



# Studies of mineralization in South African rivers

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G C Hall and A H M Görgens (editors)

A status report of the  
Working Group for Mineralization  
Committee for Inland Water Ecosystems  
National Programme for Environmental Sciences

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PREFACE

The National Programme for Environmental Sciences is one of several national scientific programmes administered by the CSIR. It aims at identifying environmental problems in South Africa which lend themselves to solution through research and at promoting and coordinating research which will contribute to the solution of these problems. The National Programme includes research relating to environmental problems in the lower atmosphere, inland waters, the sea and terrestrial ecosystems. It is designed to meet both national and international objectives and it contributes to the international programme of SCOPE (Scientific Programme on Problems of the Environment, the body set up in 1970 by ICSU (International Council for Scientific Unions)) to act as a focus of non-governmental scientific effort in the environmental field.

The Inland Water Ecosystems Section is concerned with such environmental questions as pollution, the processes by which pollutants are transported into and through inland waters, the eutrophying and toxic effects of different pollutants and the ecosystem processes within inland waters which may determine how these waters will be influenced by human activities. Much of this research is aimed at predicting the possible consequences of natural and planned events.

The Working Group for Mineralization was formed in November 1976 to promote and coordinate research on mineralization of diffuse source in South African rivers. Organizations represented in the Working Group include the Department of Water Affairs, the National Institute for Water Research of the CSIR, the Department of Agricultural Technical Services and the Universities of Stellenbosch, of Pretoria and of the Orange Free State. The Working Group has broadened out an earlier programme of research into implications of the Orange River Project.

TITLES IN THIS SERIES

1. \*A description of the Savanna Ecosystem Project, Nylsvley, South Africa. December 1975. 24 pp.
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ABSTRACT

Several South African rivers are polluted by mineral salts of diffuse source. This pollution can be related to geological phenomena and to irrigation practices. Mineralization is problematic in that it can render surface waters unsuitable for irrigation as well as for urban and industrial use.

A mathematical simulation model is being developed for the Great Fish and Sundays River systems in the eastern Cape to predict the consequences of different mineralization processes in terms of salt concentration patterns in these rivers for different system operation policies and subject to different extraneous events, such as rainfall sequences. This model is to be verified for the Fish and Sundays Rivers and then applied to two other rivers where mineralization is of concern, namely the Berg and Breë Rivers in the western Cape. The modelling study requires a large amount of data, in particular, records of river flow associated with chemical water quality, physical and chemical characteristics of irrigated soils, ground-water chemical quality and rainfall.

A large scale data collection programme has been established for each of the above mentioned river systems and in each case the programme is expected to be of three or four years' duration to permit useful modelling results.

SAMEVATTING

Verskeie Suid-Afrikaanse riviere word deur mineraalsoute uit verspreide bronne besoedel. Hierdie besoedeling hou verband met geologiese verskynsels en besproeiingspraktyke. Mineralisasie is 'n probleem in dié sin dat dit oppervlakwater onbruikbaar kan maak vir besproeiing sowel as vir stedelike en industriële gebruik.

'n Wiskundige simulasiemodel word vir die Groot Vis- en Sondagsrivierstelsel in die Oos-Kaap ontwikkel om die gevolge van verskillende sleutel-mineralisasieprosesse in terme van soutkonsentrasiepatrone te voorspel. Dit word gedoen om verskillende stelselbedryfsreëls, met inbegrip van onbeheerbare faktore soos reënvalpatrone, te evalueer. Hierdie model sal op die Vis- en Sondagsrivier getoets en daarna toegepas word op twee ander riviere waar mineralisasie 'n probleem is, naamlik die Berg- en Breërivier in die Wes-Kaap. 'n Groot hoeveelheid data word vir hierdie studie benodig, veral rekords van riviervloei tesame met die van die chemiese kwaliteit van water, die fisiese en chemiese eienskappe van besproeiingsgronde en die chemiese kwaliteit van grondwater en reënval.

'n Groot skaalse dataversamelingsprogram is vir elk van bogenoemde rivierstelsels opgestel en daar word verwag dat elke program drie of vier jaar sal duur om bruikbare modelleringsresultate te lewer.

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## INTRODUCTION

Water quality considerations are important in the management of most South African rivers. Mineralization, the contamination of surface waters with inorganic salts, is a significant water quality problem in rivers such as the Great Fish and Sundays Rivers in the eastern Cape and the Berg and Breë Rivers in the western Cape. Uncertainty about the feasibility of controlling mineralization through appropriate river management has led to a cooperative programme of research into key mineralization processes. As referred to in this report, mineralization involves both natural processes, such as the seepage into river channels of groundwater containing salts derived from rocks and soils, and processes associated with irrigation practices. Of course, mineralization results also in many instances from point discharges of municipal and industrial effluents. However, the research described in this report focuses only on diffuse source mineralization.

The current research programme of the Working Group for Mineralization is concerned with the Great Fish and Sundays Rivers in the eastern Cape (Section A of this report), and the Berg and Breë Rivers in the western Cape (Sections B and C respectively). This research programme involves the National Institute for Water Research (NIWR) of the CSIR, the Department of Agricultural Technical Services (ATS), the Department of Water Affairs and the Universities of the Orange Free State, of Stellenbosch and of Pretoria. Before launching into a detailed description of the research programme, as is done in the body of this report, brief attention is given to mineralization processes generally, and how they affect South African water resources.

## MINERALIZATION PROCESSES

Mineralization occurs wherever water has contact with soil or rock (see Figure 1). The degree of mineralization of river runoff from natural catchments appears to depend largely on the physical and chemical properties of the rocks and soils of the catchment and on the local climate, in particular the rainfall pattern. For example, in the Berg River catchment, tributaries which have their origin in the mountainous areas where the rocks are relatively inert (Table Mountain Sandstone) and where the rainfall often exceeds 1 000 mm per annum typically have total dissolved solids (TDS) concentrations of about 60 mg/l in the winter rainy season (Fourie and Steer 1970). In contrast, tributaries having their origin in the low-lying Malmesbury Shale formations where the rainfall is low (usually 400 to 500 mm per annum) typically have winter TDS concentrations of about 3 500 mg/l.

The various mineralization processes occurring in nature are complex and not completely understood. Very briefly, natural mineralization begins with the weathering of rocks and soils, thereby releasing soluble salts. Rainwater that runs off the catchment surface conveys dissolved salts (and silt) into river channels. Rainwater that percolates into the upper layers of soil in the catchment dissolves carbon dioxide released from plant roots as a product of respiration and also from decaying organic matter in soil. In this way, soil moisture usually acquires a carbon dioxide content far in excess of that in water exposed to the atmosphere.



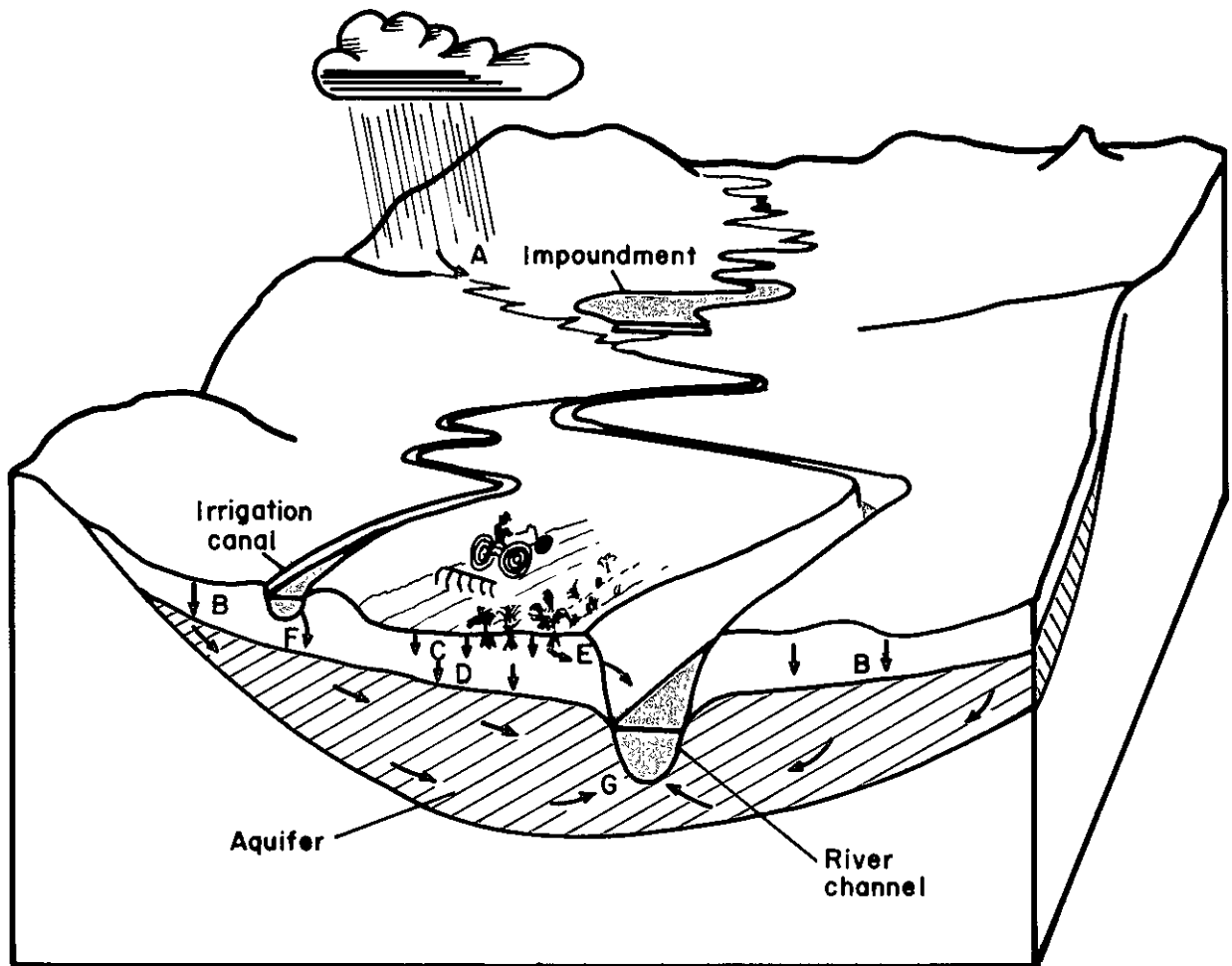


Figure 1. Salt transport processes in a river catchment.

Several surface and sub-surface transport processes contribute to river mineralization : (A) Rainfall runoff overland conveys salts derived from weathered rocks and soils. (B) Percolating rain water, containing some  $\text{CO}_2$  from contact with the atmosphere, dissolves more  $\text{CO}_2$  issued from plant roots (respiration) and from decaying organic matter in soil, and reacts with carbonate salts in soil and rock to form bicarbonates, mainly  $\text{Ca}(\text{HCO}_3)_2$  and  $\text{Mg}(\text{HCO}_3)_2$ ; other soluble salts are also leached as water percolates through the unsaturated zone. (C) Most water (typically 80-90%) applied to croplands evaporates or transpires from the root zone, leaving a concentrated leachate which either (D) percolates through the deeper soil strata to the saturated zone, or (E) flows horizontally when impervious strata are encountered, and seeps into the river channel. (F) Seepage from unlined irrigation canals can also reach the saturated zone. (G) In the saturated zone, a blend of the saline flows from (B), (D) and (F) above undergoes changes in composition through physical-chemical processes such as cation exchange and adsorption. Further dissolution takes place as the water flows towards the river channel and eventually appears as river flow.

Carbon dioxide-rich water dissolves carbonate salts and, as a result of this dissolution, recently recharged water typically has a predominantly Ca/Mg(HCO<sub>3</sub>)<sub>2</sub> composition. The subsequent mineralization processes that take place as water percolates down through the unsaturated soil zone and, on reaching the saturated zone, flows (generally) towards a river channel, are not well understood. The most important are thought to be dissolution, cation exchange and adsorption. Johnson (1975) associated different groundwater compositions with the dynamics and age of the water, hypothesizing that the dissolved salt composition of groundwaters that are old and have moved relatively far tend to be predominantly NaCl.

The irrigation of croplands gives rise to the percolation of saline water from the root zone irrigated soils. This percolate invariably returns to a river channel. The main factor in the production of saline irrigation return flow is the concentrating effect of evapotranspiration on water in the root zone soils. Typically, about 80 percent of the applied water evaporates or transpires, leaving all the salts in the applied water concentrated in the remaining 20 percent, which percolates downwards, below the root zone. Further mineralization occurs (precipitation of salts can also occur in the irrigated soils) before the percolate reaches the river channel. There are numerous cases in the literature of problematic saline return flows resulting from irrigation. In the Coachella Valley in California, for instance, irrigation from 1957 to 1965 using water with an average TDS of about 800 mg/l produced a return flow amounting to 22 percent of the water applied and with an average TDS of about 2 600 mg/l (Bower *et al* 1969).

In general, it can be argued that river impoundments and irrigation schemes do not appreciably decrease the long-term salt loads moving down the river. In effect, the same salt loads generated by natural processes are transported by less water because of the evaporative losses from impounded water surfaces and evapotranspiration losses from irrigated fields. Moreover, it is conceivable that irrigation schemes can effect *increases* in river salt loads. This can happen as a result of mineralization processes in irrigated soils and can also happen if irrigation percolate displaces highly saline groundwaters into the river channel.

In South Africa, mineralization problems are encountered in several river systems. Among these are the Great Fish, Sundays, Berg and Breë Rivers mentioned above and discussed in detail in Sections A, B and C below, as well as the Gouritz River (southern Cape), the Diep River (south-western Cape), the Hartenbos River (southern Cape), the Bushmans River (eastern Cape), the Groot River (south-eastern Cape), the Olifants River (south-western Cape) and possibly the lower Orange River (north-western Cape). In these and other river systems where the salt concentrations due to natural mineralization processes are high, impounding the river flow and utilizing the water for irrigation can result in progressively higher salt concentrations downstream, sometimes to the extent that the water is rendered useless both for downstream irrigation and municipal supplies. Mineralization is also a threatening problem in the Vaal River Barrage, from where water is supplied to the Witwatersrand and Pretoria, in this instance associated with urban and industrial pollution. It can be expected that, as the rather limited surface water resources in South Africa are developed further to satisfy future demands, mineralization will become relatively more serious.

While the most obvious problem is the increase in TDS concentration, there are cases where the concentrations of specific ions in water are problematic. For example, the concentration of the chloride ion is of concern in irrigating citrus orchards in the lower Sundays River valley (Du Plessis 1975).

Knowledge of mineralization processes in intensively developed river systems can aid in establishing appropriate river management policies to optimise the utilization of the rivers' water resources. River management might, for example, involve the operation of dams and intercatchment water transfer schemes to have the best possible quality water impounded for downstream irrigation. Moreover, prior knowledge of the natural mineralization of a river system and the physical and chemical properties of potentially irrigable soils can be of tremendous benefit in *planning* the river basin development. The sort of knowledge that is required to make this planning and management possible is of a quantitative nature; for instance, how much sodium in the river water at a specified time can be attributed to surface runoff following a specified sequence of rainfalls. It is probably impossible to establish quantitative "input-output" relationships for each and every mineralization process in a river system. However, understanding of the key processes can aid the systems analyst in formulating conceptual relationships which, after being appropriately linked together, can simulate the mineralization pattern in the river reasonably well.

## APPROACH

### *SIMULATION MODELLING*

The problem of studying the mineralization of a river system is a complex one. The effects of the different processes taking place are extremely difficult to isolate. For example, at the present time it is known only very roughly to what extent the irrigation practices along the Fish River contribute to the mineralization of the river. The water flow patterns and mineralization processes give rise to dissolved salt concentrations which vary considerably, even from day to day, at any point in the river. Mathematical modelling techniques have therefore been chosen to describe water flows and the transportation of salts in the different river systems in terms of the mineralization processes thought to be taking place.

Mathematical simulation models offer advantages in that they can be relatively simplistic representations of the real systems. Moreover, they can readily be programmed for computer solutions, making it possible to verify the models and test the assumptions made. They can also facilitate determining the consequences of major system manipulations, for example, determining the effect that impounding a river would have on downstream water quality. The model currently being developed to describe the mineralization of the Fish and Sundays Rivers and verified for other river systems will be extremely useful in predicting the water flows and salt concentrations at different points in a river system resulting from a range of extraneous events, such as rainfall sequences and irrigation applications.

### SYSTEM MODEL

The system model is shown schematically in Figure 2. The river system is divided into *modelling units*, which are usually river subcatchments. The main criteria used in dividing the river system into modelling units are the geomorphological and other physical characteristics of the catchment, the localities of irrigated lands and the siting of flow-measuring weirs and of dams.

Each modelling unit is considered independently except in the sense that, according to their locations relative to one another, the outputs of some of them (in the form of a sequence of water flows and dissolved salt concentrations) constitute part of the inputs to others. The model consists of ten different functions, ie  $F_1, F_2, \dots, F_{10}$ , each of which receives specific input data, operates upon the data using formulas based on conceptual descriptions of the system, and generates output data. Some of the functions are actually fairly complex models in their own right and warrant further discussion.

The functions  $F_1$  and  $F_4$  shown in Figure 2 together comprise the hydrological model of Pitman (1976), with a slight modification of his groundwater discharge function to incorporate salt loads. The function  $F_5$  simulates the percolation of water and the transport of salts through root zone irrigated soils. In the case of the Fish River, the model of Thomas *et al* (1971) is used as function  $F_5$ . The function  $F_6$  is similar to  $F_5$  but simulates the percolation of water and the transport of salts from the bottom of the root zone, either down to the groundwater table or, where impermeable soil and rock strata are encountered, horizontally to the river channel.

Functions  $F_7$  and  $F_8$  simulate the flow of groundwater and accompanying salt loads into the river channel resulting from rainfall and from irrigation percolate. In practice it is very difficult to assess the way in which irrigation applications affect these groundwater flows. One assumption that could be made is that irrigation percolate raises the groundwater table in irrigated areas, thus creating increased hydraulic head and increasing the flow of both natural groundwater and percolate from past irrigations into the river channel. This and alternative assumptions can be tested using the model to see which one yields the most accurate simulation of flows and dissolved salt concentrations at a control point downstream. The functions  $F_7$  and  $F_8$  must also allow for the situation where a section of river channel is "effluent", ie where the groundwater table lies below the river channel bed level. In this situation, groundwater flows and irrigation percolate and their accompanying salt loads are stored for possible later mobilization into the river channel.

Function  $F_{10}$  essentially sums the water flows and salt loads from the various sources, routes them appropriately and calculates the salt concentrations at the outlet point of the modelling unit. The function also has a facility which allows the mobilization, during times of high flow, of salts stored in river channel banks and it allows the storage of salts in the channel banks during times of low flow. The inclusion of this facility in the function is based on observations of salt loads during irrigation leads in the Fish River (eg Viljoen 1973). Function  $F_{10}$  also allows for the effluent situation, when seepage into the channel bed (or

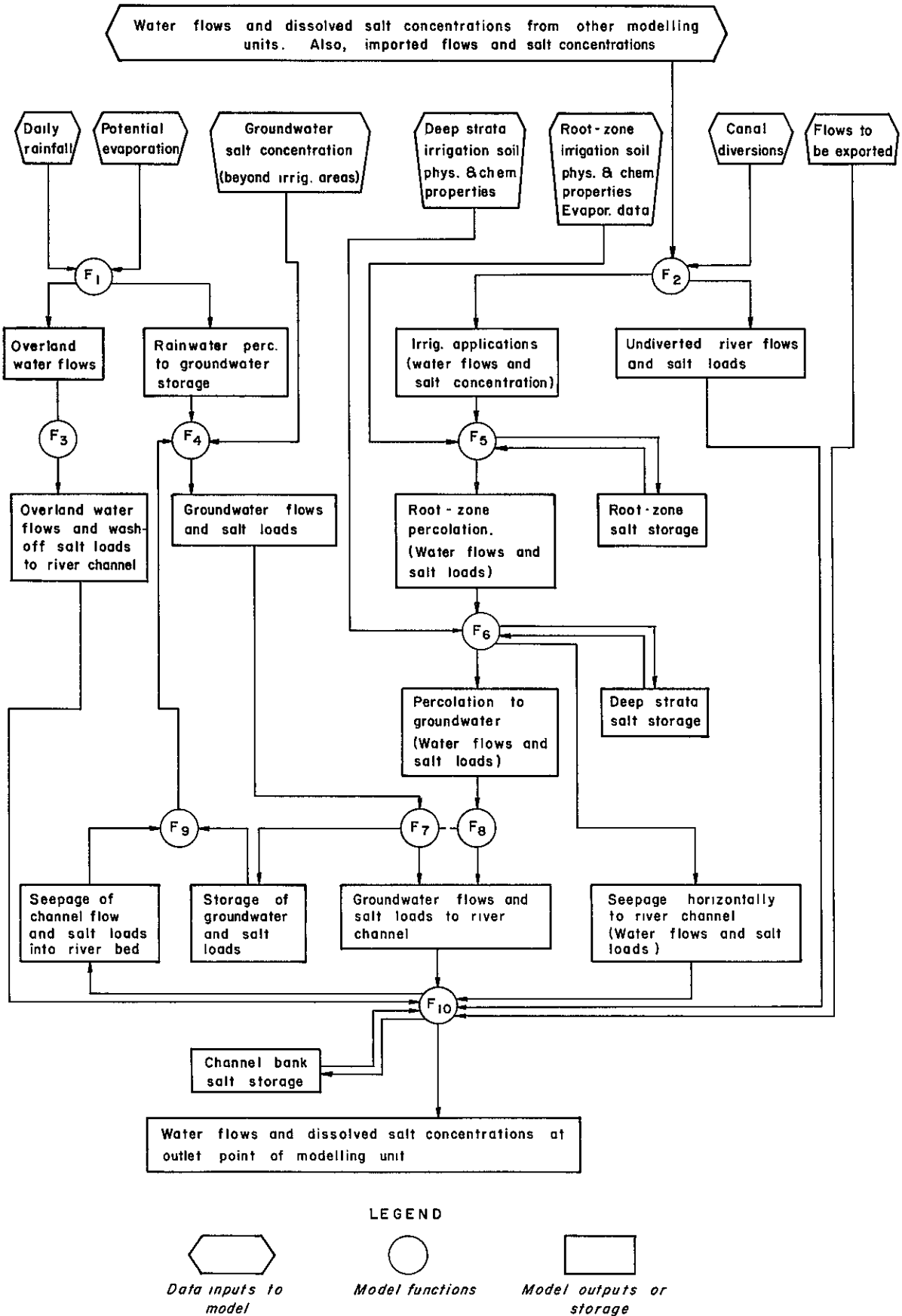


Figure 2. Schematic representation of the system model, as applied to a single modelling unit.

river channel "losses") goes to storage for possible later mobilization into the river channel.

The above overview of the system model is necessarily brief and does not include descriptions of all the assumptions, implicit and explicit, of which there are many. A modelling run on part of the Fish River system scheduled for April 1978 will be reported fully, including a comprehensive description of the model functions and their assumptions.

#### *DATA REQUIREMENTS*

It should be recognised that the current status of this mineralization research programme owes a great deal to many years' work, largely of a qualitative nature, carried out prior to 1974. This qualitative work has demonstrated the need for a sophisticated quantitative approach and led to the current use of mathematical modelling techniques.

While the qualitative work done in the past will provide a useful store of data which can be used at a later stage to test the accuracy of models in simulating river conditions over a longer time span, the shortage of adequate flow-measuring facilities during this period seriously reduces the value of the data for modelling. It is only very recently (1977 and 1978) that it has been possible for the Department of Water Affairs to provide flow-measuring weirs at certain key points in the Fish and Sundays River systems.

The research programme is thus only now at the beginning of a new quantitative phase and it will take several years (usually three years or more) before sufficient data (particularly flow data) have been collected to verify the model adequately for each river system studied. The data requirements for reasonable modelling results are considerable; full descriptions of the data collection activities currently under way are given below under the relevant sections. It is likely that experience gained in using the model will reveal shortcomings in the type and amount of data collected; this experience will be valuable in designing similar research programmes for other river systems.

#### SECTION A - GREAT FISH AND SUNDAYS RIVERS

##### *DESCRIPTION*

The Great Fish River catchment, 30 500 km<sup>2</sup> in area, and the Sundays River catchment above Lake Mentz, 17 700 km<sup>2</sup> in area, can be divided geomorphologically into four parts (Tordiffe 1975). A high-lying (1 400 m) plateau forms the catchment divides in the north. An escarpment (altitude about 1 400 m) cuts from east to west across both catchments; the towns Graaff-Reinet, Somerset East and Fort Beaufort just south of the escarpment will help to locate it approximately on Figure 3. Between the plateau and the escarpment, flat basins (altitude about 1 400 to 1 100 m) have developed, particularly in the Fish River catchment. Below the escarpment is an area of low-lying (800 m) irregular, rolling hills. Annual rainfall is about 350 mm in the upper basin areas and 350 to 450 mm in the low-lying hills below the escarpment, while the escarpment itself receives over 1 000 mm in places.

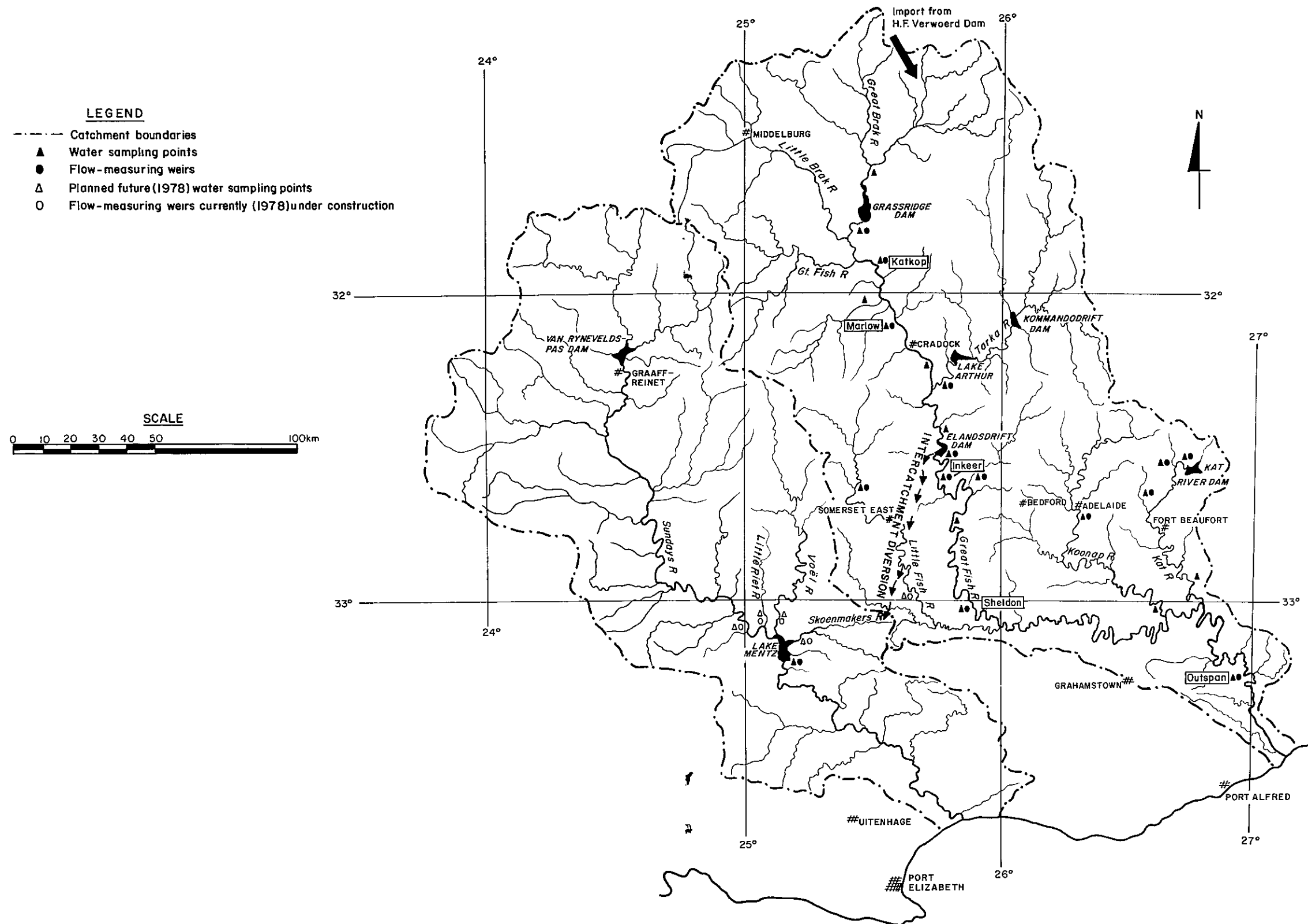


Figure 3. Great Fish and Sundays River catchments showing river flow-measuring weirs and sampling points. The main irrigated areas lie adjacent to the river channels between Grassridge Dam and Sheldon in the Fish River valley and downstream of Lake Mentz in the Sundays River valley.

The Fish River catchment north of Sheldon and the Sundays River catchment north of Lake Mentz consist of rocks and derived soils of the Beaufort Series of the Karroo System (Tordiffe 1973). The entire length of the Fish River from its junction with the Great Brak River to Sheldon is situated in the Middleton and Balfour formations of the Beaufort Series which consist largely of green mudstone. The Sundays River between Van Ryneveldspas Dam and Lake Mentz lies in the same formations. The entire catchment area above Sheldon in the Fish River and the catchment above a point about halfway between the two dams on the Sundays River is intersected with dolerite dykes and sills. Below Sheldon, the Fish River cuts through rocks and derived soils of the Ecca Series. The actual river channels invariably lie in alluvial deposits within the surrounding Karroo System formations.

Irrigation of land has been practised between Katkop and Sheldon along the Fish River for more than 60 years. Local irrigation boards lead water to croplands via canals and flood-irrigate crops of lucerne, winter wheat and mealies. By 1959, some 15 000 hectares of "scheduled" land were being irrigated using water impounded in Grassridge Dam (capacity 58 million m<sup>3</sup>), Lake Arthur (30 million m<sup>3</sup>) and Kommandodrift Dam (66 million m<sup>3</sup>). The government descheduled about 5 000 hectares in 1962, however, after the supplies in the above impoundments had proven insufficient for adequate irrigation of the full scheduled area. Recently, with the advent of Orange River water via the Orange-Fish Tunnel to augment Grassridge supplies, about 3 000 hectares have been rescheduled. The 1962 descheduling of land does not appear to have been based on problems relating to saline soils in irrigated lands. Even though irrigation water with TDS levels often exceeding 1 000 mg/l is applied to land, problems with "brak" soils appear to have been very localized in the past.

The irrigation of citrus orchards in the lower Sundays River valley has also been a practice for many years. This irrigation has not been the object of much attention in the Fish-Sundays research programme except, of course, in the sense that the supply of suitable quality water for this irrigation from Lake Mentz is one of the main goals of the Department of Water Affairs with respect to the Orange-Fish-Sundays Rivers scheme. It is considered that the research programme should only deal with the Fish River (in its entirety) and the Sundays River above and including Lake Mentz. In the Sundays River above Lake Mentz, irrigation does take place to a small extent below the Van Ryneveldspas Dam, but this is judged to be a relatively minor cause of mineralization in this river reach. Accordingly, the study of irrigation contributions to river mineralization has thus far been limited to the Fish River between Katkop and Sheldon.

The diversion of Orange River water into the Fish River and thence into the Sundays River constitutes a large part of Orange River Development Project (Department of Water Affairs 1962). Revisions to the original plan (Department of Water Affairs 1976) allow for the following ultimate developments in the Fish and Sundays Rivers -

- (a) Supplementary water for 10 000 ha existing irrigation in the Great Fish River valley (1976).
- (b) Rescheduling of approximately 3 000 ha in the Great Fish River valley (1977).



- (c) Supplementary water for 9 280 ha existing irrigation in the lower Sundays River valley (1978).
- (d) Rescheduling of approximately 2 200 ha in the lower Sundays River valley (1978).
- (e) Supply of water to the Port Elizabeth-Uitenhage complex (1984).
- (f) Development of new irrigation land in the lower Sundays River valley (8 500 ha in 1984).
- (g) Development of new irrigation land in the Fish River valley near Middleton (12 000 ha in 1986).
- (h) Supply of water from the lower Fish River to Grahamstown (1988).
- (i) Development of new irrigation land in the Bushmans River valley (8 000 ha in 1990).
- (j) Development of new irrigation land in the lower Fish River valley (12 000 ha in 1995).
- (k) Development of new irrigation land in the upper Fish River valley.

The scheme is expected to be in full operation by the year 2005.

It is not certain in what way the above quantitative requirements will affect the mineralization patterns in the Fish-Sundays Rivers system. Intuitively, the transfer of large quantities of low-salinity Orange River water into the system will dilute the natural saline flows. However, it can only be speculated at this stage as to what the effects of increased irrigation will have on the mineralization patterns.

#### *OBJECTIVES*

The research project aims at supplying the Department of Water Affairs with information on the continuous mineralization pattern in the Fish and Sundays Rivers. This information is to aid the Department in determining operation policies for the system of reservoirs and intercatchment water transfer schemes to ensure the supply of water of suitable chemical quality for irrigation and for municipal supplies to certain centres.

Central to the project is the use of the mathematical model described above, which sets out to achieve the following -

- (a) Prediction of water flows and dissolved salt concentrations at various points in the system occurring as a result of a sequence of those conditions and events, such as rainfall, intercatchment water transfers and irrigation applications, which are seen as the driving forces of the system.
- (b) Assessment of the relative contributions of irrigation return flow and natural geohydrological processes to the mineralization problem.
- (c) Evaluation of different system operation policies with respect to river flows and water quality at different points in the system.

- (d) Creation of a stereotype for modelling studies of other river systems.

### MODELLING

In modelling the mineralization patterns of the Fish and Sundays Rivers, the NIWR has assumed responsibility for developing all the system model functions except those dealing with the percolation of water and the transport of salts through irrigated soils, which are being developed by the Department of Agricultural Technical Services.

#### *Modelling results*

In June 1977, a joint modelling run was carried out by the NIWR and the Department of Agricultural Technical Services to simulate dissolved salt loads at Marlow Weir over a two year period (Van Rooyen *et al*, 1977). The modelling run was carried out to illustrate the potential of the system model to predict salt loads in the Fish River downstream from an irrigated area. Hypothetical applied irrigation data were used as input to the model and, although no reliable flow records were available to permit evaluation of the model's performance, the results obtained were realistic.

Subsequent to this modelling run, further work has been done by the NIWR towards achieving better calibration of the hydrological function for various modelling units. Work has also started on formulating conceptual model functions to cater for the transport of salts through the system. The Department of Agricultural Technical Services has implemented a complex model subroutine which simulates water flow through irrigated root zone soils. This is an improvement on the water flow subroutine used by Thomas *et al* (1971).

#### *Anticipated future benefits*

In brief, the following should be forthcoming from the modelling study by the end of 1980 -

- (a) A mathematical model which will provide insights into the range of possible river flows and qualities at different points in the Fish-Sundays Rivers system for a period in the immediate future, for instance a season or a year into the future. The predicted flows and qualities would be subject to assumptions about the rainfall and other extraneous conditions during the future period. How accurately the model will be able to predict these flows and qualities is difficult to assess at this stage, but it is certain that this will be adversely affected by the shortcomings in the data collection programme. Nevertheless, it is expected that the accuracy of the model will be within the limits required to aid in determining suitable system operation policies for a future period. The accuracy of the model will improve with time as more data are collected and used to revise the model calibration.
- (b) A good indication of the longterm effects on river mineralization of alternative irrigation developments along the Fish and Sundays Rivers.

- (c) A useful tool for evaluating the effects of different system operation policies on patterns of river flow and water quality at different points in the system. The accuracy of the model in this context will most likely be within the limits required to aid in decision making relating to regional agricultural development and urban water supply.
- (d) Provision of a model stereotype which will be of great benefit to modelling studies of other river mineralization systems.

#### *COLLECTION OF DATA*

The collection of the following types of data is an essential part of the modelling study -

##### *River quality data*

Daily river samples are taken for the NIWR at about 20 key points in the river system; the sampling points are indicated on Figure 3. Daily samples are needed to record adequately the highly variable river salt concentrations and to establish accurate relationships between these concentrations and the flows in the system. In the Fish River and its tributaries above Sheldon, sampling has been carried out since the beginning of 1975. Sampling has recently (November 1977) been instituted at several points in the lower Fish River catchment, including the three major tributaries, the Little Fish, the Kat and the Koonap Rivers. Clearly, the sampling programme yields a tremendous number of samples. To reduce the analytical work, however, sequential samples from the same location which have similar electroconductivities are combined. Analyses of the combined samples are carried out for concentrations of chloride, sulphate, bicarbonate, sodium, potassium, calcium and magnesium ions.

##### *River flow data*

It has been estimated that a minimum of three years' continuous record of river flows correlated with the water quality sampling will be required to achieve a preliminary calibration of the hydrological functions of the system model. The Department of Water Affairs obtains continuous records of flows at the various gauging weirs in the Fish and Sundays River catchments and makes these records available to the NIWR. Of particular importance are measurements of low flows which can be attributed to groundwater seepage and to irrigation return flows. During 1977, three good weirs were completed by the Department of Water Affairs in the Fish River at Marlow, Inkeer and Hunt's Drift (Outspan). However, two large tributaries of the Fish River below Sheldon, the Kat and Koonap Rivers, still do not have gauging weirs far enough down their respective catchments for the purposes of the modelling study. It appears that, unless suitable weirs are provided in these tributaries, it will only be possible to model the river system below Sheldon rather crudely and three subcatchments with rather different physical characteristics will have to be combined and treated as one modelling unit.

### *Meteorological data*

Relatively abundant meteorological data in the form of daily rainfall records and monthly pan evaporation records are made available by the Weather Bureau and the Department of Water Affairs for the Fish and Sundays River catchments. These data are used as input to the hydrological function of the model.

### *Groundwater quality data*

The Geology Department of the University of the Orange Free State has conducted a geohydrological survey of the upper Fish River basin. Several "groundwater compartments" created by dolerite dyke and sill formations have been identified. An extensive survey of groundwater levels and groundwater quality was also carried out in 1972 using samples from farm boreholes. This survey (Tordiffe 1973) revealed that in most areas of the Fish River basin the groundwater had high dissolved salt concentrations; many borehole samples yielded TDS concentrations exceeding 3 000 mg/l (some TDS concentrations were as high as 12 000 mg/l). Moreover, great spatial variability was observed in both the TDS concentrations in groundwater and in the chemical composition of the water according to the plotted position on Piper diagrams. Often boreholes in the proximity of dolerite dykes contained waters differing vastly in TDS concentration and in chemical composition. Since the age and mobility of groundwater can be related to its chemical composition, the conclusion was drawn that compartments of water of different ages and mobility occur in the basin.

Since the above mentioned survey, the NIWR has conducted intensive surveys of borehole water quality in the upper Fish River catchment and in the Sundays River catchment above Lake Mentz. This data is to be used as input to a function of the model which simulates groundwater seepage into the river channel. The borehole survey of the Lake Mentz catchment area led to the conclusion (Working Group for Mineralization 1977) that the saline surface waters could be closely associated with the natural saline groundwaters in this area. It was possible to reach this conclusion since there is relatively little irrigation in the Lake Mentz catchment area, so that any irrigation return flow could not be a significant cause of the mineralization of these surface waters. This conclusion has provided a clue as to the main origin of salts in the Sundays River waters. However, in the Fish River, where a considerable amount of irrigation takes place, it is not known as yet just how much the irrigation practices do aggravate the mineralization problem.

### *Root zone irrigated soil data*

Chemical and physical properties of the root zone irrigated soils are required as input to the irrigated soil model used by the Department of Agricultural Technical Services. A 1973/74 survey by Agricultural Technical Services (Döhse 1974) revealed more than 600 soil types in the Fish River area. These have been grouped together according to physical properties into 27 "soil modelling units". Analyses are being done to determine the chemical characteristics of each unit. These analyses are almost complete for the irrigated area above Marlow; all that remains to be done for this area is the determination of the cation exchange constants and gypsum contents of the soil units.

### *Deep strata soil data*

The NIWR in 1974 conducted a preliminary survey of the soils below the root zone in irrigated lands along the Fish River. Thirty profile holes were drilled between Fish River Station in the north and Middleton in the south. The salt contents of the different strata in each profile were determined. The results (Viljoen 1975) indicated such a large variation in soil chemical properties that it was decided that an intensive survey of the deep strata soils in a limited river reach would be necessary to understand their rôle in the mineralization of that river reach.

The river reach chosen for this intensive study was that between the Katkop and Baroda Weirs and the study is being undertaken by the Department of Soil Science of the University of the Orange Free State. Fifty test holes were drilled and the various soil strata in each identified according to their physical properties. The chemical analyses of these soils are all but complete and results should be available in March 1978.

### *Applied irrigation data*

Until recently, very little information has been available on the amount of irrigation taking place along the Fish River. Recently, however, the Department of Water Affairs has required each of the local irrigation boards to supply continuous measurements of their canal intakes from the river. The measurements are carried out using Parshall flumes fitted with automatic recording devices. There is a snag, however, in that excess water is often taken into the canals and returned to the river further downstream. It does not seem feasible to obtain accurate records of these canal return flows and the water bailiffs of the various irrigation boards will have to be relied upon to provide estimates of these.

### *Land utilization patterns*

The Department of Agricultural Technical Services carries out surveys in the Fish River valley of the area of land under different crops for the winter and summer seasons.

## *SURVEYS OF MINERALIZATION IN THE FISH RIVER*

### *Surveys during irrigation leads and special releases*

Several surveys have been carried out of progressive mineralization down the river channel during irrigation leads and special releases from Grassridge Dam, Lake Arthur and Elandsdrift Dam, all of them prior to the construction of the new weirs at Marlow and Inkeer. During these surveys, flow rates were measured at certain river sections so that incremental salt loads could be determined for the different river stretches. At some points, where no gauging weirs existed, flow measurements were achieved by obtaining a cross section of the river channel and taking spot velocity measurements across the cross section. Unfortunately, the results of the determination of incremental salt loads for the different reaches were not very conclusive because of the uncertainty in the accuracy of flow measurements. However, observations of the salt concentrations during these

special releases have provided valuable clues as to the transport of salts through the river system. In particular, information has been gained about the storage of salts in the banks of river channels.

#### *Surveys during low flow conditions*

*Ad hoc* surveys have been carried out at times of the year when the river flow is at its most uniform (usually during July or August) and when few irrigation intakes are taking place. Flows were measured and salt concentrations determined at different points in the river in order to determine the salt contribution of groundwater seepage together with irrigation return flow in the various river reaches during these low flow conditions.

### SECTION B - BERG RIVER

#### *DESCRIPTION*

The Berg River (see Figure 4) and its tributaries constitute the most important source of municipal and industrial water supply in the western Cape Province. In the past, it sustained extensive agricultural developments and, more recently, industrial and urban expansion. The Paarl-Wellington urban complex has undergone particularly rapid expansion in recent years. The Berg River is in a winter rainfall area. Rainfall is high in the mountains where it has its source (often above 2 000 mm per annum) but decreases to 400 to 500 mm in the hilly plain through which it flows for most of its length. The main source of flow consists of rapidly flowing semi-perennial streams arising in mountains composed of relatively inert Table Mountain Sandstone. Below Paarl, the bedrock is mainly Malmesbury Shale.

Fourie and Steer (1970) reported that streams arising in Table Mountain Sandstone formations typically have low winter TDS values (averaging about 60 mg/l during 1965 to 1967) whereas streams arising in Malmesbury Shale formations typically have very high winter TDS values (often as high as 3 500 mg/l during 1965 to 1967). However, the rivers draining Malmesbury Shale formations account for only a small fraction of the total flow of the Berg River. The resultant TDS concentration in the Berg River is reasonably low (averaging about 560 mg/l in the lower reaches during the winters 1965 to 1967).

Two impoundments in the Berg River catchment, namely the Wemmershoek Dam (capacity 64 million m<sup>3</sup>) and the Voëlvlei Dam (170 million m<sup>3</sup>) are used to supply the bulk of Cape Town's water requirements, and those of several other smaller municipalities in the vicinity. A large dam, namely, the Theewaterskloof Dam (486 million m<sup>3</sup>) is nearing completion on the Sonderend River, adjacent to the Berg River. The intention is to transfer water across the catchment divide into the Berg River during summer months to augment irrigation. During winter, a dam being built in the upper catchment of the Berg River will serve to direct some of its headwaters into the Theewaterskloof Dam. It is also intended to supply the Saldanha region with water from the Berg River diverted from the Misverstand Weir (see Figure 4). Irrigation has constituted a relatively minor usage of Berg River water in the past; however, increased irrigation is planned for the near future.

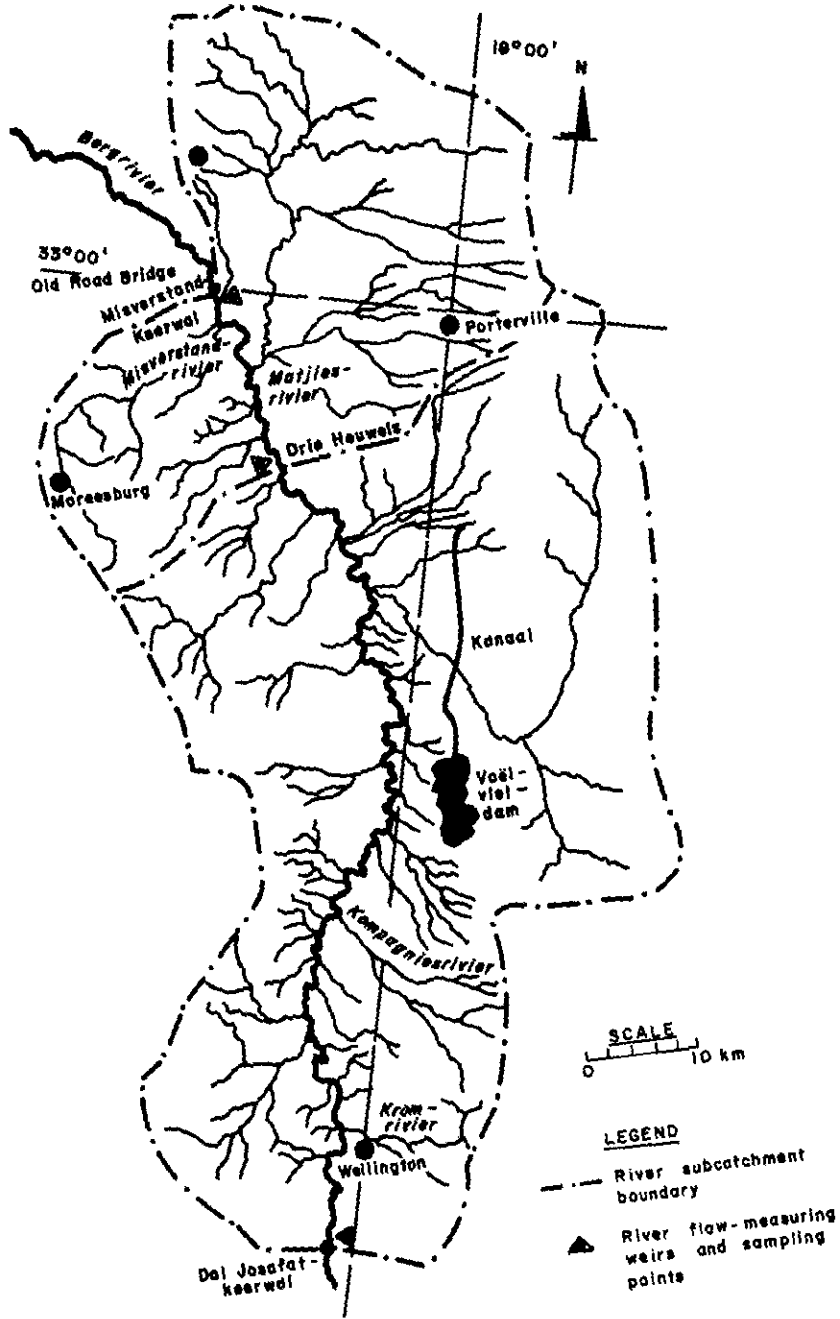


Figure 4. Berg River catchment between Paarl and the Miverstand Weir, showing key sampling and flow-measuring points.

An implication of the increased utilization of the Berg River resources is further progressive salination. One of the causes of this increased salination will almost certainly be increased irrigation return flow. The salt concentrations at the new Misverstand Weir are of concern; TDS values which frequently exceed 500 mg/l at this point would reduce the value of this water for Saldanha water supply.

#### *OBJECTIVES*

The objectives of this research project can be listed as follows -

- (a) The supply of information to the Department of Water Affairs on the continuous mineralization pattern in the Berg River to determine how the operation of existing reservoirs and canals, as well as the location and operation of proposed extensions to the existing scheme, can ensure the supply of water of suitable chemical quality to irrigators and to the Saldanha complex.
- (b) The determination of relative contributions to the mineralization of the river by irrigation return flows from the irrigated areas and by groundwater seepage from the natural and dryland catchment areas in order that areas may be identified which might aggravate soil and water mineralization under more intensive irrigation.
- (c) The development of a systems model to study the interaction of the components of the system so that the effects of remedial measures and operational manipulations can be simulated and investigated.

#### *PROGRAMME*

The following activities are presently being undertaken on a continuous basis -

- (a) flow and reservoir data at several locations (Department of Water Affairs),
- (b) meteorological data collected at a selected number of locations (Weather Bureau, Department of Water Affairs, Department of Agricultural Technical Services),
- (c) daily river sampling at five locations and relevant chemical analysis of samples (NIWR), and
- (d) preliminary mathematical modelling of the hydrological and mineralization processes and patterns in the catchment (Department of Water Affairs in collaboration with the University of Pretoria).

No irrigation soil surveys are being carried out as they are considered unimportant at this stage.

The following further activities are planned -

- (e) improvement of existing flow-measuring facilities in the Berg River (Department of Water Affairs), and



- (f) possible expansion of the modelling study to comprise a complete systems model - depending on the results obtained in (d) (Department of Water Affairs).

### *RESULTS*

Sampling of the Berg River at several points has taken place since 1963 (Fourie and Steer 1970, Fourie and Görgens 1977). The sampling points are shown in Figure 4. Unfortunately, sampling before 1974 was rather unsystematic so that it has not been possible to draw any conclusions about trends in river mineralization. The sampling from 1974 to 1976 was systematic enough to permit several observations to be made. The most important of these was that the TDS concentration at the Misverstand Weir was often higher than 500 mg/ℓ, the standard most often used as the maximum for drinking water supplies. There were several occasions during which TDS concentrations exceeded 500 mg/ℓ for periods longer than five consecutive days. This fact, and the fact that increased quantities of high quality headwaters will be diverted in the future, poses quality problems for the future Saldanha water supplies, unless careful attention is given to river management.

### SECTION C - BREË RIVER

#### *DESCRIPTION*

The Breë River (see Figure 5) has its source in the Skurweberge north of Ceres. In its upper reaches it flows over Table Mountain Sandstone formations; between Wolseley and Robertson the river has carved through into the underlying Malmesbury Shale formations. Downstream of Robertson, the river flows mainly over Bokkeveld Shales, draining eventually into the Indian Ocean. Saline tributary flows are associated with the Malmesbury and Bokkeveld Shales. The main tributary of the Breë is the Sonderend River, which has its origin in the Franschhoek Mountains and contributes a strong, low salinity flow. The average annual rainfall over most of the Breë River catchment is about 250 mm, and it falls mainly in the winter months.

The new 484 million m<sup>3</sup> Theewaterskloof Dam on the Sonderend River (see discussion on the Berg River, Section B) will supply 150 million m<sup>3</sup> of water to the Berg and Eerste Rivers annually during summer months as well as 24 million m<sup>3</sup> per annum for irrigation along the Sonderend. Winter diversions will also be made from the upper reaches of the Berg River into the Theewaterskloof Dam. At present, a total of 45 600 hectares of land is irrigated in the Breë River valley, most of this in a large scheme below the Brandvlei Dam (capacity 89 million m<sup>3</sup>). During the next 13 years, the irrigated area will be increased by a further 27 000 hectares. There are, however, already indications that the irrigated soils in some areas have been spoiled by irrigation with saline water. Certainly, the development of further irrigable land will aggravate an already serious mineralization problem.

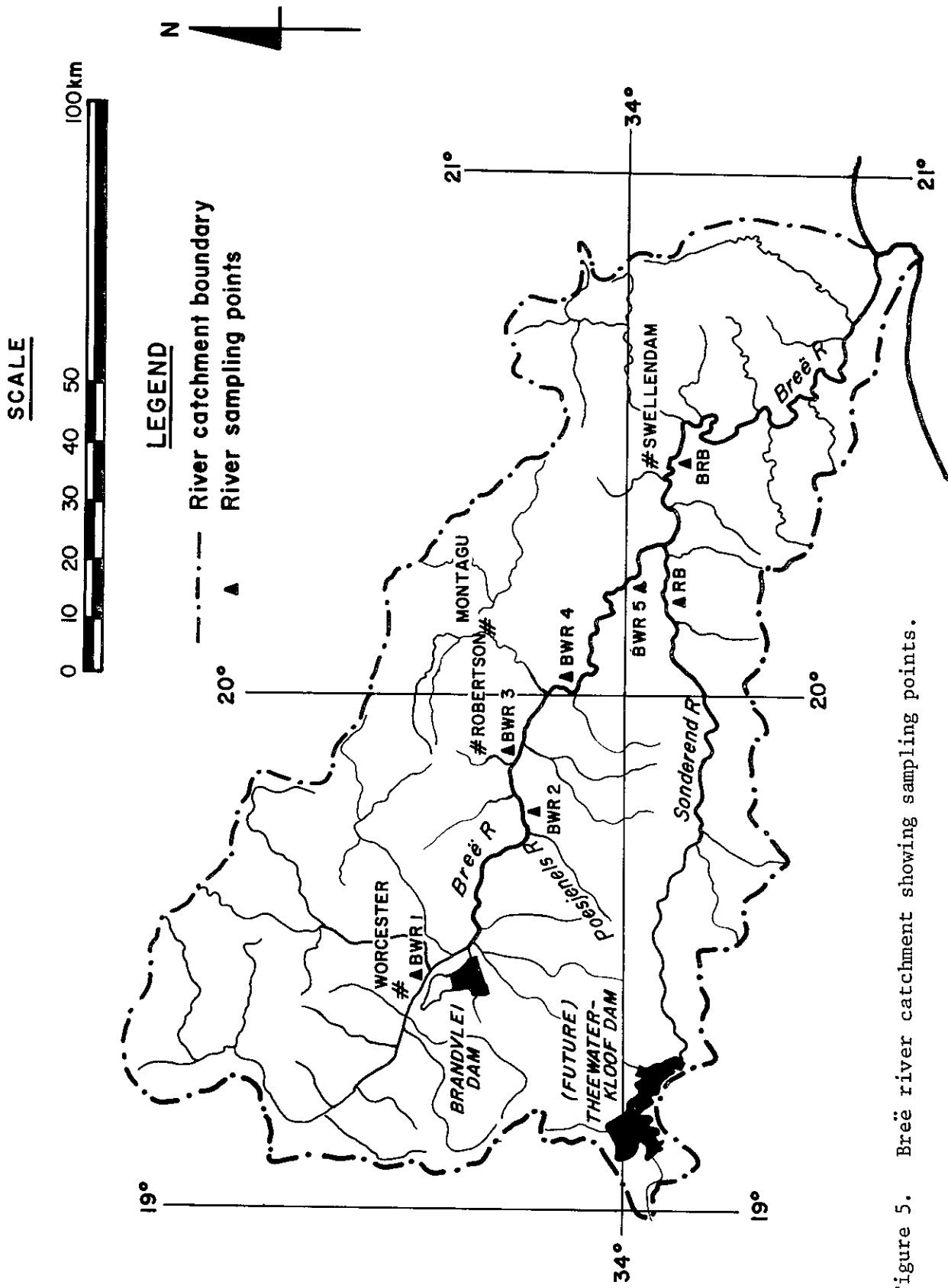


Figure 5. Breë river catchment showing sampling points.

### OBJECTIVES

The objectives of the research project can be listed as follows -

- (a) The supply of information to the Department of Water Affairs on the continuous mineralization pattern in the Breë River to determine how the operation of existing reservoirs and canals, as well as the location and operation of proposed extensions to the existing scheme, can ensure the supply of water of suitable chemical quality to irrigators and municipalities.
- (b) The determination of the relative contributions to the mineralization of the river by irrigation return flows from the irrigated areas and by groundwater seepage from the natural catchment areas in order that areas can be identified which might aggravate soil and water mineralization under more intensive irrigation.
- (c) The development of a systems model to study the interaction of the components of the system so that the effects of remedial measures and operational manipulations can be simulated and investigated.

### PROGRAMME

The following activities are at present being undertaken on a continuous basis -

- (a) flow and reservoir data at a number of locations (Department of Water Affairs),
- (b) meteorological data at a selected number of locations (Weather Bureau, Department of Water Affairs, Department of Agricultural Technical Services),
- (c) rough bookkeeping of irrigation demands (Breë River Irrigation Board), and
- (d) daily river sampling at five or more locations and relevant chemical analyses (NIWR).

The following surveys are being undertaken -

- (e) a survey of some aspects of water quality in boreholes in the Breë River catchment upstream of Robertson (50 boreholes in an area of ~ 800 km<sup>2</sup>, Department of Soil and Water Science, University of Stellenbosch); the results from this survey should provide more background information on the mineralization of the river,
- (f) a soil survey of irrigation soils and the characterization of the main soil bodies in the Breë River valley between Brandvlei Dam and Robertson (Department of Agricultural Technical Services),
- (g) an intensive borehole survey of the catchment of the Poesjenels River, a major saline tributary (Department of Soil and Water Science, University of Stellenbosch), and

- (h) the land utilization pattern of the irrigated area upstream of Robertson (Department of Agricultural Technical Services).

The following further activities are planned -

- (i) development of a soil chemical model of the root zone irrigated soils in the valley upstream of Robertson (Department of Agricultural Technical Services),
- (j) development of a hydrological and natural water quality model of the whole river system above Robertson (Department of Water Affairs),
- (k) linking of the above models and applying them to the further planning and operation of the system (Department of Water Affairs in collaboration with the Department of Agricultural Technical Services), and
- (l) development of a complex soil chemical model of the irrigated soils along the Poesjenels River, and application of this model to the entire irrigated area above Robertson (subject to staff availability; Department of Water Affairs, National Institute for Water Research and University of Stellenbosch).

#### RESULTS

River sampling at several points in the Breë and Sonderend Rivers has been carried out daily since 1975 (Fourie 1978). Summer (October through May) and winter (June through September) seasonal average TDS concentrations for selected sampling points are shown in Table 1. The relevant sampling points can be located on Figure 5.

Table 1. Seasonal average TDS concentrations at selected points in the Breë and Sonderend Rivers.

Sampling points	TDS concentrations (mg/l)			
	Winter 1975	Summer 1975	Winter 1976	Summer 1976
BWR1	121	103	64	93
BWR3	231	262	190	218
BWR5	292	728	297	409
RB	183	192	352	195
BRB	209	501	308	272

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