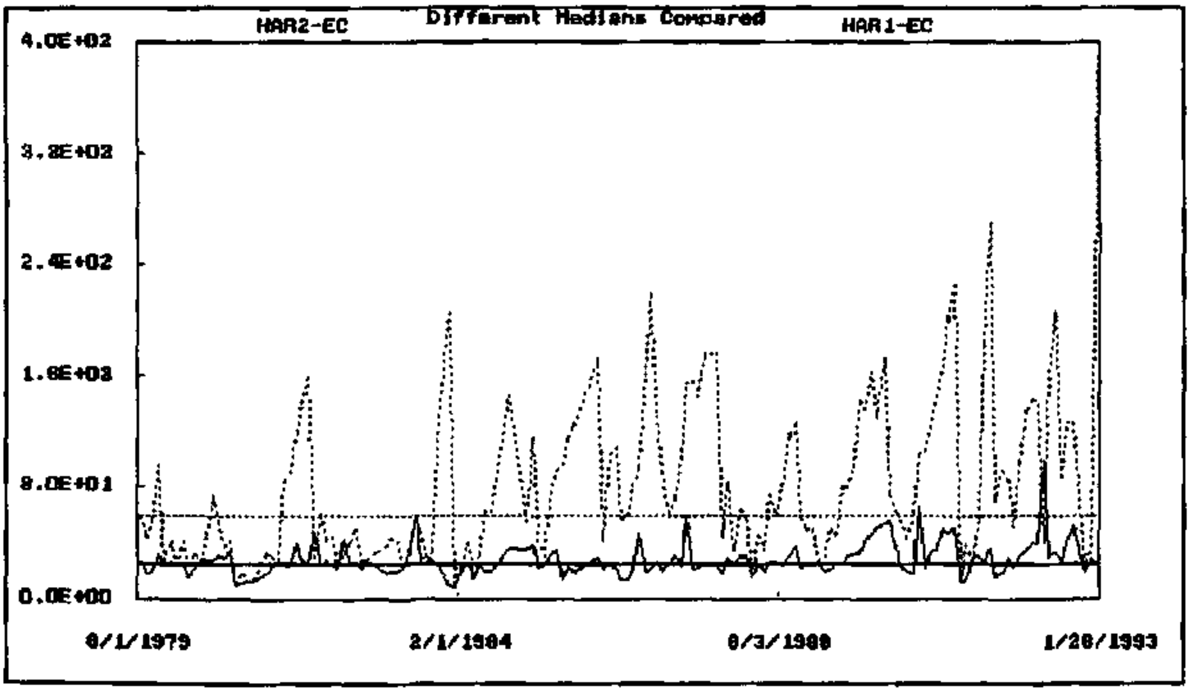

Fig. 4.4 : Comparison of EC values in the Sand River at station HAR1 at the railway bridge upstream of Virginia (solid line) **and station HAR2 downstream of the "waste dump stream"** (dotted line) **- units: mS/m**

Station HAR3 is located a short distance downstream station HAR2. The main feature between the two stations is the "donga dump stream". This polluted stream ends in a pool bordered by a retaining wall that prevents direct runoff to the Sand River. Harmony Mine operates a return water pump at this site. However, this does not preclude the possibility of seepage to the Sand River. Fig. 4.5 shows no significant difference in EC between stations HAR2 and HAR3.

High EC values (an order of magnitude higher than those in the Sand River) were recorded at stations HAR6, in the "waste dump stream", and HAR7, in the "donga dump stream" (see Appendix D).

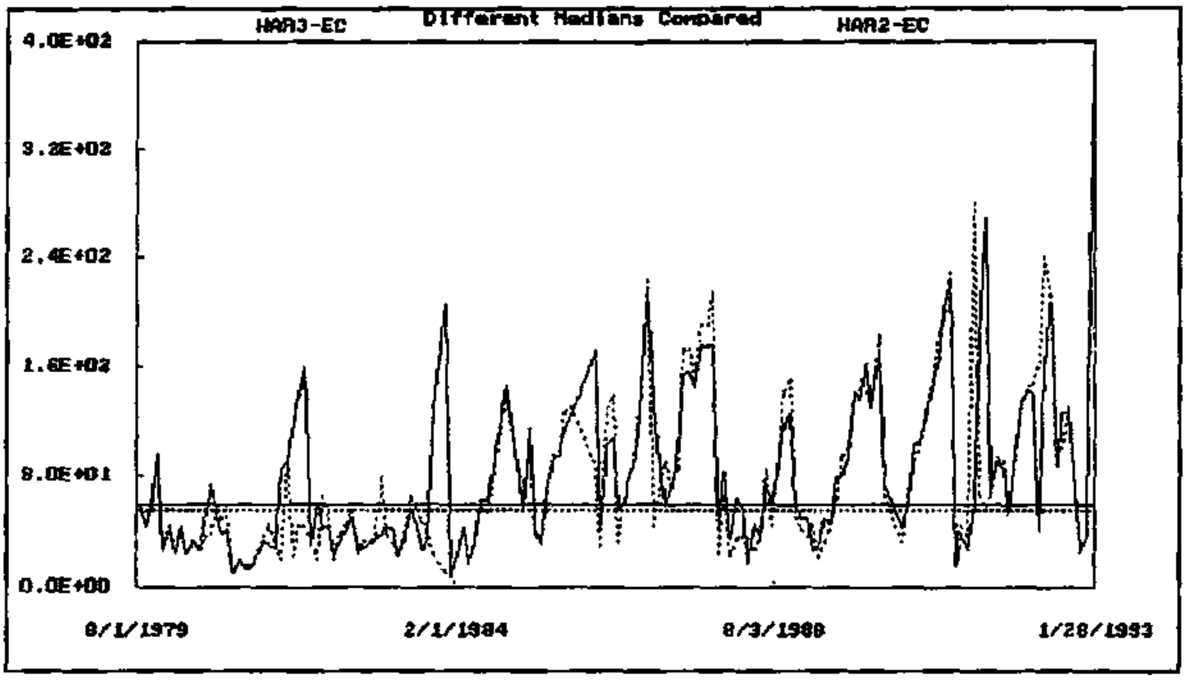

Fig. 4.5 : Comparison of EC values in the Sand River at station HAR2 downstream of the "waste dump stream" (solid line) and station HAR3 downstream of the "donga dump stream" (dotted line) - units: mS/m

The following conclusions were based on this information:

(i) The relatively small change in EC between stations HAR2 and HAR3, despite the fact that the EC levels in both polluted streams are much higher than those in the Sand River, suggests that the polluted runoff volume from the "donga dump stream" is relatively small, compared with that from upstream pollution sources.

(ii) Seepage from Harmony Mine's Virginia section slimes dams and the rock dump appear to be the main causes of the rise in salinity in the Sand River at station HAR2.

The lack of flow data at any of these four stations prevents estimation of the pollutant load entering the Sand River.

(c) **Station HAR3 to HAR4**

Fig. 4.6 shows a significant decrease in the median EC (by about 22%) and an even bigger decrease in the peak values between the "donga dump stream" (station HAR3) and the pipe bridge crossing of the Sand River north-east of Virginia (station HAR4).

The improvement in water quality could be attributable to dilution from the Rietspruit, which has its confluence with the Sand River between stations HAR3 and HAR4. Urban runoff from the town of Harmony could also contribute to the dilution of the Sand River in this river reach. Storage attenuation in the pool backed up by Virginia weir may also have had the effect of damping out peak TDS concentrations associated with pollution episodes.

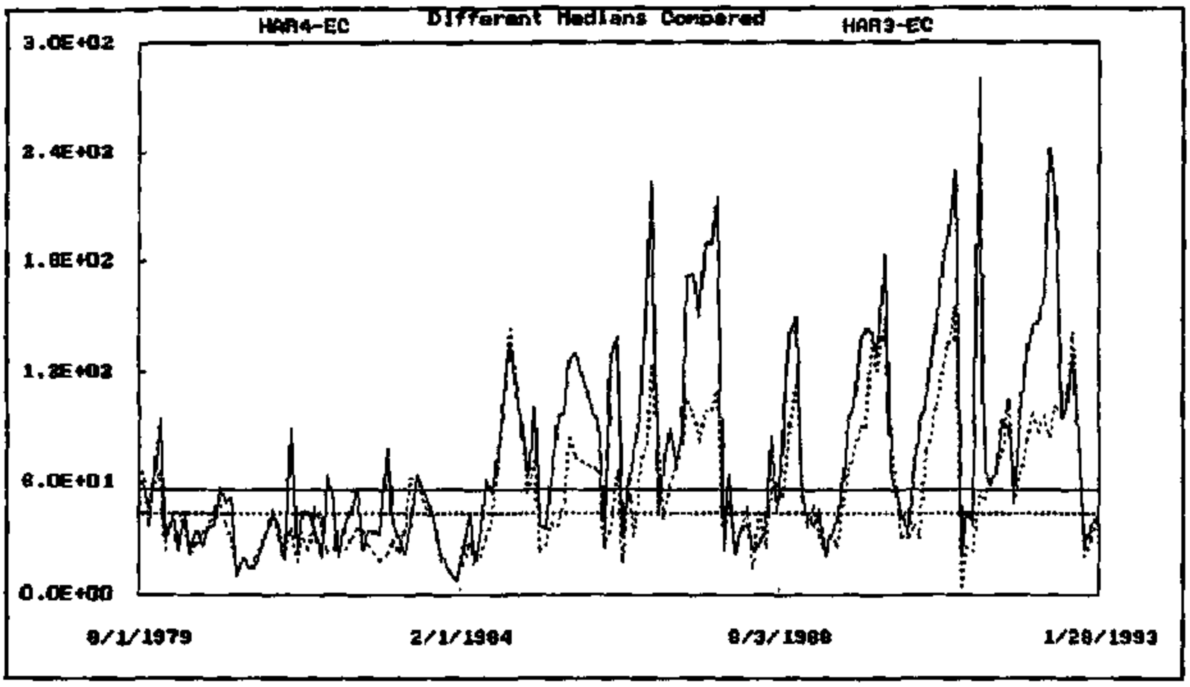

Fig. 4.6 : Comparison of EC values in the Sand River at station HAR3 downstream of the "donga dump stream" (solid line) and station HAR4 at the pipe bridge north-east of Virginia (dotted line) - units: mS/m

The borehole water quality analyses carried by Cogho *et. al.* (1992) indicated seepage from Harmony Mine's slimes dam C1 towards the Rietspruit (the estimated seepage zone is indicated in Fig. A.3).

It can be concluded from the above that:

(i) The reduction in EC between stations HAR3 and HAR4 could indicate that the seepage from Harmony Mine's slimes dam C1 into the Rietspruit indicated by Cogho *et. al.* (1992) may not yet be having a very significant effect on water quality in the Sand River.

(ii) Runoff from the eastern half of the town of Harmony (located on the right bank of the Sand River) makes relatively little contribution to the salinisation of the Sand River.

The lack of flow data and water quality monitoring in the Rietspruit prevents conclusive verification of these two deductions. It is still possible that pollution inputs from these two potential sources is being masked by dilution with catchment runoff and the already polluted state of the Sand River.

(d) Station HAR4 to DWA3

Fig. 4.7 shows an increase in the median EC of 12 mS/m between the pipe bridge (station HAR4 - see Fig. A.3) and the Sand River downstream of the point of discharge of Harmony Mine's sewage effluent at Virginia Park (station DWA3). However, this increase is statistically insignificant at the 80% confidence level. On five occasions between 11 June 1991 and 10 June 1992 pollution incidents were reported when Harmony Mine's processing plant released high salinity water to the Sand River in this river reach.

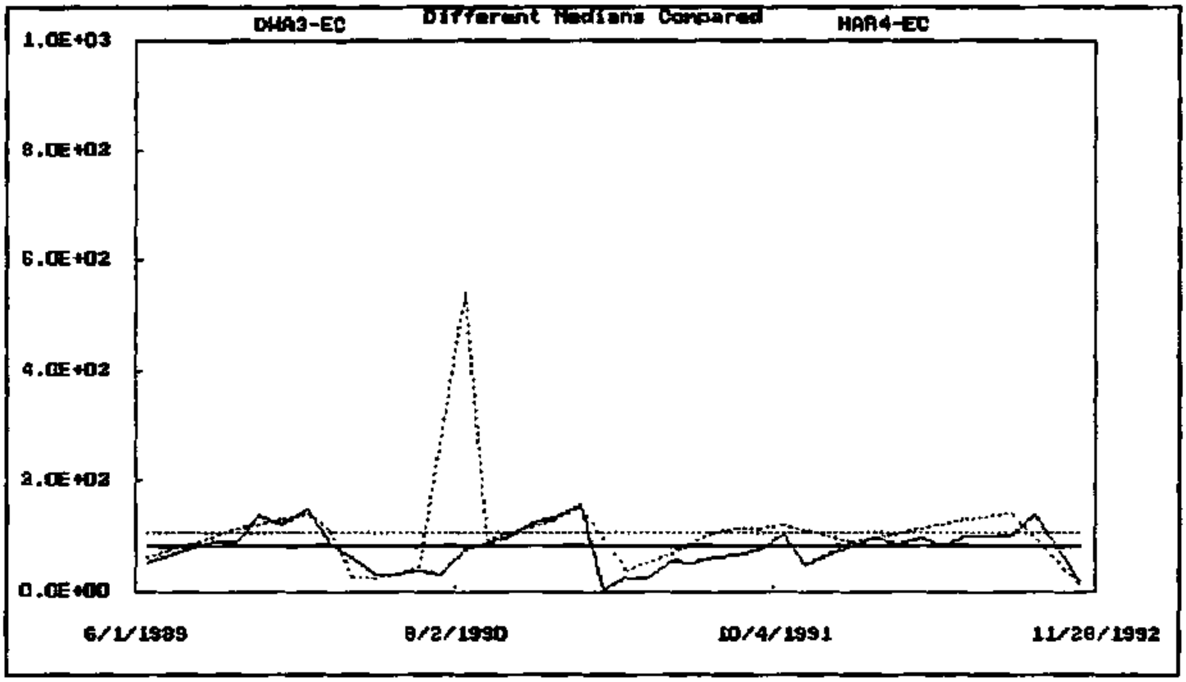

Fig. 4.7 : Comparison of EC values in the Sand River at station HAR4 at the pipe bridge north-east of Virginia (solid line) and station DWA3 at Virginia Park (dotted line) - units: mS/m

The reduction in salinity between stations HAR4 and DW3 suggests that:

(i) Aside from isolated spillage incidents from Harmony Mine's reduction works, there do not appear to be any significant saline pollution sources between stations HAR4 and DWA3.

(e) Station DWA3 to DWA4

Fig. 4.8 shows a relatively small increase in the median EC of 11 mS/m between stations DWA3 (Virginia Park - see Fig. A.4) and DWA4 (Sand River near Desna farm, about three kilometres upstream of the Sand River Canal). However, since the sample is small, the difference in median values is statistically insignificant at the 80% confidence level. Although the median nitrate and phosphate concentrations show no change, increased peak phosphate and nitrate levels indicate occasional pollution events.

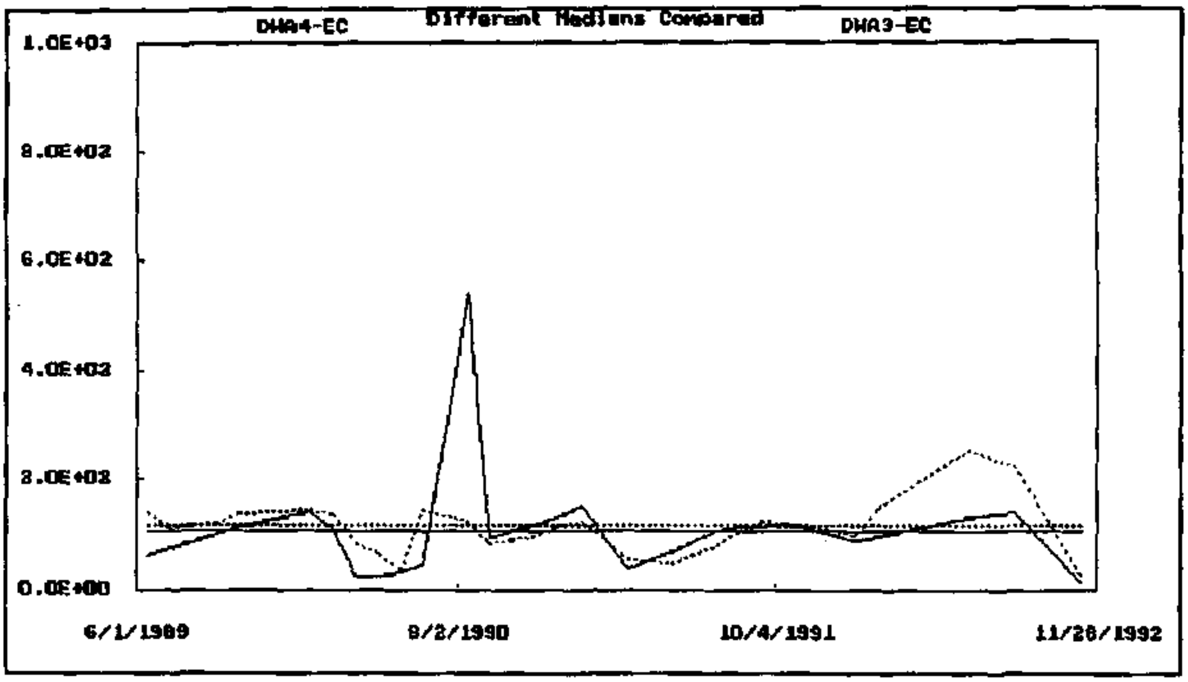

Fig. 4.8 : Comparison of EC values in the Sand River at station DWA3 at Virginia Park (solid line) and station DWA4 at Desna farm (dotted line) - units: mS/m

SRK (1993) found an area of pollution at De Kroon in the form of seepage from the north bank of the Sand River between the points CP and CX (shown in Fig. A.4). Flow along a 150 m length of seepage face was measured at 1 l/s and an Electrical conductivity of 700 mS/m was measured. This gives a load of 11.8 t/month. Wet weather readings gave much lower electrical conductivity readings, between 20 to 190 mS/m for the Sand River, which shows that the Sand River/Sand River Canal system is considerably flushed by stormwater. A large slimes dam complex belonging to Harmony Mine (H1+H3A+H3B and H3 in Fig. A.4), a number of smaller toe dams (dams TR, B, C and D) and part of Harmony Mines large Video evaporation area are located to the north of the Sand River between points CP and CX. Fig. A.4 indicates the Sand River Canal as an alternative source of the seepage.

A small stream leading from the Merriespruit section of Harmony Mine enters the Sand River from the south between stations DWA3 and DWA4. This stream is dammed in two places by the Convent dam and the Lower Convent Dam. Appendix D shows that high EC values (with averages in excess of 500 mS/m) have been recorded in all of these polluted water storage facilities.

The relatively small increase in salinity between stations DWA3 and DWA4, together with other evidence, leads to the following tentative conclusion:

(i) Based on scientific field observations, at least some seepage into the Sand River is taking place between points CP and CX (see Fig. A.4).

(ii) During dry weather there is less pollution emanating from the observed seepage front on the north bank of the Sand River than might be expected and there is little or no seepage or spillage from the storage facilities to the south in the Merriespruit section. However, since the sampling frequency is only monthly, the data provides little information regarding the relative inputs during wet weather. Information received from the DWA&F OFS Regional Office indicates that during rain storms there is definite spillage from the Convent Dam and the Lower Convent Dam (personal communication, 1993).

(iii) urban runoff from the western portion of Virgina may account for the observed increase in peak nutrient levels at station DWA4.

Given the rather short water quality record, low frequency (monthly) sampling frequency, total absence of flow gauging and the already elevated EC levels in the Sand River, it is impossible to verify the second deduction regarding the significance of the seepage.

(f) Station DWA4 to DWA6

Fig. 4.9 shows a large and statistically significant increase in the median EC of 140 mS/m between monitoring stations DWA4 (Desna farm - Fig. A.4) and DWA6 (WW Huis, a few kilometres downstream of the Sand River Canal).

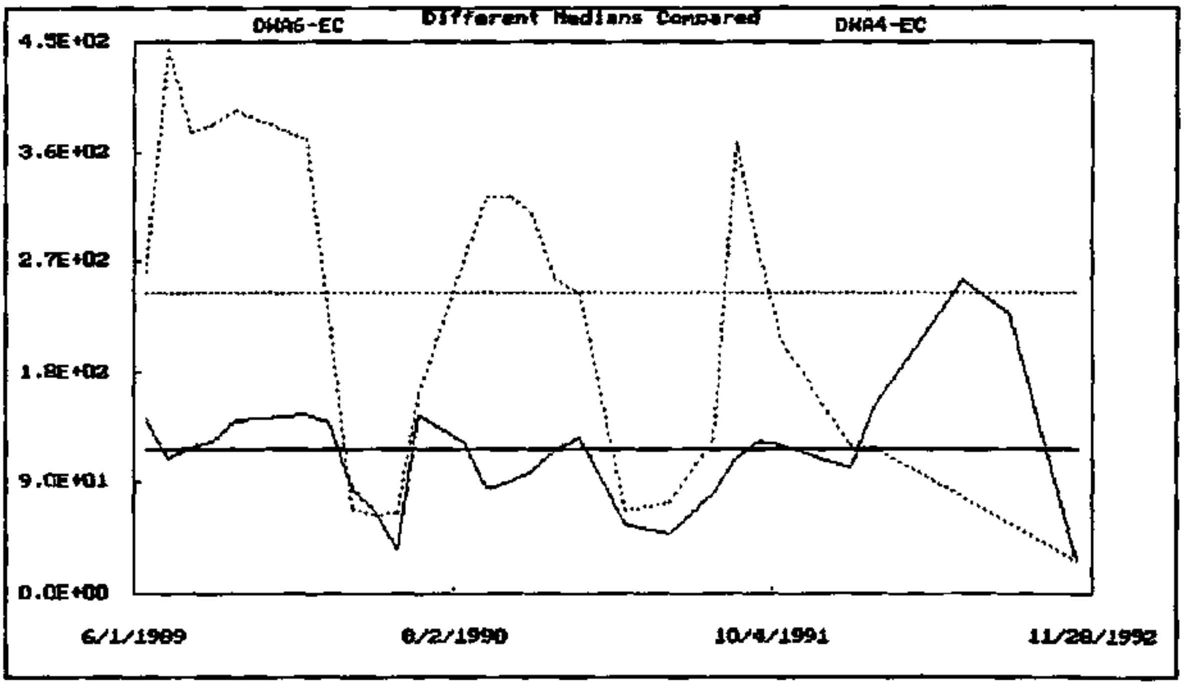

Fig. 4.9 : Comparison of EC values in the Sand River at station DWA4 at Desna farm (solid line) and station DWA6 at "WW Huis" downstream of the Sand River Canal (dotted line) - units: mS/m

Both the median and peak EC levels in the Sand River have doubled between these two stations. Appendix D shows that the concentrations of all of the main ions have increased accordingly. The large increase in the median EC (equivalent to an increase in TDS concentration of about 1000 mg/l) is attributable to the influence of the Sand River canal, which is the only identified pollution source located between the two monitoring points.

It can be concluded that:

(i) The Sand River canal represents a highly significant pollution input to the Sand River.

(g) Station DWA6 to HAR5

Although Fig. 4.10 shows a 40 mS/m decrease in the median EC value in the Sand River between the stations DWA6 (WW Huis - see Fig. A.7) and HAR5 (about 2,5 km further downstream), the small sample size renders the difference statistically insignificant at the 80% confidence level. The hypothesis of no change in the median EC between stations DWA6 and HAR5 is supported by the fact that the average EC showed no change (see Appendix D). Moreover, the incremental catchment between the two stations is small. However, it is not inconceivable that some dilution could occur due to tailwater spillage from the ends of farmer's irrigation canals.

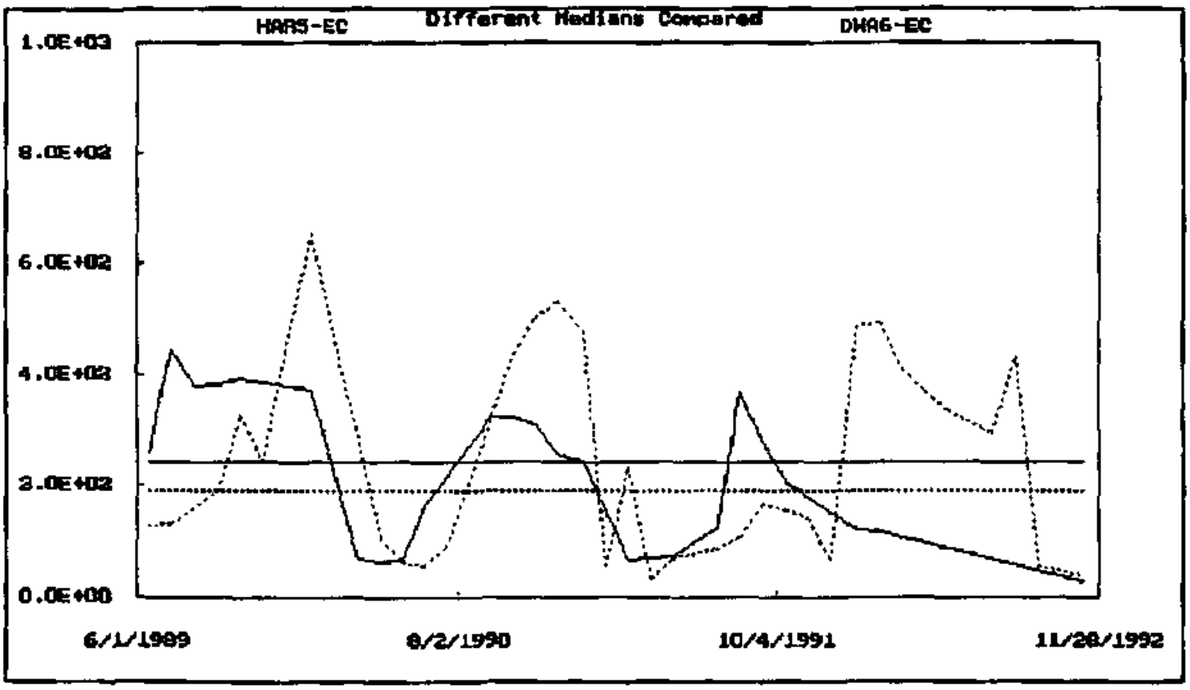

Fig. 4.10 : Comparison of EC values in the Sand River at station DWA6 at "WW Huis" (solid line) and station HAR5 2,5 km further downstream (dotted line) - units: mS/m

(h) Station HAR5 to DWA7

Fig. 4.11 shows a statistically insignificant 11% increase in the median EC in the Sand River between stations HAR5 and DWA7 (Blaaudrift road bridge, which is downstream of the Doring River - see Fig. A.7). The observed reduction in peak dry weather EC values could be due to dilution by tailwater spillage from farmer's irrigation canals. During dry weather the Doring River is generally dry and has little influence on water quality in the Sand River. The small increase in the median EC, despite the reduction in peak values, indicates that the Doring River may be a significant TDS pollution source during wet weather. From the above it can be concluded that:

(i) During dry conditions dilution of the Sand River occurs between stations HAR5 and DWA7. Irrigation tailwater is the most likely source of diluting water.

(ii) During dry conditions pollution sources in the Doring River have little influence on water quality in the Sand River. This is because the lower portion of this stream generally dries up in winter. This does not preclude the possibility of substantial pollution reaching the Sand River via the Doring River during wet weather.

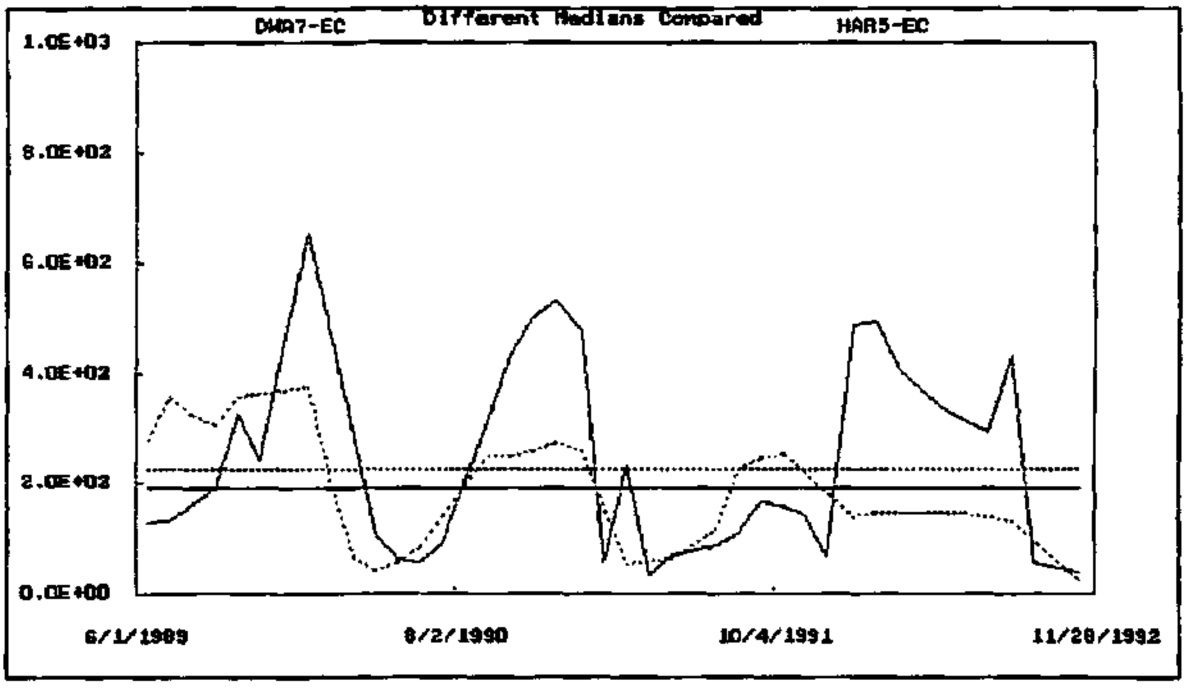

Fig. 4.11 : Comparison of EC values in the Sand River at station HAR5 (solid line) and station DWA7 downstream of the Doring River confluence (dotted line) - units: mS/m

(i) Station HAR1 to DWA7

The large deterioration in salinity brought about by the OFS Goldfields mining developments is illustrated by Fig. 4.12, which compares EC values in the Sand River at Station HAR1 (at the railway bridge upstream of Harmony - Fig. A.3) with station DWA7 (at Blaaudrift bridge, downstream of the mining areas - Fig. A.7). During the period shown in Fig. 4.12 there is a statistically significant net increase in the median EC of 200 mS/m (i.e. an increase of nearly 700%) and a similar proportional increase in peak EC values. Similarly large increases in most of the main ions comprising the TDS have occurred. The dominance of chloride in the pollution sources is demonstrated by the fact that the median chloride concentration has increased by no less than 2000% (see Appendix D). Chloride is also the most dominant anion present in the mining waste water.

The following overall conclusions can be drawn:

(i) Serious salinisation of the Sand River occurs between the Western extremity of Virginia and Blaaudrift bridge.

(ii) Mining activities appear to be the main cause of the deterioration in water quality.

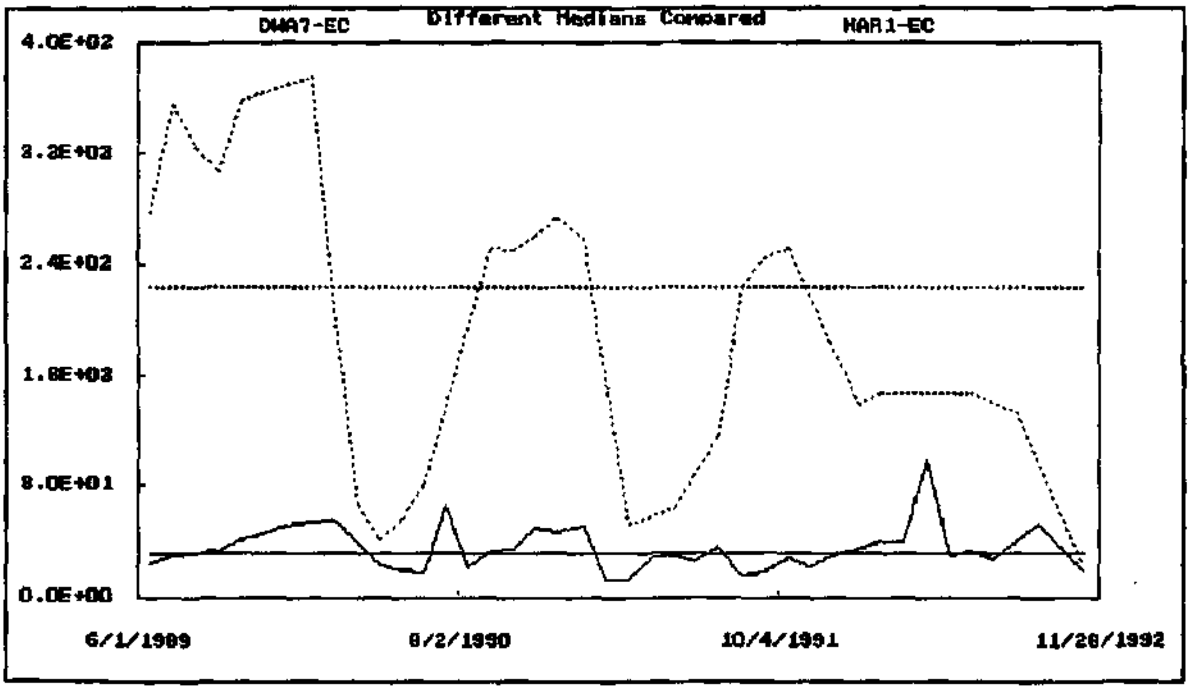

Fig. 4.12 : Comparison of EC values in the Sand River at station HAR1 upstream of Harmony (solid line) **and station DWA7 downstream of the Doring River confluence** (dotted line) **- units: mS/m**

(j) Station DWA7 to mouth of Vet River

There are no more mining areas or significant urban areas downstream of Blaaudrift bridge. The only other man made inputs are irrigation return seepage and water releases from the Sand-Vet GWS canals. In the remainder of the Sand River the irrigation return flows are expected to dilute the polluted river water. This is because the TDS concentration in the supply water from the canals is low. In the case of the Vet River upstream of the confluence the irrigation return flows should lead to an increase in TDS concentrations, although these should remain well below the levels in the Sand River. Downstream of each of the five canal release points the water quality should improve in steps. Further downstream there should be a steady deterioration in water quality as the cascading re-use of irrigation return flows mixed with river water reduces the flow, thereby concentrating the salts. The above description of the change in salinity in the river reach between Blaaudrift bridge and hydrological station C4H004 on the lower Vet River is based on deduction alone, since there are no intermediate flow or water quality monitoring stations. However, the water quality data at station C4H004 (with a mean EC of 49 mS/m) substantiates the main deduction that there is considerable dilution downstream of Blaaudrift bridge.

Conclusions:

(i) There are no significant mining or urban pollution sources downstream of Blaaudrift bridge (monitoring station DWA7).

(ii) The lower Sand and Vet Rivers are substantially diluted by irrigation tailwater, releases from the Sand-Vet canals for riparian water use and natural catchment runoff. This results in a large improvement in water quality.

(iii) Despite this dilution, the lower Vet River water quality is significantly affected by pollution sources in the OFS Goldfields region.

4.3.2 Merriespruit

No water quality data was available to estimate the possible impact of Meloding on the Merriespruit.

4.3.3 "Waste dump stream" and "donga dump stream" (east of Virginia)

Fig. 4.13 shows the strong upward trend in the median EC values in the "waste dump stream" at a small weir which is known to spill into the Sand River during wet weather. The median EC at this station has risen at a rate of 12.6 mS/m per annum (i.e. equivalent to an annual TDS increase of about 88 mg/l, giving a total increase over the period of about 1230 mg/l).

A similar trend was observed for the "donga dump stream", however, this stream is controlled by a dam at which Harmony Mine operates a return water pump. Direct spillage from this source is therefore unlikely.

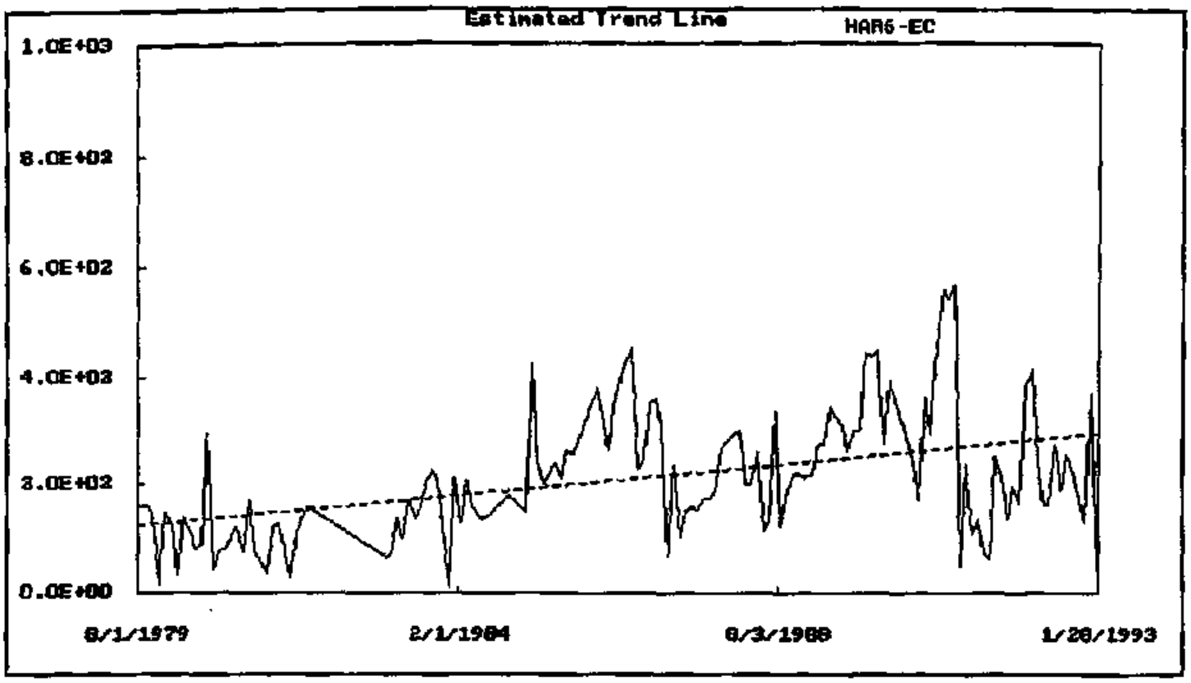

Fig. 4.13 : Trend in median EC values in the "waste dump stream" at station HAR6
(units: mS/m)

The upward trends of EC in these two small streams, and in the Sand River immediately downstream of them, indicates the following:

(i) Harmony Mine's Virginia Section waste dumps are causing severe local pollution of the "Waste dump stream" and the "donga dump stream".

(ii) The pollution levels in these two streams appear to be increasing.

4.3.4 Rietspruit

Fig. A.3 shows the sub-surface seepage zone from Harmony Mine's no. C1 slimes dam towards the Rietspruit that was identified by Cogho *et. al.* (1992) from the analysis of borehole water quality samples.

There is insufficient water quality data available for the Rietspruit to draw definite conclusions regarding the impact on river water quality of this pollution source. The reduction in recorded EC values between the Sand River monitoring stations HAR3 and HAR4 indicates that the dilution afforded by natural runoff has a larger beneficial effect than the detrimental effect of the sub-surface seepage to the Rietspruit. This implies that the sub-surface flow rate is low. However, this does not necessarily mean that the contribution is insignificant as this depends on the relative magnitudes of the natural flow rates in the Rietspruit and the Sand River.

4.3.5 Sand River Canal

The large increase in salinity between monitoring stations DWA4 and DWA6 indicates the presence of a major pollution source. The Sand River Canal, which discharges into the right bank of the Sand River from a northerly direction is the only plausible source of this pollution. This canal drains the Welkom area and also picks up seepage from mine slimes dams and waste water disposal sites. The median EC measured in this canal at monitoring station DWA5 in the canal was 830 mS/m from October 1988 to September 1992 (see Appendix D).

Table 4.2 indicates the deterioration in water quality in the Sand River Canal as measured by Cogho *et. al.* (1992).

TABLE 4.2
Electrical conductivity at different points in the Sand River Canal (Cogho et. al., 1992)

Position number*	Electrical Conductivity (mS/m)
1	380
2	390
3	460
4	500
5	800
6	740

NOTE: * Refer to Fig. A.4, Appendix A.

Cogho *et. al.* gave an estimate of the flow in the canal on 21 June 1989 at 1.8 m^3/s at a TDS concentration of 3575 mg/l (see Table 4.3), which corresponds to a daily TDS load of 556 t per day. They estimated the flow in the Sand River just upstream of the canal at 8.2 m^3/s. However, these flow estimates appeared to be much too large for the middle of winter. Upon further enquiry it was ascertained from the authors that the measurements actually took place during March or April 1988, during and extremely wet period immediately following the massive floods of late February/early March 1988 (H. Pretorius - personal communication, 1993). The revised date renders the high flows given in Table 4.3 much more plausible. After these floods the gold mine's surface storage facilities were full and increased de-watering of underground mine workings was necessary, resulting in a high flow rate in the Sand River Canal.

TABLE 4.3
Salt loads of the Sand River and the Sand River Canal sometime in March/April 1988* **(Cogho, 1992)**

Site	Electrical Conductivity (mS/m)	Flow (m^3/s)	TDS (mg/l)	Salt load (t/day)
Sand River above Virginia	19	7.9	124	85
Sand River above the Sand River Canal	112	8.2	728	541
Sand River Canal	550	1.8	3575	556
Sand River at Bloudrif	185	11.5	1202	1194

NOTE: * Cogho *et. al.* (1992) give the date of the observation as 21 June 1989. However, on further enquiry this date was found to be in error and was revised to some time in March or April 1988.

If it is assumed that most of the flow observed by Cogho *et. al.* in the Sand River Canal originated from pollution sources and that 124 mg/l (as measured in the Sand River upstream of Virginia) is representative of the natural catchment runoff salinity, then Table 4.3 implies that the natural TDS contribution from the OFS Goldfields catchment during the observed event would have been of the order of only 19 t per day. Hence pollution sources in the area were adding about 1090 t per day, of which 42% originated from sources upstream of the Sand River Canal, 51% was discharged via the Sand River Canal and the remaining 7% was derived from the downstream catchment (most probably the Doring River). A TDS pollution load input rate of 1090 t per day is equivalent to an annual contribution of nearly 400 000 t per annum, if sustained for an entire year. However, during the relatively dry five months of the 1987/88 hydrological year preceding the late February flood the TDS load input rate is likely to have been very much lower. The discharge rate also declined considerably during the later winter months. Hence the annual pollution source contribution during 1987/88 would have been substantially lower than 400 000 t. This is supported by the observed and virgin TDS load estimates given in section 8.3, which indicate that during the 1987/88 hydrological year pollution sources in the OFS Goldfields area increased the annual TDS load by about 60 000 t.

During a more recent site visit of the area, it was reported by staff of the OFS Regional Office that EC readings of 600 - 700 mS/m , indicating TDS concentrations of the order of 4000 to 5000 mg/l, are common at the SRK V-notch weir E (refer to Fig. A.4, Appendix A for the location). On the day when the site was inspected (3 December 1992) the EC was measured at 386 mS/m (i.e. about 2700 mg/l TDS). The lower than reported EC during the site visit was attributed to dilution caused by the rainy conditions.

The following sources of pollution in the Sand River Canal were identified by the DWA&F OFS Regional Office during an investigation in 1989 (Van der Merwe, 1989):

a) Leakage from slimes dams near the canal.

b) Inflow from a return water channel (between dam 13 and position 2 at the mine road crossing).

c) Inflow of poor quality water from the Harmony evaporation areas.

d) Mine water which overflows from Freegold and/or Unisel through dam 33's overflow.

During this investigation, the overflow from the mines was approximately 60 l/s.

A study was carried out by Steffen, Robertson and Kirsten (SRK) in March 1993 - "Preliminary Study of Pollution of the Sand River". In the dry season it was found that there are generally fairly large pools of standing water formed by overflow and seepage from evaporation dams.

The Sand River Canal is intended for stormwater use and has its origin near the President Steyn Mine (refer to Fig. A.4). Stormwater from Thabong and Riebeeckstad enters this canal. Stormwater from the western parts of Welkom flows into another canal near the President Steyn mine which joins the Sand River Canal south of President Steyn mine. In times of drought, this (unnamed) canal is used to route water to the Freegold mines. A third canal runs from the President Steyn mine return water dam to dam 13 of Free Gold.

SRK constructed five V-notch weirs in the Sand River Canal to measure flow volumes (marked A to E in Fig. A.4). Flows were measured in the dry season from June to August 1992 and the average flows at the V-notch weirs over this period were as given in Table 4.4:

TABLE 4.4
Flow at V-notch weirs in the Sand River Canal (June - August 1992)

Notch	Flow (l/s)
A	2
B	0
C	2
D	4
E	4

V-notch D is located just downstream of the confluence of the main leg of the Sand River Canal and the stream to Dam 33, therefore the flow in this stream can be taken as 2 l/s. The flow at notch A is scalped back to the President Steyn mine.

These flow estimates are nearly three orders of magnitude lower than those made by Cogho *et. al.* (see Table 4.2). However, during the dry conditions that prevailed since the 1988 floods the water balance of the mines improved very significantly, resulting in much less spillage to surface streams.

Electrical Conductivity readings of up to 1990 mS/m were recorded in pools of standing water in the canal. This water will at some stage be washed down into the Sand River. Between stations BN and BU at Vermeulenskraal (shown in Fig. A.4), dry weather flow was measured at 4 l/s and conductivity at 450 mS/m. This gives a load of about 30.3 t/month. Sampling points were taken at 100 m intervals along the length of the Sand River Canal and conductivity graphs have been given in Appendix E along with a water quality table (all this data was obtained from the SRK report). In the dry periods, conductivity readings of between 500 and 1000 mS/m were common and at times went right up to 2000 mS/m. In wet weather, there was a distinct decrease in conductivity values down to between 160 and 250 mS/m except in close proximity to President Steyn Mine where values of 500 mS/m to 700 mS/m were obtained. In January 1992, conductivity readings of between 800 mS/m and 1400 mS/m were measured in the canal from Dam 33 to the Sand River Canal.

This contention is supported by direct measurement in the canal itself, which reveal extremely high EC levels, and the geophysical surveys carried out by SRK (1993), which indicated sub-surface seepage towards the Sand River along the line of the canal. According to Cogho (personal communication, 1993) electro-magnetic surveys can sometimes yield misleading results when applied to Karoo sediments. However, in this instance the presence of visible seepage faces appears to conclusively confirm the findings of the geophysical surveys.

From water quality monitoring in the Sand River, SRK found that pollution was entering the river at Vermeulenskraal North and De Kroon. Geophysical techniques such as electromagnetic methods, magnetic methods and resistivity methods were then used to analyze ground water pollution. Pollution plumes were then mapped out. It was found that the De Kroon pollution plume appears to originate from Harmony slimes dam. Another pollution plume was found below Unisel. The most likely source is the slimes and effluent dams, particularly the Jurgenshof/Dam 13 complex.

SRK found that during wet weather flows, conductivities in the Sand River Canal ranged from 160 to 250 mS/m except in the vicinity of President Steyn No. 5 slimes dam where conductivities of 500 to 700 mS/m were measured. They also found that small quantities of polluted surface water occur during dry weather in the stream bed leading from the Jurgenshof Dam/Dam 13 complex to the Sand River Canal. This polluted surface water is a manifestation of polluted ground water flow.

The main conclusions regarding the Sand River Canal are as follows:

(i) The Sand River canal is highly polluted and makes a very substantial contribution to the salinisation of the Sand River.

(ii) Welkom and the Thabong township may contribute some storm water runoff. However, it is highly unlikely that such runoff could contribute significantly to the exceptionally high EC levels recorded in the canal. Moreover, the Welkom City Council is at present diverting most of its storm water runoff into Witpan.

(iii) High EC levels measured by SRK (1993) adjacent to President Steyn's Nos. 5, 3, 1 and 6 tailings dams, a return water dam (opposite tailings dam no. 1) and waste water storage dam no. 13 point to these sites as potential pollution sources. However, the high EC levels in this upper portion of the Sand River Canal were measured in deep pools of standing water that were separated from the downstream portion of the canal by stretches of dry canal. It follows that these storages contribute little (other than possibly sub-surface drainage in the direction of the canal) to the dry weather input of the Sand River Canal to the Sand River. Nevertheless, during wet weather these pools of saline accumulated seepage water are flushed out into the Sand River. During such wet conditions the rate of seepage into the canal may also increase, although there is insufficient flow and water quality data to confirm or refute this possibility.

(iv) The Sand River canal passes close to portions of Harmony Gold Mine's Video evaporation paddocks. However, during dry weather portions of the canal immediately downstream of these paddocks were observed to be dry (SRK,1993), indicating that they are not a significant source of pollution during dry weather. (Although this does not rule out the possibility of inputs during wet weather).

(v) High EC values were measured in a small stream entering the Sand River Canal from a north-easterly direction (at point D in Fig. A.4). This stream was observed to flow continuously and appears to be the only contributor to the lower portion of the Sand River Canal during dry weather. (The Sand River is perennial downstream of point D.) SRK (1993) concluded that the most likely pollution sources feeding this stream are the President Steyn/President Brand complex of waste water dams located upstream of Unisel Gold Mine in the vicinity of Dam 13 and Jurgenshof Dam (dam 32). The sub-surface seepage from this area appears to reach dam 33 (downstream of Unisel Gold Mine) from where it seeps into the stream. According to SRK, Unisel Gold Mine does not appear to be contributing significantly to the pollution of this stream. (Since there are no polluted water storage dams in operation on their property, any such contribution could only be by direct discharge to the surface. Presumably any such discharge should be fairly obvious and would have been detected by now if it has been occurring.)

4.3.6 Doring River

Beatrix, Joel and Oryx gold mines and the Star diamond mine are located in the Doring River catchment (see Figs. A.6 and A.7).

Despite the obvious reduction in peak EC levels between monitoring stations HAR5 and DWA7, Fig. 4.11 shows an 18% increase in the median EC downstream of the Doring River confluence. Although the sample size is too small for this increase to be significant at the 80% confidence level, given the reduced peak values (which generally correspond to dry conditions) the increased median EC provides indirect evidence of significant diffuse source pollution load inputs via the Sand River during wet conditions.

Appendix D shows a median EC in the Doring River at station DWA1 of 343 mS/m, with peak levels as high as 482 mS/m. This gives concrete evidence of severe pollution of the Doring River. The most plausible sources of this pollution are Beatrix Gold Mine, which is located in the Theronspruit tributary, or Joel Gold Mine, which is located in the headwaters of the Doring River, (or both).

Joel Mine straddles a small stream in the headwaters of the Doring River due east of the Theronspruit. The OFS Regional Office indicated that Joel Mine contributes little by way of surface water pollution. This is consistent with a new mine that is still in the initial development stages.

Oryx Mine, located in the Bosluisspruit, is also a potential source of pollution of the lower Doring River.

During dry weather there is little (if any) flow contribution from the heavily polluted portions of the Doring River and its tributaries, the Bosluisspruit and the Theronspruit. The lower portion of the Doring River often ceases to flow during the winter period. Hence, although large portions of the upstream river system is heavily polluted locally, the base flow pollution load entering the system during dry weather is relatively small, in the context of the main stem of the Sand River. This does not preclude the possibility of more significant pollution export during wet weather or during pollution incidents.

It can be concluded that:

(i) The Doring River itself is severely polluted by upstream mining activities.

(ii) Most of the pollution appears to originate in the Theronspruit.

(iii) As yet Joel Mine does not appear to be a significant pollution source. However, this situation could change as this relatively new mine develops further.

(iv) The polluted base flow in the Doring River is small and has little influence on the peak TDS concentrations experienced in the Sand River during dry weather. However, it could still make a significant contribution during wet weather.

4.3.7 Theronspruit

The Star diamond mine is located in the headwaters of the Theronspruit (see Fig. A.6). The DWA&F OFS Regional Office indicated that little pollution is evident from this diamond mine.

Beatrix Mine is located downstream of the Star diamond mine adjacent to the west bank of the Theronspruit (see Fig. A.6). There is evidence of significant pollution of the Theronspruit by Beatrix Gold Mine. Cogho *et. al.* (1992) identified a large seepage zone extending towards the Theronspruit from Beatrix Mine. This seepage area is indicated in Fig. A.6 (see Appendix A). The DWA&F OFS Regional Office reported that intermittent surface discharges of water were made by Beatrix Mine to the Theronspruit from 1988 to 1992, when these releases were stopped.

During the course of the Cogho *et. al.* study, some of the evaporation dams of the Beatrix Mine discharged excess effluent water via two canals into the Theronspruit, which reaches the Doring River and finally flows into the Sand River.

During a site visit in December 1992, EC readings were taken at certain strategic locations. The highest EC readings were taken at a mine water collection sump at Beatrix Mine (555 mS/m), and in the Theronspruit near Joel Mine (342 mS/m). Although the Beatrix Mine collection sump EC is the highest, this water will be returned to an evaporation area and should therefore not affect any river water quality. The high EC in the Theronspruit, which showed a steady base flow at the time, is a cause for concern. This pollution is thought to emanate from Beatrix Mine.

From the above it can be concluded that:

(i) The Theronspruit is severely polluted.

(ii) Wide spread ground-water contamination in the vicinity of Beatrix Mine appears to be the main cause of the pollution.

(iii) The dry weather seepage rate is relatively small. However, this does not preclude the possibility of larger dissolved solids export to the downstream river system during wet weather.

4.3.8 Bosluisspruit

The OFS Regional Office indicated that there is little pollution of the Bosluisspruit, which drains the Oryx Gold Mine area (see Fig. A.7). However, no water quality data was provided to support this assumption. Only one water quality sample could be found for the Bosluisspruit, which was taken by Cogho *et. al.* (1992) on 5 June 1989. This sample showed an EC of 194 mS/m. This EC value is far too high to represent natural background winter conditions and therefore indicates at least some pollution of the stream by Oryx Gold Mine. During winter the flow in the Bosluisspruit appears to cease.

From the above it can be concluded that:

(i) The Bosluisspruit is polluted by Oryx Mine.

(ii) During dry weather conditions the contribution of Oryx Mine to the pollution of the Sand River appears to be negligible. However, this does not necessarily preclude the possibility of significant TDS pollution loads being washed from this area during wet conditions.

4.3.9 Mahemspruit

A man-made canal coming from within the premises of the Western Holdings Gold Mine (located immediately north-west of Welkom) and in close proximity to the D dam return water facility, discharges effluent directly into a farmer's dam which, in turn, overflows into the Mahemspruit (see Fig. A.5). Water with an electrical conductivity in excess of 350 mS/m, has been sampled more than 6 km west of this facility, as it flows down the stream. The Mahemspruit does not appear to link up with the Sand River, but instead terminates in an enclosed drainage area.

It can be concluded that:

(i) The Mahemspruit is severely polluted by Western Holdings Gold Mine.

(ii) The pollution of the Mahemspruit appears to be localised and does not affect the greater Sand-Vet River system.

4.3.10 Witpan

Witpan is located immediately south-east of Welkom (see Fig. A.4). Various stormwater channels which flow to Witpan regularly carry pollution from the mines and industries to this pan. Seeing as the Witpan sewage treatment works (which is located on the northern shoreline of Witpan) functions well above its design capacity, raw sewage is sometimes channelled to Witpan during problematic periods.

4.3.11 Doringpan

Doringpan is located to the east of Welkom (see Fig. A.4). In the past this pan was used as an effluent disposal site by the NCP yeast factory. This practice has since been discontinued. Mining waste water is also disposed of in Doringpan. The water stored in Doringpan is therefore saline.

4.3.12 Blesbokpan

Blesbokpan is located south-west of Doringpan (see Fig. A.4). Until recently (when the factory was closed) the NCP yeast factory discharged effluent over about 24 ha of grassland immediately north of Blesbokpan. The TDS of the effluent discharged from tankers was found to be 32 000 mg/l (i.e. equivalent to that of sea water). The effluent also exhibited a low pH (4,5) and a very high COD (chemical oxygen demand) of 25 000 to 30 000. During the 1988/89 rain season this effluent contaminated parts of the downstream system of pans and wetlands, resulting in the deaths of fish and water fowl.

4.3.13 Torontopan and Flamingopan

Torontopan is located adjacent to the south-west corner of Welkom (see Fig. A.5). Flamingopan is located just west of Torontopan. Welkom's solid waste disposal site is located immediately to the north of the pan. However, this will be closing down before the end of 1993. It will be replaced by a new site on an old slimes dam located south of Bronville (President Brand slimes dam B -

see Fig. A.5). Welkom's Theronia STW (sewage treatment works) is located nearby to the south-west and discharges purified sewage effluent to Flamingopan.

The data presented by Cogho *et. al.* (1992) shows that sodium and chloride, followed by sulphate are the most dominant major ions present in the water in Torontopan. This water is highly salinized. Although Cogho *et. al.* found evidence of severe heavy metal contamination of the ground-water in the immediate vicinity of the solid waste disposal site, they concluded that there is no sign of significant pollution of surface streams or nearby pans.

4.3.14 Natural pans used to dispose of mine waste water

In addition to those already mentioned, a number of other natural pans are use to dispose of redundant mine drainage and process water. These include the following:

(a) Dankbaarpan - a large pan located about 15 km west of Welkom,

(b) Brakpan - a smaller pan located just west of Dankbaarpan,

(c) Rietpan - located about 8 km south-west of Welkom (see Fig. A.5),

(d) Wolvepan 1 & 2 - located just east of Rietpan (see Fig. A.5), and

(e) Swartpan - located west of Odendaalsrus (i.e. north of the study area).

4.4 Ground-water quality

An extensive ground-water investigation of the OFS Goldfields region has been carried out by Cogho *et. al.* (1992). This chapter is an overview of the findings of this investigation. The reader is referred to the original report for a more comprehensive insight into ground-water conditions in the study area.

In the central, north and north-western parts of the area, mining has been ongoing at Freegold, St. Helena, Unisel and Harmony Gold Mines (also Loraine which is outside the study area) for about 40 years. Disposal sites in this area, which is relatively flat, are mainly located on Ecca sediments which have low permeability. This has limited the most severe ground-water contamination to within about 5 km downstream of the pollution sources. Cogho *et. al.* suggest that the pollution levels in this portion of the catchment have probably reached a quasi steady state situation.

In the southern parts of the study area, most of the disposal sites are situated on Beaufort sediments which are more permeable than Ecca sediments. In addition, mining (at Beatrix, Oryx and Joel Gold Mines) has only been ongoing for about 10 years and the disposal sites are consequently much younger than the central and northern parts. Another factor is that drainage in the southern areas is well developed towards the Sand River and its tributaries which makes it highly probable that contaminants are actively dispersing. As a result of the more active dispersion and the relative youth of the mines, the contamination levels in the southern areas are not as high as in the northern areas. The worst pollution levels in this area were found to be closer to the source (within about 1 km). This apparently limited spread of contamination is due in part to the relatively young age of disposal facilities and the higher permeability of the Beaufort sediments, which allow wider dispersion and greater dilution. However, although the more permeable sediments in the southern area result in less severe *local* pollution levels, this also implies that whatever ground-water pollution does occur will more readily reach the surface water drainage system. The low observed levels near the pollution sources are therefore not a cause for complacency, since they can imply greater mobility of the contaminants. This is of importance with regard to the wider impact on the Sand River System.

The ancient ground-water in the deep strata that are currently being mined. comprised mainly sodium-chloride of marine origin. The older mines have been almost totally de-watered and therefore there are not great volumes of stagnant sodium-chloride water to remove. However, SO_4 production in these mines has been going on for almost 40 years. As a result the water pumped to surface from these mines shows elevated sulphate levels. Since relatively little ingress of underground water has to be dealt with, these mines pump less water to the surface than is the case for the mines in the southern area. In contrast, the younger mines are de-watering extensively, pumping large volumes of stagnant water to the surface and storing this water in evaporation areas. The chemistry of this water is predominantly sodium-chloride, with relatively little sulphate present.

This provides a useful indirect indication of the source of pollution in ground-water and surface water. However, this is of little practical value since excess water from the southern mines is supplied as process water to the drier northern mines. Hence the dominance of the chloride ion in a polluted river (say, the Sand River) could have seeped from a storage facility belonging to one of the older mines, just as easily as it could have come from one in the south. Furthermore, the dominance of the sodium and chloride ions in natural ground-water, which in some unpolluted areas also exhibits high TDS levels, makes it harder to differentiate between natural and polluted water. In this context, the report by Cogho *et. al.* (1992) states that one of the major problems encountered during their investigation was in distinguishing between ground water with a naturally poor quality and ground water that was polluted due to mining, industrial and municipal activities. This is especially true of the area west and north-west of Odendaalsrust, which is characterised by flat terrain with internal surface drainage to a number of natural pans located on Ecca sediments.

It has been noticed that the Cl^- element has spread to a greater extent than any other ion and therefore the spread of Cl^- contamination can be used as an approximate indicator of the maximum spread of pollution. This indicator should be reasonably valid for the southern mining areas that are located on Beaufort sediments. Further to the north and north-west, where natural pans overlay Ecca sediments, chloride is less reliable as an indicator of mining pollution, since the ground-water is often naturally saline with sodium and chloride being the most dominant ions. In these areas is extremely difficult to differentiate between the effects of mining pollution and naturally a saline ground-water, although high chloride levels surrounding slimes dams or artificial saline water storage facilities do provide additional circumstantial evidence of the likelihood of mining effects.

At Beatrix and Harmony mines, the Cl^- concentrations in the ground water are higher than the concentrations of the other ions (at Harmony SO_4 is also as high). In Fig. 4.14 a contour map of chloride concentrations in the ground water is given for the whole Goldfields area, while Figs. 4.15 and 4.22 (refer to sections 4.8.1 and 4.8.5) show the chloride and sulphate concentrations in more detail for Harmony and Beatrix mines. Closely spaced chloride concentration contours in the vicinity of waste disposal sites offer a reasonably good indication of ground-water contamination. However, this may not always be conclusive, since natural pans are often used as evaporation pans. The natural salinity levels in these pans prior to their use as disposal sites can sometimes account for the high salinity of the surrounding ground-water.

Hodgson (1987) found that mine water disposed of on the surface seems to recharge the ground-water, which reflects some of the characteristics of the mine water. The chemical constituents in the ground water which originate from mine water seem to be aluminium, calcium, chloride, sodium, sulphate and zinc. Chemical constituents originating from mine waters which are not reflected in ground-water are cyanide and lead.

Heavy metals seem to have only increased concentrations in the close vicinity of pollution sources, especially at slimes dams which tend to generate acid mine drainage. It was noticed that the spread of pollution follows the direction of ground water gradients (Refer to Figs. 4.16 and 4.21 in sections 4.8.1 and 4.8.5). The spread of pollution is also exacerbated by sporadic discharges of effluent water into natural surface water systems, e.g. the Mahemspruit which is polluted up to Ganspan near Wesselsbron (west of Welkom and outside the study area).

Cogho *et. al.* identified the following main seepage areas that appear to affect surface water:

(a) In the vicinity of Loraine Mine (outside the study area).

(b) The Harmony Mine new disposal area north of Virginia, consisting of seepage into the Rietspruit River.

(c) The Beatrix Mine disposal area into the Theronspruit.

The pollution plumes delineated by Cogho *et. al.* (1992) for (b) and (c) are shown in Figs. A.3 and A.6 respectively (see Appendix A). Close examination of Fig. 4.14 also reveals chloride concentration peaks, with surrounding high chloride concentration contours that intersect rivers and streams, at the other sites discussed below:

(d) Bosluisspruit in vicinity of Oryx Mine.

(e) Sand River in vicinity of Harmony Gold Mine (Virginia section). This plume appears to originate at or near to the waste disposal sites located just south of the "Waste dump stream" and the "Donga dump stream"may also affect the Merriespruit.

(f) The Sand River in the vicinity of the Sand River Canal. A high chloride plateau covers most of Harmony Mine's Video polluted water disposal site and the President Brand Mine.

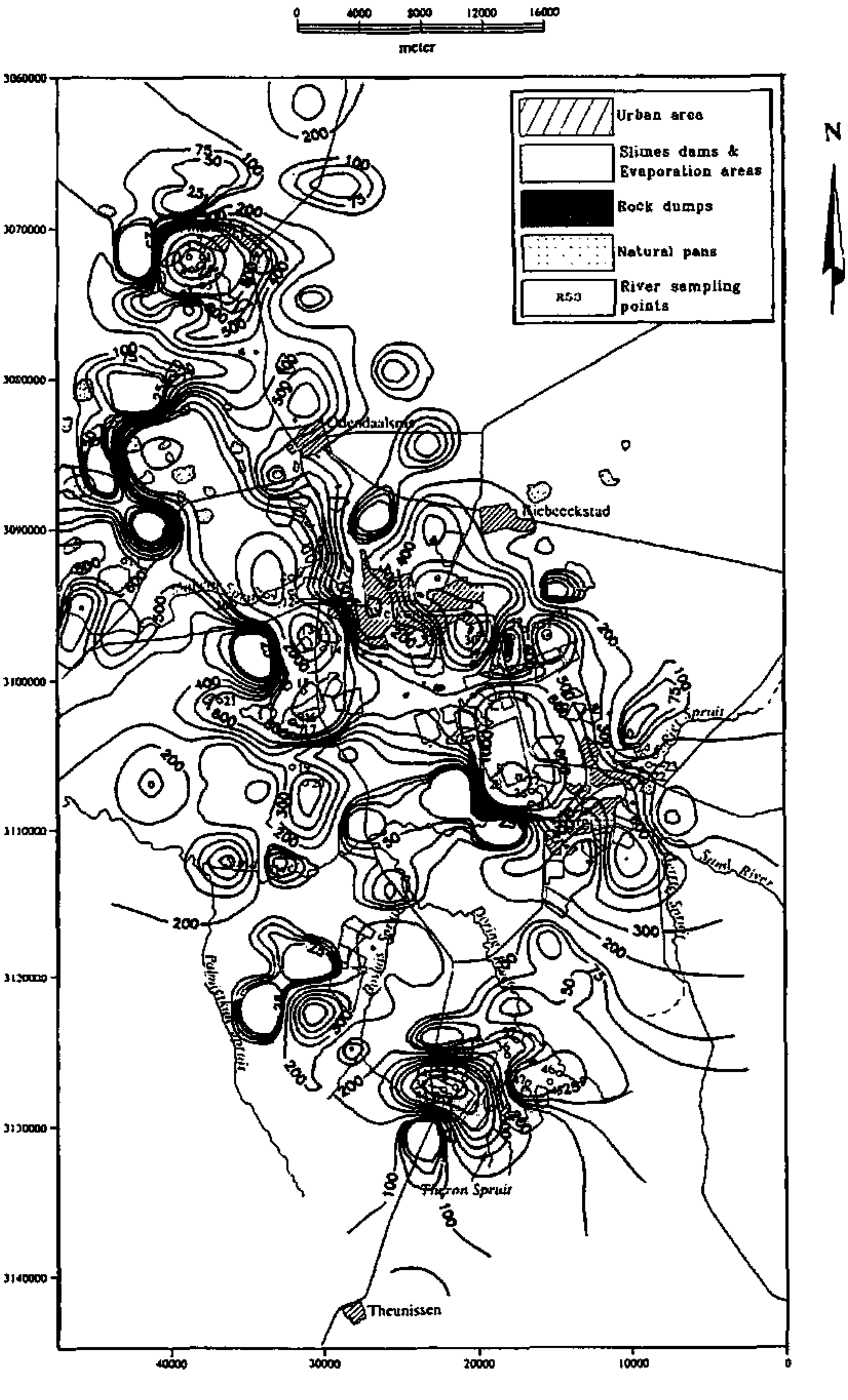

Fig. 4.14 : Contour map of ground-water chloride concentrations (mg/l)

(g) A plume originating from the opposite (south) side of the Sand River in the vicinity of Harmony Mine's Merriespruit section Convent dams appears to merge with the Sand River Canal plume. (However, the two plumes are probably independent of one another since the invert level of the Sand River is near the level of the underlying fine grained bedrock. Since this is the lowest point in the drainage system, it is most unlikely that a pollution plume on one side of the river is affecting ground-water quality on the other side.)

(h) The NCP yeast factory waste disposal site (east of Welkom).

(i) The Welkom waste disposal site/Torontopan area.

(j) Doringpan.

(k) A large area stretching from the St. Helena Mine complex south-west of Welkom to the Freddies Mine complex west of Odendaalsrus. The Mahemspruit intersects this area. This plume merges with another large plume to the north centred on the mines in the Allanridge area.

(l) The pollution plumes surrounding the yeast factory site east of Welkom and the Sand River Canal areas appear to have merged with one of slightly lower intensity centred on the Harmony Mine (Harmony section) and Freestate Saaiplaas mine. This plume is bounded to the south and south-east by the Sand River and the Rietspruit. The latter boundary coincides with the seepage zone identified by Cogho *et. al.*

In areas covered by the Beaufort sediments the high chloride contours provide a reasonable indication of mining pollution (i.e. areas (b), (c), (d), (e), (f), (g), (h), (j) and (l)). The high chloride zones in areas (a), (i) and (k) are less conclusive since they are in Ecca sediments where naturally high chloride levels can occur in the ground-water.

A notable feature is the tendency for the plumes to terminate at significant river courses. For example, Beatrix Mine plume is bounded on the east by the Theronspruit and the Doring River. The Sand River Canal/Harmony plume terminates in the south against the Sand River, and the Virginia section plume is bounded by the Sand River in the east. This is to be expected since the underlying fine-grained sedimentary rock that forms the river bed in many areas is unlikely to transmit much seepage under the rivers. This also means that the polluted ground-water is seeping into the surface water courses in these contact areas. Much of this seepage may not visible, except after periods of heavy rainfall, since in most areas the ground-water level will tend to dip downwards to meet the water level in the river.

4.5 Pollution incidents

The DWA&F OFS Regional Office in Bloemfontein have documented the following incidents:

a) 11/6/91 Harmony Mine's processing plant released effluent to the Sand River. Electrical conductivity of 450 mS/m.

b) 20/6/91 Harmony Mine's processing plant released effluent to the Sand River. No analysis.

c) 25/7/91 Harmony Mine's processing plant released effluent to the Sand River. Dead fish were found. Approximately 200 m^3 was discharged. (Refer to Table 4.5).

d) 13/10/91 Harmony Mine's processing plant released effluent to the Sand River. No analysis.

e) 10/6/92 Harmony Mine's processing plant released effluent to the Sand River. Approximately 200 m^3 was discharged. (Refer to Table 4.5). This pollution occurred at the point marked "Harmony Mine effluent outflow point" shown in Fig. A.4, Appendix A. These above mentioned pollution incidents were the subject of a court hearing. A section of the mine causing this pollution was closed down towards the end of 1992.

The DWA&F OFS Regional Office also confirmed the SRK findings that:

f) Pollution occurred periodically in the Sand River Canal and from the Harmony "paddyfields" between points CP and CX in the Sand River (see Fig. A.4).

The OFS Regional Office also found that during a wet season, pollution incidents occurred after a storm at the following locations:

g) Harmony Mine's D dam (see Fig. A.4).

h) Harmony Mine's Dam at Merriespruit (see Fig. A.3).

i) Mahemspruit near Jacobsdal (see Fig. A.5).

j) Various stormwater channels which flow to Witpan regularly carry pollution from the mines and industries to this pan (see Fig. A.4). Seeing as the Witpan sewage treatment works function well above its design capacity, raw sewage is sometimes channelled to Witpan during problematic periods.

k) From 1988, water from Beatrix Mine was discharged into the Theronspruit on an occasional basis (see Fig. A.6). This was stopped in 1992.

Water quality analyses for some of the above incidents are given in Table 4.5.

In addition to the recognised effluent point sources mentioned above, occasional spillages of water from various holding dams have been known to occur from time to time.

TABLE 4.5
Water quality analyses for various pollution incidents

Determinands	10/6/92 (e)	25/7/91 (c)	9/6/89 (k)	10/11/92 (g)	9/2/93 (h)	14/10/92 (f)
pH at 25°C	-	8.0	7.7		7.36	8.02
Conductivity at 25°C (mS/m)	939	586	522		616	569
Dissolved solids at 180°C (mg/l)			3 240			
Suspended solids at 105°C (mg/l)	-				13.00	10.3
Dissolved calcium as Ca (mg/l)	580		600		383	766
Dissolved magnesium as Mg (mg/l)	56		176		46	234
Sodium as Na (mg/l)	1 380		140	1580	933	213
Free and saline ammonia as N (mg/l)	13.4	0.5	<0.2			
Nitrate as N (mg/l)	3.8		5.0		7.89	2.17
Chloride as Cl (mg/l)	2 320		1690	1340	1626.0	1841
Sulphate as So_4 (mg/l)	1 200		120	896	957	827
Total alkalinity as $CaCO_3$ (mg/l)	-					
Ortho-phosphate as P (mg/l)	<0.05		<0.05		2.153	0.00
Oxygen absorbed as O_2 (mg/l)	26					
Chemical oxygen demand as O_2 (mg/l)	ND		54		59.0	1970*
Cyanide as CN (mg/l)		1.11		0.221		

4.6 Overview of effluent point sources

Effluent point sources have been divided into two broad categories:

- Sewage effluent (usually predominantly of a domestic nature)
- Industrial effluent (excluding mines, which have been dealt with in a separate section).

The location of each effluent point source is given in Fig. A.1 (Appendix A).

4.6.1 Sewage effluent sources

If a sewage works does not function effectively, effluent can be produced which does not comply with acceptable standards. When this effluent is discharged into a river it can result in pollution. The enrichment of streams with nutrients i.e. phosphorus and nitrogen can lead to eutrophication and result in water quality characteristics which are undesirable. Eutrophication results in sudden and rapid growth of water plants which have secondary effects which may alter the chemical quality of the water. Algae growth also has negative effects on recreational water use.

High chemical oxygen demand (COD) of a poor quality effluent may result in total eradication of water life in streams and dams.

Various mines and municipalities produce large amounts of sewage effluent daily. The capacities of sewage purification works are given in Table 4.6.

TABLE 4.6
Capacities of sewage works

Sewage Purification Works	Capacity (10^3m^3/day)
Welkom (Thabong)	12
Welkom (Witpan)	27
Welkom (Theronia)	27
Virginia	26
Free State Geduld	5
Beatrix	3.8
Oryx	1.2
Joel	1.5
Senekal	3
Hennenman	2
Winburg	1

Table 4.7 shows the quantity and the use of purified sewage effluent of the major sewage works in the Goldfields.

TABLE 4.7
Quantities of purified sewage effluent disposed in the OFS Goldfields region (as per Cogho *et. al.*, 1992)

Sewage Purification Works	Influent (10^3m^3/day)	Effluent (10^3m^3/day)	Use of Effluent
WELKOM - THERONIA	20	19	Winter: 8 Ml/d re-used by municipality. 11* Ml/d flow into Flamingopan. Summer: Everything re-used by municipality.
WELKOM - WITPAN	30	29	23 Ml/d re-used by mines. 6 Ml/d flow into Witpan.
ODENDAALSRUS	4	3,9	Everything re-used by mines.
VIRGINIA	20	17	Biggest proportion re-used by mines. The rest by municipality. A portion flows into the Sand River.

NOTE: * According to the DWA&F OFS Regional Office the current (i.e. 1993) winter discharge to Flamingopan is less than 4 Ml/d (personal communication, 1993).

4.6.2 Industrial effluent sources

Only one significant industrial effluent point source was located. This is the NCP yeast factory that used to discharge an average of 195 m^3/day of yeast effluent over an area of open grassland of approximately 24 ha near a system of natural pans and vleis near the Blesbokpan (see Fig. A.4). Table 4.8 lists the chemical parameters pertinent to this effluent discharge. The NCP yeast factory recently closed down.

TABLE 4.8
Yeast effluent produced by the NCP Yeast Factory
(as per Cogho *et. al.* (1992)

Constituent	Effluent sampled from tanker	Borehole DD 55 (On the disposal site)
COD	25 000 - 30 000	967
pH	4.5	7.1
EC	4571	460
TDS	32 000	3583

During the 1988/89 rainy season, large amounts of this highly polluted yeast effluent contaminated some of the pans killing fish and bird life.

Since this factory has been closed it is not discussed in any further detail in the remainder of the text. However, the high level of chloride concentration in vicinity of the old factory and waste disposal site (see Fig. 4.14) indicates that the results of earlier contamination of this site may linger for many years to come.

4.7 Overview of diffuse source pollution

Potential diffuse sources of pollution are covered in this section. Although they also retain some characteristics of point sources, developments such as mines and solid waste sites have been included in this category, along with urban areas. This is because the pollution emanating from such developments often spreads over a wide area, commonly via the ground-water, or in the form of uncontrolled intermittent spillage, both of which are extremely difficult to detect and quantify.

4.7.1 Cultivated lands (dry land farming)

Wheat is the most important crop in winter and maize, potatoes and vegetables the most important in summer. Diffuse source pollution can originate from accelerated weathering of natural soils due to the ploughing of cultivated lands, the application of fertilizers, pesticides and other chemicals e.g lime and gypsum. The basic fertilizers are ammonium, phosphate, potassium, zinc (in trace quantities), and dolomitic limestone. Fertilizers are generally leached through the soil into the ground water regime. Most phosphate fertilizers are adsorbed on soil particles and do not contribute to the ground water pollution but nitrogen is only adsorbed to a limited degree. Erosion by wind or water also spreads pollutants. The magnitude of the threat of pesticides and herbicides depends on the properties of the pesticide/herbicide, the volume, whether liquid or solid state and the application rate. Little is known about the potential pollution from this source.

4.7.2 Irrigation return seepage

Irrigation farming has the effect of concentrating salts due to the evaporation of water. It can also accelerate the release of salts from natural soils and underlying rock strata. For both of these reasons, the return seepage from riparian irrigation schemes exhibits a higher salt concentration than that of the irrigation supply water. The area of land under irrigation varies from year to year and the total area actually used is usually unknown. However, at present approximately 11 549 ha are allocated, most of which is located along the banks of the Sand and Vet Rivers.

In the context of the current study irrigation appears to have the following main effects:

(i) Reduction in catchment runoff - Numerous small farm dams and small private irrigation schemes have the effect of reducing runoff. This reduces the dilution available for mitigating the effects of pollution from mining areas and also concentrates salts in the river system.

(ii) Dilution - Return flows in the lower Sand River and the lower Vet River, together with deliberate discharges of irrigation water from the ends of canals for downstream riparian use have the highly beneficial effect of diluting the polluted water emanating from the OFS Goldfields area.

4.7.3 Urban and industrial areas

The main urban areas comprise Welkom, Virginia, Senekal, Ventersburg, Winburg, Theunissen, and Bultfontein. The washoff of dissolved salts from Welkom can be expected to increase in step with industrial and mining development although this development is heavily dependant on the future of the gold mines.

Pollution from urban areas results from washoff of contaminants during storms from CBDs (central business districts), residential and industrial areas. Informal settlements are also beginning to play a major role in some parts of the country.

The pollution from CBDs and both formal and informal residential areas is generally limited to biological contaminants and, to a limited degree, heavy metals resulting from lead in petrol, etc. These developments usually have very little effect on salinity. The biological pollution (in the form of BOD, pathogens and nutrients) is often most severe in informal settlements where there is often little control over sanitation.

Industrial sites can generate virtually any type of pollution. Mineral pollution is commonly associated with wet industries (where water is used in the industrial process). Biological pollution is commonly emitted by food processing industries, while metal finishing industries often give rise to pollution with heavy metals.

In practice it is extremely difficult to separate out the pollution loads from various types of urban development. In the OFS Goldfields region this is rendered virtually impossible by the widespread pollution from mining areas that are intermingled with urban areas.

Solid waste disposal sites are associated with urban developments. Acids resulting from the degradation of solid waste may dissolve minerals, resulting in a highly mineralised leachate. The quality of this leachate from a solid waste disposal site depends on the age of the dump, the composition of the solid waste and the geohydrological characteristics of the underlying strata. Solid waste produced by residential areas and commercial establishments is dumped at three major sites in the study area, two of which are located in natural pans (Welkom and Odendaalsrus - just outside the study area) and the remaining site, which belongs to Virginia, is located on the bank of the Sand River. No significant contamination was observed in the respective pans and river nearby these sites (Cogho *et. al.* (1992).

In industrial areas part of what is classified as diffuse pollution by default is often little more than the sum of a large number of diverse intermittent point sources that have not been detected.

4.7.4 Mines

There are numerous gold mines in the lower Sand River catchment which have constructed a number of large slimes dams. All of these slimes dams have been provided with containment works to prevent the seepage of saline water to local streams. However, the high salt concentrations in the streams draining the mine properties indicate that the containment measures are not totally effective. The inadequacies of some of the works used to intercept and return seepage to retaining dams make inevitable the seepage and spillage of saline water to the Sand River via the Sand River Canal, the Theronspruit and other tributaries. Wind blown mine sand can also contribute to the diffuse source salt washoff from the surrounding catchment.

The gold mine slimes dams and return water dams occupy an area of about 4870 ha. This area is very approximate due to inadequacy of the data supplied by some of the mines. Without recourse to costly and time consuming investigations it is virtually impossible to quantify the pollutant loads seeping from all of the gold mine slimes dams. Such investigations are beyond the scope of the study. Table 4.9 summarises some key details of the gold mine saline water containment works and slimes dams.

TABLE 4.9
Capacity and area of slimes dams

Mine	Capacity	Full surface area (ha)
Beatrix	47.6×10^6 t	147 (120 excluding paddocks)
Oryx	13 500$m^{3\&}$	90 + 35 *
Joel		100 *
Harmony: Harmony Virginia Merriespruit		 576 * 400 * 224 *
St. Helena		348 *
Unisel	0	0
President Brand	135.9×10^6 t	871 *
President Steyn#	127.8×10^6 t	780
Saaiplaas		241 *
Erfdeel	0	0
Free State Geduld	133.4×10^6 t	664 *
Western Holdings	44.5×10^6 t	456 *

NOTES:
- * Planimetered (no other data).
- & The stated capacity of Oryx mine's slimes dam appears to be too small compared with the surface area, since this would imply a height of only 15 mm
- \+ Planimetered value differs considerably.
- \# An area of 265 ha which was part of Welkom Gold Mine has been included in the President Steyn total. It is not known whether Welkom Mine is now part of President Steyn Mine or whether Welkom Mine has been totally closed down.

The following sections contain details of each entity that can be considered as an identifiable potential pollution source. In some cases of pollution, it is extremely difficult to pinpoint which user is responsible for the pollution. This is because some facilities are shared by mines, municipalities or industries. Some mines are very close to each other as well as to a stream or canal and it is extremely difficult to ascertain which mine is causing the pollution. This is also exacerbated by the fact that seepage from slimes dams, evaporation areas etc. is not easily detectable. All the mines have been covered in this section due to the fact that they have a potential for pollution. Inclusion in this section does not in any way imply that a mine or municipality is necessarily responsible for a pollution problem.

Mines and municipalities are dealt with in sections 4.8 and 4.9 respectively.

4.8 Mines

4.8.1 Harmony

General

Harmony mine (see Fig. A.3) is split into three sections, namely: Harmony, Virginia and Merriespruit, and uses deep ground-water with a poor quality. This water is used together with water from other sources until the quality is too poor, whereupon it is channelled to evaporation areas (paddy fields) south of Virginia as well as the farms Video and western parts of Vermeulenskraal. This water was also routed to Jurgenshofdam (which is now owned by Unisel). This practice was stopped in 1987.

This mine used to have its own sewage works but it closed down in 1989 because the outflow was of poor quality.

Flow and Water quality

Reports of water quality are available for the last twenty years at several strategic points. Chloride and sulphate contours are shown in Figure 4.15 and ground water flow directions are given in Figure 4.16.

Disposal of effluent

The only method of disposal of mining effluent is by pumping to evaporation areas.

The new sewage works at Virginia came into operation in 1989 and takes on raw sewage from Harmony. All purified sewage effluent is used for irrigation of parks.

Permits issued to dispose of effluent

Schedule to exemption 870B (30/9/1987) allows for the disposal of industrial effluent of up to 12 000 m^3/day into evaporation dams.

Permit 575N (30/9/1987) allows for the disposal of purified effluent but does not specify any volume.

Capacities of slimes dams, evaporation areas, gravity and pumping pipelines

Areas and capacities of evaporation areas and certain storage dams were received but the slimes dam areas had to be planimetered.

Salinity trends have been examined for a few of the storage dams for which water quality records of reasonable length are available. The results are discussed below:

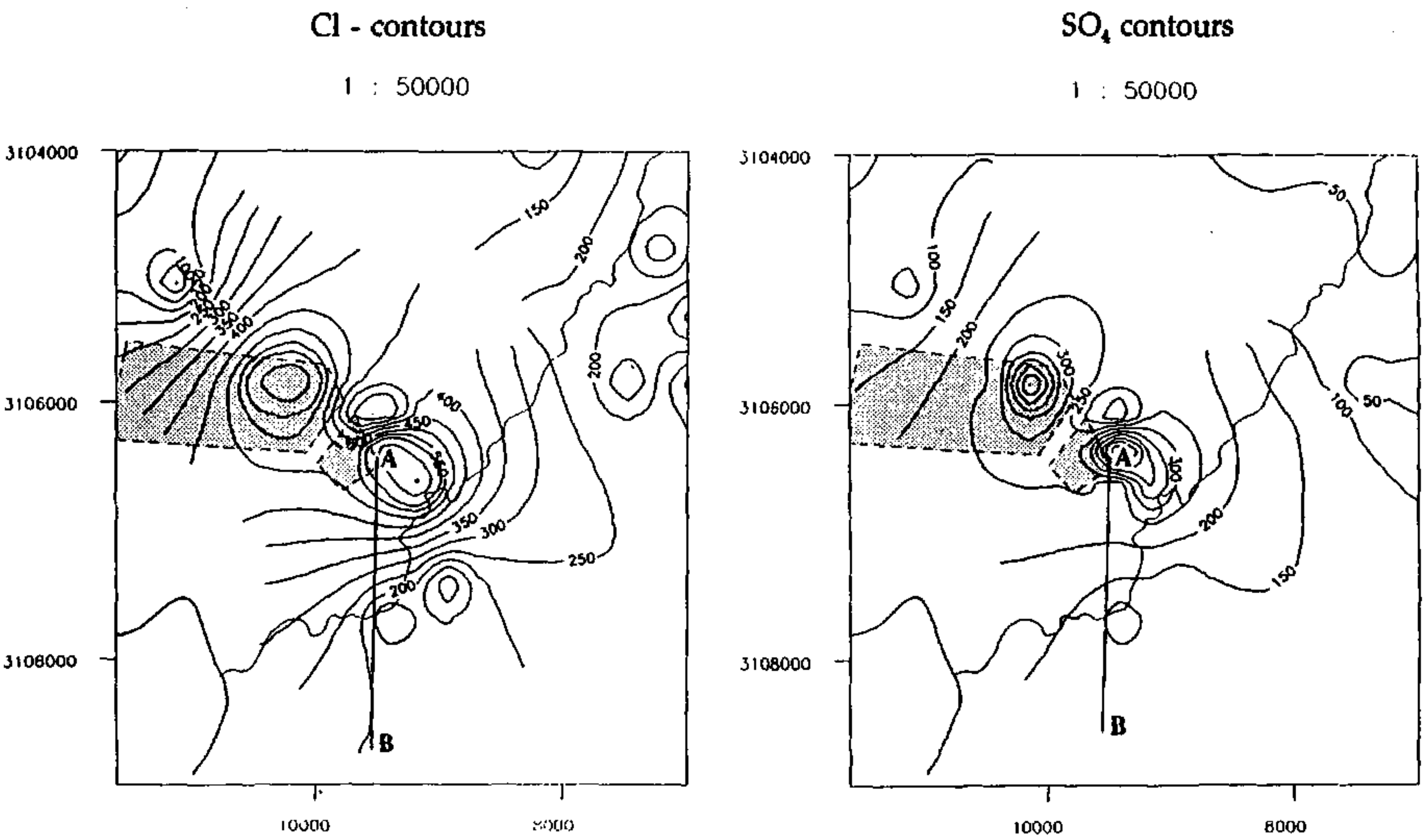

Fig. 4.15 : Cl^- and SO_4^{2-} contours of the Harmony disposal facility (as per Cogho *et.al.*,1992)

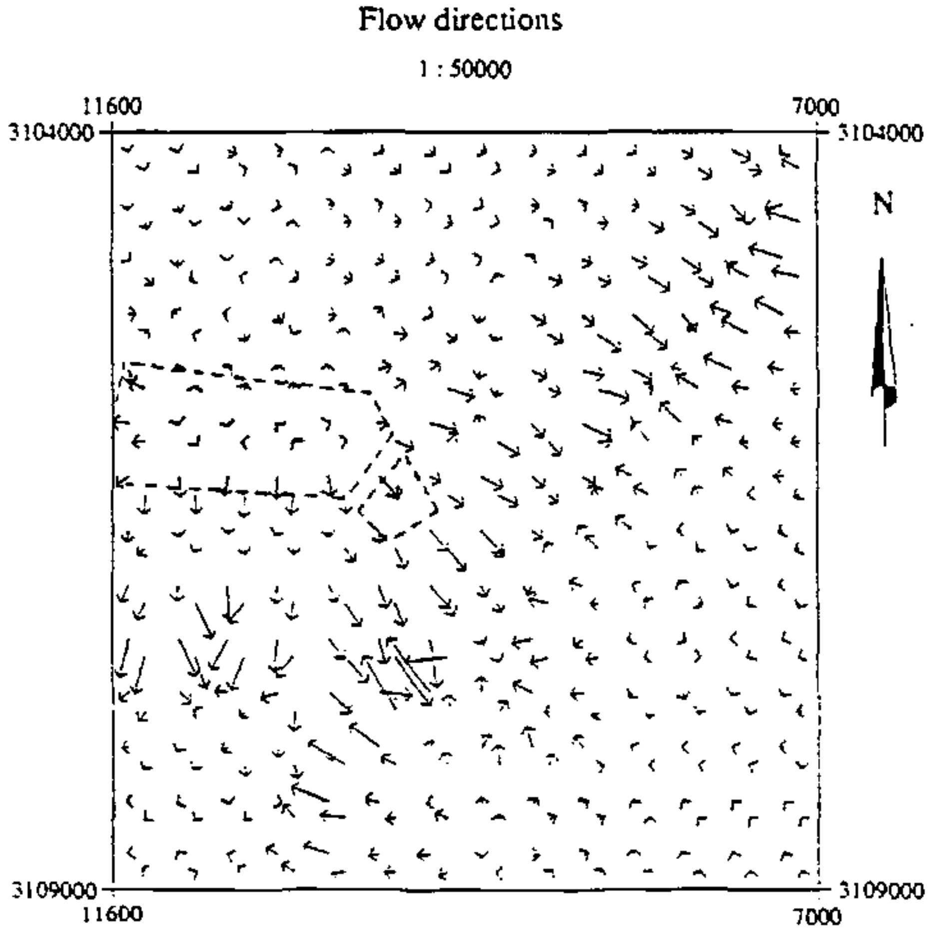

Fig. 4.16 : Ground-water flow directions at the Harmony disposal facility (as per Cogho *et. al.*, 1992)

(a) Harmony Mine's Dam C (North-west of Virginia)

Fig. 4.17 shows the long term trend in the median EC in Harmony Mine's Dam C (located north-west of Virginia on the right bank of the Sand River). Harmony Mine provided data for this dam indicating a full storage capacity of 300 000 *l* corresponding to a full surface area of 3 ha. This would place the average full storage depth at only 0.01 m. Clearly a full storage depth of only one centimetre is far too shallow to be correct. If it is assumed that the full storage capacity should read 300 000 m^3 instead of 300 000 *l*, then the average storage depth would be 10 m. Since this dam is not a closed system (water is pumped from it to evaporation areas) it is impossible to draw any conclusions from the EC trend alone regarding the accumulation of salts or estimate seepage or spillage from the dam. Information regarding the quality of the incoming water and the monthly volumes of water discharged to and pumped from the dam is essential for this purpose.

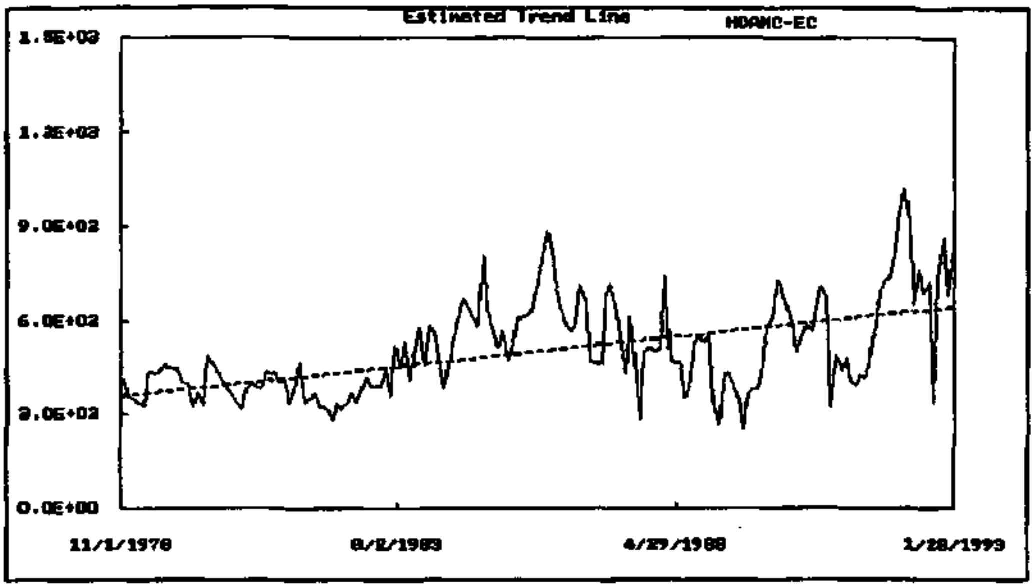

Fig. 4.17 : Trend in median EC values in Harmony Mine's Dam C (units: mS/m)

(b) Harmony Mine's Dam D (North-west of Virginia)

Fig. 4.18 shows the long term trend in the median EC in Harmony Mine's Dam D (located north-west of Virginia on the right bank of the Sand River).

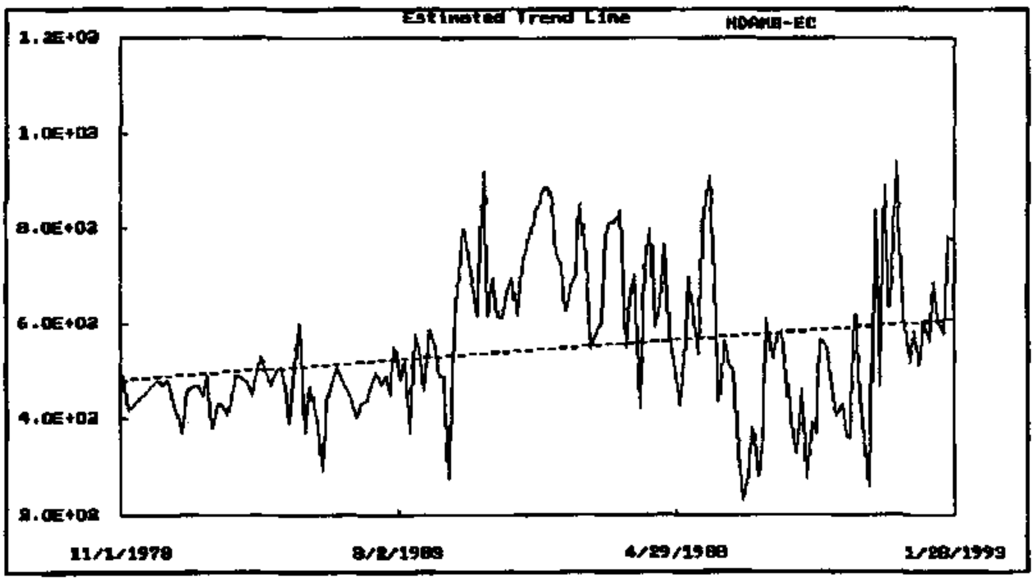

Fig. 4.18 : Trend in median EC values in Harmony Mine's Dam D (units: mS/m)

As in the case for Dam C, the full storage capacity and surface area data provided by Harmony Mine for Dam D indicated an average full storage depth of only 0.01 m, which is obviously incorrect. No conclusions regarding the possible spillage or seepage from the dam could be made since the water and salt balance is incomplete. (Records of historical inflow quality and inflow and outflow volumes do not appear to be available.)

(c) Harmony Mine's Dam D, slimes dams H1, H3, H3A and H3B and Video evaporation paddocks (North-west of Virginia on the right bank of the Sand River)

Fig. A.4 shows that all of the above facilities are potential pollution sources located in the incremental catchment between monitoring stations DWA3 and DWA4. The geophysical surveys carried out by SRK (1993) indicated zones of sub-surface saline discharge towards the Sand River from the vicinity of the south-east corner of the Video evaporation area (which is also near dams B and D). These same surveys indicated another sub-surface seepage zone branching away from the Sand River Canal in a south-easterly direction, which merges with the first seepage zone just before it reaches the Sand River a short distance upstream of monitoring station DWA4 (see Fig. A.4). SRK (1993) observed dry weather seepage from the right bank of the Sand River along a 150 m long front between points CX and CP (see Fig. A.4) near De Kroon. They estimated the seepage rate at about 1 l/s, with a measured EC of 700 mS/m (giving a dry weather TDS load input of about 12 to 13 t per month). Further examination of these seepage zones to identify the pollution sources and estimate the flow rates may be warranted.

(d) Harmony Mine's Convent Dam and Lower Convent Dam

Fig. 4.19 shows the long term trend in the median EC in Harmony Mine's Convent Dam, which is located south-west of Virginia on a small stream entering the left bank of the Sand River (see Fig. A.3). The Convent Dam is located downstream of a number of slimes dams.

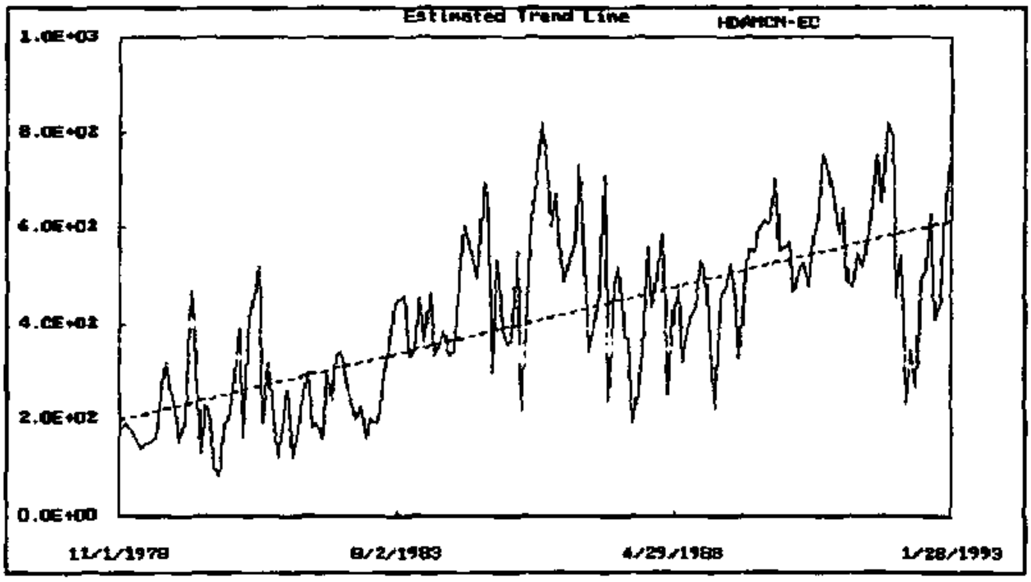

Fig. 4.19 : Trend in median EC values in Harmony Mine's Convent Dam (units: mS/m)

Based on the full storage capacity and surface area data provided by Harmony Mine the average full storage depth of the Convent Dam is 5.1 m. Since inflow and outflow records are not available it is impossible to analyze the water and salt balance. However, according to the DWA&F OFS Regional Office (personal communication, 1993) spillage does occur to the Lower

Convent Dam. Instances of spillage from the Lower Dam to the Sand River were also reported.

Future developments

No data were received in this regard

Potential pollution problems

The two main areas that have already been documented are:

(i) Seepage and/or overflow from slimes dams H1, H3A and H3B and the Video evaporation dams towards the Sand River. The return water dam at Harmony catches water from slimes dams and pumps it back but it is very small and spills are possible.

(ii) Seepage and/or overflow from slimes dam C1 into the Rietspruit River.

In addition to the above, evidence has been presented in the earlier part of this Chapter to suggest that the following areas are also potential pollution sites that are deserving of attention:

(iii) Spillage of saline water to the Sand River from the Lower Convent Dam (see section 4.4).

(iv) Seepage and/or spillage towards the Sand River from Virginia Section's slimes dams located south-east of Virginia and the "Waste dump stream" (see section 4.3(b)). Pollution of the Merriespruit may also be occurring (see sections 4.3(a) and 4.4).

4.8.2 Freegold

General

Freegold comprises six mines in the study area as specified in Table 2.9. Freddies Mine also falls under Freegold but is situated outside the study area. These mines were largely autonomous until the early 1980's when, due to an excess of water, co-operation between the mines started. As regionalisation took place, better controls were instituted. Up until 1974, Dam 12A was totally dry, Dam 12B was not being used as an active process dam and Dam 12C was a return water dam (see Fig. A.4). Good rains in 1974 to 1976 filled the area with water which resulted in the overflow of these dams. This proved to be fortuitous as these dams have since been the main reservoirs for water generally.

The northern area of Freegold has always been a net importer of process water and has in fact been the route for removal of excess water from the south via the Welkom plant reservoir, the trench to the Free State Geduld (FSG) D Dam and the gravity pipe to Dankbaarpan for final evaporation. The FSG D dam is situated in the upper part of the Mahemspruit. A canal on the south side of the dam flows strongly and an EC of 286 mS/m has been measured i.e not just stormwater. The overflow from the FSG D dam is into this canal. This canal flows into farm dams which probably overflow into the Mahemspruit. The Mahemspruit does not, however, flow into the Sand River.

All slimes dams have their own runoff/seepage collection trenches that channel water to return water dams for re-use. Process water seepage has only relatively recently been fully understood, with the result that storm water runoff trenches could have been better located. Spillage occurs relatively infrequently and is constrained to a few sites e.g. Dam 12C, FSG D Dam. Seepage is generally the only pollutant and therefore seepage volumes are fairly low. There have, however, been a few flood situations which were impossible to control. During such events it is possible that impurities may be diluted by flood water, however, this may not always be the case.

The following pollution incidents were reported by Freegold:

i) Heavy rainfall in January 1989 resulted in the overflow of process water dams at the President Brand Mine. This water would have entered the Sand River on 8 January 1989.

ii) Reports of flamingoes and blesbok dying at Doringpan occurred in January 1990. Samples showed that TDS and chloride levels were very high. Inflow was traced back to Saaiplaas No. 4 shaft as the source. Samples taken on 3 February 1990 gave an average EC of 639 mS/m and on 22 February 1990 enormous EC's of up to 19 200 mS/m were recorded.

iii) Overflow of a Welkom plant effluent water dam into the rainfall drainage system after heavy rainfall on 12 November 1992. This resulted in overflow of Western Holdings effluent dams also overflowing.

Western Holdings were not in operation from 1986 to 1989.

Flow and Water quality

Very little water quality data exists. TDS values were, however, taken at Dankbaarpan on 22/2/1990 which give an average TDS of 12 006 mg/l. At Doringpan, EC values were measured at four locations on 2/2/1990. If a ratio of 6.5 is used to convert from EC to TDS, an average TDS value of 5192 can be assumed.

Various other water quality tests were carried out but not on a consistent basis. Table 4.10 gives an indication of the range of conductivities at various sites.

TABLE 4.10
EC values at various locations in Freegold mining complex

SOURCE	Conductivity (mS/m)	
	Low	High
Dam 12A	520	850
Dam 12B	427	825
Dam 12C	308	1 050
Dam 13	580	1 009
Stuurmanspan	149	2 010
Sand River Canal (at start)	28	44
Combined trench at Witpan	610	
Municipal trench at Witpan	308	
Witpan	220	351
FSG D Dam	669	1 169
FSG float plant return dam	1 047	1 093
Western Holdings return dam	1 152	1 213

All mine excess water is discharged to either Dankbaarpan or Doringpan. Stormwater is discharged to Witpan. Dam 13 spills into both Dam 12A and Dam 12C. Dam 12B spills into Dam 12C as well. Water is pumped from Dam 12B to the Welkom gold plant reservoir and from there to the FSG D Dam and on to Dankbaarpan. Some spillage from Dam 12C does however occur. Freddies Mine (outside the study area) discharges water into the North Vlei. A pipeline from the North Vlei discharges water into a trench just upstream of the FSG D Dam. Doringpan receives underground water.

A simplified schematic discharge network diagram for Freegold is given in Fig. 4.20.

Table 4.11 gives monthly discharges to Dankbaarpan and Doringpan.

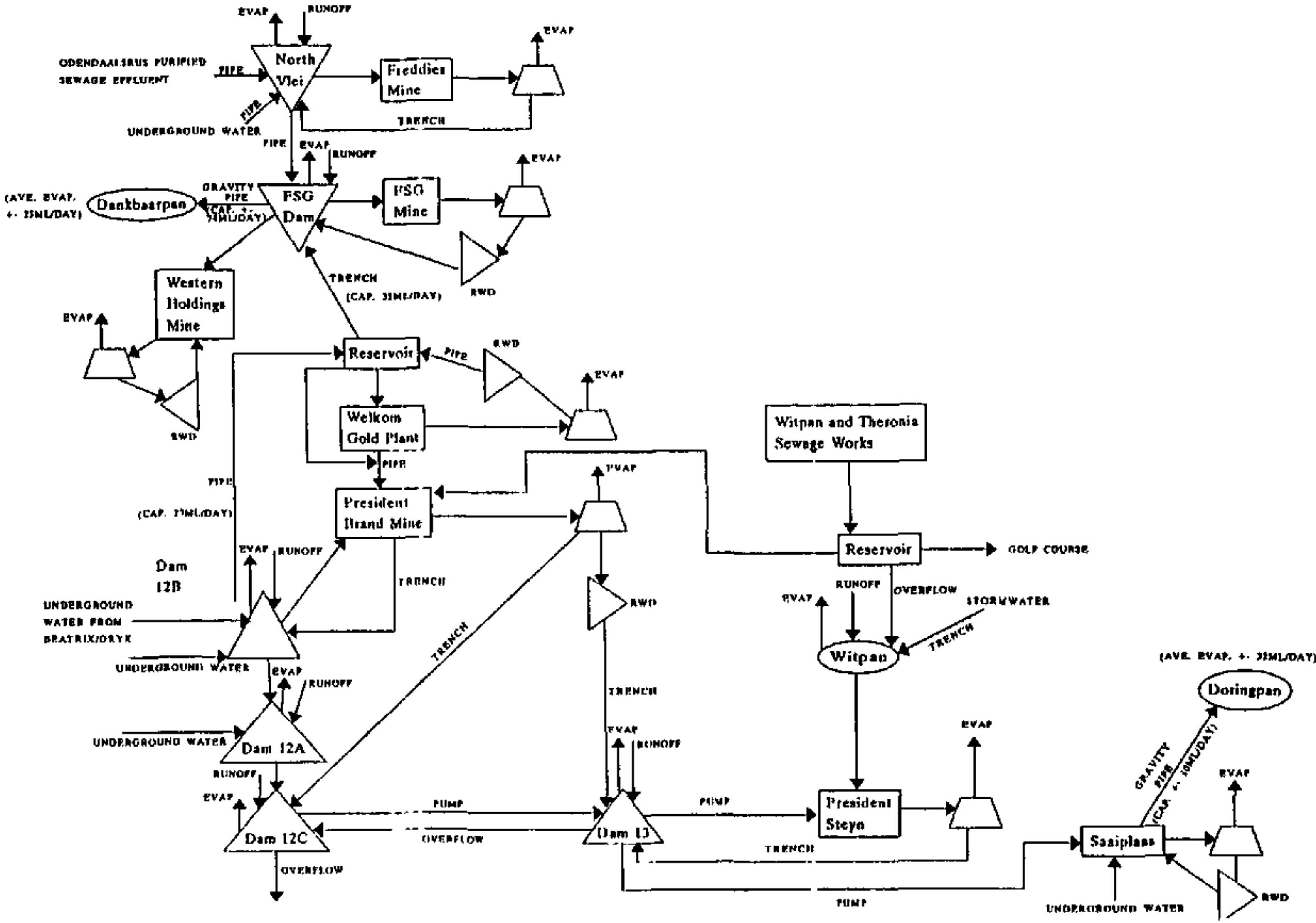

Fig. 4.20 : Freegold discharge water network diagram

TABLE 4.11
Monthly discharge to Dankbaarpan and Doringpan (10^3m^3)

Month/year	Dankbaarpan	Doringpan
April 1990	80	160
May 1990	107	160
June 1990	28	160
July 1990	0	165
August 1990	20	164
September 1990	22	160
October 1990	0	160
November 1990	0	160
December 1990	2	160
January 1991	8	160
February 1991	38	160
March 1991	173	165
April 1991	53	14
May 1991	13	14
June 1991	5	14
July 1991	17	14
August 1991	63	14
September 1991	15	14
October 1991	0	14
November 1991	15	14
December 1991	60	14
January 1992	10	0
February 1992	0	0
March 1992	0	0
April 1992	0	0
May 1992	0	0
June 1992	0	0
July 1992	0	0
August 1992	0	0
September 1992	35	0
Average	26.34	71.03

Disposal of effluent

Mr. Wentzel reported (in 1987) that surplus sewage effluent was gravity fed in Dankbaarpan and Brakpan which at that time was quite small. Plans for disposal to Doringpan were being investigated at that time. A new sewage works has been constructed and purified sewage effluent is now discharged along with stormwater to Witpan.

Permits issued to dispose of effluent

A permit (no number) allows for the disposal of 20 000 m^3/day of the water found underground into Doringpan and Dankbaarpan to evaporate.

Permit 1345B allows for the disposal of 43 001 m^3/day of effluent to Dankbaarpan for evaporation and of 4275 m^3/day of effluent purified by the FSG Sewage Purification Works to irrigate sports fields and gardens.

Capacities of slimes dams, evaporation areas, gravity and pumping pipelines

Capacities of slimes dams and evaporation areas are given in Figs. A.3 to A.7 (see Appendix A).

Underground water is discharged to Doringpan by means of a gravity pipeline with a capacity of about 10 Ml/day. From Dam 12 B, a pipeline of capacity 27 Ml/day conveys mine process water to Welkom. From there it is conveyed by means of a trench of capacity 35 Ml/day to the FSG D Dam. The gravity pipelines from FSG D Dam to Dankbaarpan have a capacity of about 74 Ml/day.

Future developments

Certain measures are being considered with regard to limiting pollution as follows:

(i) Re-installation of slats at the slimes dam return trench/"inner" storm water runoff trench crossover at President Steyn Mine. This is required to control the flow adequately, and to isolate any possible contamination in the "inner" storm water trench from the Sand River Canal.

(ii) Construction of a sump/bund area and adequate pumping control at the Witpan intermediate sewage transfer pump house.

(iii) Deep cut-off trench with lining across the FSG D Dam site.

Potential pollution problems

(i) Deep ground-water with a poor quality routed to Doringpan could result in the deterioration of ground-water.

(ii) Mine process water from the Welkom outlet pumped to Dankbaarpan could also result in the deterioration of ground-water.

(iii) Acid rock drainage evident at FSG 7 shaft which is adjacent to a rock dump and could therefore adversely interact with solids waste.

(iv) Contamination by seepage into the uprated diversion trench between the Sand River Canal and Witpan.

(v) Contamination of the fresh water trench from the Welkom plant slimes dam return water dam area, ultimately discharging into Witpan.

(vi) Contamination of the fresh water trench at FSG's D Dam.

(vii) The Sand River Canal is not capable of dealing with very severe storms (the limit is about a 1 in 20 year storm) and this can cause flooding of the President Brand No. 4 shaft. This could result in spillage of pollutants but they would be considerably diluted.

4.8.3 St. Helena and Unisel

General

Situated south of Welkom (see Figs. A.4 and A.5), these two mines are owned by Gencor. St. Helena mine sometimes uses water from Torontopan. It is very important that Torontopan does not overflow because there is a ventilation shaft for this mine nearby the pan.

Flow and Water quality

Table 4.12 gives water quality data for mining effluent for both St. Helena and Unisel mines.

TABLE 4.12
St. Helena and Unisel mine effluent water quality data

Mine	St Helena	Unisel
Test position	Dam A	10 Meg. Dam
Electrical Conductivity	690 mS/m	855 mS/m
Total dissolved solids	4346	6034
Magnesium	32	24
Calcium	324	622
Chloride	1942	1772
Fluoride	1	1.08
Nitrate	45	160
Potassium	39	Not available
Sodium	1152	1125
Sulphate	80	1380
Cyanide	Not available	0.02

NOTE: All figures in mg/l unless otherwise stated.

Disposal of effluent

Effluent water from No. 4 slimes dam is collected in dam "D" and re-circulated back to the reduction plant. Overflows, if any are collected in the Wolwepan and Rietpan dams.

Sewage effluent is discharged to the Theronia Sewage Works. Some of the purified effluent is returned to St. Helena and the rest goes to the Klippan Nursery.

Permits issued to dispose of effluent

Permit 718 N applies but no details were received on it.

Capacities of slimes dams, evaporation areas, gravity and pumping pipelines

Stage-capacity curves were received from St. Helena Mine for Rietpan, Wolwepan (No. 1 and 2) and Torontopan. Areas and capacities were received for slimes dams and evaporation areas. Unisel Mine has no need for evaporation areas, nor does it operate any slimes dams since all its ore is sent to St. Helena Mine for processing.

Future developments

No new developments are envisaged.

Potential pollution problems

(i) The whole area around the slimes dams is a marsh. Mine water seeping and/or spilling into this marsh flows into the Wolwepan-Rietpan system to evaporate. This entire area is a designated evaporation area and is not used for any other purpose.

(ii) Seepage to surrounding farms is possible. St. Helena gold mine is monitoring the groundwater in the surrounding area. New evaporation dams have been built with an area of 450 ha and a capacity of 6 300 000 m^3. At the moment, no water flows into Rietpan which is on mined ground.

4.8.4 Oryx (previously Beisa)

General

Oryx Mine, which is in the southern Goldfields area (see Fig. A.7), pumps out a great deal of poor quality ground-water. Disposal is into evaporation areas along with other mine water.

The mine has its own sewage works on the banks of the Bosluisspruit. The outflow is used for irrigation of parks and gardens. Surplus purified sewage effluent may be discharged to the Bosluisspruit.

Flow and Water quality

Water quality reports exist for borehole analysis and underground water. Only three reports (for February to April 1991) give outflow of purified sewage. In all three cases 300 m^3/month of purified effluent was disposed of to the Bosluisspruit. This figure should be regarded with suspicion because according to the reports, this flow is also the inflow to the sewage works which cannot be correct. According to the water balance, the outflow from the sewage works is 1933 m^3/day which is far greater than the figure given above. This latter figure appears to be too high because the capacity of the sewage works has been given as 1000 m^3/day. The average EC value was 108 mS/m. Other reports cover February 1988 to December 1992 for the analyses given in Table 4.13.

TABLE 4.13
TDS for Oryx Sewage Works

Year	TDS (mg/l)
1988	566
1989	536
1990	786
1991	767
1992	843

NOTE: A TDS/EC ratio of 6.5 was used to convert EC values.

According to Mr. S Geldenhuis of SRK, only three stations measure surface water quality - S1, S2 and S3, all of which are located on the Bosluisspruit. S1 was, however, discontinued in October 1992 but some others were added. Between October 1988 and August 1992, only four samples were analyzed with EC ranging from 54 to 344 mS/m.

Disposal of effluent

Irrigation of gardens is practised and during peak periods overflow to the Bosluisspruit takes place. Neither inflows to, or outflows from the sewage works are measured.

TABLE 4.14
Details of routine data reporting for Oryx Sewage Works (as at 1992)

ORYX SEWAGE WORKS	
Contact person	C.M.M. Visser
Designation Telephone	Resident Engineer
Flow measurement Frequency	
Quality sampling	
LABORATORY	
Laboratory name	Western Transvaal Regional Water Company
Contact person Designation Telephone	
Analyses carried out	Frequency (combined samples)
Electrical conductivity	1 per month
Suspended solids	1 per month
Chemical oxygen demand	1 per month
Oxygen absorbed	1 per month
Ammonia	1 per month
Nitrate	1 per month
Nitrite	1 per month
Ortho Phosphate	1 per month
Fats and Oils	1 per month
Coliforms	1 per month
Free chlorine	1 per month
pH	1 per month

Permits

Permit 1560B allows for the disposal of 4910 m^3/day of industrial effluent to be discharged into a slimes dam and evaporation pond system.

Permit 10M allows for the disposal of 25 622 m^3/day of underground water to be evaporated in an evaporation pond system or pumped to adjacent mines for industrial use.

Permit 1561B allows for the disposal of 1983 m^3/day of purified domestic effluent. A maximum of 1783 m^3/day shall be used for the irrigation of gardens and sports fields and any surplus shall be discharged into the Bosluisspruit.

Capacities of gravity and pumping pipelines

The evaporation areas have an area of about 815 ha with a storage capacity of $5.744x10^6m^3$. There is only one slimes dam which has a capacity of $13.560x10^6m^3$.

Capacity of gravity pipes	:	150 mm diameter.
Capacity of underground pumping pipelines and process water pipelines	:	350 mm diameter.

Future developments

None.

Potential pollution problems

Overspills from the evaporation areas could enter the Bosluisspruit which flows into the Sand River. Complaints from farmers are being investigated by the DWA&F OFS Regional Office. The mine is also carrying out preventative steps. Cut-off trenches have been excavated. The use of some evaporation areas has been discontinued in order to prevent seepage to surrounding areas.

The sewage effluent sometimes has high phosphate concentrations up to 7.7 mg/l (14/9/88). However, the potential for downstream eutrophication problems is limited since most of the effluent is irrigated. Moreover, the Bosluisspruit is dry for most of the time. There are also extremely high faecal coliform counts on a regular basis of up to 8400 / 100 ml which can cause bacteriological pollution of the irrigated lands (and of the Bosluisspruit on those occasions when effluent is discharged to the river).

4.8.5 Beatrix

General

Beatrix (Fig. A.6) is in the Theunissen district and is a relatively new mine. Ground-water is pumped out of the mine area via Oryx to the Welkom mine.

The mine has its own sewage works and cases of pollution have been reported. The works have been enlarged.

Flow and Water quality

Reports are compiled giving flow and water quality data for the following:

(i) Sewage effluent water (every month).

(ii) Underground water leaving Beatrix (every March, June, September and December).

(iii) Water pumped from underground (every March and September)

Table 4.15 gives water quality data for discharge to the Theronspruit.

TABLE 4.15
Water quality data for discharge to the Theronspruit on 12/11/92

Determinand	Concentration (mg/l unless otherwise stated)
PH	8.0
Alkalinity	107.0
Total hardness	459.0
Magnesium	51.8
Chloride	384.0
Sulphate	89.0
Barium	0.6
Conductivity (mS/m)	131.0
TDS	872.0
Acidity	0.0
Calcium	98.9
Sodium	54.7
Iron	0.1

Water quality data received from the mine was very limited. Only 1991/1992 data was covered.

Water quality data for slimes dam return water to surface tanks for the same date (12/11/1992) gave a conductivity of 790 mS/m .

A pollution plume for Beatrix has been identified by Cogho *et. al.* (1992) and is shown in Fig. A.6 (see Appendix A). Chloride and sulphate contours are shown in Fig. 4.21. Ground water flow directions are given in Fig. 4.22.

Disposal of effluent

Throughout the life of the mine, effluent has been disposed of as follows:

(i) About 4500 m^3/day of metallurgical plant tailings are disposed of to the slimes dam. The disposal of these tailings result in a run-off of about 3000 m^3/day of water into the evaporation dams adjacent to the tailings dam.

(ii) The excess water is disposed of by discharging about 500 m^3/day of water into evaporation dams at Beatrix Mine, about 1000 m^3/day to Unisel, about 6000 m^3/day to President Brand, about 7000 m^3/day to St. Helena Mine and about 4000 m^3/day into Wolwepan.

In a telefax dated 11 March 1993 from the Resident Engineer, it was stated that during a drought season, the flow of polluted water seeping from evaporation dams towards the Theronspruit was estimated at 3000 m^3/day.

(iii) Sewage effluent of about 2600 m^3/day is disposed of as follows (average values from February 1992 to September 1992 inclusive):

Fridge plant	403 m^3/day
Irrigation	954 m^3/day
Discharge to the Theronspruit	735 m^3/day
Washing and general	476 m^3/day
Total	2568 m^3/day

In addition to the sewage effluent water above, sewage sludge of 190 m^3/day is disposed of in wet ponds with a capacity of 48 000 m^3.

The latest water balance (30 April to 31 March 1992) gave the following:

Fridge plant	1650 m^3/day
Irrigation	849 m^3/day
Discharge to the Theronspruit	170 m^3/day
Total	2669 m^3/day

TABLE 4.16
Annual discharges and TDS loads for Beatrix Sewage Works

Year	Average flow ($10^6 m^3$)	TDS (mg/l)	TDS load (t)
1990	1.025	738	756
1991	0.952	785	937
1992	0.952	948	903

NOTE: Only the EC was available, therefore the TDS was estimated at 6.5 times the EC.

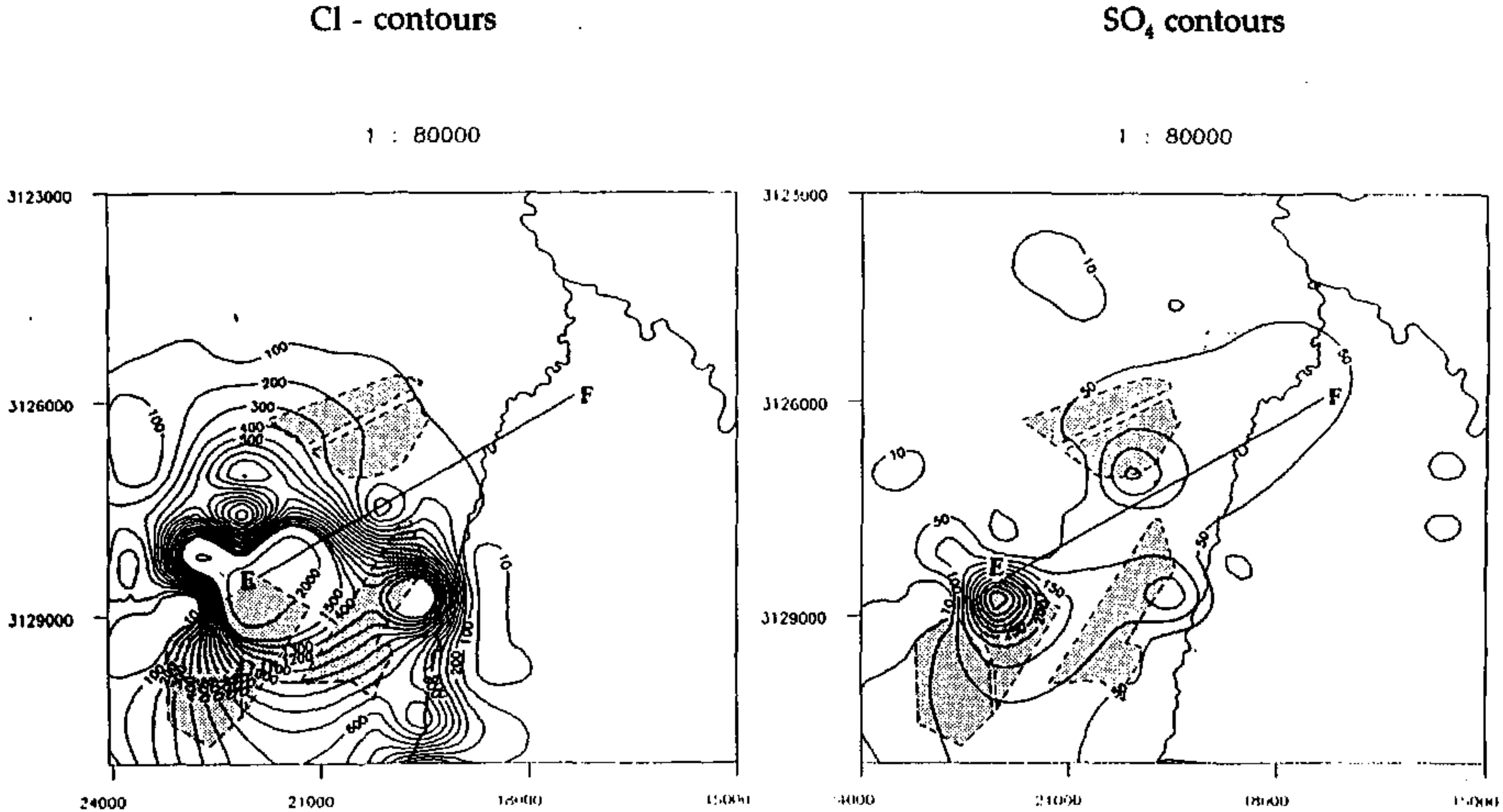

Fig. 4.22 : Cl^- and SO_4^{2-} contours of the Beatrix disposal area (as per Cogho *et.al.*,1992)

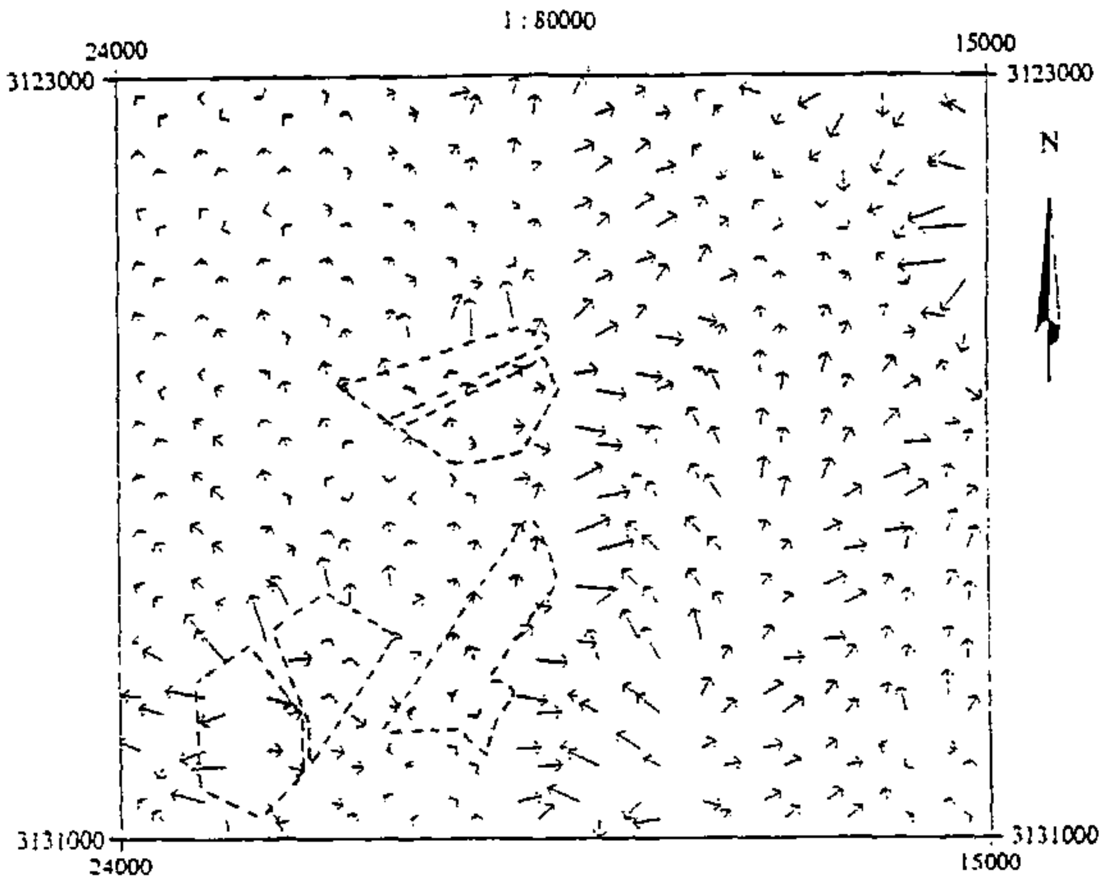

Fig. 4.23 : Ground-water flow directions at the Beatrix Mine disposal facility (as per Cogho *et. al.*, 1990)

TABLE 4.17

Details of routine data reporting for Beatrix STW (as at 1992)

BEATRIX SEWAGE WORKS	
Contact person	Mr G. Harris
Designation	Resident Engineer Limited
Flow measurement	Activated sludge extended aeration process
<u>Analyses carried out</u>	<u>Frequency</u> (combined samples)
Electrical conductivity	1 per month
Suspended solids	1 per month
Chemical oxygen demand	1 per month
Oxygen absorbed	1 per month
Ammonia	1 per month
E Coli (type 1)	1 per month
pH	1 per month

Permits

Permit M2 allows for the disposal of water found underground as follows:

Pumping to Oryx mine for distribution to other mines	:	40 000 m^3/day
Use for industrial purposes on the mine	:	4 963 m^3/day

Permit 1055B allows for discharging 597 m^3/day of slime dam effluent into evaporation dams.

Permit 1055B also allows for the utilisation of 2 973 m^3/day of purified sewage effluent for the irrigation of sports fields and gardens.

Capacities of slimes dams, evaporation dams, gravity and pumping pipelines

Stage-capacity curves were received for the evaporation dams.

Areas and capacities were also obtained for slimes dams and evaporation areas.

Slimes residue: 300 mm plastic column to the slimes dam at a rate of +- 6000 tons/day (400 l/s). Pumping to other mines and to evaporation dams : 23 000 m^3/day.

Future developments

The proposed new 3 shaft project has been planned to replace the 2 shaft ore reserves. The water balance is not expected to change.

If the slimes dam area has to be increased in the future, 90 ha is available to the north of the existing slimes dam.

Potential pollution problems

(i) The evaporation area for the mine is 429 ha with a capacity of $22.668 \times 10^6 m^3$. At present, there is overspill to the Theronspruit and Doring River which both flow into the Sand River.

(ii) Seepage from the area is also a problem as a result of the weathered dolerite.

(iii) A spill did occur during the 1988 floods and the quantity was unknown.

4.8.6 Joel

General

Joel mine borders Beatrix (see Fig. A.6) and is also relatively new. The mine is very dry. The reason for the relatively dry state of the mine is that Beatrix pumps out high volumes of deep ground-water. As the mine expands northwards, the expectation is that larger volumes of ground-water will be encountered. This relatively modern mine has made provision for the sealing of ground-water.

The mine has its own sewage works and uses the purified effluent for irrigation of parks and gardens.

Flow and water quality

Table 4.18 gives effluent water quality data as at 6 April 1993.

TABLE 4.18
Effluent water quality data for Joel Mine as at 6 April 1993

Determinant	Units	Value
COD	mg/l	76
Nitrate	mg/l	1.4
TSS	mg/l	8
TDS	mg/l	620
pH	-	7.57
Ortho Phosphate	mg/l	4.3
Conductivity	mS/m	92.8
Ammonia	mg/l	7
OA	mg/l	2.8

Disposal of effluent

Table 4.19 gives sewage effluent discharges to the Theronspruit for 1992.

TABLE 4.19
Annual discharge and TDS load for Joel sewage works

Year	Outflow (to Theronspruit) (10^6m^3)	TDS (mg/l)	Load (t)
1992	0.113	715	81

NOTE: Average EC taken in 1992 and multiplied by 6.5 to get TDS

Some problems were experienced with the water balance and Mr. Hannes Opperman promised a revised and corrected water balance. Despite numerous phone calls, this revised water balance was not received.

TABLE 4.20
Details of routine data reporting for Joel Sewage Works (as at 1992)

JOEL SEWAGE WORKS	
Contact person	H. Opperman
Quality sampling	Influent and final effluent
Analyses carried out	Frequency (combined samples)
Total dissolved solids	4 per month
Electrical conductivity	4 per month
Suspended solids	4 per month
Chemical oxygen demand	4 per month
Ammonia	4 per month
Nitrate	4 per month
Ortho Phosphate	4 per month
pH	4 per month

Permits

Exemption 1459B allows for the disposal of 2731 m^3/day of mining effluent into a slimes dam and/or evaporation dam.

Permit 3M allows for the disposal of 20 000 m^3/day of underground water by pumping to various mines in Welkom.

Permit 1460B allows for the disposal of 187 610 m^3/a of effluent for irrigation of gardens and sports fields. If the gardens and sports fields do not require this amount of 514 m^3/day, then this effluent can be discharged into the Theronspruit.

Capacities of slimes dams, evaporation areas, gravity and pumping pipelines

A stage-area capacity curve was received for the slimes dam as well as area and capacity of the evaporation area. The area of the slimes dam had to be planimetered.

Capacities of gravity and pumping pipelines are as follows:

Evap. ponds	:	625 m^3/hr
U/6	:	850 m^3/hr
Welkom	:	958 m^3/hr
Mine water to plant (gravity feed)	:	≈200 m^3/hr

Future developments

There are plans for further evaporation dams.

Potential pollution problems

The slimes dams return water dam is situated near a tributary of the Doring River.

4.9 Municipalities

4.9.1 Welkom Municipality

General description

Welkom is in the heart of the OFS Goldfields (see Fig. A.5). All drinking water is supplied by Goldfields Water from their purification works at Balkfontein, which draws raw water from the Vaal River. In addition to Welkom's own sewage, it also treats sewage from some of the mines.

Welkom has three purification works, namely: Theronia, Witpan and Thabong (commissioned in Feb. 1993).

Flow and water quality records

Table 4.21 gives Welkom's annual water purchases from Goldfields Water.

TABLE 4.21
Water bought from Goldfields Water by Welkom Municipality

Year	Water bought from Goldfields Water (10^6m^3)
1986	9.5
1987	9.7
1988	10.4
1989	10.4
1990	13.3
1991	11.8
1992	14.3

Table 4.22 gives the annual effluent discharge from the Witpan and Theronia sewage works.

TABLE 4.22
Annual discharge and TDS load from Welkom's Witpan and Theronia STW

Year	Flow (10^6m^3)	TDS (mg/l)	TDS Load (t)
1986	15.6	-	-
1987	16.1	882	14 200
1988	16.3	622	10 139
1989	16.7	844	14 095
1990	15.8	973	15 373
1991	16.1	840	13 524
1992	15.7	891	13 988

Comparison of Tables 4.23 and 4.23 shows that Welkom's purified sewage effluent discharge is larger than its supply water intake. This is due to the large amount of raw sewage that is treated by Welkom Municipality on behalf of the surrounding mines. Using Fig. 2.1, the various users were identified and their supplies from Goldfields Water were summated for the calendar year 1992. The total effluent discharged from the Witpan and Theronia STW was calculated to be only 36% of the total supply from Goldfields Water to the various users.

It was also calculated that for the same year the average difference between the flow-weighted average of the effluent (average for Witpan and Theronia STW) and water supply TDS was 324 mg/l.

Disposal of effluent

Table 4.23 shows the annual outflow from the Theronia STW to various institutions.

TABLE 4.23
Annual outflow of purified effluent from Theronia sewage works

Calendar Year	Anglo American (President Brand) (10^6m^3)	St. Helena (10^6m^3)	Parks and gardens (10^6m^3)	Other (10^6 m^3)	Total (10^6m^3)
1986	1.9	0.6	2.9	0.4	5.8
1987	3.5	0.5	3.4	0.4	7.8
1988	1.5	0.3	2.0	0.3	4.1
1989	0.7	0.3	4.1	0.2	5.4
1990	0.2	0.3	5.4	0.8	6.7
1991	0.7	0.4	2.7	0.4	4.2
1992	0.5	0.3	3.7	0.7	5.3

From the water balance data received from President Brand Mine, the volume of purified effluent received from April 1991 to March 1992 was 4802 m^3/day. For the equivalent period, Welkom gave a contradictory figure of 1747 m^3/day.

Purified effluent from Witpan flows directly into the adjacent pan Witpan. President Brand Mine have a pumping installation at the outlet of the Witpan works and abstract as much effluent as they require for irrigation, process plant water and acid plants. They also abstract from Witpan if the sewage works cannot meet their requirements. There are no records of abstractions.

Effluent from Thabong will be discharged to the Sand River Canal and from there to the Sand River. The mines, however intend diverting some of this water for their own use.

Permit

Permit 248B dated 29/5/1986 allows for the purification of 10 840 500 m^3/year unpurified effluent from the Theronia sewage works.

Permit 249B allows for the purification of unpurified effluent from the Witpan sewage works.

4.9.2 Virginia Municipality

General description

Virginia (see Fig. A.3) obtains water from Goldfields Water as well as raw sewage from the town and from Harmony Mine.

Flow and water quality records

The water quality of final treated effluent is given in Table 4.24.

TABLE 4.24
Annual discharge and TDS load for Virginia sewage treatment works

Year	Flow ($10^6 m^3$)	TDS (mg/l)	TDS load (t)
1988	5.176		
1989	-		
1990	6.342	455	2886
1991	5.408	930	5029
1992	4.726	809	3823

NOTES: 1 For 1988, an average was taken from January to June.

2 For 1989 to 1992, outflows were not recorded and therefore inflows have been given. In some cases, TDS has been estimated from EC using the ratio TDS/EC = 6.5. For some months there were also no records, therefore figures should be regarded as best estimates.

The water balance for 1992 was as follows:

Water bought from Goldfields Water	$4.183 x 10^6 m^3$
Incoming raw sewage	$5.374 x 10^6 m^3$
Total inflow	$9.557 x 10^6 m^3$
Water sold to residents	$3.533 x 10^6 m^3$
Purified sewage discharged to mines, parks etc.	$4.727 x 10^6 m^3$
Losses	$1.297 x 10^6 m^3$
Total outflow	$9.557 x 10^6 m^3$

Disposal of effluent

Virginia discharges purified effluent to the mines and parks. No water is discharged to the Sand River.

TABLE 4.25
Details of routine data reporting for Virginia Sewage Works (as at 1992)

VIRGINIA SEWAGE WORKS	
Contact person	D Esterhuizen
Designation	Operator class 4
Telephone	057 2123111
Flow measurement	Inflow and outflow
Frequency	Once per month
Quality sampling	Purified effluent
Analyses carried out	Frequency (combined samples)
Total dissolved solids	1 per month
Electrical conductivity	1 per month
Accumulated solids	1 per month
Suspended solids	1 per month
Chemical oxygen demand	1 per month
Oil in water	1 per month
Ammonia	1 per month
Nitrate	1 per month
Ortho Phosphate	1 per month
Chlorides	1 per month
pH	1 per month

Permits

Virginia have a permit 201B dated 11/5/66 for 7 000 m^3/day of purified sewage effluent. This can be disposed of as follows:

(i) 2 700 000 m^3/year to industry
(ii) 1 171 200 m^3/year irrigation of gardens etc.
(iii) The remainder can be discharged into the Sand River.

4.9.3 Senekal Municipality

General description

Senekal is located near the confluence of the Sand River and the Laerspruit, upstream of Allemanskraal Dam (see Fig. A.1).

Flow and water quality records

Senekal has two sources of water, namely: the Sandspruit (De Put Buiteloop storage dam) and the Sand River (Cyferfontein dam). Volumes used for the 1991 hydrological year are given in Table 4.26.

TABLE 4.26
Sources of water supply to Senekal

Calendar year	Annual water use (m^3)		
	Sandspruit	Sand River	Total
1989	407 871	527 415	935 286
1990	549 083	523 950	1 073 033
1991	279 056	653 314	932 370
1992	448 941	696 890	1 145 831

Water quality analyses are carried out on a monthly basis. A summary of the annual flow and TDS for 1992 is given in Table 4.27.

TABLE 4.27
Annual discharge and TDS load for Senekal Sewage Works

Year	Flow ($10^6 m^3$)	TDS (mg/l)	Load (t)
1992	.036	338	12

NOTE: Inflows exceeded outflows by more than ten times for some months.

Disposal of effluent

Purified sewage effluent is discharged to parks and golf courses. The excess goes to the Sand River.

4.9.4 Bultfontein Municipality

General description

No information was obtained regarding Bultfontein Municipality's sewage treatment works.

Flow and water quality records

No records of water quality or effluent discharge were obtained. However, since Bultfontein is situated far from the Vet River in a relatively flat semi-arid area. Therefore the effect on the Sand-Vet River system of return flows from this town should be negligible.

Disposal of effluent

Effluent is treated in oxidation ponds. There is no discharge to the Vet River system.

4.9.5 Henneman Municipality

General description

Henneman is situated just east of Welkom nearby the Rietspruit River (see Fig. A.1)

Flow and water quality records

All water is obtained from Goldfields Water. Between October 1990 and April 1993, the average was 62 044 m^3/month.

Disposal of effluent

Mr C de Jager gave the following details for the present situation:

About 5250 m^3/month of sewage effluent is discharged to the Rietspruit. About 3500 m^3/month is used for gardens and parks.

This data, however, conflicted with monitoring reports for 1992 which gave a breakdown purely between irrigation for parks and lucerne as follows:

About 4860 m^3/month of sewage effluent for park irrigation.
About 3193 m^3/month of sewage effluent for lucerne irrigation.

Recent information obtained from the DWA&F OFS Regional Office indicates that Henneman does in fact discharge effluent to the Rietspruit.

Annual flows and water quality for Henneman are summarised in Table 4.28.

TABLE 4.28
Annual discharge and TDS load for Hennenman Municipality's STW

Year	Flow (10^6m^3)	TDS (mg/l)	TDS load (t)
1991	0.052	758	39
1992	0.097	706	69

TABLE 4.29
Details of routine data reporting for Hennenman's STW (as at 1992)

HENNENMAN SEWAGE WORKS	
Contact person	JDM Stott
Designation	Head Civil Works
Telephone	05776 32055
Flow measurement	Inflow and outflow
Frequency	Once per month
Quality sampling	Purified effluent
Analyses carried out	Frequency (combined samples)
Total dissolved solids	1 per month
Electrical conductivity	1 per month
Accumulated solids	1 per month
Suspended solids	1 per month
Chemical oxygen demand	1 per month
Oil in water	1 per month
Ammonia	1 per month
Nitrate	1 per month
Ortho Phosphate	1 per month
Chlorides	1 per month
pH	1 per month

4.9.6 Hoopstad Municipality

General description

Hoopstad is situated near to Bloemhof Dam (see Fig. A.1).

Flow and water quality records

The CSIR did some water quality tests on raw supply water.

Disposal of effluent

The purified effluent is used in parks and the local golf club.

4.9.7 Theunissen Municipality

General description

Theunissen is located north-west of Erfenis Dam, about 7 km distant from the Vet River (see Fig. A.1).

Flow and water quality records

No records of water quality or effluent discharge were obtained. However, since the annual water allocation is only $0.546 \times 10^6 m^3$, the return flow from this town should have negligible effect of the salinity regime of the Sand-Vet River system.

Disposal of effluent

Theunissen Municipality's sewage effluent is treated in oxidation dams. There is no discharge to the Vet River.

4.9.8 Winburg Municipality

General description

Winburg (see Fig. A.1) commissioned its present sewage works in 1971 and an average of 9000 m^3/month of effluent is discharged into the Winburgspruit.

Flow and water quality records

There are no records of water quality or effluent discharge.

4.10 Conclusions

The following conclusions have been drawn from the results presented in this chapter:

4.10.1 Ground-water pollution

Pollution sources in the OFS Goldfields region have led to severe salinisation of the ground-water over a large area (see Fig. 4.14 and section 4.4).

4.10.2 Surface water pollution

A number of natural rivers and streams, pans and wetlands in the region have suffered severe salinisation. These include:

- Rivers: Sand River, Mahemspruit, Doring River, Theronspruit, Bosluisspruit, probably the Rietspruit and possibly the Merriespruit (the water quality data is too sparse to make definite statements about the latter two streams).

- Pans: Dankbaar, Riet, Wolwe, Stuurmans, Doring, Blesbok, Toronto, Flamingo, Wit, Swart.

4.10.3 Nature of pollution

The most dominant ions present in the polluted river water are chloride, sodium and sulphate, in that order.

4.10.4 Salinisation of Sand River

In the case of the Sand River the median EC increases seven fold, from 30 mS/m to 216 mS/m across the mining area. Median chloride concentrations increase 20-fold, from 18 to 390 mg/L.

4.10.5 Main pollution source

Gold mining in the OFS Goldfields area is the main cause of the salinisation of the ground-water, pans and rivers.

4.10.6 Mining pollution

The most likely causes of the salinisation the surface water include:

- The Sand River canal to Sand River.

- Harmony Mine (Viginia Section) near "Waste dump stream" to Sand River.

- Harmony Mine (Harmony Section) in vicinity of De Kroon to Sand River.

- Harmony Mine (Harmony Section) in vicinity of Harmony to Rietspruit.

- Harmony Mine (Merriespruit Section) in vicinity of Convent Dam to Sand River.

- Beatrix Mine to Theronspruit and Doring River.

- Western Holdings/Freestate Geduld mines to Mahemspruit.

- Oryx Mine to Bosluisspruit.

- General diffuse seepage over a wide area.

In all of these instances the main mode of entry of the contaminated water to the river system is via seepage. Intermittent spillage events also occur from time to time.

Water is also disposed of in a number of natural pans and wetland systems.

4.10.7 Industrial pollution

The wetland system near Blesbokpan was seriously polluted by yeast effluent from the NCP factory. However, this factory has recently closed.

4.10.8 Municipal pollution

Other than that disposed of in Witpan, there is little sewage effluent that is not re-used within the OFS Goldfields area. Witpan suffers occasional pollution episodes due to contaminated stormwater.

4.10.9 Effect of irrigation

Irrigation from the Sand-Vet GWS appears to add little to the salinisation of the river system. On the contrary, it plays an important beneficial role in diluting the pollution in the lower Sand and Vet rivers.

4.10.10 Solid waste sites

Municipal solid waste sites do not appear to be significantly affecting surface water quality. Ground-water contamination also seems to be confined to areas close to the sites.

4.10.11 Nutrients

Nitrate, ammonia and phosphate concentrations in the Sand River are elevated throughout the area affected by mining and urbanisation. This holds the potential for eutrophication in slow moving portions of the river, such as in the pool backed up by Virginia weir. It is difficult to identify any one source of the nutrients, since they can originate from municipal, industrial and agricultural activities, all of which are closely inter-twined in the study area.

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CHAPTER 5

ASSESSMENT OF MONITORING SYSTEMS

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5. ASSESSMENT OF EXISTING MONITORING SYSTEMS

5.1 General overview

The purpose of this chapter is to determine the availability of water quality and flow data in the Lower Vet River and its tributaries. The main aspects addressed are summarised below:

(a) Identification of the organisations operating monitoring systems.

(b) Description of monitoring systems in terms of:

- Objectives
- Monitoring sites
- Variables monitored
- Record length
- Sampling frequency
- Reliability
- Data handling and reporting
- Availability of data.

(c) Evaluation of monitoring systems.

(d) Recommendations for improving monitoring systems.

Streamflow gauging and/or water quality monitoring systems are run in parallel by six organisations, namely:

(a) the DWA&F: Directorate of Hydrology;
(b) the DWA&F OFS Regional office; and
(c) Harmony mine.
(d) Oryx Mine.
(e) Freegold Mines.
(f) Beatrix Mine

Figs. A.1 and A.3 to A.7 (see Appendix A) show the locations of all of the flow and water quality monitoring stations described in this chapter.

5.2 DWA&F Directorate of Hydrology's monitoring system

5.2.1 Streamflow monitoring

a) Objectives

Van der Merwe and Grobler (1990) outline four different types of water quality monitoring system that are operated by the Department, namely:

(i) National monitoring system;
(ii) Catchment monitoring systems;
(iii) Compliance monitoring systems; and
(iv) Project monitoring systems.

The monitoring system described in 5.2.1 falls into the first category.

b) System description

Continuous flow gauging takes place at both reservoir stations and also at station C4H004.

Table 5.1 lists the two main flow gauges in the area and Table 5.2 gives details regarding the two main dams.

TABLE 5.1
List of River Gauging Stations

Station No.	River	Place	Latitude	Longitude	Opened
C4H004	Vet	Nooitgedacht	27° 51' 05" *	26° 07' 36"	09/66
C4H005	Vet	Hoopstad	27° 50' 30"	25° 54' 00"	01/80

* This gauge appears to have an incorrect latitude (5' out). 27° 56' 05" would place it on the Vet River.

TABLE 5.2
List of Reservoir Stations

Station No.	Dam/ Reservoir	River	Latitude	Longitude	Start of Record	Dam Cap. $10^6 m^3$	MAR * $10^6 m^3$	Catchment Area km^2
C4R001	Allemanskraal	Sand	28° 17' 16"	27° 08' 45"	01/59	179.91	91.96	3665
C4R002	Erfenis	Groot-Vet	28° 30' 27"	26° 46' 42"	04/59	212.34	168.10	4750

* As per Middelton et. al., 1981 (page A.87)

c) Station details

C4R001 - Sand River at Allemanskraal Dam

Allemanskraal Dam is located on the Sand River. It has a storage capacity of approximately twice the MAR. The W-component of the dam (station C4H008) is a sharp crested weir (Fig. 5.1) and there is a Parshall flume on the left bank outlet canal (station C4H007). Outflows from the dam could be rated with reasonable accuracy. Flow gauging commenced in 1959.

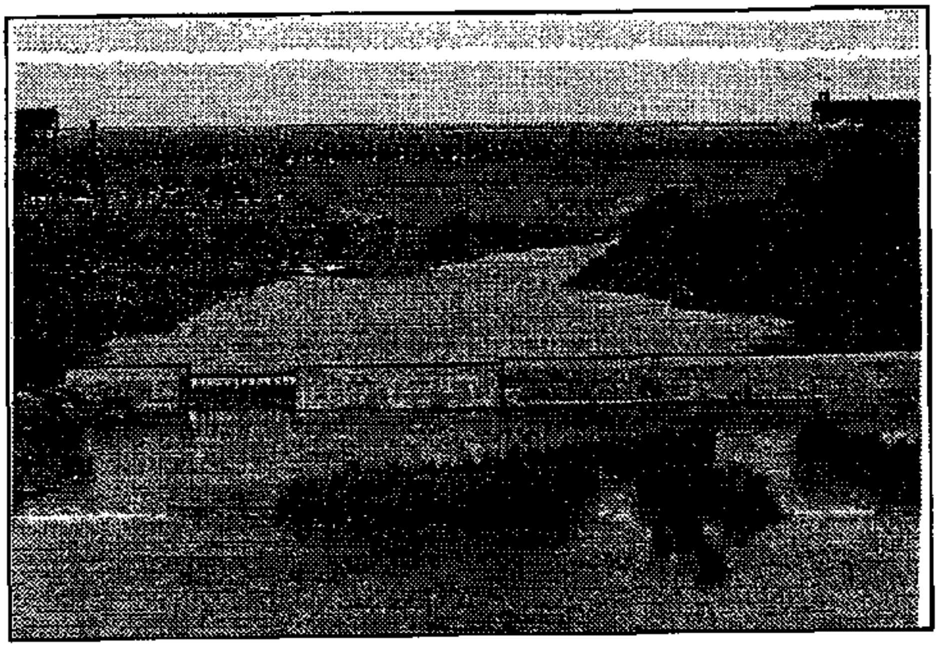

Fig. 5.1 : Station C4R001 - Sand River at Allemanskraal Dam (4/12/92)

Station C4R002 - Vet River at Erfenis Dam

Erfenis Dam has a capacity greater than one MAR and will consequently greatly modify the streamflow hydrograph and salinity regime of the Groot Vet River. Successful modelling of the Vet River will require good records of releases from the dam and of the salt concentrations of such releases.

Flood flow gauging using the Ogee spillway of the dam is supplemented by low flow gauging at the W-component (station C4H010), which comprises a Crump weir (Fig. 5.2). It was reported that submergence problems occur at the W-component at high flows and that the downstream submergence gauge, which is too close to the weir, is to be moved downstream to the access road bridge. There is a Parshall flume (station C4H009) on the left bank outlet canal. The structures gauging outflows from Erfenis Dam could be rated with reasonable accuracy.

Flow gauging commenced in 1959.

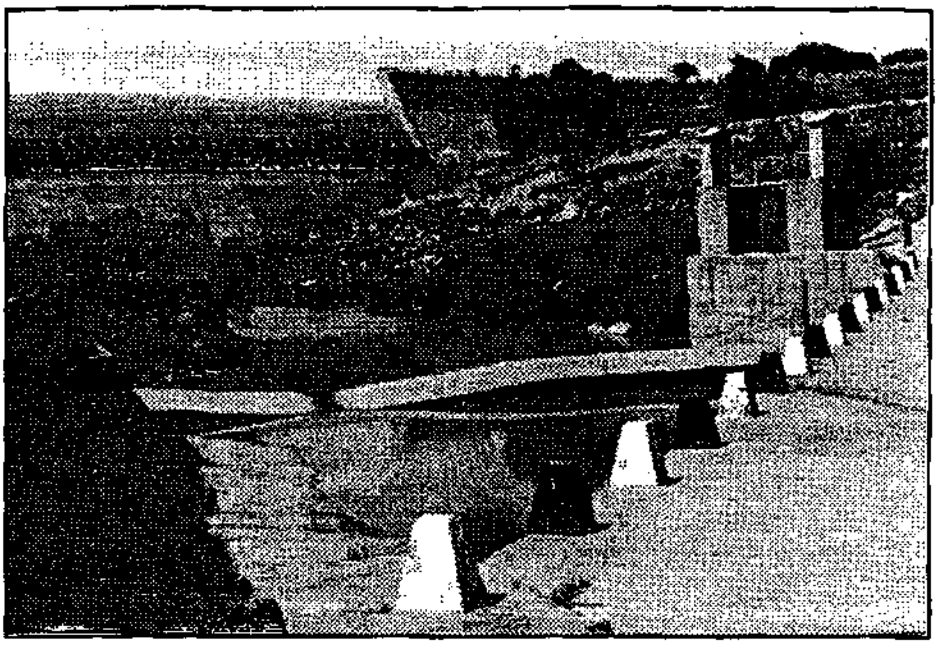

Fig. 5.2 : Station C4R002 - Vet River at Erfenis Dam (4/12/92)

Station C4H004 - Vet River at Nooitgedacht Weir

C4H004 comprises a Parshall flume set in the right flank of a broad crested weir (Fig. 5.3). It is located downstream of the Vet-Sand confluence on the lower reaches of the Vet River. The Parshall flume has a rated capacity of 38.63 m^3/s. The Directorate of Hydrology is in the process of extending the DT using the Slope-area method. This station is reported to have a reasonably reliable flow record, which commenced in 1968. The only problem that was reported was that the stilling basin inlet is prone to silting up. Care will therefore have to be taken that the stilling basin is regularly checked and cleared.

Nooitgedacht weir is strategically placed to monitor most of the water and salt contribution of the Vet River to Bloemhof Dam. In particular, it is the only gauging weir downstream of the mining developments in the lower Sand River region.

Fig. 5.3 : Station C4H004 - Vet River at Nooitgedacht Weir (3/12/92)

Station C4H005 - Vet River at Hoopstad

C4H005 is a quality monitoring station which was opened in January 1980. There is no flow gauging at this site. In view of the insignificant incremental runoff between C4H004 and C4H005, there is little to be gained in measuring streamflow at this site.

d) Data handling

i) Storage

The primary flow data for each station is entered into the Directorate of Hydrology's computerised Hydrobank. The data is stored on a hard disk on a Burroughs mainframe computer.

ii) Availability

The data is freely available to outside users on request. Authorised departmental users have direct access to the data base via their computer terminals. The data can also be supplied on magnetic tape or floppy diskettes. The data can be supplied in primary, daily or monthly formats. Daily and monthly data are available either in tabulated form (printouts) or computer compatible formats.

iii) Data reporting

There is no formal system for processing the data into information and reporting to management.

5.2.2 Water quality monitoring system

a) Objectives

The objectives of the DWA&F Directorate of Hydrology's water quality monitoring system is the same as for its streamflow monitoring system (see Ch. 5.2.1)

b) Monitoring sites

At the moment the Directorate of Hydrology takes samples at six sites (see underlined codes in Table 5.3) some of which also form part of the Directorate of Hydrology's streamflow gauging system.

A few years ago the DWA&F changed the codes of all hydrological stations. However, in the DWA&F water quality data bank the old numbers have been retained. The new codes for the stations are as follows:

TABLE 5.3
Details of the DWA&F Directorate of Hydrology water quality stations

OLD CODE	NEW CODE	DESCRIPTION
C4M04	C4H004	Gauging plate in pool and submergence plate
C4M05	C4H005	Sampling point
C4R01A	C4R001-A01	Gauging plate in dam basin
C4R0101	C4R001-Q01	Sampling point near dam wall
C4R01C	C4H007	Gauging flume in canal
C4R01W	C4H008	Gauging weir for spill and releases
C4R02A	C4R002-A01	Gauging plate in dam basin
C4R0201	C4R002-Q01	Sampling point near dam wall
C4R02C	C4H009	Gauging flume in canal
C4R02W	C4H010	Gauging weir for spill and releases

The DWA&F chemical data bank has the following details for the four main gauges as follows:

TABLE 5.4
List of Chemical Data Bank Water Quality Monitoring Stations

Code	Station name	Latitude	Longitude	No. of analysis	1st sample	Last sample
C4R001	Allemanskraal	28° 17' 16"	27° 08' 45"	244	68-04-01	92-10-13
C4R002	Erfenis	28° 30' 27"	26° 46' 42"	479	68-04-01	92-10-05
C4H004	Nooitgedacht*	27° 51' 05"	26° 07' 36"	1221	72-08-03	92-10-26
C4H005	Hoopstad	27° 50' 30"	25° 54' 00"	606	80-01-29	88-01-04

* *This gauge appears to have an incorrect latitude (5' out). 27° 56' 05" would place it on the Vet River.*

The sampling frequency is irregular and varies for different stations during different time periods.

Samples are analysed at the DWA&F Hydrological Research Institute (HRI) laboratory at Roodeplaat Dam.

TABLE 5.5
Details of the Directorate of Hydrology's water quality data

CONTACT PERSON Name: Telephone: Position:	J Schutte 012-2992736 Assistant Director; Directorate of Hydrology	
LABORATORY: Name: Telephone: Position:	HRI Dr P Kempster 012-8080377 Senior Specialist Scientist	
ANALYSES MADE: *1		
Parameters	**Frequency *2 (samples/month)**	**Detection limit (mg/l)**
pH	4	N/A
TDS*3	4	N/A
EC	4	N/A
Alkalinity as $CaCO_3$	4	0
Chloride	4	3.0
Fluoride	4	0.1
Sulphate (SO_4)	4	2.0
Calcium (Ca)	4	1.0
Magnesium (Mg)	4	1.0
Potassium (K)	4	0.3
Sodium (Na)	4	2.0

NOTES: *1 Analyses made on filtered samples.
*2 This is the average frequency. In the case of station C4R001 it is every two weeks.
*3 TDS represents Total Dissolved Salts, calculated from the concentration of the main ions.

The accuracy level is strongly dependent on the concentration measured. From literature and inter-laboratory comparisons it was found that for the methods used by the HRI, the maximum possible error is 50% near the detection limit, less than 20% at concentrations around 5 times the detection limit and less than 10% at concentrations of 10 to 100 times the detection limit. However, an accuracy of better than 5% is usually achieved in the middle of the analytical range. The precision, or repeatability of a determination is often as good as 1% in the middle of the range.

c) Station details

Station descriptions are given in Ch 5.2.1.

C4R001 - Sand River at Allemanskraal Dam

The current practice is to take samples from the water leaving the dam every second week (C4R0101). The water in the canal was analysed on only three occasions and therefore cannot contribute additional information on the water quality. An increased EC sampling frequency is desirable during floods.

Modelling of the salinity regime of Allemanskraal Dam is important in view of its contemplated use as a source of fresh water for blending with saline Vaal River water in the supply to Goldfields Water (**Stewart Sviridov & Oliver,1989**). Goldfields Water already abstracts a limited amount of raw water from Allemanskraal Dam's irrigation canal for use in its Virginia purification works.

Station C4R002 - Vet River at Erfenis Dam

Weekly samples are currently taken from the water released from the dam (C4R0201). For the period 1986 to 1989 further analysis was carried out at the gauging flume in the canal and the weir (C4R02C & C4R02W). The sampling dates for these three points seldom overlapped and therefore three data files were combined to obtain a more comprehensive data set. Since 1989 this supplementary sampling was discontinued, but sampling at C4R0201 became more reliable. The present practice should suffice for most conditions. However, calibration of the hydro-salinity model for Erfenis Dam showed that when the dam level is low, flood inflows can cause rapid changes in TDS concentrations (**Stewart Sviridov & Oliver, 1989**). It follows that the frequency of EC sampling should be stepped up during floods.

Station C4H004 - Vet River at Nooitgedacht Weir

Since November 1987 daily EC samples have been taken during the summer months. Water quality sampling of other parameters is carried out every week. Because the site is remote, daily sampling is not recommended. Instead, continuous automatic EC monitoring is suggested.

Station C4H005 - Vet River at Hoopstad

C4H005 is a quality monitoring station on the lower Vet River at Hoopstad which was opened in January 1980. There is no flow gauging at this site.

Water quality samples were previously taken at weekly intervals. The last sample was taken in January 1988.

In view of the insignificant incremental runoff between C4H004 and C4H005, there seems little point (from a salinity modelling point of view) in continuing monitoring at C4H005. A high sampling frequency at C4H004, where there is a reasonable flow gauging structure, is preferable.

Evaporative concentration in the Vet River and additional return flow from riparian irrigation can be expected to result in higher TDS concentrations at C4H005 than at C4H004. An initial comparison of the data at these two stations confirmed that this is the case. Hence there is some value in carrying out low frequency (say monthly) sampling at C4H005 to measure this effect and give a better indication of the TDS concentrations in the raw water supply of Hoopstad.

d) Data handling

i) Storage

The water quality analysis data for each station is entered into the Directorate of Hydrology's computerised Chemical Data Bank. The data is stored on the hard disk of a Burroughs mainframe computer.

ii) Availability

The data is freely available to outside users on request. Authorised departmental users have direct access to the data base via their computer terminals. The necessary communication interface between remote users and the main frame containing the databases is provided by GOVNET. The data can also be supplied on request as printouts or on magnetic tape or floppy diskettes.

iii) Data reporting

In the past there was no formal system for processing the data into information and reporting to management. However, some statistical analyses can be carried out on request using in-house software. This includes minimum, maximum, mean, standard deviation, coefficient of variation, 10th, 50th and 90th percentiles and frequency tables for any specified time period. Recently, work has commenced on setting up systems for analysing the data and presenting it in report format. Four volumes are already available. They include colour coded maps and other graphical presentation (see as example HRI Report TR 145, 1990). A nationwide data inventory was created (see HRI Report TR 146, 1991). At present rivers and catchment categorisation according to water quality using a GIS system is also under development in the HRI.

5.3 DWA&F OFS Region's monitoring system

5.3.1 Streamflow monitoring

There is no streamflow monitoring system

5.3.2 Water quality monitoring

a) Objectives

The objective of this system is compliance monitoring to enforce effluent quality standards. The OFS Region is also interested in the general water quality status of the rivers.

At most sites only infrequent *ad hoc* grab sampling is done. The frequency of this sampling could be more or less frequent, depending on the situation in the area and importance of the monitoring point. Samples are rarely taken more often than once a month.

b) Monitoring sites

The DWA&F OFS Regional Office has seven regular monitoring stations, which are shown in Figs. A.3 to A.7 (Appendix A).

Descriptions of the monitoring sites on which samples were taken are given below:

DWA1 is on the Doring River under the bridge of the road leading to the Richlie farm off the Welkom to Theunissen road;

DWA2 is called "Bokant Virginia". It is on the Sand River under the railway bridge east of Virginia;

DWA3 is on the Sand River in Virginia Park;

DWA4 is called Desna. It is on the Sand River near Desna farm, west of Virginia. It is a few hundred meter upstream of the confluence with the Sand River Canal;

DWA5 is located on the Sand River Canal near to its confluence with the Sand River;

DWA6 is called WW Huis. It is on the Sand River a few hundred metres downstream of the confluence with the Sand River Canal;

DWA7 is called Bloudrif. It is on the Sand River under the Welkom to Theunissen road bridge, near the Bloudrif farm.

c) Network's details

The number of samples collected at each station ranges from 21 to 27.

Details of the Directorate of Water Pollution Control water quality sampling stations are given in Table 5.6.

TABLE 5.6
Details of Directorate of Pollution Control water quality data

CONTACT PERSON		
Organisation	Water Quality, OFS Region, DWA	
Names:	Dr J van der Merwe	
Telephone:	(051) 303-134	
Position:	Deputy Director: Pollution Control	
LABORATORY	SABS	
Name:	M J McNerney	
Telephone:	012-4286844	
Position:	Manager : Water Division	
ANALYSES MADE:*		
Parameters	Frequency (samples/month)	Detection limit (mg/l)
pH	*ad hoc*	N/A
EC	*ad hoc*	0.1
Chloride	*ad hoc*	5.0
Nitrate as N	*ad hoc*	0.2
Sulphate (SO_4)	*ad hoc*	5.0
Ortho-phosphate as P	*ad hoc*	0.05
Free/saline ammonia as N	*ad hoc*	0.2
Calcium (Ca)	*ad hoc*	1.0
Magnesium (Mg)	*ad hoc*	1.0
Sodium (Na)	*ad hoc*	1.0
STATIONS:	1 to 7	
PERIOD:	June 1989 - September 1992	

NOTE: * Analyses made on filtered samples.

All of the parameters listed in Table 5.6 were not always analysed for every sample. However, EC was always measured.

The accuracy of measurement for the analyses was not available at the time of writing, as the methods used were currently undergoing revision. Generally, the SABS accuracy is regarded as good. However, some human errors (probably typing errors) have been found. In this case the value was discarded from the data file and treated as missing (e.g. Na measured at the Sand River Canal on 17/6/1989 was 22 mg/l, while EC was 805 mS/m and Cl was 2080 mg/l).

The precision, or repeatability of a determination is a function of the analytical range. Table 5.7 shows the number of significant figures with which the results of the analyses were reported. For some of the parameters, precision was not formally validated and therefore was not included in the table.

TABLE 5.7
Precision of analyses inferred from reported results

Parameter		Range	Precision
pH		0.5 - 13.5	0.1
EC	(mS/m)	0.1 - 15.0 >15	0.1 1.0
Chloride (Cl)	(mg/l)	5 - 200 200 - 2000 >2000	1.0 10 100
Sulphate (SO_4)	(mg/l)	5 - 500 500 - 5000 > 5000	1.0 10. 100
Magnesium (Mg)	(mg/l)	1 - 200 200 - 2000 > 2000	1.0 10. 100
Sodium (Na)	(mg/l)	1 - 500 500 - 5000 > 5000	1.0 10. 100

d) Data handling

i) Storage and processing

The water quality data for each station at which grab samples are taken is stored in the files of the OFS Regional Office. Some of the data is entered into the POLMON computer data base.

ii) Availability

The grab sample water quality data measured in public streams is generally available. However, some of the data (usually that collected within factory premises) is confidential and may not always be made available to outside users.

iii) Data reporting

At present there does not appear to be any formal system for processing the data and reporting the information to management. However, the results are acted upon when non-compliance with effluent quality standards is detected.

5.4 Harmony mine's monitoring system

5.4.1 Streamflow monitoring

There is no streamflow monitoring system

5.4.1 Water quality monitoring

a) Objectives

The objective of this system is compliance monitoring to enforce effluent quality standards.

b) Monitoring sites

The Harmony mine has seventeen monitoring stations and the more important ones have been shown in Fig. A.3. There are three types of monitoring stations: stream monitoring on the Sand River, dam monitoring (storage and return dams) and internal processing (different locations within a mine)

Descriptions of the monitoring sites on which samples were taken are given below:

i) Stream monitoring stations (given in order of upstream to downstream):

HAR1 is on the Sand River under the railway bridge east to Virginia;

HAR2 is on the Sand River below waste rock dump stream

HAR3 on the Sand River below Donga stream

HAR4 on the Sand River below the pipe bridge (about in the centre of Virginia)

HAR5 is on the Sand River below the President Brand polluting stream (to the west of Virginia and a few km after the confluence with the Sand River Canal)

ii) Dam stations (from east to west):

HARDAMCN - The Convent Dam is a storage dam on the southern border of Virginia

Merriespruit Dam is a storage dam south of Virginia. It should not have any effect on the stream water quality in the region, because it is isolated from the river system. Therefore the data was not computerised and analysed;

HARDAMC - Dam C is a storage dam below the slimes dam H1 and above the Goldfields Water purification works to the west of Virginia;

HARDAMB - Dam B is a storage dam on the western border of slimes dam H3A;

HARDATR - measures seepage collected from the slime dam H3 with treated effluent;

iii) Internal monitoring stations (from west to east):

HAR6 is on the Virginia waste rock dump stream, which contributes some pollution to the Sand River at station HAR2;

HAR7 is on the Donga stream, which contributes some pollution to the Sand River at station HAR3;

Virginia effluent water is underground water mixed with effluent from Virginia municipality for internal use. It should not have impact on river water quality and therefore was not analysed;

HAR9 monitors Virginia underground mine water pumped from the shaft in the Virginia section of the mine. It is treated with flocculant and lime underground and sampled after this treatment;

Virginia flume to Convent Dam - probably conveys polluted stormwater and/or process effluent for storage at Convent Dam and further treatment. It should not have any impact on river water quality and therefore was not computerised or analysed;

HAR8 monitors Harmony underground mine water pumped from the H3 shaft of the mine. It is treated with flocculant and lime underground and sampled after this treatment;

The President Brand polluting stream is located on the eastern border of Stuurmanspan next to the Sand River Canal, north-east of Virginia. It can affect water quality in the Sand River Canal (which is already badly polluted), but should not have impact on river water quality and therefore was not computerised or analysed.

c) Network's details

The monitoring commenced in January 1977. The parameters initially measured included Total and Dissolved Solids, Ca, Cl, SO_4, pH and Cn. From August 1979, EC measurements were added, as well as once a year measurements of Total Hardness. For some of the stations Na, bicarbonate alkalinity and calcium hardness have been measured once a year since 1979. The monitoring at President Brand mine was added in February 1980. The frequency of measurements is once a month. No information is available on measurement methods and consequently on the accuracy or precision of the data.

From the data analysis it is apparent that some of the reported values are in error. Only HAR1 has more then 40 of such values, e.g. the SO_4 value of 406 on 5/1978, when TDS is only 272 or a Ca value of 3112 on 1/1985 (which is almost 10 times higher then normal Ca values with similar TDS and other components). There are nine cases of extremely low TDS for underground water pumped in the Harmony section, with TDS around 500 mg/l and other water quality parameters being representative of potable water in the area (underground water has an average TDS of above 5000 mg/l).

There are also many highly suspicious values, but because of the fact that only partial analysis has been done (e.g. Total Alkalinity and Mg were never measured, while Na was measured at only a few stations and with lower frequency), it is impossible to determine if these are errors or events with unusual water quality composition. There are also many cases when Cl and SO_4 values are below detection limits. This is practically impossible for a river which is relatively polluted. The comparison with water quality at Allemanskraal, which releases water for this part of the Sand River, showed that it is impossible to get water quality values as low as that in Allemanskraal Dam. For the same period, Allemanskraal Dam only once had SO_4 concentrations around 3 mg/l but the rest of the time had much higher SO_4 and Cl concentrations. Another anomaly is that Harmony mine's detection limit for Cl is much lower than that of other laboratories. It is 1 mg/l compared to the SABS detection limit of 5 mg/l and 3 mg/l for the HRI laboratory.

d) Data handling

i) Storage and processing

The records of water quality data for each station are kept at the Harmony mine office.

ii) Availability

The data is confidential and may not always be made available to outside users. Prior to this study the DWA&F OFS Regional Office had no knowledge of the existence of this monitoring system.

iii) Data reporting

At present there does not appear to be any formal system for processing the data and reporting the information.

5.5 Oryx Mine's monitoring system

5.5.1 Streamflow monitoring

There is no streamflow monitoring system

5.5.2 Water quality monitoring

Oryx mine started their own monitoring network in December 1987. It is a comprehensive system with almost 50 sampling points. Most of them are boreholes, a few are dams and drains and only three represent stream water quality; S1, S2 and S3. Since October 1992 measurements at S1 were discontinued, but S4 and S5 were added. Two other stations which were added at the same time are "Bosluis upstream" and "Bosluis mine". One would assume that they are stations on the Bosluisspruit, but no description or location of them could be obtained from the Oryx mine management. Unfortunately the number of analysis available were too few to carry out a meaningfull water quality analysis (about one sample per year). The comparison of upstream to downstream points (also with station DWA7 of the DWA&F OFS regional office) could not detect any trends. EC values at stations S2 and S3 varied from 53.6 mS/m to 344 mS/m, which is quite a wide range. Consequently it is impossible to determine average or representative EC values for the Bosluisspruit.

A positive aspect of Oryx monitoring is that they measure all the important parameters. The analysis includes pH, Total alkalinity, HCO_3, Total Hardness, Na, K, Ca, Mg, Cl, SO_4 and NO_3. Since 1992 TDS was included (unfortunately the analytical method of TDS determination is unknown). However analysis of fluoride (F) was discontinued in 1992, probably because measurements showed results below risk value.

Temporary water quality monitoring was operated by the Institute for Ground Water Studies to collect information for a project carried out on behalf of the Water Research Commission (see Cogho et.al., 1992)

5.6 Freegold Mine's monitoring system

5.6.1 Streamflow monitoring

a) Objectives

A study was carried out by Steffen, Robertson and Kirsten on the Sand River Canal. Five V-notch weirs (A to E) were constructed for this purpose as shown in Fig. A.4. The objective was to determine where polluted water was coming from and the severity of pollution.

b) System description

Starting at President Steyn Mine (owned by Anglo American), the Sand River Canal collects discharges from President Brand Mine (also owned by Anglo American) and Unisel Mine (owned by Gencor) before flowing past the evaporation paddyfields which collect effluent from Harmony Mine (owned by Rand Mines). Thabong Sewage Works commenced discharging purified sewage effluent into this canal at the beginning of 1993.

It was reported that the EC readings in the evaporation paddyfields operated by Harmony mine register about 1000 mS/m. Some seepage from the paddyfields into the canal is possible. The upstream portion of the canal is known as the Mostert Canal, which becomes a natural stream. Further downstream the stream is again canalised, where it is known as the Sand River Canal, which discharges into the Sand River.

c) Station details

In the natural stream section the mines installed a V notch weir downstream of a road culvert (see Fig. 5.4). It is called Mostert Canal/Sand River Canal mines V-notch weir. Fig. A.4 shows this V-notch (marked E).

The V-notch has not been rated by the Department but does not have a level recorder. The Anglo American owned mines are thought to measure flows periodically at this site.

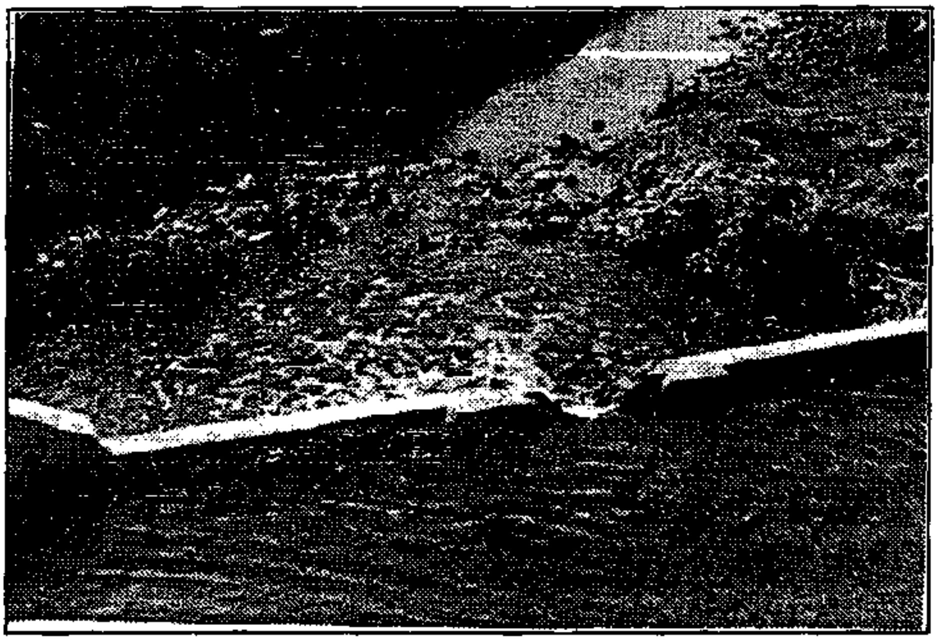

Fig. 5.4 : Mostert Canal/Sand River Canal mines V-notch weir (3/12/92)

d) Data handling

No data was available for this weir.

5.6.2 Water quality monitoring

The water quality data was received at a very late stage and was found to be rather sparse. It was, therefore, not included in this analysis.

5.7 System comparison

Harmony Mine's station HAR1, located in the Sand River under the railway bridge east of Virginia, coincides with the DWA&F OFS Regional Office's station DWA2. A median comparison of the EC data for these two monitoring stations is presented in Fig. 5.5. Fig. 5.5 shows a statistically insignificant difference between the EC measured by the two organisations 5 mS/m. However, despite the insignificant difference between the medians, it is clear that the highest peaks detected by the DWA&F OFS Region's monitoring system often correspond to low values measured by Harmony Mine. On the other hand, the peaks measured by Harmony Mine towards the end of 1991 were missed by the DWA&F OFS Region's monitoring due to a break in sampling routine. It cannot be ascertained if there is a significant difference between the data provided by the two organisations since the sample size (for the period of concurrent monitoring) is small, the sampling frequency is low *(monthly), sample dates within each month do not coincide and the river flow can vary very widely over a short period.

Figure 5.6 shows a comparison between SO_4 measurements at HAR1/DWA2, while Figures 5.7 and 5.8 show the comparisons for EC and SO_4 at HAR5 and DWA6, which are located fairly close to each other on the Sand River (see Fig. A.7).

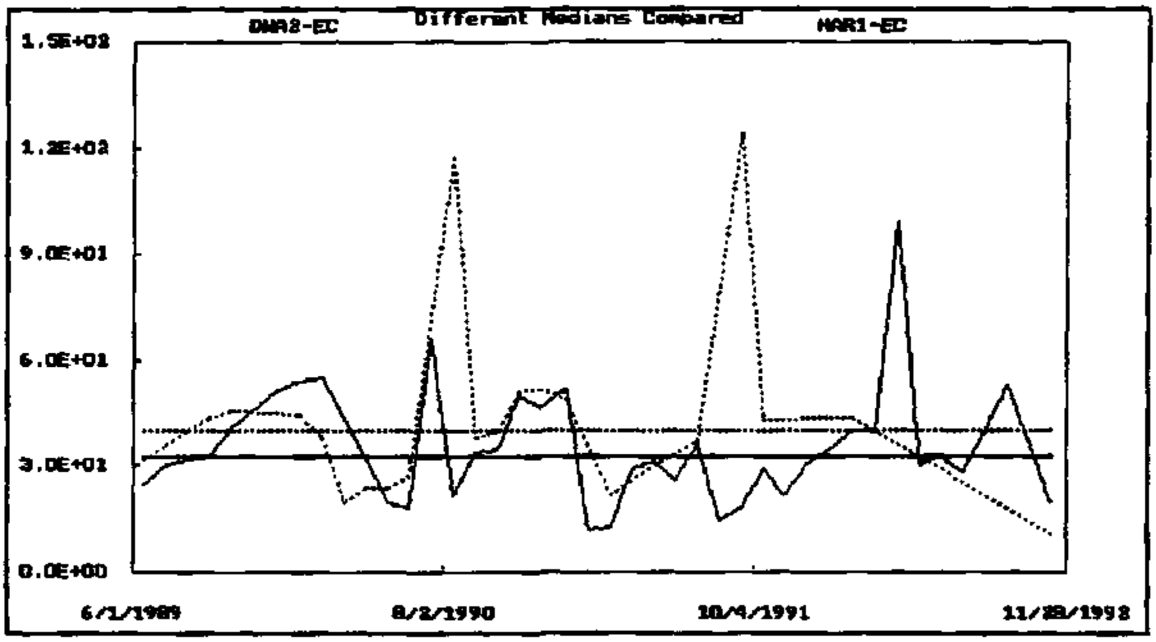

Figure 5.5: Median comparison of EC measured in the Sand River by the DWA&F OFS Regional Office at station DWA2 (dotted line) and Harmony Mine's station at HAR1 (solid line)

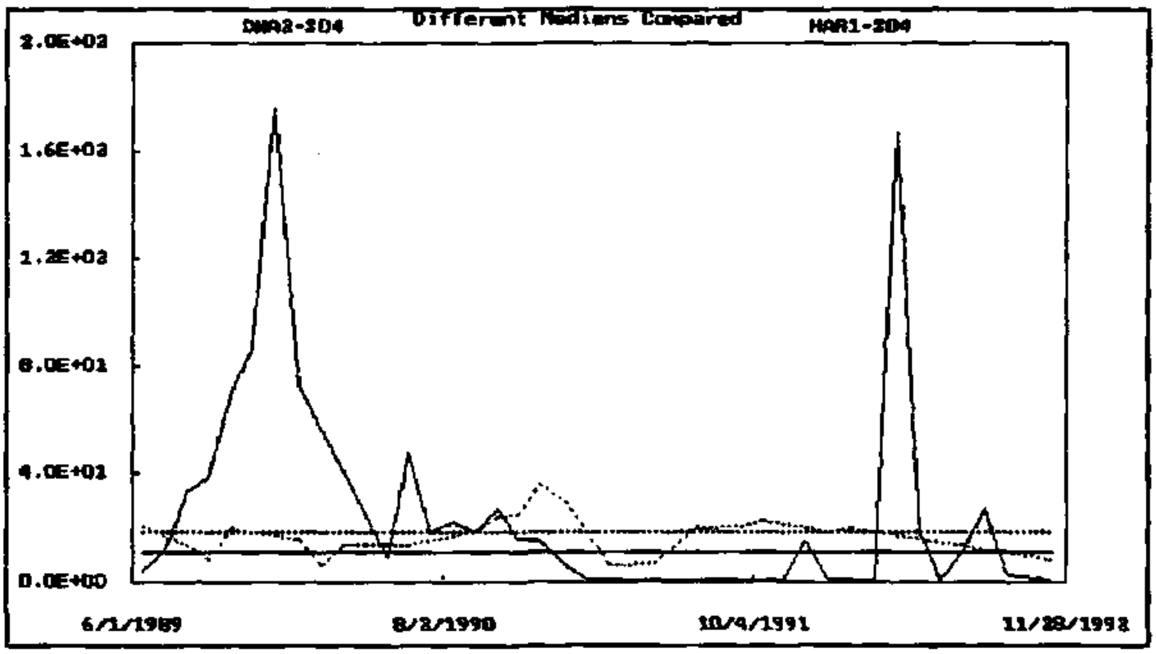

Figure 5.6: Median comparison of SO_4 measured in the Sand River by the DWA&F OFS Regional Office at station DWA2 (dotted line) and Harmony Mine's station at HAR1 (solid line)

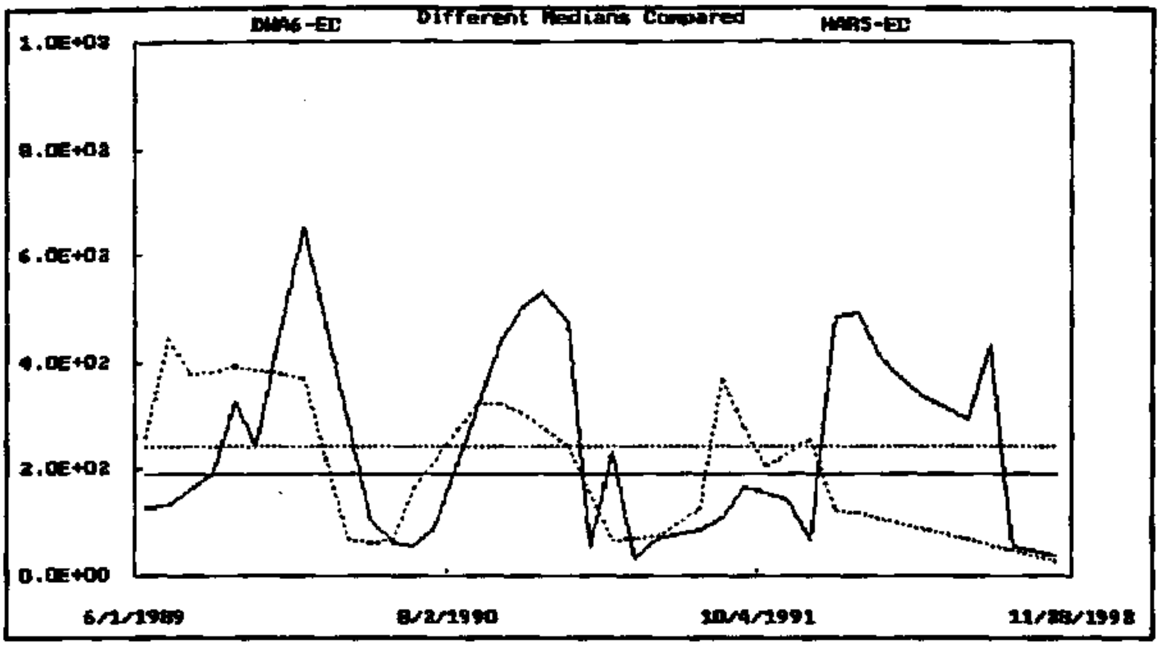

Figure 5.7: Median comparison of EC measured in the Sand River by DWA&F OFS Regional Office at station DWA6 (dotted line) and by Harmony Mine's station HAR5 (solid line)

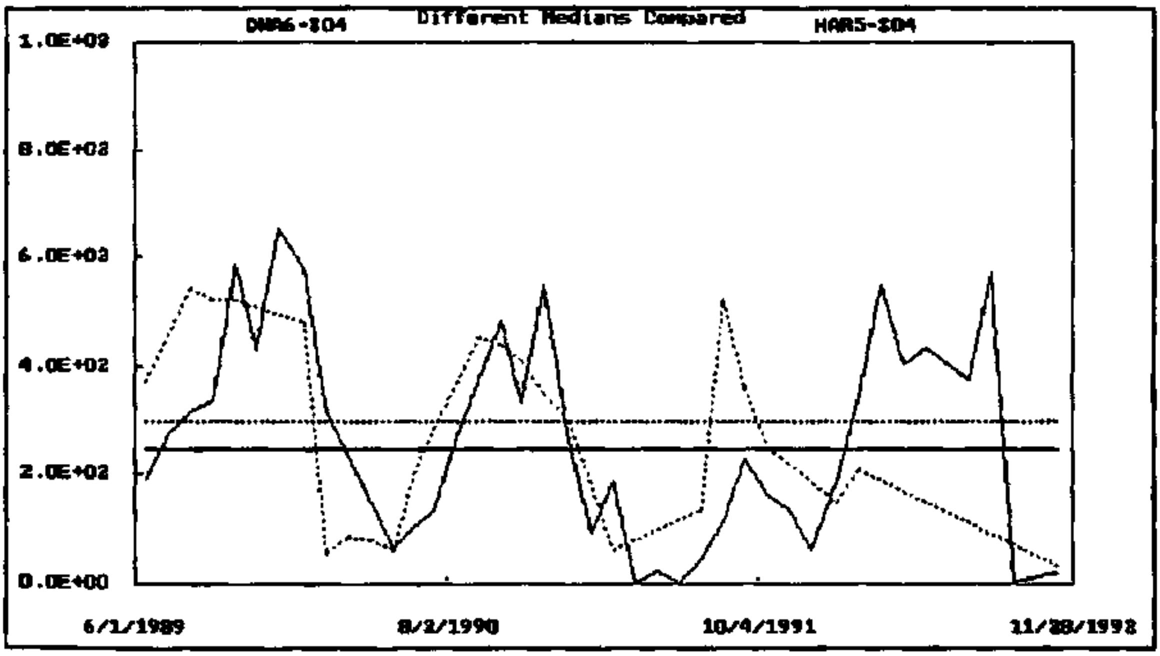

Figure 5.8: Median comparison of SO_4 measured in the Sand River by DWA&F OFS Regional Office at station DWA6 (dotted line) and by Harmony Mine's station HAR5 (solid line)

5.8 Conclusions

The catchment monitoring system was found to be deficient in a number of respects:

5.8.1 Insufficient coverage of catchment

Portions of the catchment, such as the Rietspruit and the Bosluisspruit are not regularly monitored.

5.8.2 Lack of flow gauging

There is a total lack of flow gauging at all water quality sampling points in the most polluted portion of the catchment (i.e. the OFS Goldfields area).

5.8.3 Lack of water balance monitoring

A lack of storage state, inflow and outflow data for most polluted water storage facilities makes it almost impossible to evaluate either the overall water balance for the mining area or the balances for individual facilities.

5.8.4 Sampling frequencies

At most regular monitoring stations within the study area, the monthly sampling frequency is hopelessly inadequate for estimating pollution loads or even for detecting pollution events.

5.8.5 Choice of water quality variables

In many instances important water quality variables are not measured in surface water courses by the mines. (For example, Harmony Mine's analyses of samples taken in the Sand River did not include sodium.)

5.8.6 Site identification

In many instances the identification of monitoring sites was ambiguous or inconsistent. This was particularly so for many of the mines sampling points.

5.8.7 Consistency of water quality data

(a) External consistency problems: Large discrepancies were sometimes found between observed water quality data collected by different organisations at the same (or nearby) points (eg. station DWA2/HAR1). Since the sampling frequency is so low, it could not be ascertained if these discrepancies arose from data errors or changes in flow regime between sampling dates.

(b) Internal consistency problems: The mines data in particular showed massive internal inconsistencies. For example, contradictions between EC and TDS values resulting in impossible TDS/EC ratios of 20 or more were common (almost the rule, rather than the exception). Large imbalances between anions and cations were also common. This implies poor laboratory control. Failure to detect these inconsistencies also implies that the data is not being used effectively by the mines (or that any such use is only superficial).

5.8.8 Data access and processing

(a) The long delays (up to half a year) in obtaining data from various organisations implies that the data is not being stored efficiently.

(b) Very little data appears to be computerised. This implies that most of the cost incurred in data collection is being wasted, since the data cannot be properly analyzed without first being computerised. Presumably many of the data inconsistencies noted in this report would have been detected and rectified had the data been properly processed.

5.8.9 Co-ordination of monitoring programs

Duplication of effort at various monitoring points and no sampling at all in other areas indicates a lack of co-ordination between the different monitoring programmes. Part of the problem appears to have arisen because the mines data has not been made available to the DWA&F OFS Regional Office.

5.9 Recommendations

The following recommendations are aimed at improving the individual monitoring systems and eliminating unnecessary duplication of effort.

5.9.1 Objectives

The objectives and information needs of each monitoring system should be defined as precisely as possible. Only then can an efficient monitoring system be designed.

5.9.2 Communication

Better communication between the organisation concerned is required. For example, the DWA&F OFS Regional Office had no knowledge of some of the mine's internal monitoring networks.

5.9.3 Co-ordination

Co-ordination of the individual monitoring systems is required to minimise unnecessary expenditure arising from several organisations monitoring at the same location. In instances when organisations feel the need to monitor at the same locations (for example, for compliance monitoring), an attempt should be made to coordinate the activities to ensure that samples are taken from exactly the same point at the river at regular sampling intervals (see section 5.9.7).

5.9.4 Compliance monitoring

In future the mines should be requested to send their monitoring data for designated stations to the DWA&F OFS Regional Office. At least some of the compliance monitoring should then be aimed at obtaining samples at the same time that the industries concerned take their samples. If this is not done, there will be no means of auditing the data sent to the controlling authorities.

5.9.5 Improvement of existing flow gauging system

The existing monitoring network is not adequate to monitor the pollution problem. In this regard, the following recommendations apply:

a) Sand River at Blaaudrift bridge:

This is a recommended gauging point downstream of the main pollution activities. As can be seen from Appendix D, the median EC deteriorated from 22 mS/s at Allemanskraal Dam (station C4R001) to 216 mS/m in the Sand River at the Blaaudrift Bridge (statin DWA7) as a result of pollution from gold mining activities.

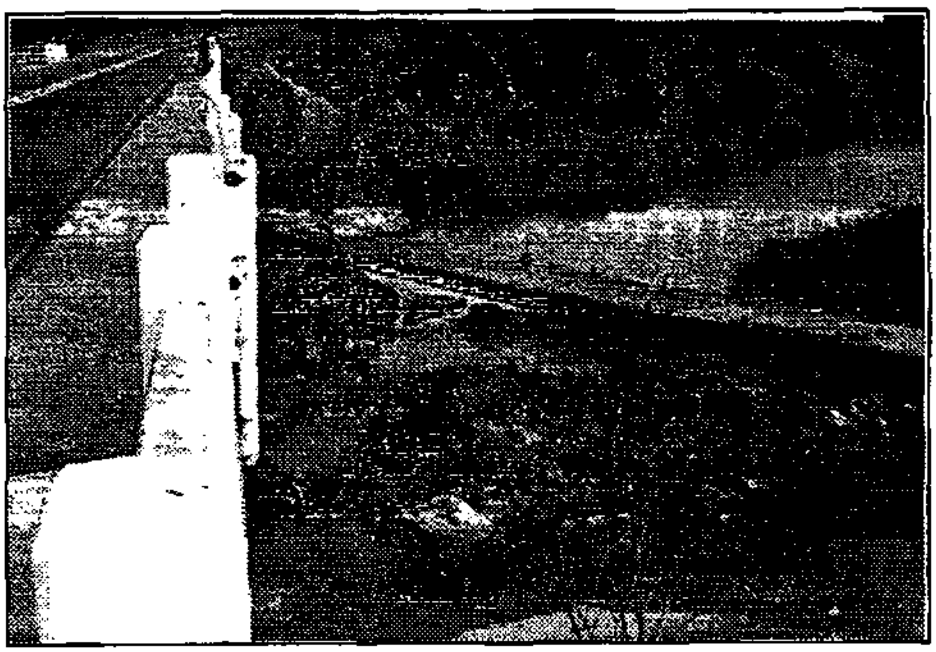

Fig. 5.9 : Sand River at road bridge downstream of gold mining areas (3/12/92)

The OFS Regional Office already uses this site as a pollution control water quality monitoring station. The OFS Region's hydrology section is investigating the possibility of building a weir at Blaaudrift. The sound rock in the river bed and the upstream old low level road causeway offer good prospects for favourable foundation conditions for the proposed weir. A weir capable of gauging low to medium flows is recommended as the first step. After the new weir has been constructed the DT should be extended using the Slope-area method to provide an interim means of estimating flood discharges. Thereafter the extended DT should be firmed up over an extended period of time by means of current metering.

A weir at this site in conjunction with daily (or continuous) EC monitoring at this strategic site will be ideal for estimating the TDS loads resulting from the mining activities in the OFS Goldfields area.

b) Sand River Canal at mines V-notch weir:

A DT for the weir should be established and extended to gauge higher flows. An automatic level recorder is required. The DWA&F should upgrade the weir and take over the operation of this flow gauge.

c) Doring River downstream of the Bosluisspruit:

A farmer's storage weir (Fig. 5.10) is located in the Theronspruit downstream of the seepage collection sump of Beatrix gold mine (Fig. 5.11).

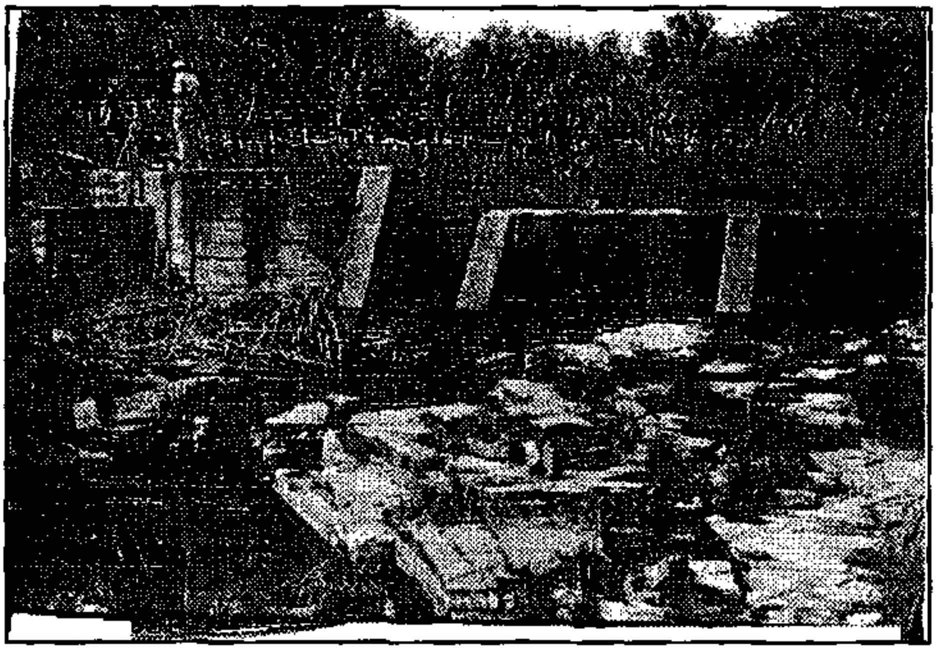

Fig. 5.10 : Theronspruit at farmer's storage weir downstream of Beatrix Mine (3/12/92)

Fig. 5.11 : Sump and pump to collect and return seepage water from Beatrix mine

Very high salinity levels (555 mS/m) were measured in this sump and it is possible that seepage to the Theronspruit could be occurring. (Alternatively, some seepage from the mine could be by-passing the collection system that drains to the sump.) Seepage is thought to occur since the EC measured in the Theronspruit during the field trip on 3 December 1992 was 342 mS/m.

The weir is not ideal for flow gauging as it is has a long irregular broad crest and is choked with vegetation. However, the weir is sited on a dolerite sill with a good rock formation that appears to extend a long distance along the river bed. This implies that there is a good chance of finding a suitable alternative weir site with favourable foundation conditions.

Beatrix Gold Mine and a diamond mine are located in the catchment of the Theronspruit upstream of the farmer's storage weir. Joel Gold Mine is located a short distance downstream of the weir. Further downstream the Theronspruit discharges into the Doring River. The Bosluisspruit, in which catchment Oryx Gold Mine is located, also discharges into the Doring River shortly before its confluence with the Sand River. It was reported that there is little seepage from the diamond mine (which is a relatively dry operation) or from Joel and Oryx gold mines, which apparently benefit from the de-watering of Beatrix gold mine. The main seepage problems appear to be associated with Beatrix Mine.

Flow and water quality monitoring in the Theronspruit should therefore suffice to estimate most of the TDS load contributed by these mines. However, it may be wise to rather seek a gauging site in the Doring River downstream of the Bosluisspruit to ensure that nothing is missed. It is also possible changes in the underground mining conditions (such as the penetration of a new area or the cessation of mining at, for example, Beatrix mine) could lead to an increase in the volume of water that has to be disposed of by the mines that are now relatively dry. If a suitable weir site cannot be located in this river reach then an alternative site further upstream in the Doring River or in the Theronspruit downstream of Beatrix and Joel mines should be sought. An automatic level recorder will be required.

5.9.6 Standardisation of methods

A coordinated effort should be made to standardise water quality sampling and water quality analysis procedures. In particular the following actions should be taken:

a) Document exact locations of sampling points, right down to the position in the river cross-section at which the sample should be taken.

b) Document the date and time of sampling and the corresponding flow depth (where applicable).

c) Adopt a uniform definition of TDS (preferably as total dissolved *salts*, based on analyses of the major ions).

d) Ensure a uniform standard for EC measurements (25°C) and regular calibration of instruments.

e) Coordinate the choice of water quality variables to be analyzed by each organisation and reach general agreement on acceptable analytical methods.

f) Carry out regular inter-laboratory comparisons. One possibility is for the DWA&F to take spilt samples.

5.9.7 Data storage

All flow and water quality data should be stored in computer files to ensure ease of processing, reporting and portability. Sharing of data bases between the participating organisations should be encouraged. This will place more comprehensive data bases in the hands of each organisation and serve as an extra insurance against loss of data. Consolidation of the data from all sources in a central data base should be aimed at.

5.9.8 Data checking

Procedures for checking the data, both before and after entry into the data base, should be introduced. Routine comparison of data derived from the different monitoring systems should be carried out. It is essential that this be done as soon as possible after the samples are collected, to ensure that inconsistencies are detected and corrected at an early stage, before too much valuable data is lost. The causes of the inconsistencies described in this report could have been detected and eliminated years ago if checking procedures had been in place.

5.9.9 Reporting

Well planned reporting procedures should be introduced to ensure that management is kept informed of new developments and long term trends.

Procedures for acting on the information provided to management should also be set up.

Any changes made to the monitoring system should be documented and the information made available to the other organisations involved.

5.9.10 Data conflicts

Every effort should be made to determine the causes of the internal inconsistency of the water quality data reported by some of the mines. External data conflicts, such as the differences between the DWA&F Regional Office's data at stations DWA2 and DWA6 and that measured by Harmony Mine's corresponding stations HAR1 and HAR5 should be investigated. In particular the identification of the sampling sites and methods of analysis should be confirmed.

5.9.11 Background water quality monitoring

Evaluation of the environmental impact of catchment development requires a good knowledge of natural background conditions. For this reason monitoring is required *upstream* as well as downstream of developed areas.

5.9.12 Overall catchment monitoring system design

There is a clear need to prepare a proper monitoring system design for the entire Sand/Vet River catchment. The monitoring system design should include clear documentation of the following:

- water quality information goals;
- define the role of each of the individual organisations;
- details of data sampling;
- definition of data analysis protocol; and
- description of reporting mechanisms.

5.10 References

Stewart Scott (1993) "*Water quality monitoring requirements for salinity modelling*", Vaal River Salinity Study, Volume 3: Middle Vaal River catchment, Report P C000/00/11092,Directorate of Project Planning, Department of Water Affairs and Forestry, Pretoria.

CHAPTER 6

NATURALISATION OF STREAMFLOW

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6. NATURALISATION OF STREAMFLOW

6.1 Hydrological and land use data

6.1.1 Introduction

The area forms part of the highveld region and is relatively flat with an average elevation of 1 360 m above sea level. The Orange Free State Goldfields area is situated in a semi-arid region with a mean precipitation of 518 mm. The area is classified as the Northern Steppe, which is defined as a climate with a chronic water shortage i.e. the annual potential to evaporate water by far exceeds the precipitation.

The February 1988 floods produced a monthly rainfall of 331 mm which corresponds to a return period of 100 years.

The area is extensively covered by soil and sands of aeolian origin covered by sour grassveld. Outcrops are limited to surface limestone, river terrace gravel, dolerite, kimberlite and sediments of the lower Beaufort group, the upper Ecca group and lava sediment of the Ventersdorp supergroup. In the western and north-western parts of the area extensive pan development has taken place. There appear to be two aquifers in the area, one rather shallow within the weathered and fractured zone of the Karoo sediments and a deeper one in the fractured and faulted Ventersdorp and Witwatersrand rocks.

6.1.2 Streamflow

Details of all the DWAF streamflow gauges in the Vet-Sand River system are given in Table 6.1. (See Fig. A.2 for their location.)

TABLE 6.1
Details of the DWAF streamflow gauges

Gauge	Name	Type	Latitude	Longitude	Opened	Closed
C4H001	Prins Willie	Storage weir	28° 28' 24"	26° 41' 09"	Sep 1923	Sep 1947
C4H002	Hoopstad	Weir	27° 50' 45"	25° 54' 32"	Dec 1935	May 1972
C4H003	Virginia	Storage Weir	28° 06' 47"	26° 54' 33"	Oct 1938	Mar 1954
C4H004	Nooitgedacht	Weir	27° 51' 05"	26° 07' 36"	Sep 1968	-
C4R001	Allemanskraal	Dam	28° 17' 16"	27° 08' 45"	Jan 1959	-
C4R002	Erfenis	Dam	28° 30' 27"	26° 46' 42"	Apr 1959	-

The two storage weirs (C4H001 and C4H003) were not used since the flow data at these gauges was considered to be inaccurate. The remaining four gauges were employed in the study, although gauge C4H004 was considered to be more useful than C4H002. The gaugings at C4H004 provide an important indication of the effect on streamflow of the Sand-Vet GWS. Gauge C4H002 was nevertheless of use in verifying model calibration in the period prior to the construction of Allemanskraal and Erfenis dams.

The discharge table (DT) limit of gauge C4H002 was 934 m^3/s, which was sufficiently high to measure virtually the full range of discharge experienced. The record also had no breaks. Accordingly, it was not necessary to patch the streamflow record at C4H002. The records at the two dams (C4R001 and C4R002) were also complete and required no patching.

Gauge C4H004 had an original DT limit of only 38 m^3/s, which was extended to 127 m^3/s by the DWAF for the express purpose of this study. Relatively short breaks in record were patched by interpolation of the daily record. Longer breaks and occurrences of exceedance of the DT limit were patched on a monthly basis using simulated flows.

6.1.3 Rainfall

The location of rainfall stations that were selected on the basis of location, period of record and reliability are shown on Fig. A.2. Details of each gauge are listed in Table 6.2.

TABLE 6.2
Details of rainfall gauges

Station	Name	Latitude	Longitude	MAP (mm)	Period of record*
262694	North End	29° 04′	26° 54′	597	1913 - 1983
293514	Stillewoning	28° 34′	26° 18′	514	1923 - 1991
293792	Brandfort	28° 42′	26° 27′	546	1913 - 1991
294124	Goedemoed	28° 34′	26° 35′	549	1972 - 1991
294154	Bellevue	28° 34′	26° 36′	451	1913 - 1991
294233	Idomia	28° 53′	26° 38′	478	1914 - 1991
294400	Koolklip	28° 40′	26° 44′	510	1951 - 1981
294461	Mount Barnard	28° 41′	26° 46′	495	1915 - 1950
294481	Erfenis Dam	28° 31′	26° 47′	502	1948 - 1991
294500	Verkeerdevlei	28° 50′	26° 47′	580	1923 - 1991
294826	Driekop	28° 46′	26° 58′	532	1927 - 1991
294847	Doornpoort	28° 37′	26° 59′	576	1929 - 1991
295001	Winburg	28° 31′	27° 01′	564	1910 - 1991
295116	Excelsior	28° 56′	27° 04′	571	1911 - 1991
295408	Moreson	28° 48′	27° 14′	636	1926 - 1991
295539	Mequatlingsnek	28° 59′	27° 18′	640	1923 - 1991
295760	Marquard	28° 40′	27° 26′	619	1915 - 1991
295770	Belmont	28° 50′	27° 26′	726	1917 - 1991
296157	Sunny Hills	28° 37′	27° 36′	747	1931 - 1990
326668	Geluk	28° 08′	25° 53′	506	1932 - 1991
327264	Kareepan	28° 24′	26° 09′	462	1919 - 1991
327426	Vooruitsig	28° 06′	26° 15′	523	1923 - 1971

Station	Name	Latitude	Longitude	MAP (mm)	Period of record*
327784	Nelsc[illegible]t	28° 04′	26° 27′	491	1908 - 1991
327883	Groot Kuil	28° 13′	26° 30′	487	1911 - 1991
327899	Pelserskraal	28° 29′	26° 30′	530	1925 - 1976
328294	Abrahamshof	28° 24′	26° 40′	550	1933 - 1982
328308	De Klerkskraal	28° 08′	26° 41′	494	1932 - 1966
328384	Theunissen	28° 24′	26° 43′	532	1914 - 1991
328425	Adamsonsvlei	28° 05′	26° 45′	537	1925 - 1991
328726	Olivine	28° 06′	26° 55′	514	1932 - 1991
328800	Rietvlei	28° 20′	26° 57′	525	1923 - 1982
329001	Whites	28° 01′	27° 01′	540	1915 - 1991
329149	Morgenzon	28° 29′	27° 05′	567	1930 - 1977
329215	Ventersburg	28° 05′	27° 08′	554	1910 - 1991
329370	Welgevonden	28° 10′	27° 13′	597	1913 - 1952
329470	Bakensvlakte	28° 20′	27° 16′	585	1922 - 1951
329783	Rooikraal	28° 03′	27° 27′	554	1923 - 1985
330098	Trekpad	28° 08′	27° 34′	518	1913 - 1982
330190	Bethel	28° 10′	27° 37′	540	1915 - 1949
330199	Senekal	28° 19′	27° 37′	629	1905 - 1991
330403	Mignonette	28° 13′	27° 44′	547	1929 - 1972
330421	Roodepoort	28° 01′	27° 45′	678	1913 - 1991
330699	Leuctra	28° 09′	27° 54′	586	1923 - 1988
330747	Fairfield	28° 27′	27° 55′	673	1904 - 1941
330797	Paul Roux	28° 17′	27° 57′	619	1926 - 1991
362710	Hoopstad	27° 50′	25° 54′	446	1904 - 1948
362862	Wintersvlei	27° 52′	25° 59′	537	1926 - 1980
362884	Ellasrus	27° 44′	26° 00′	494	1949 - 1989
363651	Wesselsbron	27° 51′	26° 22′	469	1924 - 1991
364119	Mahemspruit	27° 59′	26° 34′	521	1932 - 1974
364322	Odendaalsrus	27° 52′	26° 41′	505	1906 - 1991
365143	Holfontein	27° 53′	27° 05′	561	1913 - 1977
365444	Swartkoppie	27° 54′	27° 15′	566	1926 - 1991

* Hydrological years e.g. 1991 = Oct 1991 to Sep 1992

The Vet River catchment was subdivided into five areas for the purpose of streamflow modelling (see Section 6.2) as follows:

a) the catchment commanded by Allemanskraal Dam,
b) the catchment commanded by Erfenis Dam,
c) the catchment between Allemanskraal Dam and the Sand/Vet confluence,
d) the catchment between Erfenis Dam and the Sand/Vet confluence, and
e) the catchment between the Sand/Vet confluence and Hoopstad.

These areas are shown in Fig. A.2.

Monthly rainfalls for the period 1920 to 1991 were determined for these five subcatchments by means of program HDYP08, which outputs monthly rainfalls expressed as a percentage of mean annual precipitation (MAP).

6.1.4 Sand-Vet Government Water Scheme (GWS)

The Sand-Vet GWS constitutes by far the most significant consumer of water in the Vet River catchment. The area it covers extends from Allemanskraal Dam and Erfenis Dam to Hoopstad. Pertinent features of the scheme are given below.

<u>Scheduled from Allemanskraal Dam</u>

Canal	=	4996.6 ha
River	=	nil
Total	=	4996.6 ha
Goldfields Water	=	$12.8 \times 10^6 m^3$ p.a.
Harmony Mine	=	$1.2 \times 10^6 m^3$ p.a.
Beisa/Oryx Mine	=	$2.4 \times 10^6 m^3$ p.a.
Agric. Technical Services	=	$0.32 \times 10^6 m^3$ p.a.
Dept. of Prisons	=	$0.32 \times 10^6 m^3$ p.a.

<u>Scheduled from Erfenis Dam</u>

Canal	=	5103.7 ha
River	=	1297.4 ha
Reservoir basin	=	151.1 ha
Total	=	6552.2 ha
Brandfort Municipality	=	$1.82 \times 10^6 m^3$ p.a.
Theunissen Municipality	=	$0.55 \times 10^6 m^3$ p.a.
Bultfontein Municipality	=	$1.82 \times 10^6 m^3$ p.a.
Hoopstad Municipality	=	$0.31 \times 10^6 m^3$ p.a.
Willem Pretorius Reserve	=	$0.36 \times 10^6 m^3$ p.a.

<u>Total scheduled area of scheme</u> <u>11 548.8 ha</u>

The water allocation to the irrigators of the Sand-Vet GWS is 7200 m^3/ha/annum, which means that the total supply to irrigation is approximately 83 x 10^6m^3 p.a. However, the volume supplied varies from year to year according to the area actually irrigated, climatic conditions and restrictions (if any) on the supply.

For the purposes of model calibration (Section 6.2) the inputs from the catchments upstream of Allemanskraal and Erfenis dams are replaced by the controlled compensation releases plus the uncontrolled spillages from the dams, which have been measured since the dams were built. There are, however, additional discharges from both Allemanskraal and Erfenis canals into the Sand and Vet rivers respectively. These discharges are necessary to supply the Sand-Vet GWS irrigators that abstract water directly from the Vet River (below the Sand/Vet confluence) plus the municipality of Hoopstad.

Monthly readings of these discharges were available for the calendar years 1984 to 1990 and annual readings were available for 1991 and 1992. Information on these discharges are summarised below.

	Annual release (10^6m^3)		
	Minimum	Maximum	Mean
Allemanskraal	1.12	2.38	1.69
Erfenis	4.53	13.82	9.11
Total	6.47	15.93	10.80

The mean discharge of 10.8 x 10^6m^3 p.a. amounts to approximately 14% of the average total volume released from the two main storage dams into their respective canals. However, the average discharge from the Allemanskraal canal represents only about 5% of the release into the canal, whereas the equivalent figure for Erfenis is about 22%.

In order to provide estimates of canal discharges over the full life of the Vet-Sand GWS, the monthly data for the period 1984 to 1990 were correlated with the releases into each canal. The resulting regression equations were then used to extend the canal discharge records back to 1960, i.e. when the canals were first in operation. Results of the linear regression are summarised below. (Volumes are in million cubic metres per month.)

Allemanskraal

Discharge = 0.10 + 0.013 x Release into canal

(r^2 = 0.06)

Erfenis

Discharge = 0.28 + 0.133 x Release into canal

(r^2 = 0.25)

Although the correlations were weak, it was felt that discharges that fluctuated in accordance with releases into each canal would be more realistic than constant discharges.

Another important feature in the overall balance of the scheme is the return flow from the irrigation lands back into the Vet and Sand rivers. In their study of return flows for a number of irrigation schemes, *Ninham Shand (1985)* estimated that the total potential return flow from the Sand-Vet GWS to be of the order of 35% of the gross supply. The actual return flow would be much lower than 35% but the percentage can only be estimated by considering the water balance of the scheme. Accordingly, the following procedure was followed in order to assess the return flow from the Sand-Vet GWS.

(i) Identify months for which the natural streamflow in the Vet and Sand rivers below Erfenis and Allemanskraal dams is likely to be zero.

(ii) Estimate the irrigation abstractions from the Vet River upstream of gauge C4H004.

(iii) Calculate the contribution from return flow by considering the water balance at C4H004.

Step (i) was accomplished by examination of the simulated monthly flows for the subcatchments downstream of Allemanskraal and Erfenis dams. (If they were zero for a particular month, it was assumed that the actual (natural) runoff was also zero.)

The total irrigation area met by abstractions from the lower Vet River is approximately 1300 ha. The portion of this area situated upstream of C4H004 was estimated (by counting farms) to be 550 ha. Since the total scheduled area supplied from Erfenis Dam is 6552 ha, the supply to the 550 ha in question can be estimated at 550/6552 = 0.084 multiplied by the release into Erfenis canal for step (*ii*).

The water balance at gauge C4H004 for months in which natural flow is zero is as follows:

$$\begin{aligned}\text{Observed flow (O)} &= \text{Return flow (R)}\\ &\quad + \text{Canal discharges (D)}\\ &\quad - \text{Irrigation abstractions (I)}\end{aligned}$$

Thus

$$R = O - D + I$$

or

$$R = O - D + 0.084 \text{ (Release into Erfenis canal)}$$

Values of R were calculated for the period 1984 to 1990, viz. the only period for which monthly values of D were available. Negative values of R were generated in a few cases but most months yielded small positive values that could be attributed to return flows. Months that yielded high values were rejected on the basis that the actual runoff could have made a significant contribution to the water balance.

The average return flow was estimated to be about $0.62 \times 10^6 m^3$ per month or close to 10% of the combined release into both canals. Although the percentage return flow would depend on a number of factors including climatic conditions, a fixed 10% was used in the model calibrations and the subsequent naturalisation of flow records.

6.1.5 Private irrigation

Unfortunately it was not possible to obtain up-to-date information on the extent and distribution of private irrigation. The most recent information that could be obtained was to be found in the report "*Assessment of irrigation demands using satellite imagery*" produced by BKS (1985) as part of the Vaal River System Analysis project undertaken on behalf of the DWAF. This report also contained information on crop patterns.

Information on sources of water used for irrigation was obtained from the *Agricultural Census No. 49 (1976)*. This data was used to apportion the more recent irrigation areas in the BKS report according to whether they were supplied from (farm) dams, streams or groundwater. Information on minor dams was obtained from the DWAF.

Estimates of the growth in private irrigation were based on growth rates for the Vaal catchment as a whole since 1970. Prior to that date average growth rates appropriate to South Africa as a whole were applied. Table 6.3 summarises the information on private irrigation in the Sand-Vet catchment.

TABLE 6.3
Private irrigation details

Catchment	Irrigation areas (km^2)			Total dam capacity (10^6m^3)	Estimated demand (10^6m^3 p.a.)
	Total[1]	From streams	From dams		
(a) u/s C4R001	13.93	4.04	9.89	2.88	4.82
(b) u/s C4R002	19.75	5.33	14.42	3.60	10.07
(c) d/s C4R001	15.09	10.60	4.49	4.49	8.95
(d) d/s C4R002	9.50	9.50	-	-	5.80
Sub-total	58.27	29.47	28.80	10.97	29.64
(e) d/s conf.[2]	12.97	12.97	[3]	-	9.34
TOTAL	71.24	42.44	-	-	38.98

N.B. [1] Excludes areas supplied from groundwater.
[2] Part of Sand-Vet GWS since 1960, but included here to indicate total irrigation not supplied directly from Sand-Vet canals.
[3] Source of water is Erfenis Dam.

6.1.6 Effluent discharges

Details on effluent discharges are to be found in Chapter 4. Although important from a water quality point of view, these discharges have a negligible impact on the hydrology of the Sand-Vet river system owing to the high degree of effluent re-use. They have accordingly been ignored in the hydrological analysis.

6.2 Model Calibration

6.2.1 General approach

Calibration of the rainfall/runoff model *(Pitman, 1973)* was undertaken using the system model, WRSM90 *(Pitman & Kakebeeke, 1991)*. The entire Sand-Vet river system was divided into three subsystems according to the three DWAF tertiary catchments, as follows:

System C41 - Vet river catchment above Sand/Vet confluence

System C42 - Sand river catchment above Sand/Vet confluence

System C43 - Vet river downstream of Sand/Vet confluence

The system diagrams of the three subsystems are shown in Figure 6.1.

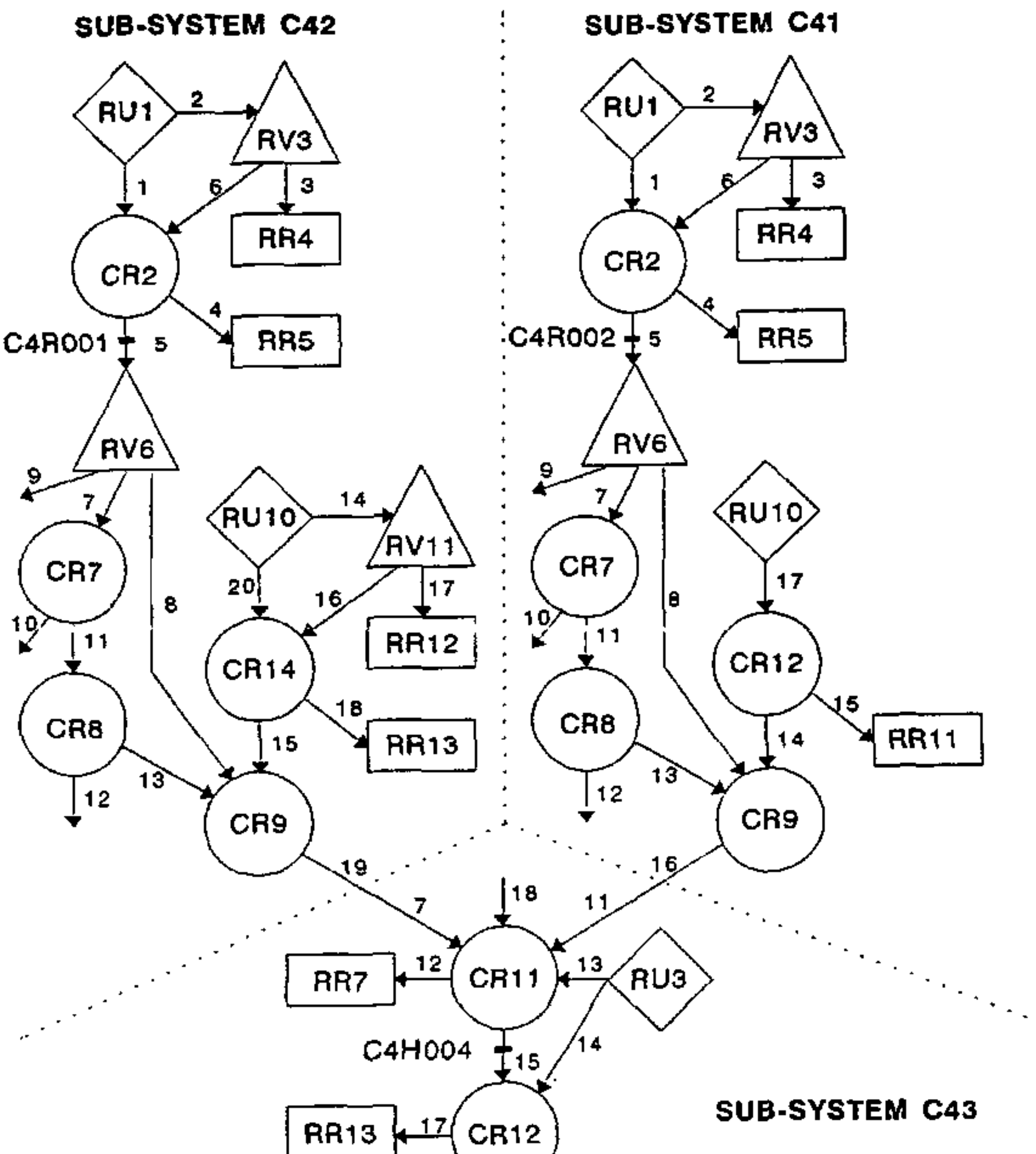
6.2.2 Results of model calibration

Statistics of observed and modelled flows at each of the few calibration points are compared in Table 6.4.

TABLE 6.4
Statistics of observed and modelled flows

GAUGE		C4H002	C4H004	C4R001	C4R002
PERIOD		1936 to 1971	1968 to 1991	1959 to 1991	1959 to 1991
MAR	observed	376	229	85	154
	modelled	349	230	85	158
	error (%)	-7	+1	0	+3
CV[1]	observed	107	134	97	98
	modelled	98	130	88	97
	error (%)	-8	-3	-9	-1
MEAN (log)	observed	2.33	2.02	1.76	2.02
	modelled	2.31	2.06	1.78	2.02
	error (%)	-2	+2	+1	0
STD. DEV. (log)	observed	0.49	0.54	0.39	0.40
	modelled	0.49	0.52	0.38	0.41
	error (%)	0	-4	-3	-3

NB [1] CV = Coefficient of Variation = Standard deviation expressed as a percentage of MAR



KEY TO DEFINED ROUTES

Sub-system	Route	Description
C41	7	Erfenis to Vet canal
C41	8	Erfenis to Vet River
C41	10	Drawoff from Vet canal
C41	13	Vet canal to river
C42	7	A'kraal to Sand canal
C42	8	A'kraal to Sand River
C42	10	Drawoff ex Sand canal
C42	13	Sand canal to river
C43	18	Irrigation return flow

Fig. 6.1 : System diagram for Sand-Vet catchment

Additional checks were also undertaken by comparing plots of the following characteristics, viz.

- monthly hydrographs
- annual hydrographs
- average monthly flows
- gross yield curves
- scatter diagram
- monthly duration curve

Particular emphasis was placed on the simulation of low flows at C4H004 and C4H002 on the lower Vet River, in order to ensure that the assumptions were valid regarding irrigation return flows and canal discharges (see Section 6.1).

6.2.3 Model parameters

The model parameters used to obtain the final calibrations are listed in Table 6.5.

TABLE 6.5
Catchment model parameters

Model parameter	Subcatchment (see page 6.4)				
	(a)	(b)	(c)	(d)	(e)
POW - Power of soil moisture/subsurface flow eqn.	3	3	-	-	-
SL - Soil moisture state when subsurface flow = 0	0	0	0	0	0
ST - Soil moisture capacity in mm	115	85	100	100	200
FT - Subsurface flow at soil moisture capacity	3	3	0	0	0
GW - Maximum groundwater flow in mm/month	0	0	0	0	0
ZMIN - Minimum catchment absorption in mm/month	35	45	50	50	50
ZMAX - Maximum catchment absorption in mm/month	550	545	470	470	900
PI - Interception storage in mm	1.5	1.5	1.5	1.5	1.5
TL - Lag of flow (excluding groundwater)	0.25	0.20	0.25	0.25	0.25
GL - Lag of groundwater flow in months	0	0	0	0	0
R - Coeff. in evaporation/soil moisture eqn.	0.0	0.5	0.0	0.0	0.0

6.3 *Naturalised flows*

6.3.1 Procedure

After a satisfactory calibration had been achieved, WRSM90 was re-run for each system with all man-made influences removed, i.e. all irrigation areas, dam capacities, canal discharges and irrigation return flows were set equal to zero. The natural hydrology was simulated for the period 1920 to 1991 (hydrological years).

The difference between the simulated natural flows and the historical flows simulated for the purpose of model calibration provides an estimate of the combined effect of all the man-made influences on the hydrology. Accordingly, the observed streamflow records were naturalised by adding back this difference, as follows:

Let O = observed flow (for a particular month)
S = simulated historical flow
V = simulated natural or virgin flow
N = naturalised observed flow

i.e. $$N = O + (V - S)$$

Natural time series of monthly flows covering the complete 1920 to 1991 period were obtained by extension of the naturalised records using the simulated natural flows were observed flows were not available.

6.3.2 Results of flow naturalisation

MARs of the natural flow records are summarised in Table 6.6.

TABLE 6.6
MARs of natural flow records

Gauge	Record	Total catchment			Incremental catchment				
		Period	MAR (10^6m^3)	MAR (1920-1991)	Period	MAR (10^6m^3)	MAR (1920-1991)	Area (km^2)	MAR (mm)
C4R001	Observed	1959-1991	85	-	1959-1991	85	-	-	-
	Natural	1959-1991	89	102	1959-1991	89	102	3665	28
C4R002	Observed	1959-1991	154	-	1959-1991	154	-	-	-
	Natural	1959-1991	164	176	1959-1991	164	176	4750	37
C4H004	Observed	1968-1991	229	-	1968-1991	-4	-	-	-
	Natural	1968-1991	362	404	1968-1991	114	126	7738	16
C4H002	Observed	1936-1971	376	-	-	-	-	-	-
	Natural	1936-1991	401	402	-	-	-	-	-

6.4 Conclusions

(a) The natural MAR of the Vet River catchment (at gauge C4H004) is estimated to be 404 x 10^6m^3 (based on 1920 to 1991 hydrology). This is about 10% of the MAR of the entire Vaal River catchment.

(b) Under present-day (1992) conditions the MAR of the catchment has decreased to about 271 x 10^6m^3. The difference in MAR is accounted for as follows:

Naturalised MAR (10^6m^3)	404
- Abstractions from Allemanskraal Dam	38
- Evaporation from Allemanskraal Dam	17
- Abstractions from Erfenis Dam	46
- Evaporation from Erfenis Dam	25
- Sand-Vet GWS irrigation from Vet River	4
- Private irrigation (plus evap. from minor dams)	22
+ Discharges from Allemanskraal (Sand) canal	2
+ Discharges from Erfenis (Vet) canal	9
+ Return flows from Sand-Vet GWS	8
Net MAR (1992 conditions)	271

6.5 References

Middleton BJ, Pitman WV and Midgely DC (1981). Surface Water Resources of South Africa, Volume II, Drainage Region C : The Vaal Basin. HRU Report 8/81, Johannesburg.

Ninham Shand Inc: (1985) The provision of estimates of irrigation return flow quantity quality for river basins with extensive irrigation development in South Africa

Pitman WV (1973): A mathematical model for generating monthly river flows from meteorological data in South Africa. Report No. 2/73, Hydrological Research Unit, University of the Witwatersrand, Johannesburg.

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CHAPTER 7

HYDRO-SALINITY MODEL CALIBRATION

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7. HYDRO-SALINITY MODEL CALIBRATION

7.1 Introduction

SSI's in-house hydro-salinity model was used to simulate the salinity regime of the Sand-Vet River system. This model operates at a monthly computational time step. The models are described in DWA&F reports P C000/00/7086, Volume A (SSO/BKS,1988) and P C000/00/9390 (Stewart, Sviridov and Oliver, 1991). The models are written in FORTRAN and run on any IBM or fully compatible PC (Personal Computer).

In this report, the hydro-salinity calibration procedure will be discussed briefly. DWA&F report P C000/00/9490 (Stewart Sviridov and Oliver, 1990) can give the reader a detailed explanation of the methodology and the sensitivity of the simulation results to the calibration parameters of the model.

7.2 Model system layout

For the purposes of hydro-salinity modelling, the study area was divided into two sub-systems. Suitable configurations were determined and various modifications were made during the modelling process in order to model the actual situation as closely as possible. The first sub-system (termed SVA) consists of the region from Allemanskraal Dam to the monitoring point DWA7 (refer to Figs. A.1, A.7 and Fig. 7.1). This sub-system incorporates all the mines and therefore covers all polluted areas. The other sub-system (termed SVB) covers the remainder of the study region from Erfenis Dam to just upstream of Bloemhof Dam (refer to Fig. A.1 and Fig. 7.2).

Streamflow and water quality data was obtained from the DWA&F. Harmony Mine provided water quality data at a number of points.

The model represents the system as a number of discrete sub-model elements (called nodes) connected by means of flow paths (called routes). The alpha-numeric code of each node is prefixed by a character code denoting its type (e.g SVA). The six types of node used to model the Sand-Vet River system are described in Table 7.1 .

TABLE 7.1
Description of sub-model types

Code	Description
SW	**Catchment salt washoff sub-model:** Simulates water and salt balance of catchment
CR	**Channel reach sub-model:** Simulates evaporation and seepage losses and wetlands
RV	**Reservoir sub-model:** Simulates water salt balance of impoundments
DC	**Demand centre sub-model:** Simulates water demands, return flows and the increase in TDS through use. This sub-model (in common with all other sub-models that can participate in a feedback loop) is structured to account for both direct and indirect recycling of effluent, with or without a desalination step.
JN	**Junction sub-model:** Mixes and distributes inflows from one or more routes. In the case of the simulation version of the model, provision is made for blending water supplied from different sources to achieve a pre-defined maximum permissable target TDS concentration.
RR	**Irrigation sub-model:** Simulates water and salt balance of irrigated lands. Provision is made for multiple crop types, canal losses, the specification of maximum water allocations and any defined pattern of increasing and decreasing irrigation areas.

AB0029.7

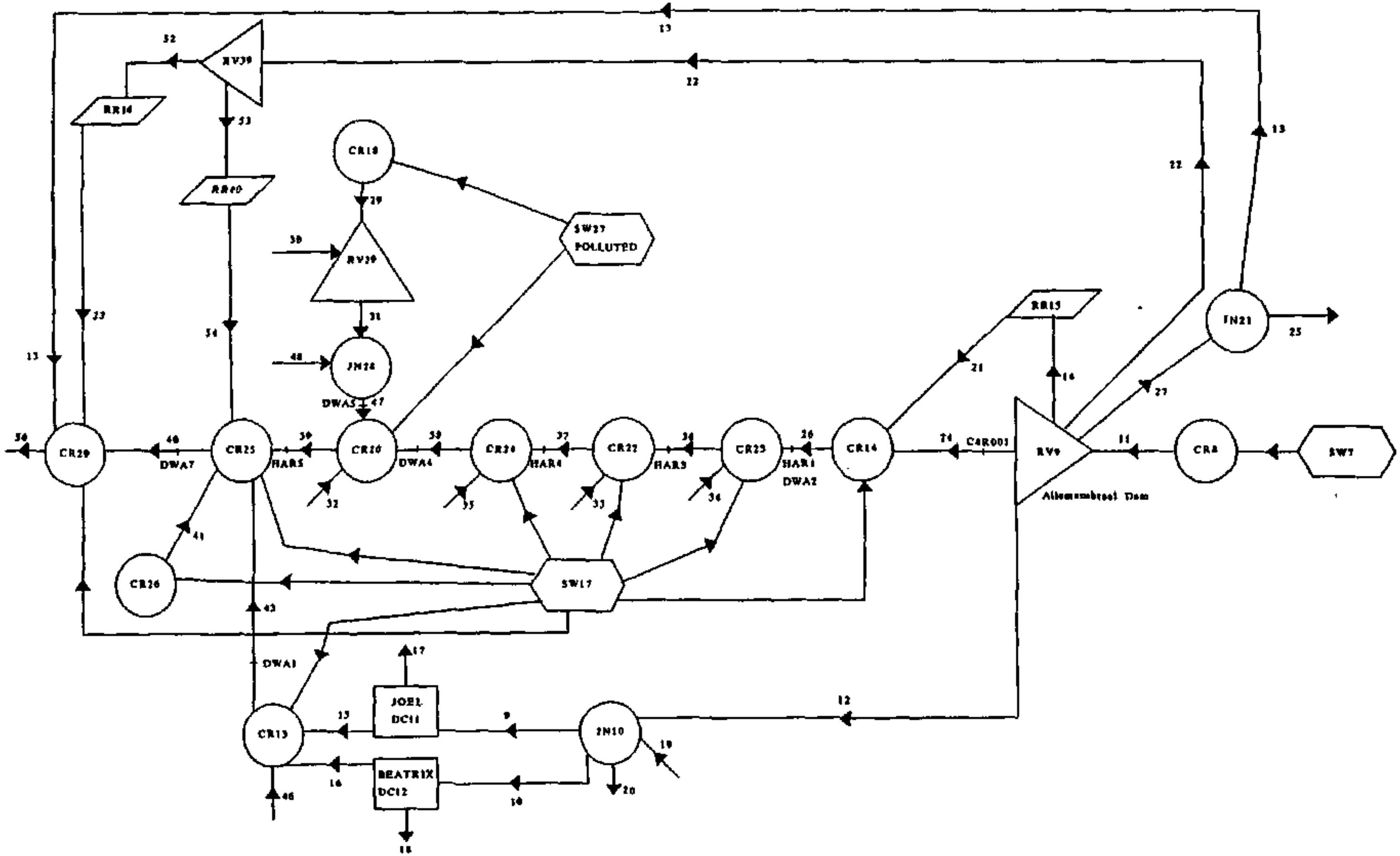

Fig. 7.1 : System configuration diagram - A (detailed Sand River)

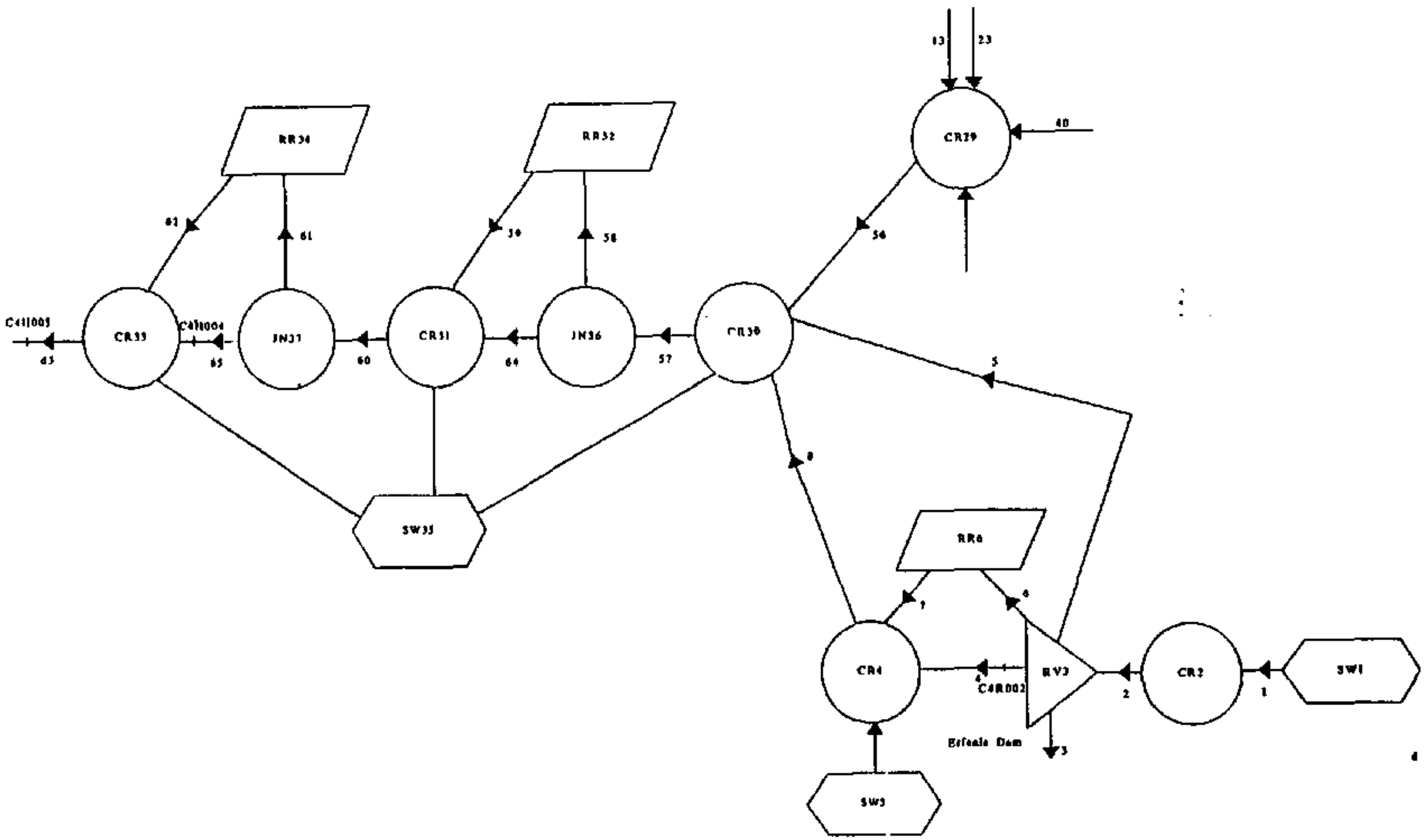

Fig. 7.2 : System configuration diagram - B

In sub-system SVA (refer to Fig. 7.1), three salt washoff sub-models have been included. SW7 covers the area upstream of Allemanskraal Dam. SW27 covers the polluted area near the Sand River Canal while SW17 covers the area downstream of Allemanskraal Dam but upstream of HAR1 as well as the area downstream of DWA7 up to the confluence of the Sand and Vet Rivers.

Three irrigation sub-models (nodes RR15, RR16 and RR40) have been used to represent the irrigation from the Allemanskraal canals. This was done to account for the effect of irrigation return flows in different river reaches. It is important to account for this since irrigation return flows play an important role in diluting the polluted portions of the Sand River. Route 21 accounts for irrigation return flows upstream of Virginia. Route 54 represents return flows between the Sand River Canal and Blaaudrift bridge and route 23 the remainder of the Lower Sand river downstream of Blaaudrift. It is important to keep these three separate to account for irrigation return flows both upstream and downstream of the polluted goldfields area. Releases from the ends of the two canals running parallel to the Sand River have been provided for in route 13.

Allemanskraal Dam supplies water to Harmony and Oryx Mines, the Department of Agricultural Technical Services and the Department of Prisons (refer to route 25). Allemanskraal Dam also supplies water for the Virginia Water Purification Works (refer to route 12). These works in turn supply Unisel, Beatrix, Harmony, Joel, Oryx, Samada and Star Diamond Mines as well as the Virginia and Meloding urban areas. Route 12 enters the junction node JN10 which is associated with two demand centres DC11 and DC12. These two demand centres provide for abstractions and effluent return flow from Joel and Beatrix Mines (the only two mines which have permits to return purified effluent to rivers). Demand Centre sub-models for Welkom and Virginia were not required since all of the effluent from these urban centres is either re-used or disposed of in pans that are isolated from the Sand-Vet River system. Other demands on the Virginia Purification Works have been provided for in route 20. Although Joel and Beatrix get their water primarily from the Virginia Purification Works, there are times when these works cannot supply any water and in that case, these two mines (and the other users mentioned above) will then have to get water from the only other Goldfields Water purification works at Balkfontein. This purification works obtains water from the Vaal River. Route 19 has a Balkfontein water quality file (TDS) associated with it which was obtained by taking observed EC values and converting to TDS by multiplying by the average ratio of TDS to EC at C2H022 (Balkfontein gauging station). By assigning a very high weighting factor to this route, it will only come into effect when there is no flow from the Virginia Purification Works, otherwise the Allemanskraal Dam quality will be used.

7.3 Model calibration for Allemanskraal and Erfenis Dam catchments.

The salt washoff sub-models SW7 and SW1 (Allemanskraal and Erfenis Dams) were calibrated first, independently of the remaining system using the configurations shown in Figs. 7.3 and 7.4 .

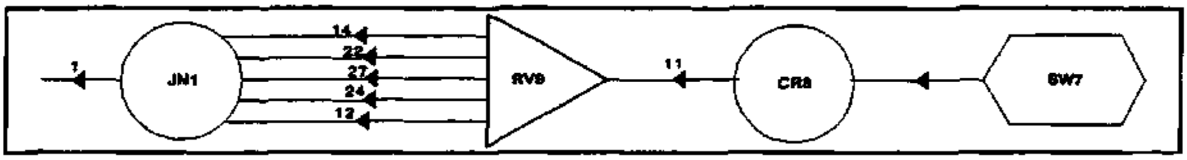

Fig. 7.3 : System configuration for Allemanskraal Dam

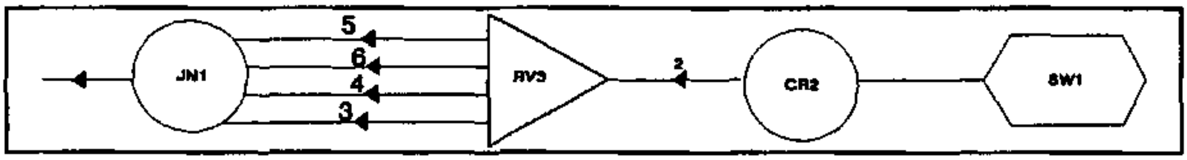

Fig. 7.4 : System configuration for Erfenis Dam

The above two configurations were used for model calibration only. The system layout given in Fig. 7.1 was used for all subsequent model runs. The outflow route from dummy junction JN1 was used to compare modelled and observed total monthly outflow from each of the dams.

The model calibration procedures described in DWA&F report P C000/00/9490 (Stewart Sviridov & Oliver, 1990) were followed in calibrating salt-washoff sub-models SW7 and SW1. In brief, model calibration takes place in two steps:

a) First, a reasonable salt catchment recharge rate is chosen and the assumed starting catchment surface and sub-surface salt storages are adjusted until they are in balance with the ending storages after simulation of a long representative sequence of naturalised hydrology. After this step has been completed, the model is in balance for natural (i.e undeveloped) catchment conditions and the assumed salt recharge rate.

b) In the second step, the naturalised monthly catchment runoff input file is replaced with the patched observed runoff file (obtained from the hydrological analysis - see Chapter 6). Since the observed runoff file has a downward trend in MAR (due to the effect of diffuse irrigation losses) but the catchment salt recharge rate (which is related to natural weather processes) remains constant, the model will now simulate a rising trend in TDS concentrations and the starting and ending salt storages will no longer be in balance. This is as it should be, since the historical growth in diffuse irrigation shifts the catchment salt balance from a steady to an unsteady state. The initially assumed salt recharge rate is then adjusted up or down to achieve a best fit between modelled and observed monthly flows, TDS concentrations and loads. Care is taken each time the recharge rate is adjusted, to adjust the starting salt storages by the same proportion to ensure that the dynamic salt balance of the catchment is maintained.

Each time one of the model parameters controlling salt washoff efficiency, infiltration rate, interflow or groundwater flow is altered, steps a) and b) above have to be repeated to re-balance the system.

The catchment salt recharge rate was chosen to yield a virgin unit salt export similar to that obtained from the calibration for the catchment upstream of Allemanskraal Dam. Once a balance was achieved for natural conditions, the model was re-run using patched observed catchment runoffs instead of naturalised runoffs. Both the naturalised and patched observed monthly flow files were obtained from the hydrological data for the incremental catchment between Allemanskraal Dam, Erfenis Dam and DWA&F hydrological station C4H004 in the lower Vet River. The total incremental catchment runoff was apportioned to each salt washoff sub-model (SW17, SW27, SW5 and SW35) in accordance with the relevant areas of each.

7.4 Model calibration for the sub-system from Allemanskraal Dam to the Sand-Vet confluence

Following calibration of the Allemanskraal Dam and Erfenis Dam catchments, the entire SVA sub-system was calibrated.

7.4.1 Demand Centre sub-models

Firstly the Demand Centres DC11 and DC12 were analysed. Load files were determined for the demand centre DC12 and using the equation:

BEATRIX.SLD = (BEATRIX.TDS - SVARTC10.ANS) x BEATRIX.ABS x 0.188

where:

0.188 is the return flow factor for Beatrix Mine

BEATRIX.FLW is the purified effluent returned to the Doring River.

BEATRIX.ABS is the water supplied to Beatrix Mine by Goldfields Water.

SVARTC10.ANS is the simulated TDS file for route 10.

Similarly for DC11.

The demand centres DC11 and DC12 have a load datafile associated which is determined by multiplying the difference between incoming and outgoing TDS (supply and effluent return) by the effluent return flow.

7.4.2 Irrigation sub-models

The next step was to calibrate the return flow factors for irrigation sub-models RR15, RR16 and RR40. Here the objective was to simulate a return flow similar to that used in naturalising the hydrology (see Chapter 6). The model simulates the monthly return flow as a fixed proportion of the specified optimum soil moisture storage depth. Assuming an average soil moisture storage of 250 mm, the model parameter defining the return flow (RRLF) was calculated by solving for RRLF from the following equation:

QR = HS/100 x RRLF x 12 x AREA

where:

QR = mean annual return flow ($m^3 \times 10^6$)
HS = average moisture soil depth in irrigated lands (mm)
RRLF = monthly return flow factor
AREA = irrigated area (km^2)

Based on a total irrigated area of 50 km^2 between Allemanskraal Dam and the Sand-Vet confluence, an HS depth of 250 mm and an annual return flow of 4×10^6 m^3 (derived from the hydrological analysis in Chapter 6), RRLF was estimated as 0.03

The mean annual irrigation return flow upstream of the Sand-Vet confluence was estimated as 8×10^6 m^3 during the hydrological analysis (see Chapter 8). Based on information concerning scheduled areas received from the Sand Vet Regional Office, half of this was apportioned to the Sand River between Allemanskraal Dam and the confluence.

The same return flow factor was used for RR15, RR16 and RR40 (in sub-system SVA) and RR6 in sub-system SVB.

7.4.3 Sand River Canal sub-model

The Sand River Canal has been modelled using a reservoir sub-model, RV19. The capacity was estimated by taking the total length of the pools upstream of the confluence of the Sand River Canal and the stream to Dam 33 and multiplying by a width of 5m and a depth of 0.5m. this was done in order to model the flushing of pools which develop in the Sand River Canal with high TDS concentrations. To cater for the inflow from Dam 33 to the Sand River Canal, a junction node JN28 was included. Inflows were obtained from discussions with SRK regarding their report on the Sand River Canal (SRK, 1993). Dry weather flow through the upstream pools was thought to be of the order of 2 l/s. Accordingly, the inflow via route 30 was taken as 2 l/s. However, during dry weather the flow ceased entirely upstream of the confluence of the main canal with the stream from Dam 33. Downstream of the Sand River Canal/Dam 33 stream confluence, SRK measured a dry weather flow at V-notch E (DWA5) of the order of 4 l/s. Since there was no dry weather flow in the canal upstream of junction node JN28, the entire 4 l/s was assumed to enter from the side stream via route 48. The TDS concentrations were based on the average of the TDS concentrations observed at monitoring point DWA5 (i.e at V-notch E). These flow and TDS values were, however, modified slightly to achieve a realistic calibration of the model. Dummy reservoir sub-model RV39 was included to distribute irrigation supply water to sub-models RR16 and RR40.

7.4.4 Doring River sub-model

Model calibration was achieved by defining the TDS concentrations in route 46 (the seepage route) at a level typical of the mine seepage water and adjusting the seepage flow rate until a reasonable fit was achieved between the modelled and observed monthly TDS concentrations in the Doring River at station DWA1.

7.4.5 Sand River sub-model

A procedure similar to that described for the Allemanskraal Dam and Erfenis Dam catchments was used to balance salt washoff sub-models SW17 and SW27. However, in this instance no attempt was made to calibrate the models. Instead the salt recharge rate for sub-model SW7 was used. This approach was adopted since the pollution inputs are so large as to render model calibrations of the catchment model meaningless.

After balancing the starting salt storages to match the assumed salt recharge rate, the naturalised catchment runoff files were replaced by the appropriate observed runoff files (which reflect the historical catchment runoff after accounting for diffuse irrigation). In the case of sub-model SW27 an urban runoff file was also included to account for urbanisation of portions of the catchment.

The naturalised and observed catchment runoff files for sub-models SW5, SW17, SW27 and SW35 were constructed by apportioning the appropriate portions of the catchment runoff files (determined in Chapter 6) for the entire incremental catchment between hydrological stations C4R001 (Allemanskraal Dam), C4R002 (Erfenis Dam) and C4H004 (located in the lower Vet River).

A number of channel reach sub-models have been included at various points in this sub-system. Those between monitoring points HAR1 and DWA7 have inflow routes to provide for seepage into the Sand River of polluted water. No inflow was required at channel reaches 20 and 22 due to the fact that modelled concentrations exceeded observed concentrations prior to adding any seepage inflow.

The simulated TDS concentrations at monitoring point HAR1 were compared against the observed. Initially the simulated concentrations were found to be too high. Little adjustment could be made to the salt washoff sub-model without arriving at unrealistic model parameter values. Instead the model parameters of irrigation sub-model RR15 were adjusted to allow a salt loss. The need to hypothesise such a salt loss has arisen in several other studies of semi-arid catchments where the observed TDS in receiving waters was found to be of a much better quality than would be the case if the salt load in the supply water matched that in the effluent return flows. A relatively high proportion of the irrigation return flow had to be assumed as tailwater.

Model calibrations for observation point HAR3 (downstream of the "waste dump stream") was achieved by assuming a TDS concentration trend in the polluted seepage route 34 similar to that observed in the "waste dump stream" (monitoring station HAR6). A constant seepage flow rate was then assumed via this route and successfully adjusted until the modelled and observed TDS concentrations in the Sand River at station HAR1 matched.

A similar procedure was used at water quality observation points HAR4, DWA4, HAR5 and DWA7. In the cases of stations HAR4 and HAR5 it was not necessary to define seepage inflows via seepage routes 33 and 32.

At observation point DWA7 (Blaaudrift bridge), the simulated peak dry weather TDS concentrations were found to be higher than those observed. It was not possible to reduce these peak concentrations by adjusting the calibrated pollution inputs in the upstream system, since this was found to result in modelled concentrations at the upstream stations that were much too low. For this reason it was hypothesised that 10% of the total irrigation return flow from the Sand River Canal portion of the Sand-Vet GWS enters the river upstream of station DWA7. This is the reason why irrigation sub-model RR40 was introduced.

7.5 Remainder of the Vet River sub-system (system SVB)

Sub-system SVB is not as complex as the SVA sub-system. It has been linked to the SVA sub-system by using the flow and concentration from route 56 as input to the SVB sub-system. Three salt washoff sub-models have been included, viz. SW1, SW5 and SW35. These sub-models provide for the areas upstream of Erfenis Dam, between Erfenis Dam and the confluence (of the Vet and Sand Rivers) and downstream of the confluence up to C4H005 respectively. There are only three observation points, viz. C4R0201, C4H004 and C4H005.

Irrigation sub-model RR6 provided for riparian irrigation direct from the canal between Erfenis Dam and the end of the canal system, downstream of the confluence. Irrigation sub-models RR32 and RR34 provided for riparian irrigation between this point and C4H004, and between C4H004 and C4H005 respectively. Parameters for these irrigation sub-models RR6, RR32 and RR34 were set equal to those from the SVA sub-system. Following an initial attempt at calibration for station C4H004, further calibration was carried out on the SVA sub-system in order to decrease the modelled concentration at C4H004. However, this iterative process could not be carried too far, since without flow data unrealistic assumptions concerning the balance between flows and polluted seepage might be made to force the model results to fit the observations.

7.6 Results

Statistics and graphs of the results have been included in Appendix F. The statistics compare the observed and modelled flow, TDS concentration and TDS load for the mean, standard deviation and correlation coefficient for all the monitoring points shown in Figs. 7.1 and 7.2 . These results have been plotted and are given in graphical form for the observed period.

7.7 Conclusions

7.7.1 The model calibration results for Allemanskraal Dam and Erfenis Dam are satisfactory.

7.7.2 Although far from ideal, the calibration results for the Sand River between Allemanskraal and Blaaudrift bridge are good enough to provide a reasonable first order representation of the system.

7.7.3 The fit between modelled and observed results at station C4H004 in the lower Vet River is poor.

7.7.4 The poor fit between modelled and observed data at C4H004 is attributable to the following factors:

a) For the entire region from Allemanskraal Dam and Erfenis Dam to C4H004 there was no streamflow data to calibrate against. This made calibration particularly difficult in the SVA sub-system, when the balance between normal river flow and seepage flow has a profound effect on water quality.

b) Data received from the mines was scarce and often inaccurate and/or incomplete. Only Harmony Mine provided a reasonable monitoring system. Regarding return flows to river systems, conflicting estimates were received from different sources.

c) Some parameters are extremely difficult to estimate, particularly actual irrigation areas (for which there do not appear to be any records), return flows, river losses etc. Data from the Sand-Vet Regional Office was generally incomplete and a reasonable water balance could not be determined from their data (refer to Chapter 2).

d) The accuracy of TDS concentrations were in doubt. In some instances there were large discrepancies between the water quality data collected by different organisations (see Chapter 3).

e) The water quality sampling frequency (generally monthly) is too low to arrive at a reliable estimate of the average TDS during the monthly time step at which the model operates. The observed values that the model was calibrated against are therefore not necessarily a true reflection of the monthly averages.

f) The important role played by irrigation return flows in diluting the polluted runoff from the Sand River could not be modelled accurately due to lack of information regarding irrigation water use and return flows.

7.7.5 Despite these limitations, the model calibration for the two dams and the Sand River to Blaaudrift bridge gives a reasonable first order fit.

7.8 Recommendations

7.5.1 A new flow and water quality monitoring system for the OFS Goldfields needs to be designed. This system should be designed to identify and quantify pollution inputs to the Sand-Vet River system.

7.5.2 Better data is required for the Sand-Vet GWS regarding actual areas irrigated, crop distribution and water use.

7.5.3 A more detailed study using a daily time step model is required to make better use of the existing data to quantify pollution inputs.

CHAPTER 8

ESTIMATION OF TDS LOADS

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8. ESTIMATION OF TDS LOADS

In this chapter an attempt has been made to estimate the TDS loads generated by the pollution sources in the study area.

8.1 Approach

The approach adopted has been to calculate the historical TDS loads passing station C4H004 on the lower Vet River from the observed daily flows and patched daily TDS concentrations. The moving regression and anchoring method described in DWA&F Report E C120/00/0192 (Stewart Scott, 1992) was used to patch missing daily TDS data, based on the observed daily flow data. The daily flow data and patched daily TDS data was then integrated to calculate a record of flow-weighted monthly TDS concentrations. Even after this patching procedure some gaps still remained in the record in instances when the break in the record was too long to permit reliable patching. A more accurate estimate could have been obtained by using daily time step modelling to patch and aggregate the observed TDS load record.

The equivalent monthly loads for the same hydrological conditions for assumed virgin conditions were derived from model simulations of monthly TDS concentrations for undeveloped catchment conditions (i.e. without any dams, irrigation or development in the OFS Goldfields region) and the naturalised monthly catchment runoffs. The virgin TDS concentrations were simulated using the model described in Chapter 7, while the naturalised flow data was derived from the hydrological analyses discussed in Chapter 6.

8.2 Data limitations

Unfortunately only one station, C4H004, provided the requisite flow and water quality data to make this type of estimate. Even at this station the relatively low water quality sampling frequency and the truncated nature of the river flow record has adversely affected the accuracy of the load estimates. The information contained in this chapter should therefore be treated as being only a first order approximation of the true TDS loads.

8.3 Results

Table 8.1 compares the mean annual runoff, flow-weighted TDS concentration and TDS load obtained for station C4H004 on the lower Vet River for estimated virgin and actual conditions for eleven years during the period October 1977 to September 1992. (Annual totals could be calculated for only eleven of the fifteen years during this period since gaps in the record prevented calculation of the observed totals for the 1978, 1979, 1983 and 1991 hydrological years.)

The large reduction in MAR is mostly attributable to the water use from the Sand-Vet GWS scheme. This scheme should add little load to the long term salt balance of the catchment. This is because the primary effect of the major dams and irrigated lands is to remove water from the system, with little (if any) net addition of salts. In point of fact, during dry years the observed annual salt load passing station C4H004 appears to be significantly lower than that for assumed virgin conditions (see Fig. 8.1). This reduction in load occurred despite the known pollution input from the OFS Goldfields area. The implication is that, at least during dry conditions, salt is being retained in the irrigated lands. This deduction is supported by the need to assume salt losses in the irrigated lands when calibrating the salinity models (see Chapter 7). The model simulation results were used to estimate the mean annual addition of TDS from the OFS Goldfields area, which amounted to about 16 000 t p.a. On this basis the irrigated lands appear to be removing about 14 000 t of TDS per annum. The calculated TDS loads that would have passed station C4H004 during the observed period without the irrigation losses are shown in Fig. 8.1.

TABLE 8.1
Estimated mean annual virgin and observed runoff, TDS concentrations and TDS loads at C4H004 for eleven years between October 1977 and September 1992+

DESCRIPTION	MAR (10^6m^3)	Flow-weighted mean annual TDS (mg/l)	Mean annual TDS load (t)
Simulated natural	389.9	117	45 459
Estimated TDS load added by OFS Goldfields users			+ 15 994
TDS load retained in irrigated lands			- 13 820
Patched observed	245.1	194	47 633
Net difference (observed - natural)	144.8 (-37%)	77 (+66%)	2 174 (+5%)

NOTE: + Observed annual totals for the 1977, 1978, 1983 and 1991 hydrological years could not be calculated due to gaps in the record.

At face value the mean annual difference in TDS loads of only 2174 t appears comparatively small, indicating a relatively small impact of Bloemhof Dam and the downstream Vaal River system. This is in sharp contrast to Cogho *et. al.*'s measured input from the OFS Goldfields area of over 1000 t per day. However, the Cogho *et. al.* (1992) measured this daily TDS input rate during wet weather soon after the large February/March 1988 flood. As such it is too high to represent average conditions.

However, the long term mean annual values given in Table 8.1 also do not give the full picture. For example, the calculated contribution from pollution sources in the OFS Goldfields area was as high as 59 000 t during the 1987/88 hydrological year (representing a 40% increase in the total Vet River catchment TDS washoff load), and 55 000 t during the following year (i.e. a 68% increase in TDS load). Appendix D (and Chapter 9) also reveals considerable shorter term variation in water quality. Hence, although the average TDS concentration observed in the Vet River at C4H004 during the last three years (ending September 1992) was only 348 mg/l (based on an EC of 49 mS/m), the P90 TDS was 667 mg/l and peak values reached as high as 1160 mg/l.

During the 1987/88 hydrological years the estimated contribution of the pollution sources in the OFS Goldfields area added about 9,4% to the total TDS load entering Bloemhof Dam. The contribution during 1988/89 was about 7,4%. Hence it can be concluded that during wet periods the pollution sources in the OFS Goldfields area can significantly affect the salt balance of Bloemhof Dam, and hence the remainder

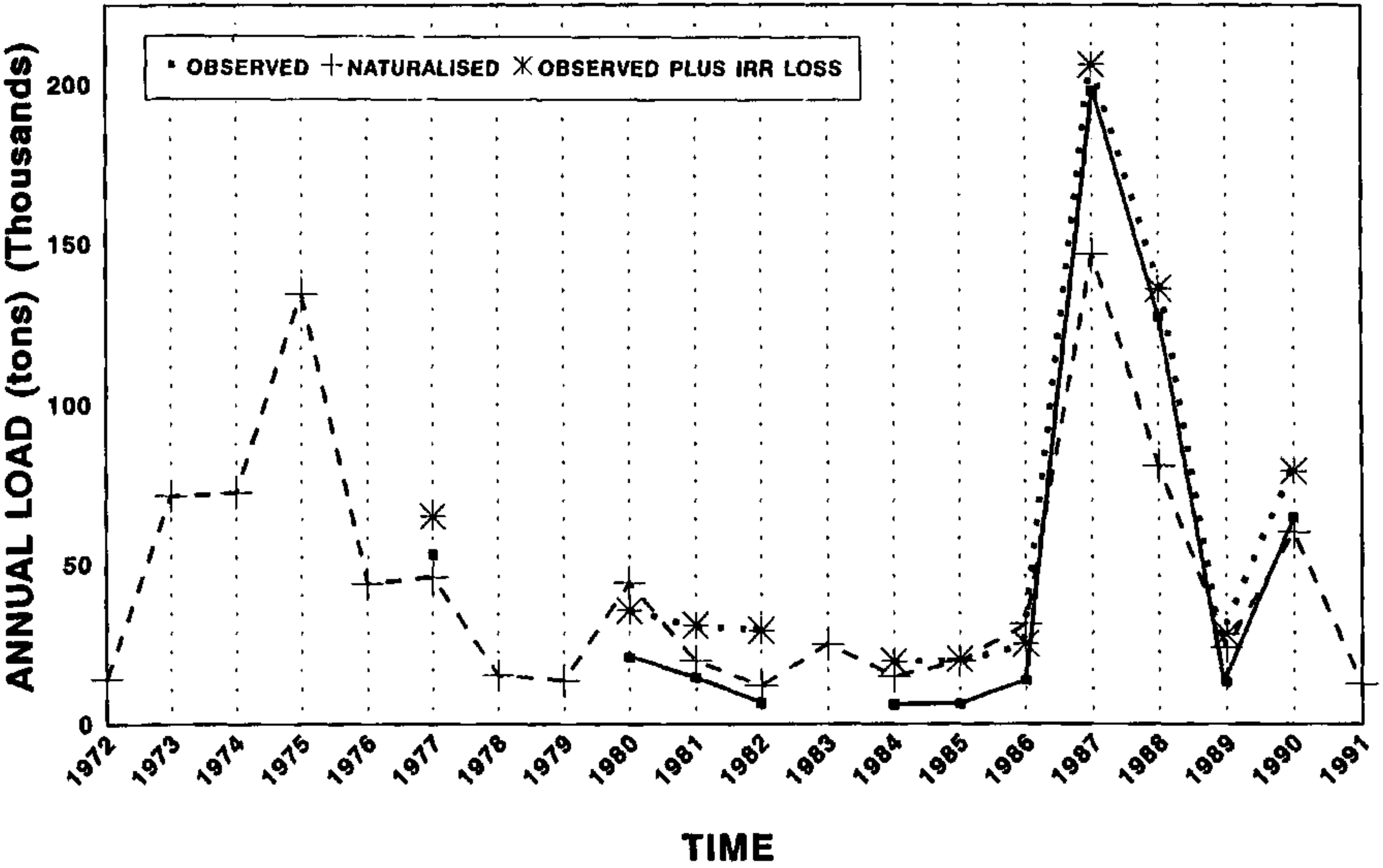

Fig. 8.1 : Naturalised and observed TDS load for gauge C4H004

of the Lower Vaal System. During dry years, when the mine effluent water balance is easier to control, the contribution is less significant. The overall impact on users in the Lower Vaal System is very much dependent on the storage state of Bloemhof Dam and the relative runoff and TDS load inputs via the Vaal and Sand Rivers.

8.4 Conclusions

8.4.1 OFS Goldfields TDS load contribution

(a) During the last fifteen years pollution sources in the OFS Goldfields region are estimated to have added about 16 000 t p.a. to the TDS washoff from the Vet River catchment. This represents an increase in the Vet River catchment TDS export of about 35%.

(b) During wet years the contribution of the OFS Goldfields region is significantly higher. For example, during the 1987/88 and 1988/89 hydrological years the pollution sources added 59 000 t (+40%) and 55 000 t (+68%) respectively.

8.4.2 Net TDS export to Lower Vaal System

(a) During dry weather there appears to be a net retention of salt in the Vet River system. Under these conditions there should be little runoff entering Bloemhof Dam and consequently little effect on downstream water quality.

(b) The retention of salt in irrigated lands appears to have reduced the mean annual net TDS export from the Vet River to the Vaal River system by about 13 800 t p.a. This had the effect of reducing the increase in the mean annual net TDS export (relative to virgin conditions) to only about 2200 t (compared to a total average annual TDS input to Bloemhof Dam of the order of 600 000 t).

(c) During wet conditions the increase in the net TDS export from the Vet River (relative to natural conditions) is estimated to have increased the TDS load entering Bloemhof Dam by up to about 9%.

8.4.3 Impact on downstream water users

The impact of increased TDS load export from the Vet River on users in the Lower Vaal System is dependent on the relative monthly runoff and TDS inputs to Bloemhof Dam from the Vet and Vaal Rivers. Modelling of the Vaal River System would be required to assess these impacts.

8.4.4 Data deficiencies

(a) Pollutant loads could not be estimated anywhere within the most polluted portion of the catchment (or even immediately downstream of it) due to a total absence of flow gauging stations and the low water quality sampling frequency.

8.3 Recommendations

8.3.1 Flow and water quality data

(a) There is an urgent need for more intensive flow and water quality monitoring in the study area. The greatest need for such monitoring is within the OFS Goldfields area bounded by station HAR1 in the east and station DWA7 in the west. Such an intensive monitoring system, should be designed and implemented without delay.

(b) The discharge table (DT) for station C4H004 needs to be extended to facilitate load estimation during floods. (The extension of the DT based on the slope-area method proved to be unreliable as it resulted in a huge over-estimation of the catchment MAR. Therefore the extended DT could not be used in the analyses.)

8.3.2 Load estimation

(a) A daily time step hydro-salinity model should be used to patch missing data at station C4H004 to arrive at a firmer estimate of the TDS load export from the Vet River catchment.

(b) Pollutant loads from problem catchment areas should be quantified to facilitate the development of a water quality management plan for the study area.

8.3.3 Impact on downstream river system

(a) A evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream Vaal River system is recommended. This will have to be done using water quality modelling techniques.

8.4 References

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Stewart Scott (1992) "*Waterval River Water Quality Study: Situation Analysis*", Report E C120/00/0192, Directorate of Water Quality Management, Department of Water Affairs and Forestry, Pretoria.

CHAPTER 9

EVALUATION OF SALINITY STATUS

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9. EVALUATION OF SALINITY STATUS

The primary purpose of this chapter is to compare the water quality requirements of users with the water quality actually occurring in the river system. In accordance with the terms of reference of the study the greatest effort has been placed on salinity (i.e. TDS and its main inorganic constituents). In the first section historical and possible future trends in water quality are examined. The second section provides an evaluation of the surface water quality status. Conclusions and recommendations arising from these findings are then given.

9.1 Trends in surface water quality

A few key stations have been selected to examine historical trends in water quality. The choice of stations was limited by the fact that few stations with long enough records are available. Even the longest of the water quality records do not pre-date the commencement of mining activities in the OFS Goldfields area. The total absence of flow data in any of the rivers and streams in the most polluted part of the study area makes it impossible to make a reliable assessment of trends in pollutant loads. The low water quality sampling frequency (monthly at best) in the OFS Goldfields area would also have been inadequate for estimating loads, even it flow data had been available. Despite these limitations the little data that is available can still provide a coarse overview of general water quality trends.

It must be recognised that hydrological fluctuations, which can span periods of a decade or more, have a profound effect on short to medium term trends in water quality. In terms of assessing the effect of pollution generating catchment developments such climatically induced trends are spurious and can result in totally misleading conclusions regarding pollution sources. Great care is therefore called for in attempting to interpret the observed short to medium term trends in water quality related activities such as drought and records.

9.1.1 Trends in point source effluent quality

(a) Welkom Municipality STWs

Trends in flow

Table 4.24 shows that between 1986 and 1992 the total discharge from Welkom's Witpan and Theronia STW showed virtually no trend, averaging $16x10^6$ m^3 p.a. This was surprising, since during this same period the amount of water purchased by Welkom from Goldfields Water grew from $9.5x10^6$ m^3 to $14.3x10^6$ m^3. It is logical to assume that Welkom's increase in water supply would have led to a corresponding growth in the amount of raw sewage produced by Welkom itself. The lack of a corresponding growth in the total sewage discharge from Welkom's two sewage treatment works implies that the amount of incoming raw sewage from other sources (notably the surrounding gold mines) may have declined. The only bodies of surface water directly affected by purified sewage effluent discharge from Welkom's Witpan and Theronia STW are Witpan (which receives Witpan STW effluent) and Torontopan (which receive Theronia STW effluent). These pans receives excess purified sewage effluent that is not re-used by the mines and other organisations.

Table 4.7 indicates that the Witpan STW annual discharges about $2.2x10^6$ m^3 of purified effluent to Witpan, which has a surface area of 280 ha. Witpan's surface area should be sufficient to evaporate the incoming effluent. However, the current input must be close to the limit of what the pan can accommodate, since it also receives some urban stormwater drainage. Toronto pan and Flamingopan, with a combined area of 252 ha, together receive about $2.0x10^6$ m^3 of treated sewage effluent from the Theronia STW (see Table 4.7). Again, given the likelihood of urban stormwater runoff inputs, this pan system must also be close to the limit of what it can handle. Any further growth in the output from these two STWs will therefore necessitate alternative arrangements for effluent disposal.

Despite the apparent lack of growth in the total output from Welkom's STWs since 1986, the municipality has just commissioned a new STW at Thabong with a capacity of $12x10^3$ m^3/day (i.e. equivalent to about $4.4x10^6$ m^3 p.a.). This implies that some growth in sewage discharge is anticipated. The opening of the Thabong STW is a significant departure from the previous situation since the intention is to discharge its effluent to the Sand River Canal, which in turn will convey the purified effluent direct to the Sand River.

Trends in effluent water quality

There is no obvious trend in the salinity of the effluent discharged by the Witpan and Theronia STW (see Table 4.24, section 4.9.1). The average TDS during this period was 842 mg/l. Although this TDS is rather high, the source of most of the salt in the sewage effluent appears to the Vaal River (from where Goldfields Water draws most of Welkom's water supply). In actual fact Welkom adds only about 324 mg/l to the TDS (see section 4.9.1), which is normal for a large town or city.

Although no water quality data for the Thabong STW has come to hand, it can be assumed that its mean TDS will be similar to that of the other two STWs, i.e. about 840 mg/l. If it services an area with a lower industrial water use (as may be expected if most of the raw sewage effluent is derived from Thabong township), then the increase in TDS concentration through use might be a little less (say about 150 to 200 mg/l). Hence the average TDS of Thabong's treated sewage effluent can be expected to lie in the range 670 to 840 mg/l, depending on the proportion of industrial water use in the area serviced by the works.

It is important to observe that the mineral quality of Welkom's sewage effluent is directly dependent on that of the supply water. At present the Vaal River is the main source of water supply. Any improvement or deterioration in the Vaal River water quality will directly affect the TDS in the effluent.

Table 4.24 shows that the annual TDS loads discharged by Welkom's STWs have remained static since 1987.

Likely effect on trends in surface water quality

It is difficult to predict the long term effect of Welkom's STW effluent on Witpan, Theroniapan and Flamingopan without a more detailed investigation.

Under normal circumstances it could be expected to result in a steady rise in TDS concentration, since evaporation from the pan will remove only water, leaving the salt behind. However, some water is also abstracted from these pans for use by various mines in the Freegold group. The existence of a steady outflow from the pans would mean that the TDS level in each pan should eventually build up to some equilibrium level at which the outgoing salt load matches the incoming load. The TDS level required for this equilibrium to occur depends on the relative magnitude of the incoming and outgoing flow rates. The lower the outflow rate, the higher the equilibrium TDS concentration. More information regarding the inflow and outflow rates is required to determine the likely trend in TDS in the pans.

The discharge of Thabong STW effluent to the Sand River Canal will dilute the high TDS levels in the canal and further downstream in the Sand River itself. However, it will have the negative effect of making it much more difficult to contain mining pollution in the Sand River Canal. For example, the option of providing diversion works and pumps near the end of the canal to return saline seepage to waste disposal dams would become virtually untenable, since this would involve having to dispose with much larger volumes of more diluted water. Greater benefit could obviously be derived from the dilution afforded by the Thabong STW effluent if it could be conveyed to the Sand River via an independent conduit (such as a pipeline), since this will not interfere with efforts to contain mine pollution.

While the discharge of the Thabong STW effluent can be expected to dilute the Sand River for several kilometres downstream of the Sand River Canal infall, its net effect will be to increase average TDS concentrations in the lower Vet River. This is because downstream of the five irrigation canal release points the Vet River is diluted to an average concentration that is lower than that of the expected STW effluent quality. For example, Appendix D shows a median EC of 37 mS/m for station C4H004 in the lower Vet River. This is equivalent to about 260 mg/l, which is considerably lower than the anticipated mean TDS of the treated sewage effluent. Even at the P90 TDS level at C4H004 (of about 670 mS/m) could be adversely affected by the Thabong STW effluent.

(b) Virginia Municipality STW

Trends in flow

Table 4.26 (section 4.9.2) shows that if anything, the effluent discharge from Virginia's STW has declined over the last five years. (The annual discharge in 1992 was 4.7×10^6 m^3, down 7% on the 1988 total.) The small decline (or stagnation) in growth rate could be attributable to the economic problems being faced by the mining industry, which directly and indirectly provides employment for most of Virginia's residents. The future trend in effluent discharge from Virginia's STW will depend on the fate of the local mines, which is very difficult to predict. The most reasonable assumption is that the output from Virginia's STW will remain similar to the present level.

Trends in effluent water quality

Only three years of water quality data could be obtained for the Virginia STW (Table 4.26, section 4.9.2). This data shows no obvious trend, although there appears to be far greater variation in TDS than was the case for Welkom (the annual TDS varied between 455 and 930 mg/l). No obvious reason could be found for the unusually low TDS (455 mg/l) in 1990. The possible explanation that Virginia received low TDS supply water via the Virginia purification works had to be rejected since during 1990 Goldfields Water did not obtain any water from the Sand-Vet GWS (see Table 2.2). The 1990 effluent TDS therefore appears to be unrealistically low.

As in the case of Welkom, Virginia's effluent TDS will be strongly affected by the quality of the water supplied to the town and surrounding mines by Goldfields Water. A lower effluent TDS can be expected during periods when Virginia is partially or completely supplied from Goldfields Water's Virginia works, since the Allemanskraal Dam salinity is generally much lower than that in the Vaal River at Balkfontein.

Likely effect on trends in surface water quality

At face value, the data provided by Virginia shows that all of its effluent is re-used (see water balance given in section 4.9.2). It follows that any small trend in Virginia's sewage effluent discharge will have no effect on water quality in the Sand River. However, the high losses (1.3×10^6 m^3 p.a., or 13.4% of total raw sewage inflow) reflected in the water balance given in section 4.9.2 gives rise to speculation that a substantial amount of water may be finding its way to the Sand River. Any such seepage or spillage of Virginia's sewage effluent would have a similar effect to that of the input of effluent from Welkom's Thabong STW (see section 9.2.1(a) above).

(c) Senekal Municipality STW

Trends in flow

Flow data for only one year was obtained for Senekal. Table 4.29 shows that the quantity of effluent involved is negligible in terms of the hydrology of the Allemanskraal Dam catchment.

Trends in effluent water quality

Trends in water quality could not be examined since only one year of data was available. However, the low TDS of the effluent (of only 338 mg/l) is indicative of the absence of significant industrial inputs. There is little reason to expect this to change in the near future.

Likely effect on trends in surface water quality

Since at present all of the effluent is re-used and the discharge is very small, any growth in Senekal's effluent output is unlikely to significantly affect water quality in Allemanskraal Dam for decades to come.

(d) Bultfontein Municipality STW

Trends in flow and effluent water quality

No effluent data was obtained for Bultfontein. Hence trends could not be examined.

Likely effect on trends in surface water quality

Since Bultfontein is a relatively small rural community located far from major river courses in a relatively flat, semi-arid area characterised by ineffective catchment areas, any effluent that is not re-used on parks and gardens is unlikely to reach the lower Vet River. The effect on the Sand-Vet River System of trends in effluent discharges from Bultfontein are therefore expected to be negligible.

(e) Henneman Municipality STW

Trends in flow

Flow data for only two years was obtained for Senekal. Table 4.30 (section 4.9.5) shows that the quantity of effluent involved is negligible in terms of the hydrology of the Sand River catchment. Contradictory information was received regarding the amount of effluent re-used. The estimates ranges between 40% and 100% re-use.

Trends in effluent water quality

Trends in water quality could not be examined since only two years of data were available. Table 4.30 shows annual TDS concentrations of 758 and 706 mg/l for 1991 and 1992 respectively. This implies a relatively small increase in effluent TDS, compared with the TDS of the Goldfields Water supply water. The TDS of the supply water therefore tends to dominate that in the effluent. There is little reason to expect any trend in the amount of salt per unit volume of effluent added through water use in Henneman. Therefore any trend in Henneman's effluent quality is likely to be driven primarily by trends in the TDS levels in the Vaal River at Balkfontein.

Likely effect on trends in surface water quality

Since the present total effluent discharge is small and a large proportion is re-used, growth in effluent discharge from Henneman is expected to have little effect on water quality in the Sand River in the short to medium term.

(f) Hoopstad Municipality STW

No effluent flow or water quality data was available for Hoopstad. Hence trends could not be examined. However, since Hoopstad re-uses all of its effluent, it is not expected to significantly affect water quality in the lower Vet River.

(g) Theunissen Municipality STW

Trends in flow and effluent water quality

No effluent flow or water quality data was obtained for Theunissen since all their treated sewage effluent is irrigated. Moreover, the total water supply to the town is relatively small. Hence trends are of little interest in the context of the present study.

Likely effect on trends in surface water quality

It is understood that some of the newer mines located in the Doring River catchment are beginning to house personnel at or near to Theunissen. This could imply an increase in the effluent discharge from this town. However, further information was not readily available for inclusion in the report.

(h) Winburg Municipality STW

The only information available for Winburg is that its STW has a capacity of 9000 m^3/month. This small discharge should have negligible impact on the hydrology and water quality of Erfenis Dam, either now or in the foreseeable future.

9.1.2 Trends in surface water salinity

Historical salinity trends in observed water quality have been examined at a few strategically located monitoring stations. The choice of stations was limited by the small number of stations with sufficiently long records. Only the DWA&F Directorate: Hydrology's three hydrological stations and Harmony Mines five river stations were deemed long enough to permit meaningful trend analyses. Either total dissolved salts (TDS) of electrical conductivity (EC) could serve as the primary indicator of salinity trends. Since the TDS data from many of the mining house sources is suspect, electrical conductivity was chosen for analysis of trends. Based on water quality data for hydrological station C4H004 on the lower Vet River, a TDS/EC ratio of 7.1 was obtained. Application of this factor to the EC data provides a means of making a rough estimate of the TDS at other stations in the study area. In some instances trends in some of the main ionic species comprising the TDS have been analyzed. This has been done to provide pointers to the likely causes of the observed trends.

(a) Sand River at Allemanskraal Dam

Fig. 9.1 shows a small upward trend of 0.11 mS/m in the median EC in Allemanskraal Dam during the last 21 years. Based on the Kendal Tau test this trend is significant at the 80% confidence level. However, the seasonal Kendall test shows that the trend is statistically insignificant at the 80% confidence level. It can be concluded that there is no significant trend in the median EC in Allemanskraal dam. No significant trends in the main ionic species comprising the TDS were detected.

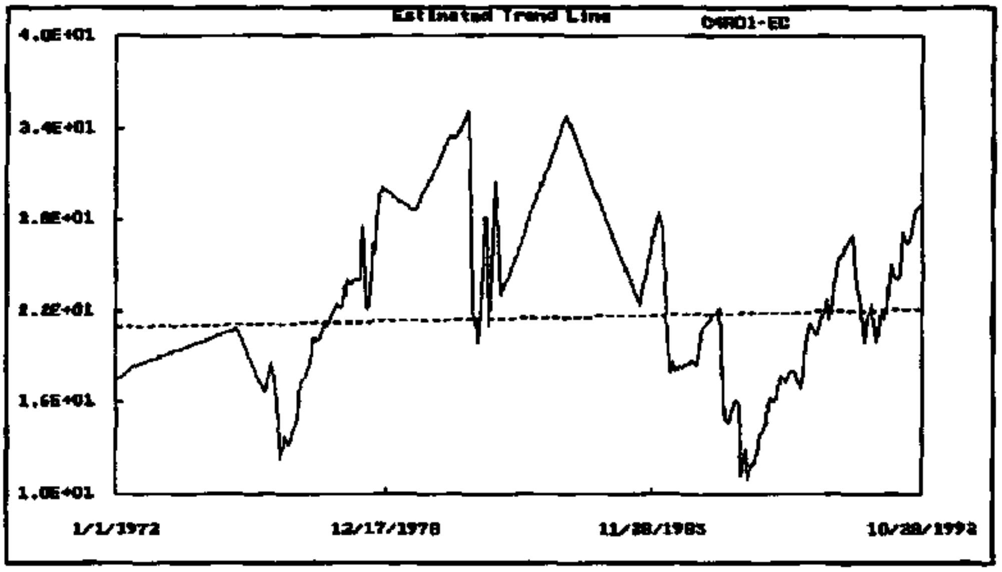


Fig. 9.1 : Trend in EC at Allemanskraal Dam (vertical axis units: 10 - 40 mS/m)

Fig. 9.1 illustrates the danger of attempting to draw conclusions regarding trends in reservoir data from a relatively short data base. For example, had only the first ten years of data been available the same trend analysis would have produced a "statistically significant" very sharp upward trend. However, blind acceptance of this trend would have led to totally misleading conclusions regarding salinisation of the Allemanskraal Dam catchment, since the upward trend during the first half of the record was driven by natural long-term hydrological fluctuations (i.e. moving from the wet early seventies into the severe eighties drought).

(b) Vet River at Erfenis Dam

Fig. 9.2 shows a small, but statistically insignificant downward trend in the median EC in Erfenis Dam for the same 21 year period. There is no reason to expect any trend in the salinity regime of this dam.

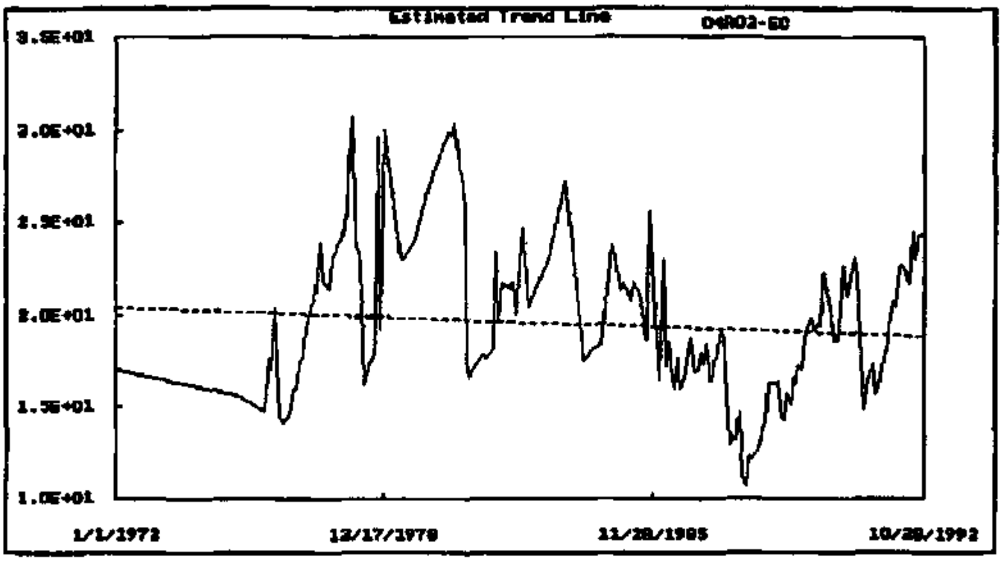


Fig. 9.2 : Trend in EC at Erfenis Dam (vertical axis units: 10 - 35 mS/m)

(c) Sand River at station HAR3 downstream of "Donga Dump Stream"

Fig. 9.3 shows a statistically significant upward trend in the median EC at station HAR3 in the Sand River immediately downstream of both the "Donga Dump Stream" and the "Waste Dump Stream" and a number of slimes dams operated by Harmony Mine's Merriespruit Section. The most dominant anions, chloride and sulphate, show similar upward trends. Similar upward trends are evident at station HAR2 in the Sand River a short distance upstream of station HAR3.

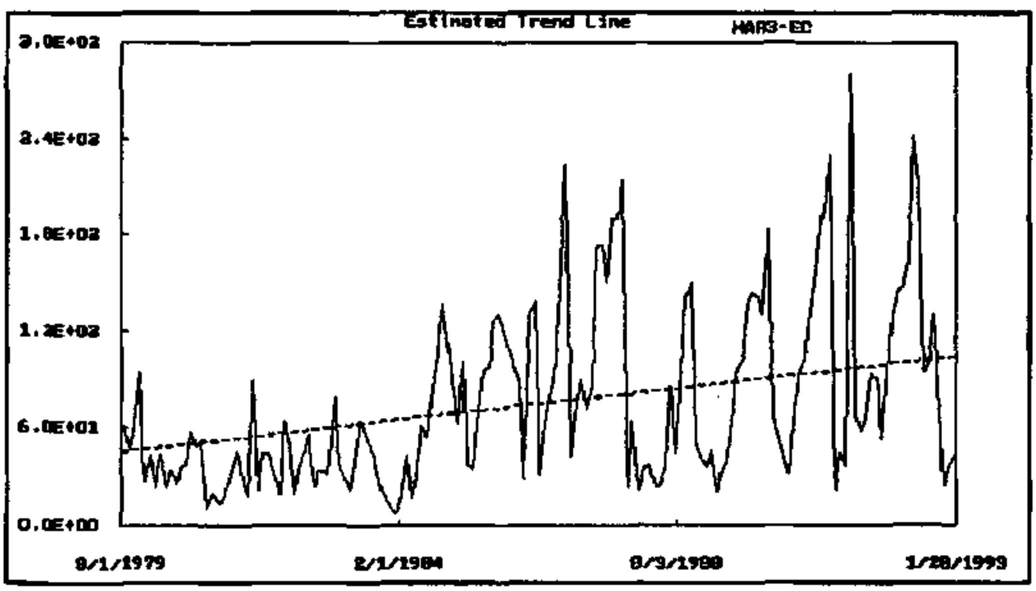


Fig. 9.3 : Trend in EC in the Sand River at station HAR3 downstream of the "Donga Dump Stream" (vertical axis units: 0 - 300 mS/m)

Given the fact that there is no trend evident at upstream stations and the large increase in EC compared with the upstream station at HAR1, it can be concluded that:

(i) there is a substantial pollution input between stations HAR1 and HAR3;

(ii) the dominance of chloride and sulphate in the polluted water in the Sand River at station HAR3 points to mining waste water as the most likely cause of the upward trend in EC;

and

(iii) either the flow rate or EC of the pollution source has a strong upward trend, indicating increasing pollution load inputs.

(d) Station HAR6 in "Waste Dump Stream"

The information given in section 4.3.1 shows that the most significant change in the EC levels in the Sand river occurs at station HAR2, which is immediately downstream of the "Waste Dump Stream" and a number of Harmony Mine's slimes dams. This points to the slimes dams and the "Waste Dump Stream" as being the most likely causes of the salinity trend evident at stations HAR2 and HAR3.

Fig. 9.4 shows a very distinct upward trend in the median EC at monitoring station HAR6 in the "Waste Dump Stream". The median EC at this station has risen at a rate of 12.6 mS/m per annum (i.e. equivalent to an annual TDS increase of about 88 mg/l, giving a total increase over the period of about 1230 mg/l).

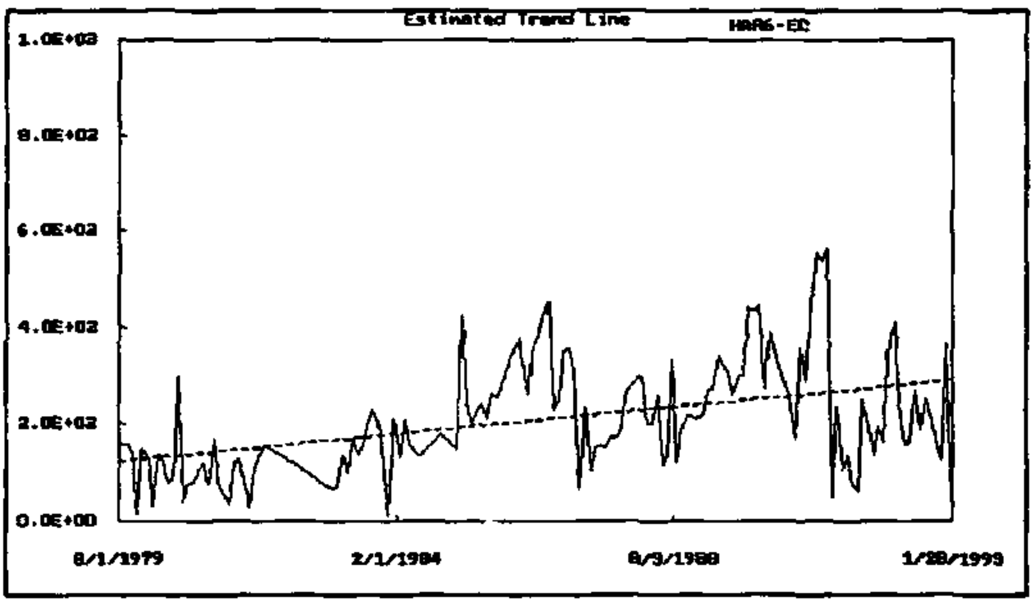


Fig. 9.4 : Trend in EC in the "Waste Dump Stream" at station HAR6
(vertical axis units: 0 - 1000 mS/m)

From the above evidence it can be deduced that:

(i) the "Waste Dump Stream", which spills into the Sand River, has been subjected to increasing pollution inputs over the last 15 years;

and

(ii) these "Waste Dump Stream" and Harmony Mine's Merriespruit Section slimes dams are the most likely causes of the upward trend in EC evident in the Sand River at station HAR3.

Although there is a strong upward trend in EC for the entire period shown in Fig. 9.4, the latter part of the record indicates that the EC levels in the "Waste Dump Stream" may already have reached a plateau. However, without flow data in the stream it is not possible to determine if the TDS load entering the Sand River via this stream is still growing or not. Hence it is not yet possible to predict whether or not the upward trend in EC observed at station HAR3 in the Sand River will be continued.

(e) Station HAR4 in Sand River at pipe bridge

Although dilution has reduced the observed EC values in the Sand River at station HAR4, relative to station HAR3 (see Fig. 4.6 in section 4.3.1(c)), the median EC still shows a similar upward trend. This provides indirect evidence that:

(i) any other pollution inputs between stations HAR3 and HAR4 are less significant than those entering via the "Waste Dump Stream" and "Donga Dump Stream".

(f) Sand River between station HAR4 and DWA7

No significant trend in the median EC values was evident in the Sand River at station HAR5, downstream of the Sand River Canal. The disappearance of the upward trend observed in the stations further upstream, combined with the much higher EC levels at station HAR5 indicates that:

(i) the pollutant loads entering the Sand River downstream of station HAR4 (especially in the vicinity of the Sand River Canal) are more dominant than those entering in the vicinity of the "Waste Dump Stream"; and

(ii) the pollutant inputs to this downstream river reach have attained a quasi steady state.

The latter deduction is consistent with the presence of a number of long established mines in the area. The polluted water dams and slimes dams of such older mines could be expected to be approaching a steady state with regard to seepage to surface water courses.

(g) Vet River at station C4H004

Fig. 9.5 shows that during the last 21 years there was no significant trend in the median EC in the lower Vet River at station C4H004.

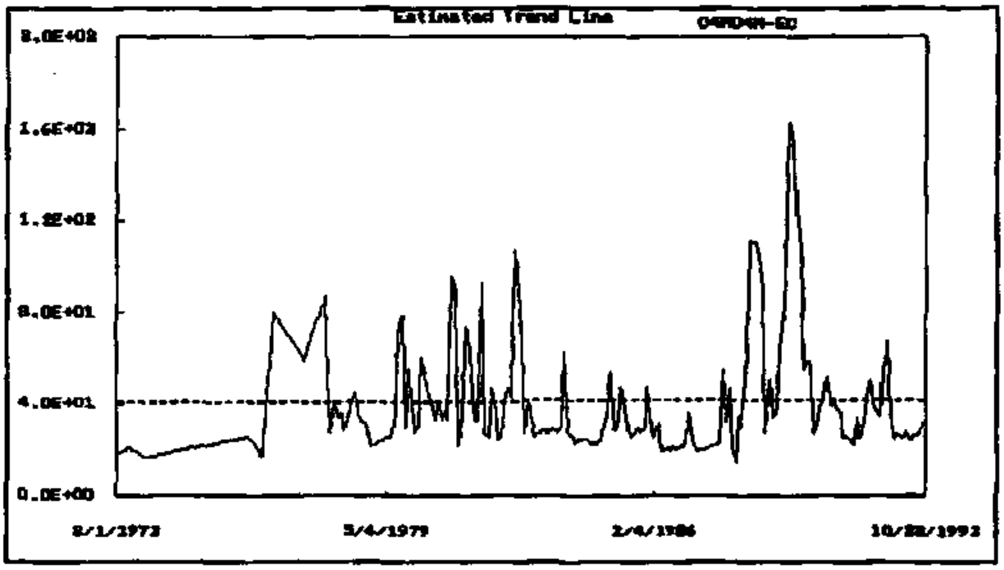


Fig. 9.5 : Trend in EC in the Vet River at station C4H004
(vertical axis units: 0 - 200 mS/m)

The lack of trend is not surprising since EC trends were not observed in the polluted portion of the Sand River at station HAR5 or in Erfenis Dam. This information, together with the absence of significant pollution sources downstream of station HAR5, leads to the expectation that there will not be any salinity trend at C4H004.

However, the lack of an observed trend in EC at station C4H004 does not mean that such a trend has not occurred. Water quality sampling at C4H004 started far too late to record the trend in water quality that would have occurred during the period following the commissioning of the first gold mines in the OFS Goldfields region in the late 1940s. Most of the mines have been operating for long enough to have reached some sort of steady state with regard to seepage of polluted water to surface streams.

Fig. 9.6 shows that the median chloride concentration at C4H004 also has no significant trend. The same is true of the remaining major ions, sulphate and sodium.

Fig. 9.7 shows no trend in the adjusted sodium absorption ratio.

Fig. 9.8 shows a remarkable lack of seasonality in the median EC. At highveld river stations much stronger seasonality normally occurs, with substantially higher EC values during the winter. The lack of distinct seasonality in the median values could be attributable in part to the effect of water releases to the lower Vet River from the Sand-Vet GWS canals. It could also imply that the rate at which saline water seeps or spills into the Sand River from polluted mining areas increases substantially during wet weather. Peak EC values tend to favour the winter months, although Fig. 9.6 shows that high values can also occur during summer months. Sodium and chloride show similar seasonal patterns.

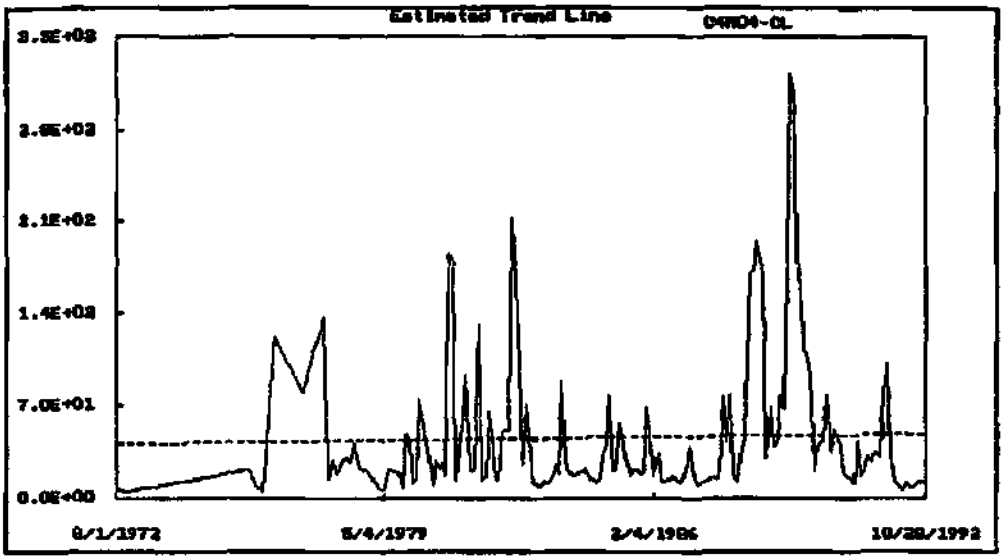


Fig. 9.6 : Trend in Chloride in the Vet River at station C4H004
(vertical axis units: 0 - 350 mg/l)

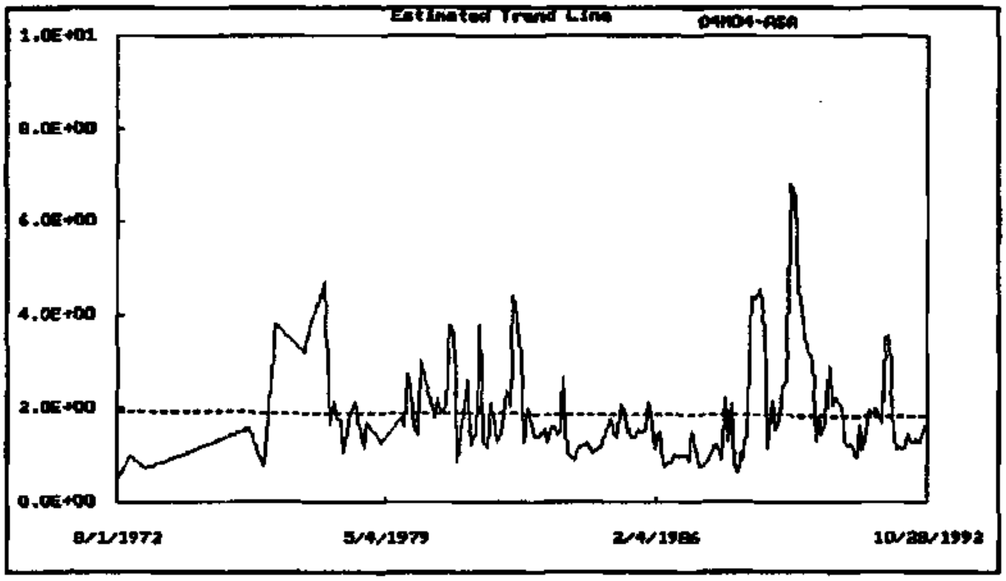


Fig. 9.7 : Trend in adjusted sodium absorption ratio in the Vet River at station C4H004 (vertical axis ratio: 0 - 10)

The lack of trend in *salt concentration* at C4H004 does not give the full picture. In terms of the impact on the salinity regime of Bloemhof Dam and the lower Vaal River system, some reference has to be made to TDS loads. In this regard, Fig. 8.1 indicates that the TDS load exported to the Vaal system rose substantially compared to the natural background condition during the last few years.

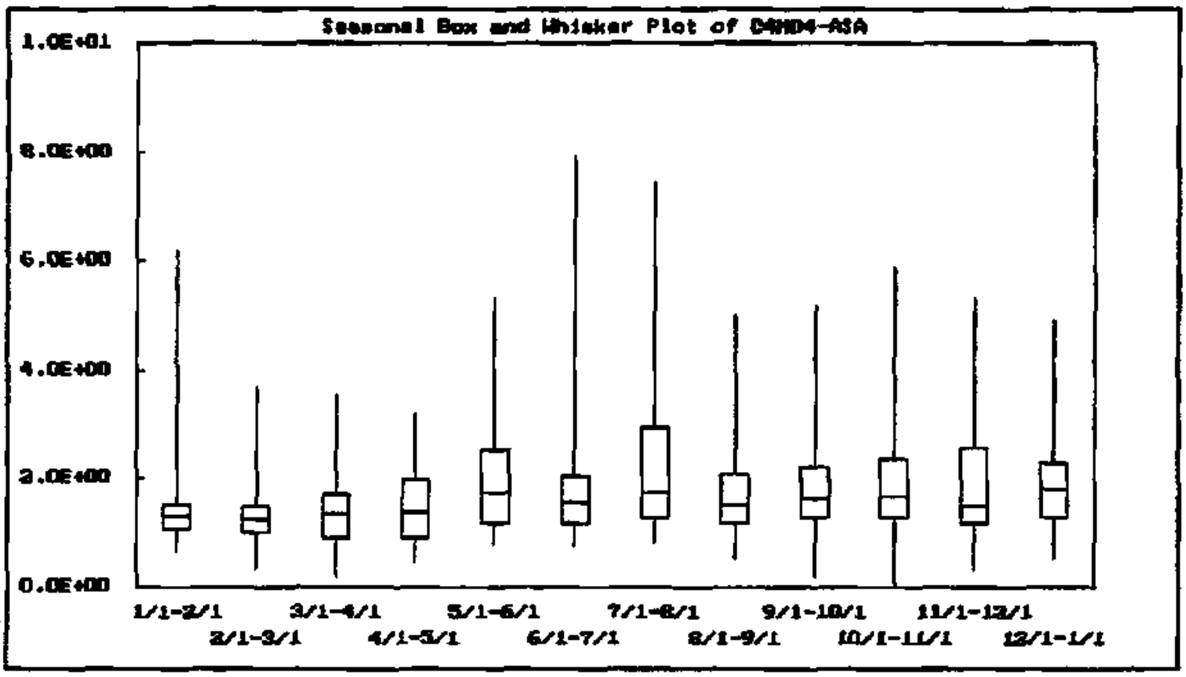


Fig. 9.8: **Seasonal box and whisker plot for adjusted sodium absorption ratio in the Vet River at station C4H004**

9.2 Evaluation of surface water quality status

9.2.1 General overview

(i) Scope

The surface water quality has been evaluated in terms of salinity, which is the main form of pollution from the OFS Goldfields region affecting water quality in the lower Sand and Vet Rivers. Although beyond the scope of the brief, a brief evaluation of some other water quality constituents has also been included.

(ii) Approach

In the following sections each of the main mineral water quality parameters of concern are discussed. (i.e. those parameters that already pose problems to users or threaten to cause problems in the short to medium term.) Aside from the long term trends already discussed in section 9.1, the record for the last four hydrological years (i.e. October 1988 to September 1992) has been examined in detail to compare the observed salinity levels with the user requirements. This period was chosen because it allows direct comparison of the data collected at all of the monitoring stations. (A longer period would have started before the DWA&F Regional Office's sampling programme commenced.) In the case of monitoring station C4H005 on the lower Vet River just upstream of its point of entry to Bloemhof Dam, an earlier four-year period had to be used, since this station closed in 1988.

(iii) Interpretation of graphical presentations

The in-house program QCHART was used to obtain a visual presentation of flow and water quality. The water quality has been depicted by means of duration curves for each water quality variable at certain key points.

Two figures have been used to present the data for each water quality parameter. The first shows the main monitoring stations in the greater Sand-Vet River system between Allemanskraal Dam, Erfenis Dam and the lower Vet River near its point of discharge into Bloemhof Dam (see Fig. 9.9 for an example). The second diagram represents the OFS Goldfields area in greater detail (i.e. the incremental catchment between monitoring stations HAR1 and DWA7 (see Fig. 9.10 for an example).

In these diagrams the rivers have been denoted by horizontal lines, the length of which are proportional to river length (to the scales indicated). The width of the area plotted normal to the river line and shaded with 45° hatching lines represents the current mean annual runoff (MAR), to the scale indicated.

Duration curves (cumulative frequency curves) of the water quality variable in question have been plotted at monitoring stations for which sufficient data was available. The horizontal axis of each duration curve represents the percentage time that a given value (vertical axis) was not exceeded.

The governing target guideline value for each water quality variable is plotted as a horizontal line. The black shaded area above this line indicates both the percentage time that the guideline level was exceeded and the degree by which it was exceeded. The target guideline values were derived from Tables 3.9 and Table 3.10 (see Chapter 3). The guideline limits used in the diagrams represent the lowest (i.e. most stringent) target guideline for all of the main categories of water use identified for the station under consideration.

The information contained in the duration curves given in these diagrams is summarised in tabular form in Appendix D.

9.2.2 Electrical conductivity (EC)

The EC is the most common measure of salinity. This variable is of particular interest with regard to irrigation use. In areas where river water is to be used for irrigation the target guideline level of 40 mS/m will ensure that even the most sensitive crops that were identified can be grown without any reduction in yield.

(a) Background EC levels

Fig. 9.9 shows that the recorded EC levels in both Allemanskraal Dam and Erfenis Dam remained well within the target guideline limit. Hence the background EC levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

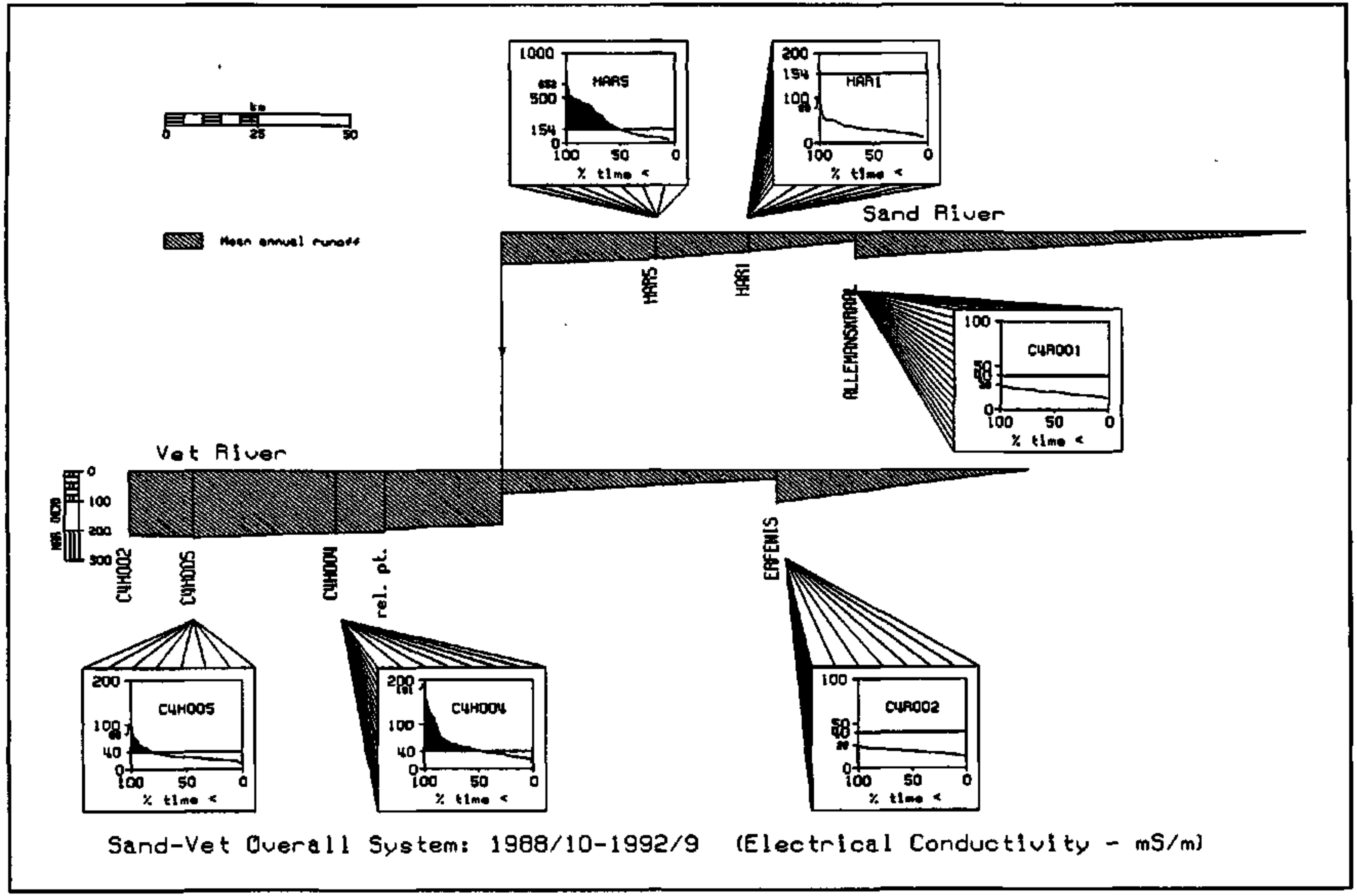
From background conditions in Allemanskraal Dam, the EC levels at station HAR1, on the eastern fringe of the OFS Goldfields area, had risen significantly. However, the less stringent target guideline for EC (based on the requirement for livestock watering) was not exceeded.

At station HAR5, near the eastern fringe of the OFS Goldfields region, the EC in the Sand River exceeded the target level for 54% of the time. The peak EC values exceeded the target more than four-fold. This means that the water at this point is unsuitable for livestock watering. With regard to domestic water use, 300 mS/m was exceeded for 35% of the time. Above this level ingestion of the water is likely to affect the long term salt balance of human users. The level above which acute (short term) health problems can be expected (450 mS/m) was exceeded for more than 10% of the time. Although domestic use was not identified as a water use in this river reach, the possibility of acute health problems arising from even short term use is a cause for concern. *The EC levels experienced in the Sand River downstream of the Sand River Canal therefore present a serious potential health threat.* Public warnings would therefore be appropriate.

The target guideline level of 40 mS/m was exceeded for 40% of the time at station C4H004 in the lower Vet River, with peaks reaching 163 mS/m. The improvement relative to station HAR5 is attributable to dilution with low TDS water released from the Sand-Vet GWS canals.

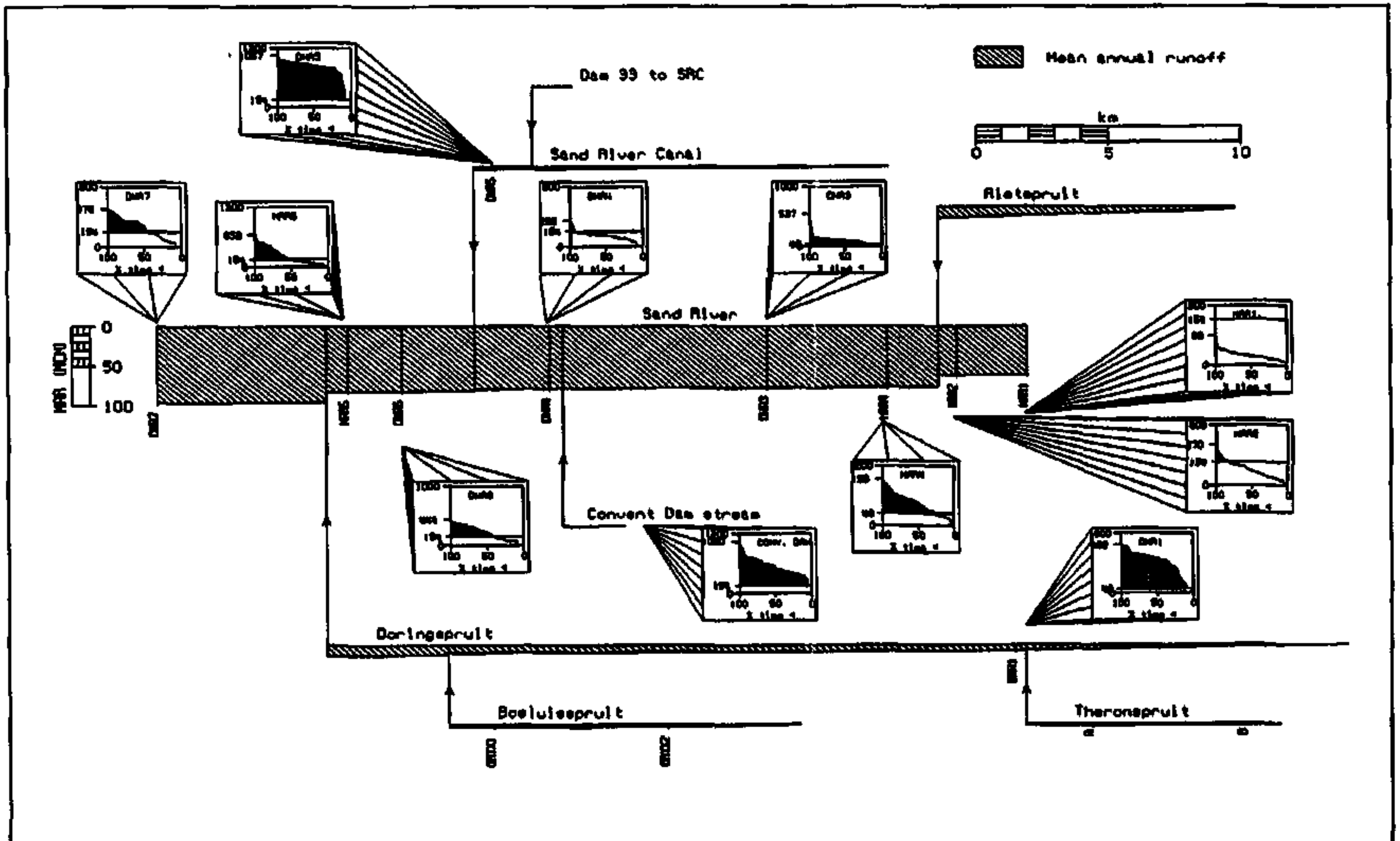
The last station, C4H005, shows further improvement. However, this result is somewhat misleading since the data for C4H005 covers a different period (it closed in 1988). A median comparison between stations C4H004 and C4H005 for the period of overlap of the two records (February 1980 to January 1988) showed little significant difference between the median EC values at the two stations. In view of the unrepresentativeness of the older record at station C4H005, this station has been omitted from the discussion of the results for the remaining water quality variables.

Fig. 9.10 shows a rapid deterioration in water quality between stations HAR1 and HAR2 (downstream of the "Waste Dump Stream").



km
0 25 50
Mean annual runoff
Sand River
Vet River
HAR5
HAR1
ALLEMANSKRAAL
C4R001
ERFENIS
C4R002
C4H002
C4H005
C4H004
rel. pt.
% time <
Sand-Vet Overall System: 1988/10-1992/9 (Electrical Conductivity - mS/m)

Figure 9.9



Sand River - detailed system 1988/10-1992/9 (Electrical Conductivity mS/m)

Figure 9.10

Some improvement in the median EC occurred at station HAR4 (at the pipe bridge), although the target guideline was still exceeded for 75% of the time.

Little change occurred between stations HAR4 and DWA4.

The worst salinity in the Sand River occurred at stations DWA6 and HAR5 in the river reach between the Sand River Canal infall and the Doring River confluence. At these stations the target EC level (based on the requirement for livestock watering) was exceeded for 64% and 54% of the time. Although regular domestic use in this river reach was not identified, the exceedance of the chronic health threat limit for domestic use for 35% to 36% of the time gives cause for concern. Warnings to riparian owners should therefore be issued to ensure that such use does not occur.

Further downstream at Blaaudrift bridge (station DWA7) the target was exceeded for 56% of the time. Dilution of the river (possibly from irrigation tailwater) reduced the exceedence of the chronic health threat level to 19% of the time.

(c) Rietspruit

There are no water quality monitoring stations in the Rietspruit. However, the improvement in water quality between stations HAR3 and HAR4 suggests that the Rietspruit is contributing little to the pollution of the Sand River.

(d) Sand River Canal

Fig. 9.10 shows that the target guideline level was exceeded for 96% of the time in the Sand River Canal. The level beyond which acute health effects could be expected from short term use of the water was exceeded for most of the time (and was exceeded two-fold for more than 10% of the time). *This water is therefore totally unfit for human consumption.* Public warnings against ingestion of the water from this canal should therefore be issued.

(e) Doring River

The target guideline level for livestock watering was exceeded at station DWA1 in the Doring River for 86% of the time. The level above which chronic health problems can be expected was exceeded for 68% of the time and the acute health threat limit was exceeded for nearly 10% of the time. *Hence this water is not only unsuitable for irrigation, it could also present serious problems for domestic water use by local riparian farmers and their labourers.*

(f) Theronspruit

No water quality data was available for the Theronspruit. However, station DWA1 in the Doring River provides an indirect indication of the water quality in the Theronspruit, since most of the dry weather flow in the Doring River X *DWA1 originates from the Theronspruit. At this point the target EC guideline limit for irrigation was exceeded for 100% of the time. The water quality data at station DW1 indicates that the Theronspruit too is unfit for beneficial use and could pose a serious health threat.

9.2.3 Calcium (Ca)

The target calcium limit for domestic use of 150 mg/l is dictated more by economic than health factors. Much higher calcium levels can be accommodated in drinking water. In river reaches where there is no actual or intended domestic use the target limit for livestock watering of 1000 mg/l has been applied.

(a) Background calcium levels

Fig. 9.11 shows that the recorded background calcium levels in both Allemanskraal Dam and Erfenis Dam are nearly an order of magnitude below the target limit. Hence the background calcium levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

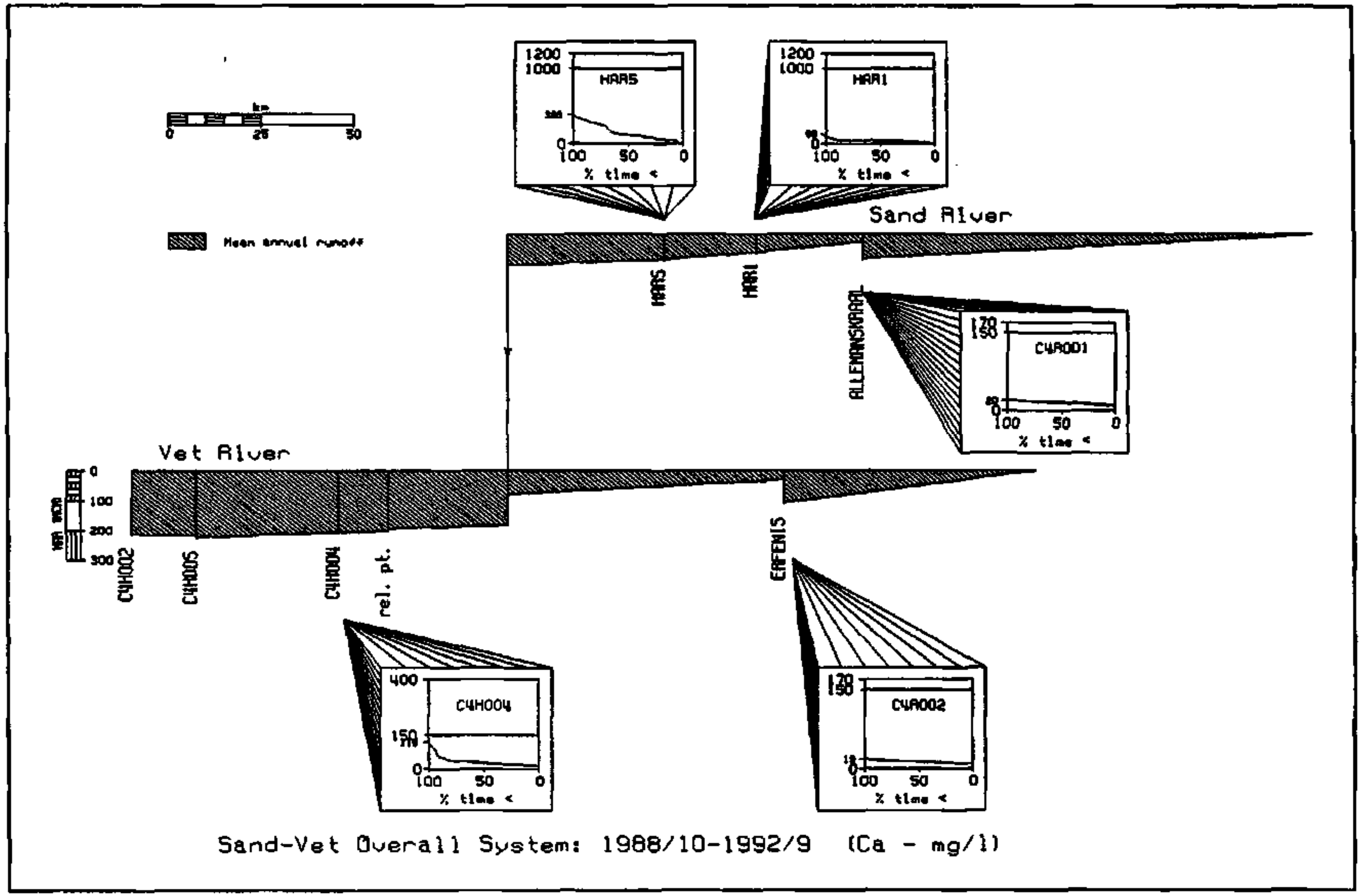
Figs. 9.11 and 9.12 show that the calcium concentration in the Sand River has remained below the target guideline level for livestock watering.

(c) Sand River Canal

Although unusually high calcium levels were recorded (up to 780 mg/l) in the Sand River Canal, the target guideline level for livestock watering was not exceeded.

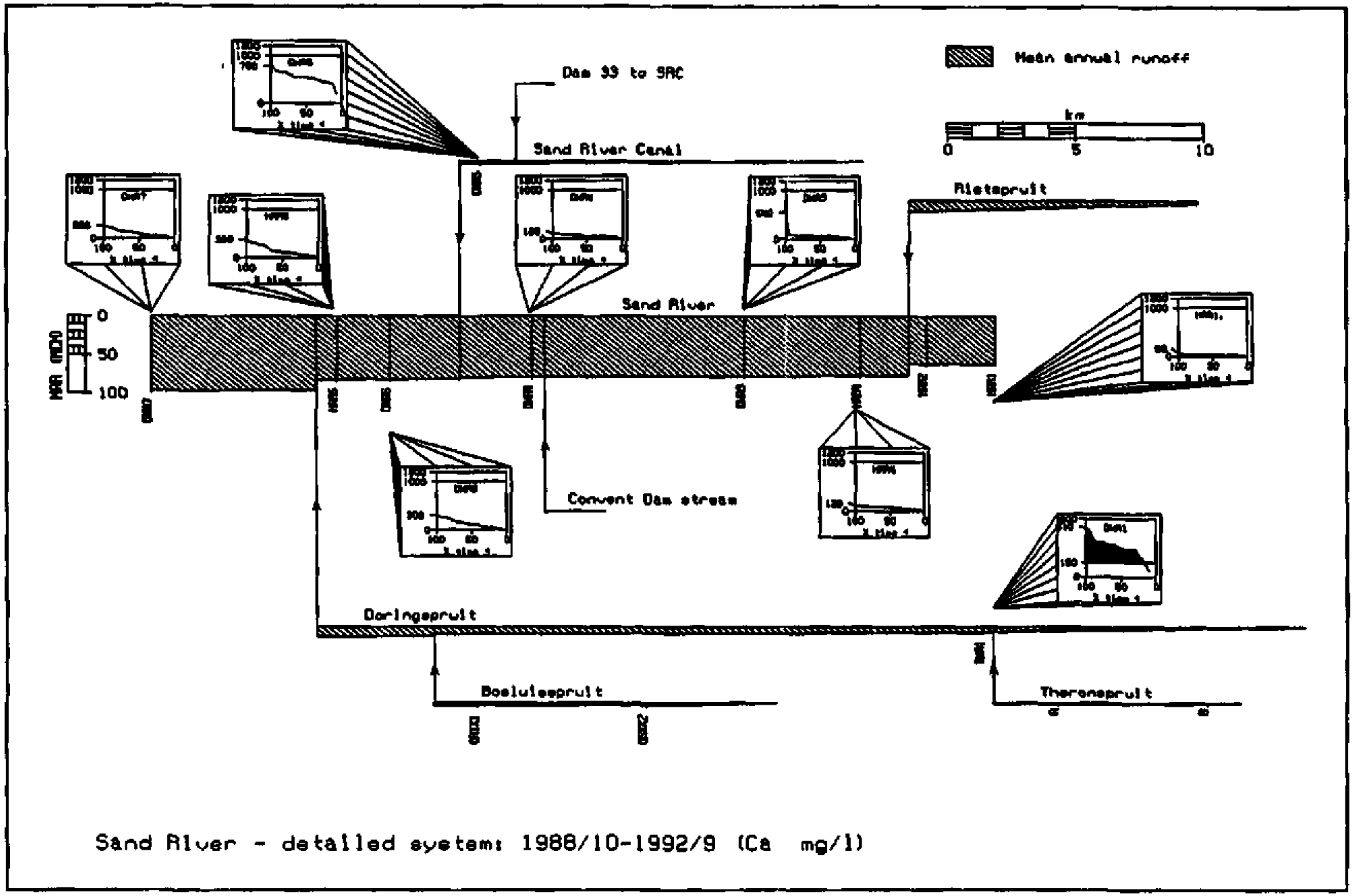
(d) Doring River and Theronspruit

The calcium target guideline limit for livestock watering was not exceeded in the Doring River. However, the limit for domestic use was exceeded for most of the time, implying that domestic use of water from further upstream in the Theronspruit could hold economic implications.



Sand River
Vet River
Mean annual runoff
HAA5
HAA1
C4A001
C4H004
C4A002
ALLEMANSKRAAL
ERFENIS
C4H002
C4H005
C4H004
rel. pt.
% time <
Sand-Vet Overall System: 1988/10-1992/9 (Ca - mg/l)

Figure 9.11



Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Rietspruit
Sand River
MAR (MCM)
0
50
100
Convent Dam stream
Doringspruit
Boeluiespruit
Theronspruit
Sand River - detailed system: 1988/10-1992/9 (Ca mg/l)

Figure 9.12

9.2.4 Magnesium (Mg)

The target magnesium limit for domestic use is 70 mg/l. In particular it imparts an objectionable taste to the water at this level. At higher concentrations it can produce negative health effects. The target limit for livestock watering of 500 mg/l has been used for river reaches from which there is no domestic water use.

(a) Background magnesium levels

Fig. 9.13 shows that the recorded background magnesium levels in both Allemanskraal Dam and Erfenis Dam are an order of magnitude below the target limit. Hence the background magnesium levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

Figs. 9.13 and 9.14 show that the magnesium guideline limit for livestock watering of 500 mg/l was not exceeded anywhere in the lower Sand River.

Despite the fact that the magnesium concentrations observed at station DWA7 reached 136 mg/l, by the time station C4H004 on the lower Vet was reached the magnesium levels had been diluted to acceptable levels for domestic water use.

(c) Sand River Canal

The magnesium target guideline level for livestock watering was not exceeded in the Sand River Canal.

(d) Doring River and Theronspruit

The magnesium target guideline limit for livestock watering was not exceeded at station DWA1 in the Doring River.

The target guideline limit for domestic use was exceeded for 86% of the time at station DWA1, implying that the upstream Theronspruit is unfit for domestic water use.

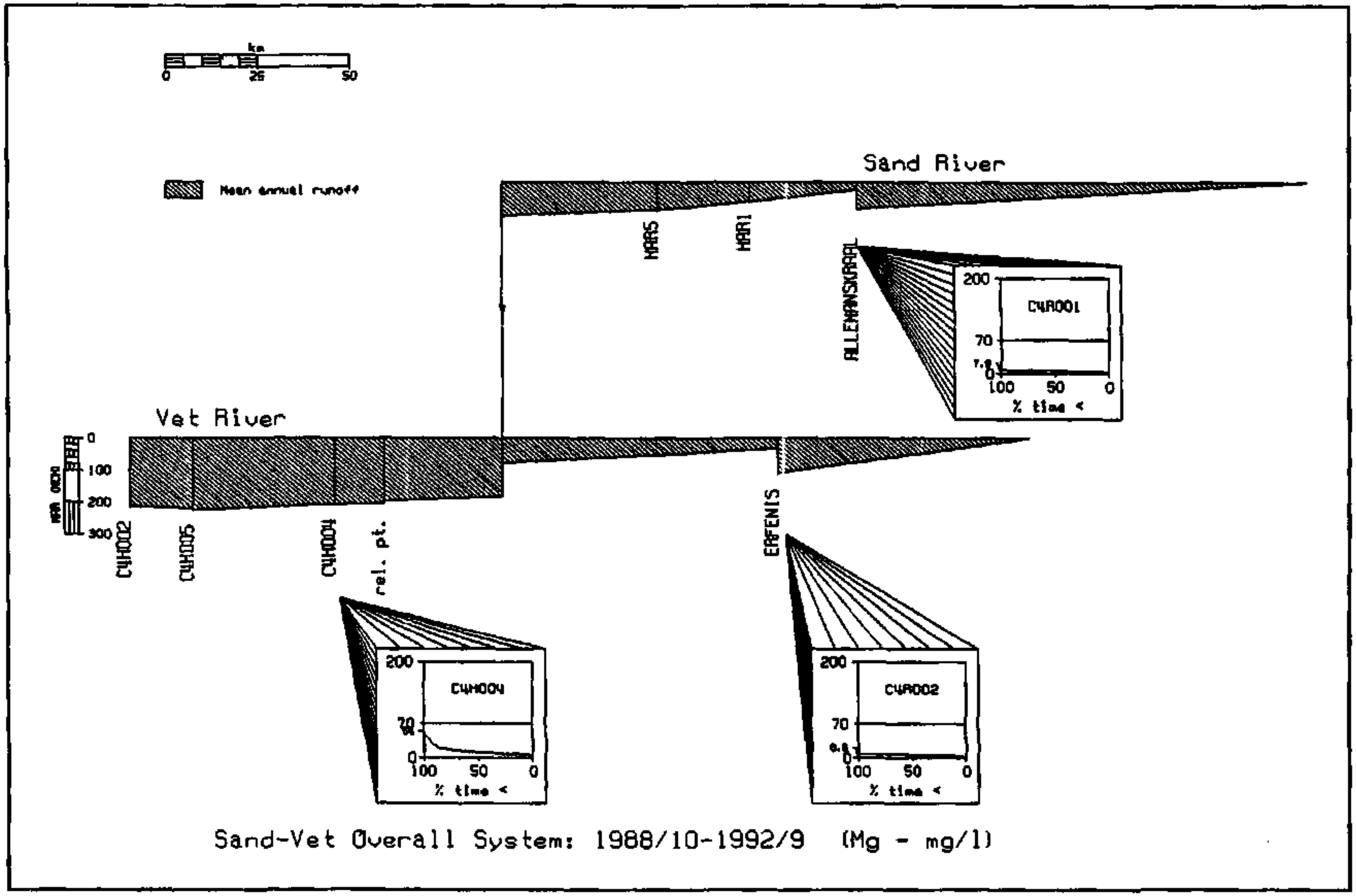

km
0
25
50
Mean annual runoff
Sand River
Vet River
MAR (mm)
0
100
200
300
C4H002
C4H005
C4H004
rel. pt.
MAR5
MAR1
ALLEMANSKRAAL
ERFENIS
C4R001
C4H004
C4R002
200
70
0
100
50
0
% time <
Sand-Vet Overall System: 1988/10-1992/9 (Mg - mg/l)

Figure 9.13

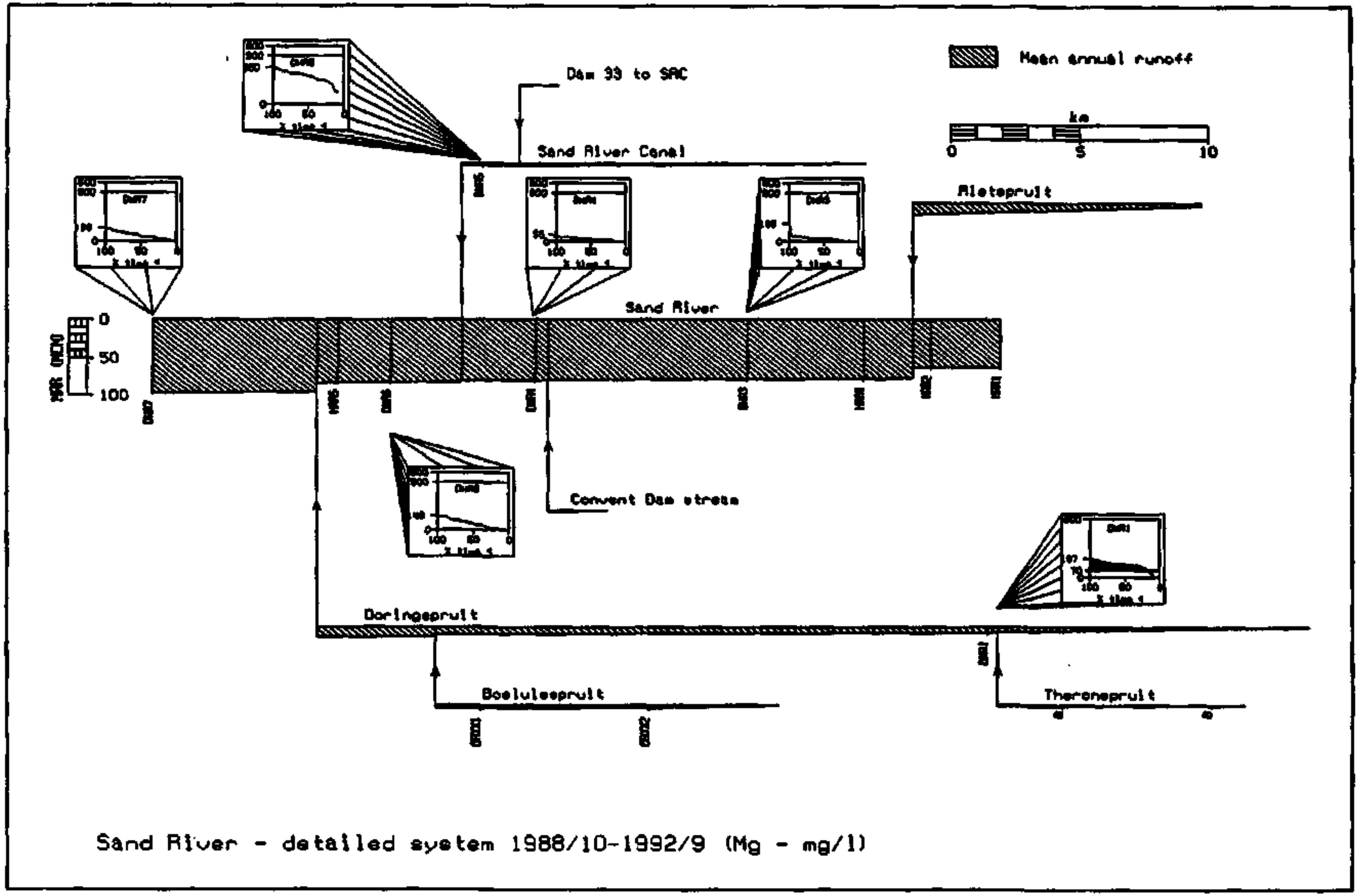

Mean annual runoff
km
0
5
10
Dam 33 to SAC
Sand River Canal
Rietspruit
Sand River
MAR (MCM)
0
50
100
Convent Dam stream
Doringspruit
Boelulesspruit
Theronspruit
Sand River - detailed system 1988/10-1992/9 (Mg - mg/l)

Figure 9.14

9.2.5 Sodium (Na)

The target sodium limit of 70 mg/l is to satisfy the requirements of the most sensitive crop that is spray irrigated. The limit for domestic use of 100 mg/l is based on the need to protect against possible chronic health problems. Livestock watering requires that sodium concentrations remain below 1000 mg/l.

(a) Background sodium levels

Fig. 9.15 shows that the recorded background sodium levels in both Allemanskraal Dam and Erfenis Dam are of the order of one third to one quarter of the target limit. Hence the background sodium levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

Figs. 9.15 and 9.16 show that the sodium guideline limit for irrigation use was exceeded in the Sand River between the Rietspruit confluence and Virginia Dam. Although much higher sodium concentrations occurred further downstream in the Sand River, they did not exceed the less stringent 1000 mg/l limit for livestock watering. However, even this limit came close to being exceeded downstream of the Sand River Canal at station DWA6, where a peak concentration of 950 mg/l was recorded.

Substantial dilution due to the water releases from the Sand-Vet GWS canals failed to prevent exceedence of the 70 mg/l guideline limit for domestic use at station C4H004 in the lower Vet River. At this point the target guideline limit was exceeded for 11% of the time, with the peak value reaching 187 mg/l.

(c) Sand River Canal

The target sodium limit livestock watering was exceeded for 22% of the time at station DWA5 in the Sand River Canal.

(d) Doring River

The sodium target guideline limit for livestock watering of 1000 mg/l was not exceeded at station DWA1 in the Doring River.

The target guideline limit of 70 mg/l for domestic use was exceeded for 91% of the time at station DWA1 in the Doring River. This indicates that the sodium levels in the upstream Theronspruit are also likely to have exceeded this limit.

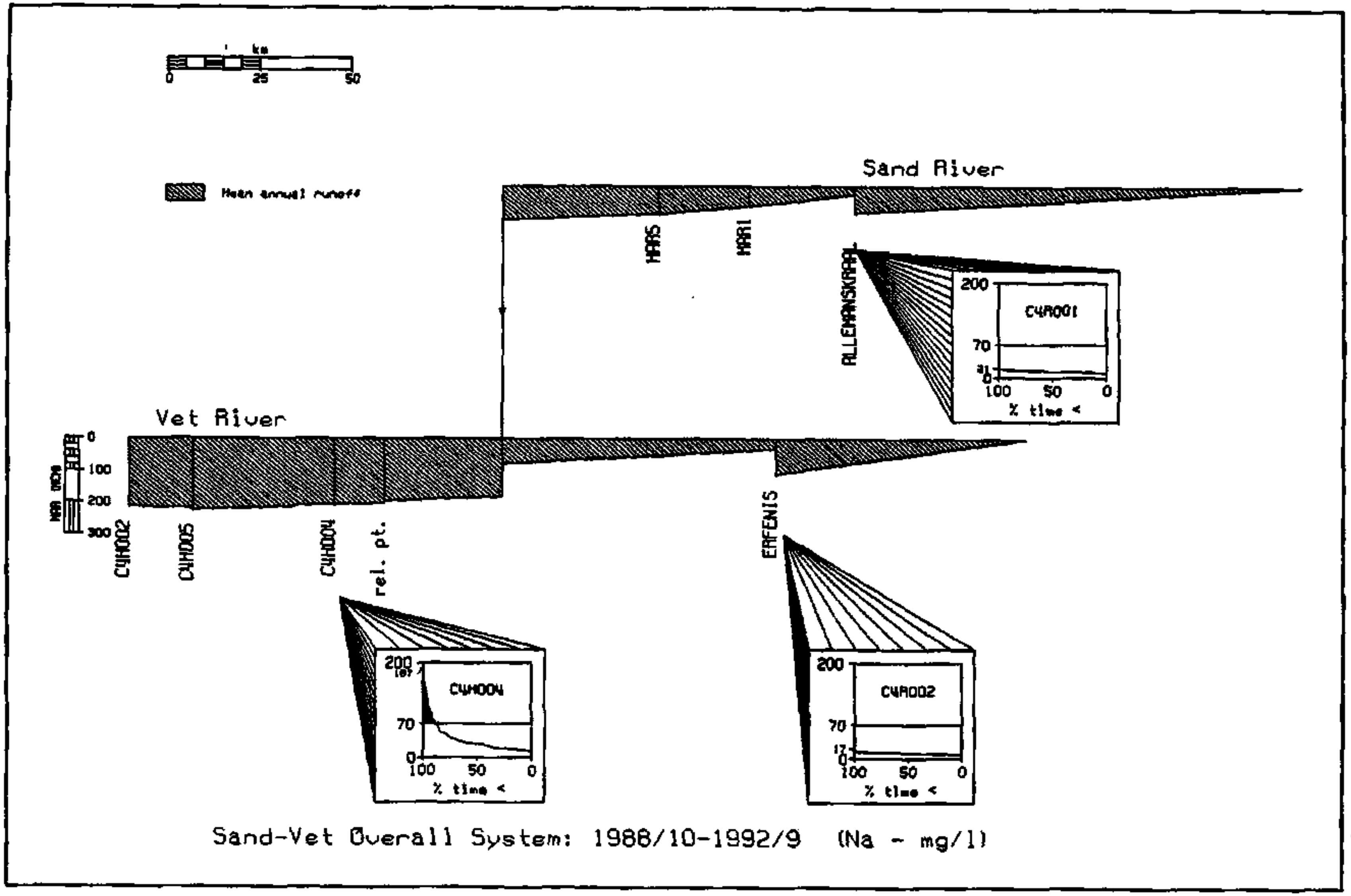

km
0
25
50
Mean annual runoff
Sand River
HAA5
HAA1
ALLEMANSKRAAL
200
C4R001
70
31
0
100
50
0
% time <
Vet River
0
100
200
300
C4H002
C4H005
C4H004
rel. pt.
ERFENIS
200
C4H004
70
0
100
50
0
% time <
200
C4R002
70
17
0
100
50
0
% time <
Sand-Vet Overall System: 1988/10-1992/9 (Na - mg/l)

Figure 9.15

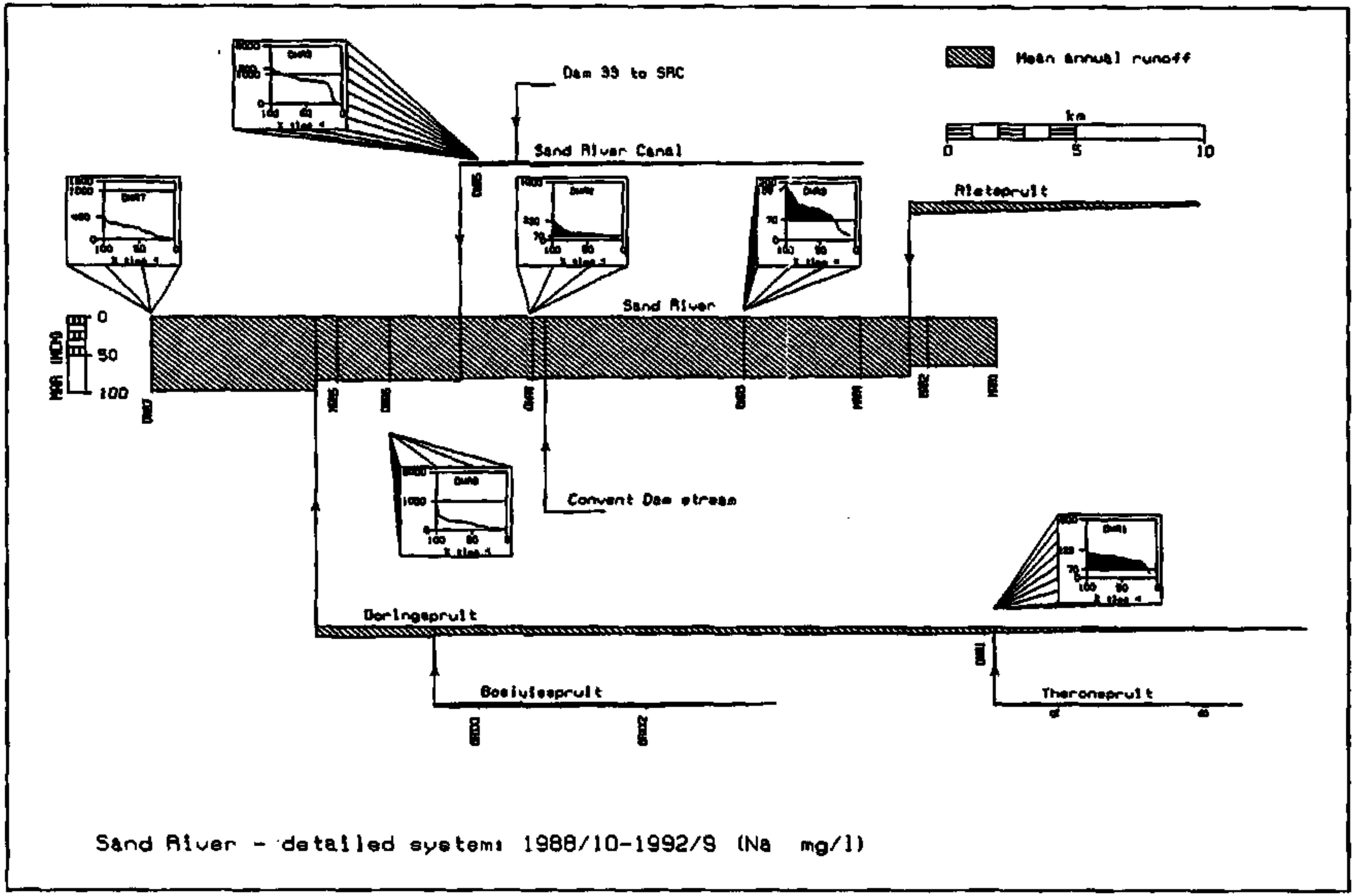

Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Rietspruit
Sand River
MAR (MCM)
0
50
100
Convent Dam stream
Doringspruit
Bosluisspruit
Theronspruit
Sand River - detailed system: 1988/10-1992/9 (Na mg/l)

Figure 9.16

9.2.6 Sodium Absorption Ratio (SAR)

The target SAR limit of 1.5 is applicable only to irrigation use. It is aimed at protecting against the dispersion of clay particles and surface sealing of irrigated lands at the onset of rains. The soils in the study area are particularly susceptible to this type of problem.

(a) Background SAR levels

Fig. 9.17 shows that the target limit for SAR was met in both Allemanskraal Dam and Erfenis Dam, which represent an approximation of background conditions. This also implies that the irrigation water supplied direct from the Sand-Vet GWS canals is not likely to present problems with regard to surface crusting.

(b) Lower Sand and Vet Rivers

Figs. 9.17 and 9.18 show that the sodium guideline limit for irrigation use was exceeded throughout the lower Sand River and lower Vet River. With regard to the Sand River, only the river reach between the Rietspruit confluence and Virginia Dam is relevant, since there is no actual or intended irrigation use in other portions of this river. In this river reach the SAR limit was exceeded for a high proportion of the time and by a wide margin. This implies that special precautions (i.e. surface application of gypsum) would have to be taken prevent surface crusting when this water is used for irrigation.

Substantial dilution due to the water releases from the Sand-Vet GWS canals failed to prevent exceedence of the 70 mg/l guideline limit for domestic use at station C4H004 in the lower Vet River. At this point the target guideline limit was exceeded for 11% of the time, with the peak value reaching 187 mg/l.

Further downstream in the lower Vet River at station C4H004 the SAR was somewhat improved. However, the target limit was still exceeded for 24% of the time. Since the soils along the lower Vet River are known to be especially susceptible to surface crusting, there is a high probability that exceedence of the SAR limit will necessitate surface application of gypsum on irrigated lands.

(c) Theronspruit

Exceedence of the SAR target guideline limit for most of the time at station DWA1 in the Doring River indicates that similar levels could apply to the upstream Theronspruit. Surface crusting problems can therefore be anticipated is water from the Theronspruit is used for irrigation.

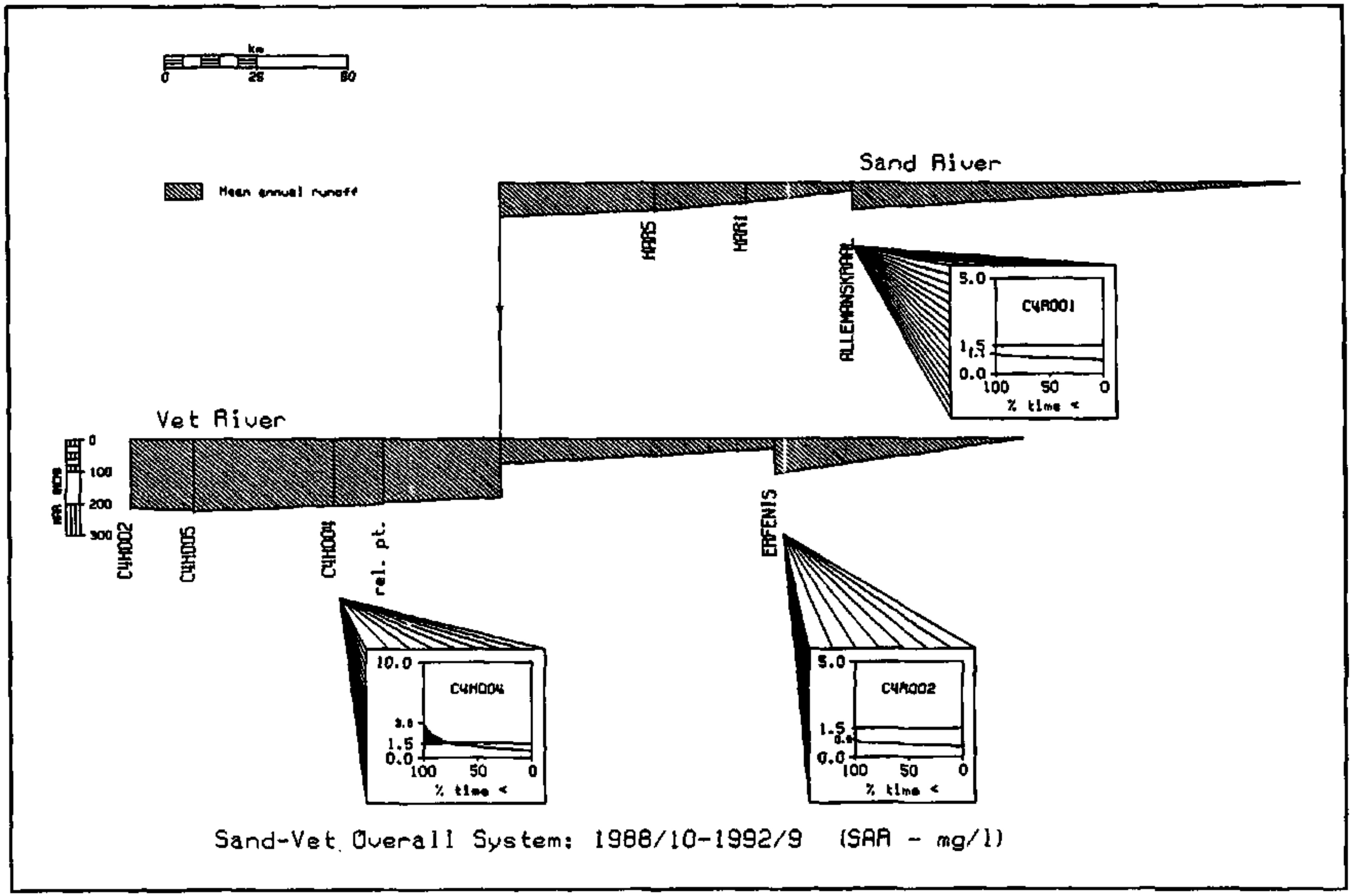
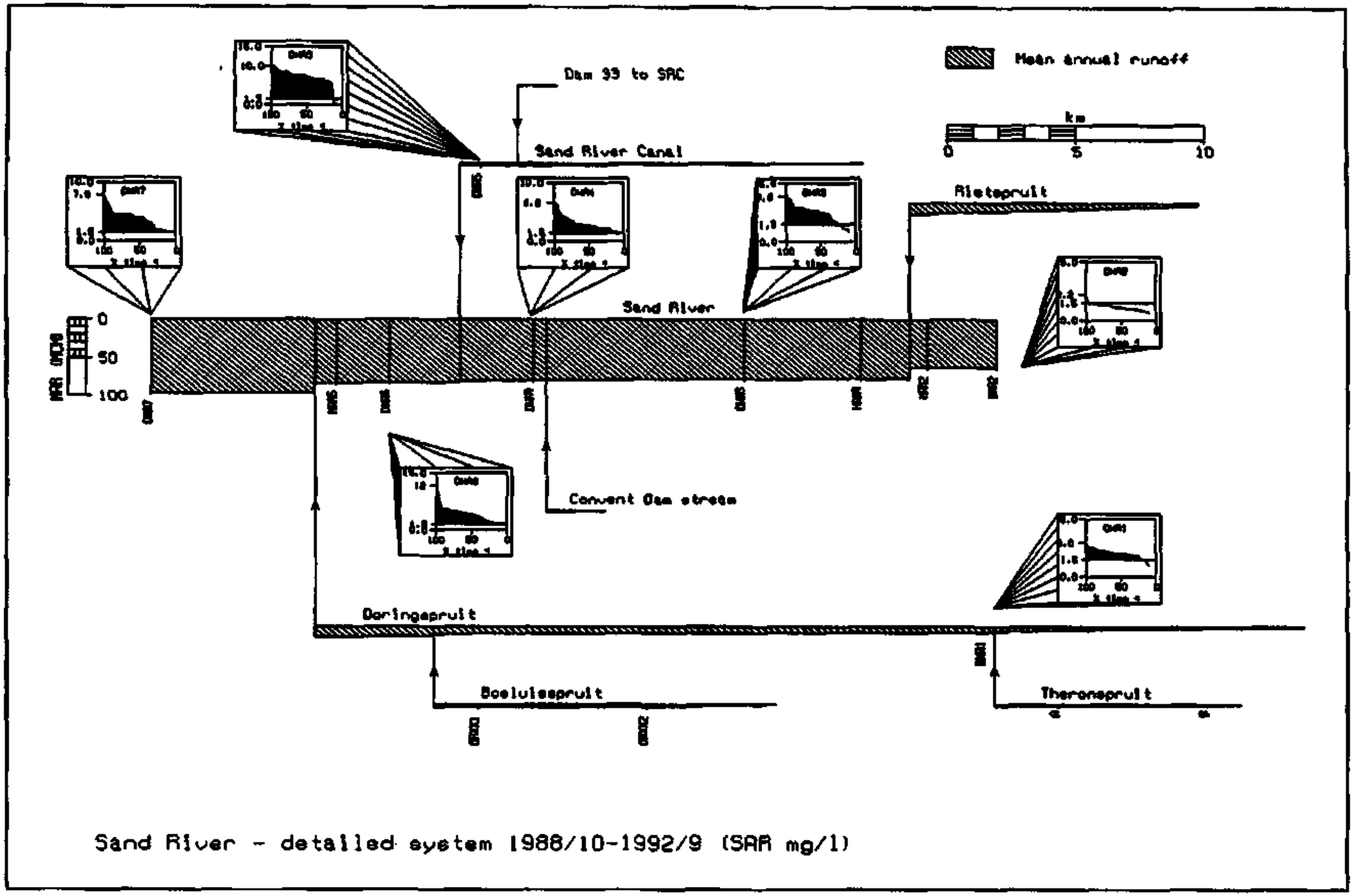

km
0
25
50
Mean annual runoff
Sand River
Vet River
MAR MCM
0
100
200
300
C4H002
C4H005
C4H004
rel. pt.
HAR5
HAR1
ALLEMANSKRAAL
ERFENIS
C4R001
5.0
1.5
0.0
100
50
0
% time <
C4H004
10.0
1.5
0.0
100
50
0
% time <
C4R002
5.0
1.5
0.0
100
50
0
% time <
Sand-Vet Overall System: 1988/10-1992/9 (SAR - mg/l)

Figure 9.17



Mean annual runoff
km
0
5
10
Dam 93 to SRC
Sand River Canal
Rietspruit
Sand River
Convent Dam stream
Doringspruit
Boelulsspruit
Theronspruit
MAR (MCM)
0
50
100
Sand River - detailed system 1988/10-1992/9 (SAR mg/l)

Figure 9.18

9.2.7 Chloride (Cl)

The target chloride limit of 105 mg/l for irrigation is to satisfy the requirements of the most sensitive crops that are known to be spray irrigated. The limit for the natural environment of 400 mg/l has been used for river reaches where there is no irrigation use.

(a) Background chloride levels

Fig. 9.19 shows that the recorded background chloride levels in both Allemanskraal Dam and Erfenis Dam are only a fraction of the target limit. Hence the background chloride levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

Figs. 9.19 and 9.20 show that with the sole exception of station HAR1 (which is located just upstream of the OFS Goldfields area), the chloride guideline was exceeded throughout the lower Sand River and the lower Vet River.

The most severe exceedence occurred at station HAR5, downstream of the Sand River Canal. At this point the 400 mg/l limit for the natural environment was exceeded for 49% of the time, with peak chloride concentrations as high as 1773 mg/l. At this point even the much less stringent target guideline limit for livestock watering of 1500 mg/l was exceeded for 2% of the time.

Dilution with water released from the canals and catchment runoff improved the situation at station C4H004, although the chloride target at this station was still exceeded for 14% of the time and a peak concentration as high as 380 mg/l occurred.

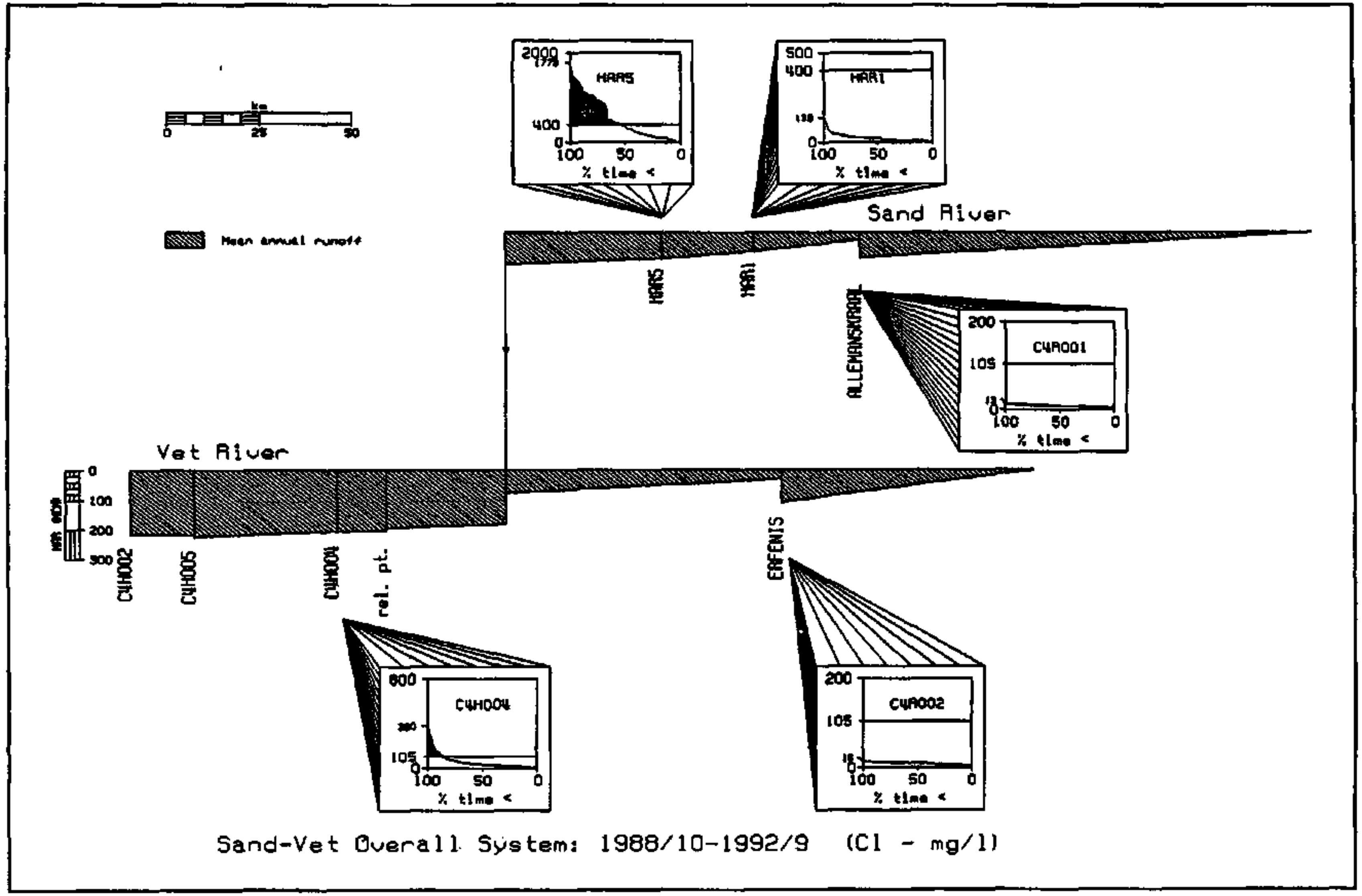
(c) Sand River Canal

The target chloride limit for the natural environment of 400 mg/l was exceeded for 96% of the time at station DWA5 in the Sand River Canal. For most of the time the chloride concentrations were five times this limit. The 1500 mg/l chloride target for livestock watering was exceeded for 93% of the time, with the peak concentration reaching 2900 mg/l.

(d) Doring River and Theronspruit

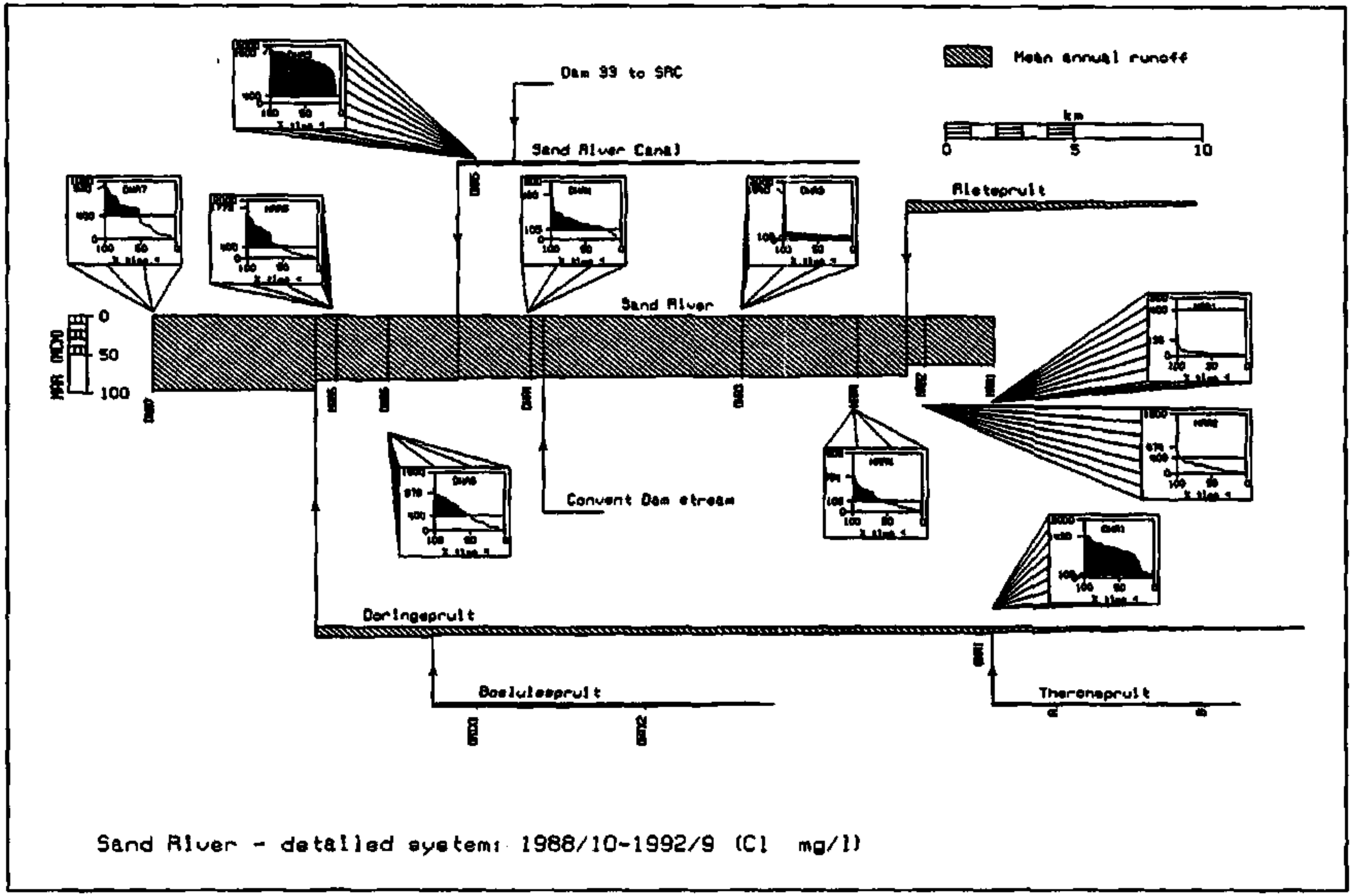
The chloride target guideline limit for the natural environment of 400 mg/l was exceeded for 82% of the time at station DWA1 in the Doring River, however, that for livestock watering (1500 mg/l) was not exceeded.

The chloride target guideline limit for irrigation use was exceeded for 96% of the time at station DWA1 in the Doring River. This implies that the chloride levels further upstream in the Theronspruit are also unfit for irrigation use.



Mean annual runoff
Sand River
Vet River
HAR5
HAR1
ALLEMANSKRAAL
C4R001
C4H002
C4H005
C4H004
rel. pt.
ERFENIS
C4R002
% time <
Sand-Vet Overall System: 1988/10-1992/9 (Cl - mg/l)

Figure 9.19



Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Rietspruit
Sand River
MAR (MCM)
0
50
100
Convent Dam stream
Doringspruit
Bosluisspruit
Theronspruit
Sand River - detailed system: 1988/10-1992/9 (Cl mg/l)

Figure 9.20

9.2.8 Sulphate (SO_4)

In river reaches with domestic water use a target sulphate limit of 200 mg/l has been used. In all other river reaches a target guideline limit of 1000 mg/l has been used, which corresponds to the requirement for both livestock watering and the natural environment.

(a) Background sulphate levels

Fig. 9.21 shows that the recorded background sulphate levels in both Allemanskraal Dam and Erfenis Dam are more than an order of magnitude lower than the target limit. Hence the background sulphate levels are well suited for all categories of water use.

(b) Lower Sand and Vet Rivers

Figs. 9.21 and 9.22 show that the sulphate guideline for livestock watering and the natural environment was met at all points in the Sand River. Although the 1000 mg/l guideline limit for this river reach was not exceeded, at station HAR5, downstream of the Sand River Canal, peak sulphate concentrations as high as 654 mg/l were experienced. At this level emetic effects will occur in human users of the water. This again points to the need to warn the public not to drink water from this part of the Sand River.

Dilution with water released from the canals and catchment runoff improved the situation at station C4H004, with the sulphate limit being exceeded for only 3% of the time. This short duration exceedence by a relatively small margin is not likely to hold serious consequences for domestic users. However, it does indicate that some action may be required to prevent further deterioration in sulphate levels.

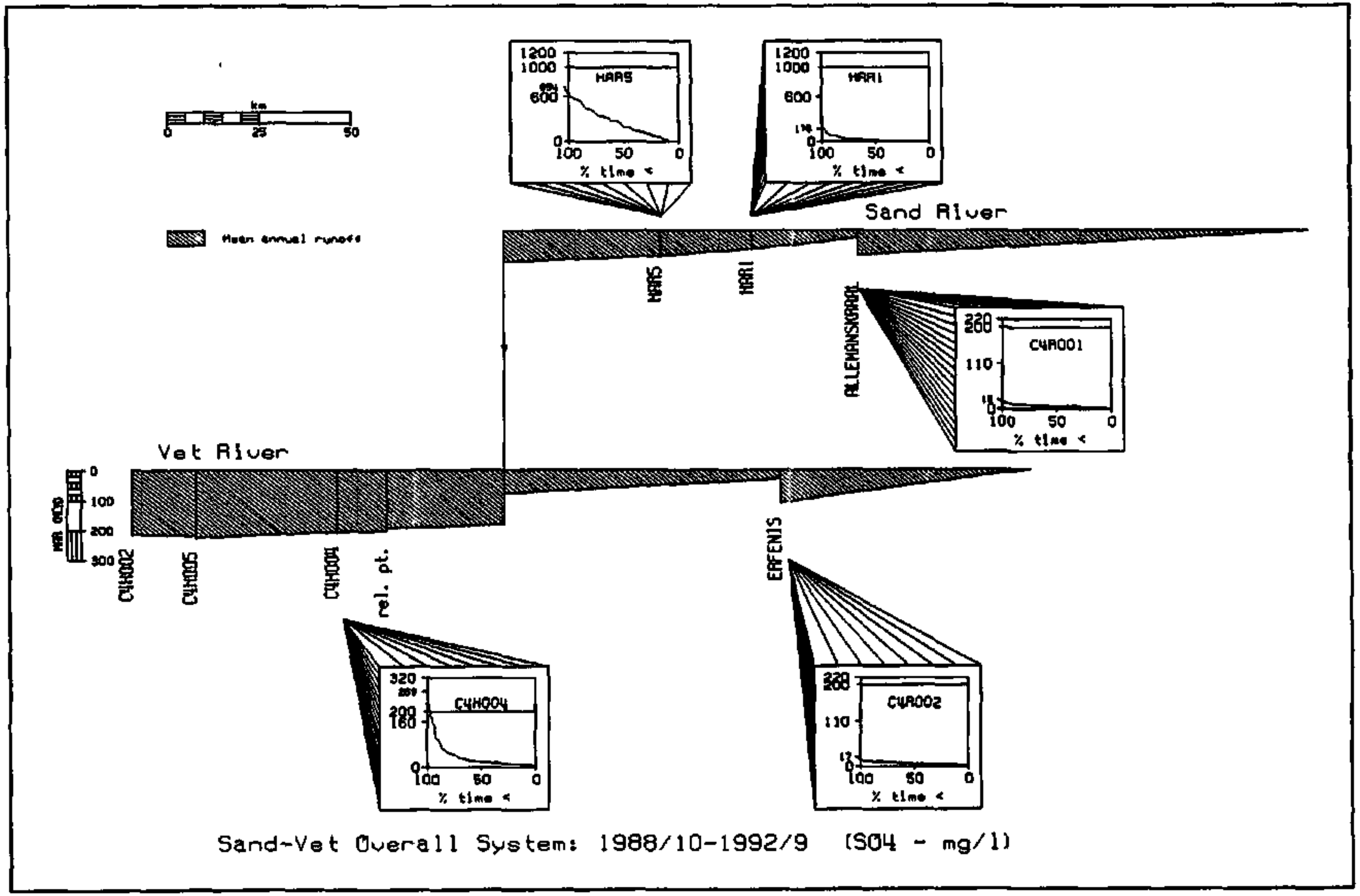
(c) Sand River Canal

The 1000 mg/l target sulphate limit was exceeded for 69% of the time at station DWA5 in the Sand River Canal, rendering the water unfit for livestock watering and environmental use. Although regular domestic use of this water is not known to take place, it is important to observe that the domestic use limit of 200 mg/l was exceeded for 92% of the time, often by more than a factor of five, thereby rendering the water totally unfit for human consumption. This adds further weight to the need to post public warnings against drinking this water.

(d) Doring River and Theronspruit

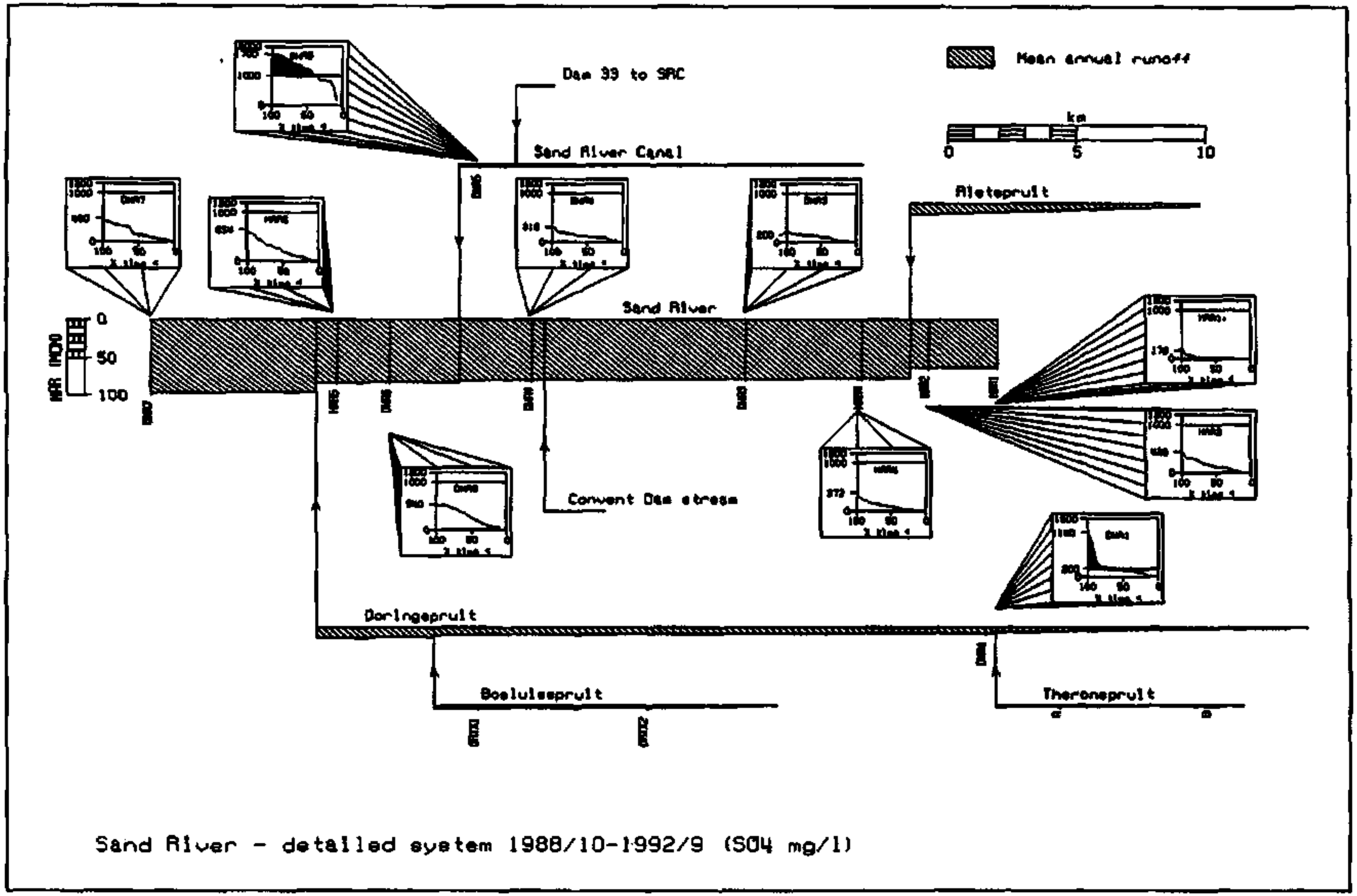
The target guideline limit for sulphate was exceeded for 5% of the time at station DWA1 in the Doring River. Since this short duration exeedence was by only a small margin it may not pose an immediate threat to livestock watering, but it does indicate the need to curtail sulphate pollution.

The 200 mg/l sulphate target limit for domestic use was exceeded for 40% of the time at station DWA1, with short duration peaks more than five times the limit. This implies that the Theronspruit may be unfit for domestic use.



km
0
25
50
Mean annual runoff
Sand River
Vet River
HAR5
HAR1
ALLEMANSKRAAL
ERFENIS
C4H002
C4H005
C4H004
rel. pt.
C4R001
C4R002
C4H004
1200
1000
600
0
100
50
% time <
220
200
110
320
160
MAR 0E6
100
200
300
Sand-Vet Overall System: 1988/10-1992/9 (SO4 - mg/l)

Figure 9.21



Dam 33 to SRC
Mean annual runoff
km
0
5
10
Sand River Canal
Rietspruit
Sand River
Convent Dam stream
Doringspruit
Bosluisspruit
Theronspruit
MAR (MM)
0
50
100
Sand River - detailed system 1988/10-1992/9 (SO4 mg/l)

Figure 9.22

9.2.9 Ammonia (NH_3)

The target limit for un-ionised ammonia of 0.025 mg/l (as N) is to satisfy the requirements for aquaculture. This limit has been adopted to protect the natural environment. The target limit for domestic use is 1 mg/l.

(a) Background ammonia levels

Fig. 9.23 shows that the recorded background ammonia levels in both Allemanskraal Dam and Erfenis Dam remained below the 0.025 mg/l target limit.

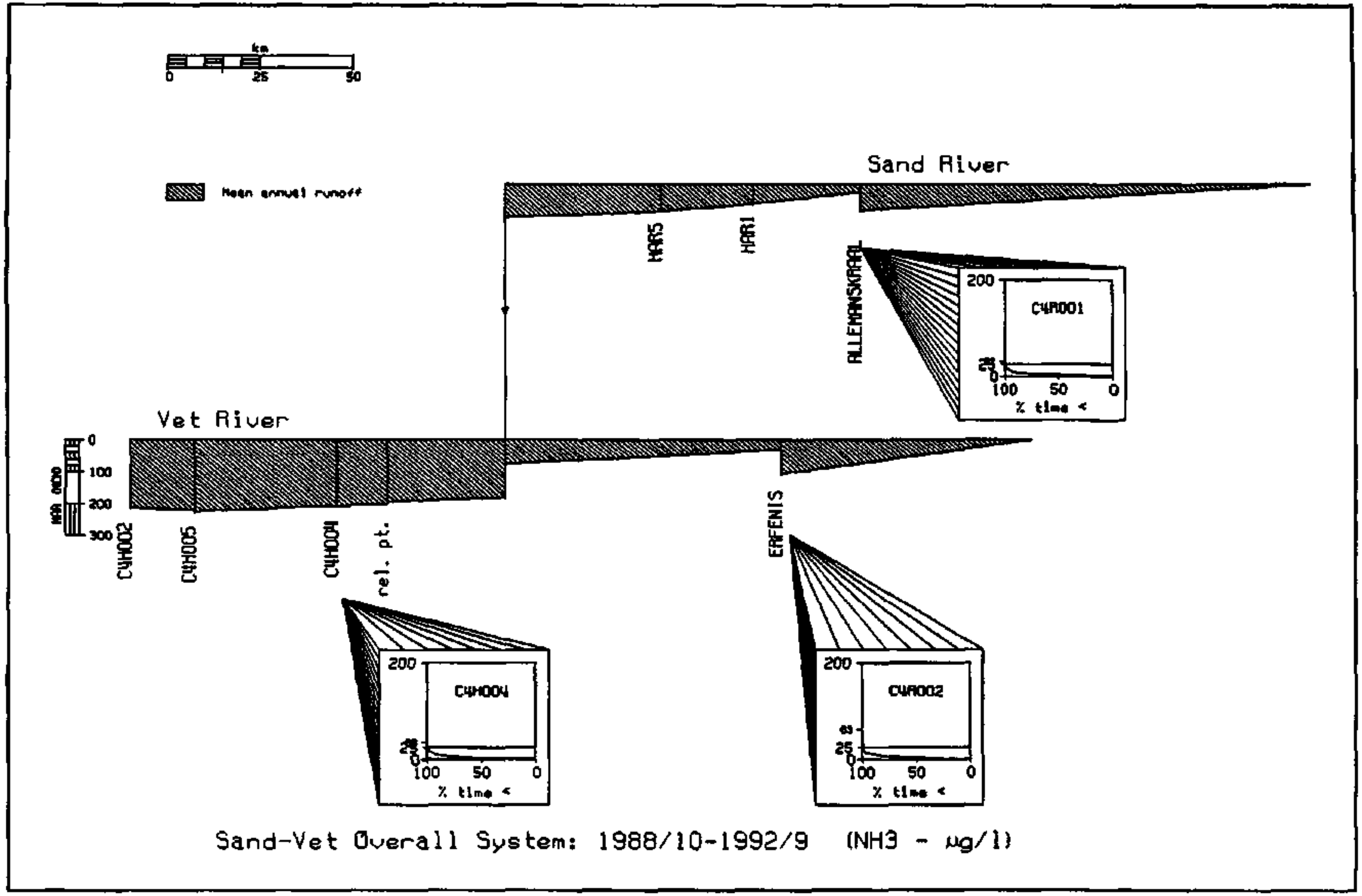
(b) Other stations

Figs. 9.23 and 9.24 show that the ammonia target limit was exceeded throughout the lower Sand and Vet Rivers. However, none of the observations exceeded the 1 mg/l limit for domestic use.

Short duration peaks of up to 0.37 mg/l in the Sand River at station DWA2 may be attributable to residues from fertilisers used by upstream irrigation farmers. Similar peaks at downstream stations DWA3 and DWA4 may also have resulted from irrigation sources upstream of station DWA2. However, since ammonia concentrations tend to decay in natural streams it is possible that local urban sources could also have contributed to the peak ammonia values observed in this reach of the Sand River. The washoff of faecal deposits from urban areas and informal settlements, and even the seepage or spillage of underground mine waste water containing residues from unused explosives, could all have added to the ammonia load.

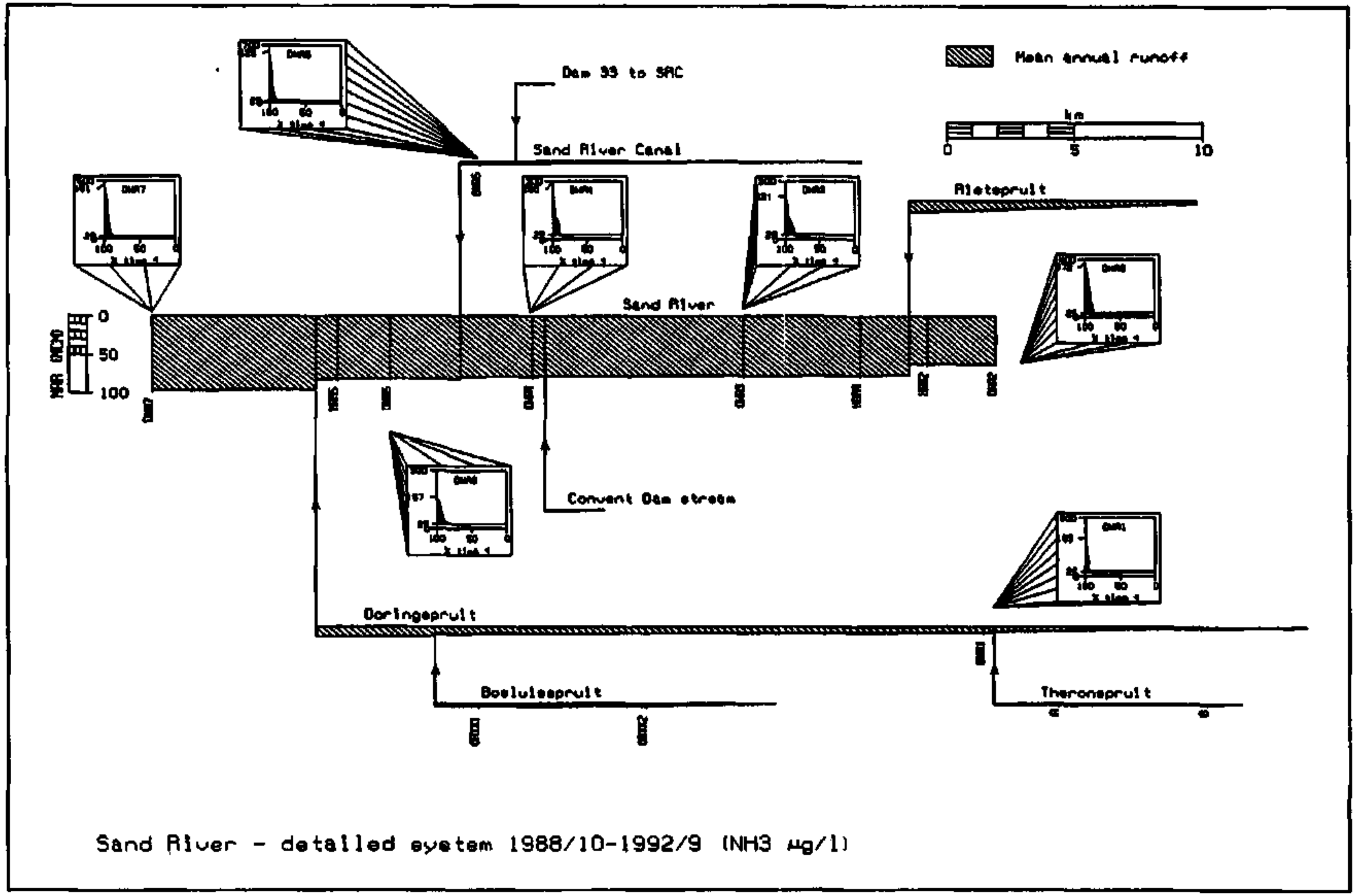
High ammonia levels in the Sand River Canal may be associated with urban runoff from the Thabong area.

At station C4H004 in the lower Vet River the ammonia concentrations only marginally exceeded the target guideline level.



km
0
25
50
Mean annual runoff
Sand River
HAR5
HAR1
ALLEMANSKRAAL
200
C4R001
25
0
100
50
0
% time <
Vet River
0
100
200
300
MAR 0000
C4H002
C4H005
C4H004
rel. pt.
ERFENIS
200
C4H004
25
0
100
50
0
% time <
200
C4R002
63
25
0
100
50
0
% time <
Sand-Vet Overall System: 1988/10-1992/9 (NH3 - µg/l)

Figure 9.23



Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Rietspruit
Sand River
Convent Dam stream
Doringspruit
Bosluisspruit
Theronspruit
MAR (MCM)
0
50
100
Sand River - detailed system 1988/10-1992/9 (NH3 µg/l)

Figure 9.24

9.2.10 Nitrate (NO_3)

The target nitrate limit for irrigation use is 5 mg/l (as N), while that for livestock watering is 10 mg/l. The domestic use limit for nitrate plus nitrite of 6 mg/l is superseded by the nitrate only limit of 5 mg/l for irrigation use, since irrigation use has been identified for all river reaches in which domestic use has been indicated.

(a) Background nitrate levels

Fig. 9.25 shows that the recorded background nitrate levels in both Allemanskraal Dam and Erfenis Dam are well within the target guideline limit.

(b) Lower Sand and Vet Rivers

Figs. 9.25 and 9.26 show that the nitrate target guidelines were satisfied at all points in the lower Sand River, with the exception of station DWA4, where the 5 mg/l limit for irrigation was marginally exceeded for only 4% of the time. The highest nitrate concentrations occurred at station DWA7, with peaks up to 9.5 mg/l. However, this was still below the 10 mg/l limit for livestock watering applicable to this portion of the river. The high nitrate levels at station DWA7 could be associated with inflows from Sand River Canal, the Doring River, or both.

Further downstream in the lower Vet River the nitrate concentrations remained well below the 5 mg/l target guideline limit for irrigation use.

(c) Sand River Canal

The target nitrate limit for livestock watering of 10 mg/l was exceeded for 7% of the time at station DWA5 in the Sand River Canal. The peak TDS level recorded at this station was as high as 42 mg/l, indicating the possibility of polluted urban runoff. Alternatively, residues from ammonium-nitrate explosives in mine service water could be a possible source.

(d) Doring River and Theronspruit

The nitrate target guideline limit of 10 mg/l for livestock watering was exceeded for 5% of the time at station DWA1 in the Doring River. This might be attributable to wasted ammonium-nitrate explosive residues finding their way into underground mine water. Agricultural sources may also have contributed to the high nitrate levels.

The target guideline limit for nitrate in domestic water was exceeded for 10% of the time at station DWA1. It is likely that this limit was also exceeded in the upstream Theronspruit.

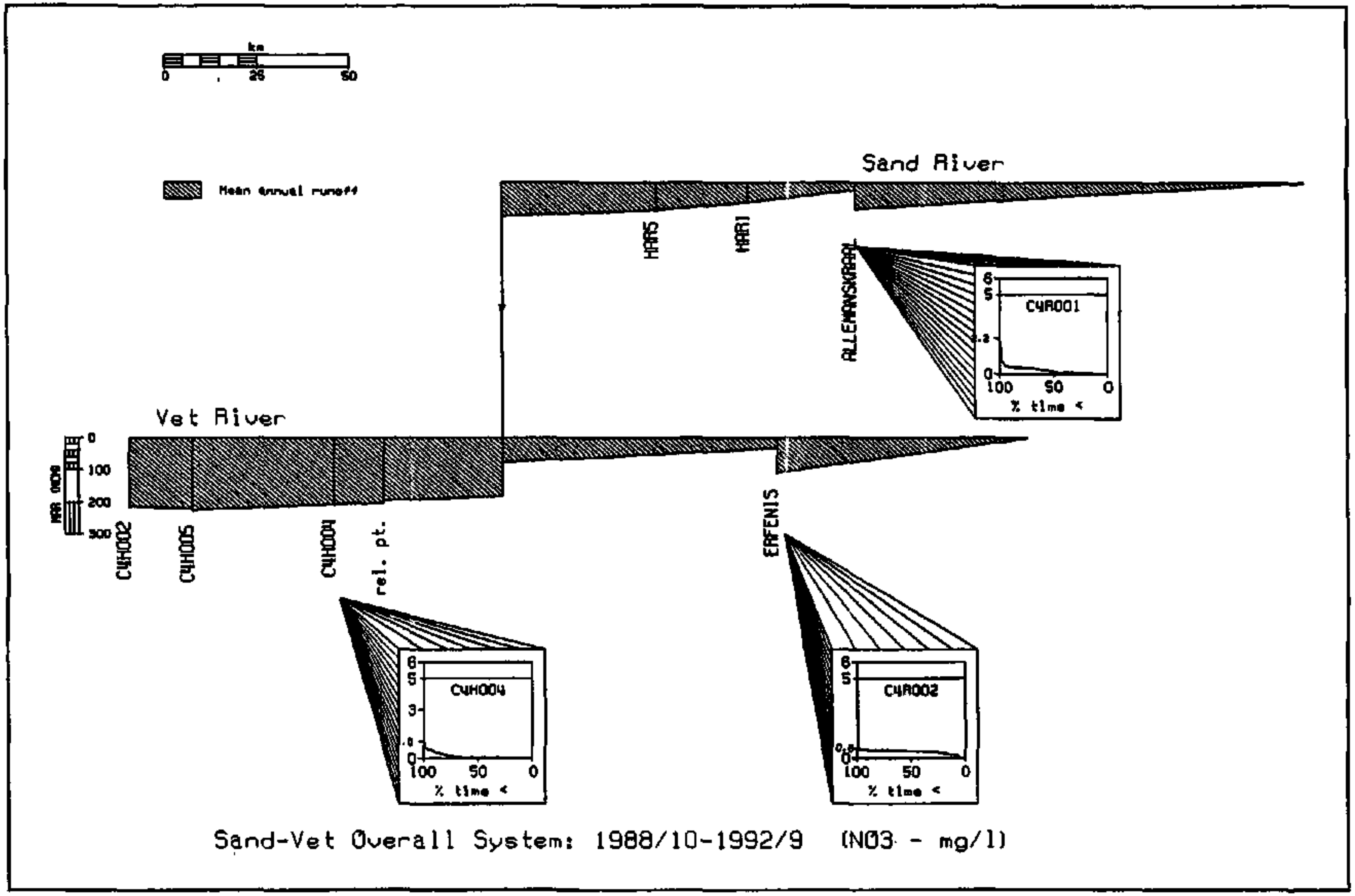
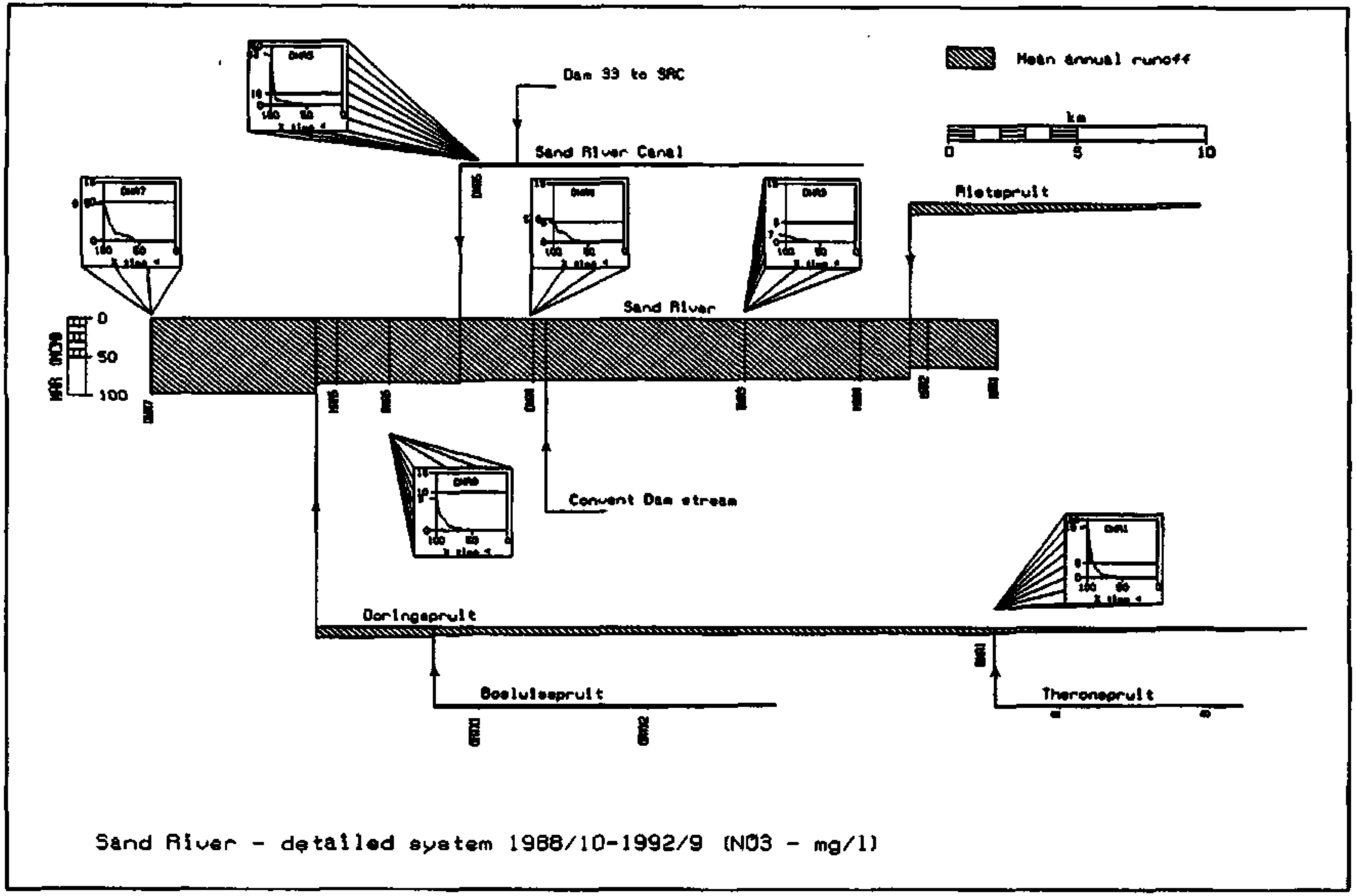

km
0
25
50
Mean annual runoff
Sand River
Vet River
MAR 0000
0
100
200
300
C4H002
C4H005
C4H004
rel. pt.
HAA5
HAA1
ALLEMANSKRAAL
ERFENIS
C4R001
C4H004
C4R002
% time <
Sand-Vet Overall System: 1988/10-1992/9 (NO3 - mg/l)

Figure 9.25



Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Rietspruit
Sand River
MAR (MCM)
0
50
100
Convent Dam stream
Doringspruit
Boesluisspruit
Theronspruit
Sand River - detailed system 1988/10-1992/9 (NO3 - mg/l)

Figure 9.26

9.2.11 Fluoride (F)

The fluoride target guideline limit for domestic use is 1 mg/l, while that for livestock watering and irrigation is 2 mg/l.

(a) Background fluoride levels

Fig. 9.27 shows that the recorded background fluoride levels in both Allemanskraal Dam and Erfenis Dam are well within the target guideline limit.

(b) Lower Vet River

Fig. 9.27 shows that the fluoride guideline for domestic use was met in the Vet River at station C4H004.

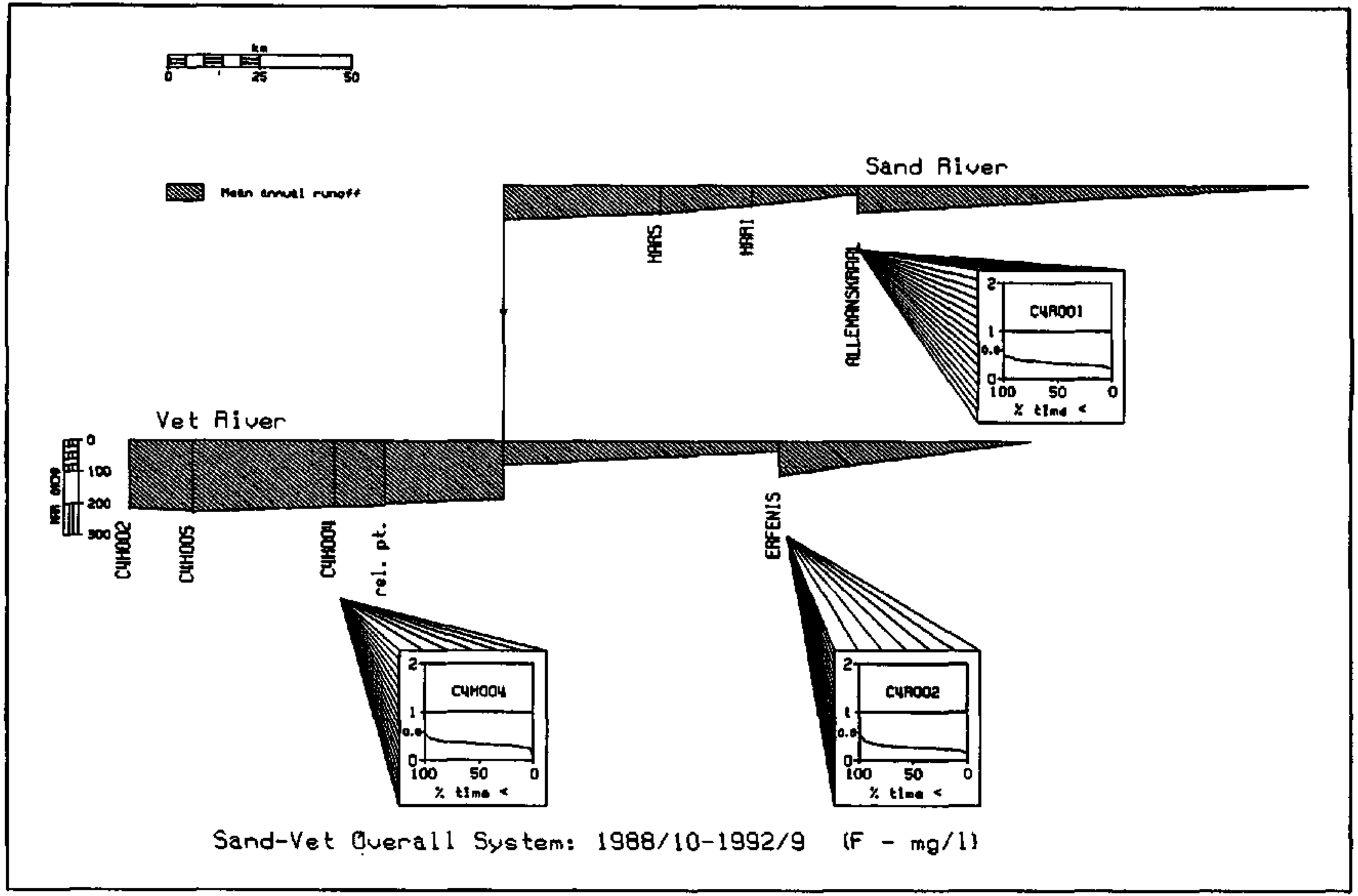

km
0
25
50
Mean annual runoff
Sand River
HAR5
HAR1
ALLEMANSKRAAL
C4R001
2
1
0.8
0
100
50
0
% time <
Vet River
0
100
200
300
C4H002
C4H005
C4H004
rel. pt.
ERFENIS
C4H004
C4R002
Sand-Vet Overall System: 1988/10-1992/9 (F - mg/l)

Figure 9.27

9.2.12 Phosphate (PO_4)

No firm phosphate guideline limit was derived, since this would require a detailed eutrophication study. Appendix D shows that at most points in the OFS Goldfields region the ideal limit of 0.1 mg/l (which should be sufficient to protect against eutrophication problems under most circumstances) was exceeded. This may not be too significant, since the Sand River is naturally turbid. However, even 1 mg/l was exceeded at a number of points. This points to the possibility of eutrophication problems in slow moving river reaches, such as the pool of Virginia weir.

9.2.13 pH

Appendix D shows that at nearly all stations the observed pH remained within the guideline range ($6 < pH < 9$) for domestic water use. The only exception was station C4R001 (Allemanskraal Dam) where the reported minimum pH value was as low as 4.4. However, this value is unlikely to be correct, since the upper Sand River is largely undeveloped. Moreover, the samples taken a fortnight before and a week after the low value of 4.42 on 4 October 1988 showed pH values of 6.97 and 7.11 respectively. Given that the dam storage at the time was high (following the February/March floods of 1988), it is hard to conceive of two events that could have reduced the pH of so large a body of water from 6.97 to only 4.42 within fourteen days and then restored it to 7.11 within a week.

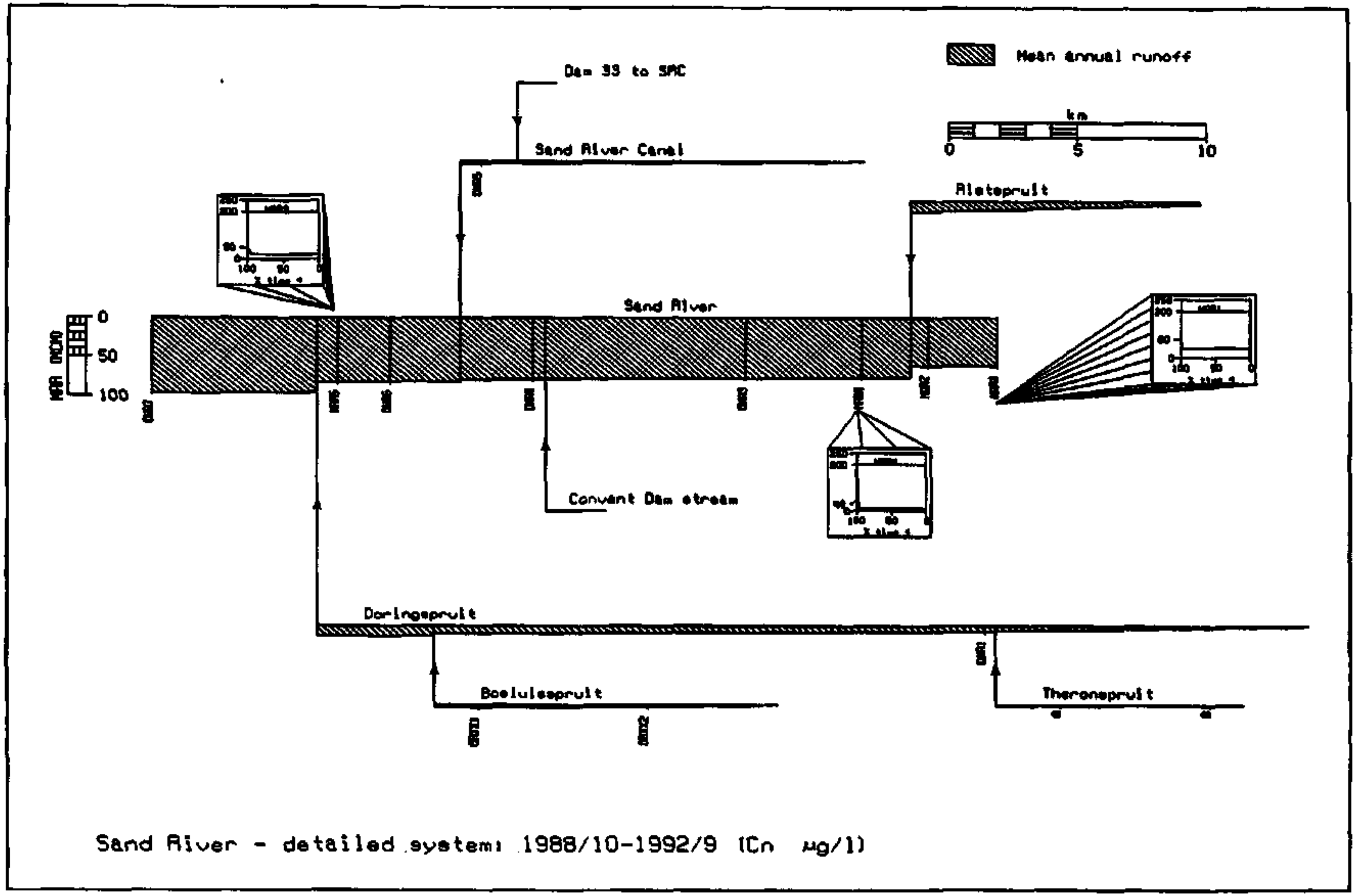
Aside from the anomalous (and probably incorrect) observation at Allemanskraal Dam on 4 October 1988, the pH appears to be acceptable for domestic use throughout the river system.

The pH target guideline range of 6.5 to 8.4 for irrigation use was marginally violated at the lower end at Erfenis Dam, where the lowest observed pH was 6.3. The upper end of the range was exceeded at a number of points for up to 21% of the time. The highest pH recorded at any point was 9. However, these exceedences are likely to have little effect on beneficial water use since the target pH range for irrigation is primarily to facilitate the mixing of pesticides. Since only a small volume of water is required for this purpose, it would be much more appropriate to pre-mix the pesticides with water that has been corrected for pH prior to mixing with the irrigation water.

9.2.14 Cyanide (CN)

The cyanide target guideline limit of 0.2 mg/l for domestic use was applied throughout the study area.

Fig. 9.28 shows that the recorded cyanide levels were well within the guideline limit.



Mean annual runoff
km
0
5
10
Dam 33 to SRC
Sand River Canal
Aletspruit
Sand River
MAR (HCM)
0
50
100
Convent Dam stream
Doringspruit
Boeluiespruit
Theronspruit
Sand River - detailed system: 1988/10-1992/9 (Cn µg/l)

Figure 9.28

9.3 Conclusions

9.3.1 Salinity trends

The only points in the system where any salinity trends were detected over the last two decades are in Harmony Mine's "Waste Dump Stream" and "Donga Dump Stream", west of Virginia, and in the Sand River immediately downstream of these two streams. In more recent years the salinity regime at these stations appears to have reached some sort of a plateau.

At all other stations there was no significant trend in EC or any of the major ions comprising the TDS. This is consistent with the predominance of older long-established gold mines in the OFS *Goldfields* region. However, as some of the new gold mines to the south of the Sand River come into full production, it is possible that further deterioration in water quality will occur.

9.3.2 Surface water quality status for salinity

The following conclusions have been drawn regarding the overall surface water quality status, with particular emphasis on the salinity status.

(a) Background surface water quality status

Based on the data for Allemanskraal Dam and Erfenis Dam, the background water quality is excellent and fully complies with the target guidelines for salinity related variables.

(b) Lower Sand and Vet Rivers

From excellent background salinity conditions in Allemanskraal Dam, the EC levels at in the Sand River at station HAR1 (DWA2), on the eastern fringe of the OFS Goldfields area, deteriorated significantly, but not sufficiently to exceed the guideline limit for livestock watering. The chloride and sulphate ions showed the largest increases at this station, however, the target guideline limits were not exceeded.

A sharp deterioration in the mineral water quality of the Sand River was observed at stations HAR2 and HAR3, in the vicinity of Harmony Mine's "Waste Dump Stream" and "Donga Dump Stream". The target guidelines for a number of salinity related variables were exceeded at these stations.

From station HAR1 all the way to Blaaudrift bridge (station DWA7), which is downstream of the western fringe of the OFS Goldfields region, the mineral water quality showed further deterioration, with the guideline target values often being exceeded by very wide margins and for large percentages of the time.

In some portions of the Sand River the deterioration is serious enough to present a very real acute health threat to potential rural or informal users who might use it for domestic purposes. The reach of the Sand River of most concern in this regard is between the Sand River Canal and Blaaudrift bridge (station DWA7). It is not known for how far downstream these dangerous salinity levels prevail, since DWA7 is the last water quality monitoring point before station C4H004 in the lower Vet River.

Dilution of the lower Vet River due to low TDS water released from the Sand-Vet GWS canals resulted in considerable improvement in the salinity status at station C4H004. However, although the salinity levels at this point no longer present a serious threat to public health, the target guideline levels for EC, chloride, sodium and the sodium absorption ratio (SAR) were all exceeded. In the case of EC the target guideline of 40 mS/m was exceeded for 40% of the time, with peaks reaching 163 mS/m. This could be detrimental to irrigation use in the lower Vet River. The observed exceedence of the target guideline limit for SAR in the lower Vet River are likely to necessitate the surface application of gypsum to prevent surface crusting when rainfall occurs on irrigated lands, since the soils in this area are particularly susceptible to sodicity problems.

(c) Rietspruit

There are no water quality monitoring stations in the Rietspruit. However, the moderate improvement in the mineral water quality between stations HAR3 and HAR4 suggests that the Rietspruit is contributing little to the pollution of the Sand River. However, given the very poor water quality in the Sand River, this does not preclude the possibility of local salinisation problems in the Rietspruit.

(d) Sand River Canal

Aside from calcium and magnesium, all of the salinity-related water quality target guidelines were exceeded in the Sand River Canal by extremely wide margins (usually several-fold) for most of the time. This water is totally unacceptable for domestic, irrigation, livestock watering or the natural environment. It also presents a serious potential acute health threat, even for casual short term ingestion.

While the canal itself was built as a stormwater drain, and as such is not intended for public use, portions of the canal follow a natural water course. A farmer's dam is also situated in the highly polluted stream into which the canal discharges. The possibility of this water being accidentally used for purposes for which it is totally unfit therefore cannot be precluded.

(e) Doring River and Theronspruit

As with the Sand River Canal, several of the mineral water quality guideline limits were exceeded for high durations and by wide margins. The EC level above which chronic health problems can be expected was exceeded for 68% of the time and the acute health threat limit was exceeded for nearly 10% of the time at station DWA1 in the Doring River downstream of the Theronspruit confluence. By implication the salinity levels in the Theronspruit are likely to be as bad, if not worse. From the scant information available, the Bosluisspruit also appears to be salinised.

Hence the Doring River is not only unsuitable for irrigation, *it could also* *present serious problems for domestic water use by local riparian farmers and their labourers.*

9.3.3 Surface water quality status for other water quality variables

Aside from salinity-related variables, which form part of the brief of the study, the water quality status for a few other water quality variables that came to hand were also dealt with. These are discussed below:

(a) Ammonia

In the case of ammonia (which is not a salinity related variable), the target guideline for aquaculture (used to represent the natural environment) was exceeded to some extent at all points in the system. In the cases of Allemanskraal Dam, Erfenis Dam and the lower Vet River only isolated events exceeded the guideline limits for short durations. More frequent and severe exceedences occurred in the Sand River and its tributaries in the vicinity of the OFS Goldfields area, indicating the possibility of faecal or other biological pollution. However, the 1 mg/l limit for domestic use was not exceeded at any monitoring stations.

(b) Nitrate

The target water quality guidelines for nitrates were generally met at all points in the Sand and Vet Rivers, with the exception of a short duration marginal exceedence at one point (station DWA4).

The target nitrate limit was exceeded for 7% and 5% of the time in the Sand River Canal and in the Doring River respectively. This could indicate the possibility of polluted urban runoff (in the case of the canal) or the seepage or spillage of mine service water containing residues from wasted ammonium-nitrate explosives.

(c) Fluoride

The recorded fluoride levels in Allemanskraal Dam, Erfenis Dam and in the lower Vet River at station C4H004 are all well within the target guideline limit.

(d) Phosphate

No firm phosphate guideline limit was derived, since this would require a detailed eutrophication study. However, exceedence of 1 mg/l at a number of points indicates the possibility of eutrophication problems in slow moving river reaches.

(e) pH

The observed pH at all surface water monitoring stations appears to be within acceptable limits for domestic water use. Despite not always being ideal for irrigation use, pH does not appear to present any serious problems in the study area.

(f) Cyanide

The recorded cyanide levels for those stations examined appear to be within the guideline limit.

9.4 Recommendations

The following recommendations arise from the results of this chapter:

9.4.1 Evaluation of water quality status in other river reaches

The surface water quality status needs to be analyzed for river reaches for which data is not yet available. These include the Rietspruit, Theronspruit, Bosluisspruit, Mahemspruit and various pans receiving polluted water. Regular sampling at these sites should be commenced to facilitate such an analysis.

9.4.2 Water quality guidelines

More site specific water quality guidelines need to be developed for the following water uses:

(a) Natural environment: In this regard the Hydrological Research Institute has been requested to carry out an evaluation of the specific needs for the study area.

(b) Agricultural use: The target water quality guidelines adopted are appropriate for the types of crops and livestock watering known to take place in the Sand-Vet catchment. However, better knowledge of the crops and soil types irrigated along the lower Vet River is required to better interpret the guideline limit for the SAR.

9.4.3 Ameliorative measures

(a) A comprehensive catchment water quality management plan is urgently required to address the extremely high salinity levels present in a number of river reaches.

(b) As an interim measure pubic warnings should be posted against drinking water from the worst affected river reaches. In this regard the Sand River Canal, the Sand River downstream of this canal and the Doring River and its tributary the Theronspruit give particular cause for concern.

CHAPTER 10

CONCLUSIONS

TABLE OF CONTENTS FOR CHAPTER 10

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10 CONCLUSIONS

10.1 Introduction

The conclusions given in this chapter are a summary of those given in chapters 2 to 9. The following sections have been numbered accordingly (i.e., section 10.2 deals with Chapter 2, and so on).

10.2 Water use

10.2.1 Water supply

(a) The suppliers of water are the Sand-Vet GWS, which draws water from Allemanskraal and Erfenis Dams, and Goldfields Water, which draws most of its raw water from the Vaal River. A number of towns abstract water from local water sources.

(b) Most of the water use from the Sand-Vet GWS is for irrigation use, part of which is supplied direct from the canals and part from the lower Vet River. It is only the latter part that could be affected by pollution emanating from the OFS Goldfields area.

(c) Of the towns supplied from the Sand-Vet river system, only Hoopstad, adjacent to the lower Vet River, is likely to be affected by pollution sources in the OFS Goldfields region.

(d) The main crops irrigated from the Sand-Vet system are wheat, maize, fodder crops, potatoes, other vegetables, ground-nuts and sunflower.

(e) Several contradictions and deficiencies were found in the water use data for the Sand-Vet GWS. The most serious of these is the apparent large *under estimation* of the actual irrigation supply from the canals.

10.2.2 Effluent discharge

(a) Most of the purified sewage effluent arising in the study area is re-used by local mines and to irrigate parks, gardens and sports fields.

(b) In the past most of the remainder is disposed of in natural pans by Welkom municipality (Witpan and Flamingopan).

(c) At present only Joel, Beatrix and Oryx mines, which discharge small quantities of treated sewage effluent to tributaries of the Doring River, and Welkom's new Thabong STW, which will discharge to the Sand River Canal, make significant direct contributions to the runoff from the OFS Goldfields study area.

10.2.3 Water balances

(a) The water balance for the main water users in the OFS Goldfields region is very complex, with water being transferred between several mines, municipalities and storage facilities. Unfortunately the water balance data provided by the different organisations (especially mines) is often contradictory. The water balances for individual pans and evaporation ponds are generally deficient.

10.3 Provisional water quality guidelines

10.3.1 Water quality variables

Since gold mining is the most dominant pollution source, the main emphasis was placed on salinity-related water quality variables (i.e. TDS and its main inorganic constituents). Although biological contaminants fall outside the terms of reference for the study, they have been included in the provisional water quality guidelines.

10.3.2 Water use categories

(a) Provisional target water quality guidelines have been derived taking account of the following water uses: domestic, agricultural, recreational, industrial and the natural environment. Of these, the guidelines for industrial use were irrelevant since no industrial use is made of water resources affected by the pollution sources in the OFS Goldfields region.

(b) In most cases the target guidelines were derived from the DWA&F S.A. Water Quality Guidelines (DWA&F, 1993), in conjunction with an evaluation of the identified water uses. In the case of nature conservation the guideline manual is still awaited. As an interim measure the target guidelines for aquaculture were used to approximate the needs of the natural environment.

(c) Domestic users likely to be affected include the town of Hoopstad, riparian farmers along the lower Vet River and farmers and (possibly) informal settlements located within OFS Goldfields region itself.

10.3.3 Water quality guidelines for specific river reaches

The provisional target water quality guidelines for different river reaches in the lower Sand and Vet catchment and the OFS Goldfields area are summarised in Table 3.10. These were derived for different water quality variables by adopting the target guidelines for those categories of water use in each river reach having the most stringent target guideline ranges.

10.4 Pollution sources

10.4.1 Ground-water pollution

Pollution sources in the OFS Goldfields region have led to salinisation of the ground-water over a large area.

10.4.2 Surface water pollution

A number of natural rivers and streams, pans and wetlands in the region have suffered severe salinisation. These include:

- Rivers: Sand River, Mahemspruit, Doring River, Theronspruit, Bosluisspruit, probably the Rietspruit and possibly the Merriespruit (the water quality data is too sparse to make definite statements about the latter two streams).

- Pans: Dankbaar, Riet, Wolwe, Stuurmans, Doring, Blesbok, Toronto, Flamingo, Wit, Swart.

10.4.3 Nature of pollution

The most dominant ions present in the polluted river water are chloride, sodium and sulphate, in that order.

10.4.4 Salinisation of Sand River

In the case of the Sand River the median EC increases seven fold, from 30 mS/m to 216 mS/m across the mining area. Median chloride concentrations increase 20-fold, from 18 to 390 mg/l.

10.4.5 Main pollution source

Gold mining in the OFS Goldfields area is the main cause of the salinisation of the ground-water, pans and rivers.

10.4.6 Mining pollution

The most likely mining causes of the salinisation of the surface water, and in particular the Sand River and its tributaries, include:

- President Brand and President Steyn mines discharge to the Sand River Canal, and hence to the Sand River.

- Harmony Mine (Virginia Section) to Sand River east of Virginia.

- Harmony Mine (Harmony Section) and/or President Brand and President Steyn mines to Sand River in vicinity of De Kroon.

- Harmony Mine (Harmony Section) in vicinity of Harmony to Rietspruit.

- Harmony Mine (Merriespruit Section) in vicinity of Convent Dam to Sand River.

- Beatrix Mine to Theronspruit and Doring River.

- Oryx Mine to Bosluisspruit.

- General diffuse seepage over a wide area.

In addition the Western Holdings and Freestate Geduld mines affect the Mahemspruit, which discharges to an area with internal drainage that does not appear to have any outlet to any major surface water drainage system. St. Helena Gold Mine discharges to the Wolwepan/Rietpan system, which also does not have any obvious outlet. However, the presence of an ancient palaeodrainage system might hold the potential for eventual seepage towards the Sand River. The mines located further to the north fall outside the Sand/Vet River catchment.

In all of these instances the main mode of entry of the contaminated water to the river system is via seepage. Intermittent spillage events also occur from time to time.

Water is also disposed of in a number of natural pans and wetland systems.

10.4.7 Industrial pollution

The wetland system near Blesbokpan was seriously polluted by yeast effluent from the NCP factory. However, this factory has recently closed.

10.4.8 Municipal pollution

Other than that disposed of in Witpan, there is little sewage effluent that is not re-used within the OFS Goldfields area. Witpan suffers occasional pollution episodes due to contaminated stormwater.

10.4.9 Effect of irrigation

Irrigation from the Sand-Vet GWS appears to add little to the salinisation of the river system. On the contrary, it plays an important beneficial role in diluting the pollution in the lower Sand and Vet rivers.

10.4.10 Solid waste sites

Municipal solid waste sites do not appear to be significantly affecting surface water quality. Ground-water contamination also seems to be confined to areas close to the sites.

10.4.11 Nutrients

Nitrate, ammonia and phosphate concentrations in the Sand River are elevated throughout the area affected by mining and urbanisation. This holds the potential for eutrophication in slow moving portions of the river, such as in the pool backed up by Virginia weir. It is difficult to identify any one source of the nutrients, since they can originate from municipal, industrial and agricultural activities, all of which are closely inter-twined in the study area.

10.5 Assessment of monitoring systems

The catchment monitoring system was found to be deficient in a number of respects:

10.5.1 Insufficient coverage of catchment

Portions of the catchment, such as the Rietspruit and the Bosluisspruit are not regularly monitored.

10.5.2 Lack of flow gauging

There is a total lack of flow gauging at all water quality sampling points in the most polluted portion of the catchment (i.e. the OFS Goldfields area).

10.5.3 Lack of water balance monitoring

A lack of storage state, inflow and outflow data for most polluted water storage facilities makes it almost impossible to evaluate either the overall water balance for the mining area or the balances for individual facilities.

10.5.4 Sampling frequencies

At most regular monitoring stations within the study area, the monthly sampling frequency is inadequate for estimating pollution loads or even for detecting pollution events.

10.5.5 Choice of water quality variables

In some instances important water quality variables (such as sodium) are not measured in surface water courses.

10.5.6 Site identification

In many instances the identification of monitoring sites was ambiguous or inconsistent. This was particularly so for many of the mines sampling points.

10.5.7 Consistency of water quality data

(a) External consistency problems: Large discrepancies were sometimes found between observed water quality data collected by different organisations at the same (or nearby) points (eg. station DWA2/HAR1). Since the sampling frequency is so low, it could not be ascertained if these discrepancies arose from data errors or changes in flow regime between sampling dates.

(b) Internal consistency problems: The mines data in particular showed large internal inconsistencies. For example, contradictions between EC and TDS values resulting in impossible TDS/EC ratios of 20 or more were common (almost the rule, rather than the exception). Large imbalances between anions and cations were also common. This implies poor laboratory control. Failure to detect these inconsistencies also implies that the data collected by the mines is not being used effectively (or that any such use is only superficial).

10.5.8 Data access and processing

(a) The long delays (up to half a year) in obtaining data from various organisations implies that the data is not being stored efficiently.

(b) Very little data appears to be computerised.

10.5.9 Co-ordination of monitoring programs

Duplication of effort at various monitoring points and no sampling at all in other areas indicates a lack of co-ordination between the different monitoring programmes. Part of the problem appears to have arisen because the mines' data has not been made available to the DWA&F OFS Regional Office.

10.6 Naturalisation of steamflow

10.6.1 Natural conditions

The natural MAR of the Vet River catchment (at gauge C4H004) is estimated to be 404 x $10^6 m^3$ (based on 1920 to 1991 hydrology). This is about 10% of the MAR of the entire Vaal River catchment.

10.6.2 Present day conditions

Under present-day (1992) conditions the MAR of the catchment has decreased to about 271 x $10^6 m^3$. The difference in MAR is accounted for as follows:

Naturalised MAR ($10^6 m^3$)	404
- Abstractions from Allemanskraal Dam	38
- Evaporation from Allemanskraal Dam	17
- Abstractions from Erfenis Dam	46
- Evaporation from Erfenis Dam	25
- Sand-Vet GWS irrigation from Vet River	4
- Private irrigation (plus evap. from minor dams)	22
+ Discharges from Allemanskraal (Sand) canal	2
+ Discharges from Erfenis (Vet) canal	9
+ Return flows from Sand-Vet GWS	8
Net MAR (1992 conditions)	271

10.7 Hydro-salinity model calibration

10.7.1 Allemanskraal Dam and Erfenis Dam catchments

The model calibration results for Allemanskraal Dam and Erfenis Dam are satisfactory.

10.7.2 Sand River in OFS Goldfields area

Although far from ideal, the calibration results for the Sand River between Allemanskraal and Blaaudrift bridge are good enough to provide a reasonable first order representation of the system.

10.7.3 Lower Vet River

The fit between modelled and observed results at station C4H004 in the lower Vet River is poor. The poor fit between modelled and observed data at C4H004 is attributable to the following factors:

(a) For the entire region from Allemanskraal Dam and Erfenis Dam to C4H004 there was no streamflow data to calibrate against. This made calibration particularly difficult in the SVA sub-system, when the balance between normal river flow and seepage flow has a profound effect on water quality.

(b) Data received from the mines was scarce and often inaccurate and/or incomplete. Only Harmony Mine provided a reasonable monitoring system. Regarding return flows to river systems, conflicting estimates were received from different sources.

(c) Some parameters are extremely difficult to estimate, particularly actual irrigation areas (for which there do not appear to be any records), return flows, river losses etc. Data from the Sand-Vet Regional Office was generally incomplete and a reasonable water balance could not be determined from their data (refer to Chapter 2).

(d) The accuracy of TDS concentrations were in doubt. In some instances there were large discrepancies between the water quality data collected by different organisations (see Chapter 3).

(e) The water quality sampling frequency (generally monthly) is too low to arrive at a reliable estimate of the average TDS during the monthly time step at which the model operates. The observed values that the model was calibrated against are therefore not necessarily a true reflection of the monthly averages.

(f) The important role played by irrigation return flows in diluting the polluted runoff from the Sand River could not be modelled accurately due to lack of information regarding irrigation water use and return flows.

10.7.4 Overall evaluation of salinity modelling

Despite the above limitations, the model calibration for the two dams and the Sand River to Blaaudrift bridge gives a reasonable first order fit.

10.8 Estimation of TDS loads

10.8.1 OFS Goldfields TDS load contribution

(a) During the last fifteen years pollution sources in the OFS Goldfields region are estimated to have added about 16 000 t p.a. to the TDS washoff from the Vet River catchment. This represents an increase in the Vet River catchment TDS export of about 35%.

(b) During wet years the contribution of the OFS Goldfields region is significantly higher. For example, during the 1987/88 and 1988/89 hydrological years the pollution sources added 59 000 t (+40%) and 55 000 t (+68%) respectively.

10.8.2 Net TDS export to Lower Vaal System

(a) During dry weather there appears to be a net retention of salt in the Vet River system. Under these conditions there should be little runoff entering Bloemhof Dam and consequently little effect on downstream water quality.

(b) The retention of salt in irrigated lands appears to have reduced the mean annual net TDS export from the Vet River to the Vaal River system by about 13 800 t p.a. This had the effect of reducing the increase in the mean annual net TDS export (relative to virgin conditions) to only about 2200 t (compared to a total average annual TDS input to Bloemhof Dam of the order of 600 000 t).

(c) During wet conditions the increase in the net TDS export from the Vet River (relative to natural conditions) is estimated to have increased the TDS load entering Bloemhof Dam by up to about 9%.

10.8.3 Impact on downstream water users

The impact of increased TDS load export from the Vet River on users in the Lower Vaal System is dependent on the relative monthly runoff and TDS inputs to Bloemhof Dam from the Vet and Vaal Rivers. Modelling of the Vaal River System would be required to assess these impacts.

10.8.4 Data deficiencies

Pollutant loads could not be estimated anywhere within the most polluted portion of the catchment (or even immediately downstream of it) due to a total absence of flow gauging stations and the low water quality sampling frequency.

10.9 Evaluation of salinity status

10.9.1 Salinity trends

The only points in the system where any salinity trends were detected over the last two decades are in Harmony Mine's "Waste Dump Stream" and "Donga Dump Stream", west of Virginia, and in the Sand River immediately downstream of these two streams. In more recent years the salinity regime at these stations appears to have reached some sort of a plateau.

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Aside from salinity-related variables, which form part of the brief of the study, the water quality status for a few other water quality variables that came to hand were also dealt with. These are discussed below:

(a) Ammonia

In the case of ammonia (which is not a salinity related variable), the target guideline for aquaculture (used to represent the natural environment) was exceeded to some extent at all points in the system. In the cases of Allemanskraal Dam, Erfenis Dam and the lower Vet River only isolated events exceeded the guideline limits for short durations. More frequent and severe exceedences occurred in the Sand River and its tributaries in the vicinity of the OFS Goldfields area, indicating the possibility of faecal or other biological pollution. However, the 1 mg/l limit for domestic use was not exceeded at any monitoring stations.

(b) Nitrate

The target water quality guidelines for nitrates were generally met at all points in the Sand and Vet Rivers, with the exception of a short duration marginal exceedence at one point (station DWA4).

The target nitrate limit was exceeded for 7% and 5% of the time in the Sand River Canal and in the Doring River respectively. This could indicate the possibility of polluted urban runoff (in the case of the canal) or the seepage or spillage of mine service water containing residues from wasted ammonium-nitrate explosives.

(c) Fluoride

The recorded fluoride levels in Allemanskraal Dam, Erfenis Dam and in the lower Vet River at station C4H004 are all well within the target guideline limit.

(d) Phosphate

No firm phosphate guideline limit was derived, since this would require a detailed eutrophication study. However, exceedence of 1 mg/l at a number of points indicates the possibility of eutrophication problems in slow moving river reaches.

(e) pH

The observed pH at all surface water monitoring stations appears to be within acceptable limits for domestic water use. Despite not always being ideal for irrigation use, pH does not appear to present any serious problems in the study area.

(f) Cyanide

The recorded cyanide levels for those stations examined appear to be within the guideline limit.

CHAPTER 11

RECOMMENDATIONS

TABLE OF CONTENTS FOR CHAPTER 11

11. RECOMMENDATIONS

11.1 Introduction

The recommendations given in this chapter are based on the findings of chapters 2 to 9. The following sections have been numbered accordingly (i.e., section 11.2 deals with recommendations stemming from the results of Chapter 2, and so on).

11.2 *Overview of water use*

11.2.1 Sand-Vet GWS water use data

The establishment of a more accurate and efficient system of irrigation records is recommended to overcome the deficiencies in the data regarding water use, crop distribution and irrigated areas.

11.2.2 Mines water use data

It is considered essential that the data reporting and checking procedures used by the mines be improved. More efficient data storage and retrieval systems, both in the mining houses and at the OFS Regional Office are recommended.

11.2.3 Water balance

(a) Improved record keeping to enable water balances to be made of polluted water storage facilities are required. Regular monitoring of the storage state in every storage facility and the total inflows and outflows is required.

(b) This points to the need to revise the exemption requirements to ensure that complete water balance information is obtained. This should be done not only for the mines in the study area, but for all exemptions issued by the DWA&F.

11.3 Water quality guidelines

11.3.1 Irrigation water use

An investigation to determine the specific water quality needs for irrigation farming in the lower Vet River is recommended. This investigation should focus on the riparian irrigation supplied from the Vet River and should take account of the crops grown, irrigation practices employed and the soils that are being irrigated.

11.3.2 Requirements for nature conservation

A study is recommended to determine the water quality requirements for nature conservation. This investigation should consider the Sand River from Virginia to the Sand-Vet confluence, the lower Vet River, the Doring River and its tributaries (the Theronspruit and the Bosluisspruit) and the natural pans that are used to dispose of mining and municipal waste water.

11.3.3 Other water quality variables

Detailed evaluation of water quality variables other than those directly related to salinity was beyond the terms of reference of the study. Therefore an investigation is recommended to identify any problematic radionuclides, pesticides, heavy metals and other trace elements.

11.3.4 Revision of target water quality guideline ranges

(a) Where appropriate, the provisional water quality target guideline ranges given in Table 3.10 should be revised to take account of the findings of the investigations recommended in sections 11.3.1 and 11.3.3 above.

(b) When the catchment Water Quality Management Plan is developed it may be necessary to tighten the guidelines for some river reaches to accommodate the more stringent requirements of downstream river reaches.

11.4 Pollution sources

The widespread pollution of the OFS Goldfields region points to the need for more detailed studies to:

(a) identify individual pollution sources responsible for the pollution of different river reaches,

(b) quantify the pollutant loads from each source,

(c) determine the water and salt balances for individual polluted water storage facilities and entire systems of such facilities,

(d) identify water quality management options (both for ameliorating water quality in affected river reaches and curtailing pollution at source),

(e) evaluate the practical and economic viability of the most promising options,

(f) implement the best management options,

(g) design and implement effective management information systems to evaluate the performance of the management plan,

and

(h) dynamically revise the management plan as more information regarding pollution sources and the performance of the options in place becomes available.

11.5 Assessment of monitoring systems

The following recommendations are aimed at improving the catchment monitoring system:

11.5.1 Design of water quality monitoring system

The overall monitoring system needs to be re-designed to meet the information needs of water quality managers. The following factors should be taken into account when re-designing the monitoring system:

(a) Adequate coverage of catchment, especially with regard to pollution sources and determining the lengths of river reaches that are being affected by pollution (eg. how far downstream from Blaaudrift bridge is the Sand River severely salinised?)

(b) Flow gauging: Flow gauging structures are urgently required at key points in the OFS Goldfields area. Sites where there is an obvious need for flow gauging include: (i) Sand River at Blaaudrift, (ii) Sand River Canal, (iii) Doring River, (iv) Sand River upstream of Virginia, (v) Riet River, (vi) "Waste Dump Stream" and/or "Donga Dump Stream", (vii) releases from holding dams, and (viii) pipelines conveying water to and from polluted water storage facilities.

(c) Sampling frequencies: These should be adequate to (i) identify pollution incidents and (ii) quantify pollutant loads.

(d) Choice of water quality variables: All of the most important water quality variables identified in this report, and in other sources should be sampled at appropriate frequencies. In the case of EC, continuous automatic monitoring is required at all points where TDS loads have to be estimated (i.e. at potential pollution sources and at key river stations.)

(e) All monitoring sites should be clearly identified and documented, including sampling frequencies and procedures.

(f) Checking procedures: Procedures should be set in place to routinely check the incoming data for both internal and external consistency.

(g) Data access and processing: Procedures should be established for entering duly checked data into a computerised data base. This data base should incorporate checking procedures and procedures for reporting data exceptions and providing other routine water quality management information. The emphasis should be on adding value to the data to make it useful for identifying problem areas and assessing the success or otherwise of the water quality management plan. Feed-back to data collectors and outside organisations providing data is essential.

(h) Co-ordination: The water quality data gathering efforts of all of the organisations running monitoring programmes should be co-ordinated to ensure minimal duplication of effort and maximum coverage of the most important points in the system. Where appropriate, laboratory methods and reporting formats should be standardised. The data collected should be centralised in a common computerised data base, preferably to be run by the DWA&F OFS Regional Office.

11.6 Naturalisation of steamflow

The naturalisation of the streamflow data should be re-evaluated once more complete data regarding irrigation use becomes available.

11.7 Hydro-salinity model calibration

11.7.1 Monitoring

A new flow and water quality monitoring system for the OFS Goldfields needs to be designed to meet the needs for salinity modelling (see section 11.5 above).

(a) In particular, continuous flow gauging and high frequency (i.e. continuous) EC and monitoring is required in the Sand River at Blaaudrift bridge, the Sand River Canal near the point of discharge to Sand River, the Doring River. Similar installations could be considered in the Rietspruit and in the Sand River at the railway bridge upstream of Virginia. Regular (preferably weekly) analyses for the main ionic species comprising the TDS are also required at these sites.

(b) In view of the sharp rise in TDS concentrations the Sand River downstream of Harmony Mine's Merriespruit Section it is desirable to install an automatic EC data logger in this part of the Sand River. Flow gauging at this site may not be feasible at this site. The need for high frequency EC monitoring at other intermediate sites in the Sand River may also have to be considered to detect seepage from other areas.

(c) A limited period (say one year) of low frequency (monthly) reconnaissance sampling of the Sand River at a few points between Blaaudrift bridge and the Sand-Vet confluence is recommended to determine the distance downstream that the zone of severely salinised water extends. Similar sampling in the Vet River upstream of the Sand-Vet confluence is recommended to determine the characteristics of irrigation return flows. A few samples should also be taken in the lower Vet River upstream and downstream of the first irrigation canal discharge point to quantify the beneficial effect of the released water on downstream water quality.

(d) More detailed investigations are required to determine the monitoring requirements for individual polluted water disposal sites.

(e) Regular monitoring of ground-water quality at and adjacent to mine water disposal sites is required.

(f) More reliable data regarding the quantity of purified sewage effluent discharged to rivers by mines is required.

11.7.2 Daily modelling

A more detailed study using a daily time step model is required to make better use of the existing data to quantify pollution inputs.

11.7.3 Investigation of salt balance of irrigated lands

The apparent retention of salts in irrigated lands along the lower Sand and Vet Rivers was found to have a significant effect on the export of TDS from the Vet River catchment to the Lower Vaal River System. This points to the need for an investigation of the salt balance of the Sand-Vet GWS. The irrigation sub-model component of the hydro-salinity model may have to be improved to accommodate the findings of the investigation.

11.8 Estimation of TDS loads

11.8.1 Flow and water quality data

(a) There is an urgent need for more intensive flow and water quality monitoring in the study area. The greatest need for such monitoring is within the OFS Goldfields area bounded by station HAR1 in the east and station DWA7 in the west. Such an intensive monitoring system, should be designed and implemented without delay.

(b) The discharge table (DT) for station C4H004 needs to be extended to facilitate load estimation during floods. (The extension of the DT based on the slope-area method proved to be unreliable as it resulted in a huge over-estimation of the catchment MAR. Therefore the extended DT could not be used in the analyses.)

11.8.2 Load estimation

(a) The data for station C4H004 should be analyzed at a daily time step to arrive at a firmer estimate of the TDS load export from the Vet River.

(b) Pollutant loads from problem catchment areas should be quantified to facilitate the development of a water quality management plan for the study area.

11.8.3 Impact on downstream river system

An evaluation of the impact of increased TDS export from the Vet River on Bloemhof Dam and the downstream Vaal River system is recommended. This will have to be done using water quality modelling techniques.

11.8.4 Development water quality data patching package

The procedures and software used to patch the daily water quality record at station C4H004 contain a number of insights and innovations that could be used beneficially in other water quality situation analyses and many other types of application. However, in their present form the methodology and computer programs cannot easily be applied by new users. The development of a user-friendly expert system for selecting patching methods and accessing the appropriate software would provide a valuable tool for researchers and other water quality practitioners.

11.9 Evaluation of salinity status

11.9.1 Evaluation of water quality status in other river reaches

The surface water quality status needs to be analyzed for river reaches for which data is not yet available. These include the Rietspruit, Theronspruit, Bosluisspruit, Mahemspruit and various pans receiving polluted water. Regular sampling at these sites should be commenced to facilitate such an analysis.

11.9.2 Water quality guidelines

More site specific water quality guidelines need to be developed for the following water uses:

(a) Natural environment: In this regard the Hydrological Research Institute has been requested to carry out an evaluation of the specific needs for the study area.

(b) Agricultural use: The target water quality guidelines adopted are appropriate for the types of crops and livestock watering known to take place in the Sand-Vet catchment. However, better knowledge of the crops and soil types irrigated along the lower Vet River is required to better interpret the guideline limit for the SAR.

11.9.3 Ameliorative measures

(a) A comprehensive catchment water quality management plan is urgently required to address the extremely high salinity levels present in a number of river reaches.

(b) As an interim measure pubic warnings should be posted against drinking water from the worst affected river reaches. In this regard the Sand River Canal, the Sand River downstream of this canal and the Doring River and its tributary the Theronspruit give particular cause for concern.

11.10 Formulation of catchment water management plan

There is an urgent need to prepare a comprehensive water management plan to address the salinisation problems experienced in the OFS Goldfields region and the downstream portions of the Sand-Vet River system.

APPENDIX A

MAPS

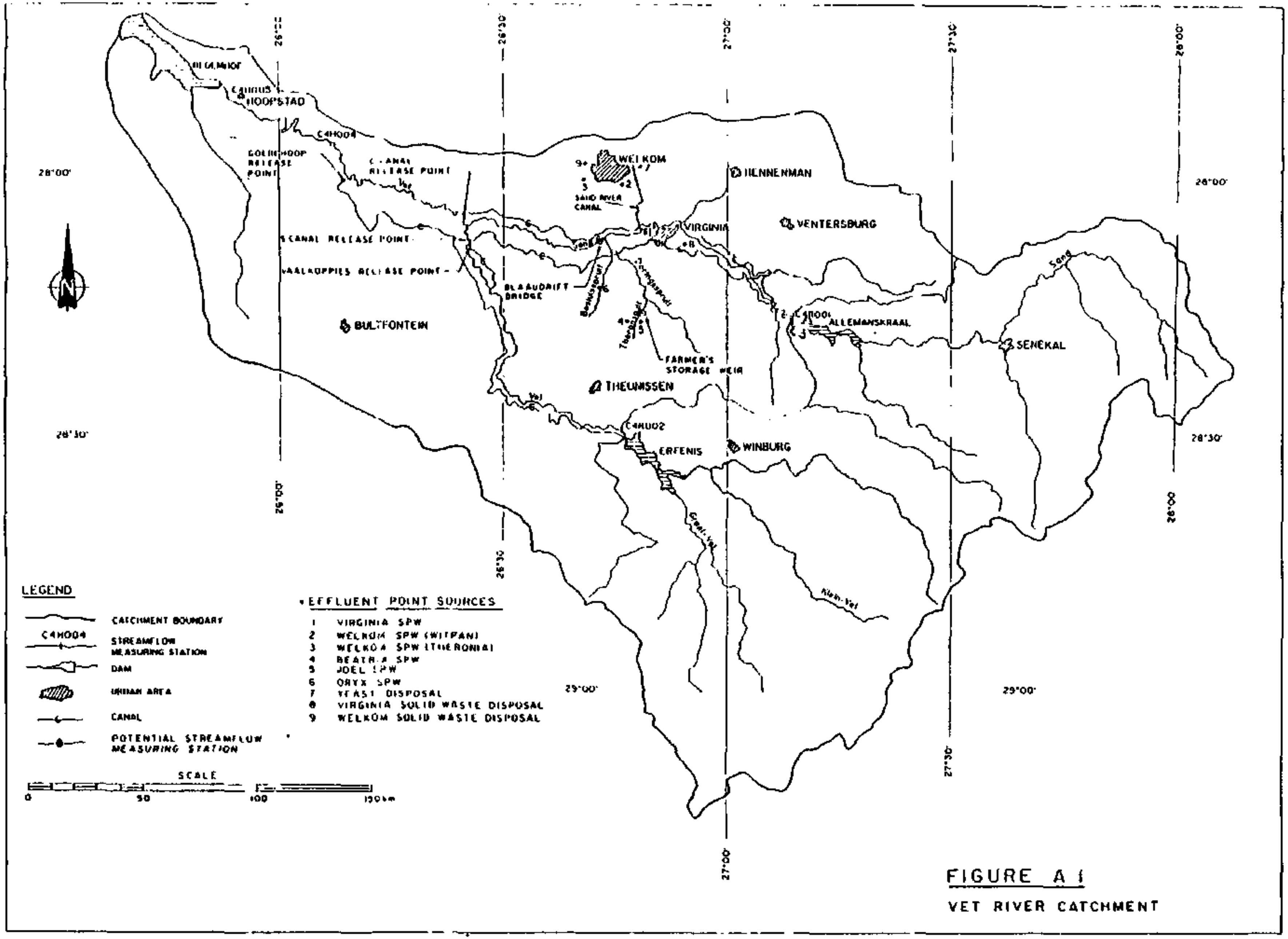


FIGURE A 1

VET RIVER CATCHMENT

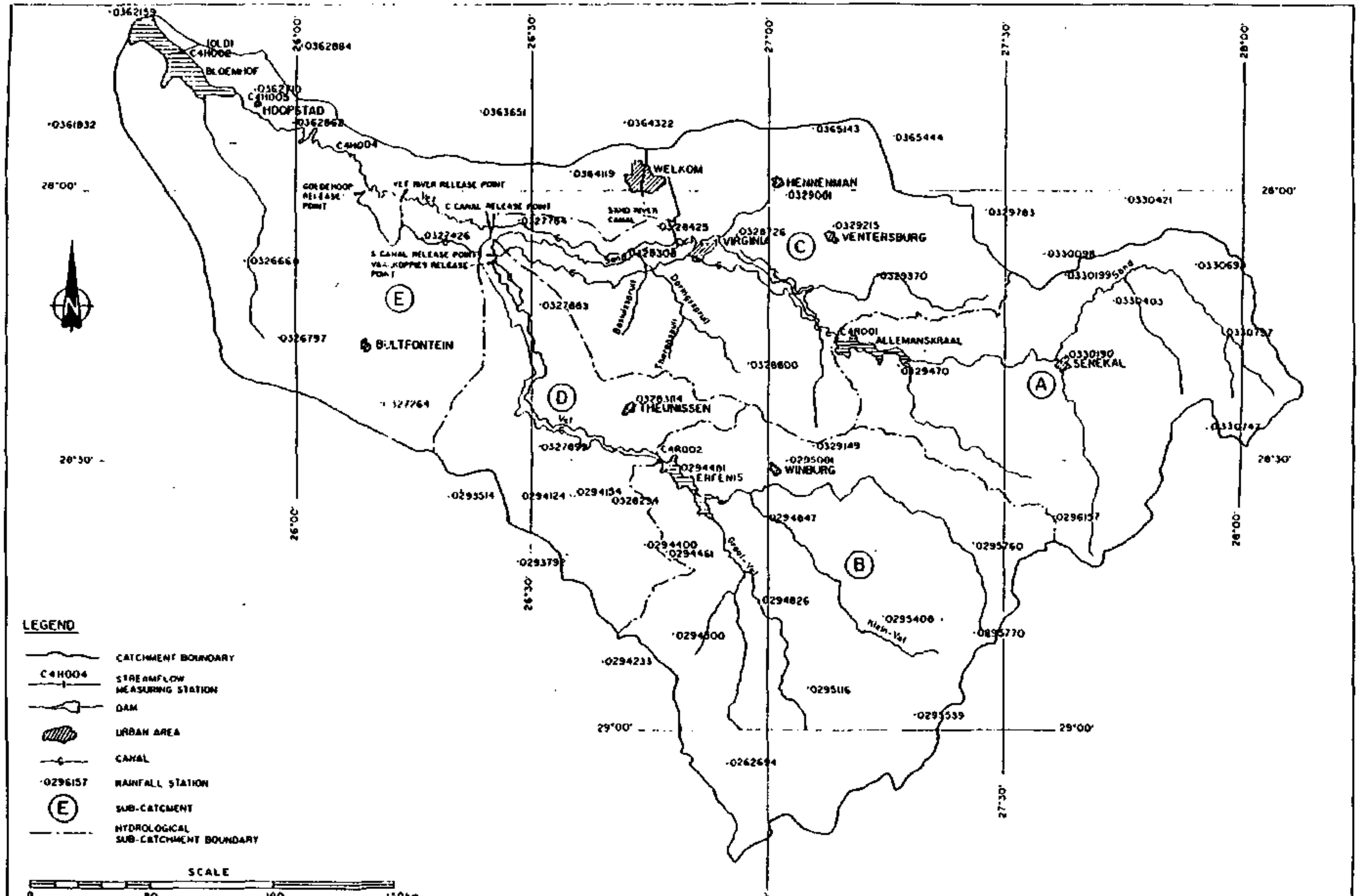
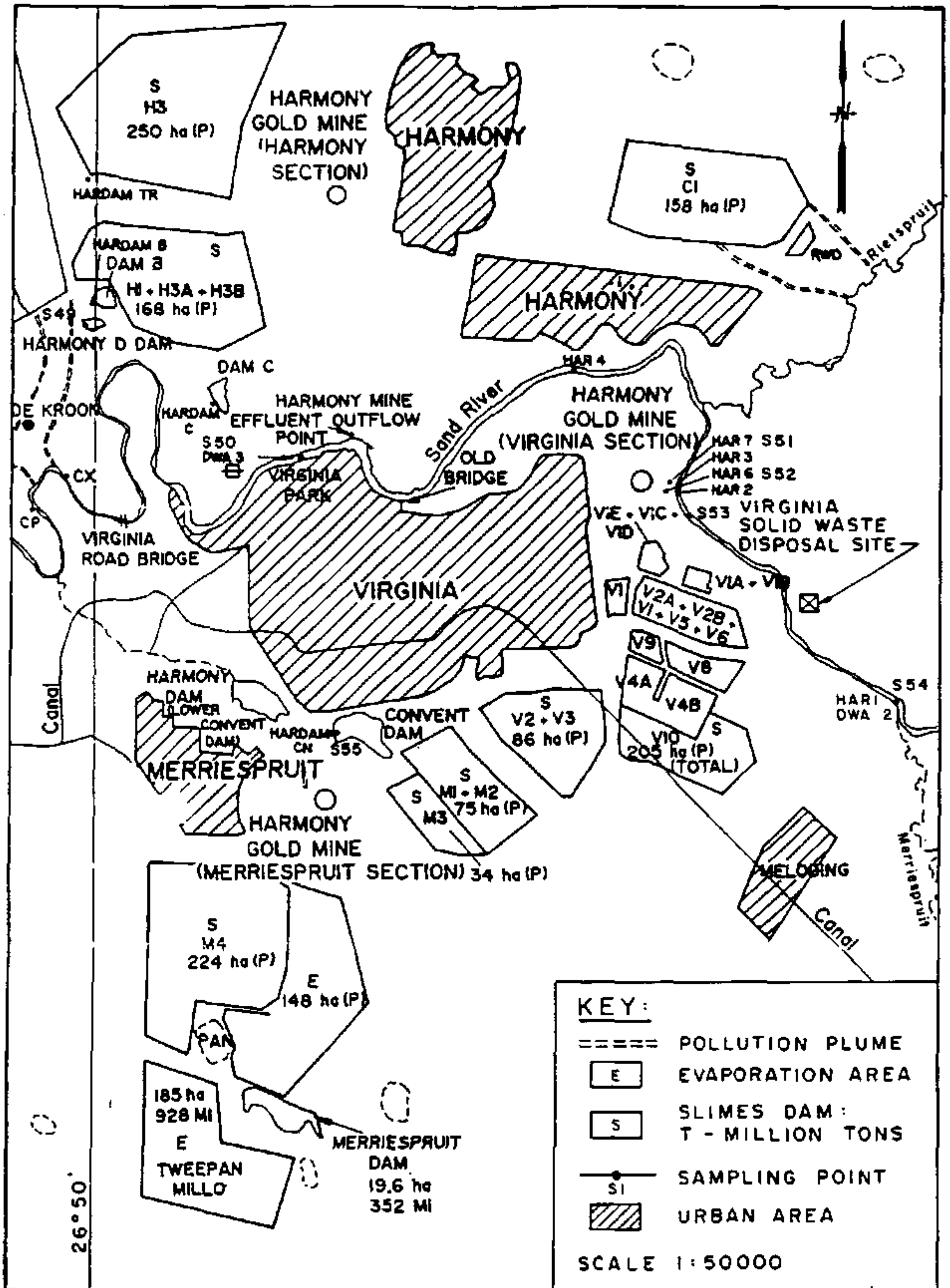


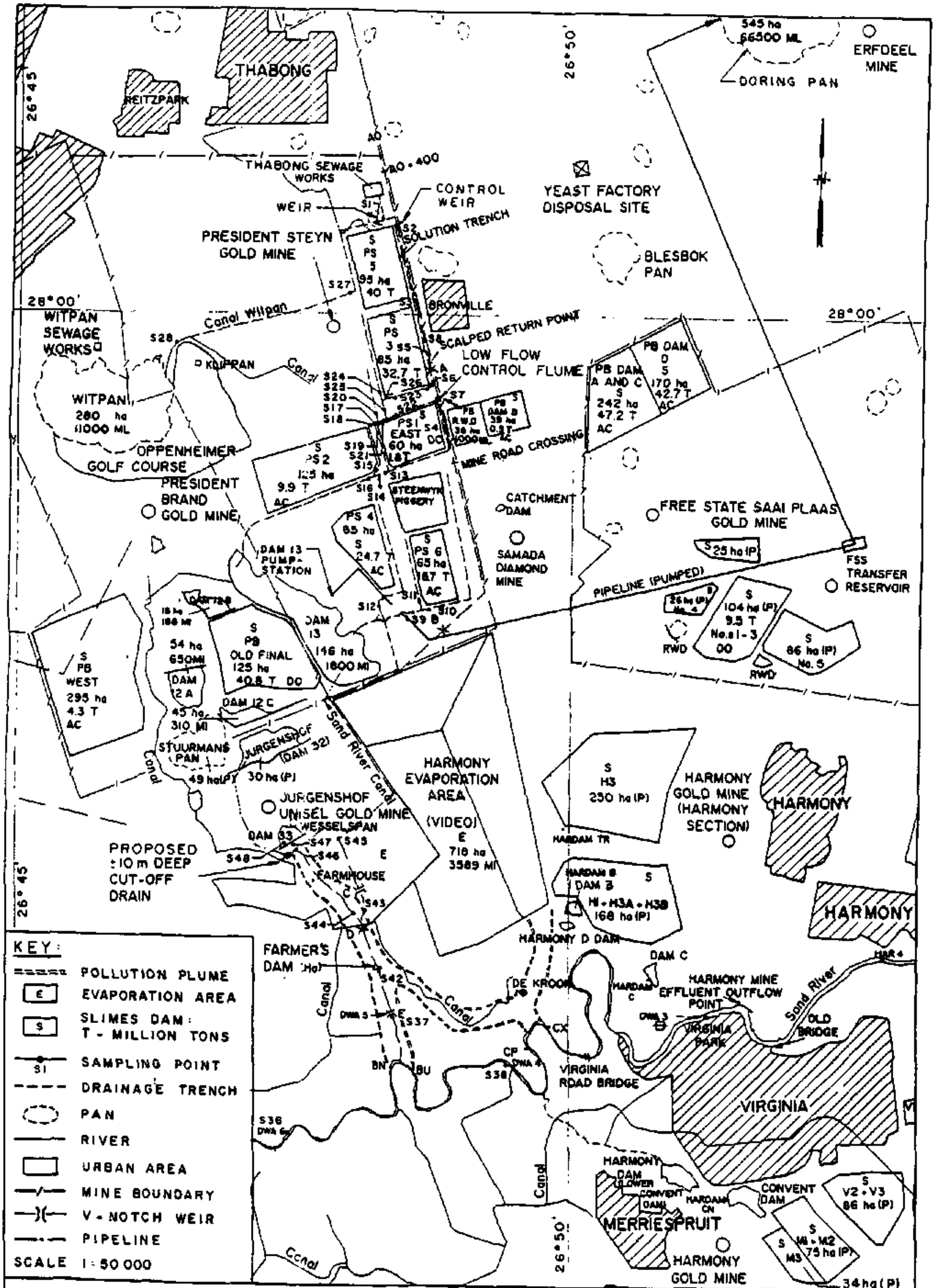
FIGURE A.2

RAINFALL STATIONS AND CATCHMENT DETAILS



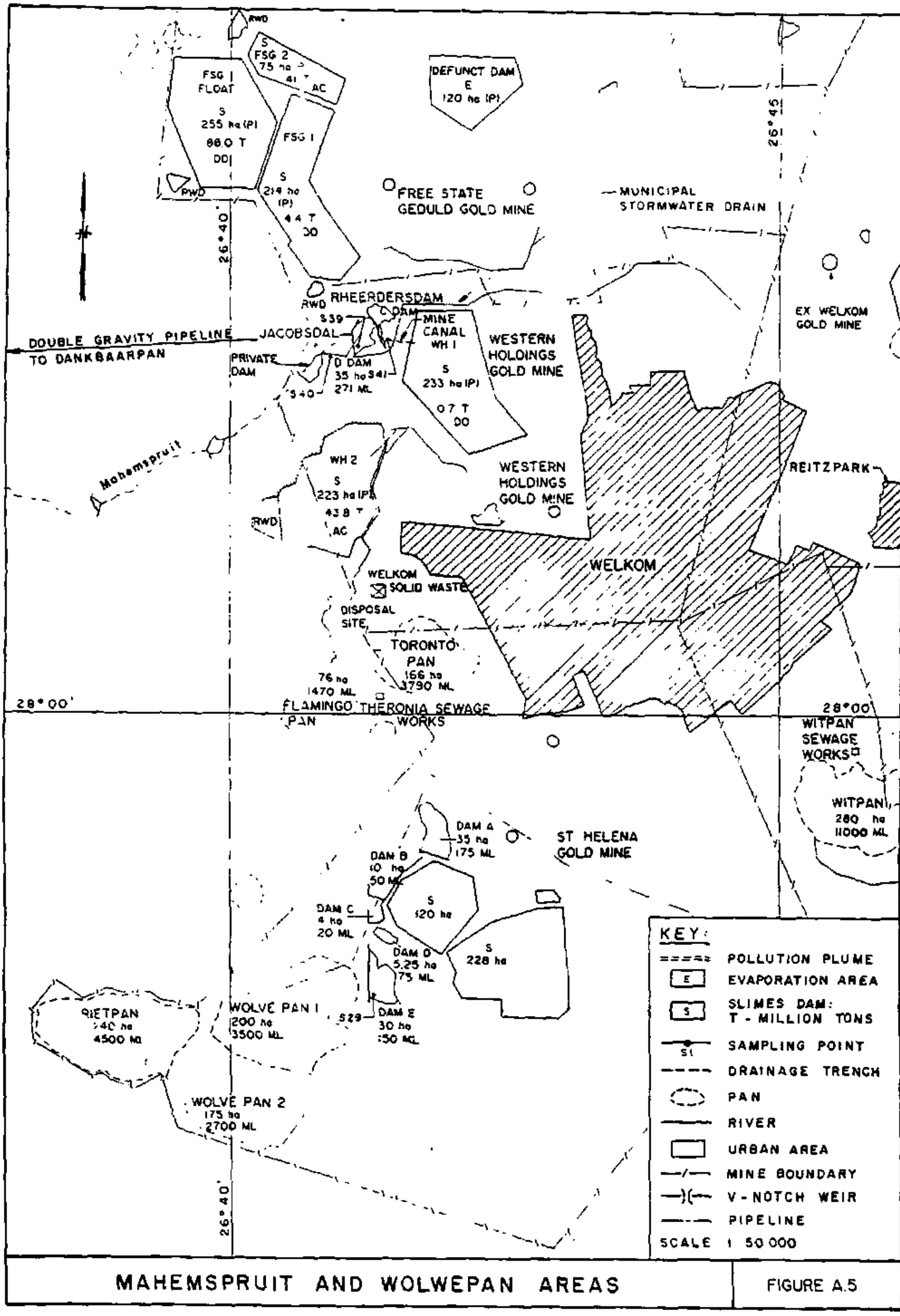
HARMONY MINE AREA

FIGURE A.3



SAND RIVER CANAL AREA

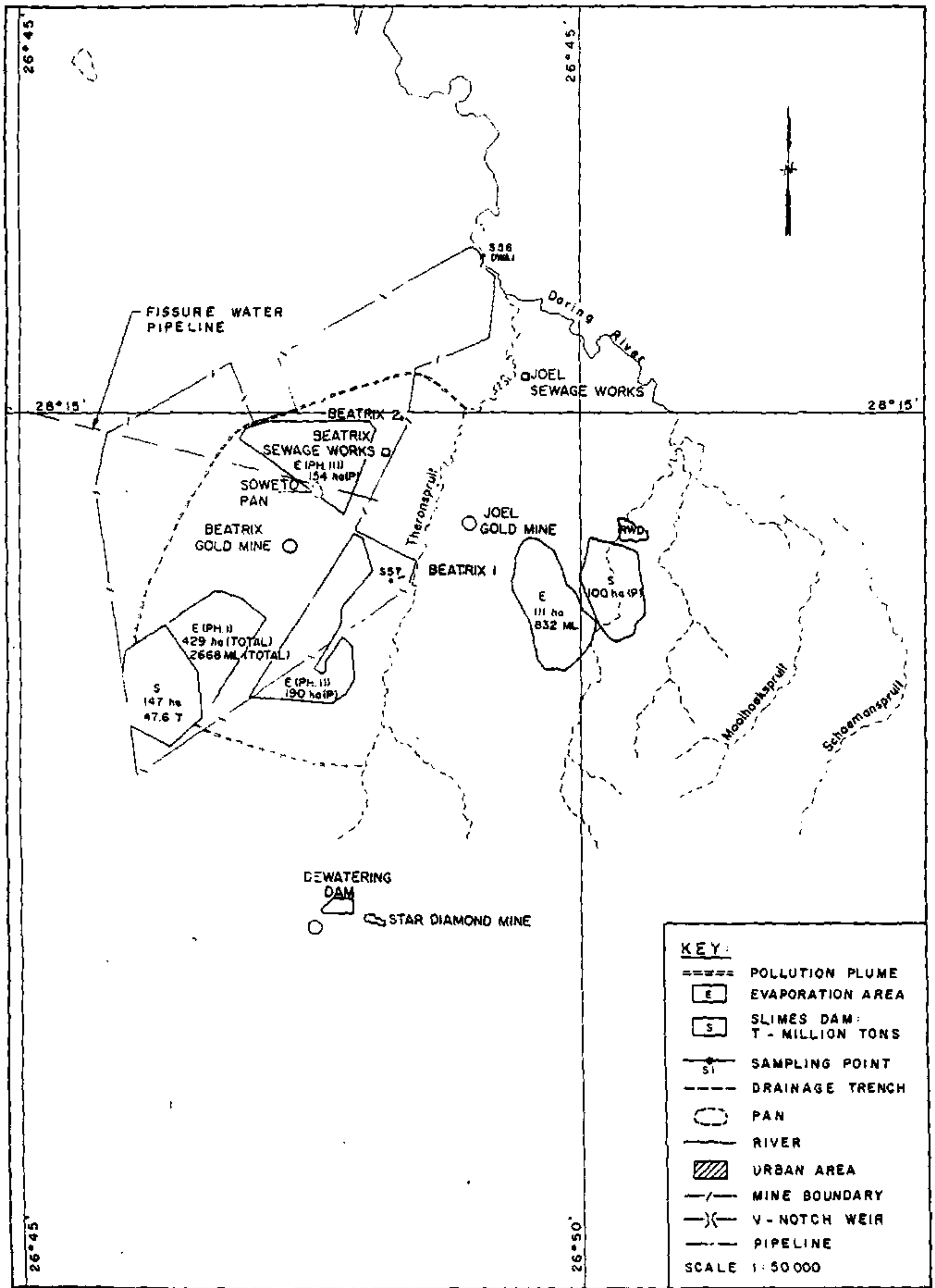
FIGURE A.4



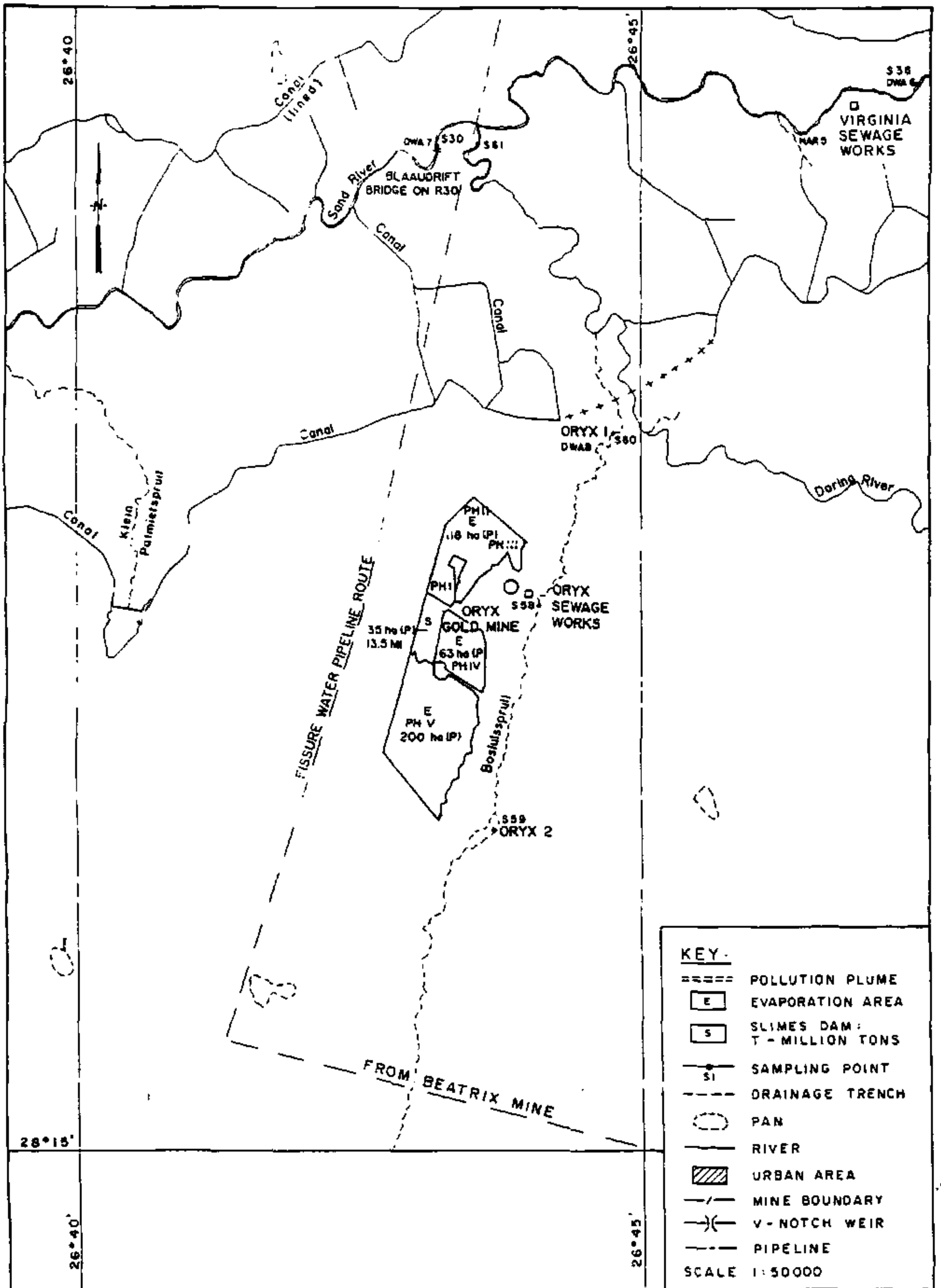
MAHEMSPRUIT AND WOLWEPAN AREAS

FIGURE A.5

A.5



BEATRIX AND JOEL MINE AREA | FIGURE A.6



ORYX GOLD MINE AREA

FIGURE A.7

APPENDIX B

TERMS OF REFERENCE FOR THE VET RIVER WATER QUALITY SITUATION ANALYSIS

TERMS OF REFERENCE FOR THE LOWER VET RIVER WATER QUALITY SITUATION ANALYSIS

B.1 AIM OF STUDY

The aim of the study is to determine the present water quality status of the Lower Vet River. The situation analysis will be confined to the study of Total Dissolved Solids (TDS) and its main inorganic constituents in the surface water.

B.2 GEOGRAPHICAL EXTENT

The project boundaries, which are shown in the accompanying figure, indicate that the rivers in the system to be analyzed include the whole of the Lower Vet River and its tributaries upstream of its confluence with the Vaal River.

B.3 SPECIFIC TASKS

The purpose of the situation analysis is to describe the major water users, the water quality monitoring systems and the present water quality status of the catchment. The specific tasks to be attended to during the course of the study are outlined below.

(a) Determine water quality guidelines

The purpose of this task is to determine the desirable water quality limits for each river reach.

- Identify the present and potential water user groups in the Lower Vet catchment. Departmental records will be examined to determine water rights.

- Identify the most important water quality requirements of the water users.

- Determine guidelines for the most problematic water quality variables for each of the major water user groups. This will include an analysis of the economic implications of the present salinity status of the Lower Vet River for consumers abstracting water from the Lower Vet River and its tributaries. As far as possible develop fitness curves based on readily available information relating crop yield losses to irrigation water quality.

(b) Document sources of pollution

Particular emphasis will be placed on TDS and those water quality variables identified in task (a) as being problematic to users.

- Identify both point and diffuse sources of pollution entering the river system. It is not the purpose to pinpoint all individual sources, but rather to use the data that is readily available.

- Examine the Department's records of permits issued to determine the existing rights of consumers.

(c) Assess present water quality monitoring systems

The availability of water quality and flow data in the Lower Vet River and its tributaries will be determined.

- Compile a list of the organisations that operate monitoring programs.
- Determine the location of monitoring stations, the water quality variables measured, the frequency and reliability of measurement and the availability of the data to the Department.
- Identify areas of deficiency in the existing monitoring programs.

(d) Patch and naturalise hydrological records

Patching and naturalisation of the hydrological records is required to estimate the mean annual runoff (MAR) and the statistical properties of the runoff from key sub-catchments.

- Acquire, check and process historical meteorological, hydrological, water usage and effluent discharge data.
- Calibrate Dr Pitman's catchment models.
- Patch and extend historical runoff records and simulate naturalised virgin hydrology.
- Estimate the effect of the current level of catchment development on the hydrology.

(e) Estimate diffuse source mineral loads

This task includes the estimation of virgin diffuse source total dissolved solids (TDS) loads and the effect of land use changes.

- Acquire, check and process historical river and effluent quality data.
- Calibrate the Consultant's daily time step hydro-salinity models for key sub-catchments.
- Patch the historical TDS and electrical conductivity records at critical river stations.
- Estimate historical TDS loads from each sub-catchment.

(f) Estimate diffuse source loads for main inorganic constituents of the TDS

- Establish relationships between TDS and some of the more important conservative chemical constituents identified in task (a).

- Use the relationships established to patch historical water quality records and estimate pollutant loads.

(g) Evaluate the present water quality status of the catchment

Due account will be taken of historical hydrological variations when examining the water quality record.

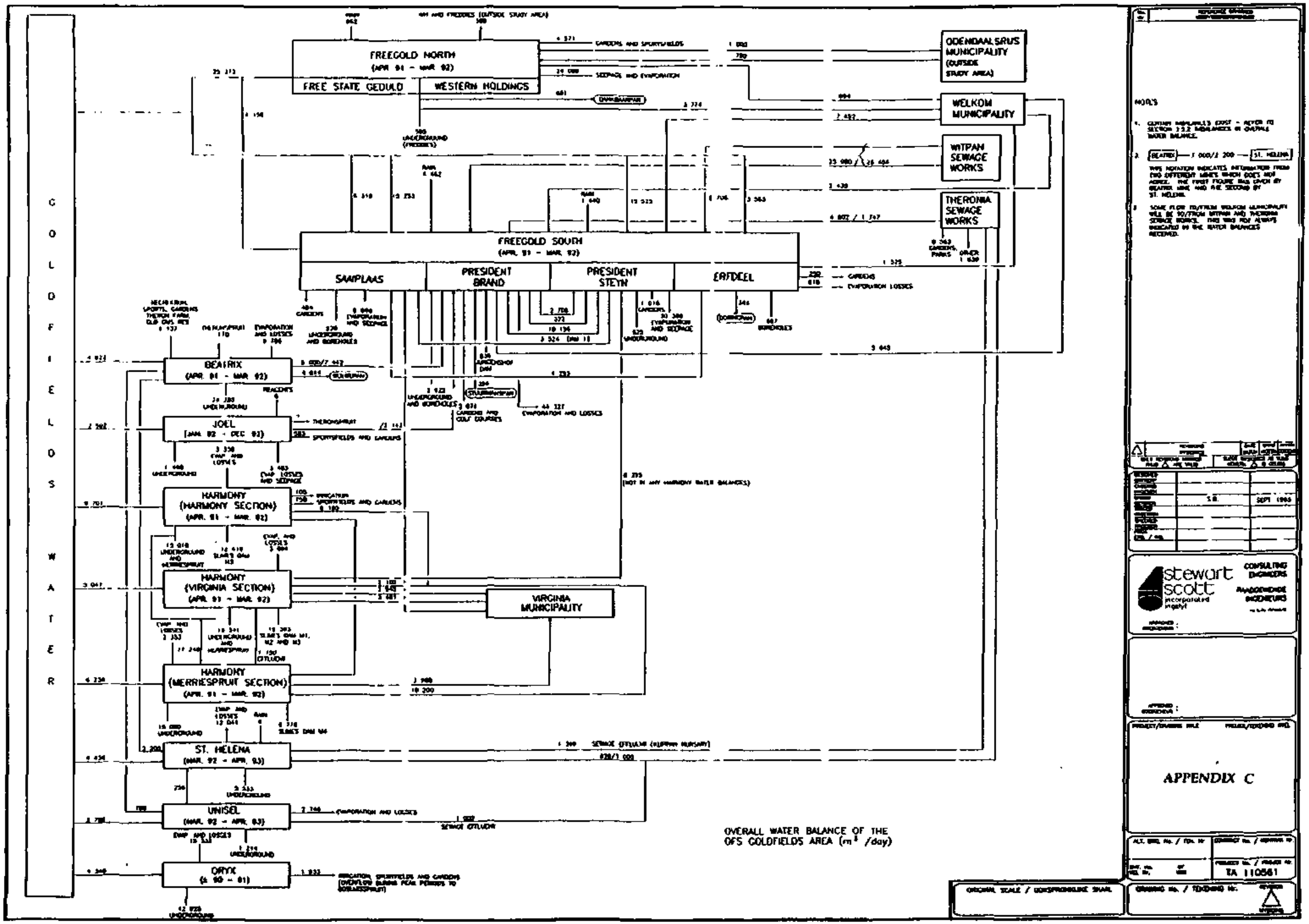
- Use the calibrated hydro-salinity models to simulate the catchment salinity regime for virgin (i.e. undeveloped) conditions. Simulate actual historical conditions.

- Analyze the results to determine historical trends in annual TDS loads, concentrations, seasonal distributions and other relevant statistical properties.

- Simulate TDS concentrations for long sequences of naturalised hydrology, with the superimposed effects of the present state of catchment development. Analyze the results to synthesise representative long term statistical properties of the salinity regime. By this means the distorting effect of recent natural hydrological fluctuations (such as the protracted drought experienced during the eighties) will be eliminated.

APPENDIX C

WATER BALANCE FOR THE OFS GOLDFIELDS



OVERALL WATER BALANCE OF THE OFS GOLDFIELDS AREA (m^3/day)

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CONSULTING ENGINEERS

APPENDIX C

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APPENDIX D

STATISTICAL SUMMARY OF OBSERVED WATER QUALITY DATA

	WATER QUALITY VARIABLE	Page

STATISTICAL SUMMARY OF OBSERVED TOTAL ALKALINITY CONCENTRATIONS (as CaCO3 - mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time <20.0	% time >175.0
C4R001	107	45.	81.	82.	102.	104.	111.	0.0	.0
C4R002	182	45.	69.	72.	84.	88.	96.	0.0	.0
C4H004	178	54.	105.	100.	139.	149.	182.	0.0	1.1

STATISTICAL SUMMARY OF OBSERVED AMMONIA (NH3) CONCENTRATIONS (as N - mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded .025	1.0	2.0
C4R001	103	.00	.00	.00	.01	.01	.03	1.9	.0	.0
DWA2	25	.00	.04	.00	.08	.24	.37	16.0	.0	.0
DWA3	26	.00	.03	.00	.07	.11	.22	19.2	.0	.0
DWA4	28	.00	.03	.01	.06	.11	.29	17.9	.0	.0
DWA6	25	.00	.03	.01	.05	.12	.17	24.0	.0	.0
DWA7	27	.00	.04	.00	.04	.22	.46	18.5	.0	.0
C4R002	171	.00	.01	.00	.01	.01	.06	1.2	.0	.0
C4H004	177	.00	.01	.00	.01	.01	.04	1.7	.0	.0
DWA5	28	.00	.04	.00	.04	.15	.63	14.3	.0	.0
DWA1	20	.00	.02	.00	.02	.03	.19	10.0	.0	.0

STATISTICAL SUMMARY OF OBSERVED CALCIUM CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 150.0	500.0	1000.0
C4R001	107	9.7	15.0	14.9	18.9	19.3	19.9	.0	.0	.0
HAR1	46	14.	38.	40.	51.	60.	98.	.0	.0	.0
DWA2	24	7.0	30.0	32.0	37.6	39.6	48.0	.0	.0	.0
HAR4	45	12.	65.	67.	94.	106.	120.	.0	.0	.0
DWA3	27	8.	71.	57.	79.	85.	540.	3.7	3.7	.0
DWA4	27	20.	66.	61.	104.	112.	120.	.0	.0	.0
DWA6	25	20.	137.	120.	258.	274.	309.	44.0	.0	.0
HAR5	43	26.	159.	119.	319.	332.	388.	37.2	.0	.0
DWA7	27	17.	115.	102.	206.	236.	268.	25.9	.0	.0
C4R002	182	8.9	13.4	13.5	16.7	17.5	18.9	.0	.0	.0
C4H004	178	13.	33.	26.	53.	89.	118.	.0	.0	.0
DWA5	27	56.	528.	545.	673.	726.	780.	96.3	66.7	.0

STATISTICAL SUMMARY OF OBSERVED CHLORIDE CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 105.0	400.0	1500.0
C4R001	107	3.8	8.4	8.2	11.4	12.1	13.2	.0	.0	.0
HAR1	46	7.	26.	18.	48.	66.	138.	4.3	.0	.0
DWA2	24	4.0	21.2	19.0	38.0	40.0	41.0	.0	.0	.0
HAR2	46	18.	176.	142.	326.	438.	674.	65.2	8.7	.0
HAR3	46	1.	168.	134.	351.	474.	709.	63.0	8.7	.0
HAR4	46	4.	123.	92.	251.	290.	354.	45.7	.0	.0
DWA3	27	9.	183.	129.	240.	253.	1640.	70.4	3.7	3.7
DWA4	27	33.	173.	162.	267.	270.	460.	81.5	3.7	.0
DWA6	25	34.	454.	425.	869.	911.	970.	84.0	56.0	.0
HAR5	43	46.	549.	355.	1211.	1425.	1773.	81.4	48.8	2.3
DWA7	27	27.	398.	390.	743.	831.	920.	74.1	51.9	.0
C4R002	182	3.1	9.4	9.7	12.5	12.9	15.6	.0	.0	.0
C4H004	178	5.	60.	35.	146.	224.	380.	14.0	.0	.0
HAR6	46	50.	515.	390.	1060.	1177.	1259.	97.8	50.0	.0
HAR7	46	14.	323.	319.	521.	746.	922.	80.4	28.3	.0
DWA5	27	158.	2159.	2300.	2600.	2665.	2900.	100.0	96.3	92.6
DWA1	22	92.	858.	900.	1296.	1410.	1430.	95.5	81.8	.0

STATISTICAL SUMMARY OF OBSERVED ELECTRICAL CONDUCTIVITY (mS/m)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 40.0	154.0	300.0
C4R001	105	14.	21.	22.	26.	28.	28.	.0	.0	.0
HAR1	46	12.	34.	30.	52.	55.	99.	30.4	.0	.0
DWA2	25	11.	43.	39.	52.	101.	124.	44.0	.0	.0
HAR2	46	15.	105.	94.	177.	204.	270.	87.0	19.6	.0
HAR3	46	21.	107.	95.	188.	224.	280.	84.8	17.4	.0
HAR4	47	4.	75.	78.	127.	141.	155.	74.5	2.1	.0
DWA3	27	13.	107.	102.	143.	149.	537.	81.5	3.7	3.7
DWA4	28	28.	114.	116.	147.	197.	255.	92.9	7.1	.0
DWA6	25	27.	226.	233.	380.	391.	444.	96.0	64.0	36.0
HAR5	37	32.	238.	162.	487.	505.	652.	97.3	54.1	35.1
DWA7	27	24.	196.	216.	333.	358.	375.	96.3	55.6	18.5
C4R002	179	13.	19.	19.	23.	24.	26.	.0	.0	.0
C4H004	626	11.	52.	42.	100.	127.	191.	54.0	1.4	.0
HAR6	46	50.	273.	254.	444.	513.	563.	100.0	87.0	30.4
HAR7	46	21.	210.	222.	348.	385.	430.	95.7	67.4	23.9
HARMONY TR DAM	46	337.	822.	849.	997.	1027.	1135.	100.0	100.0	100.0
HARMONY DAM C	47	255.	556.	545.	749.	886.	1020.	100.0	100.0	95.7
HARMONY DAM B	46	230.	519.	515.	797.	881.	940.	100.0	100.0	89.1
HARMONY CONVENT DAM	47	223.	541.	537.	709.	754.	818.	100.0	100.0	93.6
HARMONY MINE	47	42.	556.	644.	750.	766.	790.	100.0	93.6	78.7
VIRGINIA MINE	44	456.	637.	639.	732.	745.	776.	100.0	100.0	100.0
DWA5	28	78.	793.	830.	937.	947.	1057.	100.0	96.4	96.4
DWA1	22	45.	309.	343.	445.	465.	482.	100.0	86.4	68.2

STATISTICAL SUMMARY OF OBSERVED FLUORIDE CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 1.0	2.0	3.0
C4R001	107	.22	.35	.34	.43	.47	.61	.0	.0	.0
C4R002	182	.17	.28	.27	.36	.39	.57	.0	.0	.0
C4H004	178	.10	.34	.33	.42	.46	.58	.0	.0	.0

STATISTICAL SUMMARY OF OBSERVED MAGNESIUM CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 70.0	100.0	500.0
C4R001	105	3.5	6.0	6.1	7.4	7.5	7.9	.0	.0	.0
DWA2	24	3.0	13.1	12.0	18.6	19.0	39.0	.0	.0	.0
DWA3	27	3.	34.	29.	50.	60.	185.	3.7	3.7	.0
DWA4	27	6.0	28.6	29.5	46.0	49.9	56.0	.0	.0	.0
DWA6	25	6.	68.	64.	137.	140.	148.	48.0	24.0	.0
DWA7	27	5.	61.	57.	110.	126.	136.	48.1	14.8	.0
C4R002	182	4.1	6.3	6.2	7.7	7.9	8.6	.0	.0	.0
C4H004	178	2.4	14.3	11.7	24.4	37.3	54.1	.0	.0	.0
DWA5	27	18.	275.	290.	355.	368.	380.	96.3	96.3	.0
DWA1	22	15.	124.	129.	179.	182.	197.	86.4	72.7	.0

STATISTICAL SUMMARY OF OBSERVED NITRATE CONCENTRATIONS (as N - mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 5.0	10.0	25.0
C4R001	105	.01	.26	.19	.48	.53	2.24	.0	.0	.0
DWA2	24	.10	.35	.10	.75	1.44	2.30	.0	.0	.0
DWA3	24	.10	.42	.10	.98	1.34	1.70	.0	.0	.0
DWA4	27	.10	.98	.10	2.66	3.45	5.80	3.7	.0	.0
DWA6	23	.10	1.05	.10	3.03	3.89	8.30	4.3	.0	.0
DWA7	26	.10	1.51	.10	4.14	6.81	9.50	7.7	.0	.0
C4R002	181	.01	.41	.45	.53	.55	.57	.0	.0	.0
C4H004	154	.01	.13	.04	.41	.51	1.02	.0	.0	.0
DWA5	27	.10	3.56	1.05	4.70	13.21	42.00	7.4	7.4	3.7
DWA1	20	.07	1.77	.10	3.60	7.10	17.70	10.0	5.0	.0

STATISTICAL SUMMARY OF OBSERVED PHOSPHATE CONCENTRATIONS (as P - mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded .1	.5	1.0
C4R001	107	.00	.02	.01	.03	.04	.11	.9	.0	.0
DWA2	23	.03	.49	.03	.84	1.44	7.70	26.1	13.0	13.0
DWA3	24	.01	.07	.03	.10	.15	.90	8.3	4.2	.0
DWA4	26	.03	.40	.03	1.40	1.54	3.70	30.8	19.2	19.2
DWA6	23	.03	.19	.03	.41	1.09	1.70	21.7	8.7	8.7
DWA7	25	.03	.17	.03	.56	.90	1.20	24.0	16.0	4.0
C4R002	180	.00	.02	.02	.04	.05	.07	.0	.0	.0
C4H004	167	.00	.02	.01	.04	.06	.20	.6	.0	.0
DWA5	26	.03	.17	.03	.54	1.07	1.40	19.2	11.5	7.7
DWA1	21	.03	1.55	1.35	2.73	3.46	5.50	90.5	81.0	71.4

STATISTICAL SUMMARY OF OBSERVED POTASSIUM CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time >200
C4H004	178	.10	.34	.33	.42	.46	.58	.0

STATISTICAL SUMMARY OF OBSERVED SODIUM CONCENTRATIONS (mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 70.0	100.0	1000.0
C4R001	105	11.	16.	16.	19.	20.	21.	.0	.0	.0
DWA2	23	10.	30.	28.	40.	42.	64.	.0	.0	.0
DWA3	26	12.	93.	100.	156.	170.	185.	69.2	50.0	.0
DWA4	26	23.	124.	105.	234.	281.	330.	80.8	57.7	.0
DWA6	25	24.	251.	245.	423.	477.	950.	76.0	72.0	.0
DWA7	27	20.	208.	233.	335.	374.	460.	74.1	74.1	.0
C4R002	182	8.3	11.7	12.2	14.2	14.6	17.2	.0	.0	.0
C4H004	178	12.	39.	28.	77.	113.	187.	11.2	6.7	.0
HARMONY DAM C	4	651.	1062.	853.	1387.	1417.	1447.	100.0	100.0	50.0
HARMONY DAM B	46	357.	859.	816.	1262.	1355.	1478.	100.0	100.0	30.4
HARMONY CONVENT DAM	4	402.	829.	822.	1072.	1123.	1174.	100.0	100.0	25.0
HARMONY MINE	47	51.	982.	1149.	1324.	1389.	1610.	95.7	91.5	68.1
DWA5	27	22.	785.	805.	1080.	1158.	1200.	96.3	88.9	22.2
DWA1	21	34.	154.	165.	199.	200.	233.	90.5	85.7	.0

STATISTICAL SUMMARY OF OBSERVED SODIUM ABSORBTION RATIO (SAR)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 1.5	3.0	6.0
C4R001	103	.72	.87	.87	.95	1.00	1.07	.0	.0	.0
DWA2	23	.64	1.12	1.04	1.40	1.45	2.23	4.3	.0	.0
DWA3	26	.92	2.32	2.44	3.19	3.67	3.85	80.8	11.5	.0
DWA4	26	1.2	3.1	2.8	4.8	6.1	6.6	88.5	34.6	7.7
DWA5	27	.19	6.88	7.28	9.09	9.76	9.98	92.6	88.9	77.8
DWA6	25	1.2	4.1	3.9	5.4	7.5	11.7	96.0	68.0	8.0
DWA7	27	1.1	3.7	3.9	5.4	6.7	7.9	92.6	70.4	11.1
C4R002	179	.50	.66	.66	.73	.75	.91	.0	.0	.0
C4H004	179	.67	1.33	1.13	2.22	2.75	3.62	24.0	2.8	.0

STATISTICAL SUMMARY OF OBSERVED SULPHATE CONCENTRATIONS (SO4 mg/l)

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 200.0	1000.0
C4R001	105	.30	7.10	6.10	12.55	14.18	17.60	.0	.0
HAR1	45	1.	27.	11.	73.	103.	176.	.0	.0
DWA2	23	6.0	17.3	17.5	24.7	29.2	36.0	.0	.0
HAR2	46	1.	155.	128.	305.	377.	428.	30.4	.0
HAR3	46	1.	162.	142.	342.	378.	528.	28.3	.0
HAR4	46	1.	106.	89.	231.	274.	372.	15.2	.0
DWA3	25	13.	104.	103.	178.	193.	200.	.0	.0
DWA4	26	28.	136.	120.	206.	274.	310.	15.4	.0
DWA6	23	35.	287.	275.	520.	520.	540.	60.9	.0
HAR5	43	1.	255.	211.	549.	575.	654.	51.2	.0
DWA7	25	29.	214.	151.	390.	418.	480.	44.0	.0
C4R002	178	2.0	7.8	7.0	12.7	14.1	16.7	.0	.0
C4H004	179	4.	40.	20.	98.	158.	269.	2.8	.0
HAR6	46	1.	468.	527.	610.	623.	645.	91.3	.0
HAR7	46	12.	391.	446.	582.	593.	625.	78.3	.0
DWA5	26	108.	1186.	1220.	1688.	1700.	1700.	92.3	69.2
DWA1	20	28.	250.	170.	420.	860.	1140.	40.0	5.0

STATISTICAL SUMMARY OF OBSERVED PH

Period: 1988/10-1992/ 9

Station	N	Min.	Ave.	50%	90%	95%	Max.	% time exceeded 6.0	6.5	8.4
C4R001	105	4.4	8.0	8.1	8.4	8.5	8.9	99.0	99.0	14.3
DWA2	25	7.5	7.9	7.8	8.3	8.4	8.6	100.0	100.0	4.0
DWA3	27	6.8	7.8	7.9	8.2	8.3	8.6	100.0	100.0	3.7
DWA4	28	7.2	7.9	7.9	8.3	8.5	9.0	100.0	100.0	7.1
DWA5	28	7.0	7.8	7.8	8.1	8.3	8.4	100.0	100.0	.0
DWA6	25	7.5	8.1	8.1	8.5	8.6	8.7	100.0	100.0	16.0
DWA7	27	7.4	8.0	7.9	8.3	8.5	8.9	100.0	100.0	7.4
C4R002	179	6.3	8.0	8.1	8.4	8.5	8.9	100.0	97.2	11.7
C4H004	179	6.8	8.1	8.1	8.5	8.6	8.9	100.0	100.0	21.2

APPENDIX E

SAND RIVER AND SAND RIVER CANAL EC GRAPHS

ABD029.spp

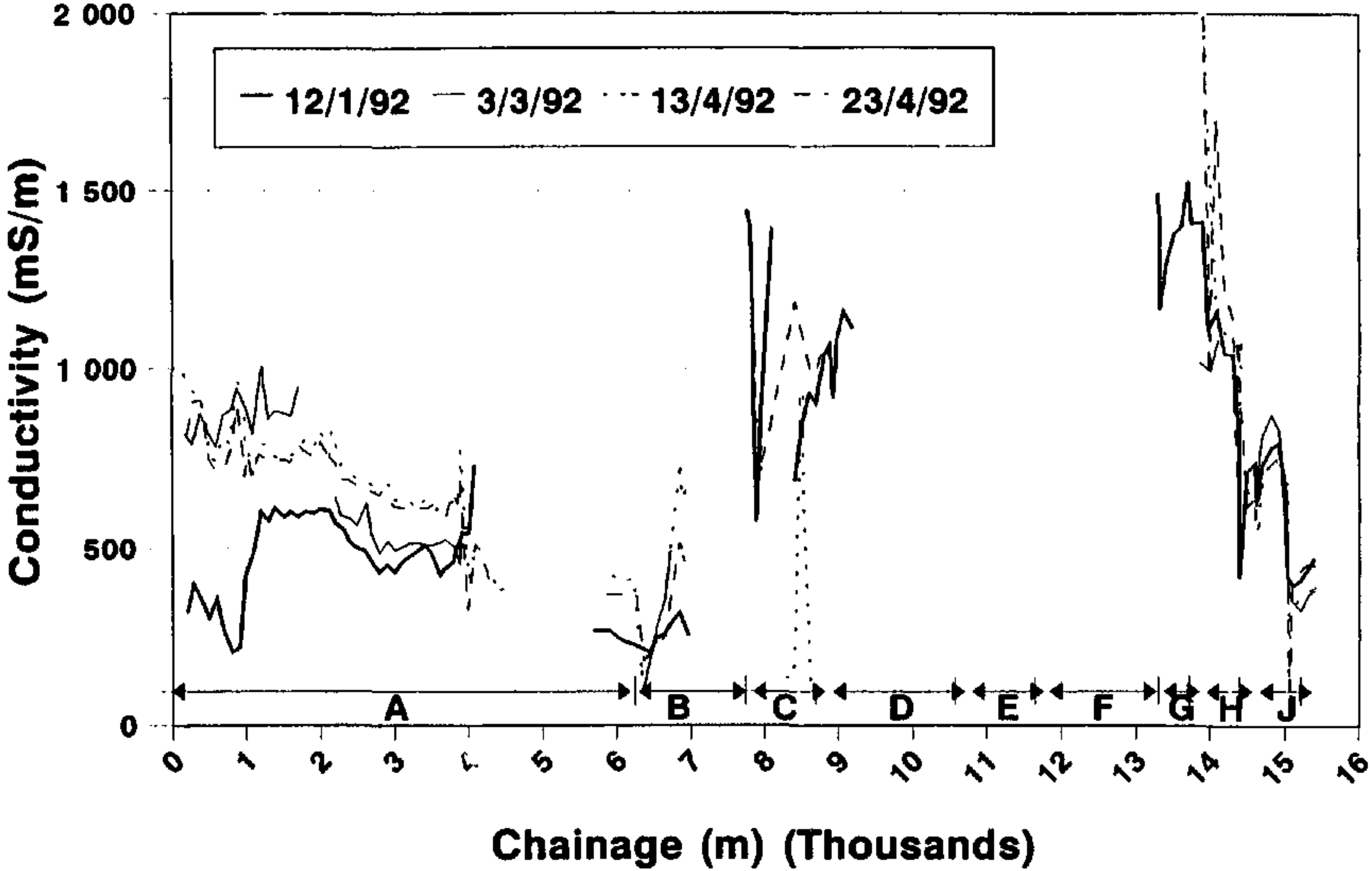


Fig. E.1 : Longitudinal section showing conductivity along the Sand River canal (January to April 1992)

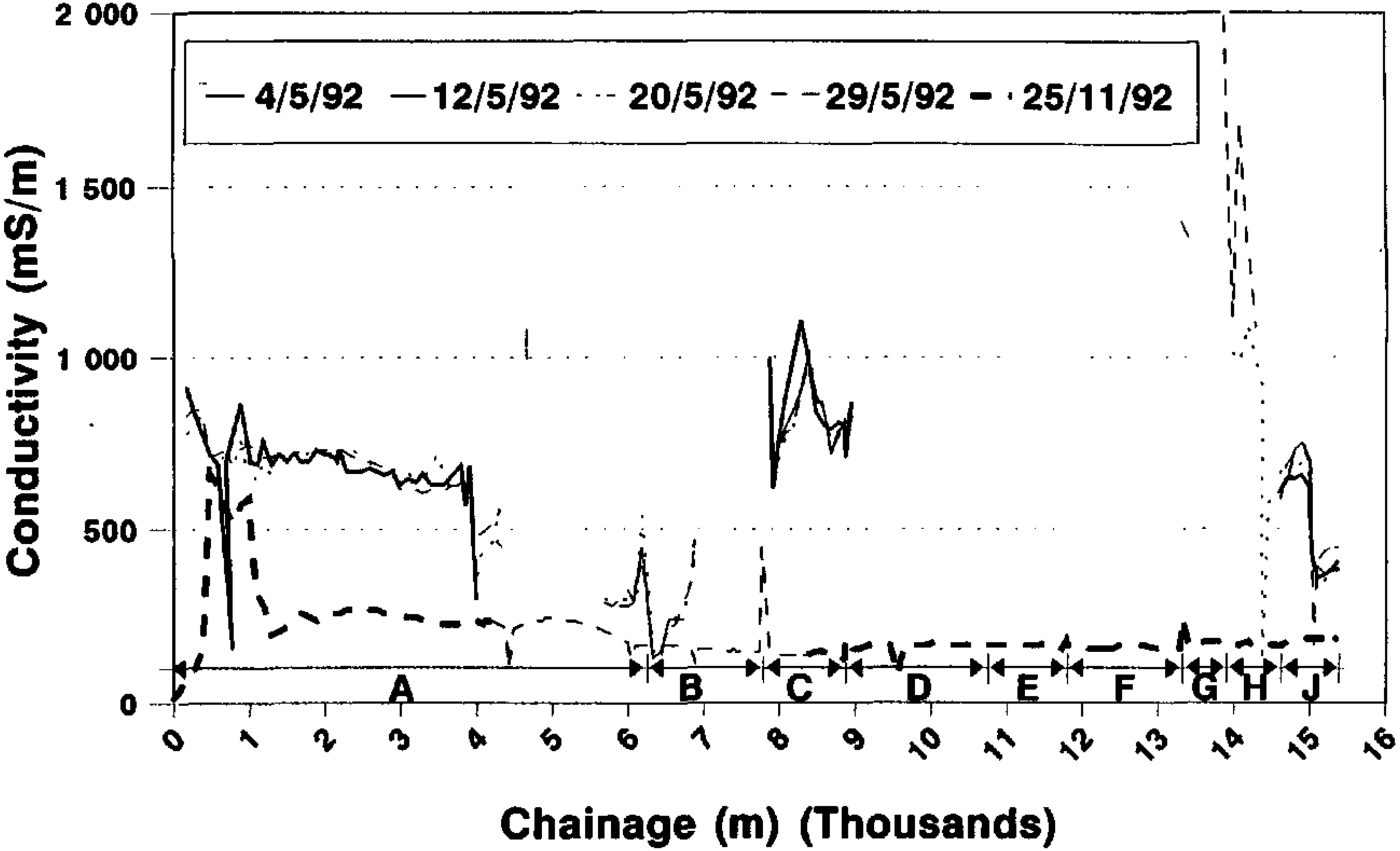


Fig. E.2 : Longitudinal section showing conductivity along the Sand River canal (May to November 1992)

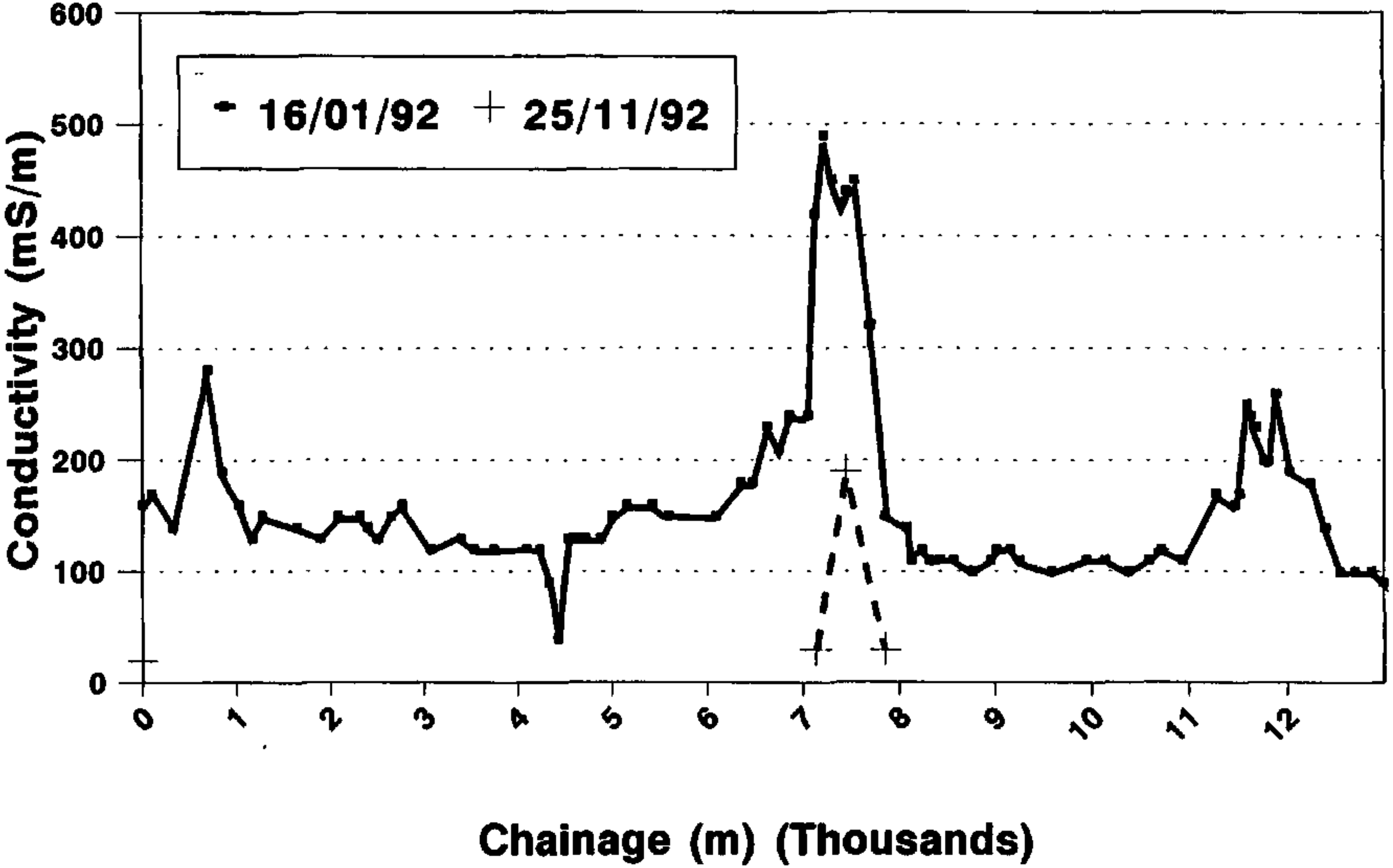


Fig. E.3 : Longitudinal section showing conductivity along the Sand River

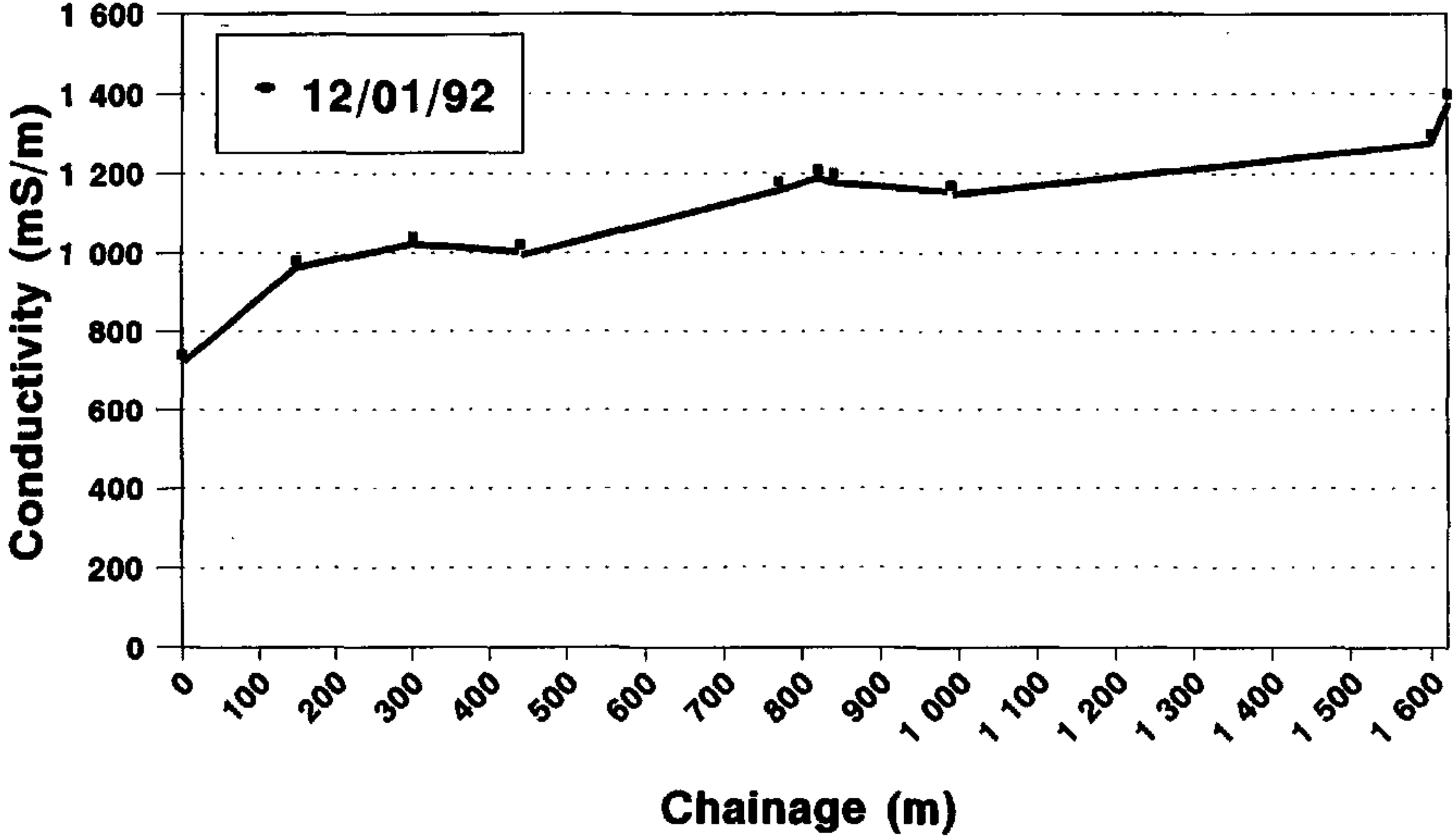


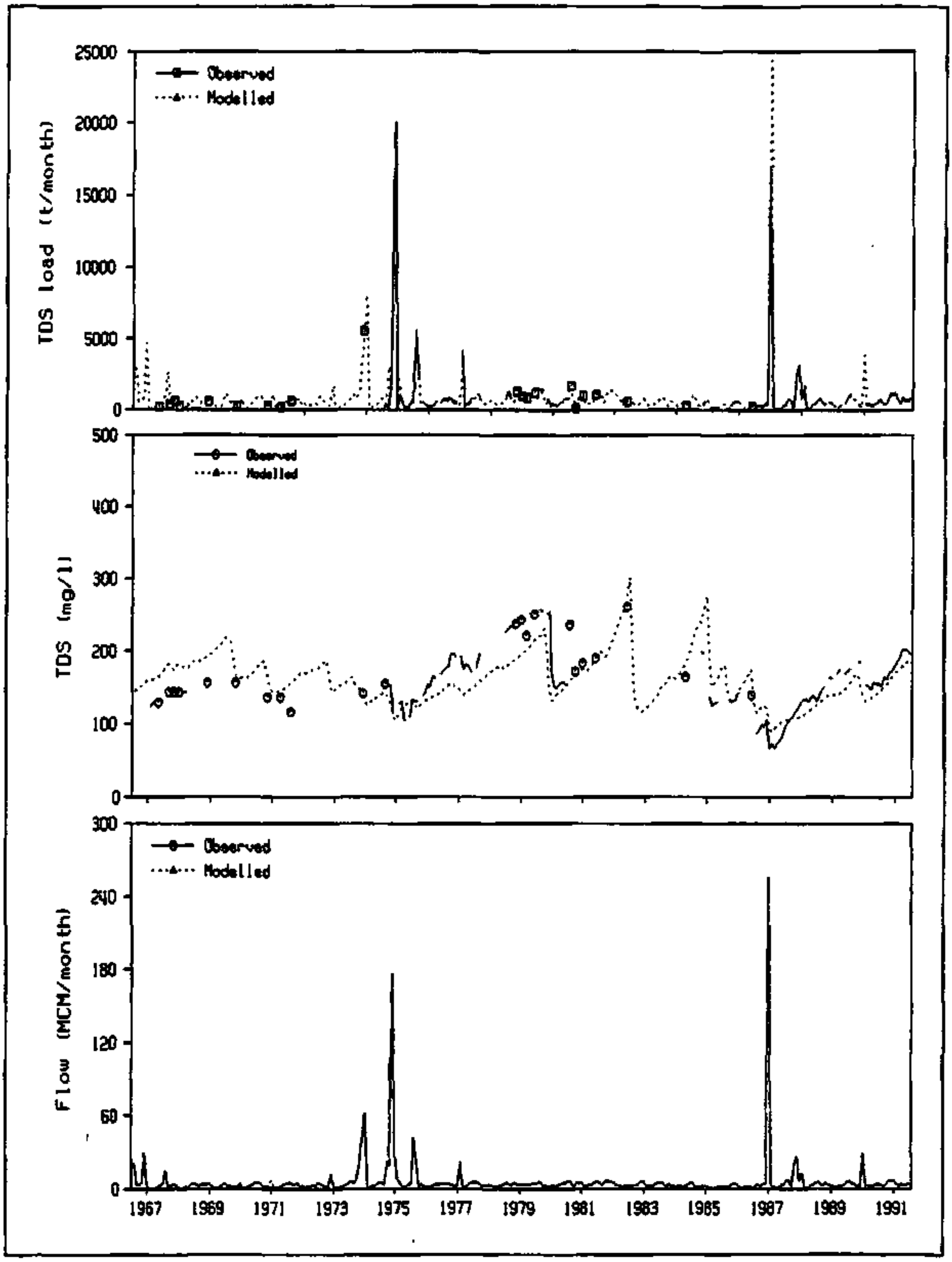
Fig. E.4 : Longitudinal section showing conductivity from Dam 33 to the Sand River canal

E.4

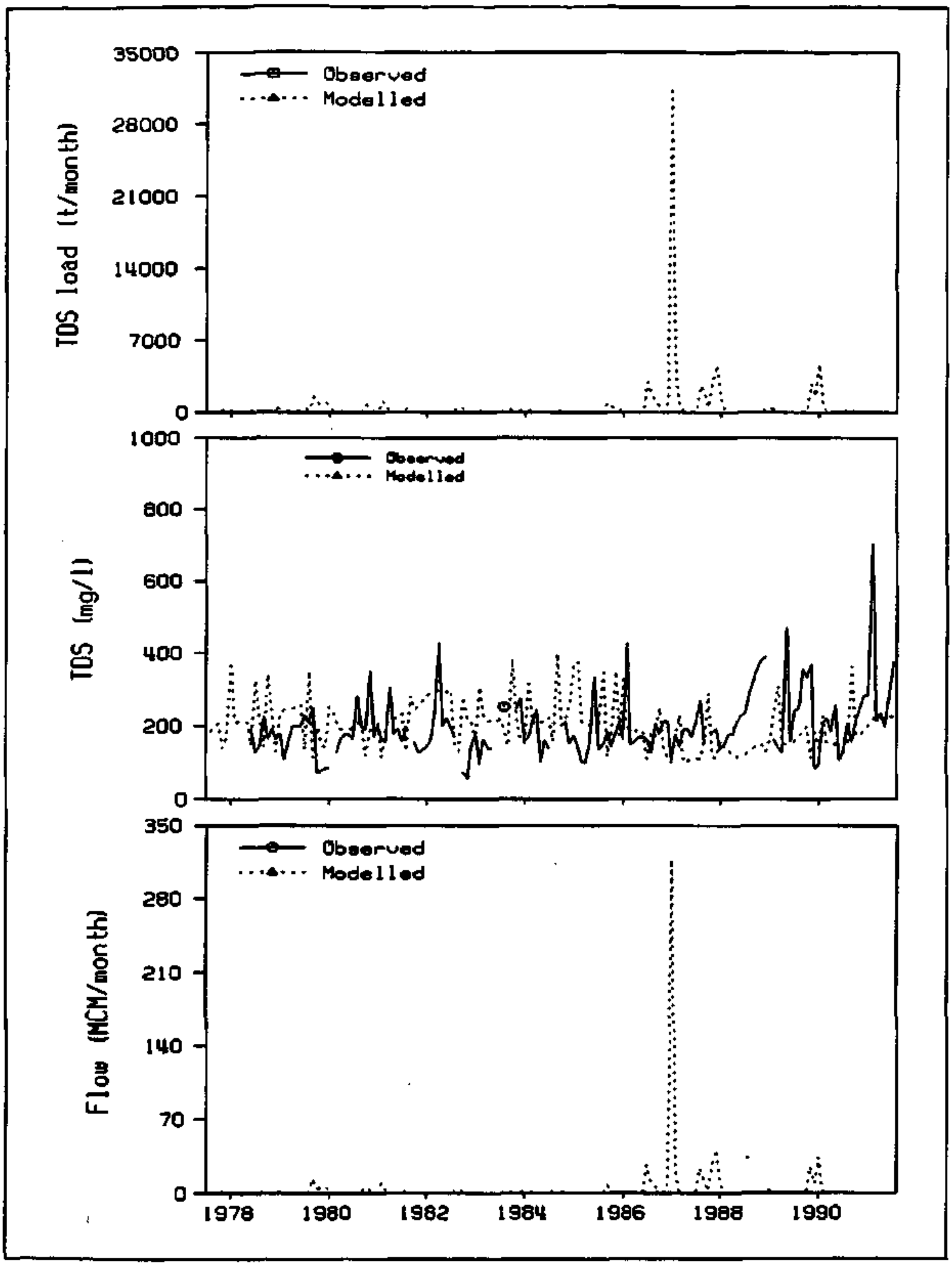
APPENDIX F

HYDRO-SALINITY MODELLING: STATISTICS AND GRAPHS OF RESULTS

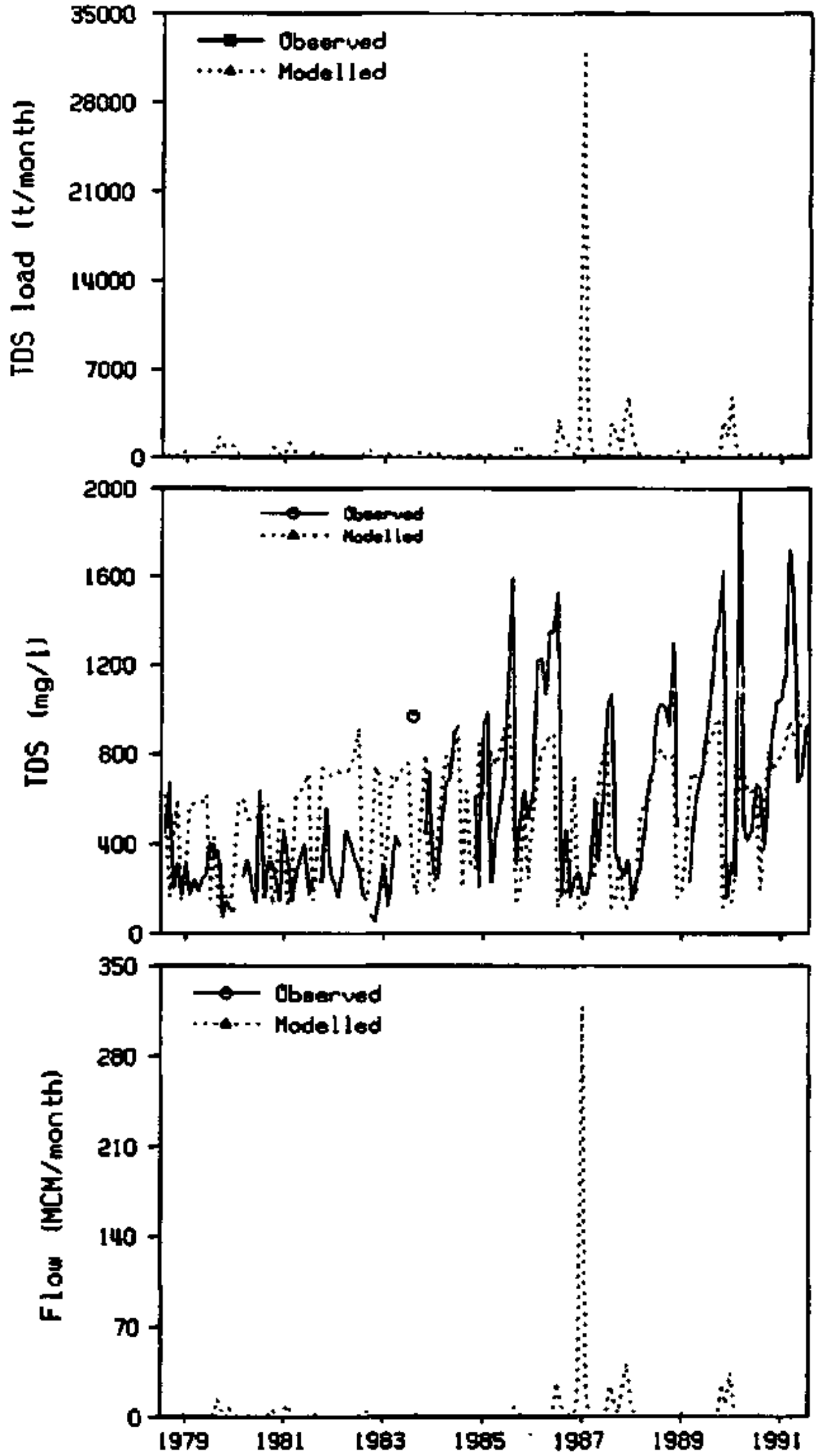
SVA SUB-SYSTEM



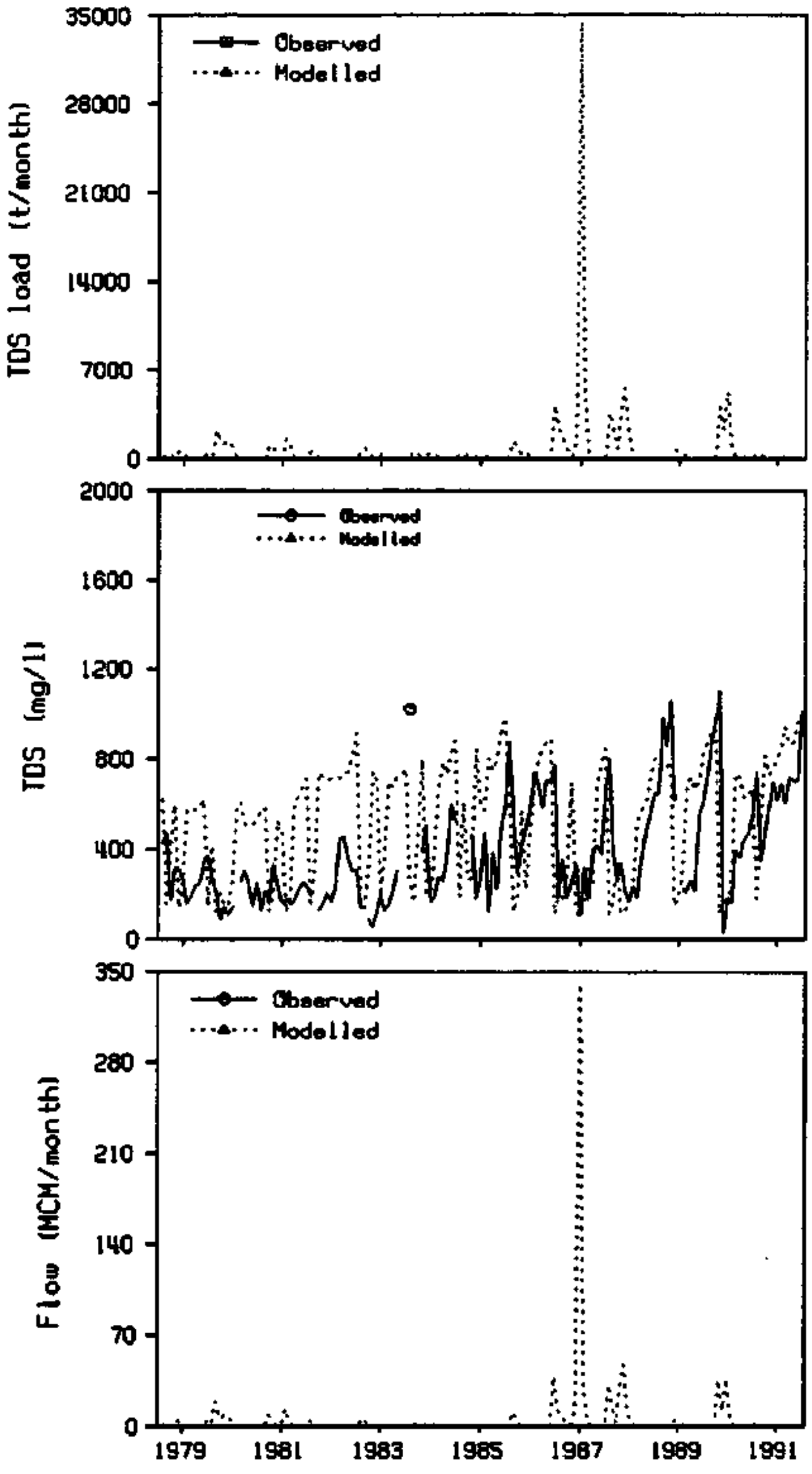
Modelled and observed monthly values at Allemanskraal Dam (C4R0101)



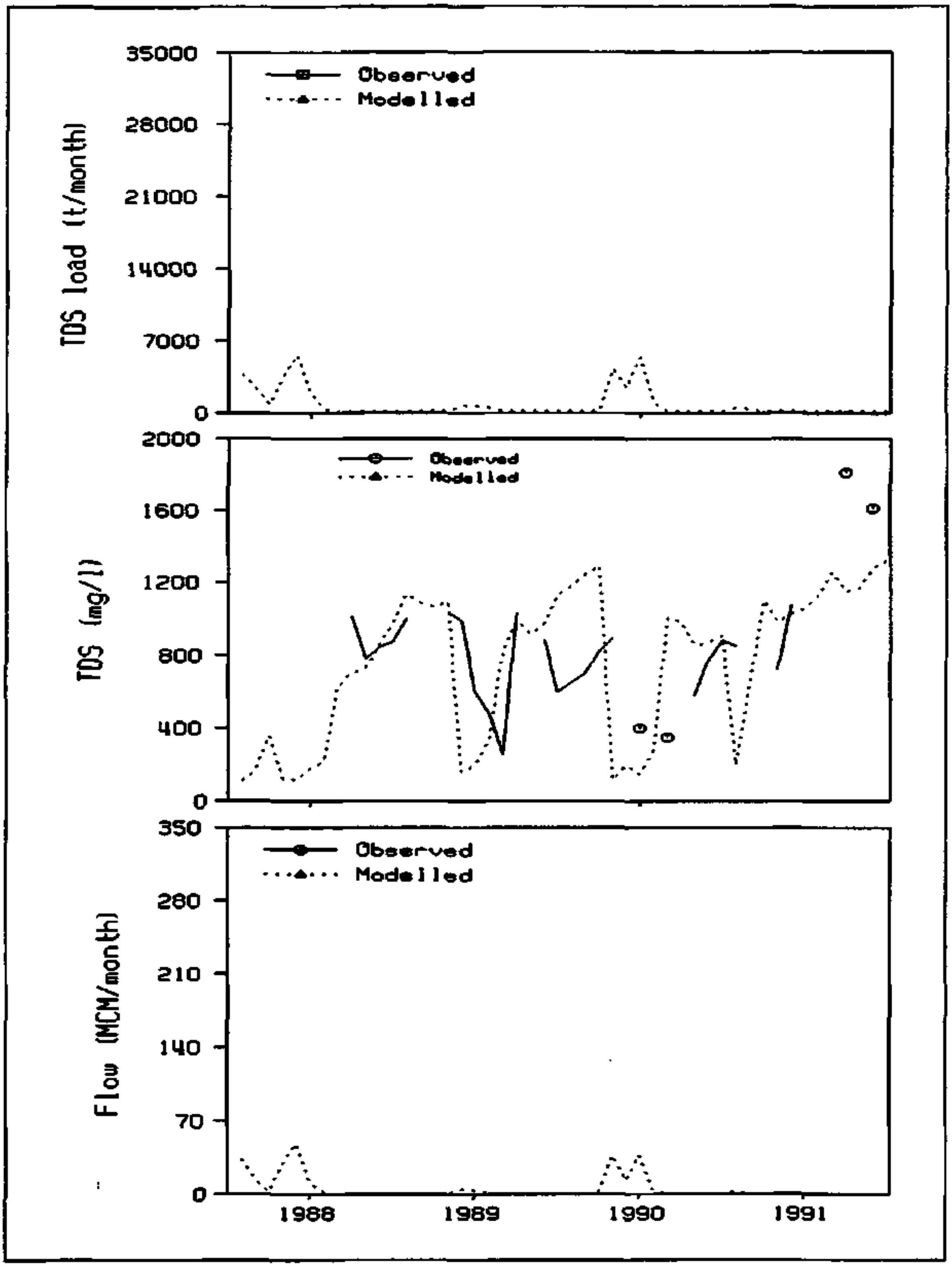
Modelled flow, modelled and observed concentration and modelled load at the HAR1 monitoring station



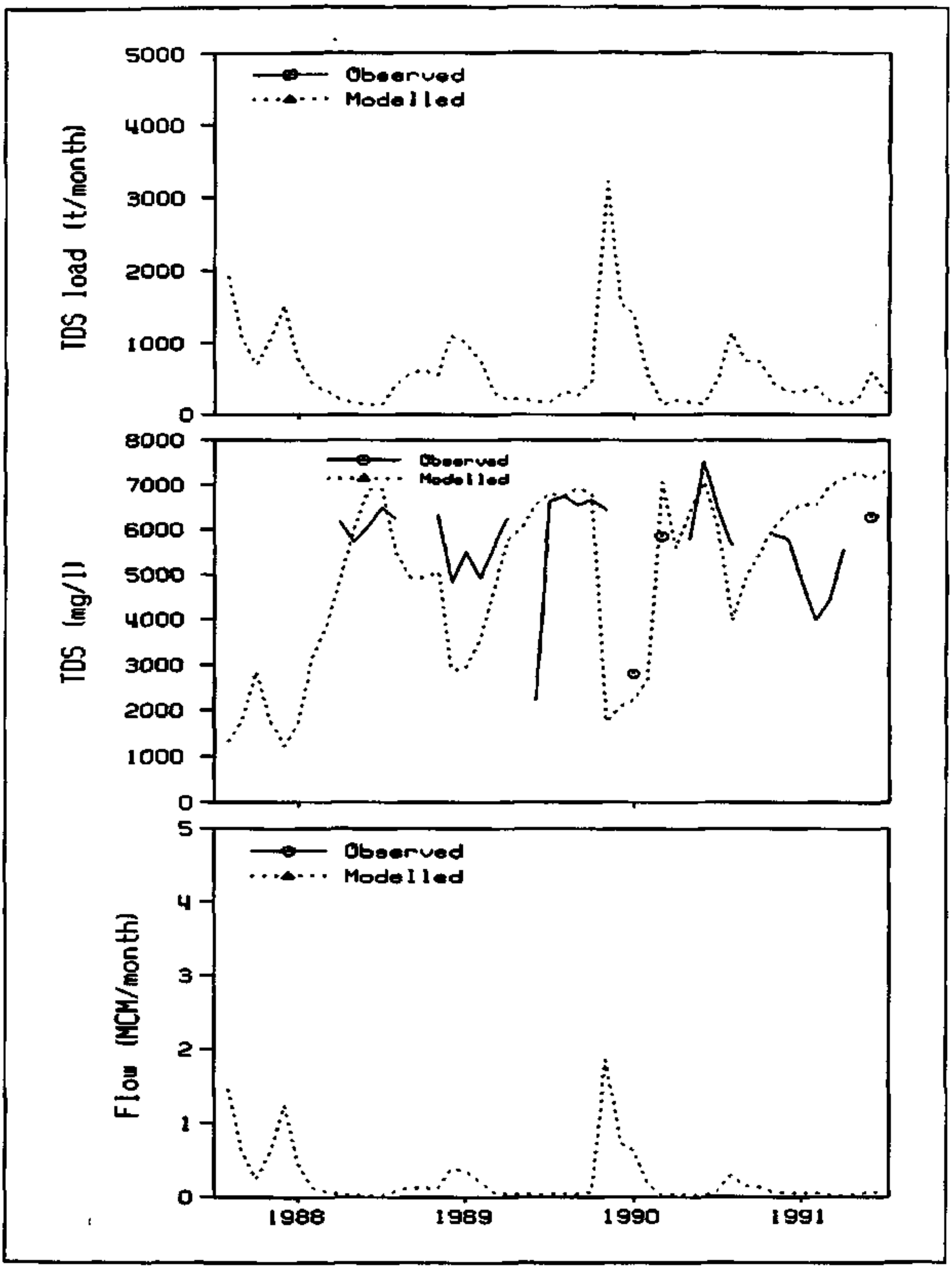
Modelled flow, modelled and observed concentration and modelled load at the HAR3 monitoring station



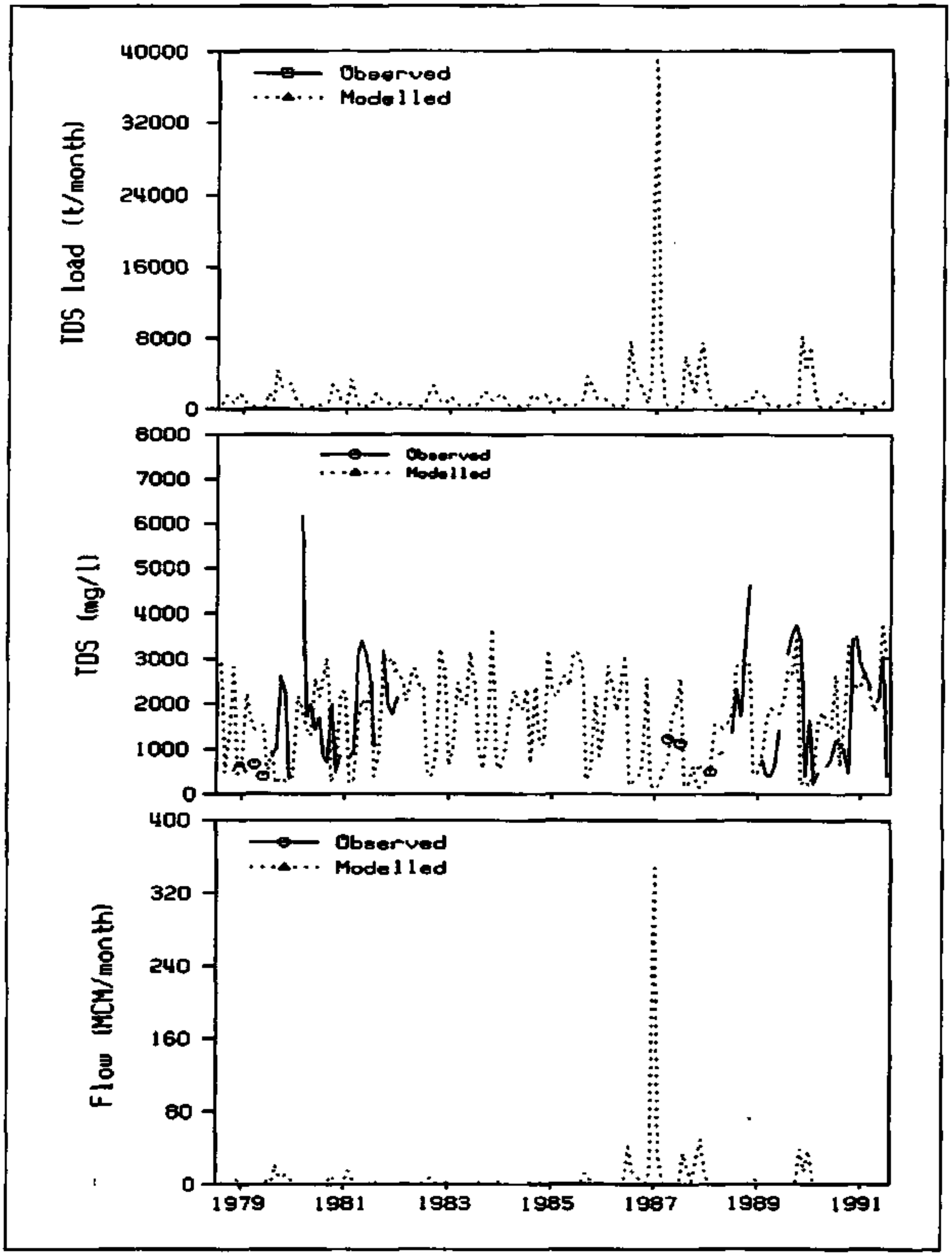
Modelled flow, modelled and observed concentration and modelled load at the HAR4 monitoring station



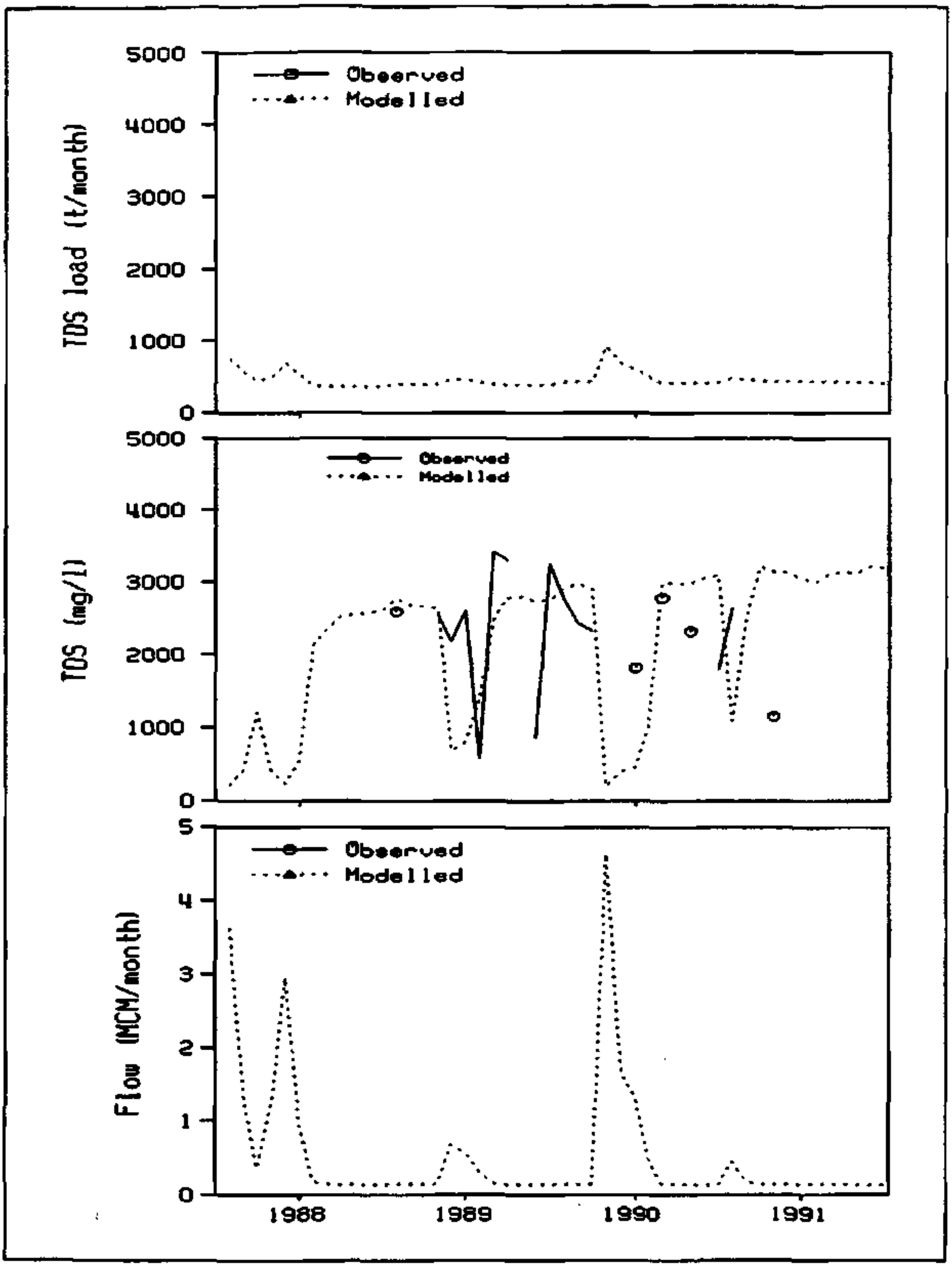
Modelled flow, modelled and observed concentration and modelled load at the DWA4 monitoring station



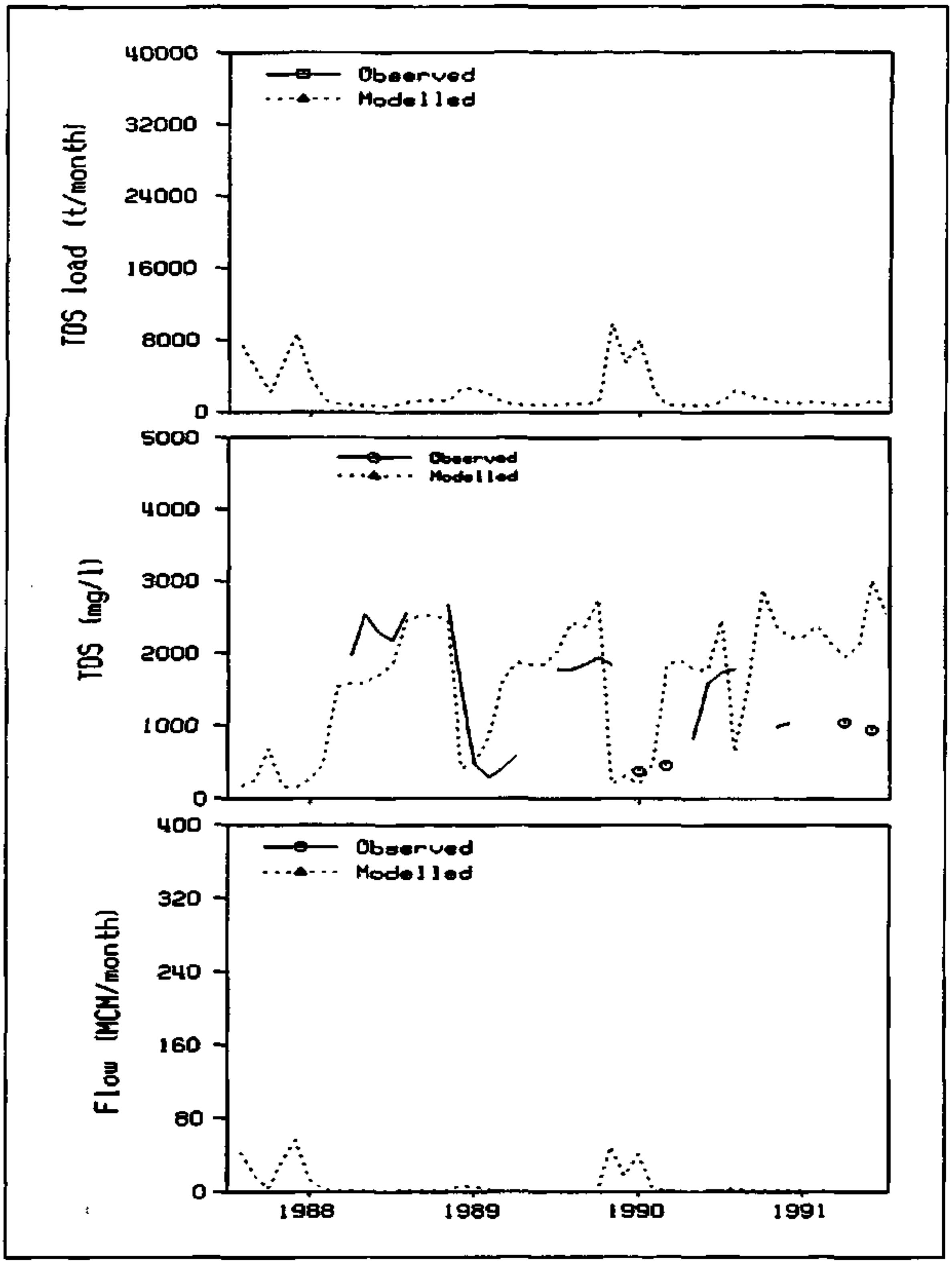
Modelled flow, modelled and observed concentration and modelled load at the DWA5 monitoring station



Modelled flow, modelled and observed concentration and modelled load at the HAR5 monitoring station



Modelled flow, modelled and observed concentration and modelled load at the DWA1 monitoring station



Modelled flow, modelled and observed concentration and modelled load at the DWA7 monitoring station

OBS POINT AT C4R001 ROUTE No. 24 1966-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	6.14	6.28	156.53	148.01	984.24	984.43
Std. dev.	19.46	20.11	41.98	29.90	2341.93	2791.73
N	312	312	132	132	132	132
r		.998332		.735510		.971099
E1		2.41		-5.44		.02
E2		3.34		-28.77		19.21
SF		1.00		.96		.81
Mean		6.28		158.90		867.85
Std. dev.		20.11		30.30		2153.72
N		312		312		312

OBS POINT AT HAR1 ROUTE No. 26 1978-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	198.37	199.18	.00	.00
Std. dev.	.00	.00	86.53	64.47	.00	.00
N	0	0	146	146	0	0
r		.000000		.142496		.000000
E1		.00		.41		.00
E2		.00		-25.49		.00
SF		-1.00		.98		-1.00
Mean		4.17		202.38		511.70
Std. dev.		25.00		66.48		2528.04
N		168		168		168

OBS POINT AT HAR3 ROUTE No. 36 1979-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	545.34	542.75	.00	.00
Std. dev.	.00	.00	405.86	270.58	.00	.00
N	0	0	144	144	0	0
r		.000000		.420091		.000000
E1		.00		-.48		.00
E2		.00		-33.33		.00
SF		-1.00		.99		-1.00
Mean		4.50		532.44		621.61
Std. dev.		26.01		269.21		2632.47
N		156		156		156

OBS POINT AT HAR4 ROUTE No. 37 1979-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	386.70	538.10	.00	.00
Std. dev.	.00	.00	240.88	271.92	.00	.00
N	0	0	145	145	0	0
r		.000000		.336380		.000000
E1		.00		39.15		.00
E2		.00		12.88		.00
SF		-1.00		.99		-1.00
Mean		5.36		528.70		742.68
Std. dev.		28.12		271.12		2886.72
N		156		156		156

OBS POINT AT DWA4 ROUTE No. 38 1988-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	832.01	826.80	.00	.00
Std. dev.	.00	.00	335.38	378.92	.00	.00
N	0	0	27	27	0	0
r		.000000		.301727		.000000
E1		.00		-.63		.00
E2		.00		12.98		.00
SF		-1.00		.91		-1.00
Mean		5.15		757.92		821.28
Std. dev.		11.51		417.03		1398.57
N		48		48		48

OBS. POINT AT DWA5 ROUTE No. 47 1988-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	5676.45	5674.25	.00	.00
Std. dev.	.00	.00	1141.92	1601.44	.00	.00
N	0	0	30	30	0	0
r		.000000		.259394		.000000
E1		.00		-.04		.00
E2		.00		40.24		.00
SF		-1.00		.83		-1.00
Mean		.23		4981.77		603.42
Std. dev.		.38		1972.72		575.88
N		48		48		48

OBS POINT AT HARS ROUTE No. 39 1979-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	1637.73	1705.57	.00	.00
Std. dev.	.00	.00	1225.98	1036.24	.00	.00
N	0	0	72	72	0	0
r		.000000		.391215		.000000
E1		.00		4.14		.00
E2		.00		-15.48		.00
SF		-1.00		.97		-1.00
Mean		5.75		1663.16		1541.92
Std. dev.		28.83		1002.98		3414.87
N		156		156		156

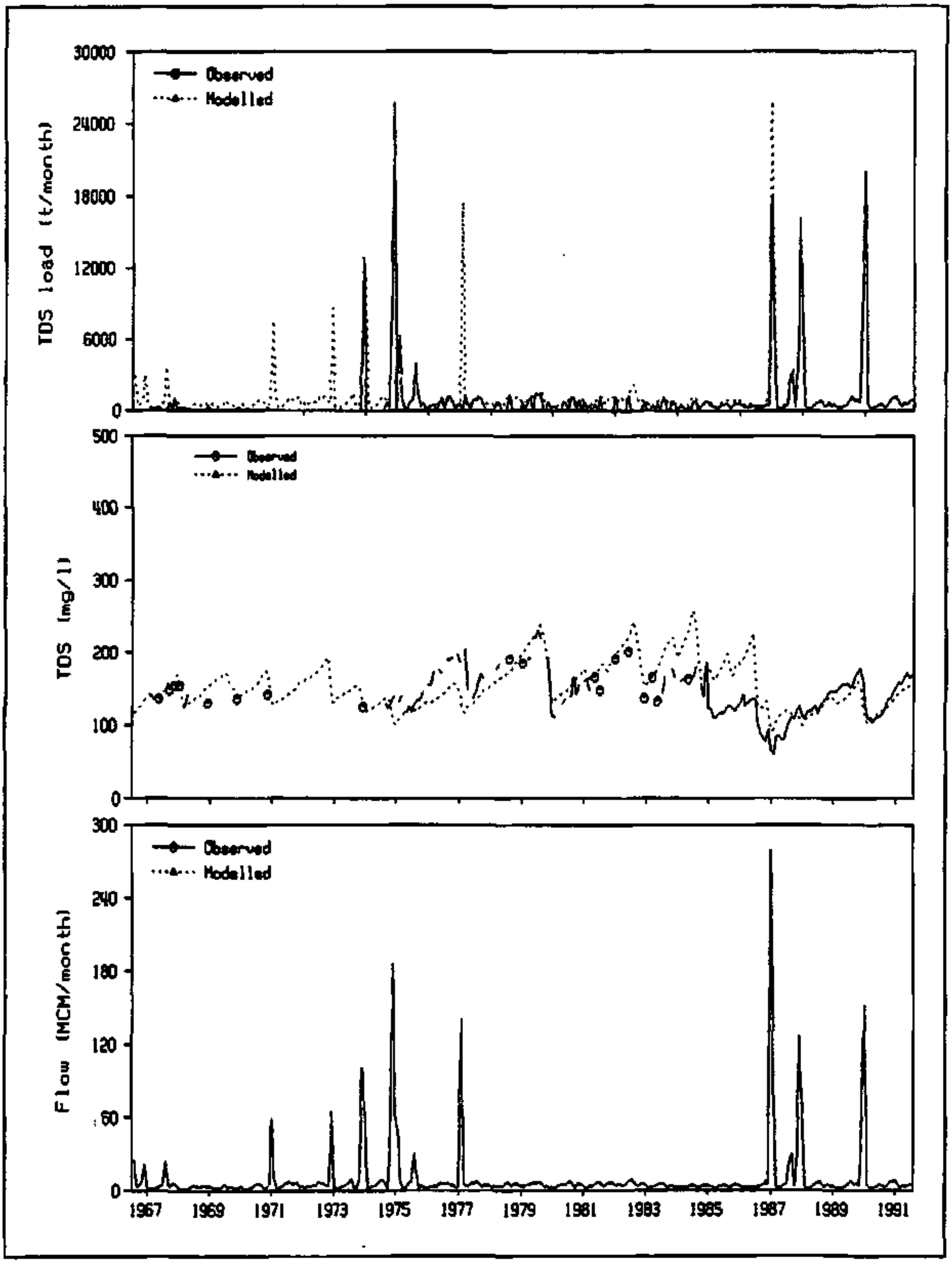
OBS. POINT AT DWA1 ROUTE No. 43 1988-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	2297.24	2310.43	.00	.00
Std. dev.	.00	.00	798.45	940.68	.00	.00
N	0	0	18	18	0	0
r		.000000		.145493		.000000
E1		.00		.57		.00
E2		.00		17.81		.00
SF		-1.00		.92		-1.00
Mean		.53		2205.90		455.55
Std. dev.		.93		1058.20		108.64
N		48		48		48

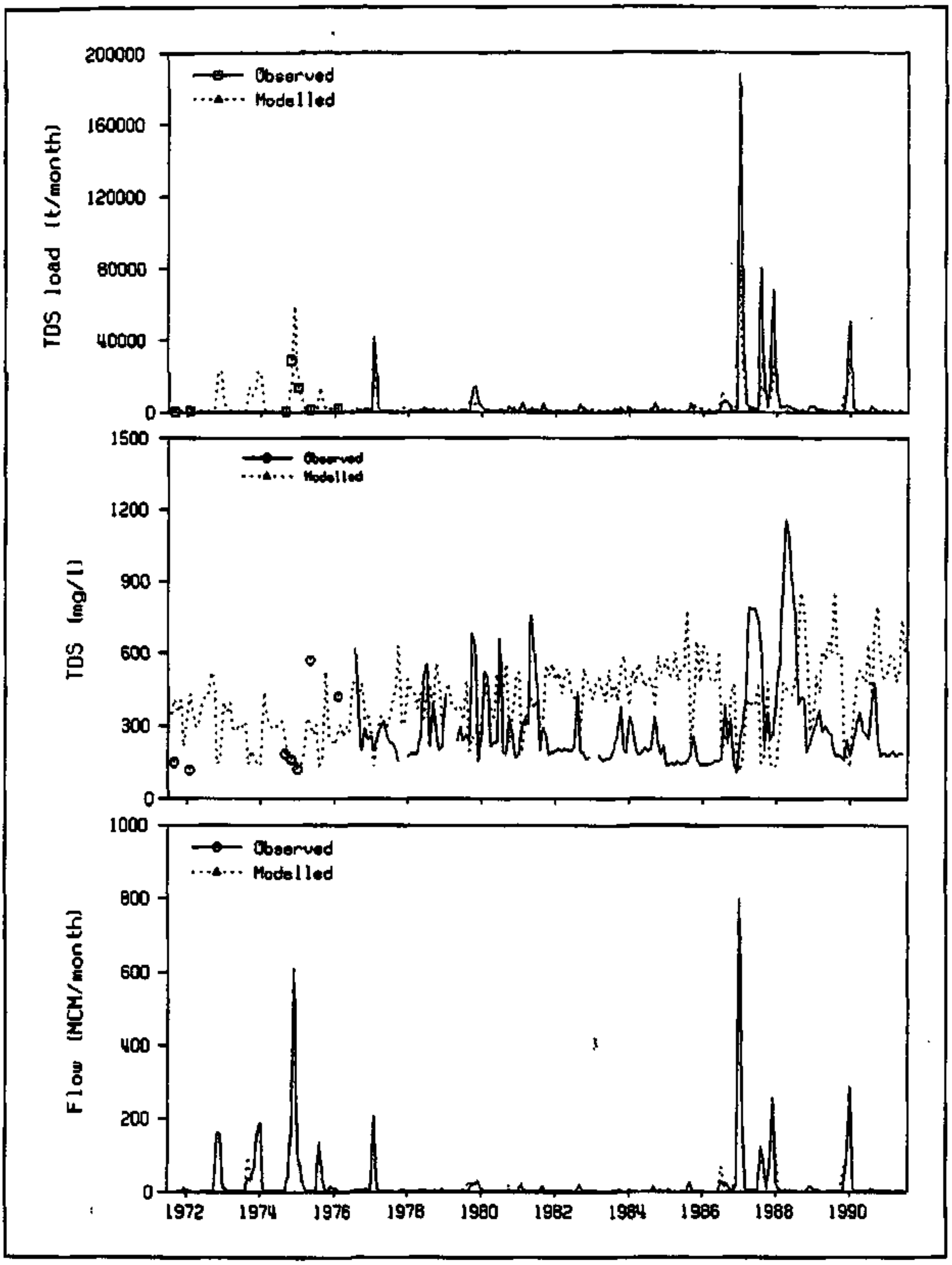
OBS POINT AT DWA7 ROUTE No. 40 1988-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	1437.75	1722.32	.00	.00
Std. dev.	.00	.00	742.49	799.02	.00	.00
N	0	0	26	26	0	0
r		.000000		.289365		.000000
E1		.00		19.79		.00
E2		.00		7.61		.00
SF		-1.00		.90		-1.00
Mean		6.51		1580.01		2084.66
Std. dev.		13.76		888.78		2256.53
N		48		48		48

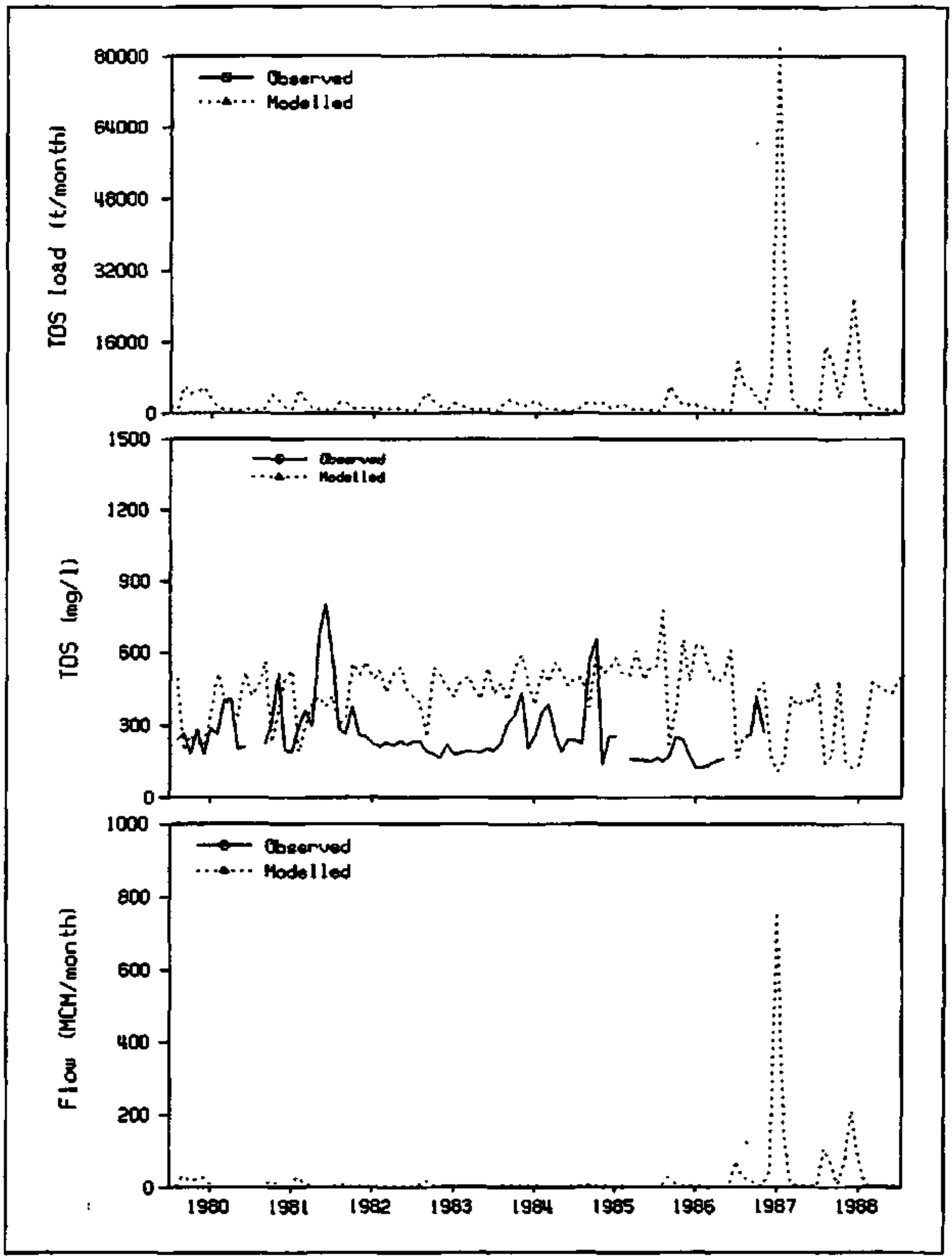
SVB SUB-SYSTEM



Modelled and observed values at Erfenis Dam (C4R0201)



Modelled and observed concentration, flow and load at the C4H004 monitoring station



Modelled flow, modelled and observed concentration and modelled load at the C4H005 monitoring station

OBS POINT AT C4R002 ROUTE No. 4 1966-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	11.24	11.40	141.99	149.62	1421.81	1419.09
Std. dev.	33.77	33.88	30.75	34.13	3433.71	3278.49
N	312	312	162	162	162	162
r		.997758		.564110		.961562
E1		1.46		5.38		-.19
E2		.32		11.01		-4.52
SF		1.00		.97		.98
Mean		11.40		152.20		1413.35
Std. dev.		33.88		32.39		3385.35
N		312		312		312

OBS POINT AT C4H004 ROUTE No. 65 1972-1991

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	20.96	20.19	293.03	432.40	4520.57	3228.06
Std. dev.	75.78	67.65	185.45	148.80	17351.21	7534.35
N	240	240	179	179	179	179
r		.990214		.105547		.945887
E1		-3.65		47.56		-28.59
E2		-10.74		-19.76		-56.58
SF		1.00		.96		.93
Mean		20.19		400.92		3539.87
Std. dev.		67.65		150.15		7977.18
N		240		240		240

OBS POINT AT C4H005 ROUTE No. 63 1980-1988

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	.00	.00	264.31	453.05	.00	.00
Std. dev.	.00	.00	126.29	114.02	.00	.00
N	0	0	82	82	0	0
r		.992976		.178429		.958548
E1		.00		71.41		.00
E2		.00		-9.71		.00
SF		-1.00		.89		-1.00
Mean		19.35		424.89		3529.64
Std. dev.		77.82		134.03		8715.09
N		108		108		108