WATER RESEARCH COMMISSION

A PILOT STUDY OF THE IRRIGATED AREAS SERVED BY THE BREEDE RIVER (Robertson) IRRIGATION CANAL

PART I : TECHNICAL REPORT

(PART 11 : APPENDIXES, IS PUBLISHED SEPARATELY)

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Reg No 77/04283/21

ISBN : 0 947447 53 9
ISBN SET : 0 947447 55 5

WRC No 184/1/89

R 0500
MARCH 1988

EXECUTIVE SUMMARY

1. INTRODUCTION

On the recommendation of an ad hoc meeting on the salination of the Breede River, this project was funded by the Water Research Commission and launched in January 1986.

The main objective of the project was to conduct a feasibility study on the monitoring of water volumes and salt loads moving through an irrigation scheme. The secondary objective was to obtain information which could be used to compile and calibrate a hydro-salinity mass balance model for use in the Breede River. In the project proposal submitted to the Water Research Commission, the objectives were listed as follows:

a) In conjunction with the HRI and SIRI, to formulate a suitable approach (model) for the characterisation and mathematical description of water and salt movement into and out of a suitably delineated study area within the larger Breede River Irrigation Scheme.

b) To use this in conjunction with the HRI and SIRI, to guide the measurement of as many components as possible of the water and salt balance of the delineated area, and the estimation of those remaining, in order to arrive at a characterisation of the water and salt balance of the delineated area.

c) To carry out a sensitivity analysis to ascertain how sensitive estimates of irrigation return flows would be to trends or variation in (i) the various water balance components including errors in their measurement and/or estimation, (ii) irrigation efficiencies, (iii) irrigation techniques, (iv) errors in estimates of irrigated areas, etc. and

d) To use the above results to formulate a suitable methodology for acquiring the necessary input information for adequate characterisation of the water and salt balance, and to provide guidelines for extending this methodology to the entire Breede River Valley and other irrigation schemes.

While this Executive Summary gives only the essence of the findings of this study, a comprehensive report is available from the Water Research Commission. The main report is subdivided into four sections as follows:

a) Section A containing all the findings, results and conclusions derived from the study,

b) Section B describing in detail the methodology used in the different aspects of the study.

c) Section C containing all the background material and information relevant to the water and salt mass balance modelling that was undertaken for the study area, and

d) Section D comprising of the appendices containing tables of readings, recordings and semi-processed information gathered during the study and subsequently used in the mass balance modelling.

2. PROJECT EXECUTION

While the major portion of the project was executed by the Robertson office of Murray, Biesenbach & Badenhorst Inc. the development of the mathematical model was done by Mr S F Forster of the Department of Water Affairs.

A study area extending over 2 081 ha of which 1 241 ha is irrigated, was chosen for the study. A detailed survey to determine the land use and irrigation systems used, was carried out. For each of the 25 individual farms in the study area the present water allocation, area under irrigation, and cropping pattern were determined.

The irrigation water distribution and storage system in the study area was characterised by doing a detailed survey of both the 12,8 km section of the Breede River (Robertson) Irrigation Canal flowing through the study area and the 42 farm dams situated in the study area. Both the canal and farm dams were prepared for daily monitoring of water volumes moving into and out of the study area. This was achieved by installing water level recorders and water depth gauges at a number of locations along the canal and water depth gauges in each of the farm dams.

For a 260 day period starting on 6 August 1986, daily monitoring and recording of the following parameters were conducted:

a) Canal inflow
b) Canal outflow
c) Volumes abstracted or rejected from canal
d) Volumes abstracted by pumps on the Breede River
e) Farm dam storage volumes
f) Electrical conductivity of all relevant volumes
g) Changes in cropping patterns such as planting and harvesting dates of cash crops.

Rainfall and evaporation records for the same period obtained from the Western Cape regional office of the SIRI.

From the daily records of the parameters listed above, the inputs for the IRRISS hydro-salinity model as developed by Mr Forster, could be derived. This, together with the characterisation of the study area and the water distribution and storage system was used to conduct a water and salt balance calculation using the IRRISS model.

Finally, a sensitivity analysis of the return flows and return salt loads as calculated by the IRRISS model to changes in application technique, canal seepage loss rate, farm dam seepage loss rate and modelling starting conditions was executed. An error analysis of the data presented in the main report was also carried out.

3. RESULTS AND CONCLUSIONS

a) The chosen study area encompasses 25 individual farms. These farms extend over an area of 2 081 ha, of which 1 241 ha is irrigated. The corresponding scheduled area is 1 281,4 ha. The crop distribution found in the study area is as follows:

(i)	Vines	:	65,3%
(ii)	Peaches	:	5,4%
(iii)	Apricots	:	8,7%
(iv)	Lucerne	:	8,3%
(v)	Grazing	:	6,7%
(vi)	Grain	:	1,7%
(vii)	Maize	:	2,1%
(viii)	Tomatoes	:	3,0%
(ix)	Nurseries	:	0,4%

b) The 12,8 km section of the Breede River (Robertson) Irrigation Canal which flows through the study area, was found to have very flat invert slopes - in places as flat as 1:16 000, resulting in very low flow velocities. From this section of canal, water is abstracted by 45 farm off-takes and one reject off-take. Although visually in an excellent condition because of proper maintenance, a canal seepage loss rate of 3,13 l/s/1000 m^2 of lining was calculated. In terms of the total volume of water transported in the canal, these seepage losses amount to approximately 14%. Generally speaking the canal is operated on an informal supply-on-demand system with each off-take capable of delivering the full quota as a permanent stream. Farmers are allowed to open and shut their off-takes at will. Any excess water is returned to the Breede River at the reject off-takes.

c) The 45 farm off-takes on the canal are of similar design and consist of a vertical blade set in a steel frame. These off-takes operate as rectangular orifices with the water jet confined on one side. The flow rate Q through an off-take for a canal flow-depth, h_s, and a sluice opening, K, can be calculated by the equation:

$$Q = C_d A (2gh_s)^{1/2} \quad (m^3/s)$$

with $A = K \times$ opening width b, and $g = 9{,}81\ m/s^2$

From calibration measurements values of the discharge coefficient, C_d was found to be:

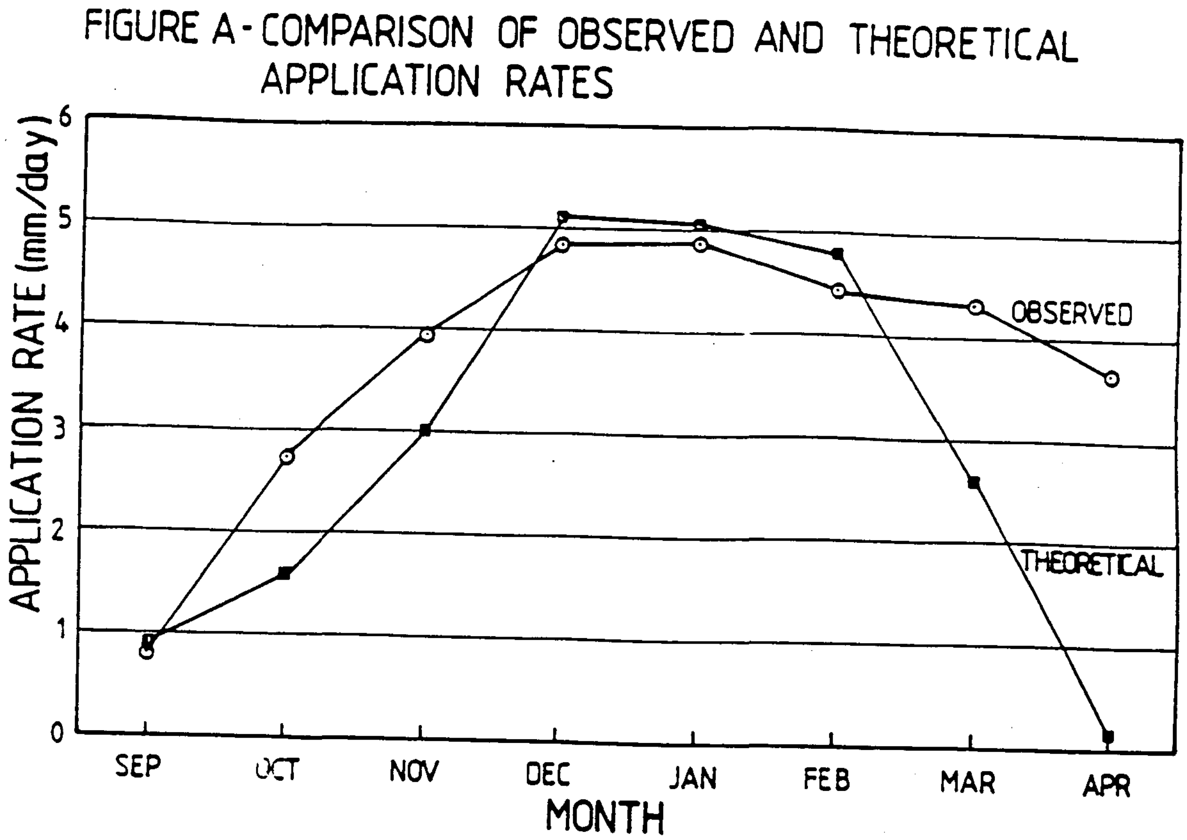
(i)	Free flow	$C_d = 0{,}73$
(ii)	Submerged flow	$C_d = 0{,}65$

d) For the 42 farm dams situated in the study area a total full supply capacity of 875 500 m^3 and a maximum surface area of 38,4 ha was determined. Seepage loss rates ranging between 0,14% and 2,87% of the previous days storage were calculated, while the average seepage loss rate amounted to 0,60% of the previous days storage.

e) The distribution of irrigation systems found in the study area is as follows:

(i)	Drip	:	55,8%
(ii)	Overhead sprinklers	:	25,9%
(iii)	Micro sprinklers	:	8,8%
(iv)	Flood	:	5,3%
(v)	Centre pivots	:	2,7%

Irrigation control systems range from manual control to highly sophisticated electronic systems. Although no tensiometers or evaporation pans were found to be used for the purpose of irrigation scheduling, the actual application rates observed conform remarkably closely to theoretical crop water requirements as is evident from the graph below.



f) From the data collected, it was possible to conduct a water and salt balance calculation using the IRRISS model. From the modelling of a 200 day irrigation season for an irrigated area of 1 064 ha the following results were obtained:

(i)	Total water intake	:	13 663 000 m^3
(ii)	Total salt intake	:	1 728 000 kg
(iii)	Return flow volume	:	1 541 000 m^3
(iv)	Return flow salt load	:	4 595 000 kg

From these results a return flow salinity of 2 980 mg/l is calculated which conforms closely to salinities as measured in some drains in the study area.

g) It was found to be practically possible to measure all the components of water and salt movement through an irrigation scheme from which adequate input data for the IRRISS model could be derived.

4. RECOMMENDATIONS

a) It is possible to isolate and measure the return flows from irrigation along the tributaries of the Breede River. In order to determine the return flow from irrigated soil riparian to the Breede River, the methodology derived from this study should be extended to the remainder of the Breede River Valley where salination is expected to occur. This would enable researchers to isolate and identify those parts of the Breede River Valley which contribute significantly to the salination of the Breede River.

b) The canal seepage loss rate, as calculated, can conceivably be reduced. An attempt should be made to verify these loss rates by doing proper ponding tests in the canals in the Breede River Valley and economical ameliorative measures determined.

c) Permanent flow depth recording stations should be constructed at intelligently chosen points on each canal. With proper calibration these stations can serve as flow measuring instruments.

d) The entire irrigated area along the Breede River should be divided into a series of topographical or geographical units. Land use maps for each unit should be compiled.

e) With a number of minor modifications such as the modelling timestep, the IRRISS model should be used to determine the return flow from each predetermined unit. The data needed for such modelling efforts could be derived from flow measuring records of the canals, land use maps, and a well-planned round of farmer interviews.

f) Finally it is recommended that the methodology developed in this study, be refined for application in other areas where salination of important river channels is experienced.

PART I : TECHNICAL REPORT

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1. PREFACE AND ACKNOWLEDGEMENTS

The work presented in this report relates to research, funded by the Water Research Commission, into the movement of water and the associated salt load through a typical irrigation district in the Breede River Valley. The primary objective of the project was to conduct a study on the feasibility of monitoring water and salt movement through an irrigation district, with the secondary objective of conducting a water and salt mass balance calculation for the chosen study area.

A large amount of information regarding water distribution and irrigation practices in a typical irrigation district was gathered during the study - information which should be very useful to anybody concerned with irrigation and agriculture in the Breede River Valley. It is envisaged that this report will be read by different people with different interests, and the layout of the report was done accordingly.

The Executive Summary gives the essence of the findings of the study.

SECTION A of the report gives all the findings, results, conclusions and recommendations derived from the study.

SECTION B describes in detail the methodology used in the different aspects of the study.

SECTION C contains all the background material and information (both inputs and outputs) relevant to the water and salt mass balance modelling that was undertaken for the study area.

SECTION D consists of tables of readings, recordings and semi-processed information gathered during the study and subsequently used in the mass balance modelling.

The research team wishes to thank the following persons and organisations without whose advice, co-operation and assistance the successful completion of the study would have been impossible:

a) The members of the advisory committee:

Mr D C van der Merwe	:	Water Research Commission
Dr G C Green	:	Water Research Commission
Mr H C Chapman	:	Water Research Commission
Mr H M du Plessis	:	Water Research Commission
Mr F P Marais	:	Water Research Commission
Mr H A Smit	:	Dept of Water Affairs
Dr P C M Reid	:	Dept of Water Affairs
Mr D C R Davidson	:	Dept of Water Affairs
Mr S F Forster	:	Dept of Water Affairs
Dr J J du Toit	:	Dept of Agriculture and Water Supply
Mr I Scheepers	:	Dept of Agriculture and Water Supply
Mr E Braune	:	Hydrological Research Institute
Mr H Maaren	:	Hydrological Research Institute
Dr A J van der Merwe	:	Soil and Irrigation Research Institute
Mr J K Murray	:	Murray, Biesenbach & Badenhorst Inc.

b) The Breede River (Robertson) Irrigation Board who allowed the study to be conducted in its irrigation district.

c) The owners of the farms that were included in the study area and who were always willing to co-operate:

Mr G J Barry
Mr J Britz
Mr A S Bruwer
Mr L B Bruwer
Mr P Bruwer
Mr G C Burger
Mr J M Burger
Mr A E de Waal
Mssrs F and H Doms
Mr B A Fouche
Dr T Foulkes
Mrs S T Kriel
Mr E A Lategan (deceased)

Mr B Marais
Mr E Marais
Mr P Marais
Mr P C Marais
Mr C F H Meiring
Mssrs J M and B Rabie
Mssrs W J and N J Retief
Mssrs G H and A Smuts
Mr G van Deventer
Mr W A van Deventer
Mr C A Waller

d) The personnel of the HRI involved in supplying very useful help by analyzing water samples.

e) Mr S F Forster of the Department of Water Affairs (formerly of the HRI) for his invaluable contribution in the water and salt mass balance modelling.

f) Mr A Joubert, field technician of the HRI for all kinds of assistance throughout the project.

The research team involved in the project consisted of:

J K Murray	:	Project leader
J G Kriel	:	Principal researcher
L H Bruwer	:	Project engineer
I L Rabie	:	Technician
J G Windvogel	:	Technical assistant

Murray, Biesenbach & Badenhorst Inc.
November 1987

2. INTRODUCTION

On 25 November 1984 an ad hoc meeting was held in Grahamstown to discuss a means of monitoring water volumes and associated salt loads in the Breede River Valley. The meeting concluded that it would be impossible to attempt to monitor water volumes in the entire valley from the outset. The idea arose of closely monitoring a representative irrigation district and using the information gathered to compile a mathematical model with which the Breede River Valley as a system could be simulated and then test its feasibility. The existence of a calibrated model would enable the Department of Water Affairs to plan future development of water resources in the valley with more confidence.

During January 1985, Mr S F Forster of the Hydrological Research Institute (HRI) of the Department of Water Affairs (DWA) followed up the recommendations of the above-mentioned ad hoc meeting. He compiled a very detailed proposal for a pilot research project to determine the feasibility of the monitoring and modelling of individual irrigation districts, rather than sub-catchments. At a follow-up meeting on 19 February 1985 in Cape Town it was decided that Mr J G Kriel, representing the Robertson office of Murray, Biesenbach & Badenhorst Inc. (MBB), and Mr Forster would prepare a research proposal for submission to the Water Research Commission (WRC).

The main objective of the project was to conduct a feasibility study on the monitoring of water volumes and salt loads on the scale of an irrigation district. The secondary objective was to obtain information which could be used to compile and calibrate a hydro-salinity mass balance model.

In the proposal submitted to the WRC, the objectives were listed as follows:

a) In conjunction with the HRI and SIRI, to formulate a suitable approach (model) for the characterisation and mathematical description of water and salt movement into and out of a suitably delineated study area within the larger Breede River Irrigation Scheme.

b) To use this in conjunction with the HRI and SIRI, to guide the measurement of as many components as possible of the water and salt balance of the delineated area, and the estimation of those remaining, in order to arrive at a characterisation of the water and salt balance of the delineated area.

c) To carry out a sensitivity analysis to ascertain how sensitive estimates of irrigation return flows would be to trends or variations in (i) the various water balance components including errors in their measurement and/or estimation (ii) irrigation efficiencies, (iii) irrigation techniques (iv) errors in estimates of irrigated areas, etc. and

d) To use the above results to formulate a suitable methodology for acquiring the necessary input information for adequate characterisation of the water and salt balance, and to provide guidelines for extending this methodology to the entire Breede River Valley and other irrigation schemes.

These objectives were to be attained by choosing a suitable study area and preparing it for the detailed monitoring of the movement of water through it during an irrigation season. At the same time Mr Forster would compile the so-called IRRISS hydro-salinity model - a conceptual model with which a mass balance of water and solutes can be conducted for an irrigation district. Information obtained during the season to be monitored would be used to de-bug, calibrate and verify the IRRISS model.

The project was conducted in three phases:

a) Preparation and characterisation of the chosen study area.

b) Close monitoring of water volumes and associated salt loads moving through the study area for the period from August 1986 to April 1987.

c) Processing information including mass balance modelling using the IRRISS model.

A RESULTS AND CONCLUSIONS

3. THE STUDY AREA

3.1 General

Figure 1 - "Location of Study Area" shows that the study area extends from approximately 2,5 km to 11 km east of Robertson. The area straddles the Robertson-Bonnievale road, and includes all the farms which receive irrigation water from a 12,6 km stretch of the Breede River (Robertson) Irrigation Canal.

3.2 Choice

Every irrigation district or sub-district in the Breede River Valley is unique in respect of irrigation methods and cropping patterns. After considering all the important factors such as location, geography and the relative ease with which the specific area could be isolated in terms of inflow and outflow of irrigation water, it was decided that the study area chosen was fairly representative of the irrigation districts in the valley.

Another consideration was that the study area encompasses more that 1 000 ha of unbroken irrigated land, that is, irrigation is not practised on separate isolated patches of land. The final consideration, however, was that the Robertson office of MBB, through work previously done for clients in the study area, already had access to a vast amount of invaluable information on irrigation as practised in the area.

A map, based on 1:10 000 orthophoto maps showing the study area boundary, farm boundaries, 5 metre contours, major roads, the canal, canal off-takes, farm dams, and the Breede River, is given in reduced form as Figure 2.

For modelling purposes, farms numbers 9, 11, 12, 14, 16 and 20 have been excluded from the chosen study area, although all the relevant information on these farms has been included in this report. The reasons for this decision are discussed in detail in Section C.

3.3 Description

The study area encompasses 25 individual farms consisting of some 80 subdivisions, the particulars of which are given in Appendix B. These are owned by 28 individual farmers. The farms included in the study area extend over 2 081 ha, representing a total scheduled area of 1 281,4 ha.

Physically the study area can be described as flat, undulating land extending over the lower parts of 8 subcatchments, two of which are the Klein and Groot Klaasvoogds Rivers. The area is situated on the northern bank of the Breede River, 4,5 km downstream of the Hoops River, and directly upstream of the Cogmanskloof River.

The soils vary from typical Karoo clay-loam intersticed with lime hardpan "hills" originating from Bokkeveld shales, to fine sandy silt deposits on the river bank - what is locally known as the island soils. Figure 3 is a schematic representation of the soils found in the Breede River Valley.

Climatologically the study area falls in the Winter Rainfall Region with an average annual rainfall of between 300 and 350 mm, and an average annual A-pan evaporation of approximately 2 400 mm. This necessitates intensive irrigation of all crops during the summer months, mainly from mid-September to the end of April.

3.4 Land use

The pilot study was conducted in a traditional wine producing area. The total area is 1 240,9 ha of which 809,7 ha (or 65,3%) is planted with wine grapes. For the model however only 1 063,8 ha was considered.

The irrigated area consists of 586 individual fields or plantations. These were mapped and numbered by means of a letter identifying the farm, and a two-figure serial number identifying the specific field. Figure 4 is a reduced version of the 1:10 000 land use map. In Appendix B an index is given of the size, crops, and irrigation method of each individual field.

FIGURE 3 - RELATIVE POSITION OF SOIL TYPES IN THE BREEDE RIVIER VALLEY
(taken from "A Reconnaissance survey of the Breede River Valley," SIRI, Report 861/45/77)

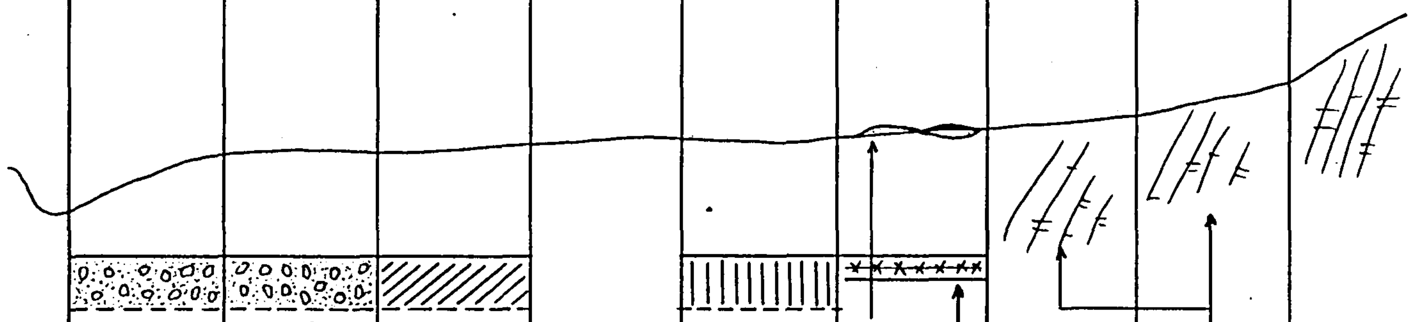
	1	2	3	4	5	6	7	8	9
GENERAL NAME	Deep Dry Sandy Soil	Deep Island Soil	Deep Saline Soil	Soft Karoo	Tough Karoo	Hard Karoo	Medium Depth Shale	Shallow Karoo	Veld
DESCRIPTION AND RELATIVE POSITION	 Boulders and	sand	Soil over clay substrata	Red to yellow-brown	Tough clay layer	Lime hills Dorbank		Shale or clay	
SOIL CLASSIFICATION DOMINANT FORM	Fernwood Dundee	Oakleaf Clovelly Fernwood Dundee	Westleigh Sterkspruit Valsrivier Oakleaf	Oakleaf Clovelly Hutton	Sterkspruit Valsrivier Hutton Oakleaf	Valsrivier Sterkspruit Clovelly Hutton Oakleaf	Glenrosa	Glenrosa Sterkspruit Swartland Hutton	

Table 1 is a summary of the above-mentioned index, and lists the total area for each irrigation method and each crop for every farm in the study area.

3.5 Trends

The study area is a traditional wine-producing area, and all indications are that for the foreseeable future it will remain so. However, the single most important factor dictating land use is the economy. Interest rates are particulary important to farmers when deciding on new plantings, both on previously uncultivated land and when replacement of existing crops becomes imminent. Establishment costs for intensively cultivated grapes (6) amount to as much as R15 000/ha over the first three years after planting. This compels many farmers to obtain loans with which to make new plantings.

Rising costs and interest rates over the last two decades forced many farmers in the Robertson area to start producing cash crops.

Tomato production for the fresh-produce market is very popular and the Robertson area is acclaimed for the high quality of tomato produced. In more recent years a growing number of farmers have started producing wheat and maize. In this case high production costs and the not too favourable climate are offset by very favourable rebates on maize supplied to the consumers in the Western Cape, thus eliminating high transport costs.

All this has led to the practice of cash crops being grown on land previously planted with one of the perennial crops which was due to be renewed. After a maximum of two or three seasons of cash crop production, the land is again planted with a perennial crop. An interesting phenomenon however is that tomatoes as a cash crop is found on approximately 50% of the farms, the other 50% prefering lucerne, wheat, or maize.

TABLE I - IRRIGATION AND CROP DISTRIBUTION PER FARM

	IRRIGATION TYPE (ha)					CROP TYPE (ha)										
Farm No	Mecha-nical	Sprink-ler	Micro	Drip	Flood	Vine	Peaches	Apri-cots	Lucerne	Graz-ing	Grain	Maize	Tomatoes	Nursery	Fallow	TOTAL
1	33,7	36,6	1,8	53,4	17,6	61,6	17,6	8,4	17,5	-	12,2	25,8	-	-	-	143,1
2	-	35,9	7,2	57,0	-	65,9	5,1	16,2	12,9	-	-	-	-	-	-	100,1
3	-	10,6	32,9	38,4	-	71,2	3,7	-	2,5	1,1	3,4	-	-	-	-	81,9
4	-	27,0	-	-	-	-	-	-	23,9	3,1	-	-	-	-	-	27,0
5	-	13,1	-	52,2	8,5	43,5	3,4	5,3	7,9	10,7	3,0	-	-	-	-	73,8
6	-	-	6,2	22,9	-	24,9	2,2	2,0	-	-	-	-	-	-	-	29,1
7	-	-	6,4	3,9	-	7,6	-	1,0	-	-	-	-	1,5	0,2	0,6	10,9
8	-	-	-	3,1	-	-	-	-	-	-	-	-	3,1	-	6,9	10,0
10	-	1,1	-	103,7	-	89,6	8,9	5,2	-	1,1	-	-	-	-	3,2	108,0
13	-	-	-	9,7	8,2	9,7	5,4	2,5	-	0,3	-	-	-	-	-	17,9
15	-	3,5	-	18,8	-	17,5	-	1,6	-	-	-	-	3,2	-	-	22,3
17	-	1,0	8,0	58,3	-	46,3	-	16,5	-	1,0	-	-	3,5	-	-	67,3
18	-	13,4	1,9	55,1	2,9	38,6	13,8	3,1	9,3	2,1	-	-	6,4	-	-	73,3
19	-	42,4	21,1	-	2,9	65,0	1,4	-	-	-	-	-	-	-	-	66,4
21	-	97,3	-	12,6	-	63,5	-	-	7,2	38,6	-	-	0,6	-	-	109,9
22	-	3,0	-	23,3	-	17,6	-	-	-	-	3,0	-	5,7	-	-	26,3
23	-	16,8	-	-	-	-	-	-	-	16,8	-	-	-	-	-	16,8
24	-	3,1	-	22,4	-	18,9	-	3,5	-	-	-	-	-	3,1	-	25,5
25	-	0,5	10,3	54,1	-	53,3	0,5	4,5	-	0,5	-	-	6,1	-	-	64,9
Total	**33,7**	**305,3**	**95,8**	**588,9**	**40,1**	**694,7**	**62,0**	**69,8**	**81,2**	**75,3**	**21,6**	**25,8**	**30,1**	**3,3**	**10,7**	**1 074,5**
9	-	0,5	-	-	-	-	-	-	-	0,5	-	-	-	-	-	0,5
11	-	3,4	-	16,4	0,8	15,7	1,4	1,5	-	-	-	-	-	2,0	3,4	24,0
12	-	0,5	-	-	-	-	-	-	-	0,5	-	-	-	-	-	0,5
14	-	0,6	-	-	-	-	-	-	0,6	-	-	-	-	-	-	0,6
16	-	9,6	13,9	30,4	1,9	29,9	3,7	5,5	2,9	6,7	-	-	7,1	-	2,9	58,7
20	-	1,7	-	57,5	22,9	69,4	-	12,0	0,7	-	-	-	-	-	-	82,1
TOTAL	33,7	321,6	109,7	693,2	65,7	809,7	67,1	88,8	85,4	83,0	21,6	25,8	37,2	5,3	17,0	1240,9

The proclamation of the Breede River Government Water Control Area on 21 February 1986 will certainly affect land use patterns. It is expected that, through the sale of water rights, previously uncultivated and unirrigated land will be developed. Water will be pumped from the river. This will enlarge the total area under irrigation and create a "widening" of the strip of irrigated land on either side of the Breede River. It is also expected that there will be a tendency towards mechanical irrigation systems such as centre pivots on cash crops on this newly irrigated land. The reasons for this are marginally lower capital costs, lower labour costs, and the inherent lower production potential of the soil.

4. WATER SOURCES

4.1 The Breede River

The Breede River is the most important source of irrigation water in the Breede River Valley, and at gauging station H5MO2 (Wolvendrift) a mean annual run-off of 970 x 10^6 m^3 has been recorded. (9) It is important to note that all diversion works serving the BRWCB canals are situated upstream of H5MO2 which means that the figure given above really is a "residual mean annual run-off".

The Breede River originates in the mountains surrounding the Ceres Basin, and upstream of H5MO2 some 18 tributaries from the mountain ranges on either side of the Valley contribute significantly to the flow in the Breede River. The wide variation in flow rates found in the Breede River results from the non-perennial behaviour of the tributaries. In geological terms, all the tributaries can be described as relatively "young" rivers associated with short-lived floods following any significant precipitation in the steep mountain catchments. On the other hand, the Breede River itself has all the characteristics of an "old" river, meandering through flood plains and an unknown number of islands.

The first significant development of the main river flood plain took place in the period 1898 - 1918. Previously, development was limited to small scale diversion works serving small, isolated (10) patches of irrigated land. The high cost of diversion works and canals was mainly caused by the low river gradients and high winter flood levels which inhibited the scale of irrigation works.

In the period 1898 - 1918, large scale development resulted from (10) the proclamation of the following irrigation boards:

a) Breede River (Robertson) Irrigation Board, by Proclamation 21 of 1898.
b) Zanddrift Irrigation Board, by Proclamation 189 of 1909.
c) Le Chasseur-Goree Irrigation Board, by Proclamation 169 of 1910.

d) Angora Irrigation Board, by Proclamation 127 of 1917.

e) Breede River Water Conservation Board (BRWCB) by Proclamation 124 of 1913 and 72 of 1918.

With the exeption of the BRWCB all these boards constructed diversion weirs and unlined furrows by which water was supplied to riparian properties.

From 1918 to the present, the irrigated area served by each steadily increased because of

a) the advent of better irrigation techniques enabling farmers to irrigate a larger area with the same volume of water

b) the construction of the Brandvlei Dam which eliminated periodical water shortages, and

c) the lining of canals reducing distribution losses.

These three events made more irrigation water available to the farmers in the Breede River Valley - water which could be used to expand the irrigated area. At present the actual irrigated area in the study area amounts to 96% of the scheduled area.

4.2 Brandvlei Dam

Initially all the above-mentioned Boards depended on the normal flow in the Breede River, but because of sustained development in the upper reaches of the river, the flow during the summer months became insufficient. This resulted in the construction of the Brandvlei Dam (Lake Marais) at Worcester with a capacity (5) of $45{,}8 \times 10^6$ m^3 in 1922. The Brandvlei Dam is an off-channel storage dam fed by the Smalblaar and Holsloot Rivers. In 1950 the storage capacity of the dam was enlarged to $95{,}3 \times 10^6$ m^3.

Construction on the adjacent Kwaggaskloof Dam started in 1968 and eventually the Department of Water Affairs took over control of the Greater Brandvlei Dam by Proclamation 63 of 1973. The Greater Brandvlei Government Water Scheme as described in White Papers WPJ-72 and WPM-81 entailed the enlargement of the Brandvlei and Kwaggaskloof Dams in two phases as well as upgrading the intake works from the Smalblaar and Holsloot Rivers.

The Papenkuils pump station with which water from the Breede River can be pumped into the Brandvlei Dam was also added. At present the Greater Brandvlei Dam has an active storage (10) of 457×10^6 m^3.

As compensation for the take-over of the Brandvlei Dam by the DWA a preferential right of $94{,}4 \times 10^6$ m^3 has been allocated to the BRWCB. At present this preferential right is used by the BRWCB to supplement the supply of irrigation water drawn in summer by the lesser boards under its jurisdiction.

4.3 Salinity Problem

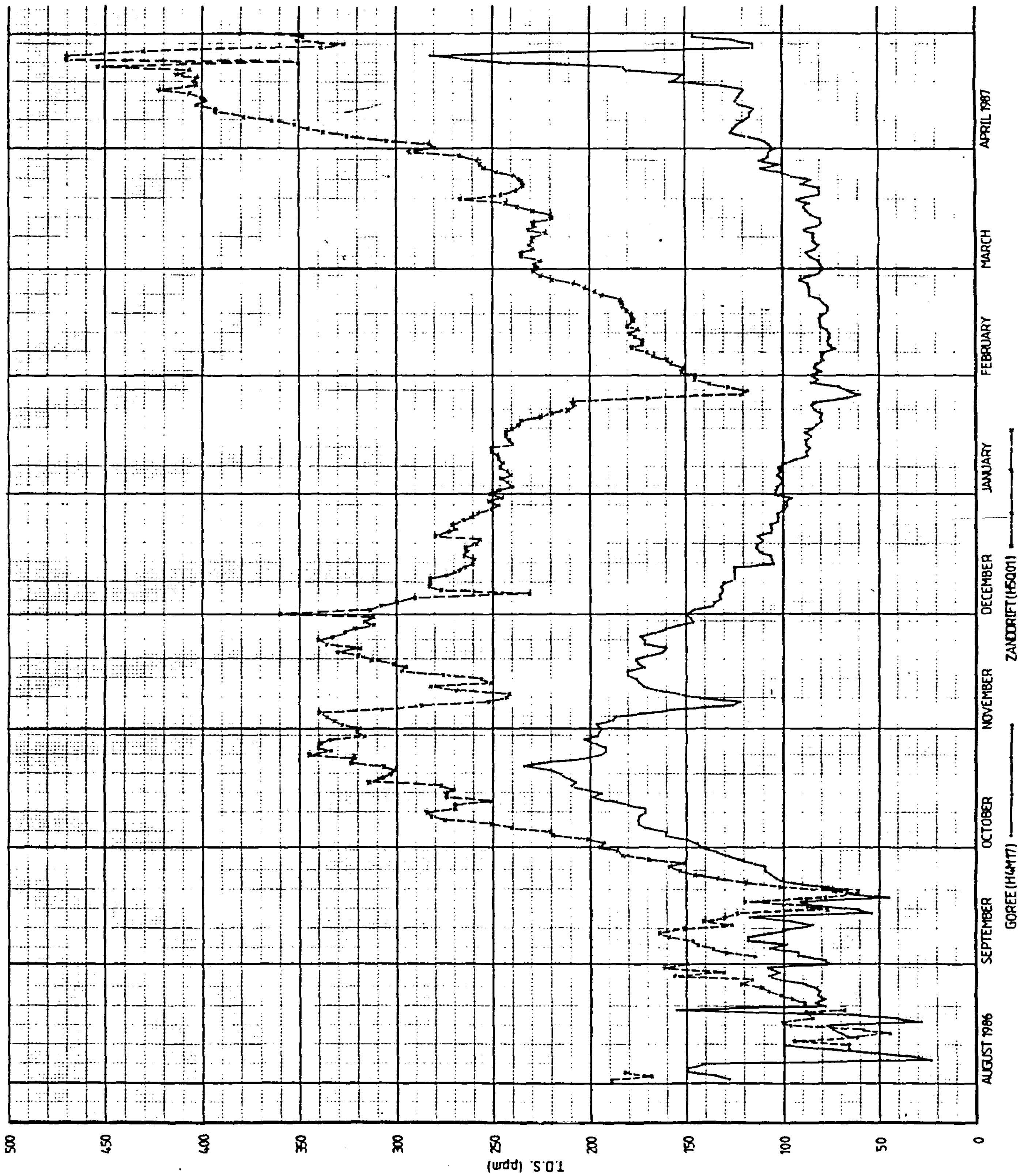
A potentially serious salinity problem exists in the Breede River - and in particular downstream of the Brandvlei Dam. The problem has become so serious that 9×10^6 m^3 of water is reserved annually in the Greater Brandvlei Dam to dilute the highly saline flows during the summer months. This so-called "freshening water" could otherwise be used to irrigate approximately 1 200 ha of land annually.

Figure 5 is a graphical representation of the daily variation in TDS values as recorded by the HRI field technician. The two graphs represent, respectively, the TDS directly upstream of the Robertson Canal diversion weir at Goree (H4M17) and at the Zanddrift Canal diversion weir (H5Q01). In the operation of the Greater Brandvlei Dam, a prerequisite was that the salinity at H4M17 and H5Q01 be kept below 150 and 300 ppm respectively. All the available freshening water was used annually, often without fully complying with the stipulated norms. (During 1987 new norms deviating slightly from the above-mentioned were introduced).

A typical analysis of TDS for a sample of water taken from the Breede River (Robertson) Canal had the following results:

FIGURE 5 - DAILY T D S VALUES IN THE BREEDE RIVER

(data supplied by H R I)



pH = 6,9; EC = 27,5 mS/m

Total alcalinity	:	21 mg/ℓ (as $CaCO_3$)
NH_4	:	0,05
Ca	:	6
Cl	:	46
NO_3	:	0,03 (as Nitrates and Nitrite)
Na	:	31
Mg	:	6
F	:	0,1 (as Phosphates)
Si	:	0,3
K	:	1,2
SO_4	:	19
P	:	0,009
TDS		136 mg/ℓ

From the above it is evident that approximately 50% of the TDS is contributed by NaCl.

Table 2 is the complete table of results of the chemical analysis done by the HRI for this study.

4.4 Other Water Sources

Apart from the Breede River and its tributaries there are no other significant water sources in the Valley.

The tributaries of the Breede River have been developed to the point where all the normal flow is used before it can reach the main river. If inflows into the Breede River do occur during the summer months, these are normally either extremely saline or of very short duration. This results from the fact that all the tributaries originate in mountain ranges with a winter rainfall. Low volume, saline summer inflows can most likely be attributed to irrigation return flow.

Most of the lower parts of the Breede River Valley are underlaid by Bokkeveld Shales which are notorious for both their imper- (3) meability and high salt content. These are the reasons why groundwater cannot be a significant source of irrigation water in the Valley.

TABLE 2 - CHEMICAL ANALYSIS RESULTS

TAL = Total alkalinity as $CaCO_3$ NO_3 = Nitrate as nitrate plus nitrite nitrogen P = Phosphorus as phosphate phophorus
(Values in mg/ℓ)

Date	Station No	EC (mS/m)	pH	TAL	NH_4	Ca	Cl	NO_3	Na	Mg	P	Si	K	SO_4	P	TDS
02-10-86	OTT 1	23	6,7	11	0,13	5	45	0,27	26	5	0	1,3	1,8	15	0,005	114
	OTT 2	23	6,6	10	0,12	5	44	0,25	27	5	0	1,3	1,9	15	0,009	113
	OTT 3	22,4	6,7	11	0,16	5	44	0,23	26	5	0,1	1,3	1,9	14	0,009	113
	DAM 1	26,2	6,9	17	0,14	7	48	0	30	6	0	0,3	2	19	0,007	134
	DAM 17	15,4	6,8	16	0,13	6	24	0,1	15	4	0	0,6	1,2	9	0,004	80
	DAM 35	20,2	6,9	14	0,12	7	36	0,01	22	5	0	1,1	1,6	14	0,008	
12-12-86	OTT 1	32,1	7,1	20	0,03	7	59	0,02	35	7	0,1	0,4	0,9	20	0,012	154
	OTT 2	32,1	7	20	0,06	7	58	0,02	35	7	0,2	0,3	0,9	21	0,012	154
	OTT 3	33	7,1	21	0,06	8	57	0,03	38	8	0,2	0,2	1,2	20	0,011	156
09-01-87	OTT 1	27,5	6,9	21	0,05	6	46	0,03	31	6	0,1	0,3	1,2	19	0,009	136
	OTT 2	27,4	6,9	18	0,05	6	45	0	30	6	0,1	0,4	1,1	17	0,009	128
	OTT 3	27,3	7	17	0,06	6	46	0,02	30	6	0,1	0,4	1,2	17	0,009	127
	DAM 1	29,8	6,9	20	0,06	7	51	0,03	33	7	0,1	0,4	1,4	19	0,009	143
	DAM 17	27,5	6,9	19	0,05	6	46	0,04	31	6	0,2	0,7	1	16	0,015	130
	DAM 35	28	6,8	18	0,06	6	48	0,12	32	6	0,1	0,3	1,4	16	0,018	133
27-01-87	OTT 1	22,7	6,2	17	0,04	5	40	0,05	23	5	0,1	1	1,4	11	0,014	108
	OTT 2	23,6	6,5	21	0,04	5	42	0,05	25	5	0,1	0,5	1	12	0,007	117
	OTT 3	22	6,3	11	0,08	5	39	0,03	23	5	0,1	0,7	1,3	13	0,009	100
28-01-87	DAM 1	17	5,5	5	0,07	4	31	0,02	16	4	0,1	1	1,1	9	0	71
	DAM 17	16,2	5,3	6	0,06	3	33	0,02	17	4	0,1	1	1,2	8	0,007	75
	DAM 35	16,9	5,5	5	0,07	4	33	0,02	18	4	0	1	1,2	9	0,009	75
09-02-87	OTT 1	24,3	6,5	12	0,07	6	43	0,03	26	5	0,1	0,5	1,3	11	0,007	109
	OTT 2	21,1	6,4	8	0,07	5	40	0,03	23	5	0,1	0,5	1,4	10	0,007	95
	OTT 3	20,4	6,4	11	0,1	5	38	0,03	22	5	0,1	0,5	0,9	11	0,007	96
25-02-87	OTT 1	22,4	6,2	11	0,05	5	42	0,03	25	5	0,1	0,5	1,1	11	0,009	103
	OTT 2	22,7	6,3	14	0,04	5	42	0,02	26	5	0,1	0,4	1	11	0,007	108
	OTT 3	22,7	6,4	14	0,05	5	42	0,02	26	5	0,1	0,5	1	11	0,007	108
10-03-87	DAM 1	23,6	6,4	22	0,08	6	43	0,02	27	5	0,1	0,9	2	12	0,009	124
	DAM 17	21,1	6,2	13	0,06	5	40	0,02	24	5	0,1	0,3	1	11	0,007	101
	DAM 35	22,4	6,5	17	0,05	5	42	0,05	25	4	0,1	0,5	1,1	11	0,059	110
24-03-87	DAM 1	24,9	6,6	27	0,09	7	47	0,04	28	6	0,1	0,9	2	9	0,009	132
	DAM 17	22,4	6,5	14	0,05	5	43	0,04	26	5	0,1	0,5	1,1	11	0,009	108
	DAM 35	23,3	6,4	16	0,06	6	43	0,25	27	5	0,1	0,5	1,2	12	0,016	117
08-04-87	DAM 1	27,5	6,7	27	0,03	7	54	0,23	33	6	0,1	0,8	2,4	23	0,011	160
	DAM 17	26,5	6,8	21	0,03	6	52	0,01	33	6	0,1	0,4	1,8	20	0,011	145
	DAM 35	27,5	6,8	21	0,04	6	53	0,16	33	6	0,1	0,6	2	20	0,235	147
23-04-87	DAM 1	42,2	6,8	22	0,05	13	81	0,39	48	9	0,1	1,6	3,3	44	0,02	229
	DAM 17	28,1	6,9	24	0,04	7	54	0,06	35	6	0,1	0,4	1,8	21	0,011	155
	DAM 35	30,4	6,7	27	0,05	6	60	0,02	36	7	0,1	0,7	2	23	0,611	168

5. BREEDE RIVER (ROBERTSON) CANAL

5.1 History

As mentioned previously, the Breede River (Robertson) Irrigation Board was proclaimed by Proclamation 21 of 1898.

Work started during 1899 and was completed in February 1904 at a capital cost of £33 000. The work consisted of a mass concrete weir in the Breede River at Goree and hand-dug furrow, 10 feet wide for the first 14 miles, tapering off to 6 feet wide at Zandvliet. The furrow had a depth of 3 feet and crossed the six mountain streams in its way by means of masonry aquaducts. (2)

Initially the canal delivered irrigation water to 2 568 morgen (2 200 ha) of land owned by the 22 shareholders in the scheme. A rate of 9 shillings 5 pennies per acre per annum was levied in order to repay the capital borrowed from the Government.

From the outset it was recorded in the minutes of the Board that several farmers lodged complaints about water-logging caused by seepage from the furrow. The problem of salination of land below the furrow became so serious that in May 1938 the Board agreed to having certain stretches of the furrow lined with concrete where seepage could directly be proved to be the culprit, and the owner of the affected land had to contribute half of the cost of the lining.

During the years 1952 - 1957 a construction unit of the Department (1) of Water Affairs constructed a concrete lining in the old furrow. The work was done under difficult circumstances because during the irrigation season the water supply could not be interrupted for more than three weeks at a time, and on certain farms access to the work was severely restricted. This led to an experimental section on the Breede River (Robertson) Canal being constructed from prefabricated panels - a method that proved to be very satisfactory.

5.2 Characterisation of Canal

The part of the Breede River (Robertson) Canal within the boundaries of the study Area, a stretch of 12 853 m, was accurately surveyed and drawn to a scale of 1:1 000. For the purposes of the survey the canal was divided into 18 sections, each sub-divided into approximately 6 sub-sections.

For each sub-section the following information was compiled in tabular form and given as Appendix C :-

a) Chainage
b) Canal wall crest level
c) Canal invert level
d) Canal width
e) Slope of invert
f) General invert slope for section

In the same table each off-take situated within a specific section is listed together with its chainage, invert level, and size.

The information given in Appendix C is summarized and given in Table 3.

TABLE 3 - SUMMARIZED CHARACTERISTICS OF CANAL

	1	2	3	4	5	6	7
Chainage (m)	0-2302	2302-5078	5078-8079	8079-8664	8664-9660	9660-12318	12318-12853
Depth (m)	1,15	1,15	1,00	1,00	1,10	1,00	1,00
Width (m)	3,00	2,70	2,70	2,30	2,40	2,40	1,80
Slope of invert	1:3542	1:16329	1:15005	1:1500	1:4527	1:4027	1:5350

The rather flat invert slopes result in sluggish flow with flow velocities rarely exceeding 0,5 m/s. Under normal conditions the canal is operated with approximately 100 mm of free-board. However, after unexpected rainfall in midsummer, the canal overflowed in a number of places. This should rather be attributed to farmers shutting their off-takes than to inflows resulting from run-off.

A typical characteristic of all the canals in the Breede River Valley is the proliferation of algae during summer. This is caused by

a) shallow water depths and low turbidity allowing abundant sunlight to reach all submerged parts of the canal
b) sluggish flow permitting algae to grow on the rough concrete surfaces of the canal, and
c) constant replenishment of nutrients from irrigation and urban return flows upstream of canal intake works.

The algae problem necessitates sporadic cleaning operations during which the canal has to be "dried out" for at least two days, followed by laborious manual cleaning.

5.3 Present Condition

Some years ago, the Breede River (Robertson) Irrigation Board adopted a maintenance programme by which their canal would be renovated in sections.

At the end of the irrigation season in approximately mid-April each year, the canal intake is shut off for a period of two to three weeks. During this period a contractor does the following work on the section scheduled for that particular year:

a) All vegetation is removed from the banks of the canal.
b) All mud and debris is removed by a team of labourers.
c) The concrete surface of the canal is thoroughly cleaned by means of high-pressure water jets.
d) Seriously damaged sections of the lining are removed and replaced by concrete in the case of floor slabs and brick masonry in the case of wall panels.

e) The canal lining is prepared to accept cement plaster by brushing a cement-water mixture onto the lining.

f) The canal walls are plastered with a 1:3 cement-sand mixture. Simultaneously a gusset is shaped on the wall-floor joint.

g) After smoothing off of the plaster layer, all excess plaster is spread out evenly on the floor of the canal by means of brooms.

The method described above proved to be highly satisfactory since there was a lower roughness coefficient leading to a markedly lower flow depth.

It also resulted in a marked reduction of water-logging of land adjacent to the canal in a number of locations.

For the duration of the monitoring period some 8 450 m of the 12 853 m of canal included in the study was in an excellent condition. The remaining part was renovated during March 1987.

In conclusion it can be stated that despite the age of the concrete lining of the Breede River (Robertson) Canal, it is visually in an excellent condition because of proper maintenance.

5.4 Seepage losses

During a visit to the study area, Dr P C M Reid and Mr D Davidson of the Department of Water Affairs inspected the canal visually, and during a cleaning operation (17 to 21 October 1986) a number of photographs were taken of the canal lining. After studying these photographs, Dr Reid and Mr Davidson stated that considering the actual measured seepage losses in canals of similar condition elsewhere, they would expect the seepage loss in the Breede River (Robertson) Canal to be 2 to 3 ℓ/s/1 000 m^2 of lining.

Dr Reid suggested that proper ponding tests be done, but the Board was reluctant to put the canal out of commission for a long period of time. This left no alternative other than indirect calculation of seepage losses.

In the table of data containing the canal flow rates and off-take flow rates (Appendix G), all the "inexplicable" losses were calculated from the known inflows and outflows for each of the two main sections of the canal - that is from Ott recorder no 1 (Ch 20) to Ott recorder no 2 (Ch 6450) and from Ott recorder no 2 to Ott recorder no 3 (Ch 12620).

These "inexplicable" losses can only consist of domestic off-take flows, evaporation, and seepage losses. Evaporation losses were calculated from the known surface area of the canal and A-pan evaporation. The calculation of seepage losses for the two sections of the canal is given in Table 4.

TABLE 4 - CALCULATION OF CANAL SEEPAGE LOSS

	SECTION 1	SECTION 2
Average "inexplicable" loss flow rate	89 ℓ/s	88 ℓ/s
Average flow depth	0,815 m	0,739 m
Wetted area of lining	28 619 m^2	24 940 m^2
Water surface area	18 106 m^2	15 476 m^2
Daily average nett evaporation	5,2 mm	5,2 mm
Rate of evaporation	1,09 ℓ/s	0,93 ℓ/s
Number of domestic off-takes	6	4
Domestic off-take flow rate	4,44 ℓ/s	2,96 ℓ/s
Seepage loss flow rate	83,47 ℓ/s	84,11 ℓ/s
Seepage loss/1000 m^2 of lining	2,92 ℓ/s	3,37 ℓ/s

The seepage loss for the two sections fit in with the relative condition of the two sections during the monitoring period. The weighed average seepage loss for the whole stretch of canal is 3,13 ℓ/s/1000 m^2 of lining. This means that from the 12,85 km of canal included in the Study Area some 14 530 m^3 is lost through seepage each day. This amounts to 37% of the volume abstracted by the farmers on the same stretch of canal during the irrigation season. In terms of the total volume of water transported in the canal, the seepage losses amount to approximately 14%.

5.5 Operation procedures

With the swing of irrigation methods from flood irrigation to the more sophisticated drip and microjet systems, the operation of a canal such as the Breede River (Robertson) Canal was also affected.

Before the advent of sophisticated irrigation systems, the canal was operated on a turn system by which each farm received a large volume of water for only a limited period of time on a weekly or fortnightly basis. During his turn, the farmer spread the water over the entire irrigated area by means of flooding. Minimal storage capacity was needed and then only to store water received during the night or a weekend.

As more and more farmers started installing drip and microjet systems, the operation of the canal also had to change. Each farmer now needed a permanent low volume water supply to suit the demand of his irrigation system. This finally led to an informal supply-on-demand system.

Each individual off-take is set (and locked) to deliver the full quota of water as a permanent stream. Dams serve the purpose of buffer storage-cum-sump units, and should a farmer not need any water for any period of time, he himself closes his off-take.

The resultant infinitely variable demand on the canal is met by the bailiff by diverting the maximum demand into the canal and on a daily basis rejecting any excess water at a number of specially built reject points back into the river. The bailiff's task is therefore reduced to a matter of maintaining as accurately as possible a preselected flow depth in all individual sections of canal once all the off-take openings have been set.

During any irrigation season, however, no record is kept of the volume diverted into the canal or the volume abstracted from it. No permanent recording facilities exist on the canal.

For the purposes of the study, flow recording was a necessity and the problem was overcome by installing Ott water level recorders on specially prepared sections of the canal. This proved to be highly satisfactory and can definitely be recommended as an alternative to Parshall flumes or similar control sections.

6. CANAL OFF-TAKES

6.1 General

On the 12 853 m of canal included in the study, there are 45 sluice off-takes, 10 domestic water pipes and 3 reject points. Of the 45 sluice off-takes, off-takes numbers 5, 6, 10, 11, and 13 are not in daily use any more. In fact, these 5 off-takes never discharged any water during the monitoring period.

All farm off-takes are of similar design and consist of a rectangular steel blade sliding into a vertical steel frame built into the canal wall. The handle shaft fixed to the blade passes between two horizontal members, and a system of holes in the shaft allow setting of the sluice opening in single millimeter increments.

The position and width of all off-takes are included in the table given in Appendix C.

6.2 Condition

Of the 40 sluice off-takes in constant use, 10 were found to be very badly corroded. This caused serious leakage and an unacceptably high degree of inaccuracy in the discharge flow rate. It was pointed out to the Irrigation Board that these off-takes would have to be replaced, and eventually the Board agreed to contribute half the cost of replacing the 10 off-takes with new ones constructed of 3 CR12 nickle-enriched steel.

The off-takes replaced with 3 CR12 were numbers, 3, 14, 20, 23, 24, 27, 30, 31, 34 and 43. Although corrosion of the remaining 30 off-takes constructed of mild steel will remain a problem, these were considered to be in a satisfactory condition for the purposes of the study.

In April 1986 the following prices for off-takes constructed of different materials were quoted:

a)	Mild Steel	:	R80-00 (frame and blade)
b)	3 CR12	:	R210-00 "
c)	304 VS	:	R300-00 "

The obvious success of the 3 CR12 type sluices has certainly convinced the bailiff that the extra cost is warranted and it is doubtful whether the Board will ever again revert to mild steel sluices.

6.3 Calibration

A sluice off-take operates as a rectangular orifice with the water jet confined on only one side. In some cases the off-take discharges freely and in others it is submerged.

A problem was caused by the fact that a typical sluice off-take, due to its construction, does not resemble an idealized orifice of the type for which discharge coefficients are readily available in literature. This led to the necessity of finding a value of the discharge coefficient, C_d by means of measurements. With a value of C_d available, the flow rate Q, through an off-take for a known canal flow-depth, h_s, and a known sluice opening, K, can be calculated with the well-known equation:

$$Q = C_d \ A\,(2gh)^{1/2} \qquad (m^3/s) \ldots\ldots (1)$$

with $A = K \times$ opening width, b

For the purpose of calibrating equation (1) a number of secondary weirs was constructed downstream of typical sluice off-takes. These were rectangular for which the following equation is applicable:

$$Q = \frac{2}{3}\ (2g)^{1/2}\ \ C.b.\ \ he^{3/2} \ldots\ldots (2) \qquad (11)$$

$$\text{and } C = 0{,}602 + 0{,}083\ ^{h/p}$$

$$he = h + 0{,}0012$$

with Q = flow rate (m^3/s)

b = width of weir (m)

h = depth of flow over weir crest (m)

p = height of weir (m)

It was therefore possible to determine the discharge flow rate for a typical off-take by using equation (2). Then with only C_d unknown in equation (1), it was possible to calculate values for C_d for a number of combinations of the canal flow depth, sluice opening, and tailwater-depth. From these values it was possible to obtain average values for C_d for :

a) Free flow : $C_d = 0{,}73$

b) Submerged flow : $C_d = 0{,}65$

The Irrigation Board only acknowledges free-flow sluices and the bailiff uses a setting chart which gives orifice opening height for required flow rate and so-called normal water depth. The factor used at present is of the order 0,67 and differs widely from the figure given above.

6.4 Leakage

Some of the off-takes were leaking visibly during the monitoring period, and since it was considered to be contributing significantly to the overall distribution losses, the leakage flow rate of each off-take was measured. It should however be pointed out that leakage from any off-take is not completely lost, but in all cases ends up in a farm dam.

A portable V-notch with overall dimensions suited to the typical off-take construction was obtained. The V-notch was installed directly downstream of each off-take, and the installation made completely watertight so that any leakage from the off-take had to pass over the V-notch. Then the sluice was moved about in the frame in order to induce the maximum possible leakage flow rate from that specific off-take. By measuring the depth of flow over the V-notch, it was possible to calculate the leakage flow rate for each individual off-take.

In Table 5 the measured leakages are listed. It is interesting to note that at a quota of 0,472 ℓ/s/ha as applied by the BRWCB, the 45 off-takes included in the study can potentially generate enough leakage to irrigate some 22 ha of land.

TABLE 5 - MAXIMUM INDUCED OFF-TAKE LEAKAGE FLOW RATES

Off-take Nr	Flow rate (ℓ/s)	Off-take Nr	Flow rate (ℓ/s)	Off-take Nr	Flow rate (ℓ/s)
1	-	16	1,070	31	0,088
2	0,215	17	-	32	0,014
3	0,215	18	-	33	0,052
4	0,253	19	-	34	0,363
5	0,273	20	0,233	35	0,008
6	0,136	21	1,167	36	0,593
7	0,136	22	1,789	37	-
8	0,215	23	0,111	38	-
9	-	24	0,045	39	-
10	-	25	0,014	40	-
11	-	26	-	41	0,442
12	-	27	0,032	42	0,442
13	-	28	0,415	43	0,078
14	0,198	29	0,697	44	0,593
15	0,215	30	0,165	45	-

TOTAL 10,267 ℓ/s
AVERAGE 0,228 ℓ/s

7. PUMP INSTALLATIONS

7.1 General

Although the BRWCB serves mainly as an "umbrella board" for all the lesser boards under its jurisdiction and as such has the primary function of taking care of matters of mutual interest to these lesser boards, it also acts as a normal irrigation board with an own scheduled area. This scheduled area is served by a number of privately owned pumps extracting water directly from the Breede River.

On the stretch of river adjacent to the study area there are three privately owned pump installations and the Klaasvoogds Irrigation Board pump station. The position of each is indicated on Figure 2.

7.2 Private pumps

The three privately owned pumps within the study area serve a total scheduled area of 213,9 ha. This is made up as given in Table 6.

TABLE 6 - AREA SERVED BY PRIVATE PUMPS

Pump No	Owner	Farm No	Scheduled Area (ha)
1	Bruwer , P	1	132,0
2	Bruwer, L B	2	70,7
3	Smuts Bros	18	11,2
		TOTAL	213,9 ha

The scheduled area served by pumps numbers 1 and 2 originate from a re-allocation of rateable area from the now abandoned Hanf furrow to the BRWCB. The so-called Hanf furrow was an unlined furrow which diverted water from the Breede River at a point approximately 1 km upstream of the Robertson-McGregor bridge to the so-called islands area. These "islands" extend from the Robertson McGregor bridge to approximately 2 km upstream of the Angora Canal diversion weir. (1)

The furrow passed through the typical sandy island soils, and maintenance proved to be very difficult especially because of periodical flooding by the Breede River. Eventually an unusually high flood rendered the furrow irreparable and the owners of land served by the furrow applied for re-allocation of their scheduled area to the BRWCB. Ministerial approval was granted and the owners were allowed to pump the quantity of water previously diverted by the Hanf furrow directly from the Breede River.

With the construction of the Brandvlei Dam it was possible to reschedule the riparian properties in the Breede River Valley. The irrigation boards which existed at the time revised their scheduled areas and properties which aquired additional water rights had to pay the appropiate rates to the different irrigation boards. There were however owners who for various reasons could not shoulder the increased tax burden until much later.

When the different boards started lining their canals, each canal capacity was based on the rateable area of each board that existed at that time. When those owners who had not taken up their maximum water right gained the means to do so, they could no longer be accommodated by the different boards. Therefore they had to apply to the BRWCB for permission to install pumps on the River in order to utilize their water rights. Pump number 3 is an example of these pumps.

The BRWCB is responsible for the administration and control of all privately owned pumps on the Breede River, and makes use of the bailiffs of the lesser irrigation boards to take weekly readings of the water meters which are compulsory on all pump installations.

7.3 Klaasvoogds Irrigation Board pump

The Klaasvoogds Irrigation Board is one of five boards which supplement their water supply from relatively small mountain streams by pumping water from the Breede River.

During a dry period preceding 1970 the Klein Klaasvoogds and Groot Klaasvoogds Irrigation Boards applied to the DWA for additional water from the Brandvlei Dam. The two boards amalgamated and in 1975 White Paper WPQ-'75 was tabled in Parliament to obtain funding for the proposed pump scheme of the Klaasvoogds Irrigation Board. The pump scheme was designed to deliver additional water for 559 ha of land at a quota of 0,252 ℓ/s/ha to the Klaasvoogds Irrigation District. The scheme was commissioned in 1977.

Of the farms included in the study area, farms numbers 11, 16 and 20 are included in the districts of both the Breede River (Robertson) and Klaasvoogds Irrigation Boards. This means that these three farms are each scheduled under three different water sources as given in Table 7.

TABLE 7 - SCHEDULED AREAS OF FARMS 11, 16 & 20

Farm	Owner	BR(R)IB (ha)	KVIB		Total
			Original (ha)	Additional (ha)	(ha)
11	Van Deventer, W A	5,1	6,6	13,7	25,4
16	Kriel, S T	2,6	15,9	19,6	38,1
20	Burger, J M	18,4	48,2	31,5	98,1
				Total	161,6

Because of certain domestic problems experienced by the Klaasvoogds Irrigation Board, the exact quantity of water received by any farm in the district over any period of time is unknown. However, taxes are levied based on the financial responsibilities of the Board, one of which is the tax payable for water extracted from the Breede River and which is metered at the pump station.

8. FARM DAMS

8.1 Characterisation of dams

Some 42 dams have been included in the study area. The position pof each of these is indicated on Figure 2. It should be noted that for modelling purposes dams number 24, 31, 40, 41 and 42 have been ignored. This results from the exclusion of farm numbers 9, 11, 12, 14, 16, and 20.

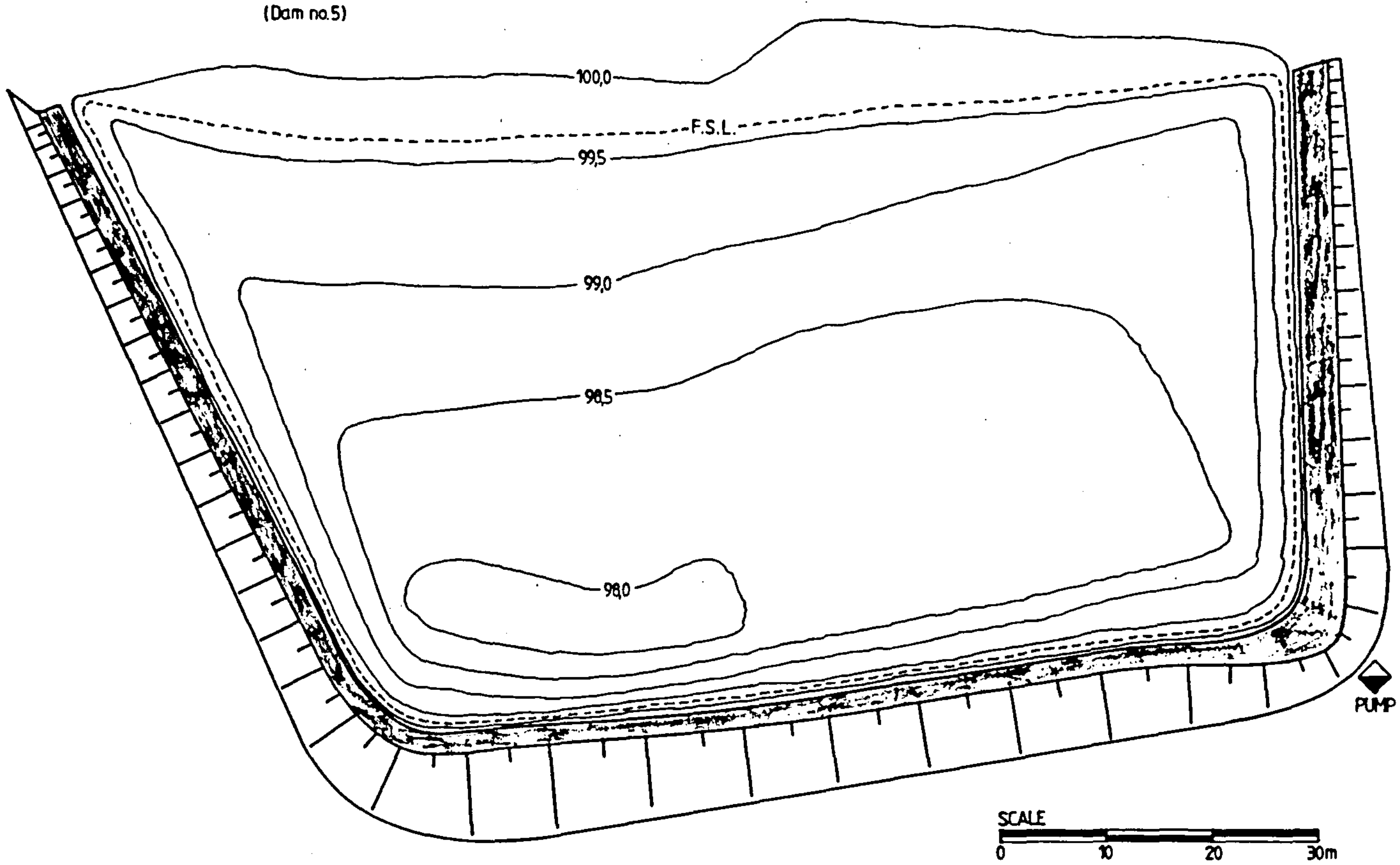
For the purpose of the study each dam has been surveyed in detail - in most cases by using an inflatable vessel and a plumb bob to survey the submerged part of the basin. From the survey a contour plan (see Fig 6(a)) has been drawn to a suitable scale.

From the contour plan the surface area corresponding to different water depths has been determined using a planimeter. Simpson's volume rule was used in a computer routine to calculate the storage volume for different water depths (see Fig 6(c)). From this information it was possible to draw curves representing the depth volume and depth surface area relationships of each dam (see Fig 6(b)). The complete set of curves for the 42 dams is given in Appendix D.

In Table 8 below the full supply capacity and maximum surface area of each dam is listed.

FIGURE 6 - CHARACTERISATION OF FARM DAMS

(a) Contour plan
(Dam no.5)



(c) Compilation data

CONTOUR (m)	WATER DEPTH (m)	AREA (ha)	VOLUME (m^3)
97,5	0	0	0
98,0	0,5	0,023	340
98,5	1,0	0,213	1000
99,0	1,5	0,365	2070
99,5	2,0	0,500	3800
100,0	2,5	0,613	7030

(b) Depth-volume & depth-surface area relationships

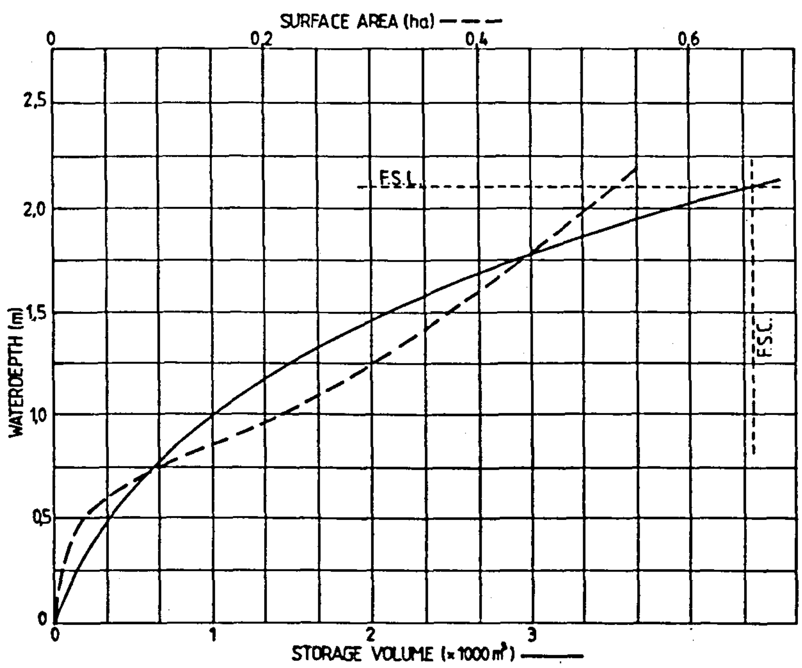


TABLE 8 - FARM DAM CAPACITIES AND SURFACE AREAS

Dam No	Full Supply Capacity (m^3)	Surface Area (ha)	Dam No	Full Supply Capacity (m^3)	Surface Area (ha)
1	12 000	0,82	22	7 050	0,65
2	11 800	1,15	23	6 200	0,68
3	11 145	0,68	24*	2 600	0,25
4	13 750	0,68	25	7 620	0,49
5	4 400	0,53	26	11 500	0,77
6	11 400	0,95	27	7 530	0,46
7	11 800	0,67	28	17 150	0,97
8	1 620	0,06	29	5 500	0,50
9	2 270	0,29	30	222 000	5,80
10	6 800	0,70	31*	193 100	5,30
11	570	0,07	32	3 330	0,29
12	105 000	5,00	33	2 400	0,17
13	1 460	0,15	34	2 400	0,37
14	4 730	0,26	35	3 500	0,38
15	1 750	0,17	36	2 880	0,25
16	3 200	0,43	37	250	0,02
17	6 300	0,28	38	3 880	0,63
18	15 400	0,62	39	2 600	0,29
19	4 320	0,28	40*	30 000	1,20
20	4 800	0,45	41*	31 550	1,23
21	13 000	0,77	42*	65 000	2,70
			TOTAL	875 555	**38,41**

*Excluded from mass balance modelling.

As noted above dams numbers 24, 31, 40, 41, and 42 have been excluded from the mass balance modelling of the study area, leaving a total storage capacity of 553 305 m^3 and a maximum surface area of 27,73 ha. Of these, dams numbers 12 and 30 alone contribute 327 000 m^3 of storage and 10,8 ha of surface area.

For the unified storage dam considered for modelling purposes, a storage capacity to surface area ratio of 1 m^3 to 1,995 m^2 is calculated. This shows that despite the fact that approximately 60% of the storage capacity is contributed by two single large dams, the unified storage dam is still relatively shallow with a large surface area and a large wetted surface area making for significant evaporation and seepage losses.

It should also be pointed out that with the exeption of dams numbers 12, 30, 31 and 42, the rest of the dams were most probably built by means of ox or horse drawn scoops. Most of these dams are nothing more than shallow holes in the ground, and in many cases the sub-soil is permeable.

8.2 Seepage losses

As mentioned above, the construction of many of the dams in the study area is of dubious quality. Since most of these dams are very old, well-defined flow paths contributing to seepage losses have probably had time to develop.

During the period August 19 to September 15 1986, a number of dams was monitored while very little irrigation had taken place. Therefore it was possible to isolate certain dams which had no inflows and no outflows other than seepage losses for a number of days during the above-mentioned period. By taking into account evaporation and precipitation, it was possible to calculate the average daily seepage loss for each of these dams.

In the table given in Appendix E, the following calculation procedure has been adopted:-

a) The storage volume (m^3) and surface area (ha) was derived from the daily stage reading.

b) The nett evaporation (m^3) for day n was calculated as:

$$\text{Nett Evap}_{(n)} = (\text{Evap}_{(n-1)} - \text{Rain}) \times \text{Area} \times 10$$

c) The volume difference (m^3) for day n was calculated as:

$$\text{Vol diff}_{(n)} = \text{Volume}_{(n)} - \text{Volume}_{(n-1)}$$

A negative value will indicate an outflow or a loss, and a positive value an inflow.

d) The percentage loss for a day n was calculated as:

$$\%\text{Loss}_{(n)} = \text{Loss}_{(n)}/\text{Volume}_{(n-1)} \times 100$$

With the above-mentioned calculations performed by a simple computer routine, explicable inflows, (INF) and outflows (OUTF) were indicated as such. The "unexplained" losses were taken to be seepage losses.

For each dam (numbers 1-7 and 9-37) an average daily loss percentage and the associated average volume is given in Appendix E. These loss percentages vary from an acceptable 0,14% to an alarming 2,87%. This wide variation must be seen against the differences in age, construction method and founding materials.

For the unified total storage dam including dams 1-7 and 9-37, the weighed average daily loss percentage of 0,5977% for an associated volume of 588 956 m^3 or 79,5% of full supply capacity was calculated.

During the 200 day irrigation season (16 September 1986 to 3 April 1987) used for modelling purposes, the average daily storage volume was 269 271 m^3. This means that some 1 609 m^3 of water is lost through seepage per day, or during a 200 day irrigation season the seepage loss amounts to 321 887 m^3. In comparison the evaporation loss for the same dams during the same period was 288 806 m^3.

9. ON-FARM DISTRIBUTION

9.1 General

On-farm distribution of irrigation water consists of two main facets: the distribution method and the programme or schedule of water distribution. Both have a direct influence on the efficiency of irrigation water usage - the irrigation method in terms of efficient spatial distribution and the schedule in terms of efficient timing and quantity of irrigations.

From a managerial point of view it is important to maximize irrigation water-use efficiency. Serious droughts are experienced periodically throughout the country and as a result the decision makers of our day appeal to every individual, and the irrigation farmer in particular, to conserve water.

The farmer, however, has to deal with his own set of problems. His main objective is to generate the maximum profit on his own unique piece of land, and labour costs and capital expenditure are two of the more important denominators when he calculates the profit made in any given year. It is ironical then that although irrigation water is probably the single most important production resource, in all the irrigation districts served by canals from the Breede River, the cost of water is really insignificant compared to total production costs. This would seem to tempt the farmer to choose the irrigation method and schedule which would minimize capital expenditure and labour costs with no heed to efficient water usage.

A certain degree of restraint is exercised by the quota of water allocated to each scheduled hectare. These quotas, however, are at best only vaguely adhered to with none of the diversion volumes of any Robertson Canal Irrigation Board recorded in any way.

Another alleviating factor is the fact that many of the farms along the Breede River are not yet fully developed. This compels the farmer to use water sparingly on existing irrigated land in order to be able to expand his irrigated area while receiving the same volume of water.

A further move in the right direction came when farmers realized that over-irrigation on poorly drained soils caused salination of these previously productive soils.

Whatever the reasons, the farmers in the study area possess irrigation systems ranging from flooding to high-tech computerized drip systems, with scheduling skills ranging from "I-do-what-Grandpa-did" to "I-do-what-the-extension-service-tells-me-to".

9.2 Irrigation methods

TABLE 9 - IRRIGATION METHOD VERSUS CROP DISTRIBUTION

	Mechanical	Sprinkler	Micro	Drip	Flood	Dry Land	Total (ha)
Vines	-	135,1	82,3	471,5	5,8	-	694,7
Peaches	-	1,5	3,8	33,7	23,0	-	62,0
Apricots	-	3,6	9,5	54,2	2,5	-	69,8
Lucerne	7,9	73,3	-	-	-	-	81,2
Grazing	-	66,5	-	-	8,8	-	75,3
Grain	-	21,6	-	-	-	-	21,6
Maize	25,8	-	-	-	-	-	25,8
Tomatoes	-	0,6	-	29,5	-	-	30,1
Nursery	-	3,1	0,2	-	-	-	3,3
Fallow	-	-	-	-	-	(10,7)	(10,7)
TOTAL (ha)	33,7	305,3	95,8	588,4	40,1	(10,7)	1063,8

Table 9 represents the irrigation method versus crop distribution pattern used in the mass balance modelling. These figures apply to the study area excluding farms numbers 9, 11, 12, 14, 16 and 20, and therefore represent the irrigation found on land with a total extent of 1 709,45 ha and a scheduled area of 1 111,60 ha.

It is noteworthy that flood irrigation is practised on only 3,8% of the irrigated area, while drip irrigation is found on 55,3% of the irrigated area. It was also found that as much as 90% of all drip and micro systems are fitted with electronic control systems of a varying degree of sophistication. The proliferation of automated irrigation systems should be seen against the fact that the peak irrigation season coincides with the busiest time of year on an irrigation farm in the Breede River Valley. Thus automated systems are installed to reduce the stress on the managerial skills of the farmer.

9.3 Scheduling and application

Interviews with the farmers indicated that not a single tensiometer or evaporation pan is used in the study area to schedule irrigation and of all the sophisticated irrigation control systems mentioned above, not one makes use of agro-meteorological observations.

From interviews conducted with all the farmers in the study area it emerged that they could be divided into three categories:

a) Those who do no follow any pattern of irrigation but irrigate when they feel it is necessary. These farmers apparently take into account the occurrence of precipitation and dry, hot spells, but unfortunately not in any scientific way.

b) Those who have three irrigation schedules:

    i) a early season schedule
    ii) a peak season schedule, and
    iii) a post-harvest schedule.

The exact period for which each schedule is applied differs from year to year depending on the occurrence of precipitation and dry, hot spells as well as the crop growth stage.

c) Those who almost blindly adhere to a single irrigation schedule regardless of agro-meteorological factors or the time of season. These farmers make only two decisions regarding irrigation each season, and that is when to start and when to stop irrigating. For the 1986/1987 irrigation season, irrigation started on 16 September 1986 and stopped on 24 April 1987 when the canal water supply was stopped for maintenance purposes.

The farmers involved in the study were requested to keep a detailed record of irrigation during the 1986/1987 season, and the information subsequently received is given in Appendix F. A cursory glance at this record shows to which of the above-mentioned categories each farmer belongs. It also shows for which individual blocks of land irrigation scheduling is done on a volumetric basis or on a time basis. These two methods of scheduling result from the two basic control systems available with most fully automatic systems working on a time basis and semi-automatic systems working on a volumetric basis.

During any irrigation season a farmer has to make do with the total volume of water at his disposal. This consists of water stored during the winter months if any and water received during the irrigation season. In determining an application rate, he also has to take into account the portion of his scheduled area he actually irrigates.

For the 200 day irrigation season considered for modelling purposes a total volume of 8 232 494 m^3 was applied to 1063,8 ha of land. This volume excludes distribution and storage losses but includes secondary losses on the farm. A general application rate of 3,87 mm/day is calculated from the above-mentioned figures.

Table 10 gives the application rates observed for 1063,8 ha of land on a monthly basis during the monitoring period.

TABLE 10 - MONTHLY VARIATION IN APPLICATION RATES

PERIOD	VOLUME APPLIED (m^3)	APPLICATION RATE (mm/day)
16-30 September 1986	129 417	0,8
October 1986	900 853	2,7
November 1986	1 257 359	3,9
December 1986	1 595 996	4,8
January 1987	1 604 605	4,9
February 1987	1 314 455	4,4
March 1987	1 419 327	4,3
1-3 April 1987	115 989	3,6

Table 11 is a comparison of observed application rates and crop water requirements as calculated with a weighed average crop factor from A-pan evaporation. (8)

TABLE 11 - APPLICATION RATE VERSUS CROP WATER REQUIREMENTS

Month	Average Daily Nett Evaporation (mm/day)	Weighed Average Crop Factor	Crop Water Requirement (mm/month)	Application Rate (mm/month)
September	3,34	0,27	27,5	24,3
October	4,27	0,37	47,3	82,0
November	6,54	0,46	90,2	118,2
December	9,33	0,55	153,1	145,2
January	8,87	0,57	151,4	146,0
February	8,47	0,56	143,3	132,4
March	5,85	0,44	77,6	129,1
April	0,58	0,24	4,1	109,0

Table 11 verifies the assumption that farmers in the Breede River Valley tend to over-irrigate towards the beginning and end of the irrigation season and under-irrigate during the peak season. This tendency must be attributed to the fact that very little storage facilities exist on most farms and that water is supplied at a continuous, constant flow rate. On the other hand the farmers cannot be accused of over-irrigation before the actual leaching requirements of the combination of soils and water at their disposal have been quantified.

9.4 Trends

The younger generation of farmers are generally better qualified than their forebears with progressively more aspiring young farmers attending universities and agricultural colleges. As they have a sound scientific background, these young farmers tend to be more susceptible to "new" ideas, and therefore they are more willing to experiment with various aspects of farming - including irrigation scheduling. At the same time irrigation methods and systems are steadily becoming more sophisticated - each year new electronic control systems and gadgetry appear on the market.

These two factors have the effect of a steady increase in irrigation efficiency. Although this process appears to be a slow one, it should be possible to speed up the progress with proper guidance from the Agricultural Extension Service. It should however be noted that with agriculture rapidly becoming more business orientated, an emphasis on the financial benefits of correct irrigation scheduling would help to get more farmers interested.

In the study area it is predicted that flooding as an irrigation method will disappear within the next 5 to 10 years. Even sprinkler systems on vines and deciduous fruit seem to be diminishing in importance, while drip and micro systems are still growing in popularity.

10. DOMESTIC AND INDUSTRIAL WATER USE

10.1 Regulations

As mentioned in Chapter 4, there are no water sources of acceptable quality other than that supplied by the Breede River (Robertson) Canal in the study area. This includes water for domestic use and water used in privately owned estate wineries.

The by-laws of the Breede River (Robertson) Irrigation Board make provision for the abstraction of domestic water from the canal. One outlet per farm is allowed. These outlets consist of a short length of pipe of 1 inch in diameter protruding through the wall of the canal at a height of 300 mm above the canal invert level. Water is delivered into an open concrete lined sump from which it can be pumped into storage tanks or reservoirs.

Water needed for cleansing purposes in an estate winery has to be provided by the farmer from his normal supply of irrigation water.

10.2 Domestic use

As mentioned in Chapter 6 only 10 domestic water off-takes are found in the study area despite the fact there are 25 farms. The 15 farms which do not exercise their domestic water rights, abstract water for domestic purposes from farm dams.

It is calculated from recorded canal water depths that it is theoretically possible to abstract 64 m^3 of water per day from a domestic off-take. This would in most cases make continuous pumping necessary and therefore it is seriously doubted if nearly as much water as indicated above would ever be abstracted. In any case the total volume of water that can be discharged from 10 small diameter outlets is really negligible in comparison to the volumes moving through the study area.

All sewage and domestic waste water is disposed of by means of septic tanks and french drains.

10.3 Estate wineries

A recent project in which the water supply to a co-operative winery in the Robertson district was investigated, revealed that for cleansing purposes a winery needs approximately 600 ℓ of water on average for every ton of grapes processed. However the tonnage of grapes processed by each of the four estate wineries in the study area is a closely guarded secret, and none of these wineries keep any record of the volume of water used. (12)

All these relatively small wineries had to apply to the DWA for exemption from water pollution control regulations. Permits have been obtained exempting these wineries from the purification standards generally applicable and permission has been granted to use waste water for irrigation of pastures. This causes water that has been released from farm dams for use in wineries to reappear as irrigation water. Waste water from wineries can be expected to contain a large quantity of sulphates, phosphates and tartaric acid, but it is doubted if such water would show a marked increase in the sodium and chloride content.

In conclusion it can be said that the presence of wineries has a negligible impact on the overall salt and water mass balance in the study area.

11. DRAINS

11.1 General

Although the monitoring of drains had not been included in the original project proposal, Mr S F Forster requested the research team to include such drains as were easily accessible into the daily monitoring routine. The intention was to obtain at least some control data with which to check the return flow volumes calculated by the mass balance modelling.

11.2 Choice of monitoring points

Most of the drains in the study area discharge directly into the Breede River, and most of them are constructed of a layer of filter material surrounding a perforated pipe. The points of discharge of these pipes are generally not very easily accessible and all are situated well off the route used during the monitoring effort.

The position of four open drains in which control sections could be constructed and which were easily accessible are indicated in Figure 2.

11.3 Problems encountered

The control sections constructed for monitoring purposes in the four drains consisted of a masonry weir with a mild steel V-notch let into it.

These V-notches caused a considerable rise in upstream water levels and in two cases silting behind the weir threatened to cover the outlets of sub-drains discharging into the open drain.

Drain no 1 was abandoned after it was realized that only a fraction of the actual drainage volume was being measured. This was because it was inordinately expensive to construct a proper cut-off blanket underneath the masonry weir at the actual monitoring point chosen.

Drain no 2 was abandoned when on closer examination it was found to be exclusively draining seepage from Dam no 18.

Drains no's 3 and 4 were abandoned after repeated protests by the affected farmers about the silting behind the weirs.

The problem was discussed with Mr Forster who visited the study area at the time, and he tried to obtain a number of small prefabricated Parshall flumes to install at new monitoring sites. He did not succeed in obtaining these flumes in time, and all monitoring of drains was abandoned with no useful data collected.

12. WATER AND SALT MASS BALANCE

12.1 General

A detailed discussion of the water and salt mass balance calculation, including a description of the IRRISS model, is given in Section C of this report. In this chapter a brief discussion of the results derived from the mass balance modelling is presented.

12.2 Water and salt intake of the scheme

In this study a 200 day irrigation season, starting on 16 September 1986 and ending on 30 April 1987, was investigated. It is calculated that during this period the total scheme water intake amounted to 13 663 000 m^3 with a total salt intake of 1 728 000 kg.

Of the total scheme intake, the Breede River (Robertson) Canal delivered 90,44% of the water and 90,92% of the salt.

12.3 Seepage losses

While evaporation losses from both the canal and farm dams are negligible (less than 1% of the total scheme intake), canal and farm dam seepage losses are more than expected.

Canal seepage losses amount to 3 200 000 m^3 of water with an associated salt load of 463 000 kg. Farm dam seepage losses are calculated to be 455 000 m^3 of water with a salt load of 65 509 kg. These two sources of seepage loss accounts for 26,75 % of the total scheme water intake whilst a further 9,7% can be attributed to canal rejects and evaporation.

12.4 Water management efficiency

The overall water management efficiency in terms of the volume of water applied to the crops versus the total volume of water available for irrigation, is calculated to be 63,61%. This means that some 36,4% of the water intake to the scheme is lost before it reaches the edge of the field.

12.5 Returnflows

It is calculated that the irrigated area of 1 063,8 ha of land generates a returnflow of 1 541 000 m^3 with an associated salt load of 4 595 180 kg. This represents a returnflow salinity of 2 982 mg/ℓ.

The returnflow from the total scheme (as opposed to the irrigated soil) is found to be 5 196 000 m^3 with an associated salt load of 6 179 339 kg - a returnflow salinity of 1 189 mg/ℓ TDS.

In conclusion is can be pointed out that although the return loads calculated in the water and salt mass balance modelling are heavily dependant on a number of operator controlled or calibration parameters, the returnflow salinities are of the same order as those expected. Calibration is necessitated by the unknown flowpath and interaction with groundwater bodies.

13. CONCLUSIONS AND RECOMMENDATIONS

13.1 Conclusions

This study was primarily a feasibility study on the detail monitoring and subsequent calculation of a water and salt mass balance for an irrigation district. The study has clearly shown that it is practically possible to monitor the movement of water and salts through an irrigation district. It has also proven that the IRRISS model can be used to simulate an irrigation district and calculate return flows and return loads that can be expected to be generated by such districts.

These two primary conclusions derived from the study do have a number of secondary implications. It is a generally acknowledged fact that in terms of salination, the most serious problem occurs on the section of Breede River between the Le Chasseur weir (H4M17) and the Zanddrift weir. In this section, saline return flows are contributed by irrigation occuring along tributaries and irrigation on farms that are riparian to the Breede River.

Return flows from "tributary irrigation" can be measured as is presently being done for the Poesjenels River and Cogmanskloof River. Irrigation return flows from riparian land however, is not so easy to determine. Return flow from land adjacent to the main river channel does not necessarily follow distinct flow paths. Therefore it is in all probability more practical to calculate these return flows from known irrigation water inputs. This leads to the conclusion that by using the IRRISS model, it is now feasible to determine the extent to which predefined irrigated areas contribute to the salination of the problem section of river.

Having said that it is feasible to monitor water and salt movement through a preselected irrigation district, the cost of such monitoring work should also be addressed. Inflation rates being what they are, it is more meaningful to reflect the costs of this study in terms of manhours.

Project planning, preparatory research, and project guidance including attendance of Steering Committee Meetings accounted for the following:

a)	Project Leader	:	260 manhours
b)	Principal Researcher	:	400 manhours
c)	Project Engineer	:	260 manhours
d)	Travel expenses	:	4 000 km

The detail survey and preparation of the 12,8 km section of canal accounted for:

a)	Principal Researcher	:	10 manhours
b)	Project Engineer	:	210 manhours
c)	Technician	:	370 manhours
d)	Technical Assistant	:	250 manhours
e)	Travel expenses	:	1 900 km

The detail survey, characterization and preparation of 42 farm dams had the following cost implications:

a)	Project Engineer	:	10 manhours
b)	Technician	:	500 manhours
c)	Technical Assistant	:	340 manhours
d)	Travel expenses	:	600 km

Detail mapping and description of the study area including the land use and irrigation type description based on orthophoto maps, aerial photographs and farmer interviews for a total area of 2 081 ha of which 1 240,9 ha is irrigated, accounted for the following:

a)	Principal Researcher	:	10 manhours
b)	Project Engineer	:	580 manhours
c)	Technician	:	10 manhours
d)	Travel expenses	:	2 700 km

Daily monitoring of canal inflows and outflows which include 45 farm off-takes, and farm dam stage readings for 42 dams for a period from 6 August 1986 to 24 April 1987 accounted for:

a)	Project Engineer	:	150 manhours
b)	Technician	:	1 200 manhours
c)	Travel expenses	:	14 000 km

The processing of data and report production accounted for:

a)	Project Leader	:	10 manhours
b)	Principal Researcher	:	10 manhours
c)	Project Engineer	:	850 manhours
d)	Technician	:	1 090 manhours

Non-recoverable capital expenditure on this study amounted to approximately R12 000 in June 1986 prices.

From the above-mentioned figures it is clearly evident that the study was relatively expensive, but the possibility of limiting the cost of follow-up studies will be discussed under the recommendations.

As far as the water and salt mass balance for the study area is concerned, it is calculated that from a total scheme water intake of $13{,}7 \times 10^6\ m^3$ during a 200 day irrigation season, a return flow of $5{,}2 \times 10^6\ m^3$ with a salt load of $6{,}2 \times 10^6$ kg was generated. This amounts to a returnflow of 0,3 $m^3/s$with a salinity of 1 200 mg/ℓ from an irrigated area of 1 064 ha. If these figures are extrapolated to the rateable areas of the Le Chasseur-Goree, Breede River (Robertson), Angora and Zanddrift irrigation districts, a potential return flow of 3,2 m^3/s with a salinity of 1 200 mg/ℓ is calculated.

13.2 Recommendations

It is recommended that the methodology derived from this study be extended to at least the remainder of the section of the Breede River between Brandvlei Dam and Zanddrift. In doing so it would be possible to identify those parts of riparian irrigated land which generate most of the return flow and salt which threatens the continued use of the river as an irrigation water channel.

There are however a number of recommendations on how the extention of the study could be made more cost-effective and more accurate.

a) It should be attempted to conduct proper ponding tests on all the major irrigation canals in the Breede River Valley. With properly verified seepage loss rates available for each canal or section of canal, it would be possible to limit the amount of daily monitoring necessary.

b) Flow depth recording stations should be constructed at intelligently chosen points on each of the canals. With proper calibration of these stations it would be possible to determine the volume of water abstracted from each section of canal. This is however another motivation for the absolute necessity of determining canal seepage loss rates.

c) Land use maps should be prepared for each of the preselected sub-districts. These maps should preferably be on a scale of 1:10 000. This choice of scale was found to be small enough not to make the maps too bulky, but still large enough to ensure a high degree of accuracy. It was also found to be very handy to be able to refer to orthophoto maps of the same scale during farmer interviews.

d) A round of farmer interviews should be conducted in each of the sub-districts that are to be simulated. From properly conducted interviews a large amount of information can be gathered. This includes:

(i) Verification of land use information
(ii) Irrigation type distribution
(iii) Irrigation scheduling
(iv) Irrigation emittor densities
(v) Gypsum application rates

e) A method should be developed to estimate or measure dam volumes. For the purposes of monitoring and simulating water and salt movement through an irrigation district, it is important to determine the initial and final storage volumes. It should be possible to categorize farm dams and by only surveying the full supply surface area and depth, to determine the storage capacity fairly accurately without doing a detailed survey.

f) For this study a daily time step was used. Irrigation scheduling however tends to be managed in weeks. Thus it should be possible to alter the IRRISS model to conform to a weekly timestep without influencing the accuracy of the results. This would lead to a dramatic saving on the monitoring costs.

g) Although this report was not meant as a platform from which to critize the IRRISS model, a number of improvements can be suggested.

At present IRRISS handles irrigation scheduling in terms of "days on" and "days off". This should rather be changed to a percentage of time on or off. If a farmer irrigates for one hour each day of the week, it is a misrepresentation to describe his irrigation schedule as "7 days on" and "0 days off".

IRRISS also limits the user to only one soil type choice per water source. This is felt to be a gross over-generalization.

From the above-mentioned recommendations it is evident that with a few changes to the methods employed in this study, the water and salt mass balance modelling could, and should, be extended to the rest of the irrigated areas along the Breede River. If such a project is launched the problem of verification of canal seepage loss rate would have to be solved. Then canal flow rate monitoring points would have to be constructed at such points that the entire irrigated area could be divided into logical geophysical units. With land use maps prepared for each unit, a round of farmer interviews could be conducted to obtain and verify data needed to characterize each modelling unit. Monitoring canal inflows and outflows for each unit would make simulation of the water and salt movement through each unit or sub-district possible and better than - estimated values of return flows and return loads would be obtained.

B METHODS EMPLOYED

14. LAND-USE COMPILATION METHODS

14.1 Topographical maps

For the purpose of obtaining accurate information on land-use for this study, the 1:50 000 topographical maps available from the Government Printer proved to be completely inadequate. Both the small scale and the time lapsed between the survey and printing of these maps make any land-use information presented on the maps too inaccurate and out-dated to be of any use.

14.2 Orthophoto maps

Orthophoto maps on a 1:10 000 scale were found to be invaluable in the compilation of land-use information for the study area.

Although the aerial photography of the maps presently available was done during 1978, the basic layout of farms in respect of access roads and the boundaries of individual fields was found to have changed very little with time. Thus it was possible to base the land-use maps drawn for the purposes of this study on 1:10 000 ortophoto maps.

The areas of individual fields as given in Appendix B were taken from the land-use maps by means of a manual electronic planimeter. When checked by the HRI using an electronic digitizer, these figures proved to be highly accurate with the manually determined areas being the average of areas including and excluding line thicknesses determined on the digitizer.

The time lapsed since the aerial surveys on which the orthophoto maps are based made it impossible to determine crop types for each field from these maps. Since the life expectancy of vineyards and orchards is approximately 20 to 30 years, a renewal rate of up to 5% can be expected, leading to a substantial change in cropping patterns over any period of time. This is compounded by the fact that generally vineyards are substituted by orchards and <u>vice versa</u>.

14.3 Aerial photography

With the proclamation of the Greater Brandvlei Government Water Control Area, an aerial survey was done for the DWA on 26 February 1986. A set of photographs from this survey on a 1:20 000 scale was obtained from the DWA.

These photographs proved to be invaluable in determining crop types since they are the most up-to-date survey available which covers the study area. Only minor problems were experienced in identifying crops, mainly with cash crops or newly planted vineyards or orchards.

14.4 Farmer interviews

A round of interviews with all the farmers in the study area was conducted to verify and correct the crop type information compiled from the orthophoto maps and aerial photographs.

The only problem experienced with farmer interviews was that they proved to be extremely time-consuming. However, the time was well spent since the interviews ensured both the interest and co-operation of the farmers in the study.

14.5 Actual surveys

The Robertson office of MBB has access to a fair amount of actual small scale surveys previously done for clients in the study area. These were used as a random check on the areas determined in the land-use characterisation. The areas determined from orthophoto maps proved to be consistently accurate.

Actual surveys, though useful for the purposes of this study, are far too time-consuming and expensive to be of any use in future projects of similar scope and nature. It should however be noted that generally farmers do have at their disposal copies of small scale surveys done for the design of almost all irrigation systems. In future projects attempts could be made to obtain copies of these from the farmers involved, thus obviating the need for doing any small scale survey.

14.6 Satellite images

Although the research team did not have any access to satellite image compilation methods, land-use information compiled for this study was supplied to the HRI for the purpose of calibrating compilation methods based on LANDSAT images. Subsequent conversations with technicians from the HRI doing additional field surveys for this calibration effort led to the following observations:

a) LANDSAT is very useful in determining the total area under irrigation.

b) With the 80 x 80 m resolution of LANDSAT a degree of inaccuracy of the land-use information will be experienced when used in a landscape covered in a patchwork of small, irregularly shaped fields typical of the Breede River Valley.

c) Crop growth stages as affected by the age of the crop and the season is of critical importance in determining accurate cropping patterns.

d) Care has to be taken to avoid inaccuracies caused by mistaking areas of natural vegetation such as reeds along river banks for irrigated crops.

15. CANAL FLOW MEASURING

15.1 Methods investigated

The objective of this study was mainly to quantify the volumes of water and associated salt loads moving through a typical irrigation district. This made accurate measuring of canal flow rates of vital importance. No permanent means of recording flow rates exist anywhere on the Breede River (Robertson) Canal.

The stretch of canal found in the study area is characterised by very low gradients and under normal operating conditions only minimal free board - in places less than 100 mm - is available. This immediately ruled out the possibility of using any form of weir as a control section. The possibility of using a long weir was ruled out by the sheer size and cost of the structure needed for the flow rates and free board involved.

Parshall flumes as a means of flow measuring were thoroughly investigated. Because a high degree of submergence was inevitable as a result of the sub-critical nature of canal flow, only standard sizes of Parshall flumes with empirically determined flow tables could be considered. None of these proved to be suitable as the smaller sizes caused too much of a rise in water levels and the larger sizes operated at more than 95% of submergence.

It was finally decided to abandon all attempts to find a standard control structure suitable to the specific circumstances.

15.2 Method adopted

In order to record canal flow rates, three sections on the canal in the study area were specially prepared. During the annual maintenance period at each of the positions indicated on Figure 2 a section of canal 6,0 m long was shaped to an accurate rectangular cross-section. In the middle of each of these sections an Ott water level recorder was installed.

During the monitoring period a number of calibration measurements for different flow-depths were done by the field technician of the HRI using an electronic Mash-McBerney flow speed recorder. From the calibration measurements it was possible to determine an equation relating flow rate to the flow depth. Thus it was possible to calculate the daily average flow rate from the flow depths recorded by the Ott recorders.

15.3 Problems encountered

The success of any calibration effort of the kind described above lies in obtaining measurements over the whole range of values that are likely to occur. This is necessary to ensure that as little use as possible is made of extrapolation. The calibration process also has to take place under circumstances representing the situation to be monitored as closely as possible.

These two factors caused a minor problem because the growth of algae and the collection of mud and all kinds of rubbish on the canal floor tend to make the canal roughness a variable. Thus the calibration measurements had to be taken during the actual monitoring period. Unfortunately the flow depths in the canal could not be randomly varied to obtain a full range of measurements because the monitoring period coincided with the peak irrigation season.

During the monitoring period the water level in the canal had to be closely watched, and whenever a water-depth range not previously experienced occurred, the calibration measurements for that depth range had to be taken. Owing to other responsibilities the field technician of the HRI was not always available to take these measurements.

Despite this problem, a range of measurements representing the normal flow depths found in the canal was obtained and the flow measurements could be successfully calibrated.

The equations of the rating curves used were :-

a) **Ott recorder nr 1:**

$$Q = 2{,}091.d.\left(\frac{2{,}9.d}{2{,}9 + 2d}\right)^{2/3} \qquad (m^3/s)$$

b) **Ott recorder nr 2:**

$$Q = 2{,}160.d.\left(\frac{2{,}7.d}{2{,}7 + 2d}\right)^{2/3} \qquad (m^3/s)$$

c) **Ott recorder nr 3:**

$$Q = 1{,}381.d.\left(\frac{1{,}8.d}{1{,}8 + 2d}\right)^{2/3} \qquad (m^3/s)$$

15.4 Accuracy obtained

The accuracy of the flow rates as used in this study is directly dependent on the accuracy with which each flow measuring station could be calibrated.

It was thought that the Manning-equation of open channel flow would be applicable, but since the overall roughness coefficient was variable to a certain extent and the invert slopes were extremely flat, these two constants were almost impossible to determine. All the other variables in the Manning-equation were directly measurable which gave rise to the idea of combining the roughness coefficient and the invert slope into one coefficient, a.

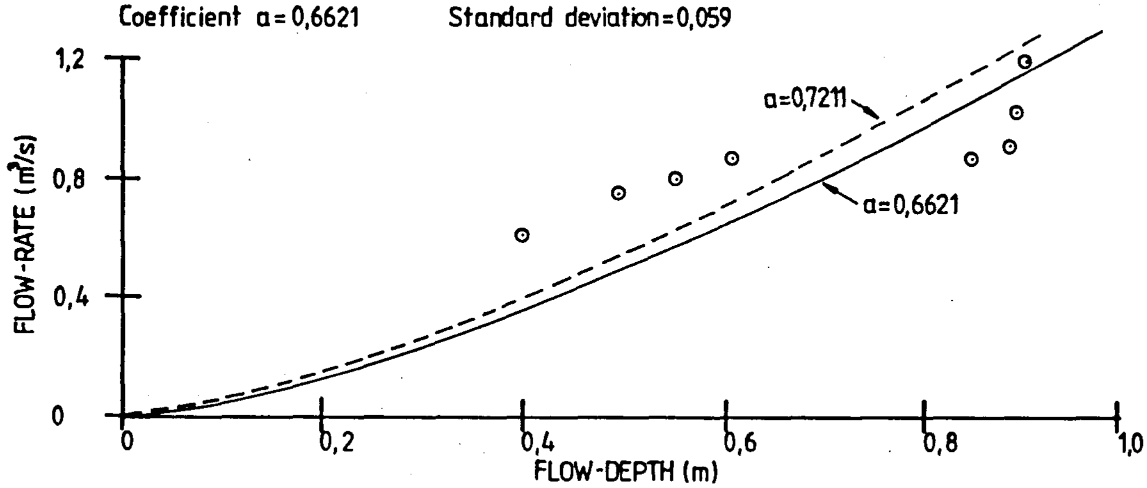
With the help of Dr D M Murray, an industrial and applications mathematics consultant, values of the combined coefficient, a, were determined for the three flow measuring stations. As is evident from Figure 7, the Manning equation fits the calibration data very well, and the standard deviations calculated are small enough to indicate more than pure coincidence.

The worst fit was found in the rating curve for Ott recorder nr 1. The three highest data points seem to be the culprits especially since

FIGURE 7 - RATING CURVES OF CANAL FLOW-MEASURING STATIONS

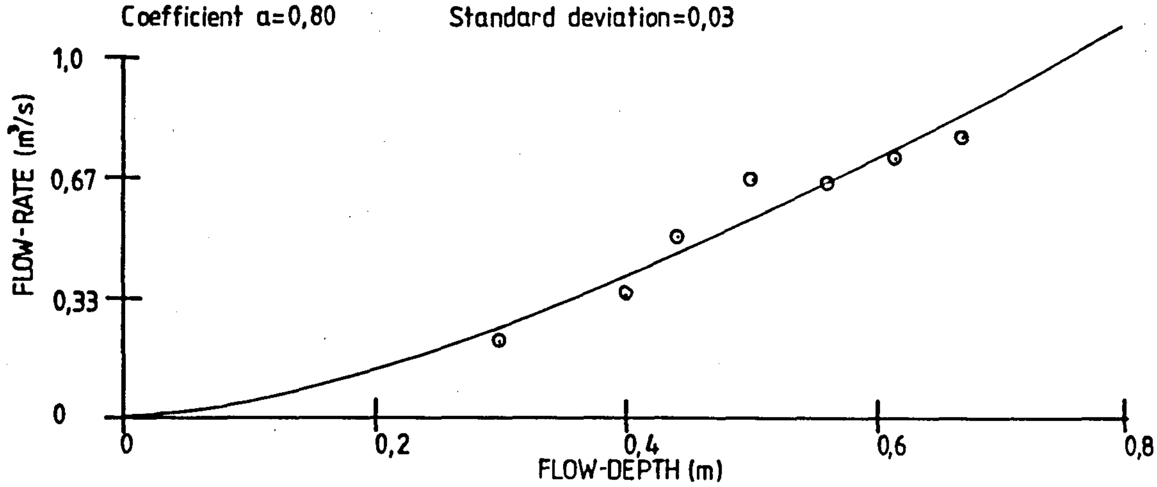
a) Ott recorder no.1

Coefficient a = 0,6621 Standard deviation = 0,059



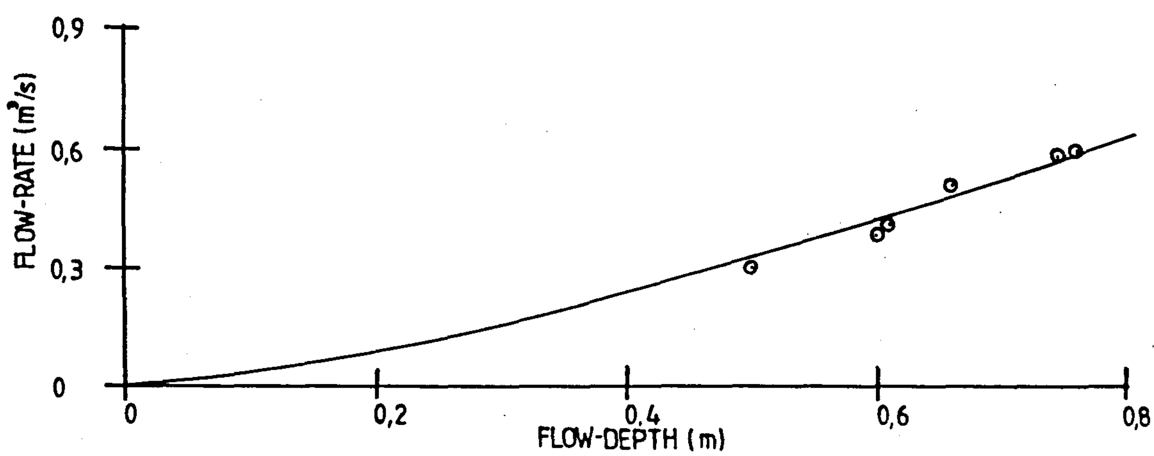
b) Ott recorder no.2

Coefficient a = 0,80 Standard deviation = 0,03



c) Ott recorder no.3

Coefficient a = 0,767 Standard deviation = 0,016



these measurements were taken while the canal flow was unstable and rising steadily. Dr Murray suggested using a value of a = 0,7211.

The high degree of accuracy obtained in this calibration effort is underlined by the fact that while the rating curves and the subsequently calculated flow rates were used in calculating the canal seepage losses, the seepage loss values were very close to the values expected.

16. OFF-TAKE FLOW MEASURING

16.1 Methods investigated

With only very few exeptions, farmers in the study area receive all their irrigation water at their respective canal off-takes. Therefore it was important to be able to measure water volumes at the point where the water leaves the canal and enters the individual distribution and storage system of each farm. It was equally important to measure the water volumes rejected from the canal back to the river.

All canal off-takes discharge into open furrows or canals of varying length which generally transport the water to a farm dam. This once again left the research team with the problem of continuous flow measurement in an open channel.

One method investigated was a flow measuring device operating at very low pressures, low flow speeds and a relatively high flow rate. It was thought that measuring devices similar to those used in measuring flow rates in pipes could be installed in a short length of large diameter conduit directly downstream from each off-take. It was however realised that the length of conduit needed to ensure stable flow through the device is directly proportional to the diameter of the conduit.

With the current price of a relatively small, 100 mm diameter flow meter of a popular make being in the order of R1 500-00, the cost of flow meters, together with the construction work needed to make use of them possible, would have been exessive.

16.2 Method adopted

The Breede River (Robertson) Irrigation Board uses the height of off-take opening together with a predetermined canal flow depth as the only means of exerting control over the volume of water supplied to each farm. This gave rise to the idea of monitoring the canal flow depth and opening height for each off-take on a daily basis.

A scale from which the canal flow depth, and where necessary, the tailwater depth could be read was installed at each of-take. A sliding calliper which could be inserted into an off-take and the off-take opening height read off was obtained.

A fixed route passing every canal off-take was chosen and every day during the monitoring period the same route was used and water depths and off-take opening at each off-take was recorded. From these recordings it was possible to calculate the flow rates and discharge volumes for each of-take on a daily basis.

As mentioned in Chapter 6 the equation used to calculate off-take discharge is as follows:

$$Q = Cd\ K\ b\ (2\ g\ h_s)^{1/2}\ (m^3/s)$$

with Cd = 0,73 for free flow

and Cd = 0,65 for submerged flow

K = off-take opening height (m)

b = off-take opening width (m)

h_s = difference in water head on either side (m)

In the case of the single reject off-take on the canal in the study area the canal which transports water from the reject point back to the river was fitted with a rectangular free overflow weir. An Ott water level recorder was installed to continuously record the water levels in the pond formed behind the weir. A daily average water level was determined from the Ott recorder graphs using a manual planimeter, and from these water levels, the reject flow rate could be calculated using the following equation:

$$Q = \frac{2}{3}\ (2g)^{1/2}\ C\ b\ h_e^{\ 3/2} \qquad (m^3/s)$$

with $C = 0{,}602 + 0{,}083^{h/p}$

$h_e = h + 0{,}0012$

b = width of weir (m)

h = depth of flow over weir (m)

p = height of weir (m)

16.3 Problems encountered

The Breede River (Robertson) canal flows through a densely populated area, and for most of its length it is not fenced in. This allows rubbish of all sorts to end up in the canal. The rubbish transported down the canal together with wads of algae is very often sucked into an off-take, partially blocking the orifice. Fortunately it is in the interest of each farmer to ensure unhindered flow through his off-take and therefore farmers regularly remove any obstacles from their off-takes.

Apart from this minor problem, the method of off-take flow measuring adopted was very successful.

16.4 Accuracy obtained

A certain degree of inaccuracy would naturally stem from the fact that off-take flow rates were not continuously monitored. Although the relevant readings at each off-take were taken at approximately the same time every day, no record could be kept of what happened at an off-take in between readings.

It is possible that an off-take was discharging water for a fraction of any 24 hour period without this discharge being recorded. It is however doubtful whether this would have happened very often since farmers seem to manage their affairs in terms of working days. If a farmer decides that he has to open his off-take, he will very likely leave it open till the same time the next day when he has to take a decision for the following day.

Without a continuous record of any off-take flow rates available it is unfortunately impossible to quantify the inaccuracy caused by the non-continuity of the record.

As for the accuracy of the flow rates that were calculated, it should again be pointed out that any gross inaccuracies would have been evident from the canal seepage loss calculation since the off-take flow rates do have a profound effect on the seepage loss values.

17. PUMP FLOW MEASURING

17.1 Existing measuring facilities

Flow measuring devices are compulsory on all pumps under the jurisdiction of the BRWCB and which extract water directly from the Breede River. These are generally of the straight flow-through type such as the Sparling water meter.

A record is kept of water pumped from the river for any period of time during which water is being released from the Brandvlei Dam. Readings are taken weekly by the bailiffs of the different canal irrigation boards whose districts adjoin different stretches of river. The readings are handed over to the secretary of the BRWCB who is responsible for keeping the record to control abstraction quantities as well as for levying taxes on all pump abstractions.

For the purposes of this study, copies of the abstraction records of each of the pump installations included in the study area were obtained from the BRWCB.

17.2 Accuracy obtained

Although manufacturers of flow measuring devices frequently quote accuracies of the order of 2% of actual flow, it should be noted that the specific position in which a water meter is installed can have a profound effect on the accuracy of the readings. It is not unheard of that a perfectly calibrated water meter, when improperly installed, can cause a margin of error of up to 20%.

It is evident that the only way to ensure a high degree of accuracy in the record of pump abstractions would be to calibrate the water meters used in situ. Such an attempt at calibration would be seriously hampered by the fact that virtually all pump installations along the Breede River discharge directly into distribution systems rather than into dams. Another obstacle was the negative attitude of the farmers to such calibration for obvious reasons.

Finally it was decided that the maintained co-operation of the farmers was much more important to the successful completion of the study than the actual accuracy of a few water meters. The results obtained were therefore used without modification or alteration.

18. STORAGE VOLUME MONITORING

18.1 Method adopted

For the purposes of the study, it was of great importance during the monitoring period to know what volume of water was being stored in farm dams each day. Only with the daily storage volume known, was it possible to determine the volume of water used for irrigation on any single day.

In Chapter 8 the work involved in the characterisation of the 42 farm dams in the study area is described. During the detailed survey of each dam a bench mark of a known height relative to the rest of the dam was provided. In each dam a set of gauge plates, each plate 1 m in length was installed, and the relative height of these gauge plates was determined from the bench mark. Now it was possible to read off the exact water depth in the dam at any given time.

In the route used for monitoring canal off-takes daily such detours necessary to include all the farm dams were incorporated. Thus it was possible to obtain a record of daily stage readings for each dam in the study area for the duration of the monitoring period.

Using the depth-volume curve of each dam (see Appendix D) it was possible to determine the daily storage volume by linear interpolation.' Interpolation was restricted to 0,5 m depth increments to allow for the non-linearity of the depth-volume relationship. The depth-surface area curve was used in the same manner to determine the daily variation in dam surface area.

18.2 Accuracy obtained

The gauge plates used for monitoring of water depths in farm dams were graded in 5 mm increments to ensure ease of reading from distances of up to 10 m.

If for arguments sake a reading error of 5 mm was made on all the stage readings for any one day, a maximum error of 540 m^3 would have been made on the storage volume for that day. This represents a mere 0,098% of the total storage volume concerned and was considered to be negligible.

19. WATER SALINITY MONITORING

19.1 General

At the inception of this study, it was agreed that the research team would be responsible for the collection of water samples to be analysed by the HRI laboratories in order to ensure cross-checking of daily electrical conductivity (EC) readings. During the monitoring period a total of 54 samples was sent to the HRI. At first the samples were sent directly from the Robertson office of MBB and later, at the request of the HRI, samples were sent via HRI field technician stationed at Robertson. Of the 54 samples sent, 12 were apparently lost in transit and on enquiry no analytical results for these 12 samples could be found.

19.2 Canal water salinity

Canal water salinity was monitored daily by taking samples at each of the three level recording stations and determining the EC of each sample. EC values were converted to Total Dissolved (8)
Salt Concentrations (TDS) in mg/ℓ by multiplying EC values in mS/m by a factor of 5,2 and are presented in Appendix G.

A number of samples was taken and chemically analysed. These results are given in Table 2, and were used to cross-check both EC values and TDS values subsequently calculated. Calculated TDS values were found to be of adequate accuracy for the purpose of this study.

19.3 Pumped water salinity

As mentioned in Chapter 17 all the pumps included in the study area discharge directly into distribution systems making sampling of water very difficult.

For the duration of the monitoring period, the HRI field technician was continuously sampling water salinity at a number of points along the Breede River. Copies of the data collected were obtained and used as a measure of salinity of the water pumped directly from the river.

19.4 Storage water salinity

Farm dams receive water directly from the canal off-takes and the water is stored for a number of days before it is released for irrigation purposes. The attenuation period in any dam would depend on the size of the dam and the flow rate through the dam. This would cause some mixing of water resulting in a difference in the salinity of water entering and leaving the dam.

The salinity of water released for irrigation was determined by taking EC readings on a regular basis in each farm dam. Care was taken to avoid inaccuracies caused by readings taken in the surface layer. An extension was fitted to the EC probe to obtain readings from well below the surface.

C MASS BALANCE MODELLING

20. THE IRRISS MODEL

(Contributed by Mr S F Forster, DWA)

20.1 The value of irrigation scheme models

20.1.1 Irrigation scheme inefficiencies

Whenever the topic of agricultural water-use efficiency is raised it is not uncommon to find that irrigation technique and the perceived over application of water, feature strongly in the discussion. These are highly visual aspects of agricultural water-use, but not necessarily the primary causes of poor agricultural water-use eficiency. Failure to divert water from a river into a canal system at the right time, leaking canals, inaccurate or non-existant flow measurements, leaking off-takes, and poor scheduling may show that inefficiencies occurring during actual irrigation, are infact smaller by comparison.

Alternatively the use of farm dams can promote on-farm water-use efficiency by reducing the need to reject water from the canal, and by permitting irrigation application to take place when the crop requires it, and not when a lead is made. However, unlined farm dams invariably leak and water stored for any length of time is likely to incur a greater evaporative loss.

It is not with the aim of allocating responsibility for the losses and inefficiencies occurring in our irrigation schemes, that detailed simulation should be undertaken. If we are to derive the maximum productivity from our agricultural water resources we must analyse our irrigation schemes, particularly the older ones, in order to identify those schemes and the components within those schemes, where potential water savings can be made. Only when such savings have been quantified and expressed in terms of additional irrigation development, can a case be made for ameleorative action.

20.1.2 Planning future expansions

The one situation in which measures can be taken to ensure a high level of irrigation scheme water management, is at the planning stage. For example, the Vaal Harts Scheme is characterised by concrete lined distribution channels, farm dams and drainage channels. These were all included in the original White Paper for the scheme, following recommendations by the Department of Agriculture. The problem with the inclusion of such works today is that they must be shown to be cost-beneficial. There is no software available at present to quantitatively assess the relative benefits of either reducing distribution and storage losses, or improving on-farm water management.

20.1.3 Irrigation return flow

In this context irrigation return flow is taken as being the entire flow returning to a river from an irrigation scheme. This includes leakage from the storage and distribution components, canal reject and tailwater, and root zone percolate.

The irrigation return flow from a scheme is important when abstractions are made from the river channel downstream of the irrigated lands. Estimates of irrigaton return flow from entire schemes are extremely difficult to make. This is largely due to the lack of information about the scheme and the absence of suitable software capable of using such information to produce estimates of potential return flow.

Assuming estimates of return flow are made, the modeller then has the task of verifying these values. It is unlikely that simulated estimates of irrigation return flow will ever be able to be verified completely. The reasons for this are twofold. Firstly, the insidious route that return flow takes through the delivery zone to the channel. Secondly, the variable time lag involved between irrigation application and return flow entering the channel, particularly where interactive groundwater bodies are involved.
Hence other methods of validating irrigation return flow estimates must be sought. One possible solution is to calculate or model an upper limit for return flow by measuring seepage losses from

canals and farm dams, and by subtracting estimated crop consumption, from irrigation application data. Subsequent volumetric and load adjustments to the return flow whilst in the so-called "delivery zone", en-route to the river channel, can be performed in accordance with field observations made at locations such as main drainage ditches.

This is the approach adopted in IRRISS.

20.2 IRRISS: General description

20.2.1 Background

Although development work on the IRRISS package began in 1985, it was only completed in October 1987 due to the need to validate and finalise the software using actual data. This work formed part of the Department's agreed input to the Water Research Commission's Robertson Canal Project. The term "package" is used in preference to "model" because the simulation model is only one of a large number of programmes which comprise the IRRISS software. The name IRRISS denotes Irrigation Scheme Simulation.

IRRISS runs on an IBM compatible 16 Bit microcomputer. The microcomputer is an ideal tool for irrigation scheme modelling. It is large enough to simulate the complexities of a scheme, and to handle the associated volume of data. Due to the widespread usage of IBM compatible microcomputers, this software can be used by all interested parties, from universities and consultants to irrigation boards and farmers.

20.2.2 Software application

The model included within IRRISS is designed for use in irrigation scheme planning and overall long term management. The model operates on the basis of daily water and salt budgets. It is a lumped model in the sense that it does not preserve the integral design of the irrigation scheme. If the model were to simulate water and salt through a specific network of canals, pumps and dams etc., it would have to be rewritten for each individual irrigation scheme. Network simulation would have the benefit of providing decision support facilities for the day-to-day operation of the scheme, however, this is not one of the aims of this software. A lumped model is therefore considered adequate to simulate the overall dynamics of an irrigation scheme on a seasonal basis.

There is no limit to the size of irrigation scheme that IRRISS can handle, it is merely a question of certainty surrounding the accuracy of the output. The model can be applied to either a farm or a large irrigation scheme. To ensure a realistic output from the simulation, it is preferable that the irrigated area is not fragmented. If an area is both particularly large and highly variable in terms of physical characteristics, accuracy would be improved by the separate simulation of physically well defined units.

20.2.3 Software limitations

IRRISS is not intended to assist in the daily operation of an irrigation scheme. Although the model does produce a number of daily timeseries as output, this data is intended for use in examining overall seasonal variations. Beyond this the daily simulated values have limited meaning. The quantitative strength of IRRISS lies in the seasonal salt and water balances.

IRRISS does not predict irrigation return flow. It does however, calculate upper limits for return flow volumes derived from the various components of an irrigation scheme. Due to the absence of process information relating to the role of groundwater in governing return flows, it is not possible to proceed beyond these limits at this moment in time.

IRRISS is primarily intended for arid and semi-arid areas. Hence it has limitations in the simulation of rainfall-runoff processes. For example, IRRISS caters for the following rainfall related processes:

(i) rainfall capture by farm dams;
(ii) rainfall capture by canals;
(iii) rainfall falling on the dry weather wetted surface area of irrigated lands.

It does not simulate the runoff caused by rainfall falling on land which is not normally wetted by irrigation water. Indeed, heavy rainfall destroys the relatively delicate water and salt equilibrium which is established during simulation. It is for this reason that IRRISS runs for a maximum irrigation season of 200 days, thereby avoiding the wet season.

20.2.4 Simulation approach

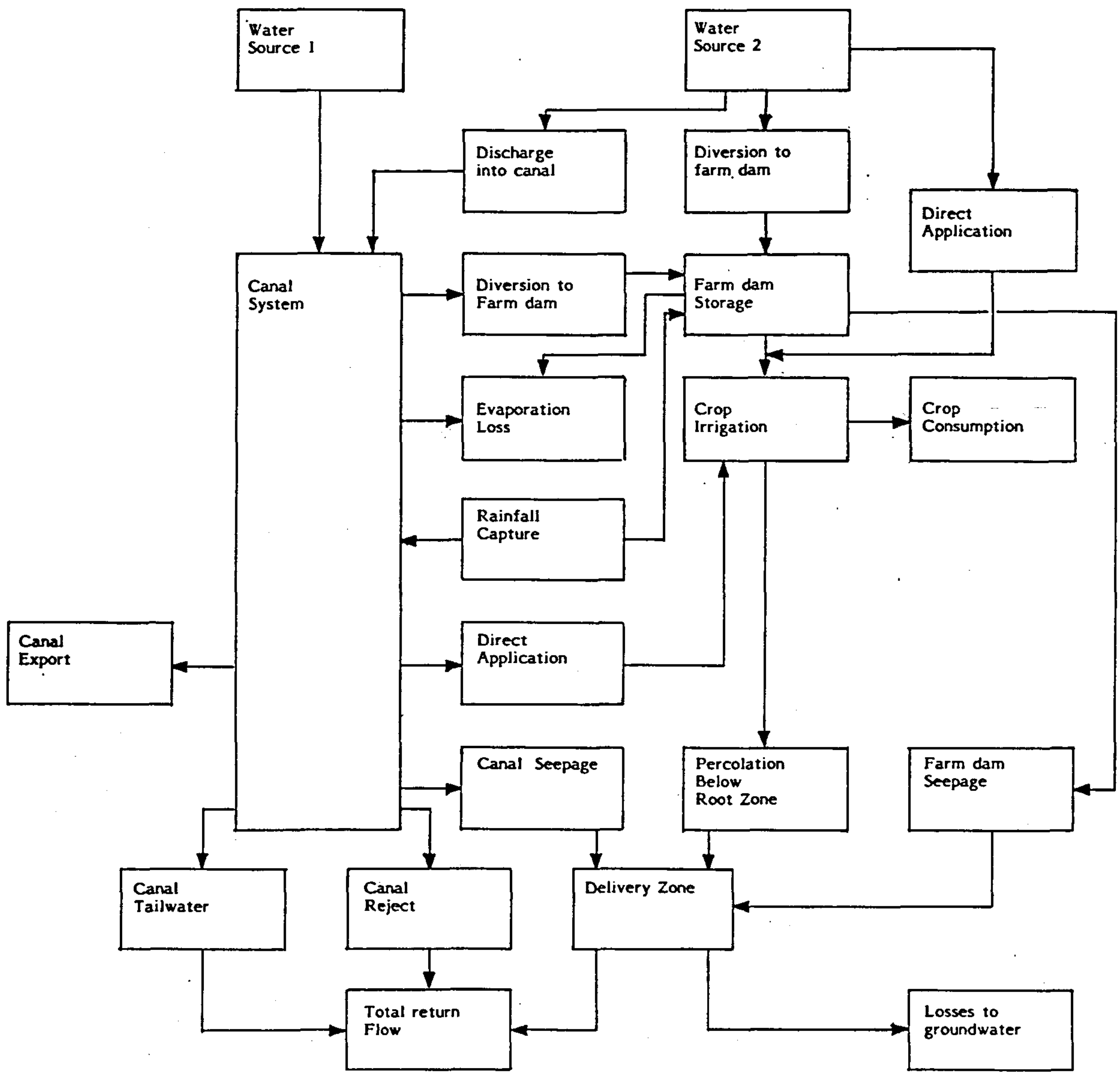
A schematic flow diagram of IRRISS is shown in Figure 8. There are six main components to the actual simulation, namely:

(i) acquisition (of water and solutes);
(ii) distribution and storage;
(iii) application;
(iv) crop consumption;
(vi) percolation and drainage.

Due to the widely differing needs of future potential IRRISS users, the simulation software has been separated into two models. The first model simulates components (i) to (iii), while the second model simulates the remaining components. If return flow predictions are required, then the output of the storage and distribution model automatically acts as an input to the irrigation and drainage model. In addition, output data relating to either water quantity or water quality, or both can be requested by the user.

The calculation of rootzone percolate is based on the principle that in order to correctly simulate drainage waters from irrigated land, the application of the correct volume of water, of the correct quality, to the exact surface area, for the correct period of time, must first be simulated.

FIGURE 8 - SCHEMATIC FLOW DIAGRAM OF THE IRRISS MODEL



20.2.5 User friendliness

One aspect of the IRRISS package which is unique to this type of simulation is the degree of programming devoted to creating a comprehensive user interface. IRRISS should be quickly useable by non-computer users, without prior training or the aid of a manual. To achieve this, extensive use has been made of structured menus and utility routines. The primary services offered by the package include the following user-interactive software:

(i) a user-interactive program to configure the irrigation scheme as a modelling unit;

(ii) a program to create, update and maintain a daily database for the irrigation scheme;

(iii) data processing software for both the model input and output databases;

(iv) a model to simulate water and salt movement through the storage and distribution components of an irrigation scheme.

(v) a model to simulate the application of water and solutes to irrigation lands, and to estimate the quality and quantity of rootzone percolate.

20.3 IRRISS: Detailed description

20.3.1 Data management

IRRISS requires a two disk drive system for operation. This can either be a hard disk and a floppy disk, or twin floppy disks. For a hard disk system, the program software is stored on disk C while the input and output data files are stored on disk in drive A. For a twin floppy disk drive system the program software is inserted in disk drive A whilst the data files are stored on the disk in drive B.

Input and output data management is strictly controlled by IRRISS to prevent data corruption, the overwriting of files, erroneous file identification and general file mismangement. This is necessary because the model both requires as input, and produces as output a considerable number of data files. The task of manually organising large numbers of data files, particularly when a model is being re-run continuously for calibration purposes or sensitivity analysis, is both time consuming and fraught with pitfalls.

IRRISS performs two primary data management functions. Firstly it names and organises all input and output datafiles for the user, and secondly it provides a software interface between the user and the data, thereby preventing direct access to both input and output databases. Both functions are performed by a series of codes. These codes are described below:

(i) an irrigation scheme identification code;
(ii) an irrigation season code;
(iii) an irrigation scheme configuration code;
(iv) a simulation code.

The simulation code is assigned automatically and is only for use in accessing the output database.

20.3.2 Configuring an irrigation scheme as a modelling unit.

20.3.2.1 Background

IRRISS simulates an irrigation scheme by combining timeseries of daily operational and agrometeorological data with the physical and technical characteristics of the scheme. This collection of characteristics is termed the scheme configuration. Configuration is used in preference to the term "design" because, as was explained in 20.2.2, the layout of the scheme is not preserved in the simulation. Indeed, IRRISS completely redesigns the scheme prior to simulation by creating a number of cells, each one containing a specific crop growing on a specific soil type and being irrigated in a particular manner with a specific water.

20.3.2.2 Water sources

IRRISS accepts data for up to two water sources of different quality. This is necessary as a large number of irrigation schemes receive water from more than one source, and invariably the quality of the two supplies is different. Water source 1 is reserved for water which is diverted into a canal system. Water source 2 can be any other supply such as river pumpage, groundwater, or natural runoff from higher ground.

20.3.2.3 Cropping patterns and irrigation techniques

In configurating a scheme the user must specify a cropping pattern for the land irrigated by each water supply. The individual crops are selected from a list of 14 crop types. Irrigation techniques and application cycles must then be specified for each crop being irrigated with each water supply. The irrigation techniques are assigned in terms of the proportions of the total area under each crop. The screen displays associated with the interactive entry of this information are shown in Figures 9, 10, 11.

20.3.2.4 Soil types

Each water supply can irrigate a specific type of soil. The soil types, which must be selected by the user, are based on the USDA soil textural classification. On selecting a particular soil type, the relevant hydrological characteristics of the chosen soils automatically become part of the scheme configuration. These characteristics are taken from Schulze (1984). Following this the user must specify the soil depth and the quantity of gypsum applied to each soil type (if any) during the course of the irrigation season. Figure 12 shows the screen displays associated with this soil information.

20.3.2.5 Canal system

If the water source 1 option is used the user must give some basic design statistics for the canal system. These include:

(i) average width of the canal;

(ii) length of the canal;

(iii) the flow to wetted perimeter ratio;

(iv) the average seepage loss rate expressed as litres/second/ 1000 m^2 of wetted lining (DWA, 1980).

Note that in this instance the lining can be a variety of materials such as earth, concrete of plastic.

20.3.2.6 Farm dam storage

The storage of water in farm dams is simulated by lumping all the farm dams together to form one large dam. The characteristics of this single dam must be declared during the configuration procedure. The characteristics include full supply capacity, capacity to surface area ratio, and seepage loss rate expressed as a percentage of the previous days storage.

FIGURE 9: SCREEN DISPLAY - SELECTING THE CROP TYPES

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IRRISS:  CONFIGURING THE IRRIGATION SCHEME AS A MODELLING UNIT

Page 3:  Crop types - Select up to five different crops

         1.   Citrus              8.   Deciduous fruit
         2.   Vines               9.   Tobacco
         3.   Lucerne             10.  Groundnuts
         4.   Maize               11.  Cotton
         5.   Potatoes            12.  Tomatoes
         6.   Wheat               13.  Pasture
         7.   Sugar cane          14.  Other vegetables

Crop 1  =  ?1
Crop 2  =  ?2
Crop 3  =  ?3
Crop 4  =  ?4

Do you wat to change the above answers (Y, N or X)?
```

FIGURE 10: SCREEN DISPLAY - SPECIFYING THE CROPPING PATTERN AND IRRIGATION CYCLE

IRRISS: CONFIGURING THE IRRIGATION SCHEME AS A MODELLING UNIT

Page 4: Irrigated areas and water-use

Enter the crop area, water source and irrigation cycle.
Do not forget to insert a comma after each entry.

		Irrigation water source		Irrigation cycle	
Crop name	Area	%Canal	%River	Days on	Days off
Citrus	? 500 ,	50 ,	50 ,	4 ,	3
Vines	? 200 ,	100 ,	0 ,	5 ,	2
Lucerne	? 100 ,	80 ,	20 ,	1 ,	1
Maize	? 200 ,	20 ,	80 ,	2 ,	1

Do you wish to correct any of the above answers (Y, N or X)?

FIGURE 11: SCREEN DISPLAY - SELECTING THE IRRIGATION TECHNIQUE AND THE ESTIMATED EMITTER DENSITY

IRRISS: CONFIGURING THE IRRIGATION SCHEME AS A MODELLING UNIT

Page 5: Irrigation application techniques

Enter irrigation techniques and emitter density for drip and micro.
Do not forget to insert a comma after each entry.

	Irrigation technique as a % of the area under each crop						
Crop name	C.Pivot	Spray	Flood	Drip	No/Ha	Micro	No/Ha
Citrus	? 0	, 0	, 10	, 0	, 0	, 90	, 400
Vines	? 0	, 20	, 0	, 20	, 600	, 60	, 500
Lucerne	? 50	, 30	, 20	, 0	, 0	, 0	, 0
Maize	? 90	, 0	, 10	, 0	, 0	, 0	, 0

Do you wish to correct any of the above answers (Y, N or X)?

FIGURE 12: SCREEN DISPLAY - SELECTING THE SOIL TYPES AND ASSOCIATED GYPSUM APPLICATION RATES

IRRISS: CONFIGURING THE IRRIGATION SCHEME AS A MODELLING UNIT

Page 6: Soil textural classes and gypsum applications

USDA SOIL TEXTURAL CLASSIFICATION

1.	Sand	7.	Sandy clay loam
2.	Loamy sand	8.	Clay loam
3.	Sandy loam	9.	Silty clay loam
4.	Loam	10.	Sandy clay
5.	Silt loam	11.	Clay
6.	Silt	12.	Silty clay

			Gypsum application	
Water source	Soil class.	Soil depth (cm)	Area (ha)	Rate (T/ha)
Canal	? 1	, 30	, 500	, 1,5
River	? 7	, 50	, 500	, 1,2

Do you want to change the above answers (Y, N or X)?

20.3.3 Daily input database

The daily input database in IRRISS comprises four separate arrays. The subjects of these arrays and their respective component variables are described below:

(i) Water source 1 supply and operational data comprising:
- day number;
- date (optional);
- volume diverted into the canal;
- volume diverted from the canal into farm dam storage;
- volume applied directly to the crop;
- volume rejected from the canal;
- salinity of the canal water.

(ii) Water source 2 supply and operational data comprising:
- day number;
- date (optional);
- volume abstracted from water sources 2;
- volume discharged into the canal system;
- volume diverted directly to the crop;
- salinity of water source 2.

(iii) Farm dam release data comprising:
- day number;
- date (optional);
- volume released from farm dam storage.

(iv) Agrometeorological data comprising:
- day number;
- date (optional);
- evaporation;
- rainfall;
- crop factors for crops 1 to 5.

Note that although the date is optional for each record in every array, the date for day 1 must always be inserted. This enables IRRISS to check that the starting dates for each array are compatible.

The selection of daily crop factors for each crop should be taken from Green (1985). The purpose of using daily crop factors is that the factor must cater for various processes that have been excluded from the model. These include:

(a) growth stage related variations in crop water requirements;
(b) canopy interception;
(c) soil evaporation.

20.3.4 Simulating the acquisition, storage and distribution of irrigation water

20.3.4.1 Canal flows

The objective of the canal flow simulation is to calculate the daily canal tailwater or export. This is the quantity of water and salt which leaves the irrigation scheme via the canal system. This water can either be returned to the river channel as tailwater or supplied to another irrigation scheme. The water volume calculation for this is shown in Equation 1.

$$CTAL_n = (CDIV_n + CDIS_n + CRAN_n)-(CFDM_n + CSEP_n + CEVP_n + CREJ_n + CAPP_n) \quad \text{....................(1)}$$

Where:

CTAL	=	Canal tailwater or export
CDIV	=	Volume diverted into the canal from Water Source 1
CDIS	=	Volumes discharged into the canal form Water Source 2
CRAN	=	Canal rainfall capture
CFDM	=	Volume diverted from the canal into farm dam storage
CSEP	=	Canal seepage loss
CEVP	=	Canal evaporation
CREJ	=	Canal reject
CAPP	=	Volume abstracted from the canal and applied directly to the crop
n	=	Day number

All the variables in Equation 1 are taken from the input database with the exception of CRAN, CEVP and CSEP. CRAN and CEVP are computed from the canal width, canal length, daily rainfall and daily evaporation. CSEP is calculated as shown in Equation 2.

$$CSEP_n = \left(\frac{CINT_n + CFIN_n}{2}\right).\ WPER.\ CLEN.SEEP \quad \text{........................(2)}$$

Where:

CINT	=	Initial canal flow
CFIN	=	Final canal flow
WPER	=	Flow to wetted perimeter ratio
CLEN	=	Canal length
SEEP	=	Canal seepage loss rate

The salt load calculation for tailwater or export is idential to Equation 1 with the exception that salt is not lost through canal evaporation.

20.3.4.2 Farm dam storage

The daily storage volumes and salt loads for a single hypothetical farm dam are simulated using Equation 3.

$$FDSTR_n = (FDSTR_{n-1} + CFDM_n + PFDM_n + FDRAN_n) - (FDSEP_n + FDREL_n + FDEVP_n) \quad \text{...................... (3)}$$

Where:

FDSTR	=	Farm dam storage volume
PFDM	=	Volume diverted into the farm dam from Water Source 2
FDRAN	=	Farm dam rainfall capture
FDSEP	=	Farm dam seepage loss
FDREL	=	Volume released from the farm dam and applied to the crops
FDEVP	=	Farm dam evaporation loss

FDRAN and FDEVP are calculated as shown in Equations 4a and 4b.

$$FDRAN_n = FDSTR_{n-1}.SACAR.RAIN_n \qquad \text{.............(4a)}$$
$$FDEVP_n = FDSTR_{n-1}.SACAR.EVAP_n \qquad \text{.............(4b)}$$

Where:

SACAR = Surface area storage capacity ratio
RAIN = Daily rainfall
EVAP = Daily evaporation

FDSEP is calculated using Equation 5.

$$FDSEP_n = FDSTR_{n-1}.LEAK \qquad \text{.............(5)}$$

Where:

LEAK = Farm dam seepage loss rate expressed as a percentage of previous days storage volume.

One again the salt load calculations are identical to the volume calculations with the exception that salt is not lost through farm dam evaporation.

20.3.5 Simulating irrigation and drainage

20.3.5.1 Calculating the wetted surface areas

The wetted surface area of the irrigation scheme is calculated according to Equation 6.

$$WSAR_k = IPROP_k.WF_k.CARE \qquad \text{...............(6)}$$

Where:

$WSAR_k$ = Wetted surface area under irrigation technique k
$IPROP_k$ = Proportion of the total irrigated area which is irrigated with irrigation technique k
WF_k = Wetted fraction of the area being irrigated with technique k
being irrigated with technique k
CARE = Total irrigated area
k = Irrigation technique reference number

The irrigation techniques and associated wetted fractions are given in Table 12. The wetted surface area is further adjusted on a daily basis to cater for the irrigation cycle for each crop.

The wetted surface area for a given soil type is then used together with the soil depth and porosity values, to estimate the volume of soil which comes in contact with percolating irrigation water. It is this volume of soil which is incorporated within the IRRISS simulation. The remaining volume of inactive soil, together with its inherent salt load is disregarded.

Table12: Irrigation techniques and associated distribution efficiencies (DE)

IRRIGATION TECHNIQUE	WETTED FRACTION
1. Flood (furrow)	0,60
2. Overhead sprinkler	0,85
3. Drip	WF_3*
4. Microjet	WF_4*
5. Centre pivot	0,95

* Note

DE_3 = $C1.EDEN_3$

DE_4 = $C2.EDEN_4$

Where:

C1 = A circle with a diameter of 20 cm

C2 = A circle with a diameter of 60 cm

EDEN = Emitter density expressed as the number of emitters per hectare

20.3.5.2 Calculations of the volumes and loads applied to the crops

The calculation of the daily water volumes and applied to the crops is performed according to Equations 7a and 7b.

$$TWS1AP_n = CAPP_n + \left[FDREL_n \cdot \frac{(TCFDM)}{(TCFDM + TPFDM)}\right] + RAIN_n . WS1CAR) \quad ..(7a)$$

$$TWS2AP_n = WS2APP + \left[FDREL_n \cdot \frac{(TPFDM)}{(TCFDM + TPFDM)}\right] + (RAIN_n . WS2CAR \quad ...(7b)$$

Where:

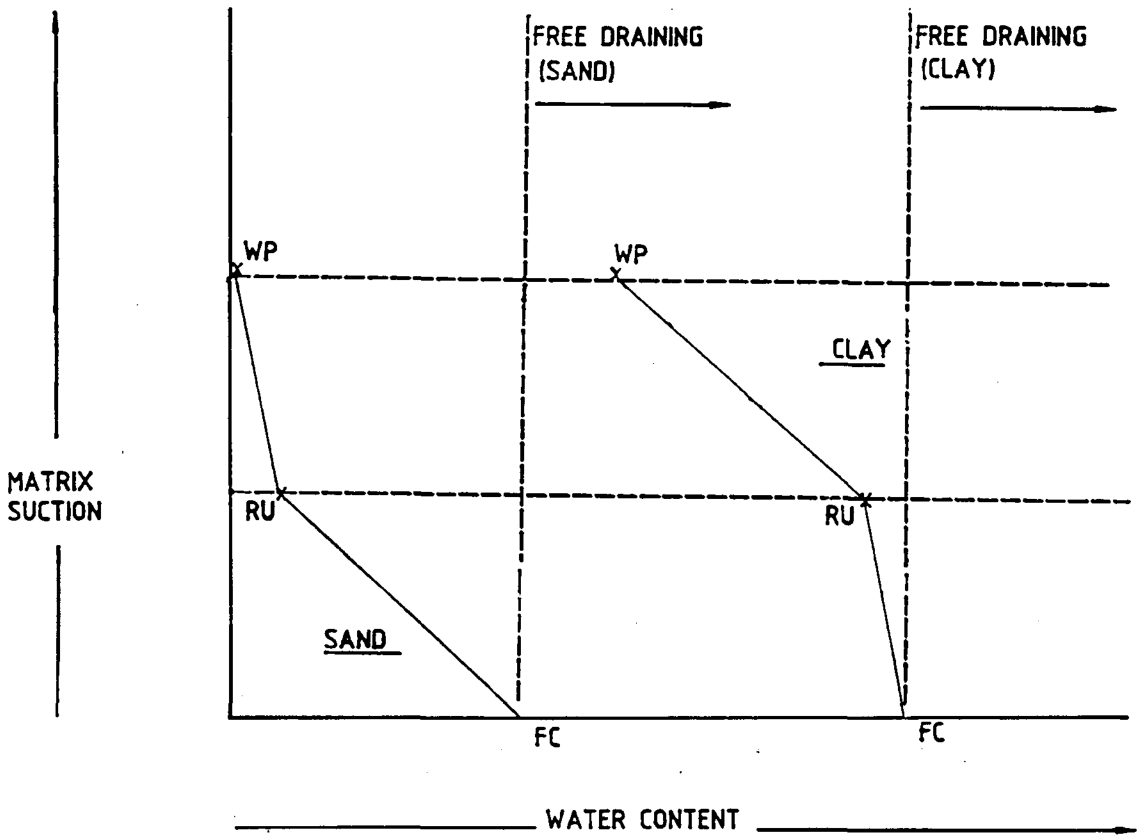
TWS1AP	=	Total water from Water Source 1 that is applied to the crops
TWS2AP	=	Total water from Water Source 2 that is applied to the crops
TCFDM	=	Total volume of water diverted from the canal to farm dam storage during the entire season
TPFDM	=	Total volume of water diverted from Water Source 2 to farm dam storage during the entire season
WS1CAR	=	Wetted surface area of crops irrigated from Water Source 1
WS2CAR	=	Wetted surface area of crops irrigated from Water Source 2
WS2APP	=	Volume of water from Water Source 2 that is applied directly to the crops

The calculation for the salt load applied to the crop is handled in an identical manner.

20.3.5.3 Crop consumption and rootzone percolation

The simulation of crop consumption and rootzone percolation cannot be conveniently expressed in a single equation form. Both processes are entirely dependent upon the hydrological characteristics of the soil and the antecedent soil moisture conditions. Figure 13 demonstrates these dependencies for a sandy soil and a clay soil.

FIGURE 13 - SOIL MOISTURE BUDGETING



Where:

FC	=	Field capacity;
RU	=	Point of restricted uptake;
WP	=	Wilting point.

Assuming the soil is in a free draining state then Equation 8 will be applicable for the estimation of rootzone percolate from a particular soil type.

$$PERC_n = (FC_j.SD_j) - [(TWAP_n + SWATR_{n-1}) - CWR_n] \quad ....(8)$$

Where:

PERC	=	Volume of rootzone percolate
FC_j	=	Field capacity of soil type J
SD_j	=	Depth of soil type J
TWAP	=	Total water applied
SWSTR	=	Initial soil water storage
CWR	=	Crop water requirement

The following points should be noted when considering Figure 13.

(i) Percolation below the rootzone only occurs when the field capacity is exceeded.

(ii) Until the point of restricted uptake (RU) is reached, the water requirements of the crop are met in full.

(iii) A linear relationship is assumed to exist between the point of restricted uptake (RU) and wilting point (WP).

(iv) Below wilting point the crop takes no water from the soil.

20.3.5.4 Soil salt dynamics

The simulation of soil salt dynamics and salt leaching from the soil profile have little in common with the moisture budgeting described in 20.3.5.3. In theory the total salt available in the soil profile is derived from four sources. These are:

(i) irrigation water;
(ii) weathering of parent material;
(iii) capillaric rise of saline water;
(iv) gypsum applications.

The salt load in the irrigation water has been dealt with in 20.3.5.2 As the respective contributions from weathering and capillaric rise are unknown, these two sources have been combined and are represented in the model by a single parameter for daily salt regeneration. The application of gypsum is obtained from the information given when selecting the soil types, (see Figure 12). The introduction of gypsum to the soil profile is distributed evenly over the duration of the simulation period.

Salt removal from the soil profile is simulated in two ways. Firstly the water taken up by the crop is assumed to contain 5 mg/ℓ of total dissolved salts (TDS). Commercial crop salt uptake during zero stress conditions is estimated by Sutcliffe and Baker (1981) to be in the order of 3 to 7 mg/ℓ TDS. Secondly, salt leaching is assumed to be a function of the volume of water percolating below the rootzone. This is calculated in accordance with Equation 9, (Herold 1979).

$$PTON_n = FSTON_n.[1 - e^{(-COSAR.PVOL)}] \qquad ....(9)$$

Where:

PTON = Salt load leached by the percolating water.
FSTON = Final salt load in the soil profile.
COSAR = Coefficient of salt removal.
PVOL = Volume of water percolating below the rootzone.

A maximum salinity of 10 000 mg/ℓ TDS for water drainage from the rootzone is permitted by IRRISS.

20.3.5.5 Delivery zone adjustments

The delivery zone is assumed to be any route which return flows take from leaving the rootzone, canal or farm dam, to reaching the river channel. The degree of mixing, loss to permanent groundwater, salt pick-up and flow attenuation is unknown. Hence these processes are dealt with by two parameters. These are:

(i) GLOSS - the percentage of water volume and associated salt load lost to permanent groundwater;
(ii) SPIK - the percentage of salt load increase.

These parameters can either be used in conjunction with field observations or merely varied arbitrarily to produce return flows with a range of assumed losses.

Note that the values of GLOSS and SPIK apply equally to canal and farm dam seepage losses, and rootzone percolate.

20.3.6 Starting conditions and irrigation return flow parameters

Prior to simulation IRRISS requires the following starting conditions to be specified by the user:

(i) the initial farm dam capacity;
(ii) the initial soil moisture content, expressed as a percentage of the field capacity of all the soil types;
(iii) the initial soil salt content.

If the simulation is to include the irrigation and drainage model, irrigation return flow parameters should be specified. Alternatively, the model can be run using generalised default parameter values. The irrigation return flow parameters need not be specified if only the storage and distribution model is being used.

The irrigation return flow parameters, some of which have already been discussed, are described below.

(i) COSAR - coefficient of salt removal;
(ii) SSREG - soil salt regeneration;
(iii) PMAX - maximum rate or rootzone percolation;
(iv) GLOSS - percentage loss of water and salt to permanent groundwater whilst in the delivery zone;
(v) SPIK - percentage increase in salt load whilst in the delivery zone.

20.3.7 Output database

The output database can be accessed either automatically on the completion of a simulation, or manually by using the codes associated with a previous simulation. The database offers the user the choice of outputs shown in Figure 14. The selected information can in most cases, be displayed on the screen. Alternatively, output data can be down loaded to a printer.

In order to remind the user of the circumstances surrounding a particular simulation output, a simulation summary is available on both the screen and printer displays. This summary contains the following information:

(i) The scheme, configuration, season and simulation codes;

(ii) The starting conditions;

(iii) The irrigation return flow parameters.

FIGURE 14: SCREEN DISPLAY - OUTPUT DATABASE OPTIONS

```
IRRISS:  OUTPUT DATABASE PROCESSING ROUTINE

                        DATABASE SELECTION MENU

Do you want the:

        1.   Storage and distribution water timeseries.
        2.   Storage and distribution water balance.
        3.   Storage and distribution salt timeseries.
        4.   Storage and distribution salt balance.
        5.   Irrigated soil water timeseries.
        6.   Irrigated soil water balance.
        7.   Irrigated soil salt timeseries.
        8.   Irrigated soil salt balance.
        9.   Total scheme water balance.
        10.  Total scheme salt  balance.
        11.  Total scheme return flow/load timeseries.
        12.  Exit to the MAIN MENU.

Enter choice  :?
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21. MODEL INPUT DATA

21.1 General

The data requirements of the IRRISS model can be divided into two main categories namely:

a) Data describing the physical characteristics or configuration of the irrigation scheme, and

b) Data describing the daily movement of water and salt through the scheme, what can be called daily timeseries data.

The irrigation scheme configuration data will be given in the text in the following discussion, but the timeseries data, because of the large volume, will be discussed in the text while the actual data is included in Appendix J.

The grouping of data as used in the IRRISS model will be adhered to, and descriptive terminology for specific parameters or groups of parameters will have the same meaning as in the model.

21.2 Irrigation scheme configuration

21.2.1 Irrigation scheme characteristics

From Chapter 3 it is evident that in the 2 081 ha study area, a total irrigated area of 1 240,9 ha was found. As pointed out, only 1 063,8 ha was considered for the water and salt mass balance modelling. This resulted from the exclusion of farms numbers 9, 11, 12, 14, 16 and 20 because of insufficient or unreliable water and land use data for these farms. Consequently it was felt that it was not justified to endanger the credibility of the modelling effort in order to include these farms.

In Chapter 4 the two water sources in the study area, namely the canal and the pumps on the Breede River are discussed in depth.

The study area is protected from on-shore winds by mountain ranges Thus the dry and wet fall out of salt is negligible. Hence a zero value was assumed.

21.2.2 Irrigation water management

TABLE 13 - IRRIGATION WATER MANAGEMENT

Crop Name	Area	%Irrigation water source			Irrigation cycle	
	(ha)	Canal	River	Additional	Days on	Days off
Vines	694,7	96,1	3,9	0	5	2
Pasture	156,6	77,4	22,6	0	5	2
Maize	47,4	45,6	54,4	0	1	4
Deciduous fruit	135,1	83,2	16,8	0	5	2
Tomatoes	30,1	100,0	0	0	5	2

In Table 13 all pastures and lucerne was lumped together under PASTURE. Likewise maize and wheat was lumped under MAIZE, still retaining differences in growing season.

The areas under different crops was derived from Table 1.

From interviews with the farmers it was possible to identify the area supplied by pumps. The remainder of the area is served by the canal.

In Appendix F the irrigation record that was kept by the farmers, is given. Although not impossible, it would have been a mammoth task to calculate an exact irrigation cycle for each crop from this record. Therefore it was decided to determine an irrigation cycle in terms of days on and days off by inspection.

21.2.3 Irrigation application techniques

The distribution of irrigation techniques given in Table 14 below, was derived from Table 9.

The nozzle densities given are calculated from the more popular plant spacings found in the study area.

TABLE 14 - IRRIGATION APPLICATION TECHNIQUES

Crop name	**%IRRIGATION TECHNIQUE AND NOZZLE DENSITY**						
	Centre Pivot	**Spray**	**Flood**	**Drip**	**No/ha**	**Micro**	**No/ha**
Vines	0	19,44	0,84	67,87	4 098	11,85	3 415
Pasture	5,06	89,33	5,61	0	0	0	0
Maize	54,43	45,57	0	0	0	0	0
Deciduous fruit	0	6,07	18,88	65,06	3 636	9,99	806
Tomatoes	0	1,99	0	98,01	8 333	0	0

21.2.4 Soil classification and gypsum application

TABLE 15 - SOIL CLASSIFICATION

Water Source	**Soil Class**	**Soil Depth (cm)**	**Gypsum Area (ha)**	**Application Rate (t/ha)**
Canal	Sandy clay loam	90	475,5	1,5
River	Sandy clay	90	56	1,5

The effective soil depth in the study area is controlled by either the depth to which the soil is ripped prior to planting, or the height of the water table during the active growing season. In both cases the soil depth was estimated to be 900 mm.

Gypsum applications as given in Table 15 were derived from interviews with the farmers.

21.2.5 Canal specifications

The canal specifications as used in the model, were derived from Chapter 5.

The canal is specified as follows:

a) Length = 12,85 km
b) Average width = 2,613 m
c) Flow to wetted perimeter ratio = 1:3,656 m^3/s : m
d) Transmission losses = 3,13 $\ell/s/m^2$ of canal lining

21.2.6 Farm dam specifications

The farm dam specifications used in the model to describe the unified total storage dam, were derived from Chapter 8.

The dam is specified as follows:

a) Total capacity = 0,553 305 million m^3
b) Seepage loss rate = 0,5977% previous days storage
c) Capacity to surface area ratio = 1:50,117 million m^3 : ha

21.3 <u>Daily timeseries data</u>

21.3.1 Water source 1 inputs

a) Volumes diverted from river to canal (CVOL) were taken from the canal and off-take flow record given in Appendix G. The flow rates recorded at recording station number 1 were converted to daily volumes.

b) Volumes diverted into farm dams (FDIV) were calculated by finding the total off-take discharge, excluding off-takes numbers 18, 25, 26, 38, 39, 32 and 33, from Appendix G. Again flow rates were converted to daily volumes.

c) Volumes applied directly to crops (DAPP) were taken to be the sum of volumes discharged by off-takes number 32 and 33 which are the only two off-takes in the study area used for direct irrigation.

d) Volumes rejected from canal to river (CREJ) were taken as the sum of the flow rates of the Klipbult Reject (K.B.A.) and off-takes numbers 18, 25, 26, 38, 39. The latter five all are ordinary farm off-takes, but since the farms served by these off-takes were excluded from the modelling effort, it was decided to handle them as reject off-takes.

e) TDS of water source 1 (CTDS):
These values were obtained from daily EC readings which were converted to TDS values. The daily values are given in Appendix G.

21.3.2 Water source 2 inputs

a) Volumes drawn from source 2 (SVOL) were taken from the pump abstraction record given in Appendix H.

b) Volumes diverted into farm dams (FDIV) consequently have a zero value since no pumps included in the study area can deliver water drawn from the river into a farm dam.

c) Volumes applied directly to crops (DAPP) have the same value as SVOL for the reason given in (b) above.

d) Volumes discharged into canals (DCAN) would also have a zero value since no pump can deliver water from the river into the canal.

e) T.D.S. of source 2 (STDS) was taken from Figure 5 in Chapter 4.

21.3.3 Volumes released from farm dams

Volumes released from farm dams (FREL) were calculated from the dam storage record in Appendix I and the farm dam inflows as follows:

$$FREL_n = FDIV_n + \text{storage volume}_n - \text{storage volume}_{n+1}$$

21.3.4 Agro-meteorological input data

a) Daily A-pan evaporation (EVAP) values were taken to be the mean of the daily values recorded at the Agricultural Experimental farm at Robertson and the farm Prospect at Ashton. The actual values used are included in both Appendices G and I.

b) Daily rainfall (RAIN): Again the mean of values recorded at Robertson and Ashton was used, and the values are given in Appendices G and I.

c) Daily crop factor for crop n (CFR_n) was taken from "Inleiding tot Besproeiing" published by the Department of Agriculture and Water Supply. (4)

Where it was necessary to lump crops like wheat and maize together, weighted average values were calculated, taking into consideration the differences in growing season of the different crops. The same procedure was followed in the case of tomatoes where different planting dates had to be taken into account.

21.4 Starting conditions and return flow control parameters

The starting conditions in the IRRIS model have to be estimated since none of them have been measured for the purposes of the study. The returnflow control parameters were set at zero for the losses to permanent groundwater, and at 200% for the salinity increase in the delivery zone. This latter parameter value was selected following the comparison between the simulated returnflow salinity and the actual returnflow salinity as measured in the drains in the Robertson area. The coefficient of salt leaching value was selected by reference to the irrigation scheme salt equilibrium status. The aim was to find a value by "trial and error" which permitted neither an exessive build-up or leaching of salts in the irrigation scheme.

The values used were:

a)	Initial soil moisture (as % of field capacity)	:	95%
b)	Initial soil salt content	:	15,0 tons/ha
c)	Initial farm dam capacity (% of full capacity)	:	80%
d)	Coefficient of salt leaching from soil	:	0,15
e)	Maximum rate of soil salt regeneration	:	1,00 kg/ha/day
f)	Maximum rate of rootzone percolation	:	900 mm/day
g)	Percent of returnflow lost to ground water	:	0%
h)	Percent increase in returnflow salinity	:	200%

22. MODEL OUTPUT DATA

22.1 General

The output from the IRRISS model can roughly be divided into two groups namely a daily timeseries of values, and number of summaries of these daily timeseries values. Again the complete output from the water and salt mass balance modelling, is included in Appendix K.

22.2 Water balance

The water balance summary for the entire irrigation scheme is given below as Table 16.

It is important to note that water rejected from the canal is not lost to the Breede River System since this water is returned to the river upstream of Zanddrift. On the other hand it is a definite eye-opener that canal seepage losses amount to some 23% of the total scheme water intake.

TABLE 16 - WATER BALANCE SUMMARY FOR THE ENTIRE IRRIGATION SCHEME

Description	1000 cubic meters	% Total intake
1. Diversion into the canal	21 763	-
2. Canal export	9 406	-
3. Supply from the canal (WSI)	12 357	90,44
4. Supply from water source 2	1 306	9,56
5. Total scheme water intake	13 663	100,00
6. Canal evaporation	48	0,35
7. Canal seepage loss	3 200	23,42
8. Canal reject	1 257	9,20
9. Farm dam evaporation	27	0,20
10. Farm dam seepage loss	455	3,33
11. Total losses (items 6-10)	4 987	36,50
12. Seepage lost to g/water	0	0,00
13. Return flow from seepage loss	3 655	26,75
14. Water management efficiency	63,61%	-
15. Operational efficiency	90,80%	-
16. Distribution and storage efficiency	63,50%	-
17. Direct application	1 393	10,20
18. Farm dam releases	7 321	53,58
19. Total water applied	8 714	63,78
20. Crop water requirement	7 702	56,37
21. Crop water consumption	7 702	56,37
22. Crop water deficit	0	0,00
23. Percolation below rootzone	1 541	11,28
24. Percolate lost to g/water	0	0,00
25. Average leaching fraction	20,11%	-
26. Returnflow from irrigated soil	1 541	11,28
27. Total scheme returnflow	5 196	38,03

Note: Water management efficiency = A/B + (C-D) x 100

Operational efficiency = (B-E)/A x 100

Distribution and storage efficiency = (B-F)/A x 100

Where A = Total water applied

B = Total water intake

C = Initial farm dam storage

D = Final farm dam storage

E = Canal reject

F = Total losses

22.3 Salt balance

The salt balance summary for the entire irrigation scheme is given below as Table 17.

From the salt balance probably the most astounding figure is the 1 728 tons of salt which moves through a 1 100 ha irrigation scheme in a single irrigation season. The total scheme return load of 6 200 tons per season is however strongly influenced by certain of the control parameters mentioned above, and should for the time being be regarded with some caution.

TABLE 17 - SALT BALANCE SUMMARY FOR THE ENTIRE IRRIGATION SCHEME

Description		Kilograms	% Total additional
1.	Salt diverted into canal	3145670	144,72
2.	Salt from water source 2	156769	7,21
3.	Total salt abstracted (1+2)	3302441	151,93
4.	Canal export	1372909	63,16
5.	Canal reject	201193	9,26
6.	Total exports and rejects	1574102	72,42
7.	Canal seepage loss	463095	21,31
8.	Farm dam seepage loss	65509	3,01
9.	Total seepage losses	528604	24,32
10.	Salt flux in delivery zone	105555	48,56
11.	Return load from seepage loss	1584159	72,88
12.	Salt in irrigation water	1197055	55,07
13.	Gypsum application	797250	36,68
14.	Salt generated in soil	179301	8,25
15.	Total additional salt in soil	2173606	100,00
16.	Crop salt consumption	38511	1,77
17.	Rootzone salt percolation	1531727	70,47
18.	Salt flux in delivery zone	3063453	140,94
19.	Soil salt equilibrium	+603368	-
20.	Return load from irrigated soil	4595180	211,41
21.	Total scheme return load	6179339	284,29

23. SENSITIVITY ANALYSIS

23.1 The need for a sensitivity analysis

With a model like IRRISS being used for the first time, it is important to evaluate the sensitivity of the model outputs especially to those parameters that cannot be exactly measured or estimated with a great degree of confidence.

With a well-founded knowledge of the simulation techniques employed in the model together with a knowledge of the relative sensitivity of the model outputs to changes in some of the calibration parameters, it is possible to make use of the model with a high degree of confidence.

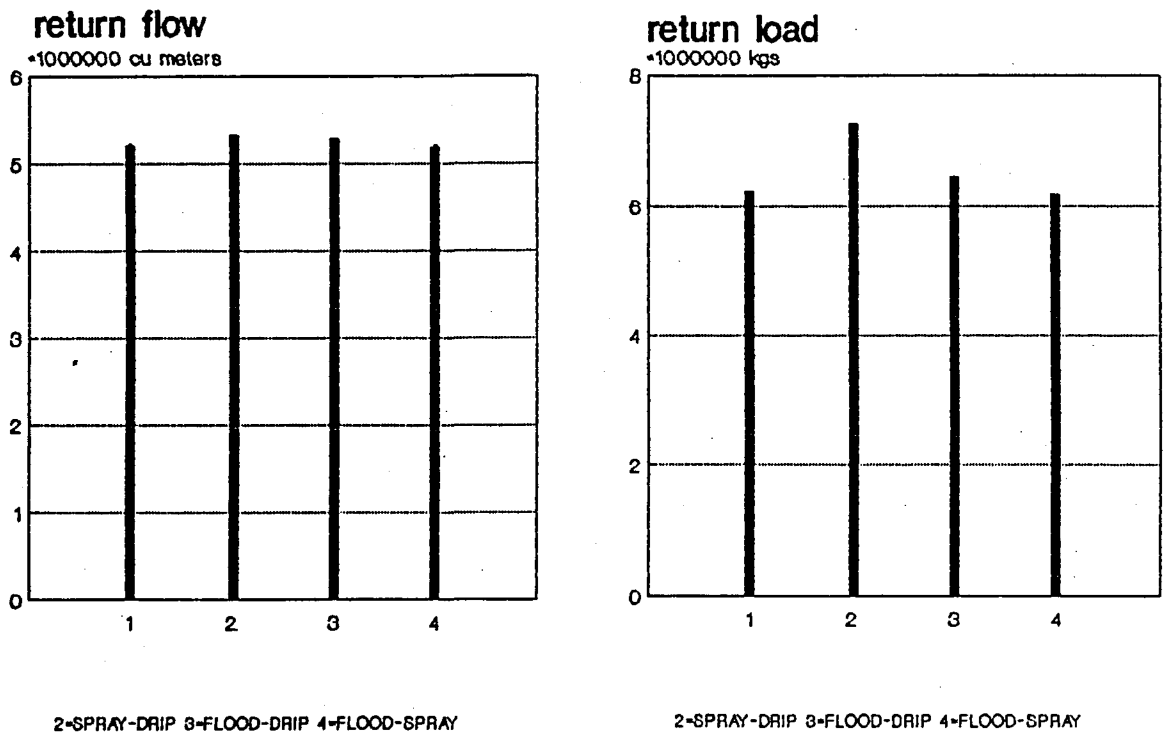
In the sensitivity analysis done for this study, two distinct groups of parameters were addressed namely a number of the irrigation scheme configuration inputs, and all the operator-controlled starting conditions. In all cases the reaction of the model to changes in any of these parameters was evaluated in terms of the total return flow and return load from the entire irrigation scheme.

In Appendix L the print-outs from the IRRISS runs done for the sensitivity analysis are given. For each run the configuration, starting conditions, and water and salt balance summaries for the entire scheme are given. In each case the specific parameter, or parameters, which were changed is indicated by a little frame drawn around it.

23.2 Sensitivity to changes in configuration

23.2.1 Application technique

FIGURE 15 - SENSITIVITY TO CHANGES IN APPLICATION TECHNIQUE

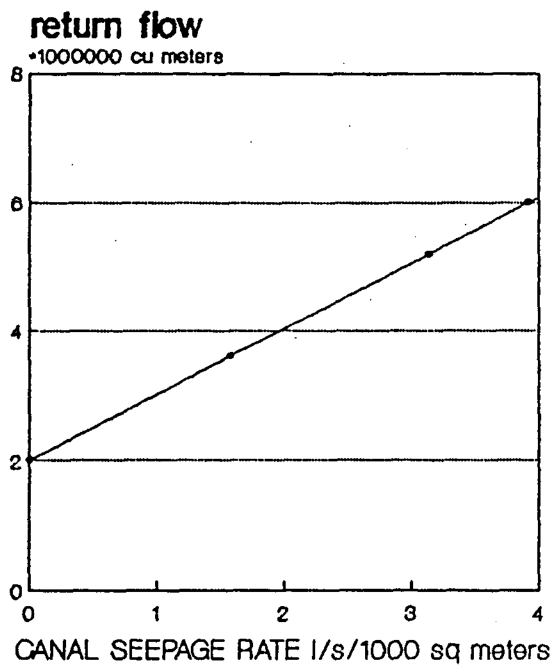


In Figure 15, Number 1 represents the return flow and load as calculated for the actual observed distribution of application techniques. Number 2 represents the scenario where all spray irrigation is replaced with drip irrigation. Numbers 3 and 4 represent the replacement of flood irrigation with drip and spray irrigation respectively.

Return flows seem to be relatively insensitive to changes in application technique, while return loads are obviously slightly more sensitive to such changes. Interesting to note is the increase in return load caused by the replacement of spray irrigation with drip irrigation. This is caused by a reduction in the "active" soil volume and a consequent higher flow rate per cubic meter of soil.

23.2.2 Canal seepage loss rate

FIGURE 16 - SENSITIVITY TO CHANGES IN CANAL SEEPAGE LOSS RATE



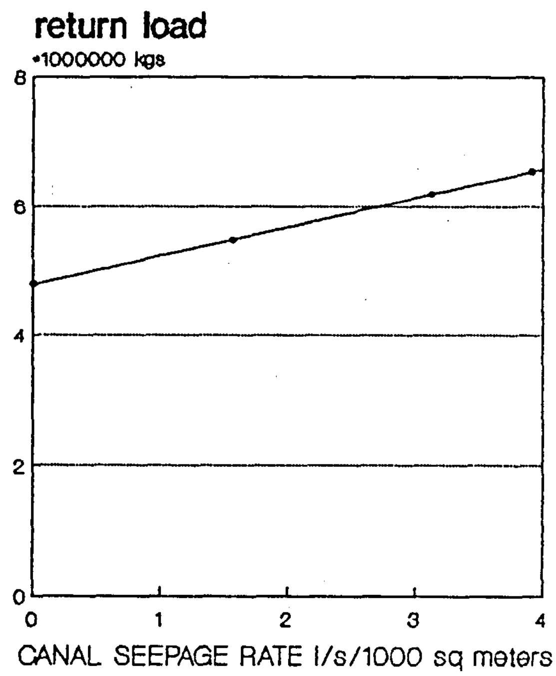
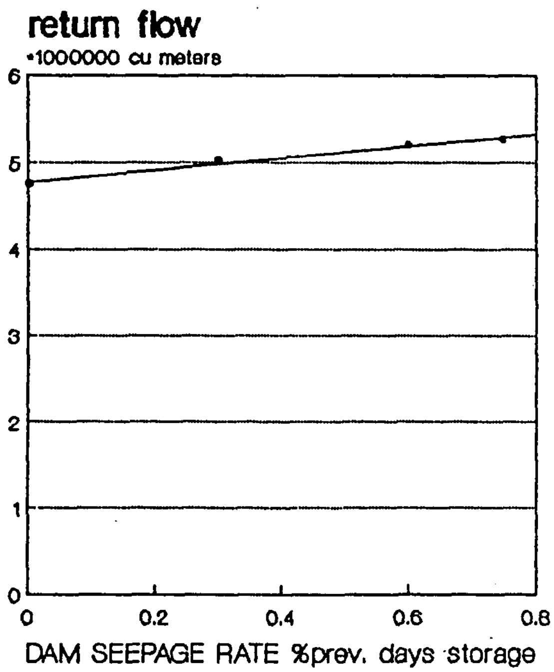


Figure 16 is an illustration of the linear variation in return flow and return load with changes in the canal seepage loss rate. It is clearly evident that the return flows and loads calculated by the IRRISS model are highly sensitive to variation in the canal seepage loss rate.

23.2.3 Farm dam seepage loss rate

FIGURE 17 - SENSITIVITY TO CHANGES IN FARM DAM SEEPAGE LOSS RATE



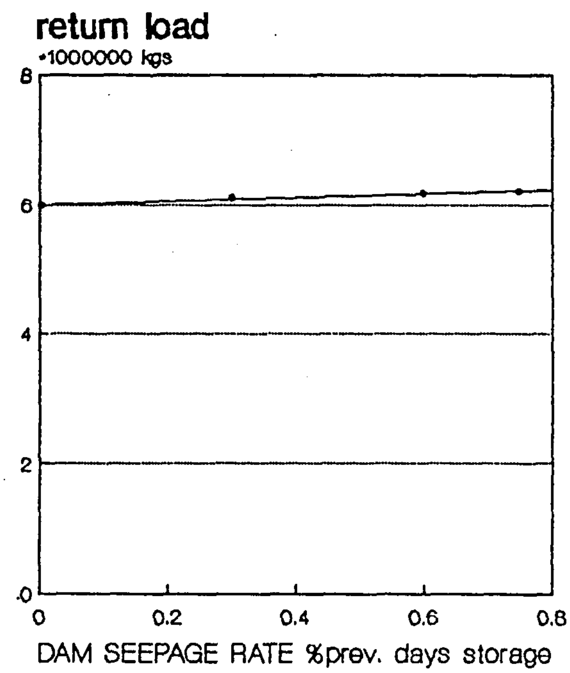
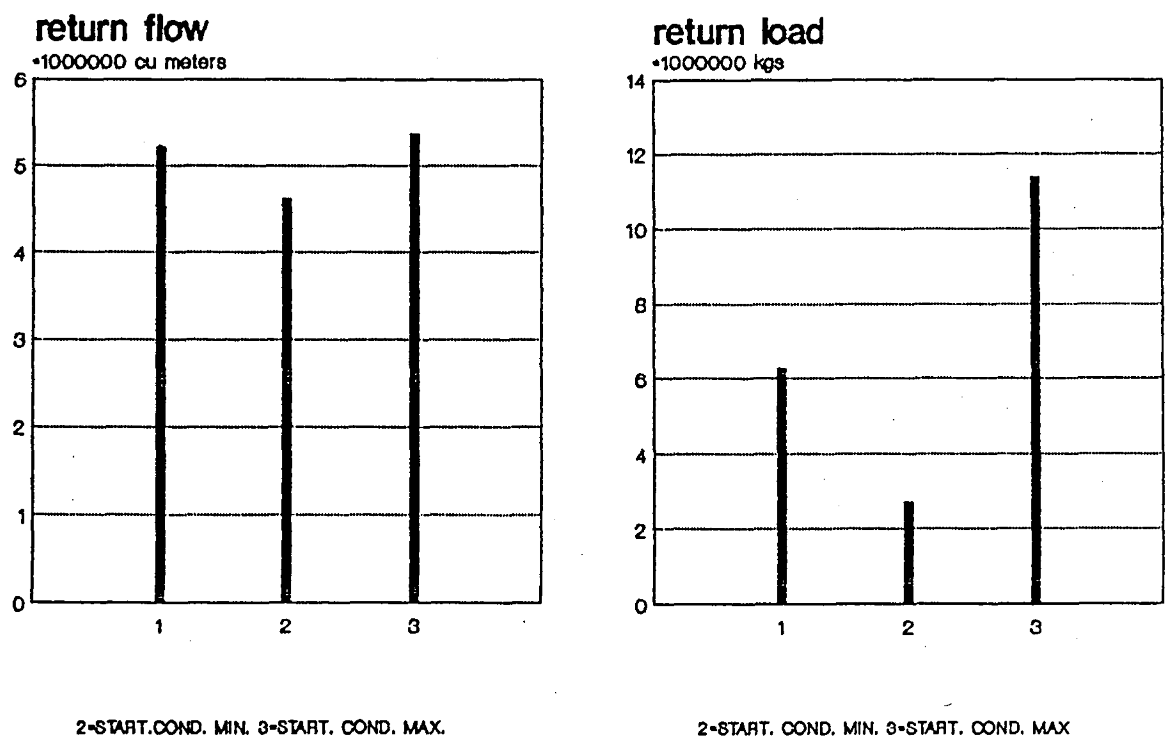


Figure 17 illustrates the linear variation in return flow and return load with changes in the farm dam seepage loss rate. The water and salt balance is relatively insensitive to changes in the seepage loss rate. Therefore the water and salt balance will be equally insensitive to errors in farm dam capacities.

23.3 Sensitivity to changes in starting conditions

23.3.1 Combined effect of starting conditions

FIGURE 18 - SENSITIVITY TO COMBINED EFFECT OF STARTING CONDITIONS



In Figure18, the Number 1 case represents the return flow and load calculated with the starting conditions and soil parameters as used in the water and salt mass balance calculation. Numbers 2 and 3 represent the return flows and loads calculated with the starting conditions and soil parameters set respectively to the minimum and maximum probable values as given below:

Parameter	Case 1	Case 2	Case 3
Initial soil moisture (% of field capacity)	95	90	100
Initial soil salt content (tons/ha)	15,0	10,0	20,0
Initial farm dam capacity (% of full capacity)	80	80	80
Coeffisient of salt leaching	0,15	0,14	0,16
Rate of soil regeneration (kg/ha/day)	1,00	0,50	1,50
Rate of rootzone percolation (mm/day)	900	800	1 000
Returnflow lost to groundwater (%)	0	10	0
Increase in returnflow salinity (%)	200	100	300

23.3.2 Initial soil moisture status

FIGURE 19 - SENSITIVITY TO CHANGES IN INITIAL SOIL MOISTURE STATUS

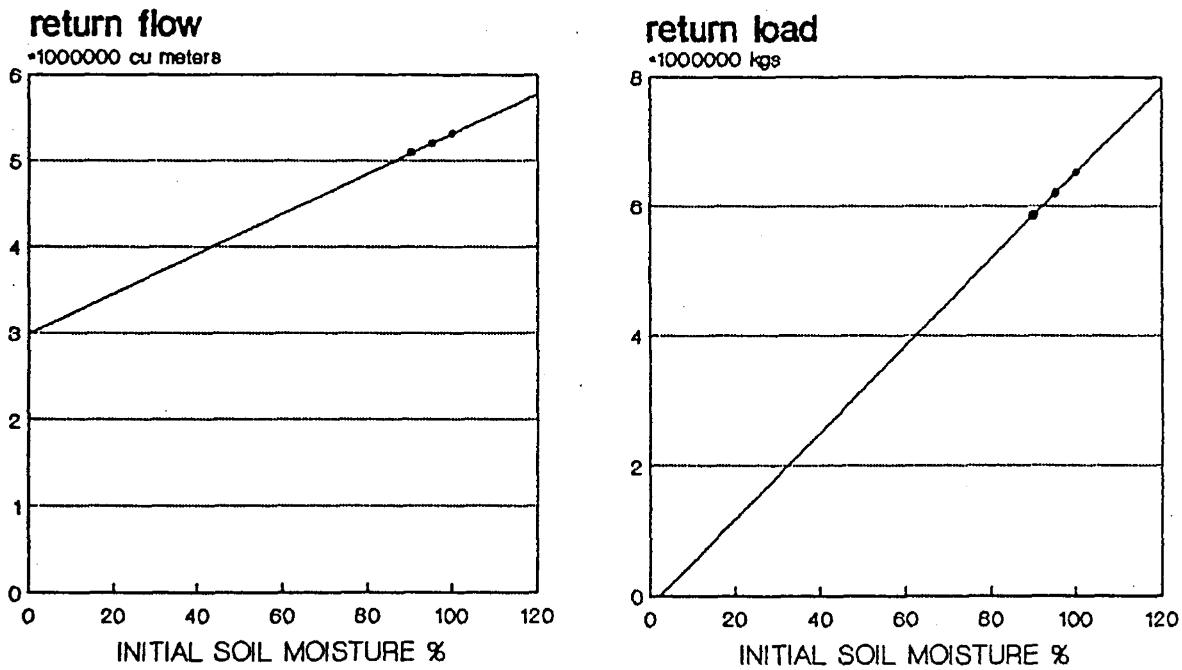
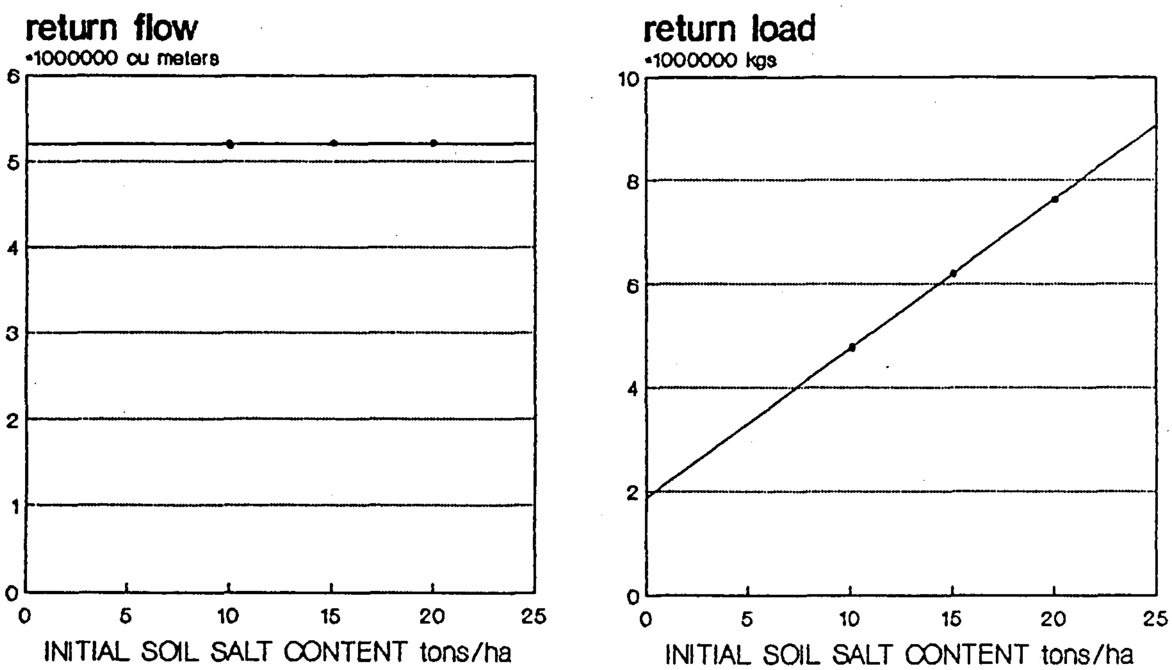


Figure 19 illustrates the linear variation in return flow and return load with a change in the initial soil moisture status. Although the steep gradients of the two graphs indicate a high degree of sensitivity, it should be remembered that an intelligent estimation of initial soil moisture would dramatically decrease the margin of error.

23.3.3 Initial soil salt content

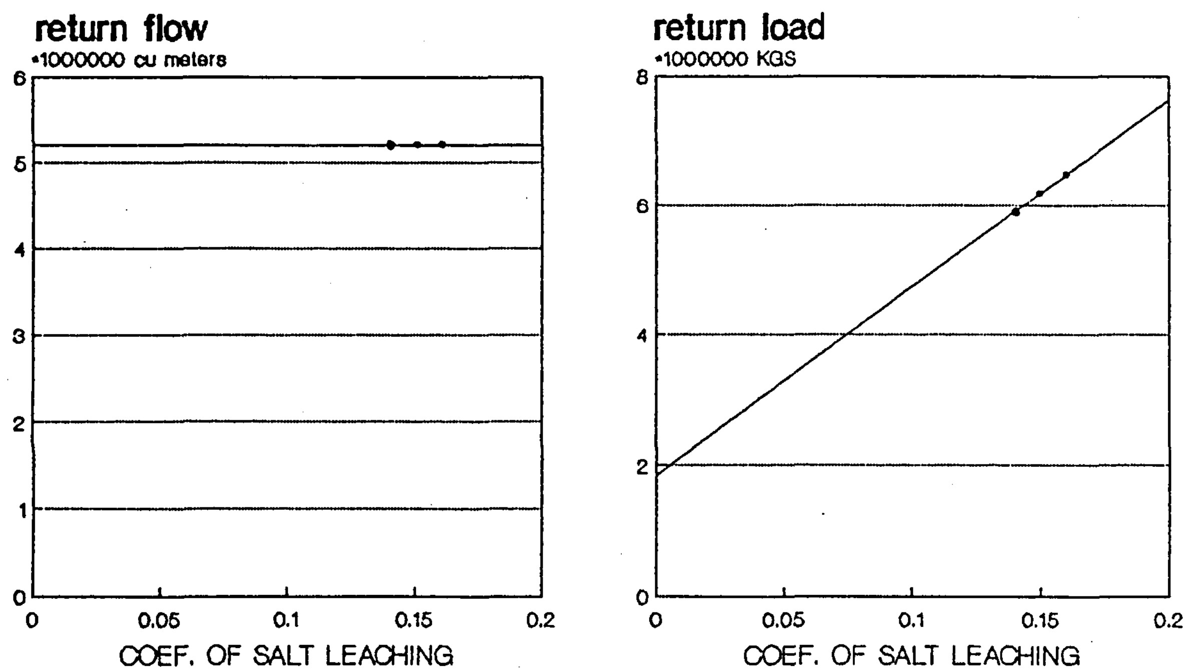
FIGURE 20 - SENSITIVITY TO CHANGES IN INITIAL SOIL SALT CONTENT



As can be expected Figure 20 indicates that return flows are not affected by changes in initial soil salt content. Return loads, however, are highly sensitive to the initial soil salt content values employed.

23.3.4 Coefficient of salt leaching from the soil

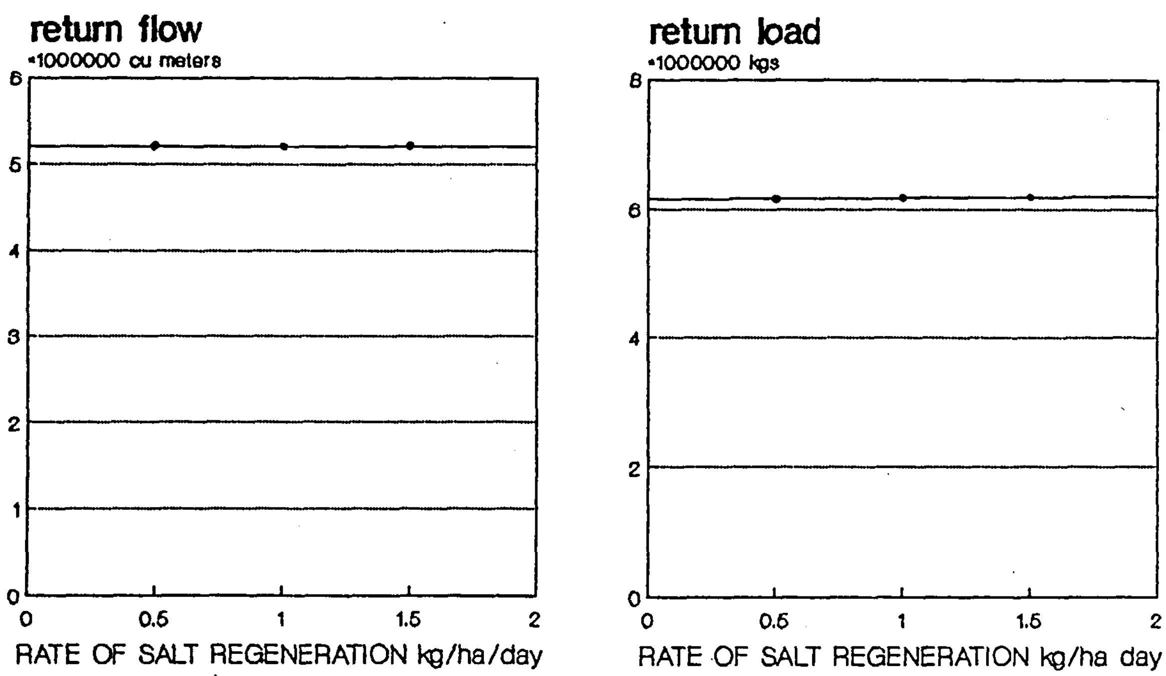
FIGURE 21 - SENSITIVITY TO CHANGES IN THE COEFFICIENT OF SALT LEACHING



Once again Figure 21 indicates a complete insensitivity of return flows to changes in the coefficient of salt leaching while return loads are clearly highly sensitive to such changes.

23.3.5 Rate of soil salt regeneration

FIGURE 22 - SENSITIVITY TO CHANGES IN THE RATE OF SALT REGENERATION



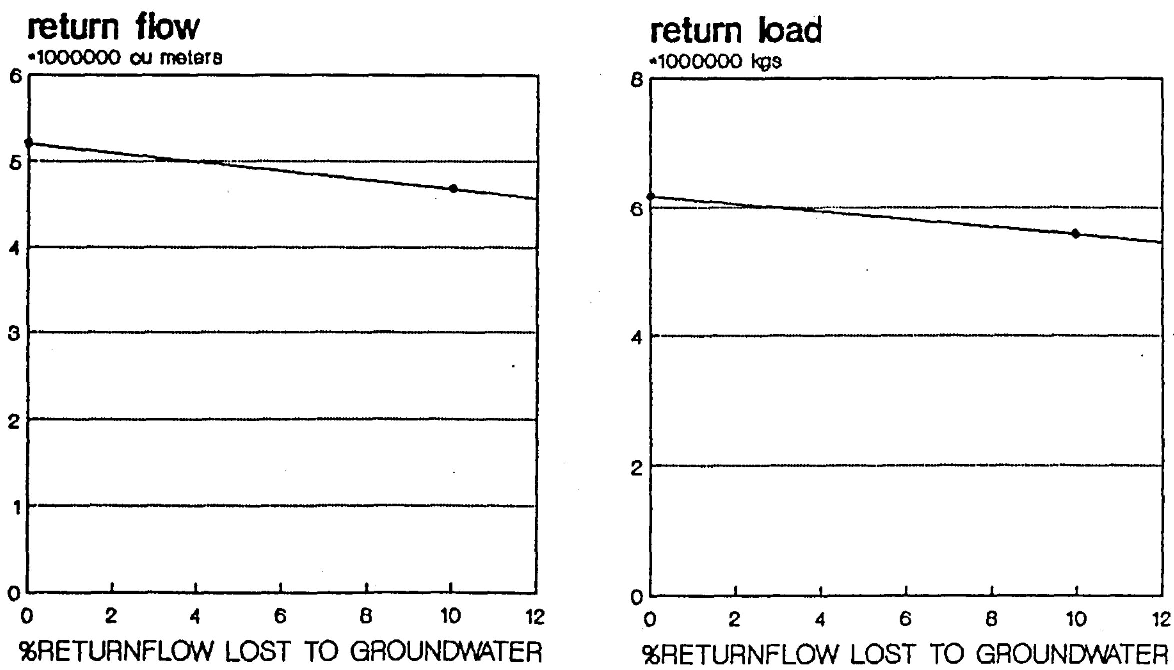
From Figure 22 it is evident that return flow and return load is virtually completely unaffected by changes in the rate of soil salt regeneration.

23.3.6 Rate of rootzone percolation

On analysis of the reaction of return flow and return load values, it was found that both are not at all affected by a change in the rate of rootzone percolation.

23.3.7 Percentage of return flow lost to groundwater

FIGURE 23 - SENSITIVITY TO CHANGES IN THE PERCENTAGE OF RETURN FLOW LOST TO GROUNDWATER



Although not spectacularly so, Figure 23 does indicate a degree of variation in return flow and return load values with a change in the percentage of return flow lost to groundwater.

23.3.8 Percentage increase in return flow salinity

FIGURE 24 - SENSITIVITY TO CHANGES IN THE PERCENTAGE OF RETURN FLOW SALINITY

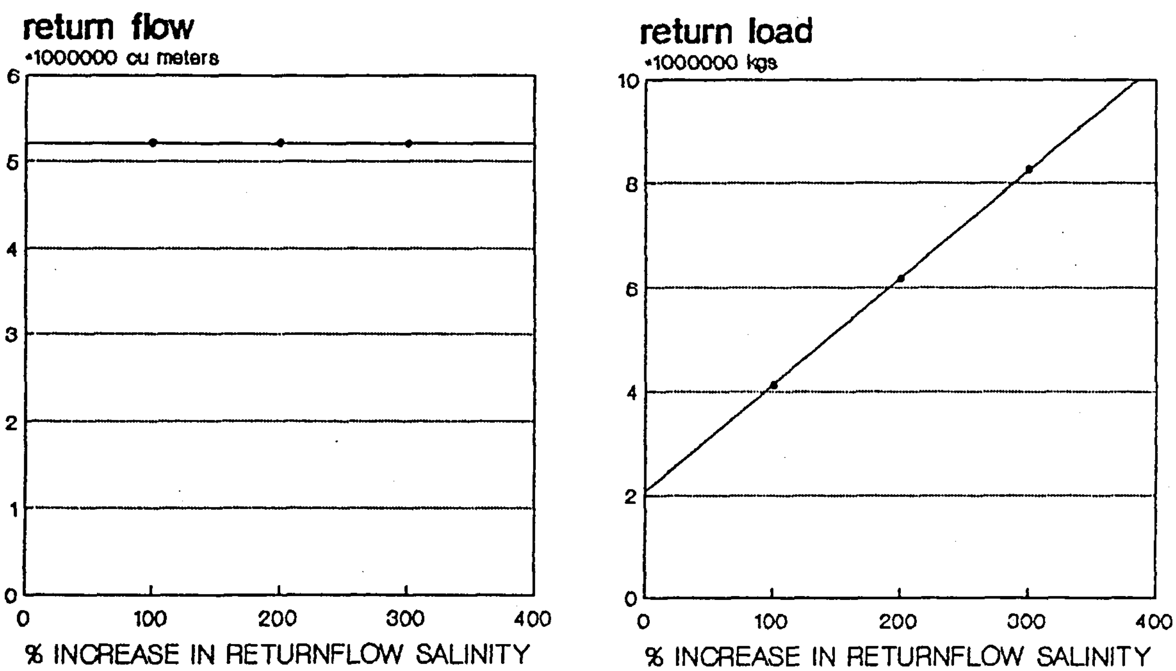


Figure 24 indicates a high degree of sensitivity of return flow values to changes in the percentage increase in return flow salinity.

24. ERROR ANALYSIS

24.1 General

This study was inter alia the testing ground for the IRRISS model. A large amount of information was gathered and it is envisaged that the data contained in this report will be used to perfect the IRRISS model or serve as an important data base for other similar models. It is therefore important to identify those parameters or groups of data in which serious errors could be incorporated.

From Section B of the report, the reader should be able to distinguish between accurately determined data, and data with potentially inaccurate elements incorporated. The following is a brief discussion on those parameters which possibly could include errors.

24.2 Soil classification

Division of the entire irrigation scheme into only two soil classes is a crude over generalisation. The soil classification, however, influences mainly the soil texture and therefore the field capacity and rate of percolation.

It was shown in Chapter 23 that the rate of rootzone percolation does not at all affect the final values of return flow and return load.

24.3 Gypsum application

The area and rate of gypsum application was derived from interviews with the farmers. Both the area and rate can be wrong, but it is unfortunately impossible to determine to what degree since the farmers who do apply gypsum on a regular basis seemingly do not keep any record. This is also aggravated by the practice of applying gypsum to localized trouble spots within a vineyard or orchard rather than a general application over the entire plantation.

24.4 Canal seepage loss rate

It was indicated in Chapter 23 that return flow and return load values are highly sensitive to changes in the canal seepage loss rate. On the other hand it was mentioned in Chapter 5 that the seepage loss rate calculated is very close to the expected.

The only way to check the seepage loss rate would be to do proper ponding tests on the canal. The negative attitude of the irrigation board towards such tests would however present a serious problem. It should be pointed out that since the groundwater table affects the canal seepage loss rate, it would be necessary to conduct such tests during the irrigation season when the board could least afford to put the canal out of commission for any period of time.

24.5 Farm dam seepage loss rate

Farm dam seepage loss rate was calculated from a relatively short record of daily stage readings. This could lead to an error in the calculation of the loss rate. However, once again the most accurate approach would be to isolate each farm dam for a considerable length of time during the irrigation season. For obvious reasons this would be impossible. Fortunately Figure 17 in Chapter 23 shows that an erroneous seepage rate would not seriously affect the water and salt balance results.

24.6 Water volumes

24.6.1 Canal flow rates

In Chapter 15 the problem of canal flow measurement is addressed. As pointed out the statistical calibration of the rating curves used to interpret canal flow depth recordings, showed a standard deviation of 8,9% on the calibrated coefficient. This leaves a margin of error of 17,8% in the canal flow rates calculated.

It should however be pointed out that this potential error would only influence results related to the primary distribution network. All diversions of water into farm dams or for direct irrigation was subjected to a separate secondary measurement.

24.6.2 Off-take flow rates

In Chapter 16 the method of off-take flow measurement adopted is described. It is also pointed out that the non-continuity of the measurements would lead to errors in the off-take flow data.

The exact margin of error is unfortunately impossible to determine but it can be pointed out that the calibration of off-take flow rates can be accepted with a high degree of confidence.

Erroneous off-take flow data will affect the calculation of volumes released from farm dams and therefore also the volumes applied to crops. This would in turn affect the irrigated soil return flows.

24.6.3 Volumes released from farm dams

Volumes released from farm dam were calculated from the differences in storage volume and measured off-take flow rates.

As mentioned above there could be an error built into the off-take flow rates. Storage volumes however, were calculated with a very high degree of accuracy. The margin of error in storage volumes is to all probability in the order of one to two percent.

Erroneous farm dam release volumes would influence irrigated soil return flow volumes.

24.7 Starting conditions and soil parameters

Apart from the initial farm dam storage volume none of the starting conditions and soil parameters were measured. All these parameters were set by calibration in which the salt equilibrium of the irrigated soil was used as the final measure of success.

Just how successful the calibration effort was, can be seen from the absence of any inexplicable trends in the daily time series outputs. Another proof of the success of the calibration effort is the final return flow salinities which very closely conform to the values that one would expect.

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