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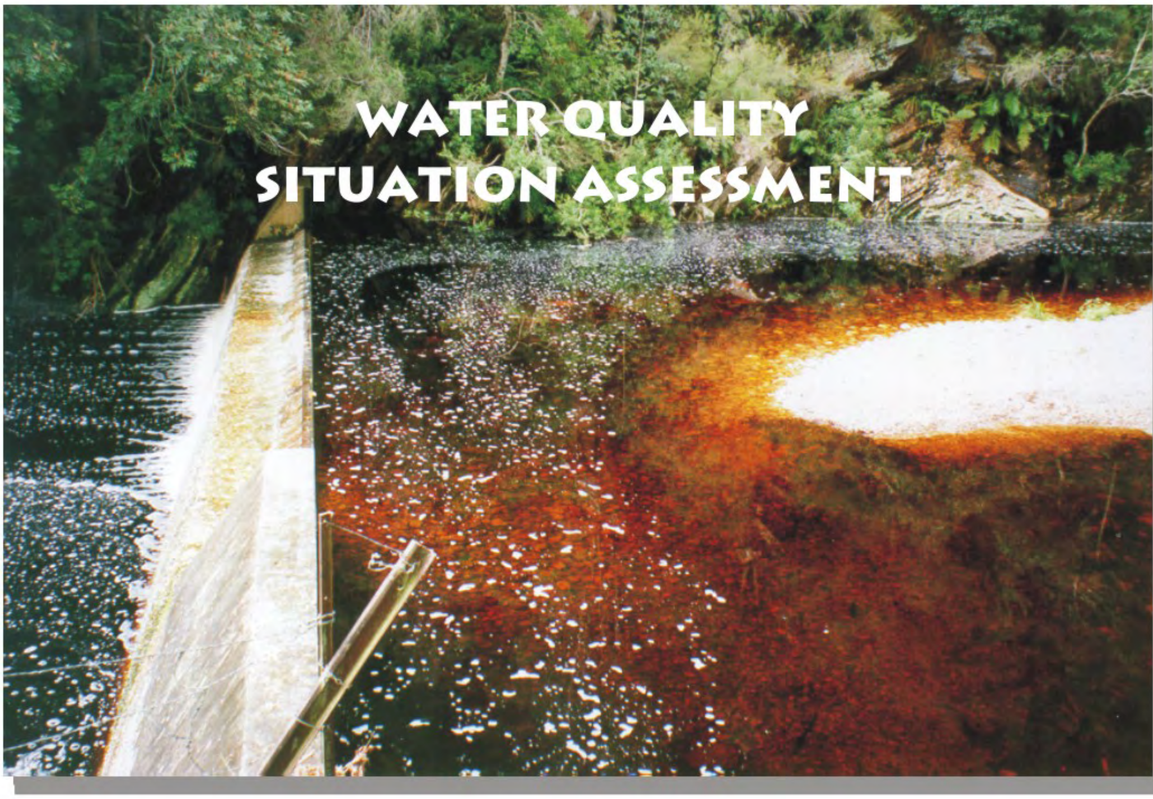
DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY



NINHAM SHAND CONSULTING SERVICES

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DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

DIRECTORATE OF
WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY

WATER QUALITY SITUATION ASSESSMENT

Final

May 2003

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BREEDE RIVER BASIN STUDY

WATER QUALITY SITUATION ASSESSMENT

EXECUTIVE SUMMARY

1. INTRODUCTION

Part 1 of this executive summary provides a broad overview of the water quality status in the Breede River Basin. The majority of agricultural activity in the Breede River catchment is dependent on irrigation water from the Greater Brandvlei Dam and the Breede River. For maximum agricultural development to be realised, it is essential that these water resources be utilised efficiently with respect to the water quality.

Apart from salinity, water quality is not perceived to be a major problem in the Breede River catchment and as a consequence only salinity has been investigated in-depth as covered in Part 2 of this Executive Summary.

2. DESCRIPTION OF THE CATCHMENT

The Breede River catchment comprises the drainage areas of six basins. These are the Ceres Basin (upper part of H100), the Upper Breede River catchment (rest of H100), the Hex River catchment (H200), the Middle Breede River catchment (H300, H400, H500), the Riviersonderend catchment (H600), and the Lower Breede River catchment (H700) (refer to Figure 1.0).

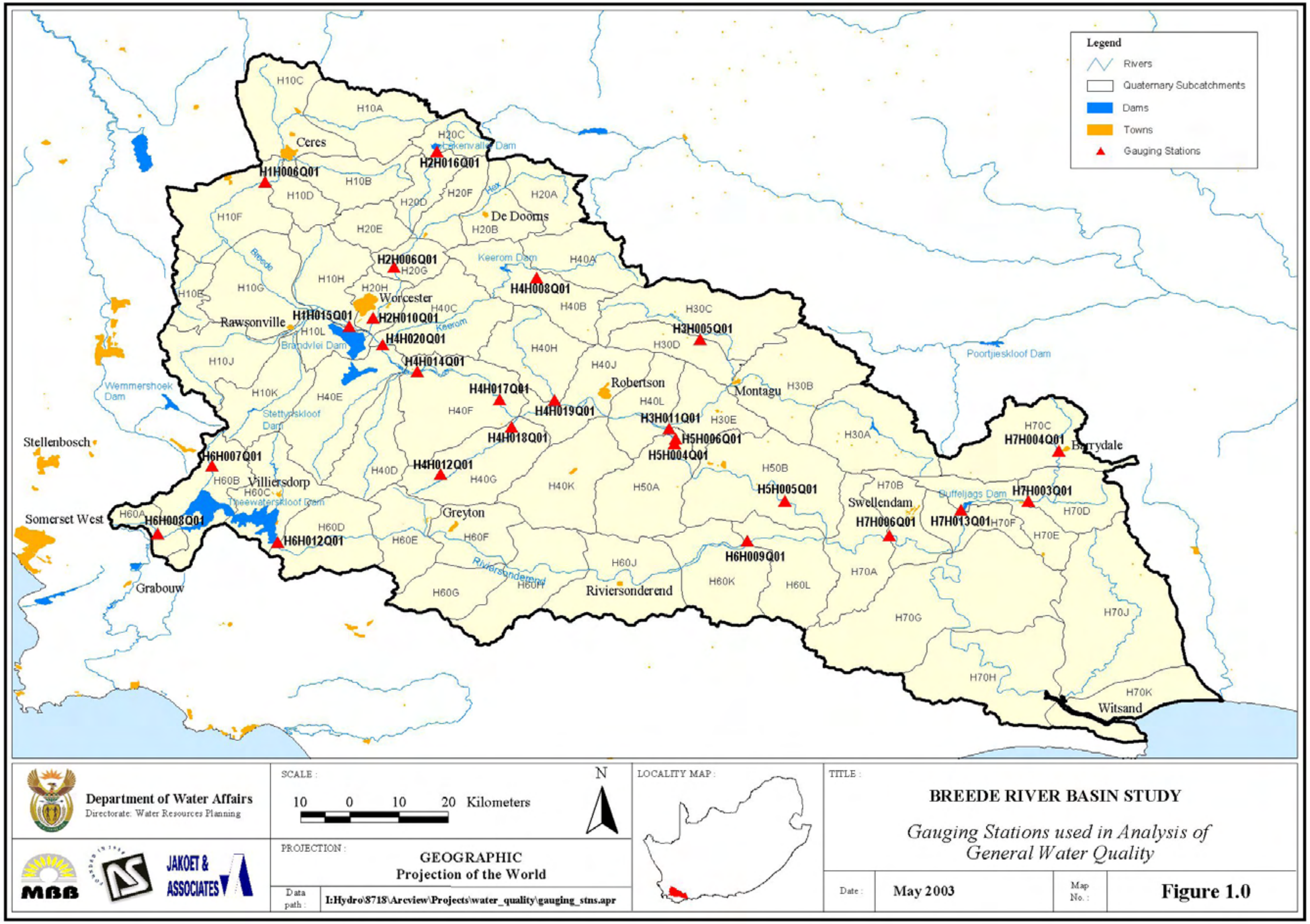
3. MONITORING STATIONS USED IN THE ANALYSIS

The Breede River Basin has some 104 gauging stations at which water quality is monitored. To use all of them in the water quality analysis, however, would be uneconomical and could lead to the misrepresentation of results due to varying data record lengths. Based on the length of data record, the sampling frequency and the spatial distribution, 25 monitoring stations were selected. These stations are depicted in Figure 1.0.

PART 1 – BROAD OVERVIEW OF THE WATER QUALITY STATUS

1. WATER QUALITY VARIABLES OF CONCERN

In the past, the general water quality in the Breede River catchment was not considered to be a major concern. Apart from the rising salinity in the Middle Breede River, the general water quality status has been good. The following issues have, however, been identified as possible problems :


Legend
Rivers
Quaternary Subcatchments
Dams
Towns
Gauging Stations
Ceres
De Doorns
Worcester
Rawsonville
Robertson
Montagu
Barrydale
Stellenbosch
Villiersdorp
Somerset West
Grabouw
Greyton
Riviersonderend
Swellendam
Witsand
Wemmershoek Dam
Brandvlei Dam
Keerom Dam
Stettynskloof Dam
Theewaterskloof Dam
Buffeljags Dam
Poortjieskloof Dam
H1H006Q01
H2H016Q01
H2H006Q01
H4H008Q01
H1H015Q01
H2H010Q01
H4H020Q01
H4H014Q01
H3H005Q01
H4H017Q01
H4H019Q01
H4H018Q01
H3H011Q01
H5H006Q01
H5H004Q01
H6H007Q01
H4H012Q01
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H7H004Q01
H7H003Q01
H6H008Q01
H6H012Q01
H7H006Q01
H7H013Q01
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Department of Water Affairs
Directorate: Water Resources Planning
SCALE :
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LOCALITY MAP :
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BREEDE RIVER BASIN STUDY
Gauging Stations used in Analysis of General Water Quality
PROJECTION :
GEOGRAPHIC
Projection of the World
Data path : I:Hydro\8718\Arcview\Projects\water_quality\gauging_stns.apr
Date : May 2003
Map No. : Figure 1.0

- The occurrence of algal blooms under low flow conditions at certain locations within the Middle Breede River.
- Clogging of canals by filamentous algae and aquatic weeds.

The concerns raised above are the result of nutrient enrichment and could possibly be explained by analysing the trends exhibited by the inorganic nitrogen and phosphorus. To obtain a more representative idea of the water quality issues of concern a Water Quality Technical Working Group was established and a workshop was held to identify all the possible constituents of concern. The additional water quality constituents identified in this way are pH, chloride, sodium, total suspended solids, sodium adsorption ratio (SAR), chemical oxygen demand (COD), pesticide concentration, dissolved oxygen, iron, manganese, bacterial count and electrical conductivity (EC)/total dissolved solids (TDS). In addition, concerns were also expressed about point pollution sources in particular distilleries, cheese and textile factories.

Agricultural activity is the major user of water in the Breede River catchment and the effects and target limits discussed below are mainly with respect to this usage. Other water uses including industrial, environmental, livestock watering, domestic and recreational use have also been considered. The aquatic ecosystem requirements were assessed in greater detail in the Reserve determination component of the Breede River Basin Study. The effect of each water quality constituent and its Target Water Quality Range has been sourced almost entirely from the *South African Water Quality Guidelines* (DWAF, 1996).

2. IMPORTANT TRENDS ISOLATED FROM THE WATER QUALITY SITUATION ASSESSMENT

Spatial variation along the Breede River Mainstream

The Total Dissolved Solids (TDS) concentration increases in a downstream direction with the biggest increase occurring in the Middle Breede River due to intensive farming activity. From gauging station H4H017 to H7H006 the water quality with respect to TDS is only marginally acceptable for domestic usage.

Nitrogen concentrations along the Breede River remain fairly low with little possibility of affecting crop yields. According to the data, eutrophic or hypertrophic conditions are unlikely. The phosphorus concentration along the entire Breede River varies very little from its background value.

The pH Target Water Quality Range (TWQR) for irrigation and industrial usage is transgressed on numerous occasions on the acidic side of the pH scale. This is largely due to naturally acidic water occurring in the Western Cape.

For chloride, sodium and Sodium Adsorption Ratio (SAR) the water quality is within the TWQR from gauging station H1H006Q01 to H4H017Q01 for irrigation and for industrial water use. Downstream of H4H017 the water quality with respect to TDS deteriorates rapidly up to gauging station H5H005. The water quality improves downstream of the Riviersonderend confluence (H7H006) due the good quality water from this river. For livestock watering, however, the water quality is acceptable along the entire mainstream.

Spatial variation along the Hex River

For the irrigation, aquatic and domestic water use the TDS is acceptable in the upper reaches of the river but becomes unacceptable in the lower reaches (H2H010Q01). Moderately enriched nutrient conditions could possibly exist along the entire river reach. For irrigation and environmental water use the pH TWQR is exceeded at all stations. The origin of the low pH water, however, is largely natural. With respect to SAR and chlorides the water quality for irrigation and industrial water use is unacceptable in the lower reaches of the river (downstream of Worcester at gauging station H2H010).

Spatial variation along the Nuy River

The water quality with respect to TDS is poorer than the TWQR for irrigation, domestic and environmental water use. The river reach is also moderately enriched with nutrients, which could cause mesotrophic or eutrophic conditions to occur. The water quality with respect to chloride, sodium and the SAR is unsuitable for irrigation purposes along the entire length of the river.

Spatial variation along the Poesjenels River

The water quality with respect to TDS for irrigation, domestic and environmental purposes is unacceptable in the lower reaches of the river. According to the data, the entire river reach could be moderately enriched with nutrients. For environmental and irrigation water use the water quality with respect to pH is poorer than the TWQR on several occasions. This is largely a natural phenomenon. The water quality with respect to chloride, sodium and the SAR is unsuitable for irrigation and industrial purposes in the lower reaches of the river (H4H018).

Spatial variation along the Kogmanskloof River

The water quality with respect to TDS is poorer than the TWQR for irrigation, domestic and environmental water use along the entire length of the river. The entire river reach is also moderately enriched with nutrients and mesotrophic or even eutrophic conditions could exist. For irrigation purposes the pH is within the TWQR along the entire reach but for environmental purposes the water quality is poorer than the TWQR along the entire river reach. The water quality with respect to chloride, sodium and the SAR is unsuitable for irrigation and industrial purposes along the entire river reach.

Spatial variation along the Riviersonderend

The water quality with respect to TDS is within the TWQR for irrigation and domestic water use along the entire reach of the river. The entire river reach is also moderately enriched with nutrients and mesotrophic conditions could exist. The pH of the water with respect to industrial, irrigation and environmental water use is mostly unacceptable. Low pH water, however, is a natural occurrence in rivers in the Western Cape. The water quality with respect to chloride and sodium is suitable for irrigation and industrial purposes along the entire river reach. The SAR is unacceptable for irrigation usage in the lower reaches of the river, just upstream of the Breede River confluence.

Spatial variation along the Huis and Buffeljags Rivers

The water quality with respect to TDS is within the TWQR for irrigation and domestic water use along the entire river reach. The entire river reach is also moderately enriched with nutrients and mesotrophic or even eutrophic conditions could exist. The pH of the water with respect to industrial, irrigation and environmental water is unacceptable from time to time. The water quality with respect to chloride and sodium is suitable for irrigation and industrial purposes along the entire river. The SAR is unacceptable for irrigation purposes along the entire river.

3. CONCLUSIONS

From the above discussion the following can be concluded :

- Sodium, chloride and electrical conductivity are water quality constituents of concern throughout the catchment and are particularly severe in the Middle Breede River and the lower reaches of its tributaries.
- The sodium adsorption ratio follows a similar trend to that of the sodium and is also a problem in the Middle Breede River and the lower reaches of the tributaries.
- The effect of the high values of the sodium, chloride and electrical conductivity is of particular concern to the irrigation and environmental water use applications.
- The nitrogen concentration is acceptable at most stations, but higher values are consistently recorded at gauging stations H2H006Q01, H4H018Q01 and H3H005Q01.
- At least 25% of the data entries at stations H1H006Q01, H5H004Q01, H4H008Q01, H4H020Q01, H7H004Q01, H7H003Q01, H7H013Q01, H3H005Q01 and H3H011Q01 were within the range for the occurrence of eutrophic conditions.
- The pH at most stations is slightly unacceptable for industrial usage and has also deviated from their background water qualities.

Apart from the high EC, chloride, SAR values and sodium concentrations the other water quality variable are not a major problem at this stage.

4. RECOMMENDATIONS

Based on the discussion and conclusions drawn above the following recommendations can be made :

- Better management strategies for the control of chloride, sodium and EC should be investigated, especially for the Middle Breede River and the lower reaches of the Kogmanskloof, Nuy, Hex and Poesjenels tributaries.
- Management strategies for the application of fertilisers should be implemented to ensure that as little as possible nitrogen and phosphorus reaches the rivers as return flow.
- The routine monitoring of water quality variables should be continued and an attempt should be made to include pesticides, total suspended solids, iron, manganese and temperature monitoring in the catchments where they have been identified as a concern.

PART 2 – SALINITY SITUATION ASSESSMENT

1. OBJECTIVE OF PART 2 AND REQUIRED TASKS

The objective of Part 2 of this executive summary is to provide an overview of salinity management issues and challenges in the Breede River catchment.

The following tasks ensued :

- Review the available literature on hydrosalinity studies performed in the Breede River catchment and confirm the relative contributions of the various sources of salinity.
- Evaluate the salinity status of the Middle Breede River and its tributaries.
- Review the above analyses with respect to the findings of the literature review, focusing on degree, causes and implications of salinisation.
- Describe and evaluate 'proposed' and new solutions to the salinity problems.

2 LITERATURE REVIEW

Thirteen reports on the salinisation of the Breede River were reviewed in an attempt to quantify the relative contribution of salt load from groundwater and from irrigation return flow. The following points from these reports would lead one to believe that irrigation return flow is the major contributor of salt to the Breede River mainstream and the lower reaches of some of its tributaries.

< Very little change was observed in the water levels of monitoring boreholes, indicating that long residence times were experienced by the water travelling to the Breede River.

< The study conducted by MBB (1988), reported return flow values, and salt loads and equivalent concentrations that correspond to observed TDS concentrations in the Middle Breede River. The mass balance study had been well regulated and considerable effort had been expended in obtaining the most accurate data available.

< The strontium ratios of the irrigation return flows corresponded very closely with the ratios found in river water, whereas the ratios in groundwater were slightly higher.

< Re-evaluation of Greeff's (1990) pumping tests revealed that 4000 m^3/day of groundwater entered the Breede River between H4H017 and H5H004. This would indicate that groundwater makes a small contribution to the total flow and salt load of the river.

The current salinity target limit had been defined as follows:

"*At least 50% of the volume of irrigation water supplied to irrigators should have an electrical conductivity (EC_i) not exceeding 70 mS/m. For up to 30 % of the volume supplied, EC_i would be allowed to fluctuate between 70 and 120 mS/m. The remaining 20% of the volume should have an EC_i not exceeding 120 mS/m.*"

3. SALINITY STATUS ALONG THE MIDDLE BREEDE

At present the salinity in the Middle Breede River is controlled by releasing water from Greater Brandvlei Dam to maintain the EC at the Zanddrift off-take at 70 mS/m or lower. At the current level of development (23 100 ha) a total of 30 x 10^6 m^3 of freshening water is required.

Eight water quality monitoring stations were used to assess the salinity status of the Middle Breede River and the exceedance plots of these stations are shown in Figure 3.0.

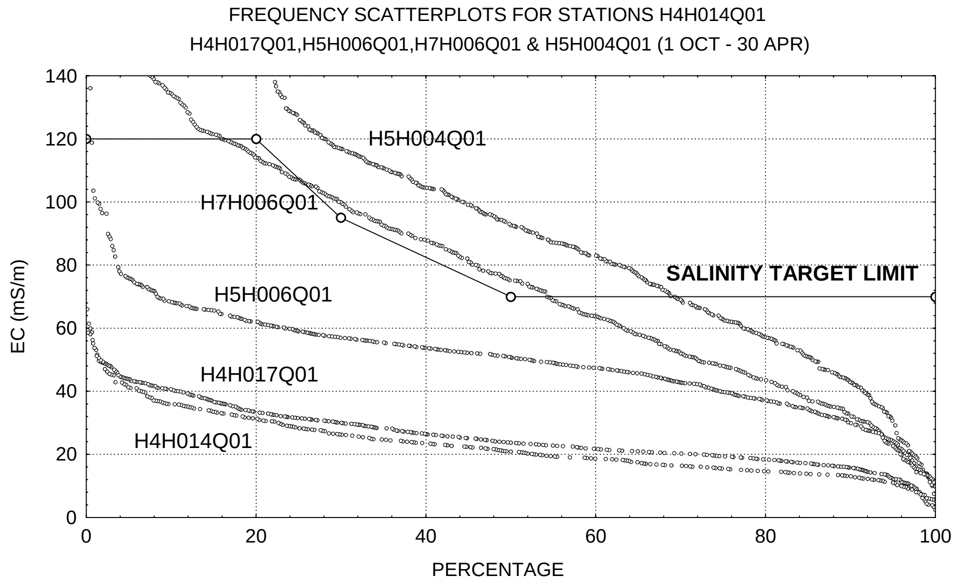

Figure 3.0 : **Exceedance graph for gauging stations along Breede River mainstream**

Salinity of the Middle Breede River deteriorates in a downstream direction (Refer to Figure 1.0). At gauging station H4H014Q01 and H4H017Q01 the water quality meets the salinity target limit for 100% of the time. Downstream of H4H017Q01 the effects of the saline tributaries and the increased irrigation return flows have a marked effect and this can be seen in the deterioration in water quality at the Zanddrift off-take (H5H006Q01) and H5H004Q01 (below Zanddrift take-off). The water quality at Swellendam (H7H006Q01) improves slightly due to the freshening effect provided by the Riviersonderend.

4. WATER QUALITY STATUS OF THE INFLOWING TRIBUTARIES

Figure 4.0 depicts the percentage compliance of the water quality with the set salinity target limit for the irrigation period (1 October - 30 April). It can clearly be seen that the lower reaches of these tributaries are unacceptable for use once the flow reaches its gauging station closest to the Breede River mainstream.

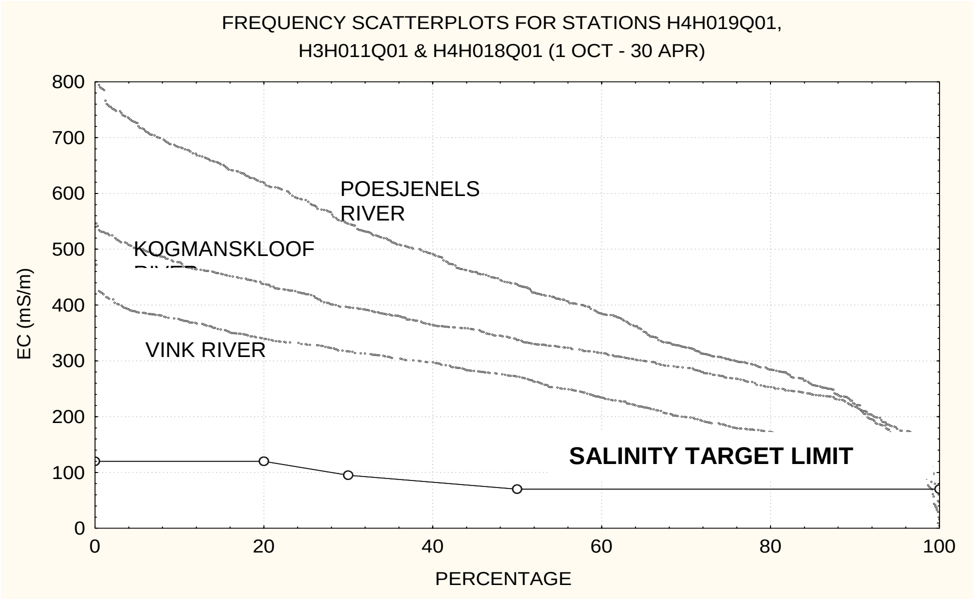

Figure 4.0: **Exceedance plot for tributaries in the Middle Breede River**

5. IMPLICATION OF HIGH SALINITY FOR CROP PRODUCTION

Moolman (1999) showed that the chloride content of leaves provides a good indication of salinity damage and that leaf harvests containing 1 to 4.5 g/kg could be associated with yield reductions of 10 to 20% respectively. More disturbing was the fact that a chloride level of 1.5 g/kg was achieved by irrigating with water that had a chloride concentration as low as 40 mg/ℓ. Although the time varying salinity profile at Zanddrift weir shows that the EC is well maintained at 70 mS/m, the equivalent chloride concentration is approximately 120 mg/ℓ and this could lead to a chloride content of 2g/kg in the leaves and an associated yield loss of up to 20%.

In experiments conducted by Moolman (1999) it was found that irrigation water from the canal with an EC_i of 25-35 mS/m resulted in a soil salinity (EC_e) of 75 mS/m after a single irrigation cycle. Above this soil salinity the yield decreased at a rate of 3% per 10 mS/m salinity increase in irrigation water (EC_i).

Moolman (1999) concluded that the EC target levels set by the Department of Water Affairs and Forestry (DWAF) for managing water quality at the lowest point of the government water scheme were too high to prevent a reduction in crop yield and that an additional target limit related to chloride content would also be appropriate.

6. EVALUATION OF 'PROPOSED' AND NEW ENGINEERING SOLUTIONS

Five engineering solutions have previously been proposed for dealing with the salinity problem in the Middle Breede River. An additional solution has been added during this study. The engineering solutions are listed below:

- **Option A – High level canal** (From Greater Brandvlei Dam starting at a level of 289 metres above sea-level (masl). Total length of the canal distribution system, on both sides of the river, and extending to areas to the east of Montagu, is 530 km with inverted siphons at Rooibrug and Skurwekop)
- **Option B – Low level canal** (Starting from approximately the same position as the existing Le Chasseur canal at a height of 198 masl. Total length of the canal distribution system, on both sides of the river, and extending to areas to the east of Montagu, will be 420 km)
- **Option C – Low level canal with pumping scheme** (The canal will start at Skurwekop at a height of 185 masl)
- **Option D – Phased canal and pump scheme** (Similar to high level canal, but will be implemented in phases as required.)
- **Option E – Diversion of saline irrigation return flows**
- **Option F – Diversion and treatment of irrigation return flows**

Analysis of the 'technical efficiency' of the high level canal and diversion of saline irrigation return flow had previously been undertaken (DWAF, 1992). The results of this analysis indicated that the implementation of a high level canal would ensure that the salinity target limit at Zanddrift weir is always met, even at full irrigation development. This would, however, imply that the reach of the river immediately upstream of the Vink River confluence would become a conduit for transporting saline irrigation return flow.

The diversion of saline irrigation water between Robertson and the Kogmanskloof River was also modelled and the results showed that this option would be ineffective by itself but could provide a meaningful short-term solution when combined with freshening releases from Greater Brandvlei Dam. The life span of this solution could be extended through disposing of the saline return flows by evaporation, or by diverting these into a canal leading to a temporary storage dam for release during winter below the irrigated areas. It would also be possible to treat the effluent by means of a bank of ion-exchange columns, but the economic implications of such a scheme are not known at present.

7. FINANCIAL INSTRUMENTS

Financial instruments for dealing with the salinity situation had been identified by Pegram, Görgens and Quibell (2000). These are listed below :

- **Registration and application fees**, which may be required for water use licences and general authorisations.
- **Penalties**, which can be implemented for offences in terms of the regulation of water use. Catchment Management Agencies may recover cost incurred to implement remediation strategies where a directive has not been complied with.
- **Pricing strategy**, which allows the cost of water to be increased or decreased depending on the quality of waste generated and management practices implemented.

These strategies would have to be implemented together with an engineering solution to be effective.

8. CONCLUSIONS

From the salinity situation assessment, the following can be concluded :

- Irrigation return flows have a major influence on the quality of water in the Breede River mainstream and its major tributaries.
- The water quality at Zanddrift canal is still within the current salinity target limit, but the situation will change once irrigation development increases.
- The farmers downstream of the Government Water Scheme are already receiving water which does not comply with the prescribed limits and this will worsen with time.
- The downstream reaches of the Poesjenels, Kogmanskloof and Vink Rivers cannot be used for irrigation purposes as they exceed the prescribed salinity limit for almost 100% of the time.
- Should salinity levels be allowed to increase, this will affect the economic growth in the area because of its negative effect on crop yields.
- The salinity issues can be remediated by freshening release increases, implementation of canal systems, end-of-line treatment and optimum management strategies.
- Even if the current salinity limits are maintained, there will still be a decrease in yield because the detrimental effects of salinity increase with time (accumulation of salt in the soil and subsequent increase in soil salinity).
- Sufficient leaching water will have to be supplied to the farmers to enable them to maintain the soil salinity as close as possible to 100 mS/m.
- The current EC limit at the Zanddrift weir is too liberal as it can still effect a 10 to 30% yield reduction in crop yield.
- The chloride ion concentration has a negative effect on the yield as a specific ion and as part of the collective in its contribution to the TDS.

9. RECOMMENDATIONS

Based on the salinity situation assessment and the conclusions drawn above the following recommendations can be made :

- Each of the solutions presented above should be evaluated for its technical effectiveness by using the DISA model.
- The economic impact of the proposed solutions should be investigated and evaluated.
- The environmental impact of each solution should be assessed.
- The current salinity target level at the Zanddrift weir should be redefined based on the outcome of the above tasks.
- The routine monitoring of total dissolved solids and its constituents should continue.

BREEDE RIVER BASIN STUDY

PART 1 : WATER QUALITY SITUATION ASSESSMENT

PART 2 : SALINITY SITUATION ASSESSMENT

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PART 1

WATER QUALITY SITUATION ASSESSMENT

BREEDE RIVER BASIN STUDY

PART 1 :
WATER QUALITY SITUATION ASSESSMENT

1. INTRODUCTION

This report provides a broad overview on the water quality situation in the Breede River Basin.

1.1 PURPOSE OF STUDY

The majority of agricultural activity in the Breede River catchment is dependent on irrigation water from the Greater Brandvlei Dam and the Breede River. For maximum agricultural development to be realised, it is essential that these water resources be utilised efficiently with respect to the water quality.

Apart from salinity, water quality is not perceived to be a major problem in the Breede River catchment and as a consequence only salinity has been investigated in-depth (Section 2 of this report). The purpose of this report is to assess and quantify the broad water quality issues in the Breede River catchment.

1.2 LAYOUT OF REPORT

This report has been divided into two major sections, viz.

Part 1 : A review of basin-wide water quality trends, and
Part 2 : An in-depth assessment into the salinisation of the Middle Breede River, focusing on magnitude, causes, implications and solutions to the salinity problem

Part 1 of this report provides a general description of the study area, followed by a discussion on the general water quality issues of concern and the criteria used for selecting monitoring points used in the graphical analyses. This is followed by a section on the trend analysis of the water quality data and the effect of point source discharges on the organic load of the river. Part 2 then follows.

2. DESCRIPTION OF STUDY AREA

2.1 GENERAL DESCRIPTION

The Breede River catchment comprises the drainage areas of six basins. These are the Ceres basin (upper part of H100), the Upper Breede River catchment (rest of H100), the Hex River catchment (H200), the Middle Breede River catchment (H300, H400, H500), the Riviersonderend catchment (H600), and the Lower Breede River catchment (H700) (refer to Figure 3.1).

3. A REVIEW OF THE AVAILABILITY OF BASIN-WIDE WATER QUALITY DATA

3.1 MONITORING POINTS

The Breede River catchment has some 104 gauging stations where the Department of Water Affairs and Forestry collects water samples to characterise water quality in the Breede River basin (Figure 3.1). The lengths of the data records and sampling frequencies differ from station to station. At best, it can be expected that the sampling stations were monitored on a weekly basis, but this is not usually the case. To obtain a representative overview of basin-wide trends it was necessary to select a smaller number of monitoring stations. The criteria for selecting these monitoring stations are described below.

3.1.1 Selection of Monitoring Points

The general water quality status of the Breede River catchment was analysed by examining the trends at a limited number of monitoring stations. To obtain meaningful overview trends, it was essential that the data records be analysed for the following :

- The length of the data record (with special reference to gaps in the data record) to assess historical and present water quality status,
- The sampling frequency (weekly, monthly or *ad hoc*), and
- The distribution of sampling points in a sub-catchment.

By adhering to these criteria it was possible to eliminate the distorted results obtained from the analyses of short or incomplete data records. Monitoring points were also selected such that a spatial trend along the Breede mainstream and along its tributaries could be identified.

3.1.2 List of Monitoring Points Selected

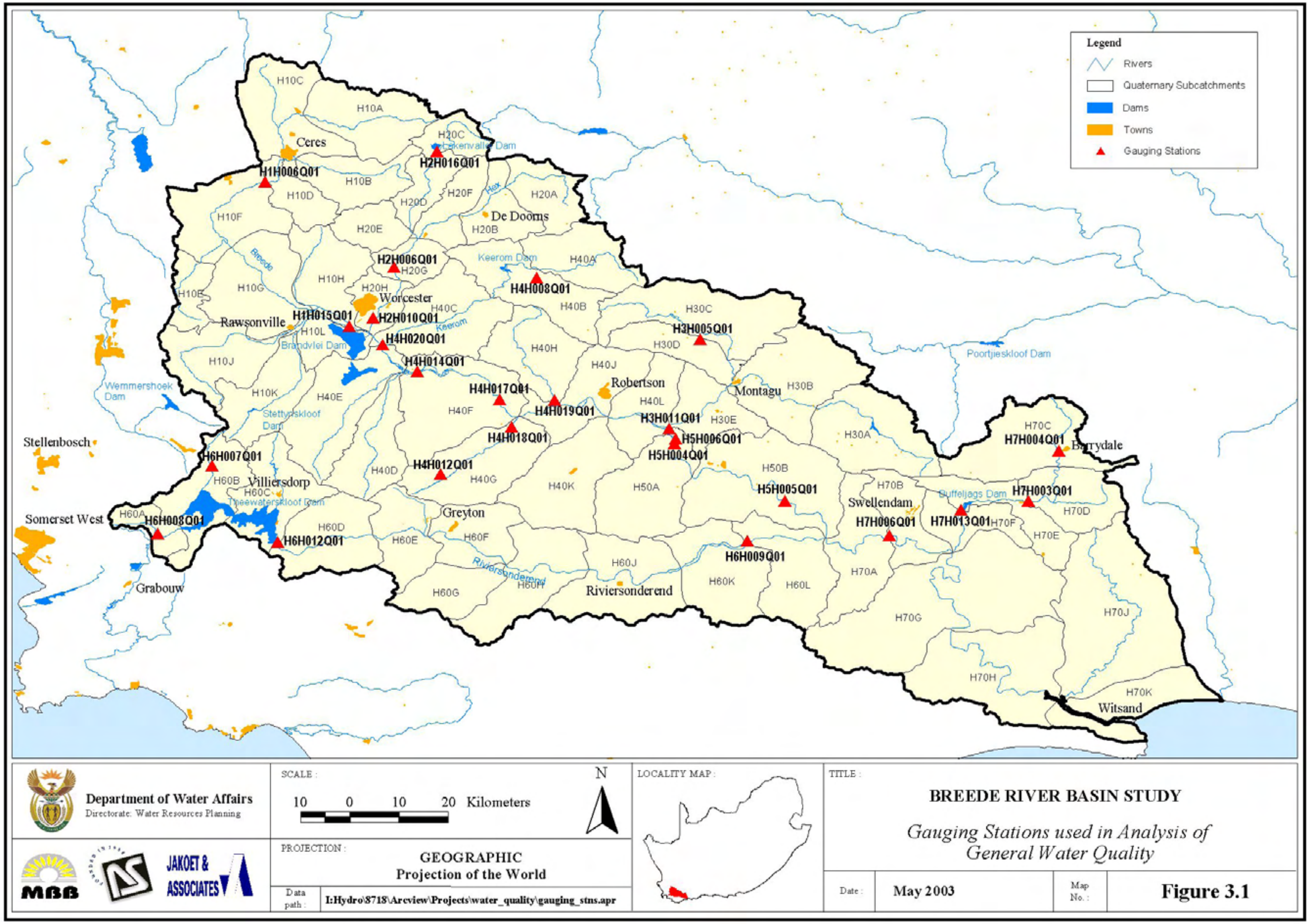
Based on the criteria above, the following gauging stations have been selected for statistical and graphical analyses.

TABLE 3.1.1 : LIST OF MONITORING STATIONS SELECTED FOR ANALYSES

STATION	DESCRIPTION	SAMPLES	FIRST DATE	LAST DATE
Breede River Main Stem				
H1H006Q01	Breede River at Ceres Commonage	923	08/20/71	09/23/99
H1H015Q01	Breede River at Die Nekkies	752	05/05/70	09/17/99
H4H014Q01	Breede River at Karroo/Moordkuil	694	02/15/73	06/15/92
H4H017Q01	Breede River at Le Chasseur	1010	07/14/80	09/21/99
H5H004Q01	Breede River at Wolvendrift/Secunda	1080	05/06/70	09/21/99
H5H005Q01	Breede River at Wagenboomsheuvel/drew	1108	02/15/73	09/14/99
H5H006Q01	Zanddrift canal from Breede River	930	11/12/79	09/21/99
H7H006Q01	Breede River at Swellendam	841	03/16/66	09/14/99
Hex River				
H2H006Q01	Hex River at Glen Heatlie	917	11/05/80	09/17/99
H2H016Q01	Lakenvallei Dam On Sanddrifskloof River	266	01/13/77	09/15/99
H2H010Q01	Hex River at Worcester/drie Riviere	872	04/03/81	08/17/99
Kogmanskloof River				
H3H005Q01	Keisie River at Keisiesdoorns	181	11/04/65	01/20/99
H3H011Q01	Kogmanskloof River at Goudmyn	992	11/27/79	09/21/99
Koo and Nuy Rivers				
H4H008Q01	Koo River at Dwars in Die Weg	171	07/12/77	09/01/92
H4H020Q01	Nuy River at Doornriver	753	05/12/81	09/21/99
Poesjenels River				
H4H018Q01	Poesjenels River at Le Chasseur	1076	11/02/73	09/21/99
H4H012Q01	Waterkloof Spruit at Poesjenels Rivier	316	12/15/70	08/24/92
H4H019Q01	Vink River at De Goree	1026	09/01/72	09/21/99
Riviersonderend River				
H6H007Q01	Du Toits River at Purgatory Outspan	375	04/17/73	08/24/92
H6H008Q01	Riviersonderend at Swarte Water	378	02/27/67	08/24/92
H6H012Q01	Theewaterskloof Dam on Riviersonderend	486	02/03/77	08/24/99
H6H009Q01	Riviersonderend at Reenen	884	12/04/73	09/14/99
Buffelsjags and Huis River				
H7H013Q01	Buffelsjags Dam on Buffeljags River	74	01/02/78	07/28/99
H7H004Q01	Huis River at Barrydale	351	08/13/77	08/24/99
H7H003Q01	Buffeljags River at Suurbraak	636	04/04/79	06/03/98

Note: The last date refers only to the last date in the data record that the team obtained from DWAF. In most cases, sampling is continuing at these monitoring stations.

It is believed that these gauging stations will give an overall picture of the general water quality status in the Breede River. The positions of these gauging stations are depicted on Figure 3.1.


Legend
Rivers
Quaternary Subcatchments
Dams
Towns
Gauging Stations
Ceres
De Doorns
Worcester
Rawsonville
Robertson
Montagu
Barrydale
Stellenbosch
Villiersdorp
Somerset West
Greyton
Swellendam
Grabouw
Riviersonderend
Witsand
Brandvlei Dam
Keerom Dam
Poortjieskloof Dam
Wemmershoek Dam
Stettynskloof Dam
Theewaterskloof Dam
Buffeljags Dam
H1H006Q01
H2H016Q01
H2H006Q01
H4H008Q01
H1H015Q01
H2H010Q01
H4H020Q01
H4H014Q01
H3H005Q01
H4H017Q01
H4H019Q01
H3H011Q01
H5H006Q01
H5H004Q01
H4H018Q01
H4H012Q01
H6H007Q01
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H5H005Q01
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H7H006Q01
H7H013Q01
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Department of Water Affairs
Directorate: Water Resources Planning
SCALE :
10 0 10 20 Kilometers
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LOCALITY MAP :
TITLE :
BREEDE RIVER BASIN STUDY
Gauging Stations used in Analysis of General Water Quality
PROJECTION :
GEOGRAPHIC
Projection of the World
Data path : I:Hydro\8718\Arcview\Projects\water_quality\gauging_stns.apr
Date : May 2003
Map No. : Figure 3.1
MBB
JAKOET & ASSOCIATES

4. WATER QUALITY ISSUES OF CONCERN

In the past, the general water quality in the Breede River catchment was not considered to be a major concern. Apart from the rising salinity in the Middle Breede River the general water quality status has been good. The following issues have, however, been identified as possible problems :

- The occurrence of algal blooms under low flow conditions at certain locations within the Middle Breede River.
- Clogging of canals by filamentous algae and aquatic weeds.

The concerns mentioned above result from nutrient enrichment of the water body and it is envisaged that trend analyses of inorganic nitrogen and phosphorus would explain the occurrence of these problems. In addition, it is believed that pH, chloride, sodium, total suspended solids, sodium adsorption ratio (SAR), chemical oxygen demand (COD), pesticide concentration, dissolved oxygen, iron, manganese, bacterial count and electrical conductivity (EC)/total dissolved solids (TDS) are also posing a problem in certain areas of the catchment.

Algae and macrophytes were also of concern to aquatic ecosystems as they reduce habitat diversity and therefore biodiversity.

Pesticides would also have a significant impact on the aquatic ecosystem if occurring in the river in certain forms.

These issues were dealt with in a qualitative manner because there was no data available to assess the present situation.

To obtain a more realistic idea of the extent of water quality problems in the Breede River a Water Quality Technical Working Group (WQTWG) was established. According to the Inception Report, two meetings were required with the WQTWG. The first of these meetings was held on 17 April 2000 where additional water quality concerns were discussed. From the discussions it was possible to construct a list of the constituents of concern as well as the catchments in which they were most severe. The constituents of concern are listed in Table 4a.

TABLE 4a : LIST OF CONCERNS RAISED BY WATER QUALITY TECHNICAL WORKING GROUP

PARAMETER OF CONCERN	CATCHMENTS						
	H1	H2	H3	H4	H5	H6	H7
Soil salinisation							
Pesticides							
Nutrients							
Groundwater Quality							
Hyacinth							
Toxic Algae							
Filamentous Algae							
Bacteriology							
Organic Load (COD/Low O_2)							
Coloured Water							
Total Suspended Solids (TSS)							
TDS in river mouth							

A more refined list of water quality constituents was also identified by the WQTWG. This list identified the macro-scale water users in the basin as well as the water quality constituents that are of concern to them. The macro-users and the constituents of concern are shown in Table 4b. Of the parameters listed it was only possible to quantify the effects of those constituents that are monitored by the DWAF on a regular basis. In addition, concerns were also expressed about point pollution sources, in particular distilleries, cheese and textile factories.

Agricultural activity is the major user of water in the Breede River catchment and the effects and target limits discussed below are mainly with respect to this usage. Other water uses including industrial, environmental, livestock watering, domestic and recreational have also been considered. The aquatic ecosystem requirements were assessed in greater detail in the Reserve determination component of the Breede River Basin Study.

The effect of each water quality constituent and its Target Water Quality Range is described below. The information has been sourced, almost entirely, from the *South African Water Quality Guidelines* (DWAF, 1992).

4.1 TOTAL DISSOLVED SOLIDS (TDS)/ELECTRICAL CONDUCTIVITY (EC)

Total dissolved solids (TDS) are a measure of the quantity of various inorganic salts dissolved in water. The EC is a measure of the ability of water to conduct electrical current and is directly proportional to the TDS concentration of the water. The causes of salinity and the implications thereof (on irrigation) will be discussed at length in Part 2 which examines the salinity water quality status in the Middle Breede River in detail.

4.1.1 Irrigation Water Use

Irrigation with saline water results in the accumulation of salts in the soil, which in turn causes crop yield reductions. A salinity target range for the irrigation of grapevines (major crop type in the basin) was specifically defined for the Breede River (SIRI, 1988). The criteria are specified in terms of the electrical conductivity of the of the irrigation water (EC_i) and were defined as follows:

"*At least 50% of the volume of irrigation water supplied to irrigators should have a electrical conductivity (EC_i) not exceeding 70 mS/m. For up to 30 % of the volume supplied, EC_i would be allowed to fluctuate between 70 and 120 mS/m. The remaining 20% of the volume should have an EC_i not exceeding 120 mS/m.*"

4.1.2 Aquatic Ecosystem Water Use

For aquatic ecosystems the absolute TDS seems to be less important than the rate of change of the TDS. Fish try to maintain their internal salt concentration at approximately 10 g/ℓ regardless of the external concentration. In fresh water the fish have a higher salt concentration than the surrounding water and as a result ions diffuse out of the body of the fish. If the concentration of salts in the water is higher than that in the fish then salts will diffuse into the fish and metabolic disfunction and mortality will occur. The Target Water Quality has been listed in Table 4.1 below.

TABLE 4b : REFINED LIST OF CONSTITUENTS OF CONCERN AS ISOLATED BY THE BREEDE RIVER BASIN WATER QUALITY TECHNICAL WORKING GROUP

	Cl	Na	SAR	TDS	N	P	TSS	pH	Fe/Mn	BACTERI-OLOGY	ALGAE	PESTICIDE	COD	DO	EMS	MACRO-PHYTES
Irrigation																
Domestic																
Industrial																
Environment																
Recreation																
Livestock Watering																

TABLE 4.1 : TARGET WATER QUALITY RANGE FOR TDS IN AQUATIC ECOSYSTEMS

WATER RESOURCE	TARGET WATER QUALITY RANGE
All inland waters	• The TDS concentration should not be changed by > 15% from the normal cycles of the water body under unimpacted conditions at any time of the year • The amplitude and frequency of natural cycles in TDS concentrations should not be changed.

4.1.3 Domestic Water Use

High concentrations of salts impart an unpleasant taste to water and may adversely affect the kidneys. Washing with water having a high TDS concentration may give rise to excessive skin dryness and soap may lather poorly due to calcium hardness. Chemical corrosion and scaling may also occur leading to increased plumbing costs. The Target Water Quality Range for TDS in domestic water supplies had been set between 0 - 450 mg/ℓ or equivalently an EC of 0 - 70 mS/m (WRC, 1989).

4.2 TOTAL NITROGEN CONTENT (NH_3, NH_4^+, NO_2^- and NO_3^-)

Nitrogen is one of the macro plant nutrients and its uptake by plants is mainly considered to be beneficial.

4.2.1 Irrigation Water Use

Inorganic nitrogen occurs mainly in the form of nitrate (NO_3^-) in irrigation water. The amount of nitrate added to the soil by irrigation water, however, is small compared to that applied as fertilizer or released from decaying organic matter. For irrigation use the Target Water Quality for nitrogen had been set at 5 mg/ℓ. Below this concentration it is believed that the nitrogen will not affect the yield of the crop nor would it cause groundwater contamination. Nitrogen in irrigation water is of concern because of the following :

- Its stimulatory effect on plant growth when applied in excess of plant requirements.
- Its potential to leach and contaminate groundwater sources.
- Its stimulatory effect on nuisance growth of algae and aquatic plants in irrigation structures (canals, storage dams etc.) that can interfere with the efficient distribution of irrigation water by clogging valves, pipelines, sprinklers and filtering equipment.

4.2.2 Environmental Water Use

A concentration of 0.5 mg N/ℓ or less is considered to be sufficiently low to limit the degree of eutrophication and nuisance growth of blue-green algae and other plants. The trophic conditions induced by varying nitrogen concentrations are given in the Table 4.2a below.

TABLE4.2a : TROPHIC CONDITIONS INDUCED BY VARYING NITROGEN CONCENTRATION

AVERAGE SUMMER INORGANIC NITROGEN CONCENTRATION (mg N/ℓ)	EFFECTS
<0.5 (Target Water Quality)	**Oligotrophic conditions**; no nuisance growth of aquatic plants or blue-green algae
0.5 - 2.5	**Mesotrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic
2.5 - 10	**Eutrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife
>10	**Hypertrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; often including species which are toxic to man, livestock and wildlife

The Target Water Quality Range for nitrogen in the aquatic environment is defined below.

TABLE 4.2b: CRITERIA FOR NITROGEN CONCENTRATION IN THE AQUATIC ENVIRONMENT

WATER RESOURCE	TARGET WATER QUALITY RANGE
All surface waters	• Inorganic nitrogen concentrations should not be changed by more than 15% from that of the water body under local unimpacted conditions at any time of the year; and • The trophic status of the water body should not increase above the its present level, though a decrease in tropic status is permissible; and • The amplitude and frequency of natural cycles in inorganic nitrogen concentrations should not be changed.

4.3 SOLUBLE REACTIVE PHOSPHORUS (ORTHOPHOSPHATES) (HPO_4^{2-}, $H_2PO_4^-$)

Phosphorus is actively taken up by plants and is seldom present in high concentrations in natural water bodies. Natural sources of phosphorus in the soil include the weathering of rock and subsequent leaching as well as the decomposition of organic matter. It is added to water bodies via domestic or industrial effluent and non-point sources. Non-point sources of phosphorus include precipitation, urban run-off and drainage from land on which fertilizers have been applied.

4.3.1 Environmental Water Use

Concentrations of phosphorus in surface waters normally range from 10 to 50 µg P/ℓ. Average summer inorganic concentrations of phosphorus provide the best basis for estimating the biological consequences of phosphorus. It has been observed that unimpacted streams typically have a N:P ratio greater than 25 to 40:1 whilst impacted streams (eutrophic and hypertrophic) had a N:P ratio less than 10:1. It is considered that a phosphorus concentration of less than 5 µg P/ℓ is sufficiently low to reduce the possibility of algal and other nuisance plant growth in water bodies (Table 4.3).

TABLE 4.3 : TROPHIC CONDITIONS INDUCED BY VARYING PHOSPHORUS LEVELS

AVERAGE SUMMER INORGANIC PHOSPHORUS CONCENTRATION (µg P/l)	EFFECTS
<5	**Oligotrophic conditions**; no nuisance growth of aquatic plants or blue-green algae
5 - 25	**Mesotrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic
25 - 250	**Eutrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife
> 250	**Hypertrophic conditions**; nuisance growth of aquatic plants and blooms of blue-green algae; often including species which are toxic to man, livestock and wildlife

4.4 TOTAL SUSPENDED SOLIDS (TSS)

TSS is a measure of the amount of solids suspended in water. The major portion of the suspended material in a river is soil derived from land surfaces. Other sources of suspended material include domestic sewage, industrial effluent, mining operations, fish farm effluent and physical disruptions from construction activities. Potential problems which could arise from high concentrations of solids are listed in Table 4.4.

4.4.1 Irrigation Water Use

The effects of the TSS concentration is most visible for irrigation uses. The following effects have been reported:

- Crop yield is affected by reduction of photosynthetic activity.
- Films formed by deposition of suspended sediments reduce the amount of sunlight obtained by the leaves.
- The marketed product's appearance is soiled by the deposition of suspended solids.
- Reduction in soil infiltration rate and/or the emergence of seedlings because of soil surface crust being deposited by suspended solids.
- Clogging can be expected in irrigation systems.
- Accelerated wear of sprinkler irrigation nozzles and other components in the distribution system.

The effects of suspended solids on drip irrigation systems are listed in Table 4.4a below:

TABLE 4.4a : LIST OF PROBLEMS WHICH COULD BE EXPERIENCED WITH SUSPENDED SEDIMENTS

CONCENTRATION RANGE (mg/ℓ)	CLOGGING OF DRIPPERS
#50	(Target guideline range) No problem with drip irrigation
50 - 100	Slight to moderate problems with drip irrigation emitters
>100	Increasingly severe problems with drip irrigation emitters

4.4.2 Environmental Water Use

The effect of TSS on the aquatic ecosystem is measured in terms of the following :

- acute and chronic physiological effects on aquatic organisms.
- changes from "natural" site-specific TSS levels that cause changes to ecosystem structure and functioning.

The presence of suspended sediments reduces the amount of sunlight available to aquatic plants for photosynthesis. This in turn would reduce food production and the availability of food to aquatic organisms higher up in the food chain. Suspended solids may also interfere with the filter-feeding organism's gill functioning, foraging efficiency and growth. Settling of suspended matter under quiescent conditions could smother the benthic plants and animals with a resultant change in the biotic community. The prescribed Target Water Quality Range for TSS in aquatic ecosystems is reflected in Table 4.4b.

TABLE 4.4b : TARGET WATER QUALITY RANGE FOR TSS IN AN AQUATIC ENVIRONMENT

ALL AQUATIC ECOSYSTEMS	TARGET WATER QUALITY RANGE
Background TSS concentrations are less than 100 mg/ℓ	Any increase in TSS concentrations must be limited to < 10 % of the background TSS concentrations at a specific site and time.

4.4.3 Domestic Water Use

The presence of suspended matter in the water could present a problem to the treatment facilities, although well designed water treatment plants are able to cope with this problem and the suspended matter can easily be removed. If no treatment is available the visual appeal of the water will be impaired and the risk of infection by waterborne diseases will increase due to the micro-organisms associated with suspended particulate matter. No limit for total suspended solids had been set for Domestic Water Usage.

4.4.4 Recreational Water Use

Suspended solids contribute to the turbidity of a water body and detract from the aesthetic appeal of the water. If the concentration of suspended solids is high the particles may hide the presence of potentially hazardous objects below the water surface. Evidence of shallow areas may also be obscured and the risk of infection may increase. No Target Water Quality Limit has been specified for total suspended solids with regard to recreational use. However, for water clarity, a target guideline range has been specified as a secchi disk depth greater than 3.0 m (or turbidity less than 1.0 NTU).

4.5 pH VALUE

The pH of a solution is defined by the expression :

$$\mathbf{pH = \log_{10} [H^+]}$$

Where $[H^+]$ is hydrogen ion concentration.

At pH values below 7 a solution is deemed to be acidic, while above 7 it is alkaline. An important concept linked to the pH of a solution is the buffering capacity which determines the rate of change of pH in a solution. The pH of surface waters in South Africa varies from 4 to 11. Very diluted sodium-chloride-dominated waters have been found to be poorly buffered because they contain virtually no carbonate or bicarbonate. Acidification of a river can be caused by the following :

- Low pH effluents received from industries.
- Acid mine drainage
- Atmospheric pollution from the burning of coal and the exhaust of combustion engines. Both SOx and NOx gases form strong mineral acids when dissolved in water.

4.5.1 Irrigation Water Use

The effects of pH on irrigation water are evaluated by the effects on crop yield, ability of the soil to sustain long term cultivation, and damage to irrigation equipment.

The soil pH changes slowly because it is very well buffered. A change in pH can be corrected by the addition of alkali or acid depending on which is required. The solubility and bio-availability of many plant nutrients and potentially toxic metals are dependent on the pH.

Direct contact of low or high pH water with crop foliage could cause foliar damage and this could result in decreased yield or damage to fruit and other marketable products.

Extreme pH values have been associated with corrosion of irrigation equipment. The Target Water Quality Range for irrigation usage has been defined to be between 6.5 and 8.4. In this range the irrigation water should cause no foliar damage or reduction in yield. The soil pH in this range does not present a problem on account of the low availability of nutrients or toxic levels of heavy metals.

4.5.2 Environmental Water Use

Direct effects of pH variation consist of changes in the ionic and osmotic balance in individual organisms. Of particular importance is the rate and the type of ion exchanged across body surfaces. Under these conditions maintenance of the osmotic balance requires a greater expenditure of energy with the result that the growth rate slows and reduced fecundity becomes apparent. Indirect effects of pH changes include the availability of toxic substances such as aluminium and un-ionized ammonia. The gradual reduction in pH could cause a change in community structure, with acid-tolerant species replacing less tolerant species. The discharge of acid waste to waters containing bi-carbonate alkalinity, and which are alkaline, will result in the liberation of carbon dioxide gas which is toxic to fish.

The pH criteria for any aquatic ecosystems are listed in Table 4.5 below.

TABLE 4.5 : TARGET WATER QUALITY RANGE FOR pH IN THE AQUATIC ECOSYSTEM

WATER RESOURCE	TARGET WATER QUALITY RANGE
All aquatic ecosystems	pH value should not be allowed to vary from the range of the background pH values for a specific site and time of day, by > 0.5 of a pH unit, or by > 5%, and should be assessed by which ever estimate is more conservative.

4.5.3 Industrial Water Use

The following effects of high and low pH water on industrial processes have been observed :

- At pH values below 5 water may be extremely corrosive and may increase the rate of disintegration of concrete. If the water has a pH above 10, a tendency for severe scaling exists. Scaling is responsible for the reduction in heat transfer efficiency of heat transfer equipment and the narrowing of flow area in the distribution systems.
- Most industries have existing processes to maintain pH within the desired operating range. Therefore it is important that the pH of the water supply be kept constant.
- pH values outside the optimum range may result in colour distortions of dyes and may also affect the taste of beverages. Extreme pH values may denature proteins. Under highly acidic conditions corrosion product may damage product quality by deposition. Highly alkaline conditions may impair product quality through scaling or precipitation of salts on or in the product. High pH water may also prevent the efficient use of surfactants.

The Target Water Quality range for pH in a Category 3[1] industrial process ranges between 6.8-8.0.

[1] **- Category 3 process - A process for which domestic water quality is the baseline minimum standard eg. beverage, food products, baking etc.**

4.6 CHLORIDE CONCENTRATION

Chloride is the anion of chlorine and is normally associated with sodium, potassium, calcium and magnesium cations.

4.6.1 Irrigation Water Use

The effect of the chloride concentration on crops is discussed in the section on hydrosalinity in the Middle Breede River. The chloride limit for root and foliar absorption had been set at 140 mg/ℓ and 106 mg/ℓ respectively. Refer to Part 2 of this report for a detailed discussion.

4.6.2 Industrial Water Use

Excessively high concentrations of chloride in the water supply can pose a problem to industrial users. The following effects have been observed :

- High chloride levels together with low pH enhance corrosion. Chlorides are particularly aggressive to stainless steel and may form rough and crystalline deposits in cadmium, copper, silver and tin plated tanks.
- In general, chlorides have little effect on industrial processes and can be removed by demineralising processes. In the dairy industry, chlorides can displace calcium from casein resulting in greater water uptake and soft curds.
- At concentrations above 20 mg Cl^-/ℓ, chlorides in rinse water may give rise to rusting of finished steel products. Above 100 mg Cl^-/ℓ, chlorides may be harmful to beer products.
- If chlorides need to be removed from the water supply then a concentrated waste stream will inevitably be generated and this effluent would more than likely exceed the limits for electrical conductivity as set out in the General Standards for Effluent Discharge.

The Target Water Quality Limit for chlorides in a Category 3* industrial process had been set between 0-100 mg Cl^-/ℓ.

4.6.3 Livestock Watering

Chloride is important because it regulates osmotic pressure and the acid-base balance. At high concentrations chlorides render the water unpalatable to most livestock. Sheep and poultry are particularly sensitive to excess chloride. The Target Water Quality for chlorides in feed water had been set between 0 - 1500 mg/ℓ.

4.7 SODIUM CONCENTRATION

Sodium is an alkali metal which reacts with water to form a sodium cation.

4.7.1 Irrigation Water Use

Sodium absorbed through the leaves is normally associated with leaf burn which can be the result of a single high exposure to a high sodium concentration. Crop quality may be compromised by sodium-induced leaf injury when the leaves are the marketed product. Crops with high sodium absorption rates at the leaf interface have a lower threshold limit for sodium. The Target Water Quality Range for sodium had been set at # 70 mg/ℓ when foliar wetting occurs.

4.7.2 Livestock Watering

Sodium is the principal cation responsible for electrolyte balance and plays a vital role in the acid-base balance and other physiological functions.

Sodium is efficiently stored in the body and its bodily requirements are therefore small. Muscular activity increases the requirement for the element. Symptoms of sodium deficiency include loss of appetite and reduced growth, milk production and reproduction.

High sodium concentrations lead to decreased palatability prior to toxicity. Symptoms of toxic effects are diarrhoea and dehydration. The Target Water Quality Range for sodium had been set between 0-2000 mg/ℓ.

4.8 SODIUM ADSORPTION RATIO (SAR)

This ratio is calculated from the concentrations of sodium, calcium and magnesium in the irrigation water.

4.8.1 Irrigation Water Use

The SAR is a measure of the potential of irrigation water to induce sodic soil conditions and is calculated by the following formula:

$$SAR = \frac{[Sodium]}{\{[Calcium] + [Magnesium]\}^{0.5}}$$

where the concentrations are in mmol/ℓ.

The effect of sodium affected soils on crops include reduced yield and quality as well as impaired soil physical conditions (reduced soil permeability) and increased tendency for hardsetting. The effect of sodium on crops is aggravated if foliar wetting also occurs. The Target Water Quality Range for the SAR has been set at # 2.

4.9 IRON CONCENTRATION

In water iron can be present as ferric iron (Fe^{3+}), ferrous iron (Fe^{2+}) or as suspended iron hydroxides. Iron is an essential micro-nutrient required by all living organisms.

4.9.1 Domestic Water Use

Excessive ingestion of iron can cause tissue damage as a result of iron accumulation. This type of iron poisoning is rare since excessively high concentrations of iron do not occur naturally in water and this type of water may be rendered unpalatable to begin with. As the concentration of iron in the system increases bacterial activity converts ferrous iron to ferric iron which deposits as slimy coatings in plumbing. The major effect is the aesthetic appearance of enamel surfaces of baths, hand basins and lavatory cisterns. Iron causes discolouration of water supply when present at low concentrations in association with aluminium. Iron deposits in the water supply system gradually reducing the water flowrate. A possible health risk is introduced by the presence of microbial deposits on the internal surfaces of pipes. Iron complexed with humic acid causes a brown discolouration of the water which may detract from the aesthetic appeal but which has no adverse health implications. The Target Water Quality Range for iron had been set between 0 - 0.1 mg/ℓ.

4.10 MANGANESE CONCENTRATION

Manganese is a grey-white, brittle metal found in several oxidation states.

4.10.1 Domestic Water Use

Adverse aesthetic effects limit the allowable level of manganese in drinking water. The presence of manganese imparts an unpleasant taste into beverages and causes staining of plumbing fixtures and laundry. Oxidation of manganese compounds results in the precipitation of hydrated manganese oxides/hydroxides causing encrustation in plumbing fixtures. Neurotoxic effects may occur at high concentrations but it is unlikely that such levels would be present in drinking water. Manganese supports the growth of certain organisms in the distribution system giving rise to taste, odour and turbidity problems. The Target Water Quality Range had been set between 0 - 0.05 mg/ℓ.

4.11 ALGAE

The effects of high nutrient concentrations are most visible in the form of algal blooms. When algal cells become too buoyant a thick scum is formed during blooms. A scum exists when the accumulation of algal cells is visible to the naked eye. An algal bloom can contain both toxic and non-toxic strains of algae.

4.11.1 Livestock Watering (blue-green algae)

As livestock are less selective about the water quality than humans they are more susceptible to poisoning by toxic algae. Algal death or disintegration releases toxins into the water. The consumption of algal scum is the most likely to cause toxic effects, because the death of the algae (in the stomach) would induce the release of toxins at a much higher concentration than would be present in the water source.

Hepatotoxins produced by the algae are largely responsible for livestock poisoning and adverse effects include liver cell shrinkage, liver haemorrhages and death due to pooling of blood in the liver.

The Target Water Quality Range for blue-green algae had been set at < 6 colonies of blue-green algae/0.5 Mℓ.

4.11.2 Recreational Water Use (blue-green and filamentous algae)

The presence of all forms of algae detracts from the aesthetic appeal of aquatic recreation. Dense growth of free floating or decaying algae are visually unappealing and can cause unpleasant odours.

Blue-green algae can be toxic when swallowed accidentally or cause irritation when in direct contact with the skin. Ingestion of blue-green algae can cause vomiting, acute gastroenteritis and impaired liver function. The Target Water Quality Range had been set at < 6 colonies of blue-green algae/0.5 Mℓ. For free floating algae the Target Water Quality Range had been set between 0 - 15 µg/ℓ *chl a* and 0 - 20 µg/ℓ *chl a* for full-contact and non-contact recreation activities respectively. Filamentous algae should be absent from areas intended for contact recreational activity.

4.12 CHEMICAL OXYGEN DEMAND (COD)

COD is defined as the measure of oxygen equivalent of organic matter content that is susceptible to oxidation and therefore gives an estimate of the organic matter present in the water body.

4.12.1 Industrial Water Use

Organic matter contributes a substantial amount to the COD of a water body and can be present as dissolved organic matter or particulate organic matter. Dissolved organic matter is associated with undesirable tastes while particulate organic matter contributes to the total suspended solids load of the water body.

Organic matter causes damage to heat transfer equipment and cooling systems by adhering to biofilms and augmenting fouling. It also provides a substrate for bacteria, in particular sulphate reducing bacteria which are responsible for damage in heat transfer equipment through microbially-induced corrosion. Organic matter could also foul ion-exchange and membrane processes.

Certain organic acids interfere with the dyes used in the finishing of leather and in the production of paper and textiles. The additional oxygen demand induced by organic matter in bleaching operations leads to the use of excess bleaching agent. Carbonation difficulties may also be experienced in the bottling of beverages.

Some organic acids of humic origin may stain leather or textiles and may also create undesirable odours and tastes. Microbial slimes may also impair paper quality by the formation of slick spots.

4.12.2 Environmental Water Use

Dallas and Day (1993) reported that organic enrichment is probably the best documented type of pollution occurring in rivers and that the main sources are domestic sewage, food processing plants, animal feedlots and abattoirs. They added that oxygen demanding waste generally led to a decrease in dissolved oxygen concentration due to aerobic decomposition of the waste. Accompanying effects include increased turbidity, increased suspended solids concentration and increased nutrient concentration. No Target Water Quality Limits for organic load in river water had been established, but the value in the General Standard for Effluent Discharge may be applied tentatively.

4.13 DISSOLVED OXYGEN (DO)

Gaseous oxygen dissolves in water and is also added by the process of photosynthesis. Oxygen is moderately soluble in water and the equilibrium solubility is a function of temperature, salinity, atmospheric pressure and other site-specific chemical and physical factors.

4.13.1 Environmental Water Use

Dissolved oxygen measurements are reported as mg/ℓ or as a percentage of the saturation value at the time of sampling. Values below the saturation concentration indicate that water has been depleted whereas values above are usually a sign that eutrophication is occurring.

Aerobic organisms are dependent on the presence of dissolved oxygen for the process of respiration. The sensitivity of fish and invertebrates to oxygen is dependent on the species as well as the life-stages. Juveniles are more prone to physiological stress resulting from oxygen depletion.

Super-saturation may cause gas bubble disease in fish, tends to inhibit photosynthesis in green algae and favours the growth of blue-green algae. The Target Water Quality for dissolved oxygen is listed in Table 4.13 below.

TABLE 4.13 : TARGET WATER QUALITY RANGE FOR DISSOLVED OXYGEN

TWQR AND CRITERIA	CONCENTRATION	CONDITION
Target Water Quality Range	80% -120% of saturation	06h00 sample or lowest instantaneous concentration recorded in a 24h-period

4.14 BACTERIA INCLUDING PROTOZOA

Microscopic organisms are normally used as an indicator of the general health of a water body.

4.14.1 Domestic Water Supply

A wide variety of pathogens are transported by water and testing for all these pathogens is impractical. Indicator organisms are those which are routinely monitored to give an indication of the presence of pathogens in water. These include the following :

- Total coliform bacteria
- Faecal coliform bacteria
- *Escherichia coli*
- Enterococci
- Bacteriophages

Faecal coliform bacteria are generally used to evaluate the quality of wastewater effluents, river water, sea water at bathing beaches, raw water for drinking water supply, and recreational waters as well as water used for irrigation, livestock watering and aquaculture. Faecal coliforms are used to indicate the presence of bacterial pathogens which can be transmitted via the faecal/oral route. The Target Water Quality for faecal coliforms is listed in Table 4.14a below.

TABLE 4.14a : TARGET WATER QUALITY FOR BACTERIA IN SURFACE WATERS

FAECAL COLIFORM RANGE (COUNTS/100 Mℓ)	EFFECTS
0	Target Water Quality Range. Negligible risk of microbial infection.
0 - 10	Slight risk of microbial infection with continuous exposure; negligible effect with occasional or short-term exposure.
10 - 20	Risk of infectious disease transmission with continuous exposure; slight risk with occasional exposure.
>20	Significant and increasing risk of infectious disease.

In addition to the above indicator organism, enteric viruses may also be tested for. The concentration of enteric viruses is expressed as $TCID_{50}$/10 l. Where $TCID_{50}$ is the tissue culture infectious dose required to cause 50% infection. Enteric viruses which may occur in polluted water can cause diseases such as gastroenteritis, pneumonia and viral hepatitis. The Target Water Quality for viruses is listed in Table 4.14b below.

TABLE 4.14b : TARGET WATER QUALITY RANGE FOR ENTERIC VIRUSES

ENTERIC VIRUS RANGE ($TCID_{50}$/10ℓ)	EFFECTS
0	Target Water Quality Range; Negligible risk of enteric virus expected.
1	Slight risk of enteric virus infection for continuous exposure.
1 - 10	Medium risk of enteric virus infection for continuous exposure.
> 10	Risk of enteric virus infection is significant and increases as virus level increases.

Protozoan parasites, *Giardia* and *Cryptosporidium* are infective to humans as cysts or oocysts. Species which infect humans are *Giardia lamblia* and *Cryptosporidium parvum.* Infection by these protozoan parasites may cause gastroenteritis, diarrhoea, vomiting and anorexia. The Target Water Quality Range for protozoans is listed in Table 4.14c below.

TABLE 4.14c : TARGET WATER QUALITY FOR PROTOZOAN PARASITES

PROTOZOAN PARASITE RANGE (CYSTS OR OOCYSTS/10ℓ)	EFFECTS
0	Target Water Quality Range; Negligible risk of protozoan parasite infection is expected.
>1	Risk of protozoan parasite infection for continuous short or occasional exposures.

4.14.2 Recreational Water Use

The Target Water Quality Range with respect to faecal coliform for full-contact water recreation had been set between 0 - 130 counts/100 mℓ. For intermediate water contact the range had been set between 0 - 1000 counts/100mℓ.

For enteric viruses the Target Water Quality Range had been set at 0 $TCID_{50/10\ell}$ for full-contact as well as intermediate contact recreational activities.

4.15 PESTICIDES

These are organic compounds used to control pest populations on agricultural crops. These substances are artificially synthesised and are known to have adverse effects on human and animal life.

Although the presence of these organic compounds in drinking water is a major concern, no Target Water Quality Limits have been determined for Domestic Water Use. Table 4.15 (Water Research Commission, 2000) provided some indication of target limits for selected pesticides in drinking water.

TABLE 4.15 :TARGET LIMITS FOR SELECTED PESTICIDES IN DRINKING WATER

HUMAN HEALTH	ENDOSULPHAN (μg/ℓ)	CHLORPYRIFOS (μg/ℓ)
Environmental Protection Agency Advisory	-	20
European Community Standard	0.1	0.1
California Inland Surface Water Plan	0.9	-

The European community (European Community, 1980) implements a standard of 0.1 μg/ℓ for a particular pesticide and 0.5 μg/ℓ for total pesticide concentration.

Chlorpyrifos has been associated with neurological, respiratory and reproductive effects while Endosulphan had been associated with effects on the liver, kidney, blood and parathyroid gland. Both the pesticides are listed as endocrine disruptors.

5. WATER QUALITY STATUS IN THE BREEDE RIVER CATCHMENT

The water quality status of the Breede River mainstream and its major tributaries is discussed below.

Dallas *et al.* (1998) showed that the background (median) electrical conductivity and pH in unimpacted streams were as follows:

TABLE 5 : BACKGROUND WATER QUALITIES FOR UNIMPACTED STREAMS

SUB-REGION	MEDIAN TDS (mg/ℓ)	MEDIAN EC (mS/m)	MEDIAN pH VALUE
Mountain stream	19.5	3.0	5.5
Foothill	20.2	3.1	6.0
Transitional	62.4	9.6	6.5
Lowland	136.5	21.0	7.3

5.1 SPATIAL VARIATION ALONG BREEDE RIVER MAINSTREAM

5.1.1 Total Dissolved Solids/Electrical Conductivity (EC)

The impact of farming on the quality of the Breede River mainstream is depicted in Figure 5.1a.

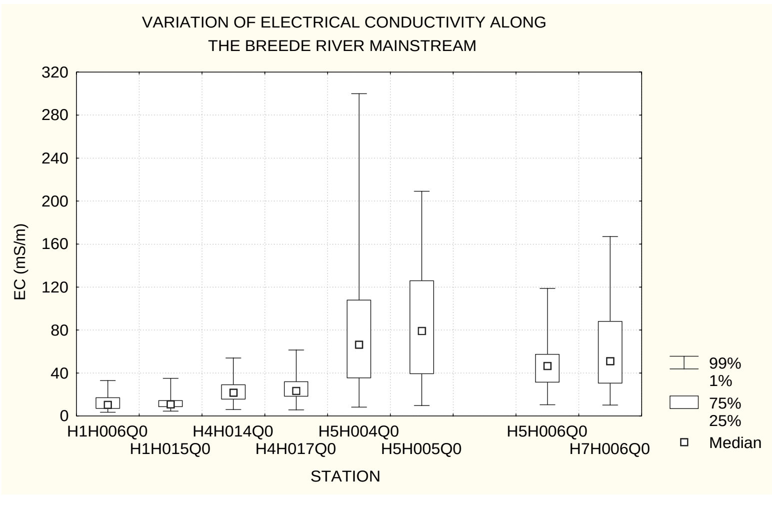


Figure 5.1a : Spatial variation of EC along the Breede River mainstream

The median EC values increase in a downstream direction with a major increase occurring in the Middle Breede River. The headwaters of the mainstream Breede River are of good quality indicating that the farming activities do not have a big impact on the TDS concentration at this position in the river (H1H006Q01 to Greater Brandvlei Dam). According to Southern Waters (2000), gauging stations H1H015Q01 to H5H005Q01 can be assigned to the foothill-gravel bed sub-region {corresponding to transitional sub-region, Dallas *et al* (1998)} while H1H006Q01 and H7H006Q01 can be assigned to the foothill-cobble bed and lowland floodplain sub-regions respectively. A comparison between Figure 5.1a and the values obtained for unimpacted streams reveals that for the foothill region of the Breede River, TDS concentrations are at least three times as high as the concentrations in unimpacted streams (median EC at H1H006Q01 approximately 10 mS/m). For the transitional and lowland sub-regions the increase above the unimpacted state is up to 8 fold and 2 fold respectively. The impact of high salinity water on irrigation is discussed in Part 2 of this report.

It is clear that the TDS concentration in the Middle Breede River has increased at least 6 fold above its unimpacted state, but this change has occurred over a few years and the original aquatic biota may have been replaced with more salt tolerant species.

Between gauging stations H4H017Q01 and H7H006Q01 the river water is marginally acceptable for domestic use, with the Target Water Quality being exceeded on numerous occasions.

5.1.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration along the Breede River mainstream is depicted in Figure 5.1b below.

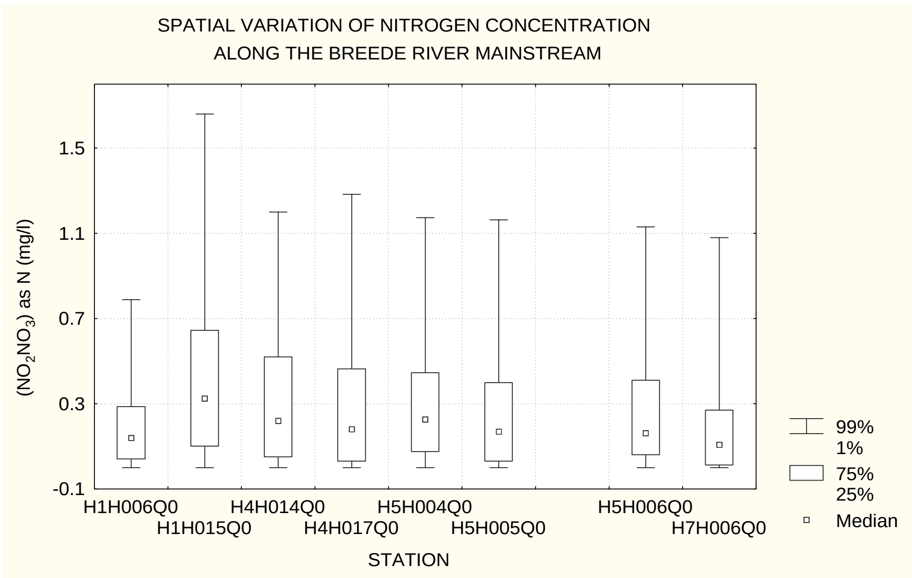


Figure 5.1b : Spatial variation of the nitrogen concentration along the Breede River mainstream

With the exception of gauging station H1H015Q01, the median values at all the other stations are below 0.3 mg/ℓ. No concentrations exceeded 5 mg/ℓ which is the Target Water Quality Range for irrigation water. It can thus be concluded that the nitrogen concentrations in the irrigation water would not affect crop yields or pose a risk of contaminating the groundwater.

In terms of the potential to stimulate algal growth, Figure 5.1b above suggests that mesotrophic (moderately enriched) conditions could possibly occur at all stations, but that eutrophic and hypertrophic conditions are unlikely.

In the absence of background nitrogen concentration determinations it can be assumed that the natural nitrogen concentration of the Breede River mainstream is represented by the gauging station H1H006Q01 and that all the downstream stations have been impacted on and modified relative to it. The median values of the stations located in the Middle Breede River are slightly higher than the background value and this can be ascribed to the increased farming activities which result in elevated nutrient concentrations in the irrigation return flows.

5.1.3 Phosphorus Concentration

Figure 5.1c below depicts the spatial variation of the phosphorus concentration along the Breede River mainstream.

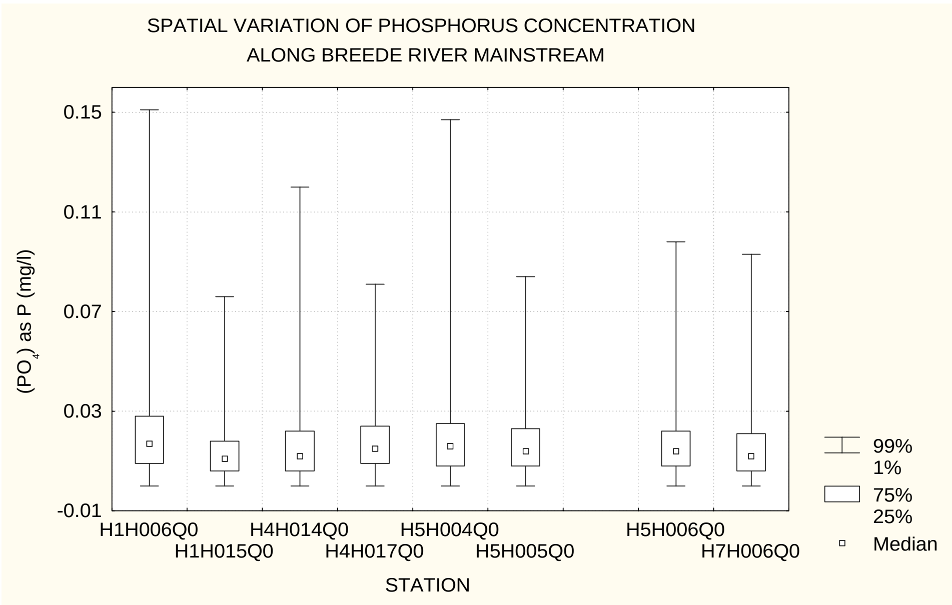


Figure 5.1c : Spatial variation of phosphorus concentration along the Breede River mainstream

The median value at all the gauging stations deviate very little from the value considered to represent the background condition (H1H006Q01), but there is a possibility that on occasion mesotropic and even eutrophic conditions exist at all the stations where phosphorus concentrations have occasionally exceeded 0,025 mg/ℓ (eutrophic threshold).

5.1.4 pH Value

The variation in pH value along the Breede River mainstream is depicted in Figure 5.1d below.

From Figure 5.1d it can be seen that the pH values (median) for the foothill stream (H1H006Q01) have increased by 0.9 of a pH unit over the background value since monitoring started. In the upper portion of the transitional zone of the Breede River (H1H015Q01 to H4H017Q01) the median pH value agrees with the background pH to within 0.5 of a pH unit.

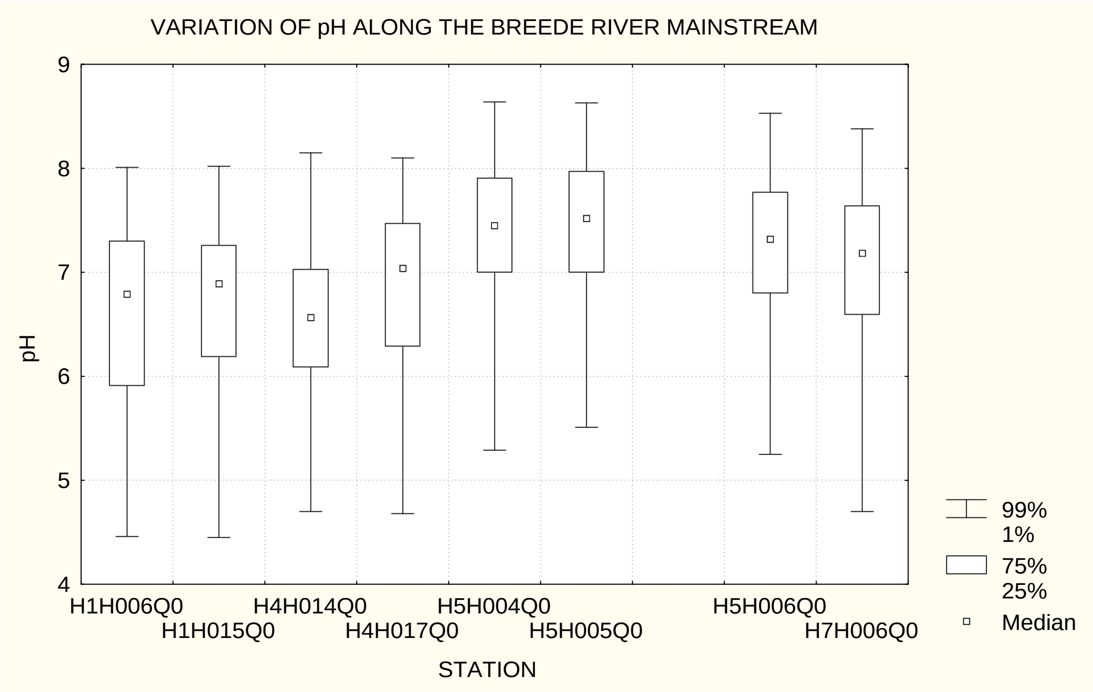


Figure 5.1d : Spatial variation of pH along the Breede River mainstream

In the lower portion (H5H004Q01 and H5H005Q01), however, the background pH value is exceeded by almost 1 pH unit. The median pH value of the lowland stream (H7H006Q01) compares well with the background value.

For irrigation water use, the pH values are on numerous occasions outside the Target Water Quality range, especially on the acidic side of the pH scale. This would most certainly contribute to increased corrosion of irrigation equipment.

For industrial water use the water quality criterion is exceeded on the acidic side of the pH scale. This is particularly severe for stations H1H006Q01 to H4H017Q01 where up to 50% of the data entries are outside the recommended water quality guideline range.

5.1.5 Chloride Concentration

The spatial variation of the chloride concentration along the Breede River mainstream is depicted in Figure 5.1e below.

The trend followed by the chloride concentration is very similar to that of the electrical conductivity, with a clear deterioration in quality in the Middle Breede River.

For irrigation water use the chloride concentration is acceptable from stations H1H006Q01 to H1H017Q01. At stations H5H004Q01 and H5H005Q01, however, the target chloride concentration is exceeded for some 50% of the time. The chloride concentration at the downstream stations is acceptable according to the current water quality criteria. A detailed discussion on the effects of elevated chloride concentrations in irrigation water follows in Part 2 of this report.

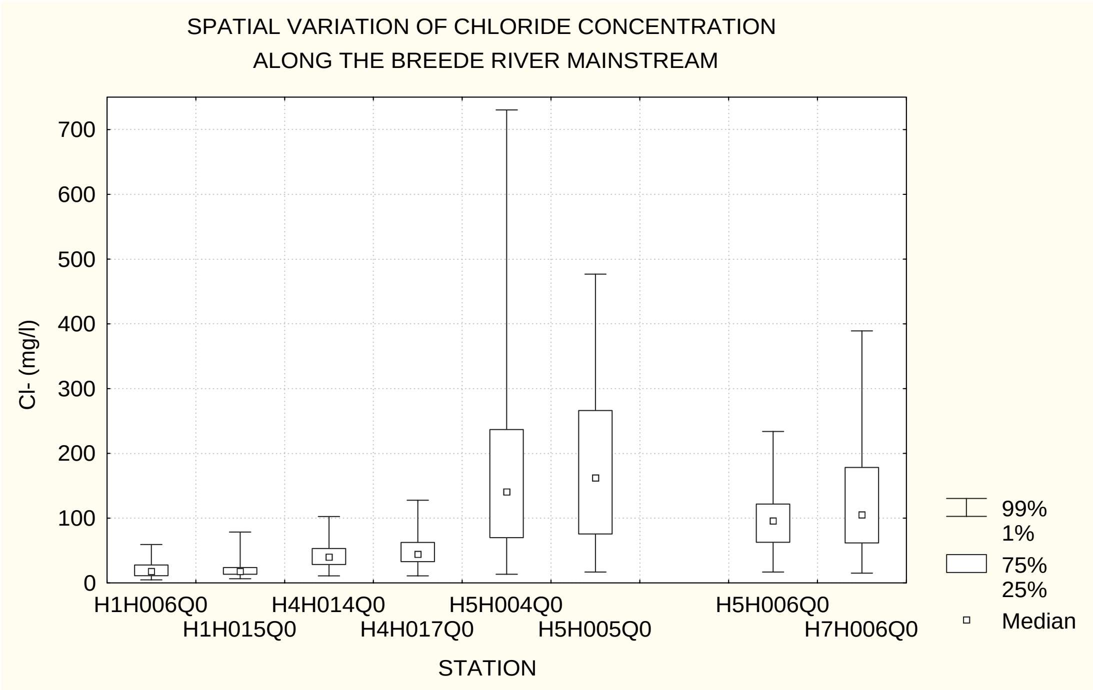


Figure 5.1e : Spatial variation of chloride concentration along the Breede River mainstream

For industrial water use the chloride concentration is acceptable from station H1H006Q01 to H4H017Q01. Downstream of H4H017Q01 the chloride concentrations become problematic to industrial users. The chloride concentrations along the entire Breede River are acceptable for livestock watering.

5.1.6 Sodium Concentration

The spatial variation of the sodium concentration is shown in Figure 5.1f below. The trend of the sodium concentration along the mainstream Breede River is similar to that of the EC and chloride concentrations.

For irrigation water use the sodium concentration is acceptable from stations H1H006Q01 to H1H017Q01. At stations H5H004Q01 and H5H005Q01, however, the target sodium concentration for irrigation water use is exceeded at least 50% of the time.

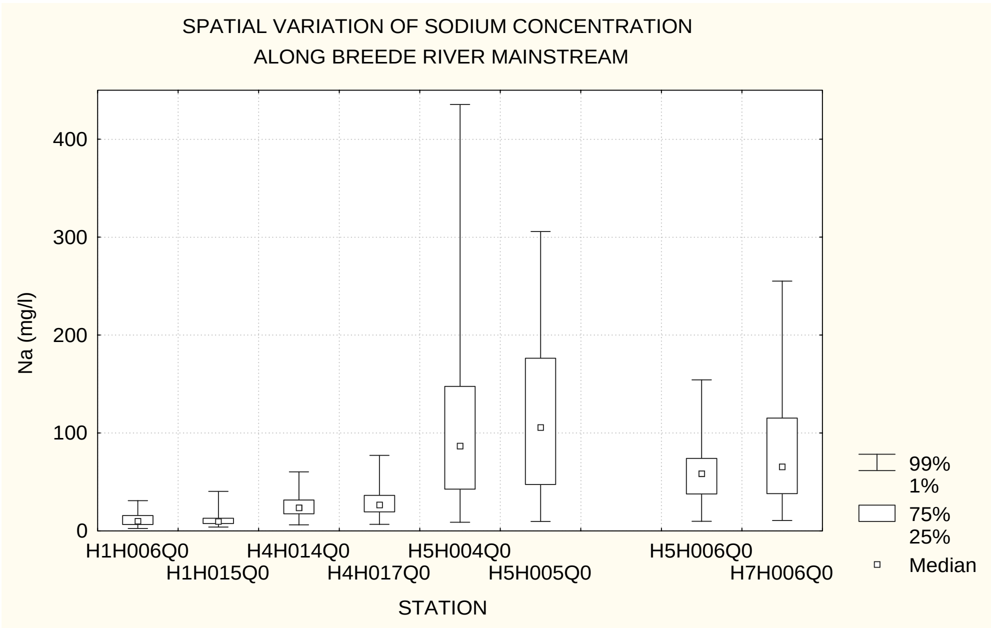


Figure 5.1f : Spatial variation of sodium concentration along the Breede River mainstream

The sodium concentration at the downstream stations is marginally acceptable for irrigation water use according to the current water quality criteria. The sodium concentrations along the entire Breede River are acceptable for livestock watering**.**

5.1.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is depicted in Figure 5.1g.

For irrigation water use the SAR is acceptable up to station H4H017Q01. Downstream from this point the water quality becomes unacceptable with respect to the SAR.

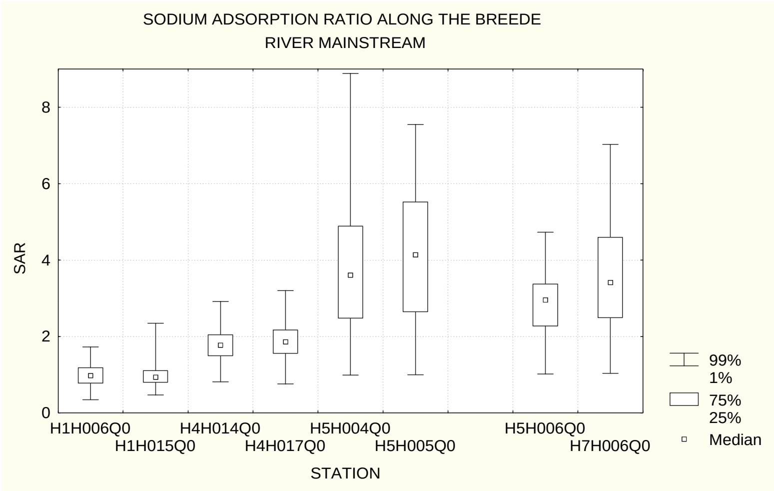


Figure 5.1g : Spatial variation of sodium adsorption ratio along the Breede River mainstream

5.2 SPATIAL VARIATION ALONG THE HEX RIVER

5.2.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is depicted in Figure 5.2a below.

Southern Waters (2000) determined that stations H2H016Q01 and H2H006Q01 can be assigned to the foothill-cobble bed sub-region whereas H2H010Q01 can be assigned to the foothill-gravel bed (transitional zone) sub-region.

The median values for H2H016Q01 and H2H006Q01 compare favourably with the background water quality whereas the quality at H2H010Q01 has increased 30 times above the background quality.

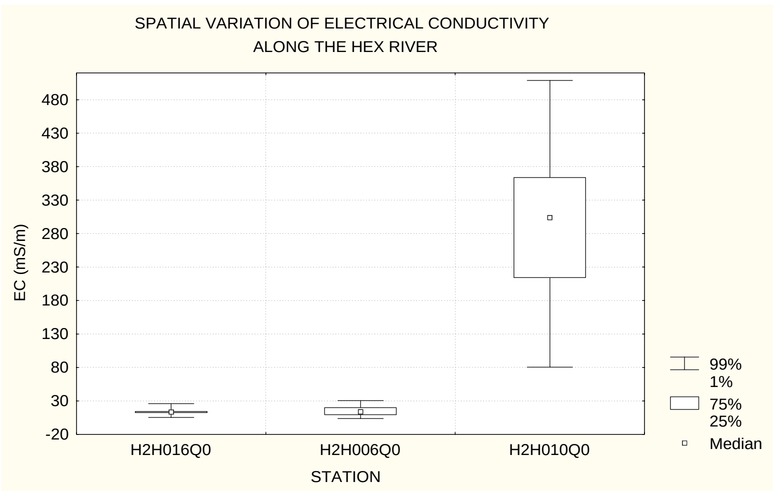


Figure 5.2a : Spatial variation of EC along the Hex River

For irrigation water use, the water at H2H016Q01 and H2H006Q01 is acceptable for use while at H2H010Q01 it is unacceptable with most of the observed ECs exceeding the upper limit of the EC water quality guidelines.

The EC at H2H016Q01 and H2H006Q01 can be tolerated by the aquatic organisms, but at H2H010Q01 the EC value has deviated by more than 100% from the background quality and this has a detrimental effect on the aquatic organisms. Water at H2H016Q01 and H2H006Q01 is acceptable for domestic water use.

5.2.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is reflected in Figure 5.2b below.

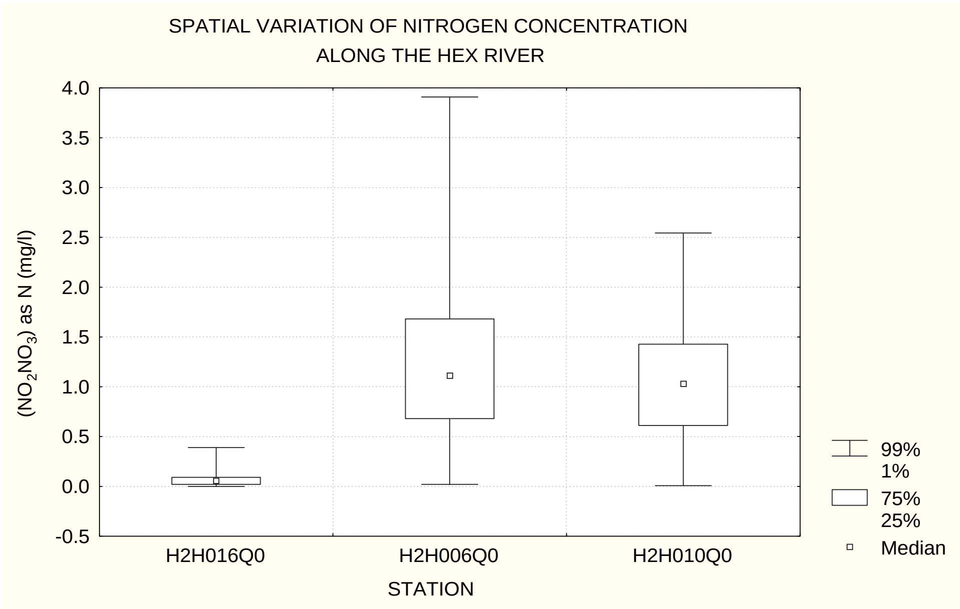


Figure 5.2b : Spatial variation of the nitrogen concentration along the Hex River

The water quality along the river is acceptable for irrigation use with respect to nitrogen. Mesotrophic and eutrophic conditions are possible at stations H2H010Q01 and H2H006Q01, respectively.

5.2.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is reflected in Figure 5.2c.

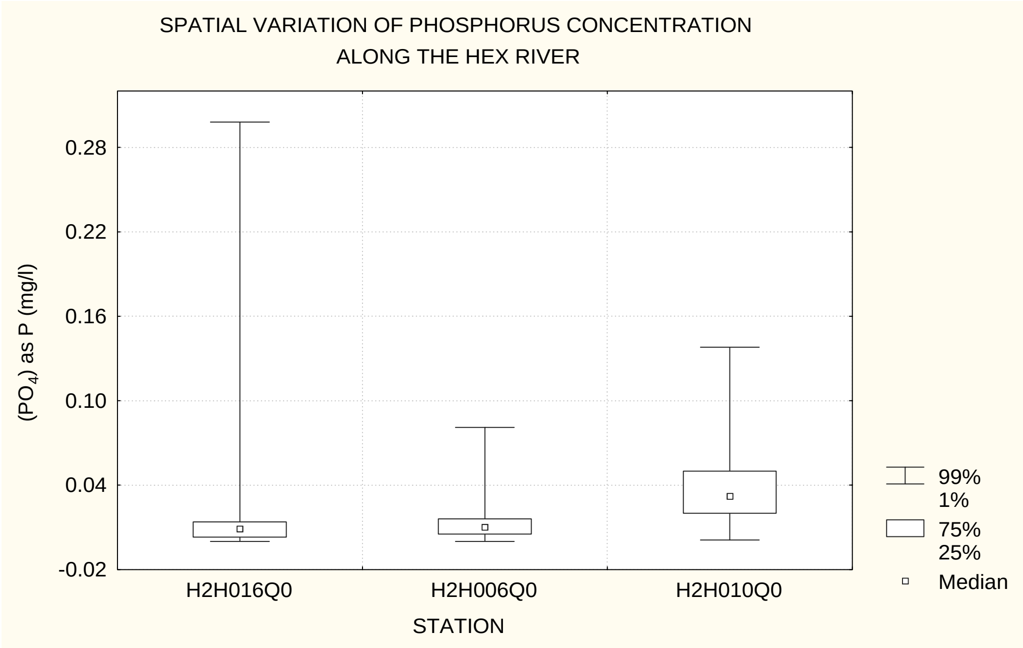


Figure 5.2c : Spatial variation of the phosphorus concentration along the Hex River

The possibility of mesotrophic conditions occurring exists at all the gauging stations and in particular at station H2H010Q01.

5.2.4 pH Value

The spatial variation of the pH concentration is reflected in Figure 5.2d below.

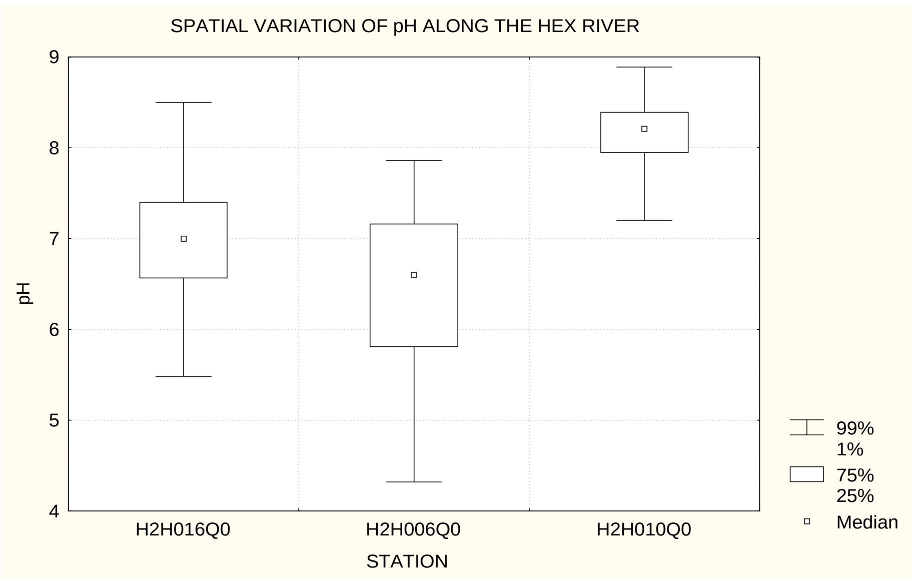


Figure 5.2d : Spatial variation of pH along the Hex River

The median pH values at H2H016Q01 and H2H006Q01 exceed the background median by 1 and 0.5 pH unit, respectively. The background pH value at H2H010Q01 is exceeded by 1.5 pH units.

For irrigation purposes the Target Water Quality Range is exceeded on the acidic portion of the pH scale and this could lead to increased corrosion of irrigation equipment.

From an environmental perspective, it can be seen that the water quality criterion has been exceeded at all the stations.

5.2.5 Chloride Concentration

The spatial variation of the chloride concentration is reflected in Figure 5.2e below.

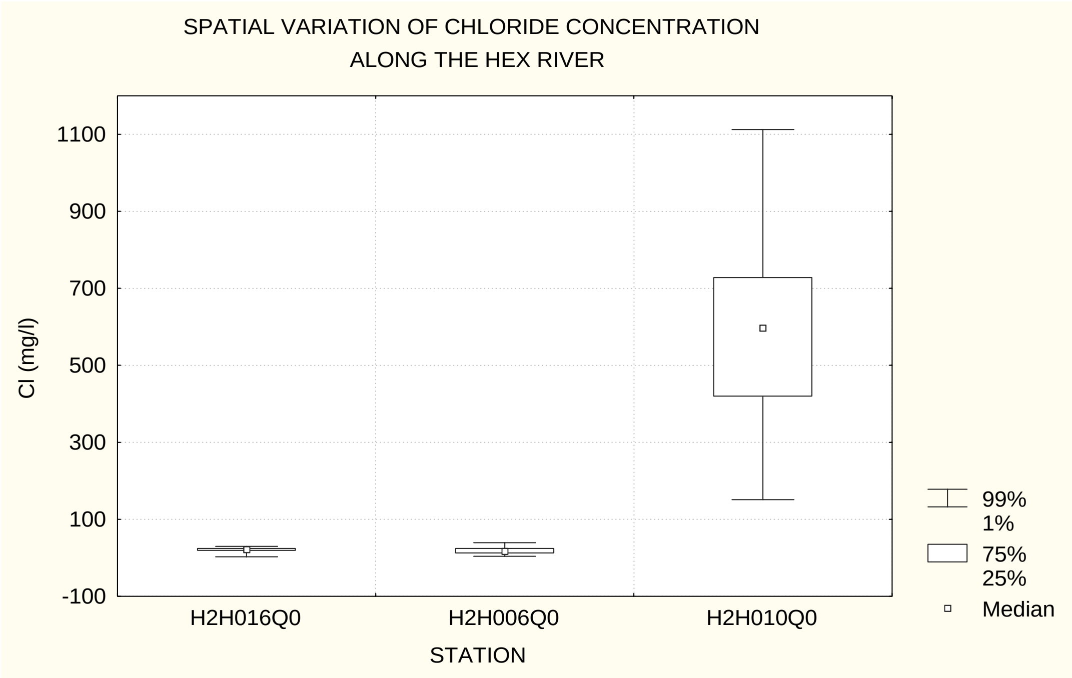


Figure 5.2e : Spatial variation of chloride concentration along the Hex River

As with the EC, it can be seen that only stations H2H016Q01 and H2H006Q01 are acceptable for irrigation or industrial usage but not at H2H010Q01. The water at all three gauging stations are acceptable for livestock watering.

5.2.6 Sodium Concentration

The spatial variation of the sodium concentration is reflected in Figure 5.2f.

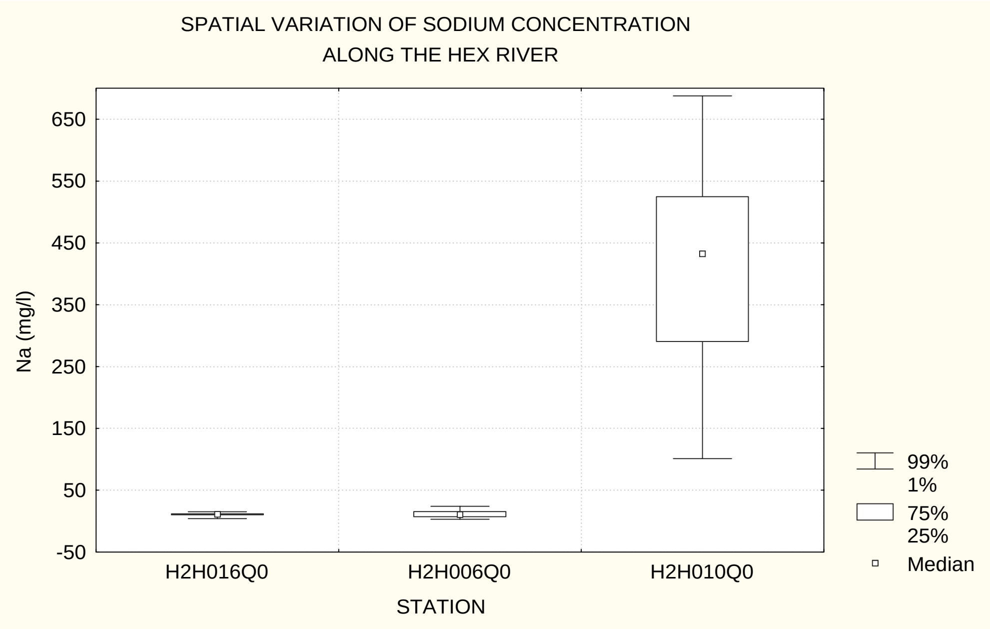


Figure 5.2f : Spatial variation of the sodium concentration along the Hex River

Figure 5.2f above shows that at H2H016Q01 and H2H006Q01 the sodium concentration is within the prescribed water quality range and that it is acceptable for irrigation usage. The water at all three gauging stations was suitable for livestock watering.

5.2.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is reflected in Figure 5.2g below.

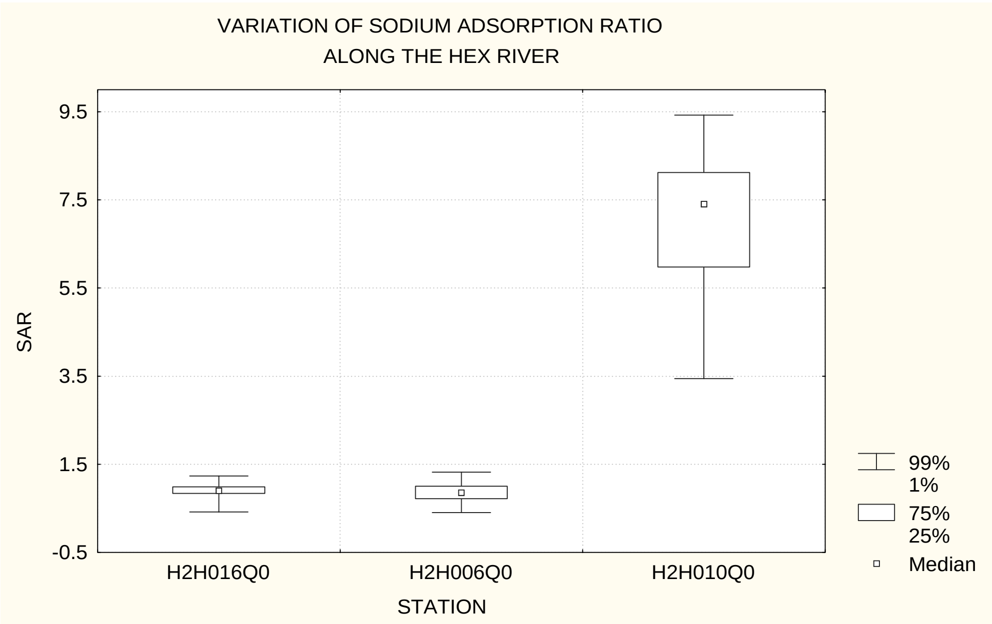


Figure 5.2g : Spatial variation of sodium adsorption ratio along the Hex River

Stations H2H016Q01 and H2H006Q01 comply with the prescribed water quality criterion for SAR, but H2H010Q01 exceeds the criterion 100% of the time.

5.3 SPATIAL VARIATION ALONG THE NUY RIVER

5.3.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is reflected in Figure 5.3a below.

Southern Waters (2000) determined that stations H4H008Q01 and H4H020Q01could be assigned to the foothill-cobble bed and foothill-gravel bed (transitional) sub-regions respectively. The mean EC values at stations H4H008Q01 and H4H020Q01 exceed the background values 80 and 36 fold respectively.

The EC at both stations are outside the prescribed water quality range for irrigation, domestic and environmental usage.

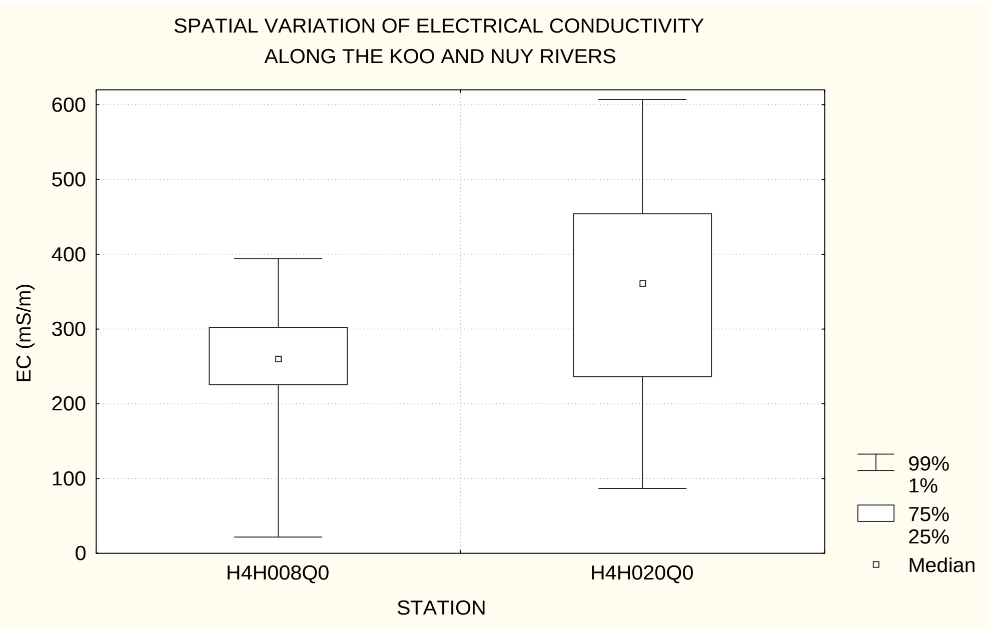


Figure 5.3a : Spatial variation of electrical conductivity along the Koo and Nuy Rivers

5.3.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is reflected in Figure 5.3b.

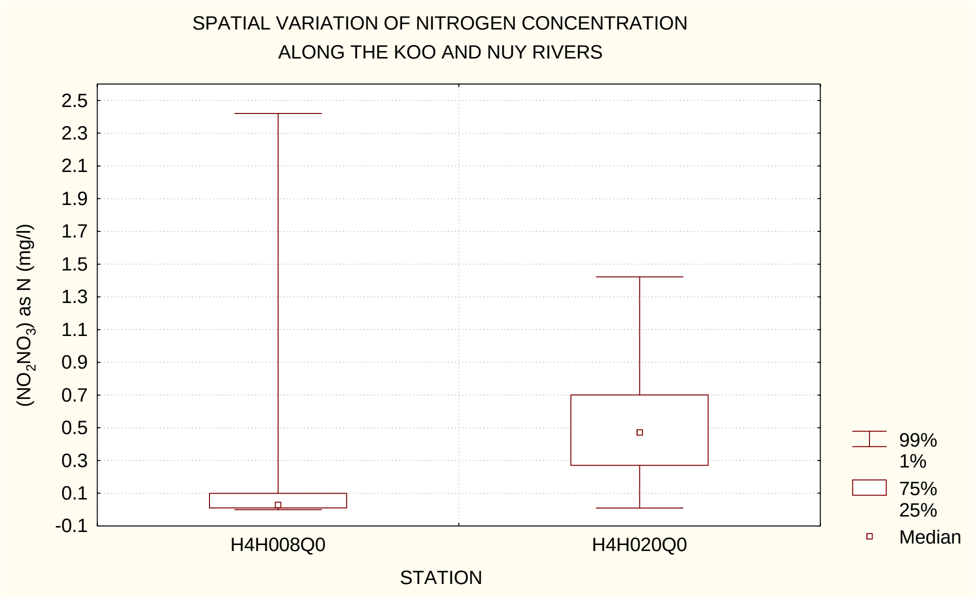


Figure 5.3b : Spatial variation of the nitrogen concentration along the Koo and Nuy Rivers

Irrigation use - With respect irrigation use and nitrogen, it can be seen that the water at both gauging stations are suitable for irrigation use. In terms of environmental use, the data also suggest that mesotrophic conditions could occur at either station.

5.3.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is reflected in Figure 5.3c below.

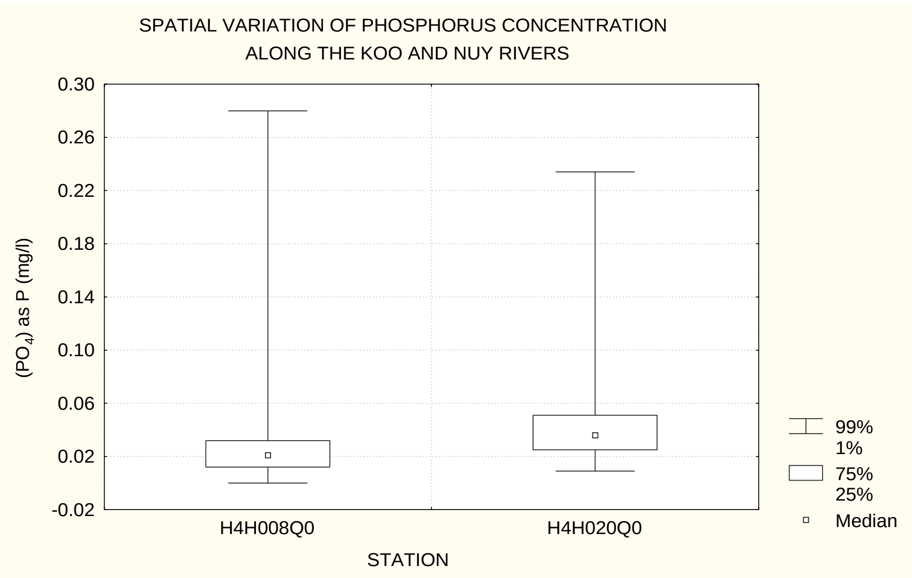


Figure 5.3c : Spatial variation of the phosphorus concentration along the Koo and Nuy Rivers

Environmental use - At least 25% of the data entries at both gauging stations are in the eutrophic range (> 0.25 mg/ℓ). This implies that the possibility of eutrophic conditions exists at both stations.

5.3.4 pH Values

The spatial variation of the pH is reflected in Figure 5.3d below.

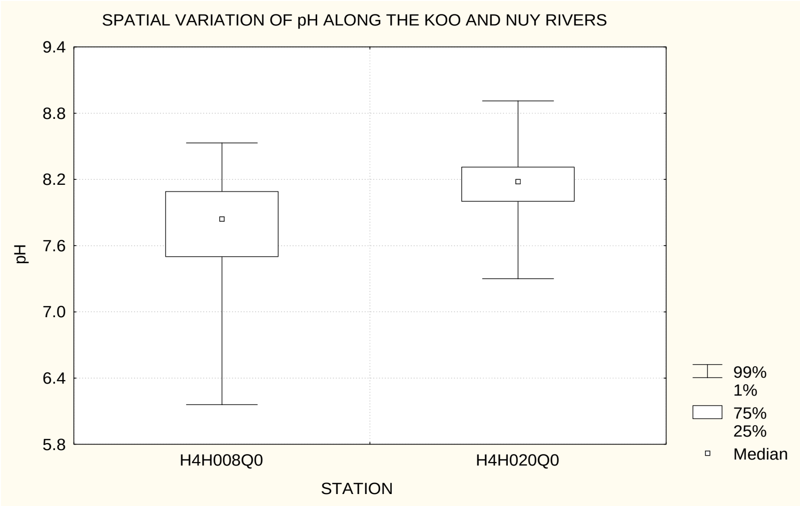


Figure 5.3d : Spatial variation of pH along the Koo and Nuy Rivers

In terms of aquatic ecosystems, the median pH values at H4H008Q01 and H4H020Q01 exceed the background pH values by 1.9 and 1.7 pH units respectively. This implies that the target water quality range for the aquatic ecosystem is exceeded for most of the time.

The pH range complies with the target water quality range for irrigation as well as for industrial use with only a few observations falling within the acidic side of the pH scale.

5.3.5 Chloride Concentration

The spatial variation of chloride concentration is reflected in Figure 5.3e below.

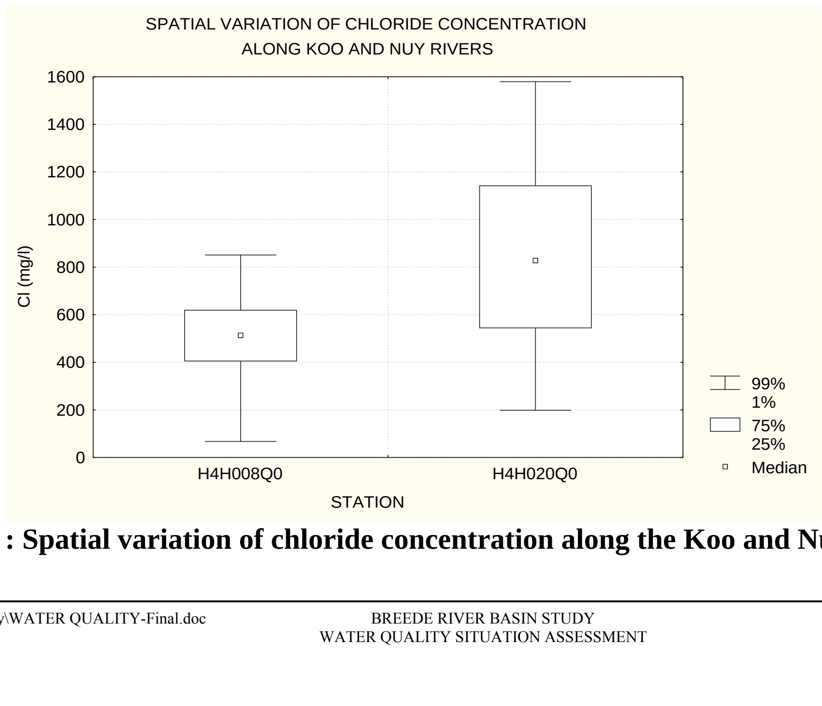


Figure 5.3e : Spatial variation of chloride concentration along the Koo and Nuy Rivers

The median chloride concentration at both stations exceeds the Target Water Quality Criterion for irrigation water use as well as for a Category 3 industrial process. At H4H008Q01 the chloride concentration is still acceptable for livestock watering but at H4H020Q01 the Target Water Quality Range is exceeded at the upper limit.

5.3.6 Sodium Concentration

The spatial variation of the sodium concentration is reflected in Figure 5.3f below. The trend followed by the sodium concentration is similar to that of the chloride and EC. At both stations the Target Water Quality Criteria for irrigation water use is exceeded for most of the time. For livestock watering the sodium concentration is acceptable at both stations.

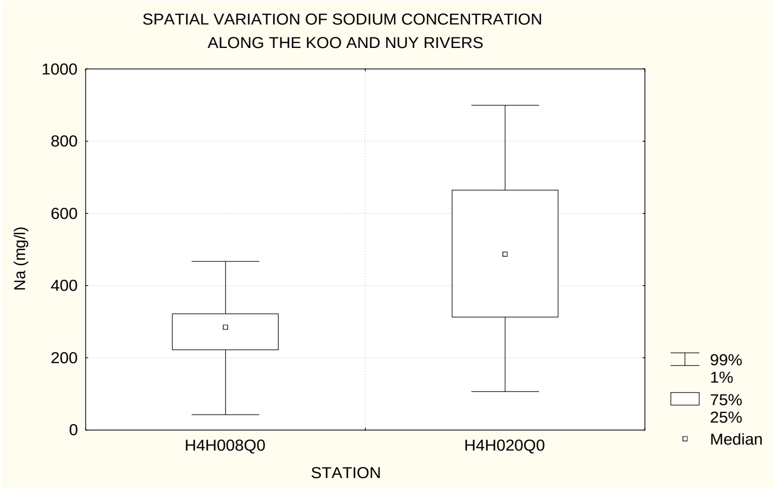


Figure 5.3f : Spatial variation of sodium concentration along the Koo and Nuy Rivers

5.3.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is reflected in Figure 5.3g.

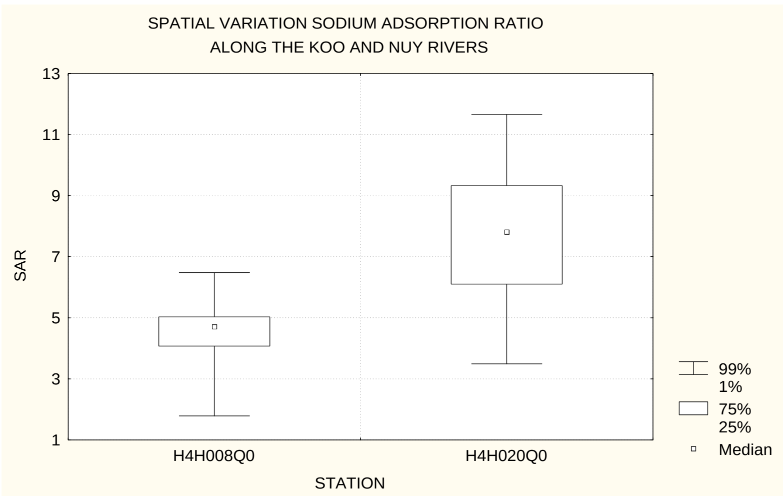


Figure 5.3g : Spatial variation of the SAR along the Koo and Nuy Rivers

The mean values at both stations show that the Target Water Quality Range is exceeded for most of the time and this implies that the water is unsuitable for irrigation with respect to the SAR and may lead to sodic soil conditions.

5.4 SPATIAL VARIATION ALONG THE POESJENELS RIVER

5.4.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is reflected in Figure 5.4a below.

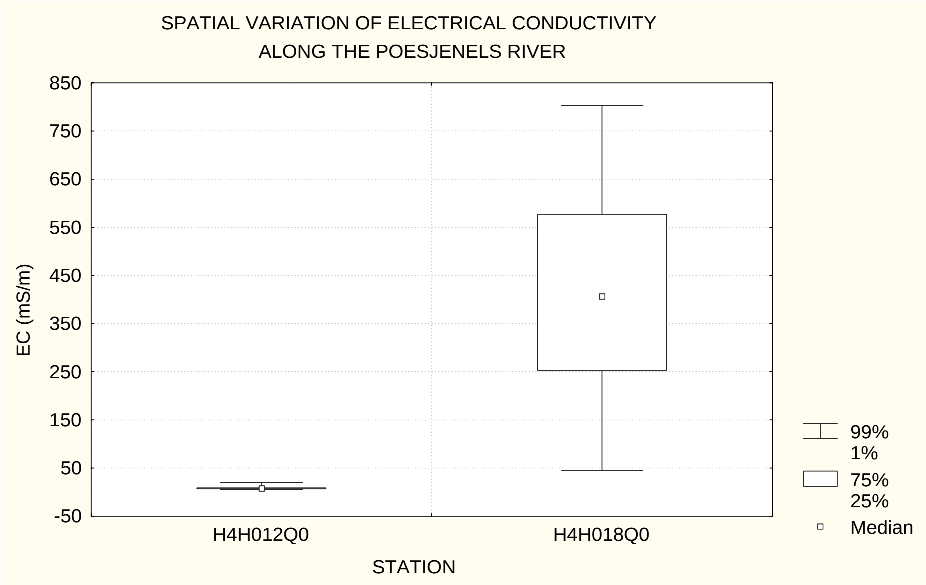


Figure 5.4a : Spatial variation of the EC along the Poesjenels River

Southern Waters (2000) determined that H4H012Q01 and H4H018Q01 could be assigned to the foothill-cobble bed and lowland floodplain sub-regions respectively. Figure 5.4a shows that the headwaters of the Poesjenels have remained fairly unimpacted and that the downstream quality has severely deteriorated. This could be attributed to the extensive farming activity occurring adjacent to the river.

At station H4H012Q01 the water quality is still acceptable for irrigation but at H4H018Q01 the Target Water Quality Range is exceeded for more than 75% of the time and this will eventually result in substantial yield losses if used for irrigation. At station H4H012Q01 the water quality with respect to EC has remained stable over the monitoring period indicating that the criteria for environmental use have been met. The water quality at H4H018Q01 has been altered significantly from its natural state and it can be assumed that a change in the aquatic community structure has occurred.

The water quality at H4H012Q01 is acceptable for domestic use while at H4H018Q01 it is not.

5.4.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is reflected in Figure 5.4b below.

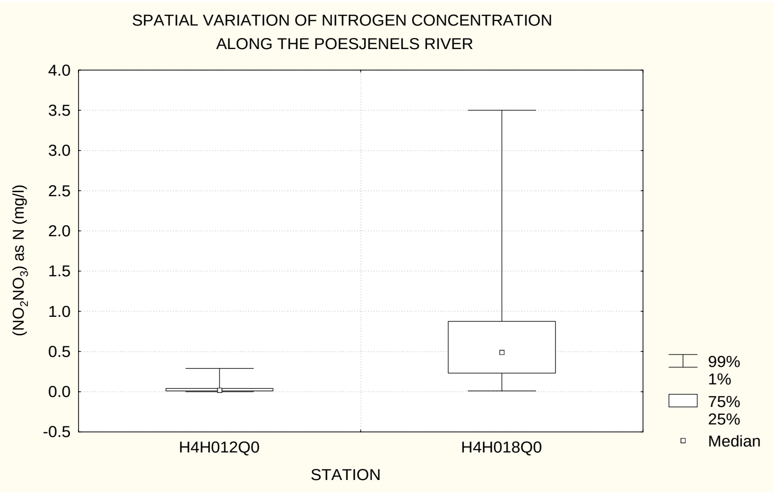


Figure 5.4b : Spatial variation of the nitrogen concentration along the Poesjenels River

There is a substantial change in nitrogen concentration from the upstream gauging station to the downstream one. The nitrogen concentration at both stations does not exceed 5 mg/ℓ and is thus suitable for irrigation use providing the other water quality criteria are met. The nitrogen concentration at station H4H012Q01 is sufficiently low to limit the degree of nutrient enrichment and oligotrophic conditions should exist here. At station H4H018Q01 it can be seen that 50% of the data entries are above the 0.5 mg/ℓ and this would create the possibility for mesotrophic conditions to occur.

5.4.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is reflected in Figure 5.4c below.

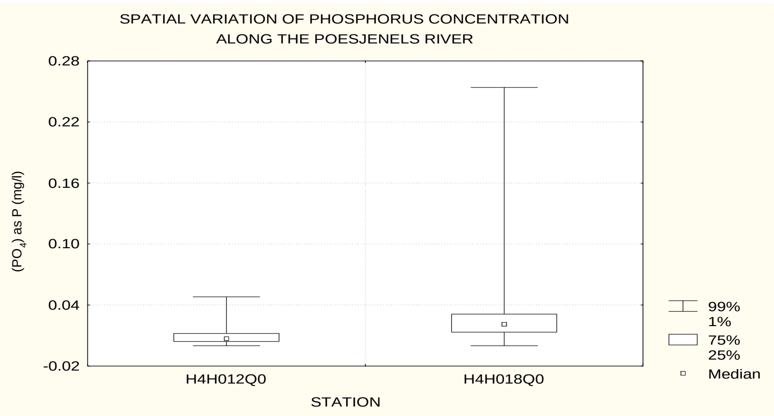


Figure 5.4c : Spatial variation of the phosphorus concentration along the Poesjenels River

The graph indicates that the median value increases slightly in a downstream direction and that higher phosphorus concentrations occur at the downstream monitoring station. Mesotrophic and eutrophic conditions are certainly possible at station H4H018Q01. No background phosphorus concentrations have been determined for unimpacted streams.

5.4.4 pH Value

The spatial variation of the pH value is reflected in Figure 5.4d below.

The water at H4H012Q01 exceeds the Target Water Quality Range on the acidic side of the pH scale and this may increase the corrosion of irrigation equipment.

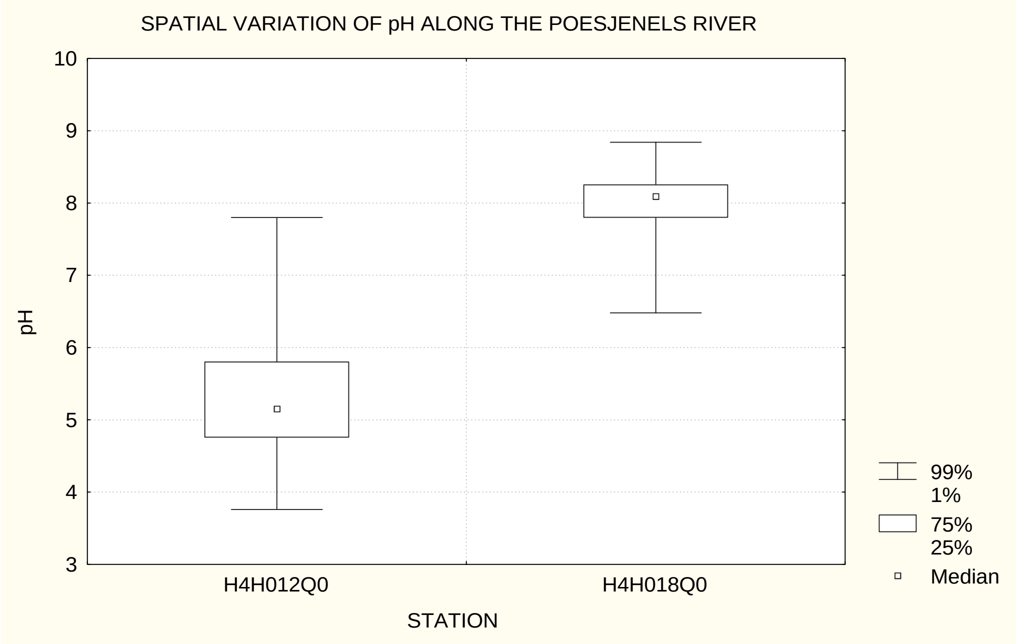


Figure 5.4d : Spatial variation of the pH value along the Poesjenels River

The median pH value at H4H012Q01 is less than the background pH by 1 pH unit while the median value at H4H018Q01 exceeds its background value by 0.7 of a pH unit. This indicates that the Target Water Quality Range for environmental water use is transgressed on several occasions at both monitoring stations.

5.4.5 Chloride Concentration

The spatial variation of the chloride concentration is reflected in Figure 5.4e.

The chloride concentration exhibits a similar trend to that of the EC. The concentration at station H4H012Q01 is very stable and shows little deviation from the mean value. This implies that it is suitable for irrigation, industrial processes and livestock watering.

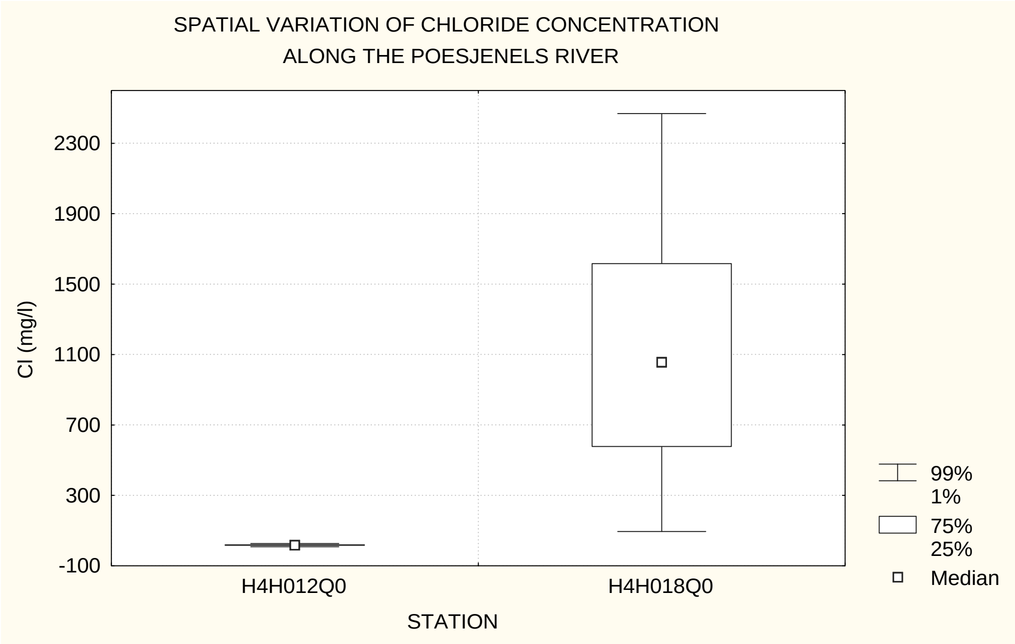


Figure 5.4e : Spatial variation of the chloride concentration along the Poesjenels River

For irrigation and industrial water use the water quality at station H4H018Q01 exceeded the target water quality range for at least 75% of the time rendering it less suitable for irrigation use.

For livestock watering the quality is unacceptable for at least 25% of the time at H4H018Q01.

5.4.6 Sodium Concentration

The spatial variation of the sodium concentration is reflected in Figure 5.4f below. The concentration at H4H012Q01 is very stable and very little deviation from the median is observed.

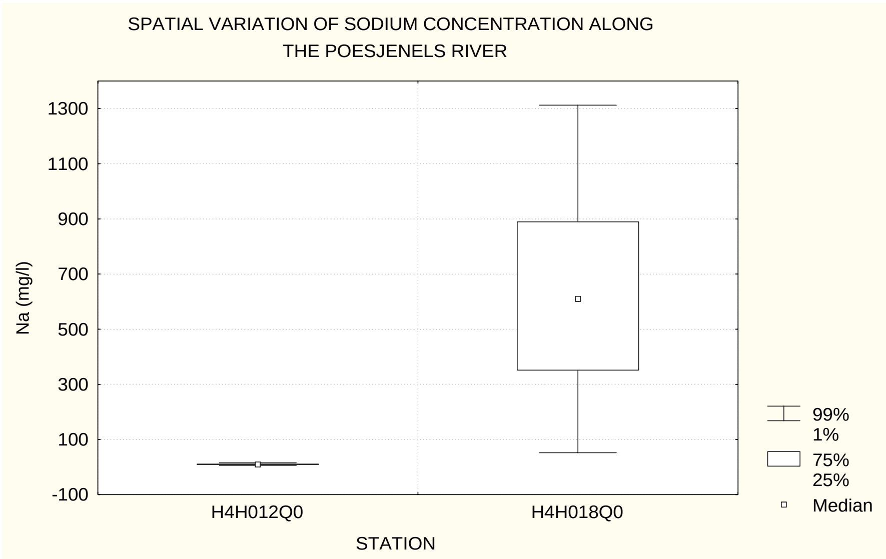


Figure 5.4f : Spatial variation of sodium concentration along the Poesjenels River

At H4H018Q01 the Target Water Quality Criterion for irrigation is exceeded for almost 100% of the time but water quality is acceptable for livestock watering.

5.4.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is reflected in Figure 5.4g below.

Irrigation use - The median value at station H4H012Q01 is within the Target Water Quality Range for irrigation, but some data entries do extend beyond the range. The water quality at H4H018Q01, however, transgresses the Target Water Quality range for 100% of the time.

For irrigation purposes the water at H4H012Q01 is acceptable for most of the time but at H4H018Q01 it is unacceptable for 100% of the time.

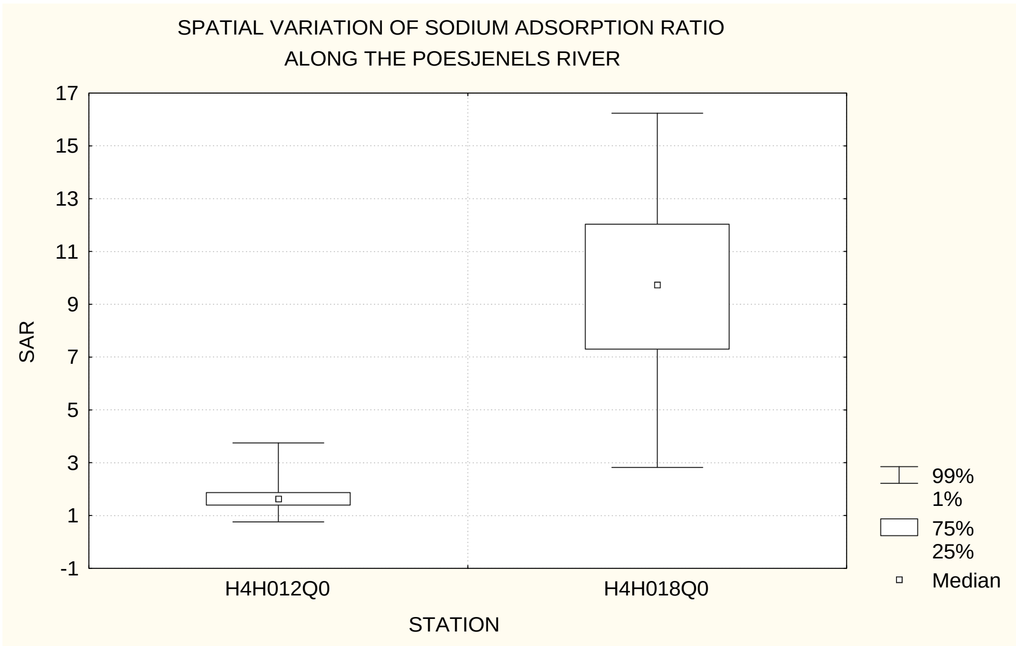


Figure 5.4g : Spatial variation of SAR along the Poesjenels River

5.5 SPATIAL VARIATION ALONG THE KOGMANSKLOOF RIVER

5.5.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is reflected in Figure 5.5a.

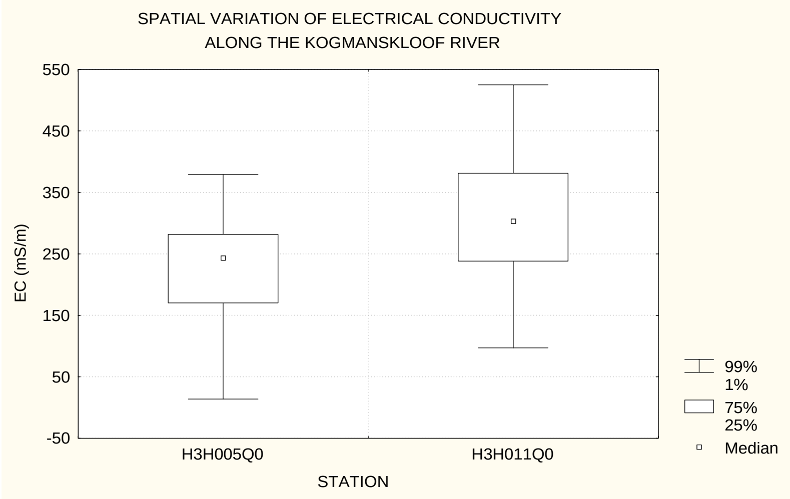


Figure 5.5a : Spatial variation of EC along the Kogmanskloof River

Southern Waters (2000) determined that station H3H005Q01 and H3H011Q01 could be assigned to the foothill-gravel bed and lowland floodplain sub-regions, respectively. The median value at H3H005Q01 exceeds its background value 26 fold while at H3H011Q01 the background value is exceeded 14 fold.

For irrigation water use the water quality at both gauging stations is unacceptable for at least 75% of the time. A slight increase in the EC value was observed in a downstream direction.

From an environmental perspective it is observed that the median value at both gauging stations is more than 10 fold removed from its respective background quality and this implies that the Target Water Quality Criterion is exceeded on several occasions.

The water at both gauging stations is unacceptable for domestic water use.

5.5.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is reflected in Figure 5.5b below.

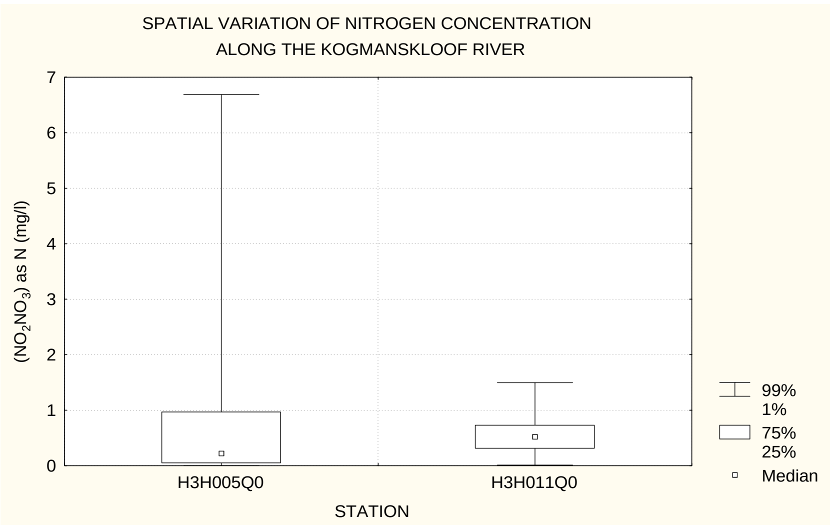


Figure 5.5b : Spatial variation of nitrogen concentration along the Kogmanskloof River

Although the median value is quite low, some observations at H3H005Q01 exceeded 5 mg/ℓ which implies that there is a possibility of the crop yield being affected as well as groundwater being contaminated. The possibility of mesotrophic and even eutrophic condition exists at this gauging station.

At station H3H011Q01 the median value is slightly higher than at H3H005Q01 but the maximum of observations was much lower. Mesotrophic conditions may exist at this station.

5.5.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is reflected in Figure 5.5c.

The median phosphorus concentration increases slightly in a downstream direction. At gauging station H3H005Q01 the median value is relatively low but some values do extend beyond the threshold values required to induce eutrophic and hypertrophic conditions. At gauging station H3H011Q01 the median value is slightly higher but a lower maximum concentration was observed at this station. The possibility of eutrophic conditions occurring still exists at this station.

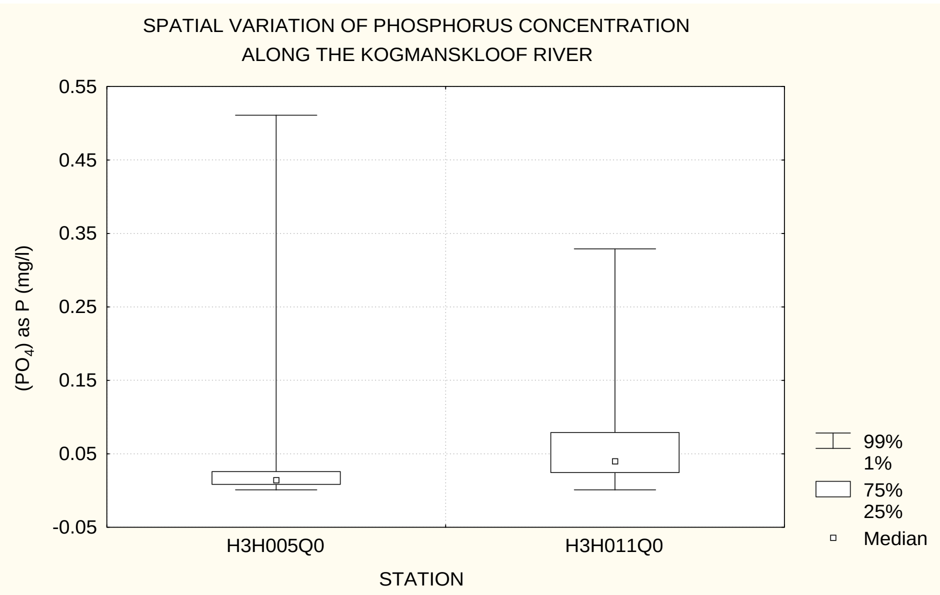


Figure 5.5c : Spatial variation of phosphorus concentration along the Kogmanskloof River

5.5.4 pH Value

The spatial variation of the pH value is reflected in Figure 5.5d.

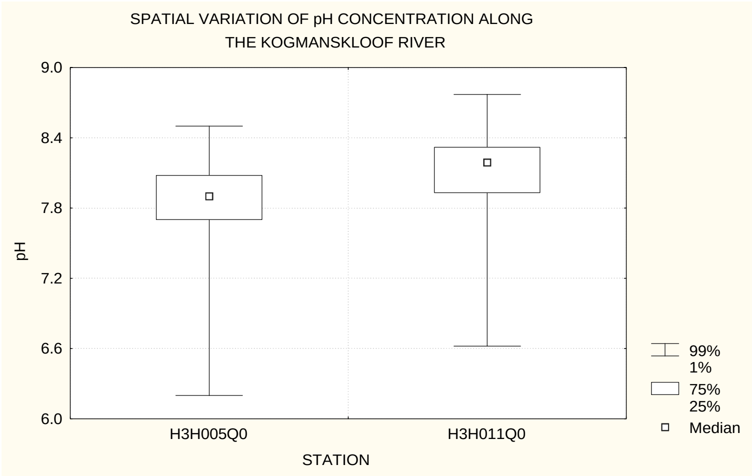


Figure 5.5d : Spatial variation of pH value along the Kogmanskloof River

The median pH values at gauging stations H3H005Q01and H3H011Q01 are approximately 1.3 pH units and 0.7 of a pH unit above the respective background values.

For irrigation purposes the pH at both stations is mostly within the desired range with only a few data entries not meeting requirements. Environmental use - Figure 5.5d shows that at least 50 % of the data entries at both gauging stations vary by more than 0.5 of a pH unit from the background water quality value. This implies that the environmental criteria are transgressed for at least 50% of the time.

Industrial use - At gauging station H3H005Q01 some values do extend beyond the Target Water Quality Range for industrial usage, but the majority of data entries are within the prescribed range. At gauging station H3H011Q01 more than 50% of the data entries are outside the Target Water Quality Range.

5.5.5 Chloride Concentration

The spatial variation of the chloride concentration is reflected in Figure 5.5e below.

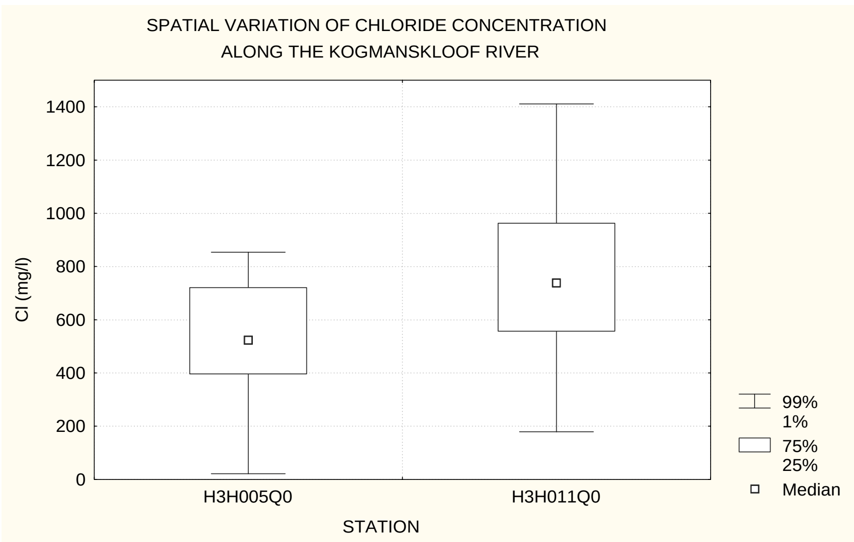


Figure 5.5e : Spatial variation of chloride along the Kogmanskloof River

The median value of the chloride concentrations increases in a downstream direction. At least 75% of the data entries at H3H005Q01 are above 400mg/ℓ, while 75% of the entries at H3H011Q01 are above 450mg/ℓ.

From the information in the graph it can be seen that the water at both gauging station is unacceptable for irrigation and industrial use for at least 75% of the time.

The water at both gauging stations can still be used for livestock watering.

5.5.6 Sodium Concentration

The spatial variation of the sodium concentration is depicted in Figure 5.5f below.

The mean sodium concentration increases in a downstream direction. At least 75% of the data entries at gauging stations H3H005Q01 and H3H011Q01 exceed 250 and 320 mg/ℓ, respectively.

For irrigation purposes the water at gauging station H3H005Q01 is acceptable for less than 25% of the time, while the water at H3H011Q01 is unacceptable for 100% of the time. The water can, however, be used for livestock watering.

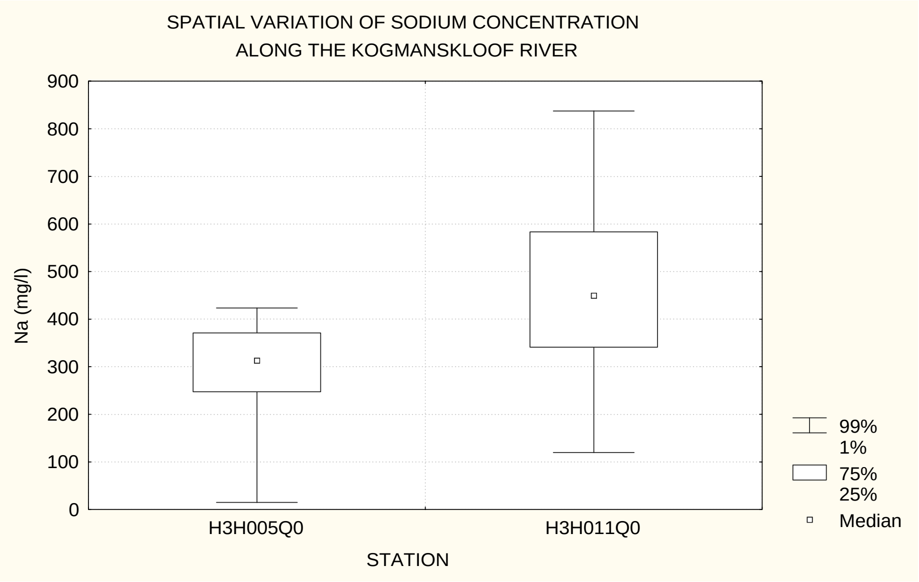


Figure 5.5f : Spatial variation of sodium concentration along the Kogmanskloof River

5.5.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is reflected in Figure 5.5g.

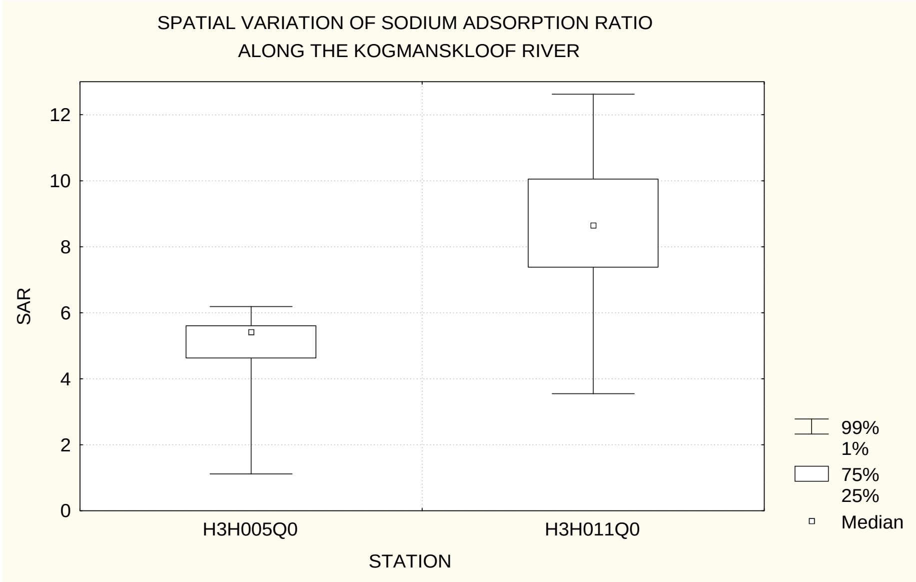


Figure 5.5g : Spatial variation of SAR along the Kogmanskloof River

The median value for the SAR increases in a downstream direction. At gauging station H3H005Q01, 75% of the data entries exceeded the prescribed Target Water Quality Range while 100% of the entries exceeded the prescribed range at H3H011Q01. This implies that water at both gauging stations was unacceptable for irrigation purposes.

5.6 SPATIAL VARIATION ALONG RIVIERSONDEREND

Southern Waters (2000) determined that selected gauging stations along the Riviersonderend could be assigned to the sub-regions as follows :

TABLE 5.6 : ASSIGNMENT OF GAUGING STATIONS TO VARIOUS SUB-REGIONS

GAUGING STATIONS	SUB-REGION
H6H007Q01	Foothill-cobble bed
H6H008Q01	Mountain stream
H6H012Q01	Mountain stream
H6H009Q01	Lowland floodplain

5.6.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is reflected in Figure 5.6a.

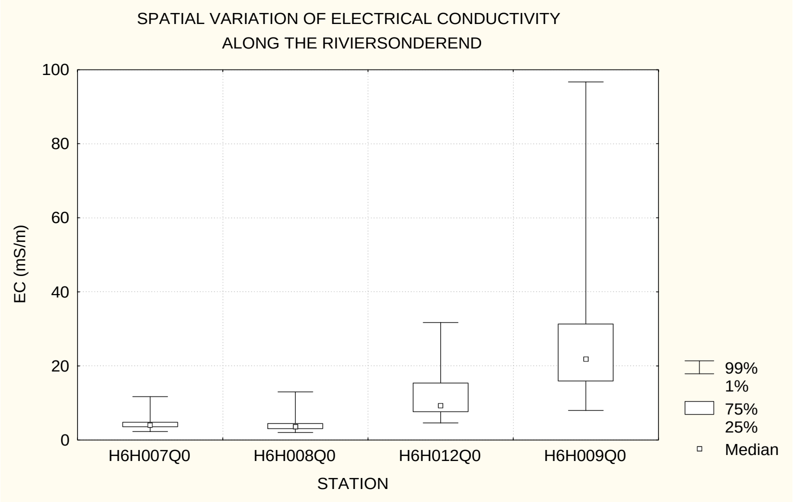


Figure 5.6a : Spatial variation of EC along Riviersonderend

The EC values at the gauging stations increase in a downstream direction. The median values at gauging stations H6H007Q01 and H6H008Q01 compare favourably with their respective background values. Gauging station H6H012Q01 has been classified as a mountain stream but the median value at this point exceeds its background quality 3 fold. The median value at station H6H009Q01 corresponds well to the background value.

Although the EC increases in a downstream direction, the water quality at all the gauging stations mentioned above is acceptable for irrigation usage. The median values at gauging stations H6H007Q01 and H6H008Q01 indicate that this portion of the river has remained fairly unimpacted. Gauging stations H6H012Q01 and H6H009Q01 have been slightly impacted but the water is still acceptable for irrigation.

The water at all the gauging stations is suitable for domestic usage provided that the other water quality criteria are also met.

5.6.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is depicted in Figure 5.6b below.

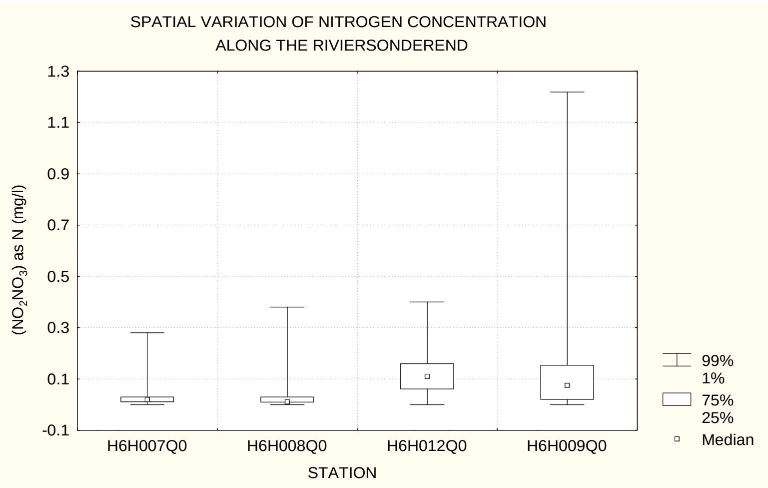


Figure 5.6b : Spatial variation of nitrogen concentration along the Riviersonderend

The median value for the nitrogen concentration remains fairly constant but does increase slightly in a downstream direction until it reaches gauging station H6H012Q01.

It can be seen that the nitrogen concentration does not extend beyond 1.3 mg/ℓ and this is well within the Target Water Quality Range for irrigation water use.

From an environmental perspective it is observed that the possibility of mesotrophic conditions exists only at gauging station H6H009Q01.

5.6.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is depicted in Figure 5.6c below.

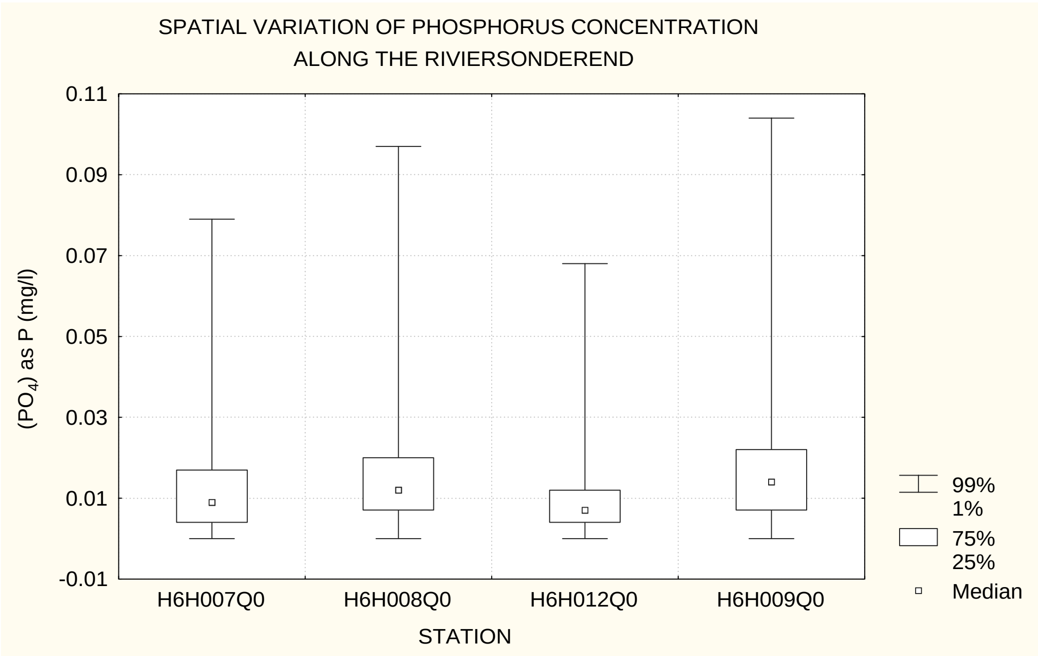


Figure 5.6c : Spatial variation of phosphorus concentration along the Riviersonderend

The median concentration at the gauging stations remains stable around the 0.01 mg/ℓ mark with the highest concentration being reached at station H6H009Q01.

From the data ranges presented above, it can be seen that the possibility for the occurrence of mesotrophic and eutrophic conditions exists at all gauging stations.

5.6.4 pH Value

The spatial variation of the pH value is depicted in Figure 5.6d.

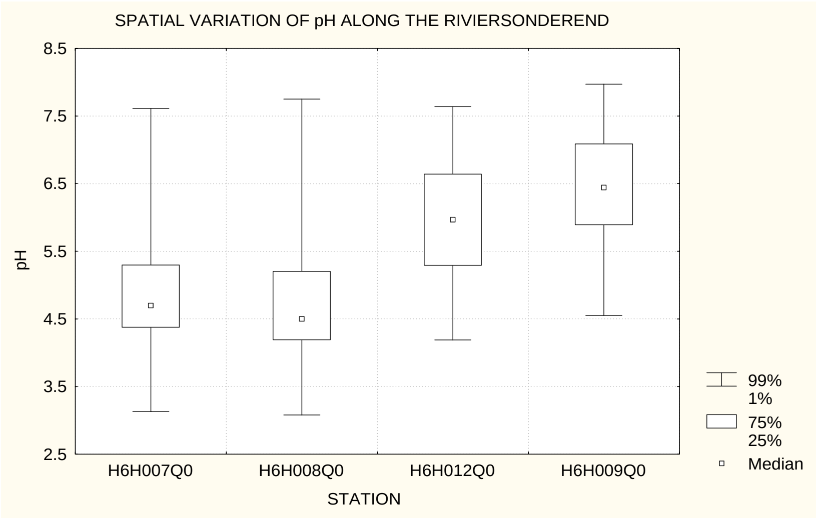


Figure 5.6d : Spatial variation of pH along the Riviersonderend

The median values of the mountain streams, H6H008Q01 and H6H012Q01 are 1 pH unit below and 0.5 pH units above their respective background qualities, while the medians at gauging stations H6H007Q01 and H6H009Q01are 1.4 and 0.8 pH units below their respective background qualities.

For irrigation purposes it should be noted that all the stations have data entries which transgress the prescribed Target Water Quality Range on the acidic side of the pH scale. From an environmental perspective it can be seen that station H6H012Q01 comes closest to satisfying the Target Water Quality Criteria but that compliance with the criteria is marginal. Most of the data entries at all the other stations are well outside the prescribed range. The Target Water Quality Range for industrial use is also exceeded on the acidic side of the pH scale at all the stations.

5.6.5 Chloride Concentration

The spatial variation of the chloride concentration is reflected in Figure 5.6e. The median value increases in a downstream direction and the trend is similar to that of the EC.

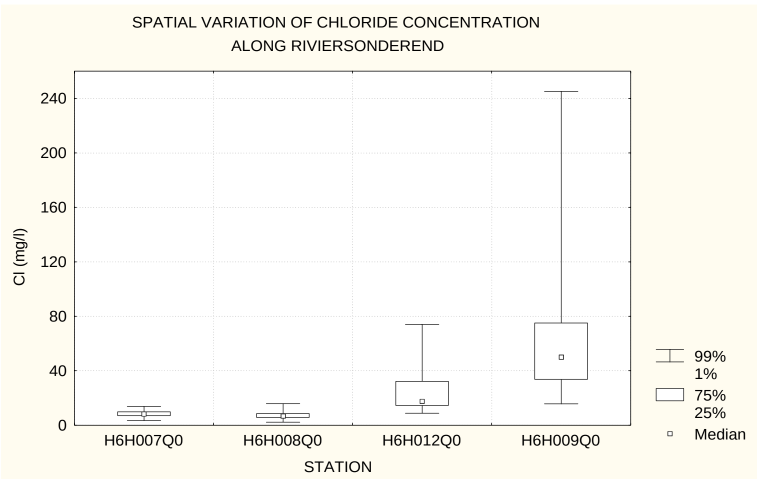


Figure 5.6e : Spatial variation of chloride concentration along the Riviersonderend

For irrigation and industrial purposes the water quality at gauging stations H6H007Q01 to H6H012Q01 is acceptable for 100% of the time. At station H6H009Q01, at least 75% of the values are within the prescribed range with only a few data entries extending outside the range. The water quality at all the stations is acceptable for livestock watering.

5.6.6 Sodium Concentration

The spatial variation of the sodium concentration is depicted in Figure 5.6f.

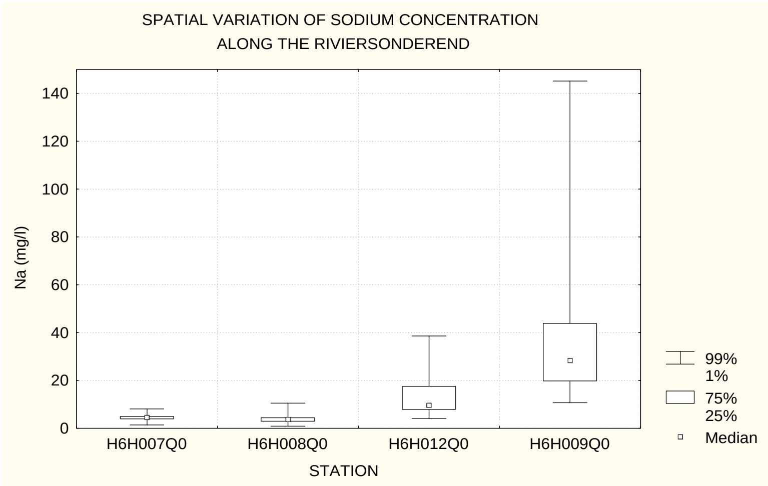


Figure 5.6f : Spatial variation of sodium concentration along the Riviersonderend

For irrigation purposes, the water at gauging stations H6H007Q01 to H6H012Q01 is acceptable for use 100% of the time. At station H6H009Q01 the water is acceptable for at least 75% of the time. The water at all the stations is acceptable for livestock watering.

5.6.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is reflected in Figure 5.6g. For irrigation purposes, the SAR value at gauging stations H6H007Q01 to H6H012Q01 is acceptable for at least 75% of the time. At gauging station H6H009Q01 the SAR value is unacceptable for at least 75% of the time.

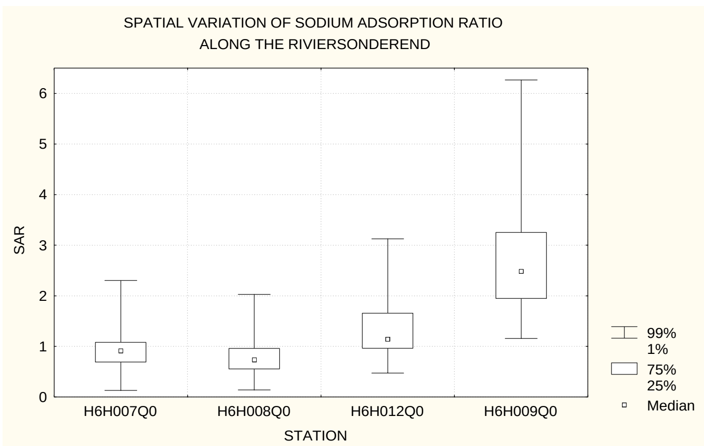


Figure 5.6g : Spatial variation of SAR along the Riviersonderend

5.7 SPATIAL VARIATION ALONG THE HUIS AND BUFFELJAGS RIVERS

Southern Waters (2000) assigned stations H7H003Q01 and H7H013Q01 to the foothill-cobble bed and foothill-gravel bed subsections respectively. Gauging station H7H004Q01 has been assigned to the rejuvenated cascade subsection.

5.7.1 Total Dissolved Solids/Electrical Conductivity (EC)

The spatial variation of the EC is depicted in Figure 5.7a below.

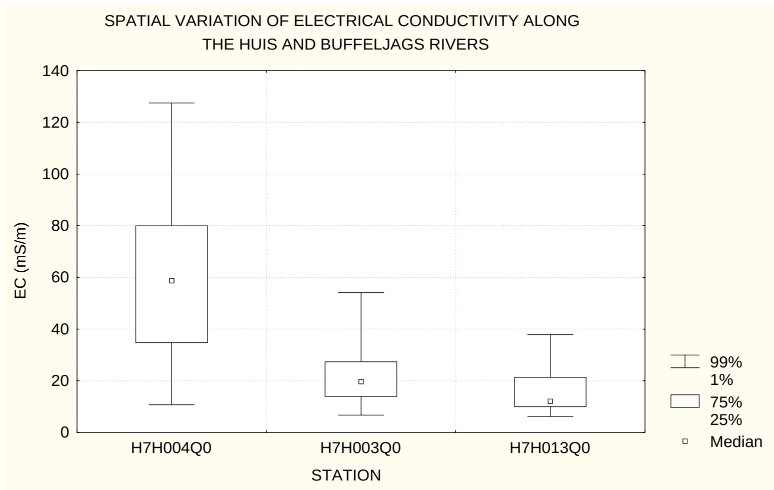


Figure 5.7a : Spatial variation of EC along the Huis and Buffeljags Rivers

The median EC value decreases in a downstream direction. No background EC has been determined for a rejuvenated cascade, but at best the median would exceed a background value 3 fold. The median at station H7H003Q01 exceeds its background value 6 fold but the median value at H7H013Q01 corresponds very well with its background value.

For irrigation purposes, the EC at all the stations is within the prescribed range. The median value at H7H004Q01 is, however, much higher than at the other gauging stations. Apart from station H7H013Q01 the other stations deviate substantially from their background values implying that the environmental EC criterion is frequently exceeded. The EC values at stations H7H003Q01 and H7H013Q01 indicate that the water is suitable for domestic use. At Station H7H004Q01, however, the water is unacceptable for domestic purposes for at least 25% of the time.

5.7.2 Nitrogen Concentration

The spatial variation of the nitrogen concentration is reflected in Figure 5.7b.

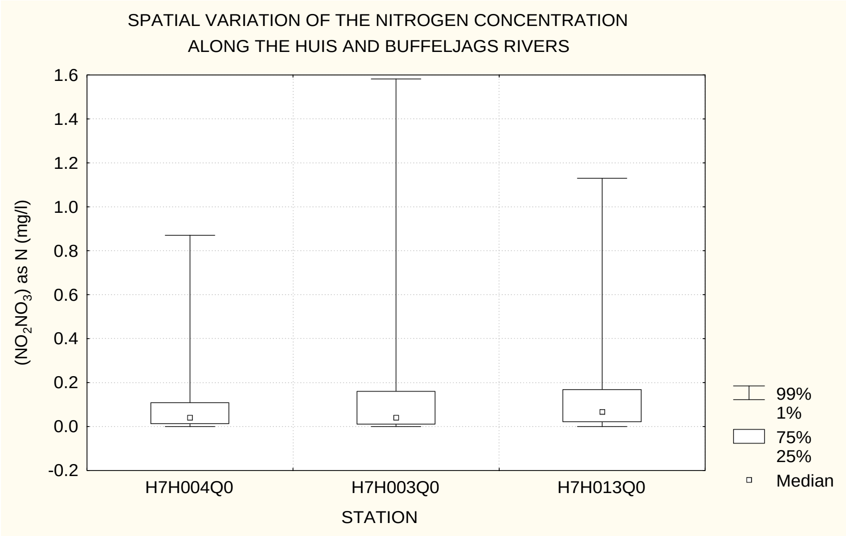


Figure 5.7b : Spatial variation of nitrogen concentration along the Huis and Buffeljags Rivers

The median nitrogen concentration changes very little in the downstream direction. For irrigation purposes the water is acceptable at all the stations. From an environmental perspective there is a possibility of mesotrophic conditions occurring at all the stations.

5.7.3 Phosphorus Concentration

The spatial variation of the phosphorus concentration is reflected in Figure 5.7c below. The median phosphorus concentration remains basically unchanged in the downstream direction but the possibility of eutrophic conditions exists at all the gauging stations.

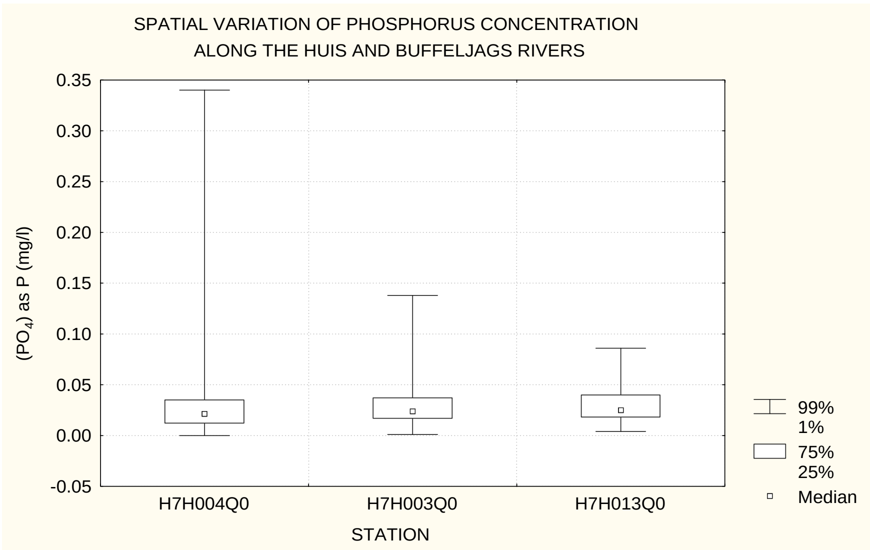


Figure 5.7c : Spatial variation of phosphorus concentration along the Huis and Buffeljags Rivers

5.7.4 pH Value

The spatial variation of the pH concentration is depicted in Figure 5.7d below.

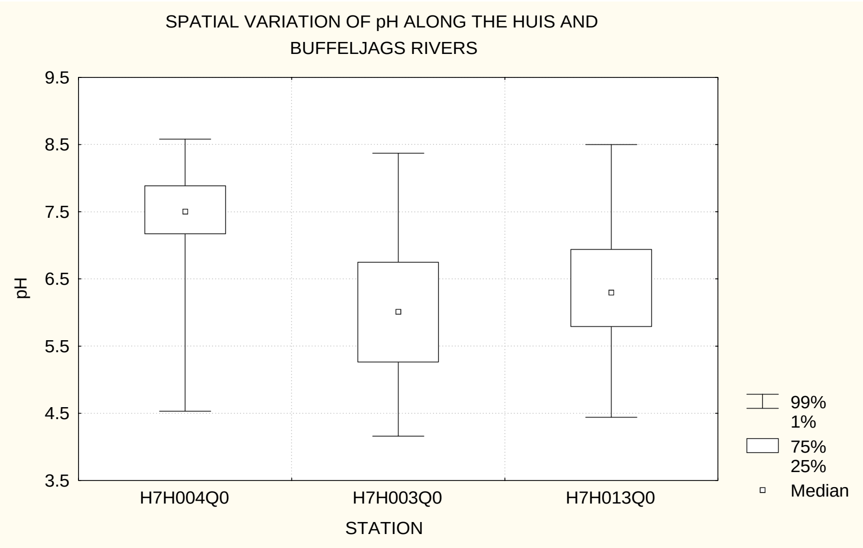


Figure 5.7d : Spatial variation of pH along the Huis and Buffeljags Rivers

The median values at gauging stations H7H003Q01 and H7H013Q01 compare very well with their respective background values. The background pH value for a rejuvenated cascade had not been determined and there is thus no basis for comparison at station H7H004Q01.

For irrigation and industrial water use it is observed that all the stations have data entries which exceed the prescribed Target Water Quality Range on the acidic side of the pH scale. Although the median values at station H7H003Q01 and H7H013Q01 correspond to the background values, there are data entries which deviate substantially from them. This implies that the environmental criteria at these stations are exceeded from time to time.

5.7.5 Chloride Concentration

The spatial variation of the chloride concentration is depicted in Figure 5.7e below.

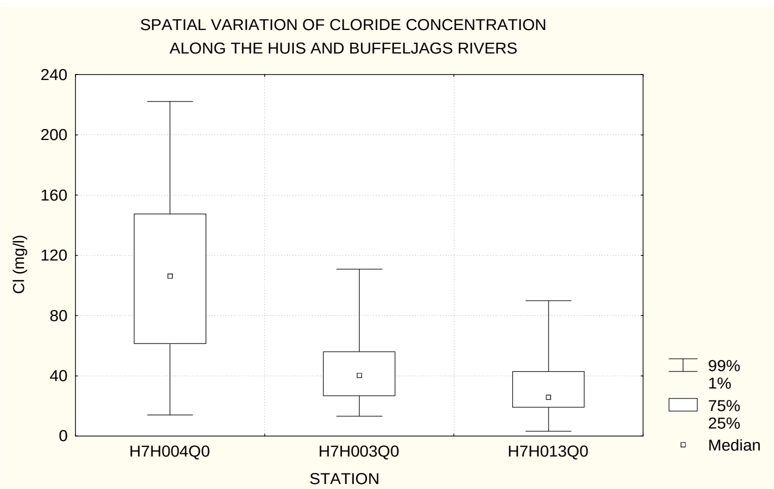


Figure 5.7e : Spatial variation of the chloride concentration along the Huis and Buffeljags Rivers

The median value decreases in a downstream direction with the highest chloride concentrations being reached at H7H004Q01. This would indicate that a substantial amount of irrigation is occurring in this section of the Huis River and that some dilution occurs after its confluence with the Buffeljags River.

At least 25% of the data values at H7H004Q01 exceed the Target Water Quality Criteria for irrigation and industrial use, while at H7H003Q01 and H7H013Q01 the chloride concentration is acceptable for 100% of the time. The water at all the stations is acceptable for livestock watering.

5.7.6 Sodium Concentration

The spatial variation of the sodium concentration is depicted in Figure 5.7f.

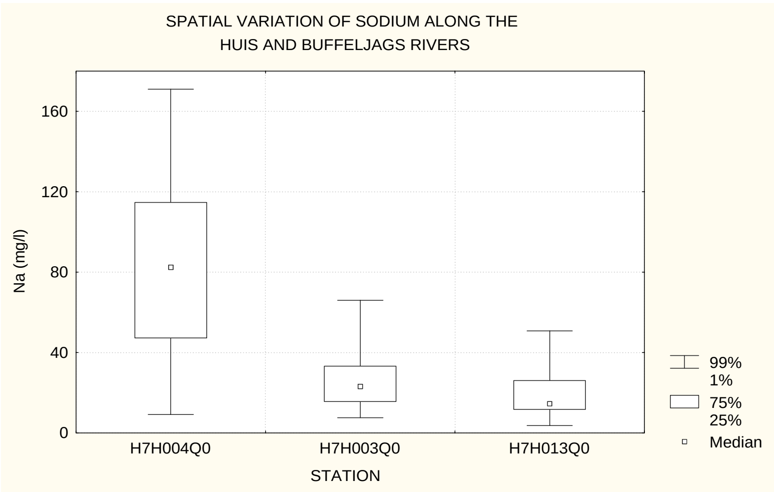


Figure 5.7f : Spatial variation of sodium concentration along the Huis and Buffeljags Rivers

The trend followed by the sodium concentration is similar to that of the EC and the chloride concentrations. At least 25% of the entries at gauging station H7H004Q01 exceed the Target Water Quality Criteria for irrigation use, while that at H7H003Q01 and H7H013Q01 the water quality is acceptable for 100% of the time. The water quality at all the stations is acceptable for livestock watering.

5.7.7 Sodium Adsorption Ratio (SAR)

The spatial variation of the SAR is depicted in Figure 5.7g.

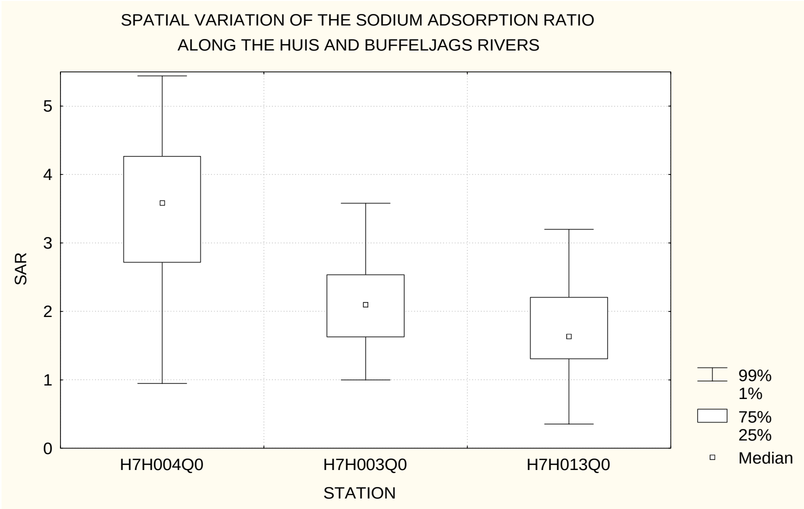


Figure 5.7g : Spatial variation of SAR along the Huis and Buffeljags Rivers

For irrigation purposes the water quality criterion at gauging station H7H004Q01 is exceeded for at least 75% of the time while at H7H003Q01 and H7H013Q01 it is exceeded for 50 and 25% of the time, respectively.

5.8 PESTICIDE CONCENTRATIONS

No detailed data on pesticide concentrations in the Breede River catchment are available. Some information was, however, available from a Water Research Commission study, *An Assessment of the water quality of water supplies in the rural Western Cape with regard to agrichemical pollutants* (London, 1999).

The pesticide data quoted in this report was obtained specifically for the Grabouw, Hex River and Piketberg areas. The criteria used to select these study areas were annual rainfall, water table levels, soil characteristics, intensity of agriculture, accessibility of area and the presence of boreholes.

Despite the fact that no two sampling points have exactly the same physical characteristics in terms of the criteria mentioned above, some of the key findings from the study would probably be valid for other areas of the Breede River Basin where land-use is similar.

In a preliminary task of the study, the State Forensic Laboratory analysed for some 31 types of pesticides and found that only Chlorpyrifos and Endosulphan were detected to any meaningful extent. As a result of these findings, only these two pesticides were tested for during the remainder of the project.

The concentrations observed for these two pesticides were generally low although there were exceptions to this. For the Hex River, it was found that about 52% of the samples had Chlorpyrifos levels greater than 10 µg/ℓ and 46% of the samples had Endosulphan levels greater than 10 µg/ℓ. Certain areas had higher concentrations, which could be attributed to localised physical conditions and pesticide management practices. It appeared that the main mechanism by which pesticides were transported into surface and groundwater was irrigation. Rain washout and spray activity (time of application) did not appear to contribute significantly to pesticide levels, although elevated levels occurred during the time of spraying.

It is probably reasonable to assume that the same patterns of pesticide contamination would be found in the rest of the Breede River Basin, but monitoring would be required to establish the exact extent of contamination.

5.9 POINT SOURCE DISCHARGES

Point source discharges include emissions from wastewater treatment works, industries and any activity where effluent is released in a concentrated and measurable form to a water body. In the Breede River Basin several point sources discharge treated effluent into the Breede River mainstream or its tributaries. The effluent discharged is generally subjected to some sort of treatment (physical or chemical) to meet general effluent standards. At present, no permits exist for the discharge of industrial effluent not complying with the General Effluent Standards, but an application has been lodged with the Department of Water Affairs and Forestry requesting permission to discharge industrial effluent that does not comply with the electrical conductivity limit of the general effluent standards.

5.9.1 Identification of Point Sources

Several point source discharges have been identified in the catchment. Those that discharge directly to rivers or streams are listed below.

TABLE 5.9a : LIST OF POINT SOURCE DISCHARGES IN THE BREEDE RIVER CATCHMENT

DWAF STATION NAME	DESCRIPTION
H101/00/E001	Ceres Municipality: Discharge to Dwars River
H200/00/E001	Worcester Municipality: Discharge to Breede River
H300/00/E001	Ashton Municipality: Discharge to Sarahs River
H300/00/E002	Montagu Municipality: Discharge to Kinga River
H402/00/E001	Robertson Municipality: Discharge to Hoops River
H600/00/E001	Villiersdorp Municipality: Discharge to Elands River
H600/00/E002	Helderstroom Prison: Discharge to Riviersonderend
	Wolseley Municipality: Discharge to unnamed tributary of Breede River
	Goudini Spa : Discharge to Breede River
	Swellendam Municipality: Discharge to Klip River
	Swellendam Municipality: Discharge to Klip River
	Umzingisi School : Discharge to Dams River

As can be seen from the above, most of the point source effluent emanates from sewage treatment works and as a result the oxygen demand of the waste should be carefully manager to mitigate its cumulative effect on the river system. Typical Biochemical Oxygen Demands (BOD) for treated effluent range between 3 - 50 mg/ℓ (Dallas and Day, 1993).

5.9.2 Organic Loads and Volumes Released from Sewage Treatment Works

Sewage treatment works may implement different processes for treating waste and may also operate at different efficiencies. Table 5.9b below summarises the pertinent information obtained from statistical analysis of the data at each point source.

The values indicate that COD concentrations can vary from within the set standard to well above the standard. The high values obtained for the maximum chemical oxygen demand (COD) concentrations could be attributed to the low efficiency of the treatment works at that specific time, or due to an emergency situation or breakage.

TABLE 5.9b : COD AND LOAD VALUES FOR POINT SOURCE DISCHARGES

STATION DESCRIPTION	MIN. COD (mg/ℓ)	MAX. COD (mg/ℓ)	MIN. COD LOAD (kg/month)	MAX. COD LOAD (kg/month)
Ceres Municipality	7.5	2000	910	317130
Worcester Municipality	26	275	239.56	74656
Ashton Municipality	40	370	1640	14330
Montagu Municipality	32	248	0	966
Robertson Municipality	34	205	2592	15186
Villiersdorp Municipality	10	236	234	8337
Helderstroom Prison	23	214	32	3218
Wolseley Municipality	22	2780	-	-
Goudini Spa Sewage Treatment Works	10	217	-	-
Swellendam Municipality New Works	52	392	-	-
Swellendam Municipality Old Works	37	210	-	-
Umzingizi School	10	154	-	-

5.10 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) is not a water quality constituent which is monitored on a regular basis and only scattered data are available. Dallas *et al.* (1998) reported a single TSS measurement for selected monitoring points. An analysis of this data revealed possible areas of concern for high TSS concentrations. Table 5.10a lists the selected stations.

TABLE 5.10a : TSS MEASUREMENTS AT SELECTED STATIONS

SITE	STATION NAME	TSS (mg/ℓ)
01/MCG	H4H016Q01	6.25
07/DRIE	H2H010Q01	22.6
10/NEK	H1H015Q01	6.33
11/CHAS	H4H017Q01	6
18/KOG	H3H011Q01	5.29
19/VINK	H4H019Q01	3.45
21/DREW	H5H005Q01	3.01
27/SWELL	H7H006Q01	2.4
32/SUUR	H7H003Q01	3.43
37/KLIP	H6H009Q01	5.4
43/DWARS	H1H003Q01	2.2

For irrigation water use none of the data entries exceeded 50 mg/ℓ, which is the threshold concentration at which problems with drip irrigation emitters are experienced. This is not a true reflection because only one sample was taken at each station. From an environmental perspective it should be observed that none of the TSS concentrations exceed 100mg/ℓ. To establish seasonal and annual fluctuations in TSS at a specific site, TSS must be included as a variable to be analysed for as part of the routine monitoring undertaken by DWAF.

5.11 IRON CONCENTRATION

Dallas *et al* (1998) reported some values for iron concentrations, and it was noted that all the data entries exceeded the Target Water Quality Range for domestic use. In the worst case scenario, the target water quality range was exceeded four fold.

5.12 MANGANESE CONCENTRATION

Dallas *et al* (1998) reported values for manganese concentrations and it was observed that most of the data entries slightly exceeded the Target Water Quality Range. Possible areas of concern include the gauging stations listed in Table 5.12a below.

TABLE 5.12a : STATIONS WHERE MANGANESE CONCENTRATIONS MAY BE A CONCERN

STATION	DESCRIPTION
H6H005Q01	Baviaans River at Genadendal mission station
H1H003Q01	Breede River at Ceres Commonage
H2H016Q01	Lakenvallei Dam on Sanddrifskloof River

5.13 INFORMATION GAP

No information could be obtained on algae blooms and bacteriological water quality. Since these were raised as issues of concern, a monitoring network should be initiated to quantify the extent of these problems.

6. CONCLUSIONS

From the above discussion the following can be concluded :

- Sodium, chloride and electrical conductivity are water quality constituents of concern throughout the catchment and their concentrations are particularly high in the Middle Breede River and the lower reaches of its tributaries.
- The sodium adsorption ratio follows a similar trend to that of sodium and is also a problem in the Middle Breede River and the lower reaches of the tributaries.
- The effect of the high values of the sodium, chloride and electrical conductivity is of particular concern to the irrigation and environmental water use applications.
- The nitrogen concentration is acceptable at most stations, but higher values are consistently recorded at gauging stations H2H006Q01, H4H018Q01 and H3H005Q01.
- At least 25% of the data entries at stations H1H006Q01, H5H004Q01, H4H008Q01, H4H020Q01, H7H004Q01, H7H003Q01, H7H013Q01, H3H005Q01 and H3H011Q01 were within the range for the occurrence of eutrophic conditions.
- The pH at most stations is slightly unacceptable for industrial usage and pHs have deviated from their background water qualities.
- Apart from the high EC, chloride, SAR values and sodium concentrations the other water quality variables are not major problems at this stage.

7. RECOMMENDATIONS

Based on the discussion and conclusions drawn above the following recommendations can be made.

- Better management strategies for the control of chloride, sodium and EC should be investigated, especially for the Middle Breede River and the Kogmanskloof, Nuy, Hex and Poesjenels tributaries.
- Management strategies for the application of fertilisers should be implemented to ensure that as little as possible nitrogen and phosphorus reaches the rivers as return flow.
- The routine monitoring of water quality variables should be continued and an attempt should be made to include pesticides, total suspended solids, iron, manganese, microbiological and temperature monitoring in the catchments where they have been identified as a concern.

PART 2

SALINITY SITUATION ASSESSMENT

BREEDE RIVER BASIN STUDY

PART 2 :
SALINITY SITUATION ASSESSMENT

1. INTRODUCTION

The Breede River is the largest river in the Western Cape and the least utilised water resource in the region. The river originates in the Ceres Valley and flows in a south-easterly direction until it reaches the Indian Ocean at St Sebastian Bay on the Southern Cape Coast. The Breede River has developed into one of the largest wine and food producing regions in South Africa and is an important area for the production of high value crops under intense cultivation. Historically, the major water quality issue has been the rising salinities in the Middle to Lower Breede River as well as some of the tributaries in this section of the basin. The major aim of this report is to assess the status of the river with respect to the salinity situation.

1.1 DESCRIPTION OF STUDY AREA

The headwaters of the Breede River are situated along the Skurweberg and Gydoberg Mountains in the Ceres Basin and the Hex River Mountains. The Upper Breede River originates in the Ceres Basin and drains through Michell's Pass in a south-easterly direction to join with the Riviersonderend before reaching the Indian Ocean at Sebastian Bay. The Breede River is bordered on the north and south-west by high mountain ranges composed of quartizites and sandstones of the Table Mountain Group. The area south of the Breede River is dominated by the sandstone and shales of the Bokkeveld and Witteberg groups, while the valley itself is comprised of sediments from the Dwyka and Ecca groups. The total catchment area is 12600 km^2.

1.2 OBJECTIVE OF REPORT AND REQUIRED TASKS

The objective of the report is to provide an overview of salinity management issues and challenges in the Breede River catchment.

The following tasks were undertaken :

- Review the available literature on hydrosalinity studies performed in the Breede River catchment and confirm the relative contributions of the various sources of salinity.
- Evaluate the salinity status of the Middle Breede River and its tributaries.
- Review the above analyses with respect to the findings of the literature review, focussing on degree, causes and implications of salinisation.
- Describe and evaluate 'proposed' and new solutions to the salinity problems.

1.3 STRUCTURE OF REPORT

The report gives a brief description of existing literature on relevant hydrosalinity studies, followed by a literature review and a section on the salinity status of the Middle Breede River. The report concludes with an evaluation of possible engineering solutions to the problem.

2. LITERATURE SURVEY

2.1 REVIEW OF PREVIOUS HYDROSALINITY STUDIES IN THE BREEDE RIVER

The following reports have been reviewed to ascertain the level and type of information available to the project members who are specifically involved with water quality.

A. HYDROSALINITY MODELLING OF THE BREë RIVER:
Review and future strategy (DWAF, February 1986)

This report identified the possible sources of the saline waters in the Middle Breede River region. Changes to the existing monitoring system were noted along with a strategy for quantifying the problem. In conclusion, the report presented a future work programme focussing on high and low priority work.

B. HERSIENE KRITERIA VIR BESPROEIINGSWATER IN DIE BREëRIVIER (Soil and Irrigation Research Institute, January 1988)

This report defined the target salinity values for the irrigation water from the Breede River. The target limit defined in this report is based on the findings of previous reports

C. HYDROSALINITY MODELLING OF THE BREEDE RIVER:
Technical description of the Greater Brandvlei Dam Government Water Scheme. (DWAF, April 1988)

The report summarised the best available technical data for the Greater Brandvlei Dam Government Water Scheme. The information in this report was gathered in a desk top study from various preceding reports and contained data on the Greater Brandvlei Dam, river channel, pumping schemes, canals, farm dams and irrigation areas. None of the information was verified in field studies.

D. HYDROSALINITY MODELLING OF THE BREEDE RIVER
Greater Brandvlei Dam Government Water Supply Scheme (DWAF, October 1988)

This report was a follow-up to the abovementioned report (B) and provided additional information sources to the hydrosalinity modellers. As opposed to the initial report, this report did not provide actual data but focussed on presenting a complete spectrum of data sources. Sources of information for Greater Brandvlei Dam operation, flow data, water quality data, irrigation data, farm dam data, river pumping data, meteorological data, geohydrological data, urban water consumption, soils data and research data were available in this report.

E. HYDROSALINITY MODELLING OF THE BREEDE RIVER
Planning Options for The Breede River (DWAF, October 1988)

This report described various options to alleviate the salinity problem in the Middle Breede River area. The report only presented a physical description of the options. Evaluation of the technical and economic feasibility was left to the hydrosalinity modellers.

F. A PILOT STUDY OF THE IRRIGATED AREAS SERVED BY THE BREEDE RIVER (ROBERTSON) IRRIGATION CANAL (MBB, March 1988)

As its main objective the report attempted to quantify via a model, IRRISS, the water volumes and salt loads moving through the irrigation scheme that receives water from the Robertson irrigation canal. The parameters required as inputs to the IRRISS hydrosalinity model were monitored over a 260 day period and the results of the subsequent mass balance were presented in the report.

G. DIE VERBAND TUSSEN GEOLOGIE, GRONDWATERGEHALTE EN BOORGATLEWERINGS: 'N HIDROSENSUS IN DIE BREEDERIVIERVALLEI TUSSEN DIE GROTER BRANDVLEI DAM EN SANDDRIFTMEETVELD (DWAF, March 1990)

This report attempted to determine a relationship between quality, yield and different geological formations for groundwater. Average electrical conductivity (EC) values for groundwater as well as upper and lower limits for EC were quoted in this report. The fact that water quality varies according to the formation from which it is abstracted was also verified.

H. BREEDE RIVER SALINATION RESEARCH PROGRAM (BRSRP)
7^{TH} Internal report
Representation of Hydro-Chemical Data (DWAF, HRI, JUNE 1990)

This report reviewed statistical procedures as well as graphical representations that could be used for interpreting water quality data. The section on data accuracy was of particular importance to the water quality task of this project. The various statistical procedures were illustrated by manipulating data at various gauging stations.

I. BREEDE RIVER SYSTEM: DISA User's Guide
(NINHAM SHAND, June 1990)

This report described the major components of a daily hydrosalinity irrigation scheme model suite, which included the Database Manager, System Configurator, System Model and Output Manager. Each component was dealt with individually and was supported by a set of operating instructions and hard copies of the actual on-screen display of the component interface. The report essentially focussed on 'how to operate DISA' as opposed to 'how DISA operates'.

J. BREEDE RIVER SYSTEM : DISA SALINITY PREDICTIONS FOR VARIOUS PLANNING SCENARIOS (NINHAM SHAND, DECEMBER 1991)

The report evaluated a number of planning options, using the DISA model, for the Breede River between Greater Brandvlei Dam and Zanddrift canal with emphasis on salinity patterns. The effects of different distribution network scenarios as well as freshening releases from Greater Brandvlei Dam were specifically modelled. The modelling exercise allowed practical planning scenarios to be tested for its effectiveness in combating the salinity situation.

K. THE GROUNDWATER CONTRIBUTION TO THE SALT LOAD AND FLOW VOLUME OF THE BREEDE RIVER IN THE ROBERTSON AREA (DWAF, March 1990)

This particular report aimed to quantify the contribution of groundwater to the flow volume and salt load along the Breede River mainstream. The groundwater contribution between weirs H4M17 and H5M04 was calculated to be 50576 m^3/day while the salt load was calculated to be 14647 tonnes per annum. The difficulties associated with determining groundwater flow and qualities were also listed.

L. DETAILED GEOHYDROLOGICAL INVESTIGATION IN THE POESJENELS RIVER CATCHMENT IN THE BREEDE RIVER VALLEY WITH SPECIAL REFERENCE TO MINERALIZATION (for WRC, by University of Stellenbosch, August 1990)

This report presented the findings of an investigation into mineralisation of the Poesjenels River. The report focussed on the leaching process that occurs within the soil as well as the quality of the resultant water. The determinations of transmissivities as well borehole yields were also discussed in the report.

M. EVALUATION OF A RANGE OF COMPUTER MODELS SIMULATING THE TRANSPORT OF SOLUTES AND WATER IN THE ROOT ZONE OF IRRIGATED SOILS (for WRC, by Dept. of Soil-and Agricultural Water Science, University of Stellenbosch,1993)

This report evaluated three computer models which simulate transport phenomena within the root zone of irrigated soils. The tests were conducted by evaluating how well the models predicted a practical situation. The experiments were conducted on a micro and meso scale.

N. THE USE OF SALINE WATER FOR IRRIGATION OF GRAPEVINES AND THE DEVELOPMENT OF CROP SALT TOLERANCE INDICES (for WRC, by Dept. of Agricultural Water Science, University of Stellenbosch, 1999)

The report presented the results of a study conducted to determine the effect of saline irrigation water on grapevines. The aim of the study was to assess and redefine the current salinity target limit with the new data available.

2.2 LITERATURE REVIEW

Howard (1987), on the basis of sequential electrical conductivity (EC) measurements between gauging stations H4H017 and H5H004, concluded that the increase in salinity on the Breede River mainstream is associated with the inflow of saline tributaries. His profile along the Breede River showed that there is a continual increase in the salinity level with sharp increases after the major tributaries (Poesjenels, Kogmanskloof and Vink) had joined. The return flow generated from adjacent farming areas was also noted as a source of salinity.

Flügel and Howard (1987) came to the conclusion that tributary inflow was an important factor in the salinisation of the Breede River, but that groundwater contributions should be investigated.

In his paper, Flügel (1989c) calculated the yield from a relatively shallow aquifer which he found, made a very small salt load contribution and could not reconcile the salt balance for the study area. The deficit in the salt load was attributed to deep groundwater. Flügel (1989) performed a salt and water balance, between H4H017 and H5H004, for the 1987/88 year and found that the output from his balance exceeded the input, leading him to conclude that the difference could be attributed to groundwater seepage, as all the other inputs and outputs were known or could be measured. Flügel remarked that he had overestimated the canal abstraction and that he had not included the contribution of the smaller tributaries and the return flow from the artificial drains. In the mass balance approach this would ultimately mean an overestimation of the calculated value, which is the groundwater contribution in this case. Later, Flügel (1990) performed a further mass balance and found that an average flow of 1633 ℓ/s (141 091 m^3/day) and an average salt load of 1648 tons/month was unaccounted for. From this unaccounted flow Flügel subtracted 70 ℓ/s, which he said was contributed by alluvial groundwater and not bedrock groundwater.

Jolly (1990) endeavoured to calculate the groundwater flow between H4H017 and H5H004, with the Robertson Irrigation Area and the lower portion of the Vink River Valley being studied in more detail. He calculated that a volumetric rate and salt load of 50 576.4 m^3/day and 14 647.7 tons/year respectively, were contributed by groundwater. The groundwater flow rate as calculated by Jolly (1990) constituted 36% of the unaccounted flow reported by Flügel (1990), while the salt load constituted 74% of the unaccounted salt load.

Kirchner (1994) re-evaluated Jolly's (1990) pumping test of the bedrock aquifers for the Vink River and Robertson area and concluded that representative transmissivities for the areas are 50 m^2/day and 3.5 m^2/day respectively, as opposed to Jolly's values of 417 m^2/day and 4.1 m^2/day. He then re-evaluated the groundwater contribution between H4H017 and H5H004, using a transmissivity of 5 m^2/day (Jolly used an average value of 62.6 m^2/day), and estimated that only 4000 m^3/day entered the Breede River. This is 8% of the value calculated by Jolly (1990). Kirchner added that higher values for groundwater seepage are most certainly possible but that it was doubtful that values could be ten times higher. He also observed that water levels changed very little during the year indicating that the residence time within the fractures was long and that very little was lost as stream seepage.

Greeff (1990) showed that a substantial amount of salts occur in the weathered zone above Bokkeveld sediments and that the average return flow had a Total Dissolved Solids (TDS) concentration of 2965.6 mg/ℓ. He found that soils in the Poesjenels River catchment had considerable salt loads between the depths of 1 to 4m. The TDS values for water abstracted from the rock structures found between H4H017 and H5H004 have been collected in studies by Greeff, Whittingham and Bertram (1989) and are shown below.

TABLE 2.2a : TDS VALUES FOR WATER ABSTRACTED FROM DIFFERENT GEOLOGICAL FORMATIONS (from Greef *et al*, 1989)

FORMATION	TDS (mg/ℓ)
Alluvium	423
Ecca Group	892
Dwyka Group	1475
Witteberg Group	1753
Bokkeveld Group	586
Table Mountain Group	92
Malmesbury Group	688

Jolly (1990) suggested that these values were underestimated because only boreholes that were in use were tested. He added that the values he obtained for the Robertson and Vink River areas were 10.7 and 5.6 times greater than the corresponding values given in Table 2.2a. Bertram (1989) pursued the same line of argument in his report. Kirchner (1994) concurred with the findings of Jolly (1990) and Bertram that only the boreholes suitable for irrigation were used, but stressed that the different transmissivities should also be considered. Kirchner (1994) ascribed the better quality of the useable boreholes to 'natural flushing of salts'. It stands to reason that if the flow (transmissivity) at a borehole is higher, it does not allow for the formation of a concentrated brine after the initial concentrated water had been abstracted. Greeff (1990) showed improving qualities from new high-yielding boreholes. Kirchner (1994) suggested that the best way of obtaining a representative electrical conductivity (EC) value is by weighting the ECs from individual boreholes according to their transmissivity or alternatively, their maximum pumping yield.

Murray, Biesenbach and Badenhorst Inc. (MBB) (1988) performed a study aimed at quantifying the irrigation return flow from 1064 ha of irrigated land along the Robertson canal. They calculated, over a 200 day irrigation period, a total return flow of 5.2 x10^6 m^3 and salt load of 6.2 x 10^6 kg. This corresponded to an average salt concentration of 1200 mg/ℓ. Canal and farm dam seepage losses amounted to 3.2 x 10^6 m^3 and 0.455 x 10^6 m^3, respectively. MBB reported that if these figures were extrapolated to include the rateable areas of Le Chasseur-Goree, Breede River (Robertson), Angora and Zanddrift irrigation districts, the possible return flow could be 55.3 x 10^6 m^3 (3.2 m^3/s) with an average salinity of 1200 mg/ℓ. The total scheme intake amounted to 13.7 x 10^6 m^3 with a total salt content of 1.73 x 10^6 kg. This translated into an average salt intake concentration of 126.3 mg/ℓ. The TDS of the return flow generated from the irrigated area was calculated at 2982 mg/l.

Kirchner (1994) believed that the shallow and deep aquifers were not the only groundwater sources discharging to the Breede River, but that a highly permeable aquifer subjected to artesian pressures was also contributing good quality seep to the river. He stated that the maximum irrigation occurred near the lower end of his study area and that maximum return flow would also occur here. This is also the area where most rapid increase in salinity is experienced. He continued by saying that from the geological structure of the area one would expect groundwater contribution to be more evenly spread throughout the length of the river. Kirchner (1994), by using strontium ratio analyses, showed that 6% of the total flow at H5H004 on 6 December 1990

(0.79 m^3/s; base-flow condition) was due to groundwater flow. It was also found that the return flow samples from various farms had strontium ratios comparable to samples of river water whereas groundwater samples had a slightly higher strontium ratio. Kirchner (1994) calculated that the groundwater contribution can either be 6500 m^3/day of Bokkeveld or 80 000 m^3/day of Table Mountain Sandstone water. He added that if the water emanated from the Bokkeveld formation it would be a small volume with a correspondingly small salt load. On the other hand, if it is Table Mountain Sandstone water it would be a larger volume, but of good quality and it would thus have a freshening effect on the river. These contributions can be put into perspective by recognising that the typical summer base flow at H5H004 ranges from 0.5 to 1.3 m^3/s.

Moolman (1993) evaluated the performance of 3 computer models aimed at predicting the transport of water and solutes in the root zone of irrigated soils. The models were tested on a micro and meso scale to ascertain how well they could predict physical operations. The results from these studies were, however, very localised and could not meaningfully be extrapolated.

Moolman (1999) described the results of a study (1991-1995) conducted on the effects of saline water on grapevines. He found that the yield was highly dependent on the time of exposure to the saline water. In addition to this, he found that no clear threshold salinity value was evident, but that the yield decreased above a soil salinity (EC_e) of 75 mS/m at a rate of 3% per 10 mS/m increase in irrigation water (EC_i). It was also established that the salinity conditions in one season had a great influence on growth in the following season. He explained that grapevines are perennial and that the effects of salinity were cumulative. He continued and stated that the potential number of bunches per vine and berries per bunch were determined in early spring of the year preceding the current year's harvest (i.e 18 months before harvest). The results further showed that osmotic pressure as well as specific ion concentration (chloride in particular) had a large effect on the yield of the grapevines. Chloride content of 1.5 to 4 g/kg in the leaves corresponded to yield reductions of 10 to 20% respectively. These leaf contents were reached by irrigating with water having a chloride concentration as low as 40 mg/ℓ. Although the wine, made from the grapes irrigated with highly saline water contained higher concentrations of Na^+ and Cl^-, the quality remained unaffected. Moolman (1999) also showed that that the salinity-treated soil had to be leached during the winter period in order for the soil salinity to be maintained below 100 mS/m. In all the experiments conducted by Moolman it was conclusively shown that irrigation with saline water led to significant salt accumulation in the root zone during the irrigation season and that this effect was cumulative. Approximately 275-300 mm of water was required during winter to reduce the salinity of the topsoil (0-0.3m) from 300 mS/m to 100 mS/m.

In his final analysis, Moolman (1999) concluded that the existing salinity and chloride target limits as set by the Department of Water Affairs and Forestry, to control the water quality in the lower reaches of the Breede River, were too liberal. In addition, he mentioned that the crop yield loss threshold salinity (EC_e) value of 150 mS/m as reported by Ayers and Westcott was too high and that the results obtained from his study suggested a salinity threshold value of 100 mS/m. He concluded that an economic analysis on the cost of maintaining the target limits at Zanddrift weir below 70 mS/m and 140 mg/ℓ for EC and chlorides respectively, should be undertaken.

Several pertinent points about the relative contribution of groundwater flow and irrigation return flow are presented above. It can be seen that the various researchers have different views as to which component of flow (groundwater or irrigation return flow) actually dominates in the contribution to the Breede River salinity. The contribution of irrigation return flow as well as salt load cannot be disregarded and its impact should be carefully evaluated. The researchers have, however, provided vital clues in the pursuit of resolving the issue. The following points would lead one to believe that irrigation return flow is indeed the major contributing factor.

- Very little change was observed in the water level in the boreholes, indicating that long residence times were experienced by the water travelling to the Breede River.
- The study conducted by MBB (1988), reported return flow values and salt loads and equivalent concentrations that correspond to observed TDS concentrations in the Middle Breede River. The mass balance study had been well regulated and considerable effort had been expended in obtaining the most accurate data available.
- The strontium ratios of the irrigation return flow corresponded very closely with the ratios found in river water, whereas the ratios in groundwater were slightly higher.
- Re-evaluation of Greeff's (1990) pumping test revealed that 4000 m^3/day of groundwater entered the Breede River between H4H017 and H5H004. This would indicate that groundwater makes a small contribution to the total flow and salt load of the river.

The current salinity target limit had been defined in Document GB/A/88/2-'Hersiene kriteria vir besproeiingswater in die Breërivier', Soil and Irrigation Research Institute, 1988. This criterion is measured in terms of the electrical conductivity of the of the irrigation water (EC_i) and was defined as follows:

"*At least 50% of the volume of irrigation water supplied to irrigators should have a electrical conductivity (EC_i) not exceeding 70 mS/m. For up to 30 % of the volume supplied, EC_i would be allowed to fluctuate between 70 and 120 mS/m. The remaining 20% of the volume should have an EC_i not exceeding 120 mS/m.*"

This is shown graphically in Figure 2.2 below. The Chloride limit for root absorption and foliar absorption had been set at 140 mg/ℓ and 106 mg/ℓ respectively.

Figure 2.2 : Target limits for salinity with respect to grapevines in the Breede River valley

The report mentioned that 100 and 90% yields were possible (for grapes) with an irrigation water having an EC_i of 68 and 116 mS/m and a leaching fraction of 0.1.

Ninham Shand (1992) *Breede River System:DISA Salinity Predictions for various Planning Scenarios,* showed that a phased high level canal was the most comprehensive solution to the salinity situation in the Breede River. They also confirmed that the system of freshening releases (current procedure) was very effective in controlling salinity in the river and that 45.7 x 10^6 m^3 of freshening water would be required at full irrigation development (44 300 ha). Their analysis further showed that 30 x 10^6 m^3 would be required at the current level of irrigation (23 100 ha). The implementation of an interceptor drain was also modelled and it was found that this option became feasible when applied together with the freshening release strategy. It was shown that the amount of freshening water required at the present level of irrigation (23 100 ha) could be reduced from 30 x 10^6 m^3 to 27 x 10^6 m^3 when an interceptor drain was installed. The use of either freshening releases or an interceptor drain as the sole means of controlling salinity was not considered to be a long term solution.

2.3 PRESENT SYSTEM FOR SALINITY CONTROL

The salinity level at the Zanddrift weir is the determining point within the Government Water Scheme. Prior to 1977 water was released in large volumes to 'flush out' the saline water behind diversion weirs (9 x 10^6 m^3/annum).

Until the mid-1980s, freshening water was released so that the electrical conductivity (EC) at the Zanddrift weir does not exceed 50 mS/m. At present the salinity target limit is maintained by releasing fresh water from the Greater Brandvlei Dam so that the EC at the Zanddrift weir does not exceed 70 mS/m. It can thus be seen that the freshening releases are implemented for dilution of the river.

At the present level of irrigation development (23 100 ha) a total of 30 x 10^6 m^3 of freshening water is required per season and it has been predicted that this will increase to 45.7 x 10^6 m^3 at full irrigation development (44 300 ha).

3. PHYSICAL CONSTRAINTS OF STUDY AREA

3.1 DESCRIPTION OF INFRASTRUCTURE IN THE MIDDLE BREEDE RIVER

Irrigation in the Middle Breede River is reliant on water from a fairly intricate system of canals which divert water from Greater Brandvlei Dam and the Breede River to the adjacent farming areas. As a result the Breede River mainstream and its tributaries are the main receivers of irrigation return flow. The sections below describe some of the important water-related infrastructure in the region.

3.1.1 Greater Brandvlei Dam

Greater Brandvlei Dam is the most upstream point in the current study area. The dam is an off-channel storage and receives water under gravity from the Holsloot/Smalblaar feeder canal. The dam has a full supply capacity of 475.7 million (FSL = 210,5m) but can only be filled by gravity to a capacity of 342 million m^3 (RL 207,12). The high level storage has not yet been utilised and can only be filled by pumping. A quota of 94.4 x 10^6 m^3/annum has been allocated to the Breede River Water Conservation Board (BRWCB). Water can be released via a tunnel at the Papenskuil Pumping Station directly into the Breede River or into the Le Chasseur canal. As in the past, the BRWCB submits the quantity of water required from the Dam on a weekly basis to DWAF. This volume is then released from the Dam. The amount of freshening water is determined by the quality at the Zanddrift Canal off-take and the availability of water in the dam. The electrical conductivity at the Zanddrift off-take should not exceed 70 mS/m.

3.1.2 Canals

There are five distribution canals on the Breede River between Greater Brandvlei Dam and Swellendam. The canals are operated on an excess supply principle with the excess being returned to the Breede River at the various reject points. All the canal take-off points are monitored and the quality of the samples collected in the canal is assumed to be representative of the quality in the Breede River at the take-off points. The irrigated area served by each canal is shown in Table 3.1.2.

TABLE 3.1.2 : AREAS SERVED BY CANAL SYSTEMS
(DWAF Report P H000/00/0388)

CANAL NAME	SCHEDULED AREA (ha)
Le Chasseur and Goree	4213.9
Robertson	2758.0
Angora	1146.2
Zanddrift	3036.4

3.2 PUMPING SCHEMES

There are six major pumping schemes within the Greater Brandvlei Dam Government Water Scheme.

3.2.1 Bossieveld Pumping Scheme

Water is pumped directly from the Greater Brandvlei Dam (GBD) to the Bossieveld Irrigation District. A maximum of 9.28 x 10^6 m^3/annum has been allocated to this board.

3.2.2 Agterkliphoogte Pumping Scheme

During winter the Agterkliphoogte uses the Le Chasseur canal to convey water to a balancing dam adjacent to the canal from where it is pumped into several farm dams. In summer water is released into the Breede River and allowed to flow to Rooiberg where it is pumped into the Le Chasseur Canal and from there to the balancing dam. The Agterkliphoogte Irrigation Scheme has been allocated 783 000 m^3/annum of water.

3.2.3 Uitnood Pumping Scheme

This pumping scheme abstracts approximately 1.36 x 10^6 m^3 directly from the Breede River during summer and provides 200 ha of land with water.

3.2.4 Klaasvoogds Pumping Scheme

The Klaasvoogds Irrigation Scheme is designed to abstract 4.42 x 10^6 m^3 directly from the Breede River.

3.2.5 Kogmanskloof Pumping Scheme

This pumping scheme abstracts 15.15 x 10^6 m^3/annum from the Breede River some 71.0 km downstream of Greater Brandvlei Dam and supplies Ashton, Montagu and Agter-de-Kogmanskloof.

4. WATER QUALITY STATUS IN THE MIDDLE BREEDE RIVER

To review the status of the Middle to Lower Breede River the following stations have been selected for statistical and graphical analysis :

TABLE 4 : STATIONS SELECTED FOR ANALYSIS

STATION	DESCRIPTION	SAMPLES	FIRST DATE	LAST DATE
H4H014Q01	Breede River at Karoo/Moordkuil	694	02/15/73	06/15/92
H4H017Q01	Breede River at Le Chasseur	1010	07/14/80	09/21/99
H5H006Q01	Zanddrift canal From Breede River at Goudmyn	930	11/12/79	09/21/99
H7H006Q01	Breede River at Swellendam	841	03/16/66	09/14/99
H5H004Q01	Breede River at Wolvendrift/Secunda	1080	05/06/70	09/21/99
H4H019Q01	Vink River at De Goree	1026	09/01/72	09/21/99
H3H011Q01	Kogmanskloof River at Goudmyn	992	11/27/79	09/21/99
H4H018Q01	Poesjenels River at Le Chasseur	1076	11/02/73	09/21/99

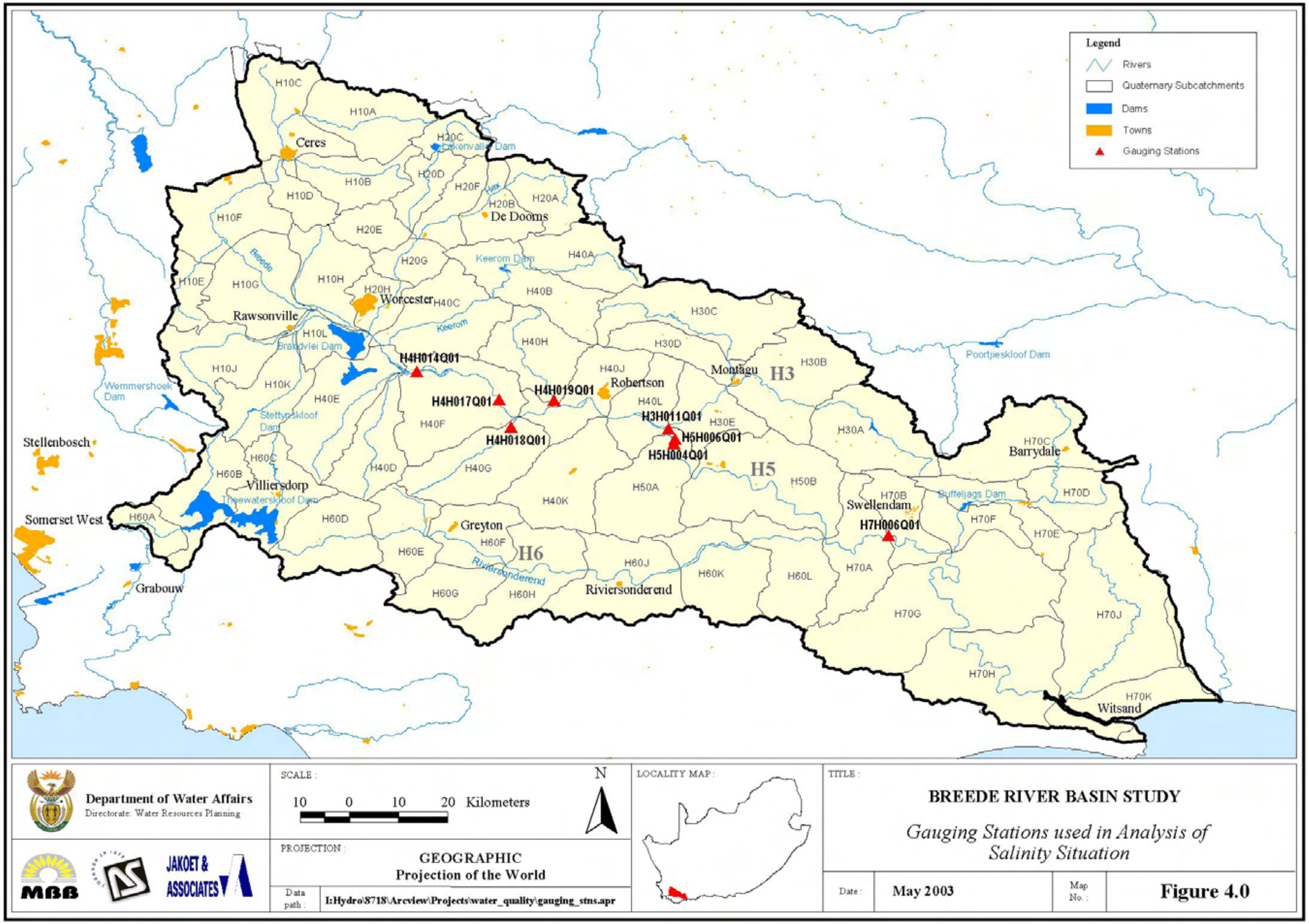
It was decided that the above gauging stations give an overall picture of the Middle to Lower Breede River area and that the addition of further monitoring points would not yield any additional information. These gauging stations are shown on Figure 4.0.

4.1 STATUS ALONG BREEDE RIVER MAINSTREAM

The portion of the Breede mainstream considered for salinity assessment extends downstream from Greater Brandvlei Dam to Swellendam. (Refer to Figure 4.0).

4.1.1 Compliance with Set Target Limits

The data available for these monitoring points were evaluated for the entire year as well as for the irrigation period (1 October - 30 April). The exceedance graph below (Figure 4.1.1 (a))reflects the percentage compliance with the salinity target limit (see Section 2.3 and Figure 2.2) at the various stations on the Breede River mainstream over the irrigation period.


Legend
Rivers
Quaternary Subcatchments
Dams
Towns
Gauging Stations
Ceres
De Doorns
Worcester
Rawsonville
Robertson
Montagu
Barrydale
Swellendam
Villiersdorp
Greyton
Riviersonderend
Witsand
Stellenbosch
Somerset West
Grabouw
Lakenvallei Dam
Keerom Dam
Brandvlei Dam
Wemmershoek Dam
Stettynskloof Dam
Theewaterskloof Dam
Poortjieskloof Dam
Buffeljags Dam
Breede
Keerom
Riviersonderend
H3
H5
H6
H10A
H10B
H10C
H10D
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H4H017Q01
H4H018Q01
H4H019Q01
H3H011Q01
H5H006Q01
H5H004Q01
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Department of Water Affairs
Directorate: Water Resources Planning
SCALE :
10 0 10 20 Kilometers
N
LOCALITY MAP :
TITLE :
BREEDE RIVER BASIN STUDY
Gauging Stations used in Analysis of Salinity Situation
PROJECTION :
GEOGRAPHIC
Projection of the World
Data path :
I:Hydro\8718\Arcview\Projects\water_quality\gauging_stns.apr
Date :
May 2003
Map No. :
Figure 4.0
MBB
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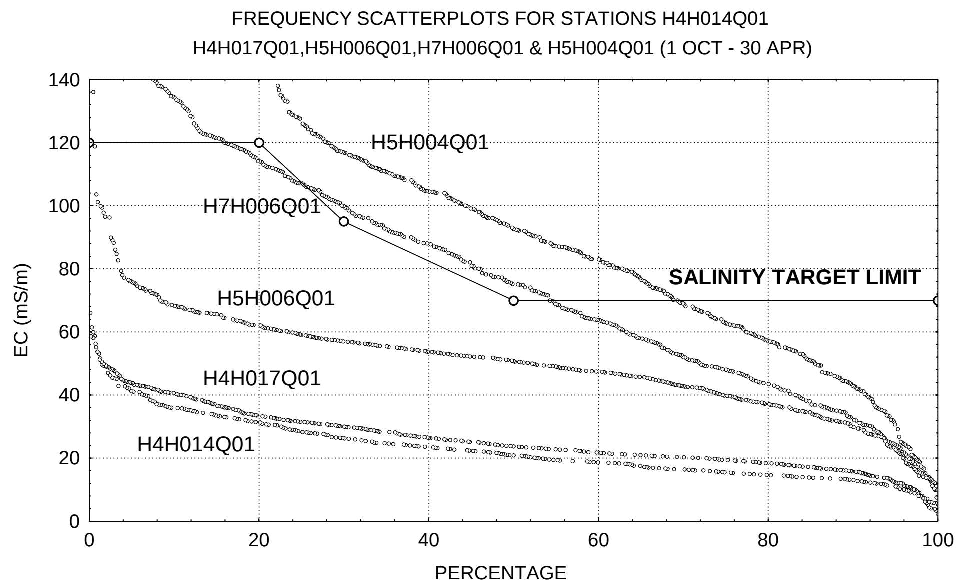

Figure 4.1.1a : Exceedance graph for gauging stations along Breede River mainstream

The quality of the water at station H4H014Q01 and H4H017Q01 is acceptable for use 100% of the time. This can be attributed to the fact that the saline tributaries have not as yet joined the mainstream and that the farming activity is less intense along the banks of the river. Since return flows are considered to provide the biggest contribution towards the Middle Breede River in terms of flow and salt load, this explanation seems plausible. Zanddrift canal (H5H006Q01) is an operational check-point within the Government Water Scheme, in that the release of freshening water from GBD is determined by the quality at this take-off point and the level of water in the dam. The influence of the Poesjenels River and the increased irrigation intensity is reflected by the deterioration of the water quality at the Zanddrift take-off. The quality is, however, still within the salinity target limit. Farmers (personal communication, 1999) who obtain water from the Zanddrift canal have expressed concern over the use of electrical conductivity (EC) as the determining factor for operating the system. They believe that the constituents that make up the EC value (chlorides in particular) should be investigated more thoroughly. According to them the crucial period for the produce is during September, March and April. These are the months when the crops are particularly sensitive and a lower Target Salinity Limit could possibly be introduced for these months.

According to the South African Water Quality Guidelines-Volume 4, increased chloride concentration in irrigation water can reduce crop yield as well as crop quality. According to Moolman (1999), chloride levels of 1.5 to 4 g/kg in the leaves can be associated with 10 to 20% reduction in yield and 1.5 g/kg was reached with irrigation water having a chloride concentration as low as 40 mg/ℓ. Figure 4.1.1b shows that the water quality is not satisfactory when the aforementioned is considered.

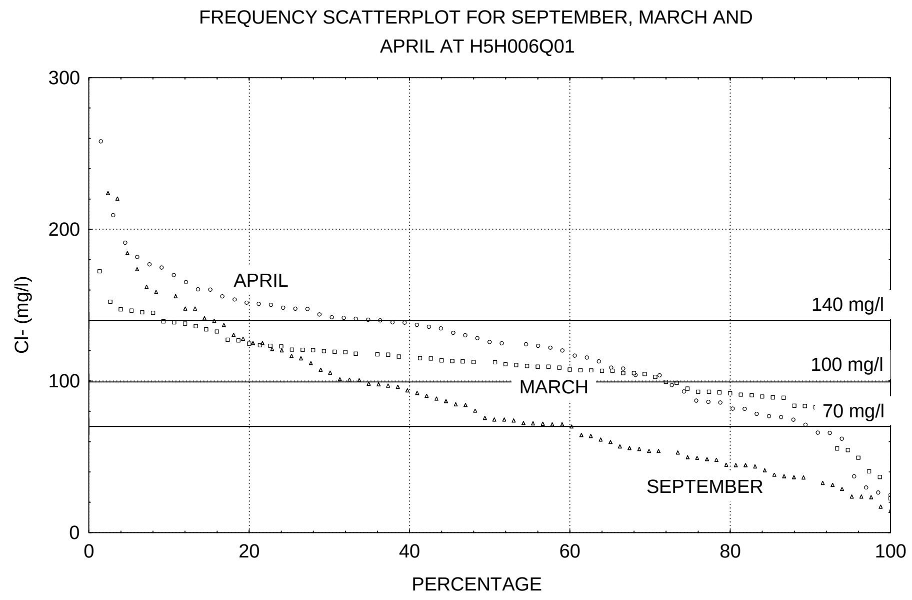

Figure 4.1.1b : Exceedance plot for chlorides during the critical months

Figure 4.1.1b has been prepared by accumulating all the data at the Zanddrift off-take for September, April and March and plotting each month as an individual series. At the current chloride target limit of 140 mg/ℓ it can clearly be seen that for September the limit is exceeded for 15% of the time whereas for March and April it is exceeded for 9 and 27% of the time, respectively. The corresponding graph (Figure 4.1.1c) which uses EC as the determining variable shows that the water quality is always within the desired limit. If the findings of Moolman (1999) are considered and a chloride target limit between 70 - 100 mg/ℓ is imposed then Figure 4.1.1b depicts that the limit for September, March and April is exceeded for some 52%, 92% and 88% of the time respectively (at 70 mg/ℓ)

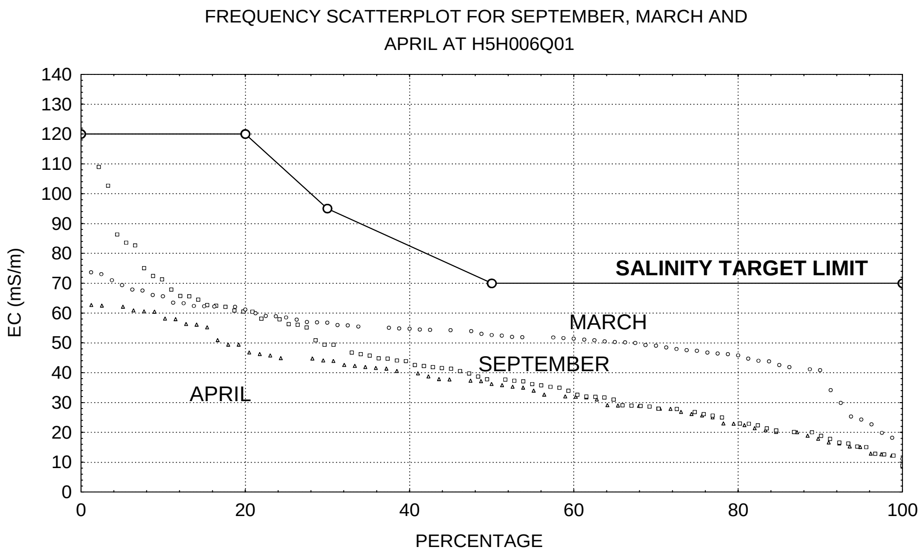

Figure 4.1.1c : Exceedance plot for critical months

It may be possible to operate the system with an alternative target limit during the critical months, but this would be dependent on the amount of water available in the dam. This scenario could possibly be modelled, as part of the Breede River Study, as an option with the chloride concentration being maintained between 70 and 100 mg/ℓ.

4.1.2 Spatial Variation along Breede River Mainstream

The influence of the tributaries and the irrigation return flows on the quality of the Breede River mainstream is best illustrated by graphical means. Figure 4.1.2a below shows the variation in EC along the route of the Breede River from Greater Brandvlei Dam to Swellendam. The graph shows the range of data values at each gauging station for the irrigation period (1 October - 30 April).

The median value at the gauging stations increases in a downstream direction until the confluence with the Riviersonderend (downstream of H5H005Q01). After this point a slight decrease in the median value is observed. The increase in EC at Zanddrift Canal (H5H006Q01) can be attributed to the salt load contributed by the Poesjenels and Vink Rivers, while the further increase at H5H005Q01 is due to the additional load from the Kogmanskloof River. Return flow directly into the Breede mainstream as well as evaporation and evapotranspiration from riparian vegetation could also contribute to the increase at H5H005Q01. The graph quite clearly shows the deterioration of water quality along the length of the river and further strengthens the case for effective water quality management. Although Figure 4.1.2a shows that the Zanddrift canal off-take (mean value) is maintained at 50 mS/m, the chloride variation along the Breede River (Figure 4.1.2b) shows that the chloride level at the take-off has a mean value of 100 mg/ℓ, which would ensure yield losses of at least 10 to 20% based on the findings of Moolman (1999). The mean values for EC and Cl^- at gauging stations H5H004Q01, H5H005Q01 and H7H006Q01 are unacceptable for irrigation purposes according to the current guidelines and would ensure substantial yield losses for the farmers downstream of Zanddrift canal.

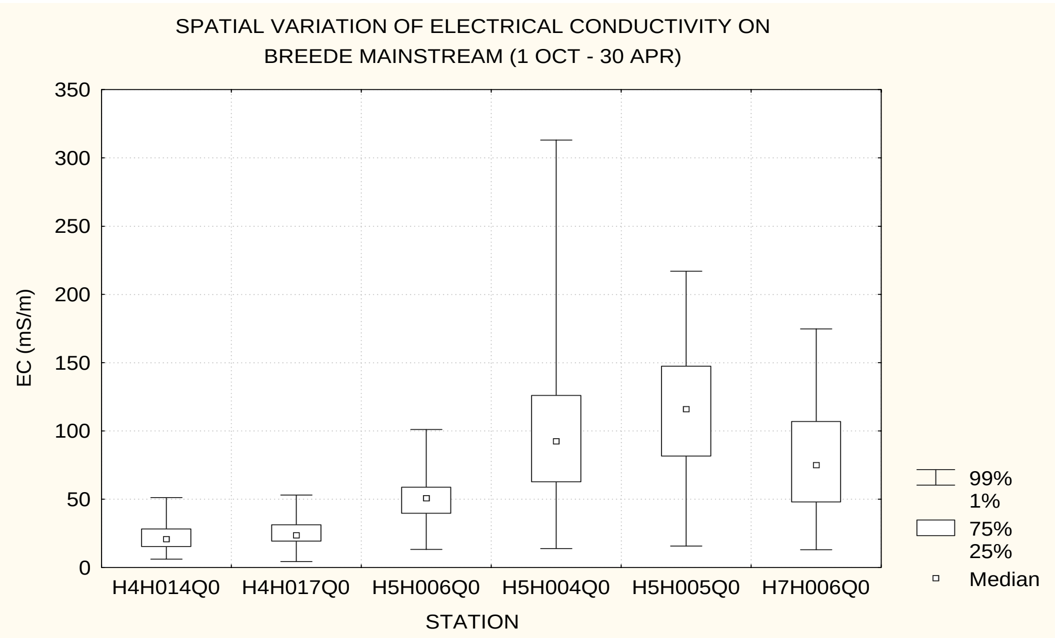

Figure 4.1.2a : Spatial variation of EC along Breede River mainstream

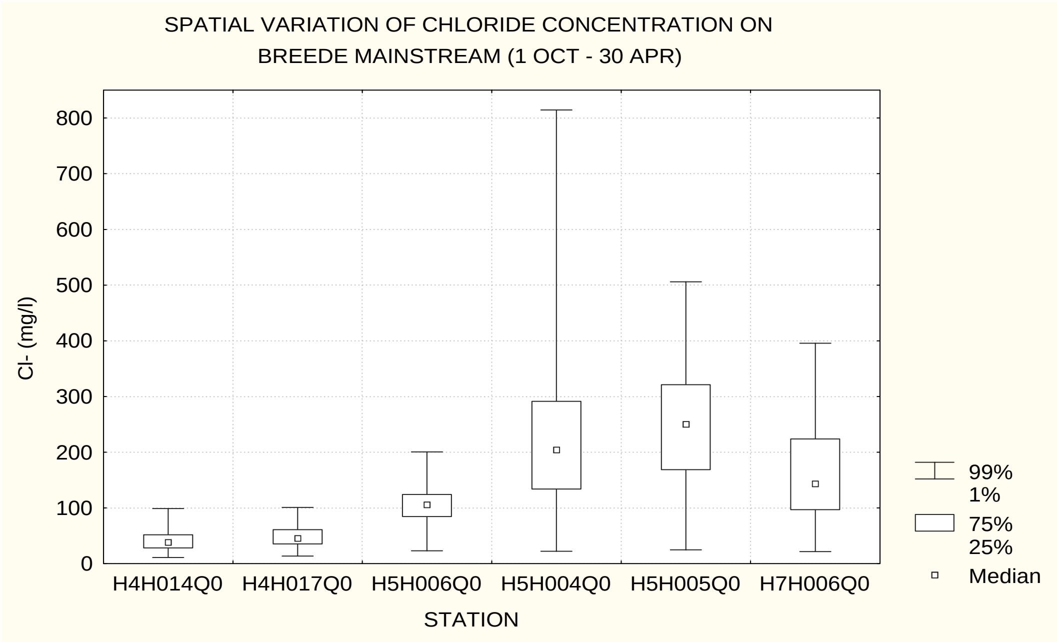

Figure 4.1.2b : Spatial variation of chloride concentration along Breede River mainstream

4.1.3 Time Varying Salinity Profile at Zanddrift Canal (H5H006Q01)

Figure 4.1.3a below depicts the variation of electrical conductivity at Zanddrift Canal and clearly reflects the inherent seasonality of the system. It also shows that the system is quite well maintained, with only a few spikes extending above the 70 mS/m mark. The Zanddrift Canal is the determining point within the system and the controlled release strategy is dependent on the quality at this point.

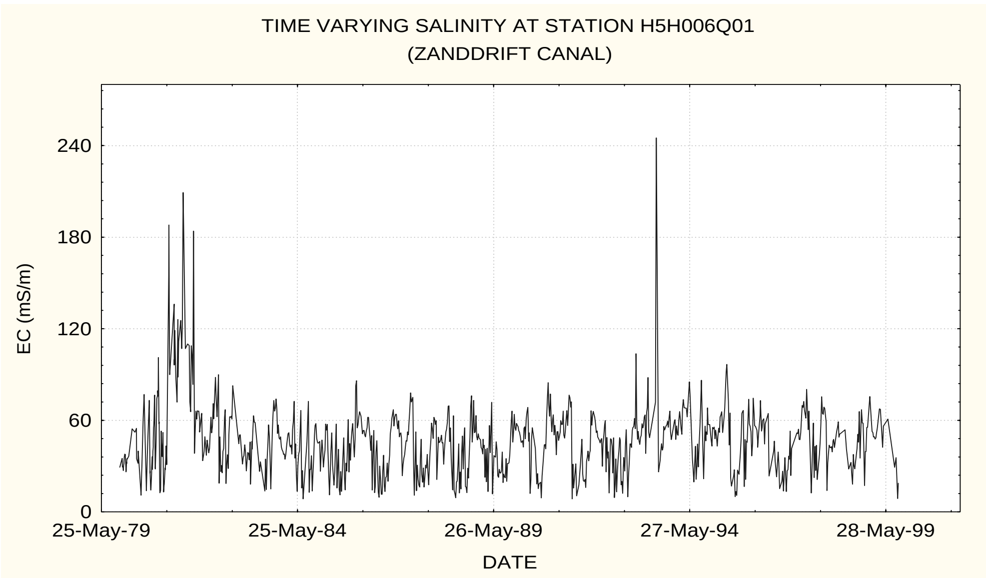

Figure 4.1.3a : Time varying salinity at Zanddrift Canal

4.1.4 Yearly Variation of Chlorides at Zanddrift Canal

Figure 4.1.4a depicts the yearly variation in chloride concentration at the Zanddrift canal take-off (H5H006Q01). The data for each year extends over the irrigation period (1 October - 30 April). Although the median value varies in a near-cyclical manner from year to year, it remains fairly steady around the 100mg/ℓ mark. This fact, however, does not exclude the possibility of substantial yield losses due to chloride damage.

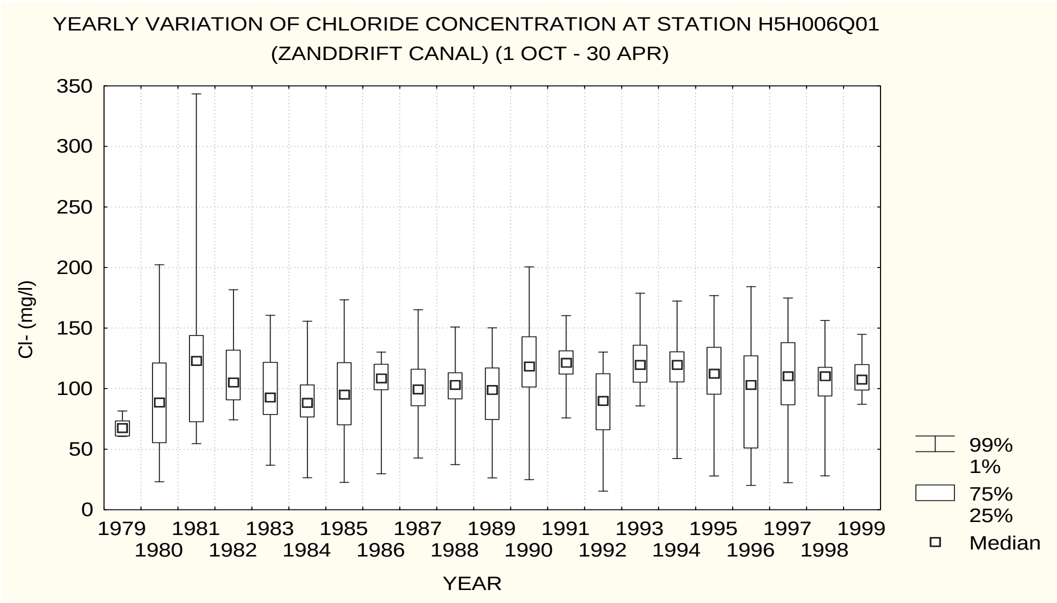

Figure 4.1.4a : Yearly variation of chlorides at Zanddrift Canal

4.2 WATER QUALITY STATUS OF INFLOWING TRIBUTARIES

4.2.1 Compliance with Set Target Limit

The Poesjenels and Kogmanskloof Rivers have historically been known for their significant salt loads contributed to the Breede River mainstream. The lower reaches of these tributaries together with those of the Vink River have essentially become conduits for transporting irrigation return flow and this fact is reflected by the quality of these streams. Figure 4.2.1a below depicts the percentage compliance of the water quality with the set target limit for the irrigation period (1 October - 30 April). It can clearly be seen that these tributaries are unacceptable for use once the flow reaches the gauging stations closest to the Breede River mainstream.

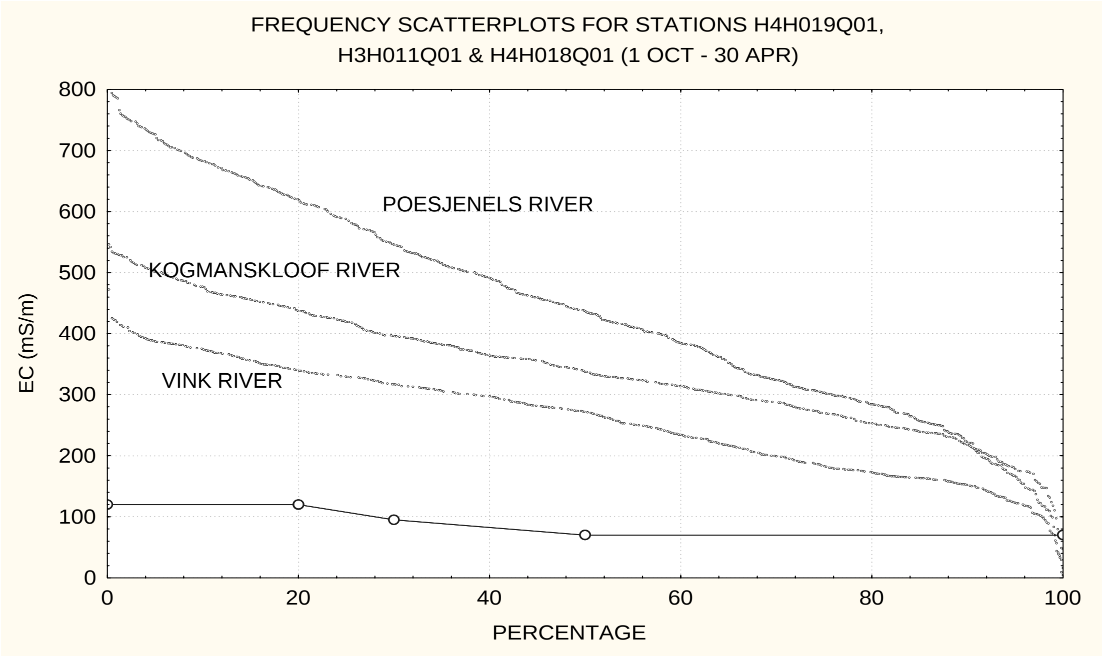

Figure 4.2.1a : Exceedance plot for tributaries in the Middle Breede River

4.2.2 Spatial Variation of Electrical Conductivity on Tributaries

The electrical conductivity data for various tributaries are depicted in Figure 4.2.2a below.

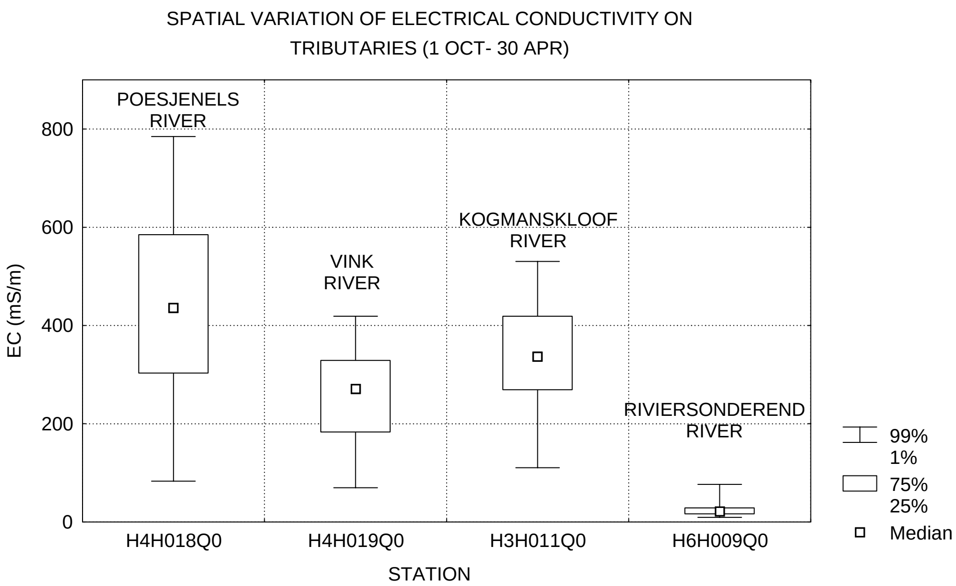

Figure 4.2.2a : Spatial variation of tributaries along Breede River

The data has been prepared for the irrigation period (1 October - 30 April). The median values for the Poesjenels, Vink and Kogmanskloof Rivers as well as 75% of the other values recorded for these stations are above the 200 mS/m mark. Only the Riviersonderend can be employed for freshening purposes.

4.3 COMPARISON OF OBSERVED TRENDS WITH THOSE FROM THE LITERATURE REVIEW

The graphical analysis of the water quality records suggests that salinity is a definite issue in the Middle to Lower Breede River. The spatial variation of electrical conductivity Figure 4.1.2a shows that there is, as suggested by Howard (1987), a definite increase in salinity levels after the saline tributaries have joined. Graphical analyses of data from these saline tributaries (Figure 4.2.2a) show that their median values for the EC are well above 200 mS/m, with values well above 600 mS/m being reached in the Poesjenels River. It should be realised that the concentrations of flows in the tributaries will certainly be diluted as soon as these reach the Breede River mainstream and that some other source of salinity is also contributing to the salt load. It is known that the lower portion of the Middle Breede River is characterised by intensive cultivation and it is reasonable to assume that irrigation return flow is responsible for the additional load. Kirchner (1994) showed that the salt load contributed by groundwater is small and that the major contribution probably comes from irrigation return flow.

4.4 IMPLICATION OF HIGH SALINITY FOR CROP PRODUCTION

According to the South African Water Quality Guidelines, Volume 4, much is known about the effects of Total Dissolved Solids (TDS) of irrigation water on crop yield, but very little about its effects on crop quality. Under irrigation the upper soil layer becomes saline as a result of high salinity irrigation water. To control the amount of salts in the root zones additional irrigation water can be applied to effect leaching. This process, however, leads to the salinisation of rivers that become salt sinks for the leached material, unless leaching occurs during the high flow winter months.

It is mentioned that the magnitude of the decrease in the crop yield is determined by the duration as well as the level of exposure to salt concentrations in water. The salt concentration of the irrigation water determines the physiological availability to the plant. As the salt concentration in the available water increases the plant becomes unable to extract sufficient water for its requirements. Subsequently, **salinity induced water stress** develops, the growth rate slows and, if it is subjected to this stress for a long enough period, the crop yield starts to decline. The concentration at which the decline in crop yield starts is known as the **threshold salinity** and is expressed as the TDS or Electrical Conductivity of the **saturated-soil extract** (EC_e). The crop yield has been found to decrease linearly with salinity levels above the threshold salinity and the threshold salinity as well as the linear relationship of yield-decrease is crop specific.

The symptoms of salinity affected plants include stunted growth, wilting, a darker bluish-green colour and sometimes thicker, waxier leaves.

Chloride is a constituent which contributes to the TDS concentration and is of particular concern to farmers. Chloride, when dissolved in water, can be absorbed by the roots as well as plant foliage. Yield reduction is also induced when the threshold concentration in the soil solution is reached. When the concentration of chloride in the leaves exceeds the specific crop tolerance, leaf burn occurs and in extreme cases early leaf drop could also occur.

Crop damage can also be affected by absorption through the leaves. Experiments have shown that reduction in crop yield due to foliar damage can be substantial. Crop tolerance to foliar absorption has not been well characterised, but it is known that foliar absorption rates vary from crop to crop. Crop quality is affected by chloride induced leaf injury when the leaves are the marketed product or when the appearance and size of fruits are affected by chloride induced yield decreases.

Moolman (1999) mentioned that chloride is absorbed and transported to the leaves more rapidly than sodium and that the accumulation of chloride in the leaves was related to the time of exposure. He showed that the negative effect of high salinity water was cumulative and that crop yield deteriorated with each year of irrigation. During the five year period of irrigating with saline water it was observed that the first noticeable negative effect of salinity on expansive growth occurred earlier each season. It was proposed that this could possibly be ascribed to the accumulation of salt in the permanent parts of the vines or to the fact that during early Spring the expansive growth was sensitive even to low soil salinities (EC_e=100 mS/m), adding weight to the farmers' request that a lower salinity limit should be implemented during this month. The potential number of bunches per vine and berries per bunch are determined early spring of the year preceding the current year's harvest. This implies that conditions during September of 1993 would determine the number of bunches per vine and berries per bunch for the harvest of the 1994/95 season. The size of the berries, however, is determined by the length and level of salinity exposure during the season. In his experiments Moolman (1999) showed that salinity induced yield reduction was probably due to the decrease in the bunches per plant rather than the berries per bunch. He added that the chloride content of leaves is a good indication of salinity damage and that harvest containing 1 to 4.5 g/kg was associated with yield reductions of 10 to 20% respectively. More disturbing was the fact that a chloride level of 1.5 g/kg was achieved by irrigating with water that had a chloride concentration as low as **40 mg/ℓ**. Although the time varying salinity profile at Zanddrift weir shows that the EC is well maintained at 70 mS/m, the equivalent chloride concentration is approximately 120 mg/ℓ and this could lead to a chloride content of 2g/kg in the leaves and an associated yield loss of up to 20%.

In experiments conducted by Moolman (1999) it was found that irrigation water from the canal with an EC of 25-35 mS/m resulted in a soil salinity (EC_e) of 75 mS/m after a single irrigation cycle. Above this soil salinity the yield decreased at a rate of 3% per 10 mS/m salinity increase in irrigation water (EC).

Moolman (1999) concluded that the EC target levels set by the Department Of Water Affairs and Forestry (DWAF) for managing water quality at the lowest point of the government water scheme was too high to prevent a reduction in yield.

4.5 SALINITY SITUATION STATEMENT FOR MIDDLE BREEDE RIVER

As a conclusion to Section 4, the following statements can be made on the status of the Middle Breede River :

Figures 4.1.2a and 4.1.2b show that the October-April water quality for the Middle Breede River is acceptable from Greater Brandvlei Dam to the Zanddrift canal take-off point if evaluated according to the current salinity target limit. When considering the new information provided by Moolman (1999), then the deterioration from gauge H4H017Q01 to H5H006Q01 is bordering on unacceptability or is already unacceptable between October and April. With the situation remaining as it is, the decrease in crop yield will worsen over the next few years **because the detrimental effect of salinity on yield increases with time**.

The water quality downstream from H5H006Q01 is unacceptable even under the current limiting criteria, and it is reasonable to assume that the farmers irrigating with this water are already experiencing major yield losses.

5. EVALUATION OF 'PROPOSED' AND NEW ENGINEERING SOLUTIONS

Various solutions have been proposed for the salinity situation in the Middle Breede River. These have not been evaluated on a quantitative economic basis. The aim of this Section is to describe and evaluate these solutions.

Four alternatives have been proposed for the distribution of water in the Middle to Lower Breede River and two further options (DWAF Report - P H000/00/0588) consisting of a pipeline or canal transporting saline return flows along the Breede River mainstream to the Kogmanskloof River channel have also been included.

5.1 DESCRIPTION OF THE 'PROPOSED' AND NEW SOLUTIONS

A physical description of each scheme is given below.

5.1.1 Increased Freshening Releases (Current Procedure)

With this scheme the current operating procedure will be maintained, with the addition of more freshening releases. This implies that the TDS concentrations in the river would decrease and that more water for leaching purposes would be available.

5.1.2 Option A - High Level Canal

This scheme starts with a pumping station at Greater Brandvlei Dam that can lift water to the inlet level of a new high level canal, some 289 m above sea-level. The total length of the canal is 530 km and inverted siphons at Rooibrug and Skurwekop provide water to farms on the left bank of the Breede River. The canal can supply most of the irrigation boards by gravity and pumping is only required for Agter de Kogmanskloof Irrigation district. Any excess water from this canal can be returned to the Breede River.

5.1.3 Option B - Low Level Canal with Pump Schemes

This new canal system emanates at approximately the same position as the current Le Chasseur canal at a height of 198m above sea level. The total length of the canal is 420 km and will have reject points to both the river and the existing canal systems. Seventeen pumping schemes will abstract water from the canal to deliver to the higher lying farm areas. These include Bossieveld, Sand River, Poesjenels River, McGregor, Hollaagte, Elandskloof, Groot River, Boesmans River, Soutpans River, Kabous River, Bonnievale, Ashton, Agter de Kogmanskloof, Klaasvoogds River, Robertson, Vink River, and Rooiberg pumping schemes.

5.1.4 Option C - Low Level Canals with Pumping Scheme (Starting at Skurwekop)

In this option water is pumped from a weir at Skurwekop (downstream of the Vink River confluence) to the canal on the right bank of the river at a height of 185m above sea level. The canal diverts water to the left bank via an inverted siphon through the river and behind Robertson. Twelve pumping schemes will abstract water directly from the canal for supply to the higher lying areas. These include Skurwekop, Hollaagte, McGregor, Elandskloof, Groot River, Boesmans River, Soutpans River, Robertson, Klaasvoogds River, Ashton, Kogmanskloof, Bonnievale, and Kabous River. Bossieveld Scheme will abstract water directly from the Greater Brandvlei Dam while Sand River, Agterkliphoogte and Vink River will abstract directly from the Breede River.

5.1.5 Option D - Phased Canal and Pump Schemes

The concept behind this Scheme is to implement sections of a canal in phases, as required. As the salinity in the Breede River deteriorates and the target limits can no longer be met, the new canals will be implemented. In this option the section of the river starting at Zanddrift is the first to be abandoned as a conduit for water. The layout of this Scheme is similar to that of Option B, except that this one is implemented in phases. The description of the phasing is given below.

Phase 1

In this phase the canal will extend from Skurwekop, through Robertson and on to Ashton. A pumping station will pump water from the river to a height of 185 m above sea-level. A dam on the farm Eureka will then be used as a balancing dam from where water can be pumped to Montagu and Agter de Kogmanskloof Irrigation Schemes. Excess water from this canal is discharged to the existing Zanddrift Canal at Goudmyn.

Phase 2

This phase will be implemented when the irrigation demand cannot be met by abstraction from the Vink River. A canal starting at 188 m above sea-level will deliver water from Rooiberg to Skurwekop. A pumpstation will be erected at Rooiberg for the transfer of water to the canal.

Phase 3

This phase will be implemented when the water at the Angora take-off can no longer be utilised due to deteriorating water quality. The canal will be extended from Goudmyn to a point where water can be siphoned to the new canal or to the existing Angora canal.

Phase 4

This phase will be implemented when the required amount of water can no longer be supplied to farmers on the right bank or when pumping at Rooiberg or Skurwekop becomes inadequate or uneconomical. The canal will be fed directly from the Kwaggaskloof Dam following the same route as proposed in Option B and terminating at the Keiser River area.

Phase 5

The canal in this phase will be constructed from Rooiberg to serve the left bank lands up to the Nuy River.

5.1.6 Option E - Diversion of Saline Irrigation Return Flows

The most rapid rise in salinity is experienced somewhere between Robertson and Kogmanskloof River and this can clearly be seen from Figure 4.1.2a. As a result, this area has been identified for possibly intercepting irrigation return flows. The objective of this option is to install a gravity pipeline that collects return flow from the downstream Robertson area and discharges it into the Kogmanskloof River downstream of the Zanddrift take-off. It is believed that this option will postpone the building of new canal systems and that the postponement period would be dependent on the water quality at the Zanddrift Canal take-off. The proposed pipeline will have an approximate length of 5.4 km, a capacity of $0.26m^3/s$ and a slope of 1 in 1350. The pipeline will intercept six existing drains.

5.1.7 Option F - Diversion and Treatment of Irrigation Return Flows

This option is essentially equivalent to Option 5 with the exception that an end-of-line process is proposed for the treatment of the effluent.

It is envisaged that a bank of mixed ion-exchange columns can be used for this purpose. The overall detailed economic implications of such treatment cannot be dealt with within the scope of this report, but it would eventually be required to evaluate the feasibility of this option.

5.1.8 Other Options

A further alternative would be :

- to pump saline return flows into one or more dams for release to the Breede River during the high flow winter months, or
- to pump the saline return flows into evaporation pans.

These options have not been evaluated.

5.2 EVALUATION OF ENGINEERING SOLUTIONS

Without performing detailed costing and environmental studies only qualitative evaluations can be made of the abovementioned options.

The **'technical effectiveness'** of the schemes is measured by the control of the TDS concentration at the Zanddrift take-off. In the report *DISA Salinity Predictions for Various Planning Scenarios* (DWAF Report no. H 000/00/0890) various canal options are modelled and the results from these exercises, provide some insight into the technical effectiveness of the various schemes.

The implementation of a high level canal (Option D) ensures that the quality at Zanddrift is always below the salinity target limit even at maximum irrigation development and with no freshening releases required. The reach of the river extending from immediately upstream of the Vink River confluence, however, then becomes a conduit for transporting saline irrigation water. Farmers downstream of the Government Water Scheme would then have to irrigate with water containing unacceptable TDS levels. Apart from the poor quality irrigation water there are also the environmental consequences that would have to be considered when implementing such an option. The Instream Flow Requirements (IFR) is one of the criteria that would have to be included when deciding upon an engineering solution. It should be noted that the crops in this region are intended for the overseas market and the provision of good quality irrigation water would have a positive effect on yield, quality and foreign income. Only a detailed economic analysis of the canal options would reveal whether the capital investment for this option is justified.

All the canal options mentioned above are capital-intensive solutions and in terms of the environmental component of the study it may only be shifting the salinity problem from an upstream to a downstream position, where its impact might be intensified.

The possibility of implementing a diversion pipeline has also been modelled using the DISA model. The results suggest that the diversion pipeline alone would have little effect on the quality at Zanddrift Canal, but combined with the freshening release strategy it could save approximately 3×10^6 m^3/annum of freshening water (at the current level of irrigation, 23100 ha) compared to the current operating system. The duration of postponement of the other schemes would depend on the maintenance of the water quality criteria at the Zanddrift weir. In addition, it is less capital-intensive than the canals and it maintains the natural flow of the Breede River mainstream. This is not a long-term solution, but it could provide a meaningful short-term solution. If this is combined with an end of line treatment (a bank of ion-exchange columns), freshening water could be returned to the Kogmanskloof River to the benefit of the farmers downstream of the scheme. The capital investment of such a scheme will have to be investigated before any conclusions can be drawn. A possible combination of the above options could also be considered as a solution.

The further options suggested in Section 5.1.8 should also be considered.

It follows that all irrigators contributing to the saline return flow should contribute towards the maintenance of any scheme that alleviates the problem of high salinity water.

These options would also need to be evaluated against Reserve requirements for the river.

5.3 FINANCIAL INSTRUMENTS

Financial instruments are additional tools at the disposal of the managing authorities. These allow water use decision-making to be influenced by attaching either an economic gain or loss to a particular activity. Pegram, Görgens and Quibell (2000) identified the following options :

- **Registration and application fees**, which may be required for water use licences and general authorisations.
- **Penalties**, which can be implemented for offences in terms of the regulation of water use. Catchment Management Agencies may recover costs incurred to implement remediation strategies where a directive has not been complied with.
- **Pricing strategy**, which allows the cost of water to be increased or decreased depending on the quality of waste generated and management practices implemented.

These options could be implemented to urge farmers to be responsible about management strategies concerning the usage of water.

6. CONCLUSIONS

From the above discussion, the following can be concluded :

- Irrigation return flows have a major influence on the quality of water in the Breede River mainstream and its major tributaries.
- The water quality at Zanddrift canal is still within the current salinity target limits, but the situation will change should irrigation development increase.
- The farmers below the Government Water Scheme are already receiving water which does not comply with the prescribed limits and this will worsen with time, should irrigation development increase.
- The downstream reaches of the Poesjenels, Kogmanskloof and Vink Rivers cannot be used for irrigation purposes as they exceed the prescribed salinity limit for almost 100% of the time.
- The continuous increase in salinity levels will affect the economic growth in the area because of its negative effect on crop yields (mainly wine grapes).
- The salinity issues can be remediated by freshening release increases, implementation of canal systems, end-of-line treatment and optimum management strategies.
- Even if the current salinity limits are maintained, there will still be a decrease in yield because the detrimental effects of salinity increase with time (accumulation of salt in the soil and subsequent increase in ECe).
- Sufficient leaching water will have to be supplied to the farmers to enable them to maintain the soil salinity (ECe) as close as possible to 100 mS/m.
- The current EC limit at the Zanddrift weir is too liberal as it can still effect a 10 to 30% yield reduction in crops.
- The chloride ion concentration has a negative effect on the yield as a specific ion and as part of the collective in its contribution to the TDS.

7. RECOMMENDATIONS

Based on the discussion and conclusions drawn above the following recommendations can be made :

- Each of the solutions presented above should be evaluated for its technical effectiveness by using the DISA model.
- The economic impact of the proposed solutions should be investigated and evaluated.
- The environmental impact of each solution should be assessed and linked to Reserve requirements.
- The current salinity target level at the Zanddrift weir should be redefined based on the outcome of the above tasks.
- The routine monitoring of total dissolved solids and its constituents should continue.

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