Under year 2000 demand conditions Vaal Dam does not spill at all because the floods of the 1933/34 wet season cannot completely fill the dam, which has been drawn down during the extremely severe 1929 - 1932 drought (see Fig. 4.4). It is of interest to note that under certain conditions peak salt concentrations in the Vaal Barrage are actually lower for year 2000 conditions than those modelled for 1990. This feature is most noticeable in November 1933 at the RWB Zuikerbosch intakes (see Fig. 4.5), and is traceable to changes in the relative magnitudes of water demands, effluent return flows, washoffs from the southern PWV catchment and the release of water from Vaal Dam required to make up the supply shortfall. In the simulation for the status quo option it is assumed that the release of water from Vaal Dam has to be minimized (as at present). Consequently, when the tributaries of the southern PWV catchment are in spate, releases from Vaal Dam are assumed to cease. For smaller floods, such as that of November 1933, the situation can arise that the tributary inflows are sufficient to satisfy demands under 1980 or 1990 conditions, but are not large enough to meet year 2000 demands. Thus under year 2000 conditions fresh water has to be called from Vaal Dam resulting in dilution of the Barrage water.

A second factor is the increasing dilution of catchment runoffs by the greater volumes of effluent discharged to the southern PWV tributaries. During small floods at the start of the wet season runoffs from developed catchments tend to be more saline than sewage effluents. As demands increase the ratios of effluent return flows to catchment runoffs also increase and, as a result, salt concentrations during small, early wet season floods can sometimes diminish. This effect is to a certain extent counteracted, however, by the increase in diffuse-source salt generation rates associated with increased catchment development. During larger floods this trend is reversed as catchment runoff salt concentrations are then lower than those of the effluent discharges. This effect is not very noticeable, however, as the flood discharges are then very much greater than the effluent discharges.

Fig. 4.5 indicates an improvement in water quality downstream of the Welkom Dam site (as shown by the plot of daily salt concentrations at the Western Transvaal Regional Water Company intakes) due to dilution by Bloemhof catchment runoffs. This could, however, be misleading for the following two reasons:

(i) Monthly catchment runoffs were used as input data. This inevitably results in an unrealistic damping of daily salt concentrations with consequently an apparent improvement in water quality.

and (ii) It has been assumed that the Bloemhof catchment is in a stationary condition (i.e. that the diffuse-source salt generation rate does not increase with time). This is patently untrue as considerable development is expected in this region (Herold, 1981b).

Improvement of the above assumptions can be made only once the Bloemhof catchment has been studied in greater detail. A study to the same depth as that undertaken for the southern PWV region will have to be initiated if greater accuracy is required.

Fig. 4.6 shows the heterogeneous nature of the present water supply distribution system (which was assumed to remain unaltered, except in scale, for the 1990 and year 2000 time horizons). In particular, users in the northern portion of the southern PWV region (e.g. supply sub-regions 1 and 3) receive a much more favourable blend of water than do those situated nearer to the Vaal Barrage (sub-regions 22 and 25). This is due to the fact that users adjacent to the Barrage (e.g. Vereeniging municipality) receive a larger proportion of water abstracted from the Barrage via the Vereeniging no. 1 and no. 2 intakes, where salt concentrations are higher, than from the RWB Zuikerbosch intakes (see Fig. 4.5).

The daily salt concentrations plotted in Fig. 4.5 are presented in the form of duration curves in Figs. 4.7 to 4.14. The salt concentrations exceeded 2, 10 and 50 percent of the time for each demand horizon have been extracted from the duration curves and these are plotted in Figs. 4.15 and 4.16. Exceedance levels for intervening time horizons have been interpolated between the points plotted for the 1980, 1990 and 2000 demand horizons. From curves such as these it is possible, using projected demands, to estimate the capital investment required (in terms of desalination plant and/or attenuation storage) to bring the water to a standard satisfactory for industrial use. Together with the annual running costs provided by the montnly model (Herold, 1981b) and estimates of engineering costs, this information can be used in benefit-cost analyses thereby allowing objective comparisons to be made among options.

Some options might be ruled out without recourse to an economic analysis (if, for example, the salinity levels reflected in Figs. 4.15 and 4.16 represent an unacceptable health hazard).

Once the best option has been found, curves such as those of Fig. 4.16 would enable individual industrialists to optimise the sizing and timing of new capital plant required to treat water to a standard suitable to their own needs.

It must be remembered that Figs. 4.15 and 4.16 do not represent the most likely projections of future TDS frequency distributions, but merely one of a large number of possibilities. Indeed, the 1933/34 hydrology can be regarded as somewhat unique in that it contains the 1934 flood which broke the most severe drought recorded in this region. Duration curves such as Figs. 4.7 to 4.14 will have to be constructed using several different hydrological sequences as input before curves representing the most likely exceedance levels can be produced (see section 4.1). Furthermore, each curve will have an associated confidence band.

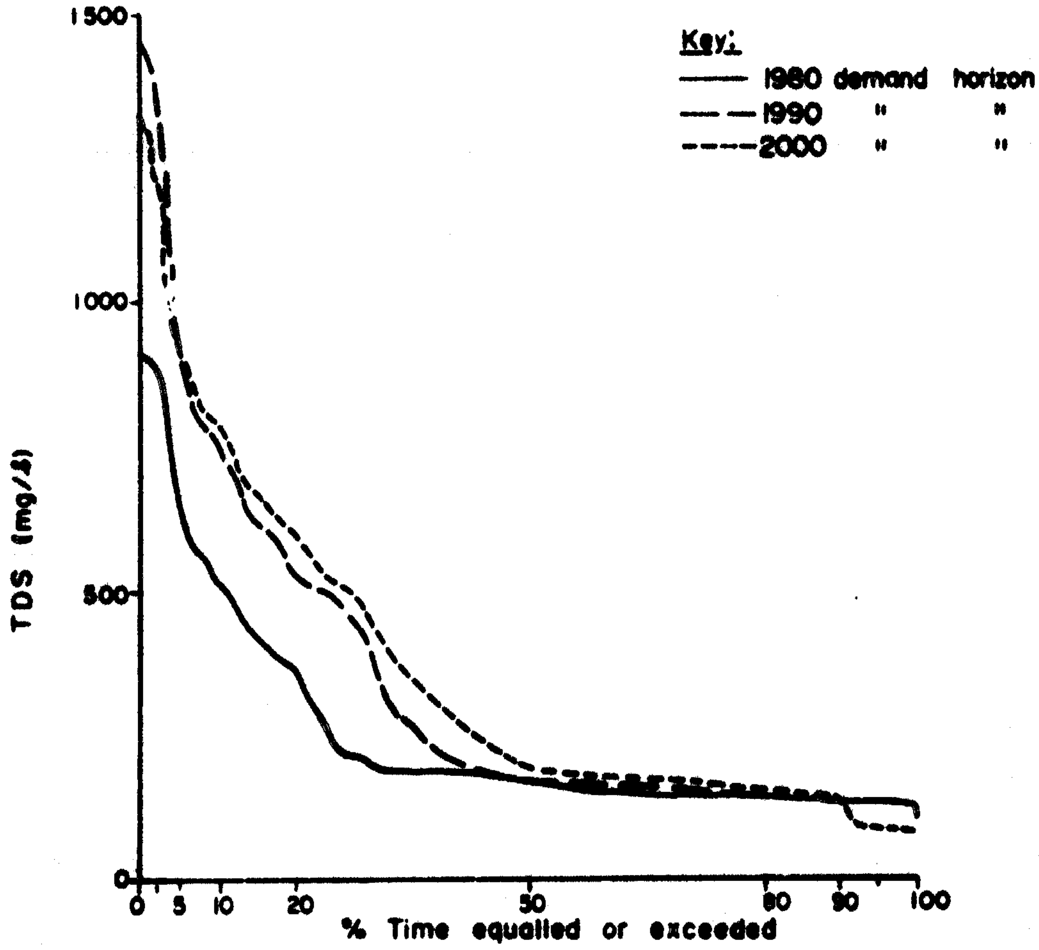

Fig.4.7: Duration curves of modelled daily TDS concentrations at RWB Zuikerbosch intakes

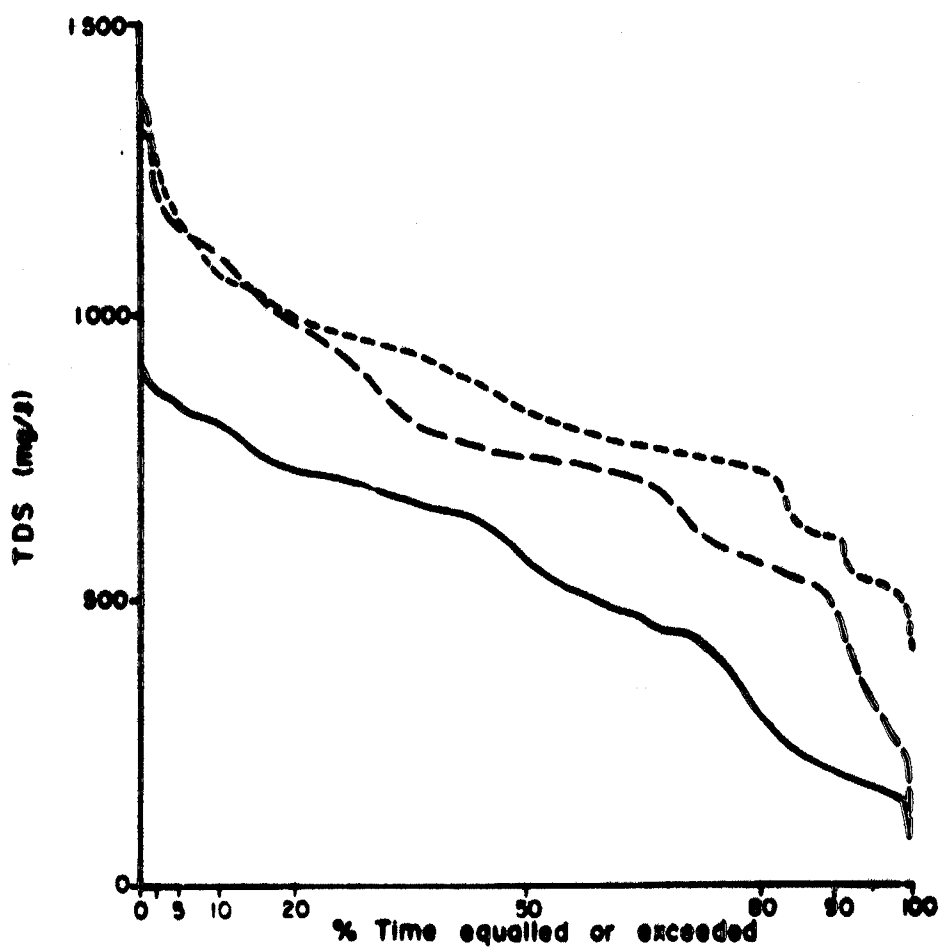

Fig.4.8: Duration curves of modelled daily TDS concentrations at RWB Vereeniging intakes

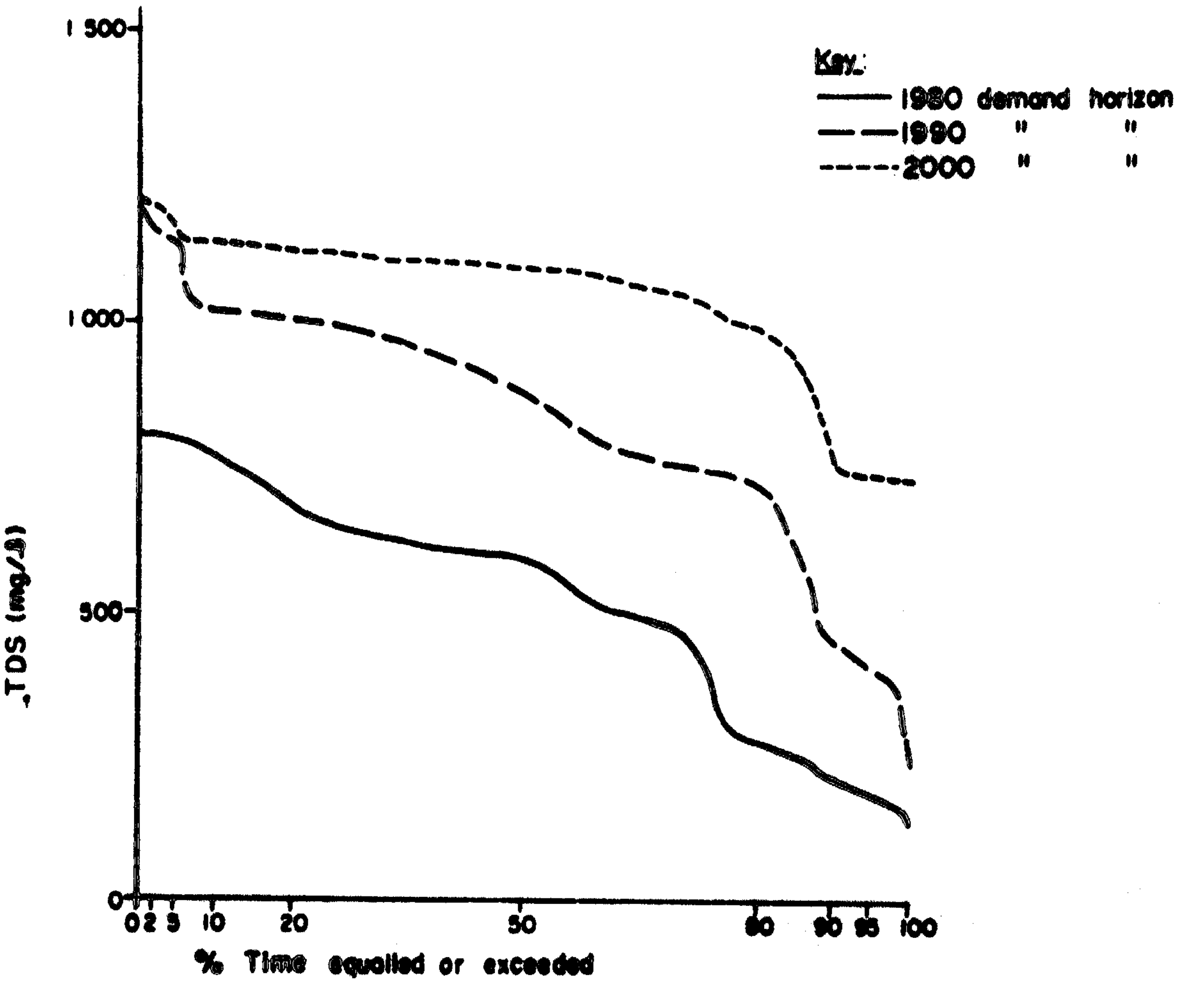

Fig. 4.9 : Duration curves of modelled daily TDS concentrations in Vaal river at Welkom Dam site

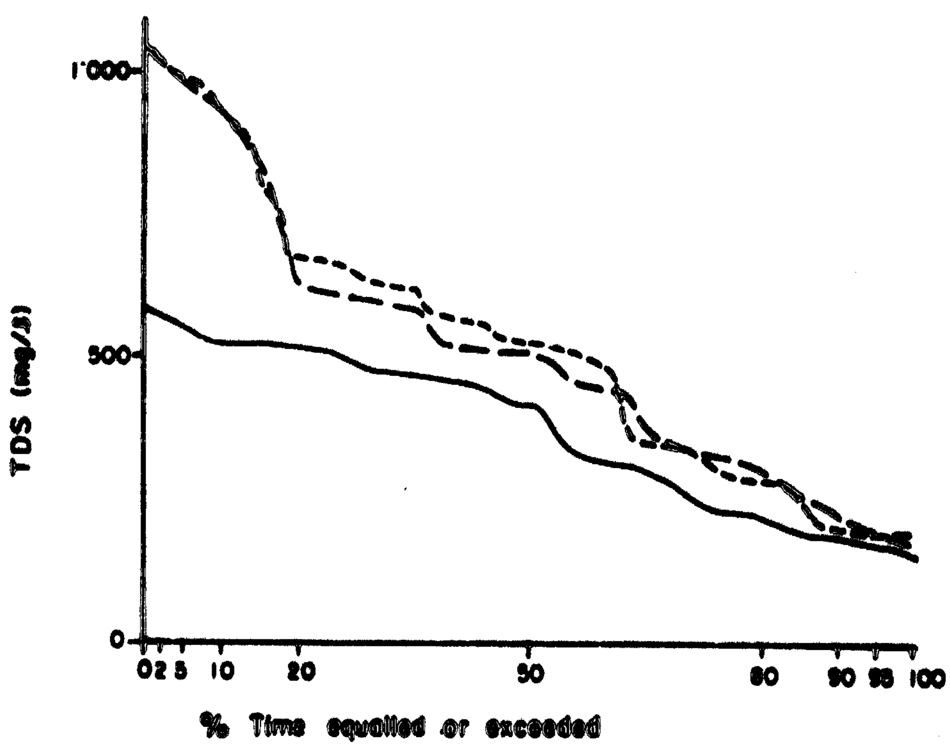

Fig. 4.10 : Duration curves of modelled daily TDS concentrations at Western Transvaal Regional Water Company Vaal river intakes

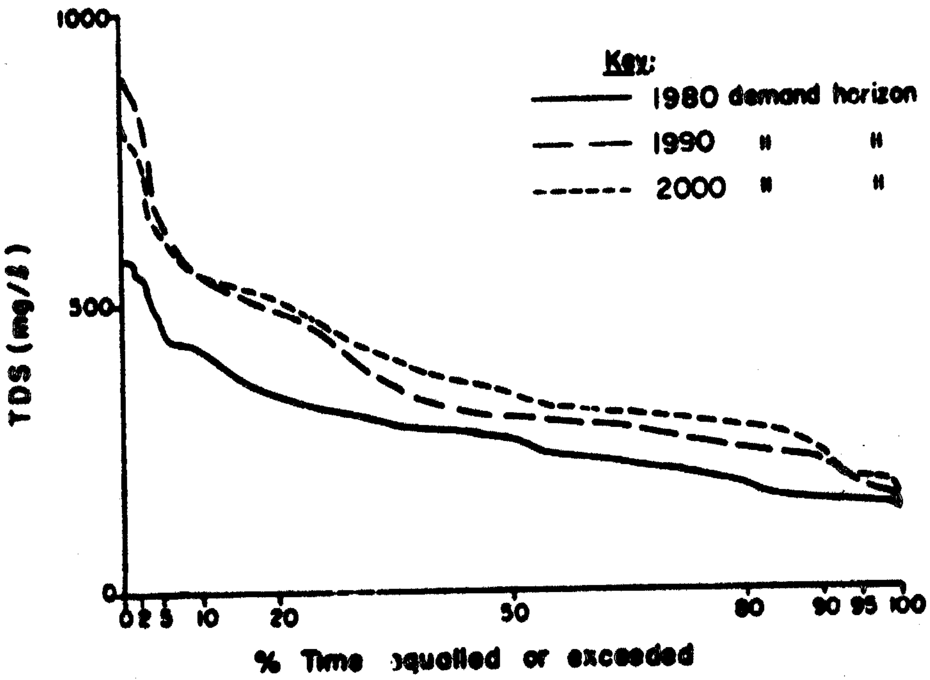

Fig.4.11: Duration curves of modelled daily TDS concentrations of water supplied to sub-region 1

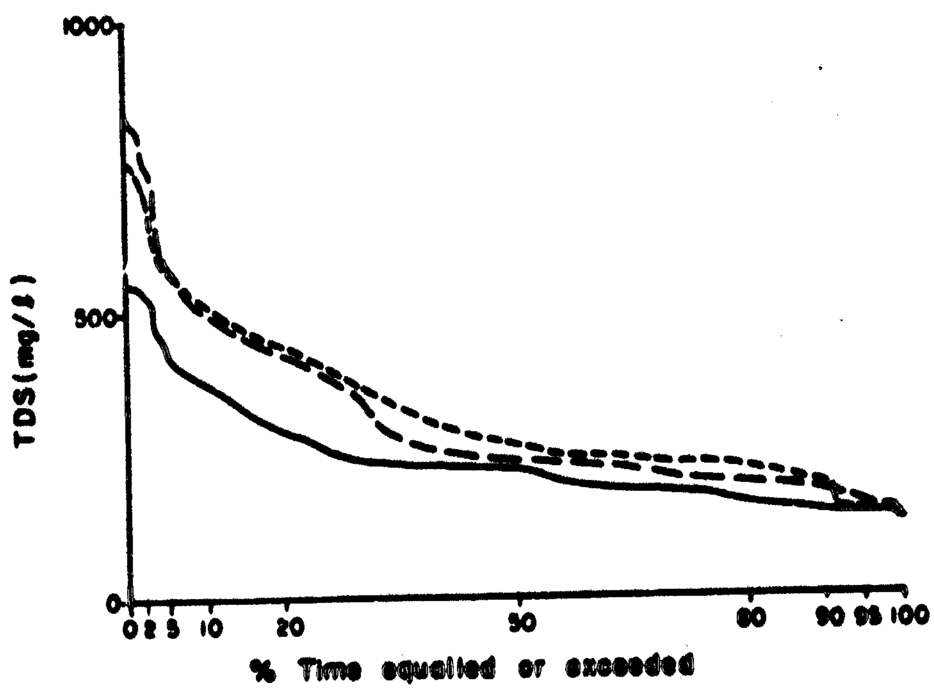

Fig.4.12: Duration curves of modelled daily TDS concentrations of water supplied to sub-region 3

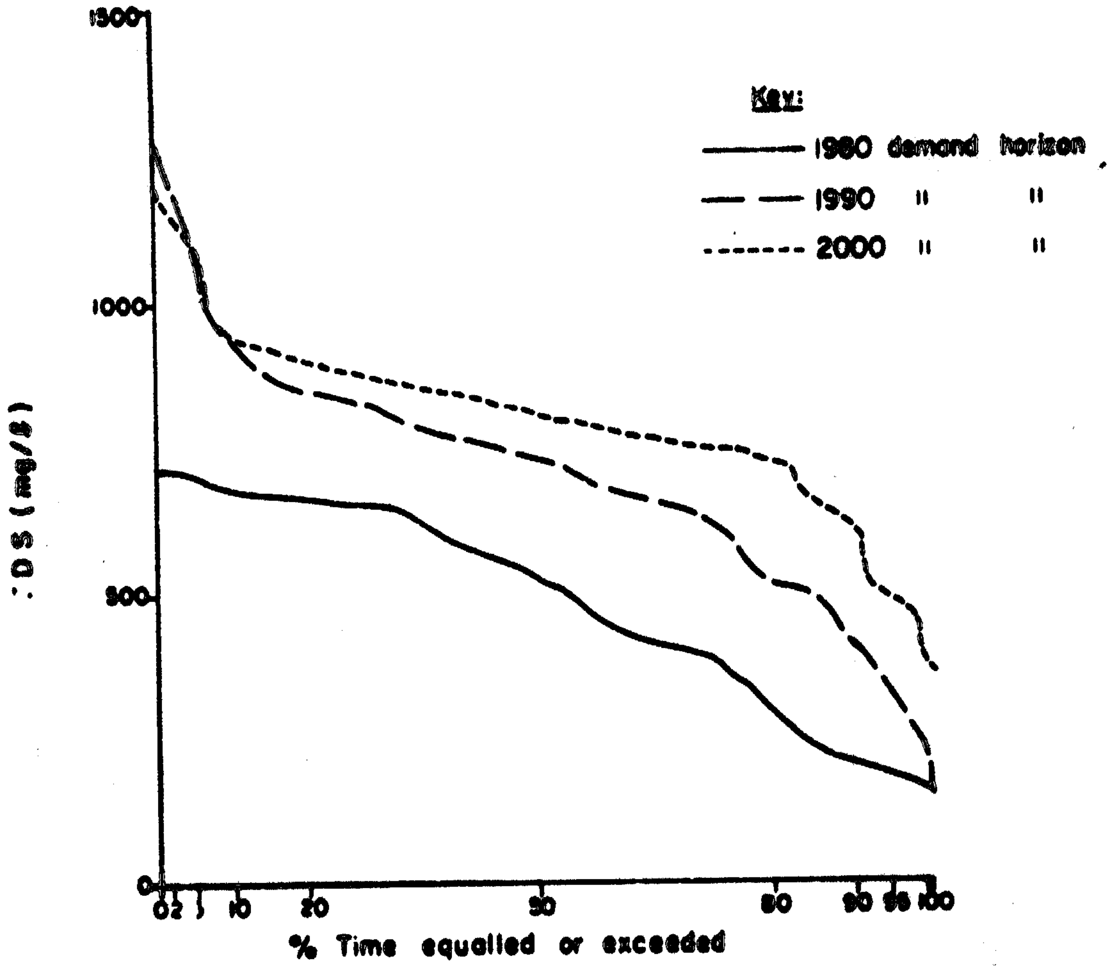

Fig.4.13: Duration curves of modelled daily TDS concentrations of water supplied to sub-region 22

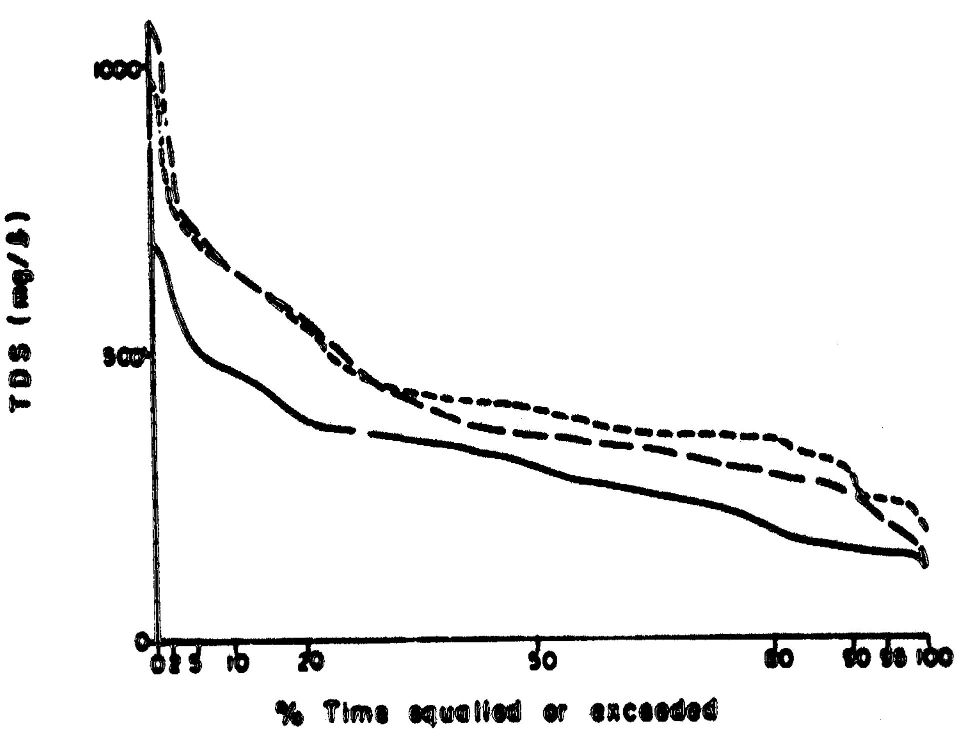

Fig.4.14: Duration curves of modelled daily TDS concentrations of water supplied to sub-region 26

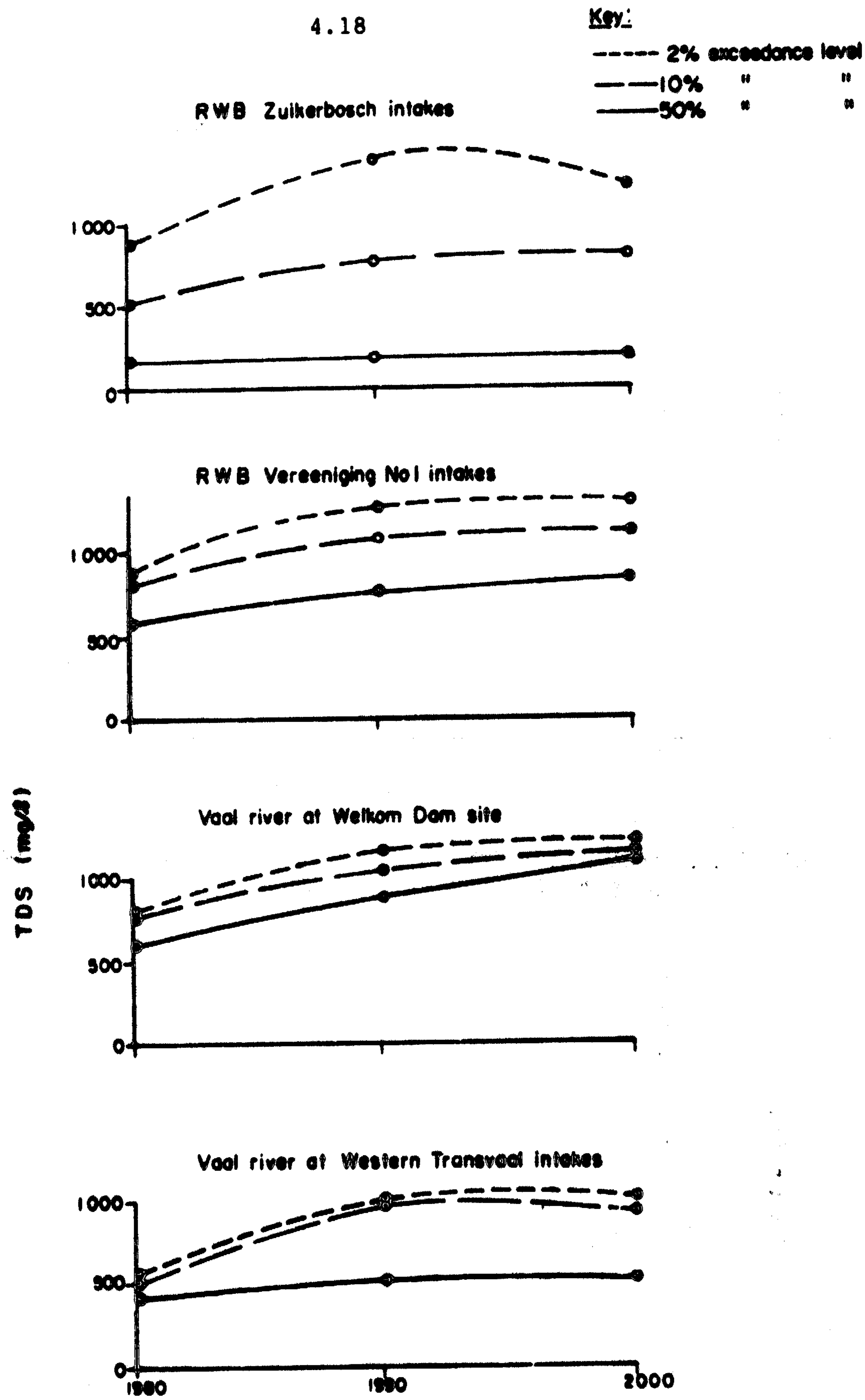

Fig. 4.15.: Time series of expected future exceedance levels of TDS at various points in the Vaal Barrage should 1933/34 hydrology recur

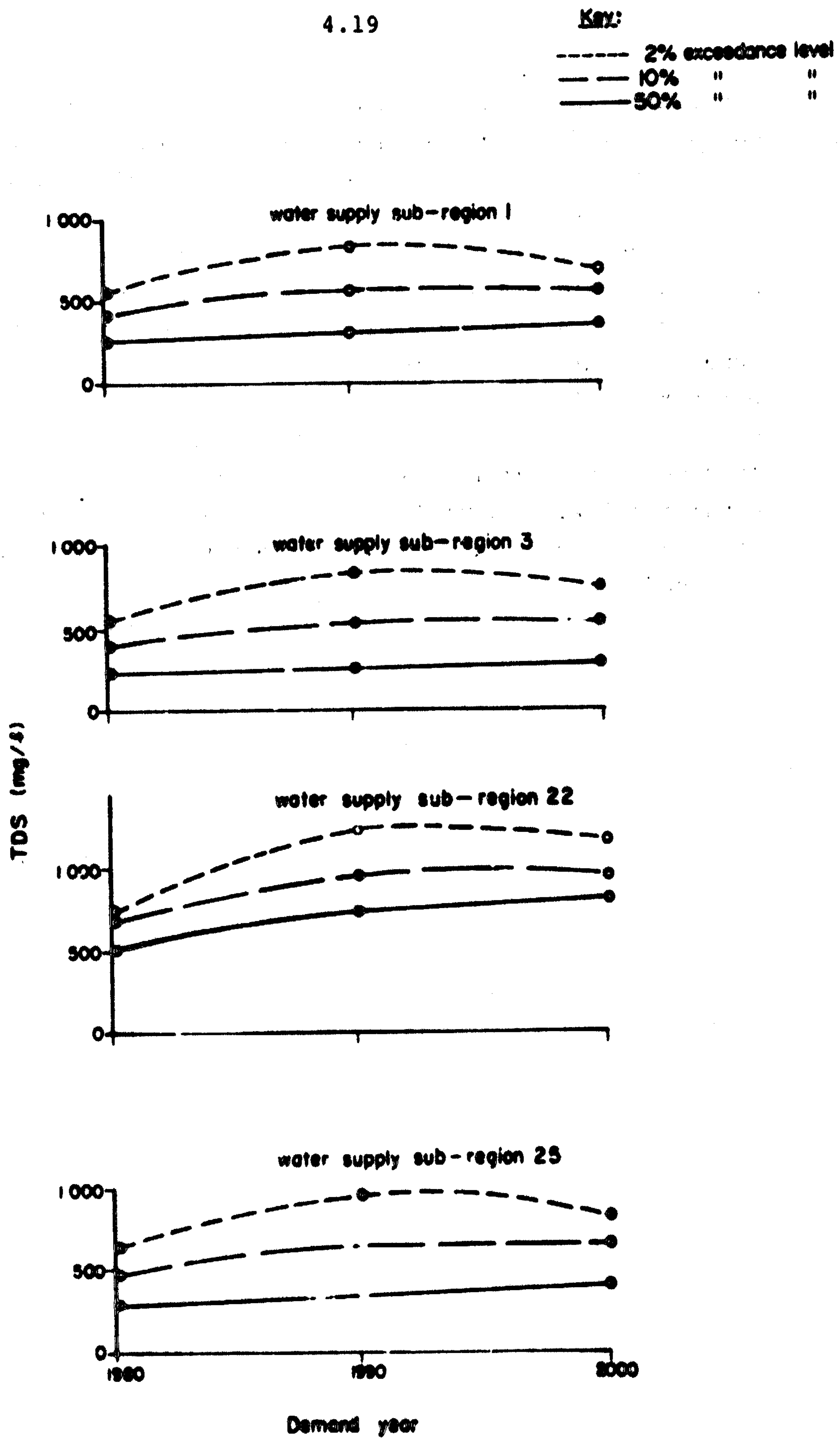

Fig. 4.18: Time series of expected future exceedance levels of TDS in water supply should 1933/34 hydrology recur

Confidence levels associated with each exceedance level may have little significance when comparing one option with another, but could be of importance to users who wish to assess the risk of having to shut down plant when the design capacities of their treatment works are exceeded. Such users might also need to examine carefully diagrams such as Fig. 4.6 to determine for how many days unfavourable conditions are likely to persist. The high salinity of the water that will be supplied under the status quo option to users in sub-region 22, should the hydrology of November 1933 recur coincidentally with the 199[illegible] or 2000 A.D. demand conditions, would probably force an industry to shut down for as long as a month if its water treatment plant is inadequately designed.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

A numerical model of the Vaal system capable of simulating daily discharges and salt concentrations in the tributaries of the southern PWV region and at key points in the Vaal river has been developed, tested and demonstrated. With the model daily TDS concentrations of water supplied to users in the southern PWV region, as well as effluent return-flow salt loads can be computed, thereby closing the water supply/effluent return flow/water supply cycle. Daily fluctuations of water and salt storages in the major dams of the Vaal basin can also be simulated.

The model is designed for use in conjunction with the other models in the series (HRU Reports 1/80 (Herold, 1980), 4/80 (Mileikowsky, 1980), 3/81 (Herold, 1981a) and 4/81 (Herold, 1981b) to compare the effectiveness of a wide variety of options for reducing mineralization levels in the water supply system of the Vaal basin.

Outputs from the model, in the form of time series plots and duration curves of daily salt concentrations at key points in the system, provide a basis for comparing the effectiveness of various ameliorative measures. In particular, present-day as well as future salinity frequency distributions appropriate to each key point and each operational strategy can be constructed in the manner described in Chapter 4, thereby facilitating estimation of capital investment in treatment plant required by consumers (HRU Report 4/81 (Herold, 1981b) outlines how this may be done).

In the feasibility study phase these results, together with the operation and maintenance costs to consumers as well as additional water requirements estimated by means of the monthly feed-back model (Herold, 1981b), can be used to compare the benefits to be derived from a wide range of alternative options. The costs of implementing these options will then have to be estimated for each of the more attractive alternatives. (Some options may be shown up by the model as making little, if any, contribution to improving water quality and could therefore be discarded without recourse to expensive engineering feasibility studies). Here, too, the model results will be of some assistance. For example, the salinity frequency distributions generated by the daily feed-back model will enable the required capacity of desalination works to be estimated, or will permit the sizing of holding dams on the Klip and Suikerbosrand to be optimized. The monthly feed-back model can also provide some indication of the additional fresh water importation required to meet system demands appropriate to each option.

Once an option has been selected the models can be used in the design stage to facilitate optimization of the sizing of structures, the operating policies and the commissioning dates for new works. Thereafter, the model can also be used to guide the day-to-day operations of the system.

Finally, predictions of salinity frequency distributions likely to be encountered in the future as the result of implementation of a selected option (compiled in the manner described in Chapter 4) can be circulated to interested parties who might benefit economically from the predictions. For example, an option that will damp out variations in TDS of the water supply would enable industrialists to reduce the design capacities of their treatment plants. On the other hand, if such information is withheld, designs based on frequency distributions experienced in the past will continue to be used, thereby partially negating the benefits that might have accrued from the new strategy. (Savings in operating and maintenance costs on the other hand would not be affected by failure to inform consumers).

The following recommendations (other than those outlined in previous reports) emerge:

a) It is desirable that the relationships between TDS concentrations and costs to consumers arrived at by Heynike (1980) be extended to take account of the effect on capital costs of changes in the TDS frequency distribution. This is considered necessary because the capital costs used by Heynike resulted from a canvass of major users who were asked to estimate capital costs associated with increases in TDS concentrations from the present 300 mg/l to 500-600 mg/l and then to 800 mg/l. It is surmised that these estimates by consumers were based on the assumption that the frequency distributions for the higher average TDS levels would be similar in shape to those experienced at present. Certain options, however, aim at reducing the TDS fluctuations with resultant reduction in plant design capacities (which are to a large extent determined by peak salinity).

b) A more detailed study of the relationship between water supply and effluent return flow quantities and salt concentrations along the lines suggested in Appendix A is recommended, both for the southern and for the northern PWV catchments. Ultimately, such a study will probably also be required for the Bloemhof catchment as well.

c) Daily TDS fluctuations in the water abstracted from the Vaal river between Vaal Barrage and Bloemhof Dam cannot be modelled with accuracy until the Bloemhof catchment has been studied in greater detail. A study of the Bloemhof catchment is considered imperative in view of the accelerating development taking place in this region (most of which is supplied with water pumped from the Vaal river). Furthermore it should be noted that simulations run with the monthly feed-back model (Herold, 1981b) indicate the likelihood of a future salinity build-up in Bloemhof Dam, which supplies water to the important Vaal-Harts irrigation scheme. The extent of the problem cannot be assessed unless the salt contribution of the Bloemhof catchment is known. Already several mines discharge saline water pumped from underground workings to streams draining this catchment and secondary industries are rapidly expanding.

d) It is strongly recommended that the models be used in the manner outlined in this report and in HRU 4/81 (Herold, 1981b) to compare the effectiveness of various options. Valuable time and money can be saved if the options are first screened by means of the model before expensive engineering feasibility studies are embarked upon. The dangers of starting engineering feasibility studies at too early a stage are threefold:

(i) In the first place, time and effort may be wasted in making detailed investigations of options that in the end will have to be abandoned in favour of more effective ones (which the model results could readily identify)

(ii) Secondly, options may exist (indeed some are highlighted in HRU Report 4/81) that could be implemented as interim measures at virtually no additional capital cost and which are likely to result in the saving of many millions of rands (possibly hundreds of millions) to users in the PWV region over the next few years. Any delay in examining such short term options will be at enormous cost to the community (whereas delay in examining the long term options which may only have to be implemented several years from now will cost nothing);

and (iii) finally, the danger exists that once substantial time and funds have been invested in engineering feasibility studies of less attractive options considerable pressure (both as a result of familiarity with the option and impatience on the part of decision-makers to see results) will build up for the adoption of those options which are investigated first, regardless of the possibility that other much more favourable options may exist.

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APPENDIX A INPUT DATA USED IN MODEL SIMULATIONS

It is not the purpose here to describe in detail all the input data used in program NACLØ9 as this appears elsewhere (Watson, 1981). Attention is instead focused on the adopted model parameter values (either assumed or derived). In some instances these have already been discussed and can be referred to in the previous reports of the PWV series (Herold, 1981a and 1981b).

For the sake of convenience the data have been divided into four sections. Section A.1 deals with input data read by sub-routine SUBTRI while sections A.2. A.3 and A.4 refer to data used by sub-routines SUBDAM, SUBFBK and SUBDAM.

A.1 Input data for subroutine SUBTRI

Channel geometry, friction factors, vlei areas, irrigated areas, bed losses, evaporation factors and other such characteristics of each river reach of the southern PWV tributary system were assumed to remain the same as at present. A full description of these data appears in HRU Report 3/81 (Herold, 1981a).

Daily catchment runoffs and associated daily salt concentrations were modelled for each of the 12 sub-catchments of the southern PWV region (see Fig. 3.1) using the daily washoff model (Herold, 1981a). It was assumed that the diffuse-source salt generation rate for each sub-catchment would grow in proportion to the growth of the industrial water demands. Details of rainfall and evaporation data, projected industrial water demands and model parameters used in this model for each sub-catchment are to be found in HRU Reports 3/81 (Herold, 1981a) and 4/81 (Herold, 1981b).

A.2 Input data for subroutine SUBBAR

A.2.1 Model parameters

The only calibration parameters used in this subroutine are the computational time-step, BARDEL, and the dispersion coefficient, BARDIS. Mileikowsky (1980) found the best values to be 43200 s and 0,020 m^2/s respectively.

A.2.2 Barrage water demands and downstream requirements

The minimum allowable release from Vaal Barrage, RELMIN, was set equal to 4 m^3/s. Annual abstraction rates from the nine Barrage intakes (see Fig. 2.2) were assumed to bear the same proportions to one another as at present. Abstraction rates for the 1990 and 2000 demand horizons were calculated as follows:

$$d_{h,i} = d_{1980,i} \cdot \frac{D_h}{D_{1980}} \qquad \text{(A.1)}$$

where $d_{h,i}$ = average abstraction rate at intake i for time horizon h

$d_{1980,i}$ = average abstraction rate at intake i for 1980 time horizon

D_h = total PWV region demand for time horizon h

D_{1980} = total PWV region demand for 1980 time horizon

Average abstraction rates for the three time horizons are given in Table A.1. The total PWV region demands given in the second column of Table A.1 are derived from Table 3.4 of HRU Report 4/81 (Herold, 1981b).

Table A.1 Vaal Barrage monthly abstraction rates for A.D. 1980, 1990 and 2000 time horizons

Demand horizon	Total PWV demand ($m^3 \times 10^6$/year)	Abstraction point no.	Abstraction rate (Ml/d)											
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1980/81	874	1	46	42	53	50	50	49	55	48	53	53	41	55
		2	49	49	48	48	48	48	46	46	47	49	47	49
		3	184	107	153	182	104	199	216	175	144	180	183	195
		4	341	245	316	347	301	379	368	357	359	266	351	393
		5	1	1	1	1	1	1	1	1	1	1	1	1
		6	23	30	21	21	26	29	25	30	29	25	29	30
		7	0	0	0	0	0	1	1	1	1	0	0	0
		8	821	816	701	941	922	902	860	882	726	823	722	793
		9	137	114	85	157	144	152	147	150	147	149	157	125
1990/91	1456	1	77	69	87	84	84	82	92	80	88	88	69	92
		2	82	82	80	80	80	80	76	76	78	82	78	82
		3	306	179	255	304	174	333	359	292	241	300	306	325
		4	568	408	527	579	503	633	613	594	598	443	585	655
		5	2	2	2	2	2	2	2	2	2	2	2	2
		6	38	49	35	34	44	48	42	50	48	42	48	50
		7	0	0	0	0	0	2	2	2	2	0	0	0
		8	1368	1359	1168	1569	1536	1504	1433	1470	1210	1372	1204	1322
		9	228	189	142	262	241	254	245	250	245	248	262	208
2000/01	2358	1	124	112	142	136	136	133	149	130	142	142	112	149
		2	133	133	130	130	130	130	124	124	127	133	127	133
		3	496	289	413	492	282	539	582	474	390	486	496	527
		4	921	661	853	938	815	1025	994	963	969	719	948	1062
		5	3	3	3	3	3	3	3	3	3	3	3	3
		6	62	80	56	56	71	77	68	81	77	68	77	81
		7	0	0	0	0	0	3	3	3	3	0	0	0
		8	2216	2201	1892	2543	2490	2438	2323	2382	1961	2224	1951	2143
		9	369	307	230	424	390	412	396	406	396	403	424	338

A.3 Input data for subroutine SUBFBK

A.3.1 Parameter RETEN

For each water supply sub-region a detention storage is specified to account for mixing of water in the distribution network and in the supply reservoirs (see section 2.5). For all 27 supply sub-regions the value of RETEN was assumed to be 3 days.

A.3.2 Parameter CRET

CRET is an initialization parameter defining the effluent return-flow salt concentration for each supply sub-region for the first day simulated. These s arting values are, however, of little significance in view of the one month warming-up period specified for each simulation.

A.3.3 Parameters ICELL, PCELL and CADD

The proportions of water abstracted from various points in the Vaal Barrage and from Vaal Dam, which define the blend of water delivered to each supply sub-region, and the average increases in TDS concentration were computed by the three alternative methods discussed in sections A.3.3.1 to A.3.3.3.

A.3.3.1 Rand Water Board water supply regions method

The Rand Water Board is responsible for water supply to most of the PWV region, the only exceptions being industries and power stations, situated near to the Vaal Barrage and operating their own pumps, and mines which use some of the water pumped from underground. Most of these, however, also buy water from the Rand Water Board (or from municipalities supplied by the Board). Estimation of the mixing proportions for users operating their own pumps is dealt with in section A.3.3.

The distribution network of the PWV region is extremely complex and for this reason it is impracticable to estimate mixing proportions on the basis of discharges through each pipe-line. (These in any case vary in accordance with day

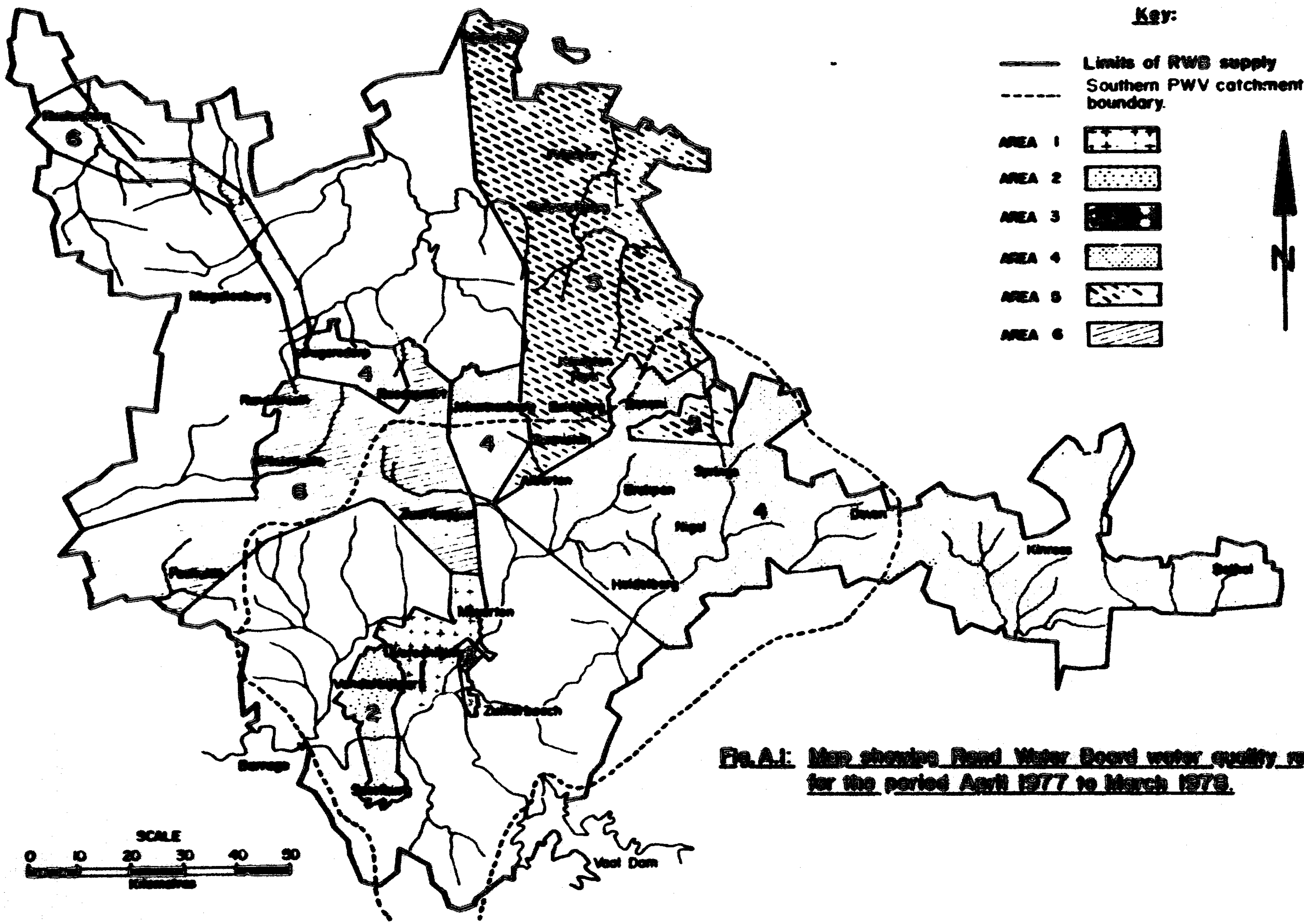


Fig. A.1: Map showing Rand Water Board water quality regions for the period April 1977 to March 1978.

by day demand fluctuations throughout the system)

The Rand Water Board has for several years collected and analysed water samples from service reservoirs in the southern PWV region. On the basis of the results of these analyses six regions have been identified as receiving homogeneous mixes of water (Fig. A.1). The average monthly TDS concentrations for the year April 1977 to March 1978 (Rand Water Board, 1978) were used in conjunction with contemporaneous salt concentrations of the water abstracted from Vaal Dam and Vaal Barrage to estimate the proportion of water abstracted at each of the four RWB abstraction points that went to each of the six RWB water supply regions.

Fortunately most of the water supplied by the RWB passes through only two purification works (Zuikerbosch and Vereeniging) and monthly values of quantity and quality of water delivered to these two works from the Vaal Barrage Vereeniging No. 1 and 2 intakes, Zuikerbosch intakes and direct from Vaal Dam are known (see Fig. A.2). It should be noted, however, that mixing in the purification works is not complete. For example, Vanderbijlpark municipality (see Fig. A.1) receives a blend of water with a higher-than-average proportion of Vaal Dam water (flow line Q_4 of Fig. A.2).

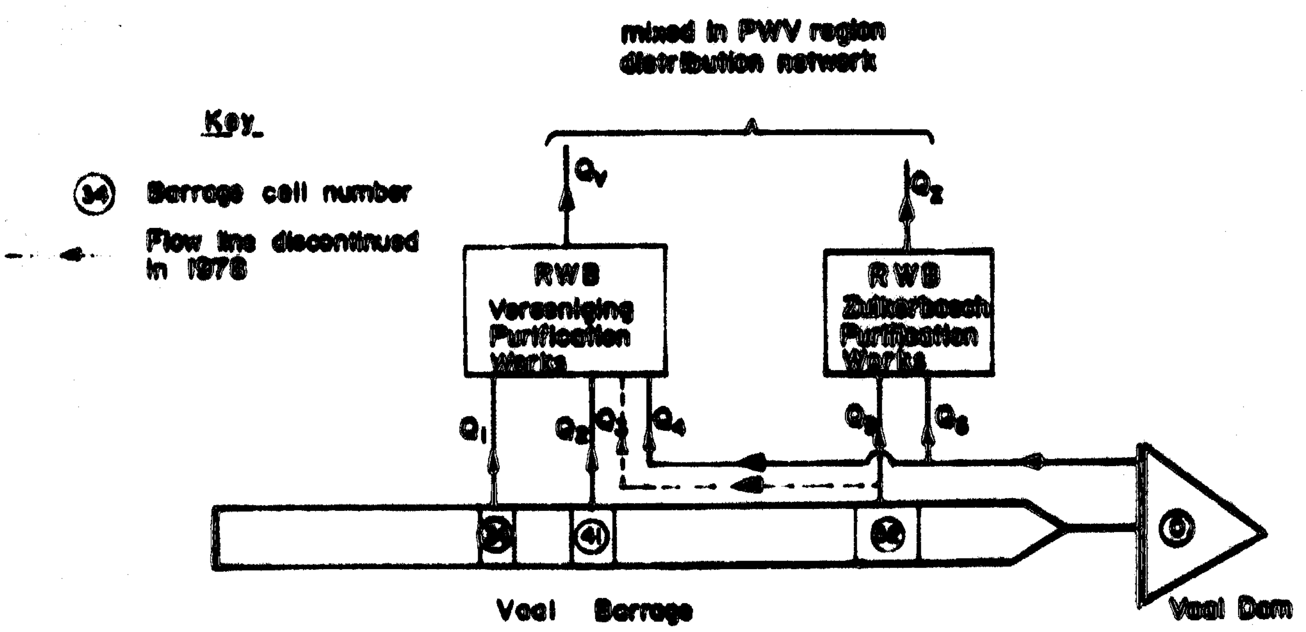


Fig. A.2: Flow diagram for RWB water supply

The average monthly discharges (Q_1 to Q_6 of Fig. A.2) together with average monthly salt concentrations measured in the Vaal Dam pipeline and in the Vaal Barrage at the Zuikerbosch and Vereeniging Nos. 1 and 2 intakes were then used to calculate C_V and C_Z, the monthly average monthly salt concentrations of water leaving the Vereeniging and Zuikerbosch purification works. The mixing proportions of Vereeniging and Zuikerbosch water for each RWB supply region were then calculated as:

$$P_{V,i} = \frac{1}{12} \cdot \sum_{j=1}^{12} \left[\frac{C_{i,j} - C_{Z,j}}{C_{V,j} - C_{Z,j}} \right] \quad \text{(A.2)}$$

and $$P_{Z,i} = 1 - P_{V,i} \quad \text{(A.3)}$$

where $P_{V,i}$ = average proportion of Vereeniging purification works water supplied to RWB region No. i for period April 1977 to March 1978

$C_{i,j}$ = observed salt concentration of water supplied to RWB region No. i during month j (mg/l)

$C_{Z,j}$ = calculated salt concentration of water leaving Zuikerbosch purification works during month j (mg/l)

$C_{V,j}$ = calculated salt concentration of water leaving Vereeniging purification works during month j (mg/l)

$P_{Z,i}$ = average proportion of Zuikerbosch purification works water supplied to RWB region No. i for the period April 1977 to March 1978

and $$C_{Z,j} = \frac{Q_5 \cdot C_{52} + Q_6 \cdot C_o}{Q_5 + Q_6} \quad \text{(A.4)}$$

$$C_{V,j} = \frac{Q_1 \cdot C_{34} + Q_2 \cdot C_{41} + Q_3 \cdot C_{52} + Q_4 \cdot C_o}{Q_1 + Q_2 + Q_3 + Q_4} \quad \text{(A.5)}$$

where $Q_1, Q_2, \ldots Q_5$ = flow line discharge during month j as defined in Fig. A.2 (Ml/d)

C_{34} = Barrage salt concentration at Vereeniging No. 2 intakes during month j (intake No. 3 of Fig. 2.2) (mg/l)

C_{41} = Barrage salt concentration at Vereeniging No. 1 intake during month j (intake No. 4 of Fig. 2.2) (mg/l)

C_{52} = Barrage salt concentration at Zuikerbosch intakes during month j (intake No. 8 of Fig. 2.2) (mg/l)

C_o = Salt concentration of water delivered to RWB works via pipeline from Vaal Dam (mg/l)

The proportions of water from Vaal Barrage cells 34, 41 and 52 and from Vaal Dam (pseudo-cell O) for each of the six RWB supply regions were then calculated as follows:

$$P_{34,i} = P_{V,i} \cdot \frac{Q_1}{Q_V} \quad \text{(A.6)}$$

$$P_{41,i} = P_{V,i} \cdot \frac{Q_2}{Q_V} \quad \text{(A.7)}$$

$$P_{52,i} = P_{V,i} \cdot \frac{Q_3}{Q_V} + P_{Z,i} \cdot \frac{Q_5}{Q_Z} \quad \text{(A.8)}$$

$$P_{O,i} = P_{V,i} \cdot \frac{Q_4}{Q_V} + P_{Z,i} \cdot \frac{Q_6}{Q_Z} \quad \text{(A.9)}$$

where $P_{k,i}$ = proportion of water supplied to RWB region i abstracted from cell k

$$Q_V = Q_1 + Q_2 + Q_3 + Q_4 \quad \text{(A.10)}$$

$$Q_Z = Q_5 + Q_6 \quad \text{(A.11)}$$

The mixing proportions for each cell for each of the six RWB regions are given in Table A.2.

Table A.2 Mixing proportions for each RWB supply region

RWB supply region	Cell number				Correlation coefficient
	34	41	52	O	
1	0,31	0,63	0,03	0,03	0,9899
2	0,10	0,19	0,34	0,37	0,8702
3	0	0	0,48	0,52	0,6754
4	0,14	0,28	0,28	0,30	0,9571
5	0,04	0,08	0,42	0,46	0,8206
6	0,03	0,06	0,44	0,47	0,9144

The mixing proportions given in Table A.2 were then used together with the observed monthly cell salt concentrations to predict the quality of the water supplied to each RWB supply region. The correlation coefficients obtained between observed and predicted monthly values are given in Table A.2. (The means are of course identical because the same twelve observed values were used to compute $P_{V,i}$ and $P_{Z,i}$ in equations A.2 and A.3). The poor correlation for sub-region 3 is attributable to variations in demands and possibly changes in valve openings. Fortunately this region is very small (see Fig. A.1) and receives only a small proportion of the total RWB supply.

It should be noted that, because of non-uniform growth rates of demand accompanied by laying of new pipelines, the boundaries of the RWB regions of homogeneous mixing proportions are by no means fixed. A recently produced RWB report (Rand Water Board, 1980), for instance, indicates slightly altered regional boundaries for the period April 1979 to March 1980.

For the purposes of the simulations in this report it was assumed that the RWB regional boundaries would remain constant as at 1977/78. (This assumption was made for the verification run from 1973/74 to 1978/79 as well as for the simulations of demand conditions for the years 1980, 1990 and 2000.

The major effluent point sources were next located and the mixing proportions for water supplied to each user discharging effluent were estimated according to the RWB region within which they were situated. In the case of municipalities straddling two or more RWB regions the mixing proportions were weighted according to the areas falling within each region. The locations of the major effluent point sources of the southern PWV region are shown in Fig. A.3 and descriptions of each are given in Table A.3. Based on the method described in this section, Table A.4 gives the mixing proportions used for municipalities and industries supplied exclusively with RWB water.

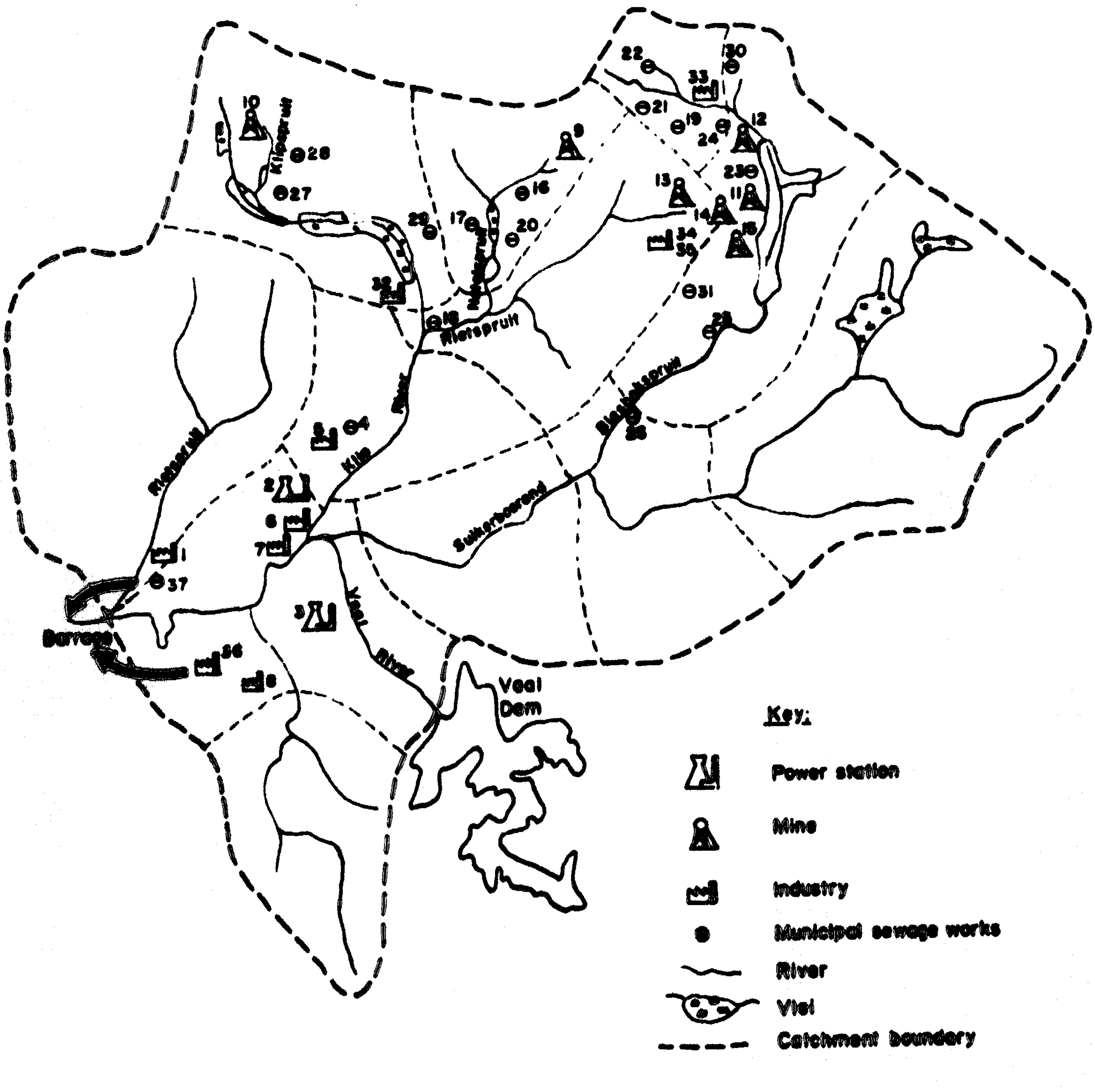


Fig.A.3: Location of major effluent point sources in the southern PWV region

Table A.3 Details of effluent point sources

Point source			Mean 1977/78 values		Period of record	
Code No. (Fig. A.3)	Flow line[1] code	Description	Discharge (Ml/d)	TDS (mg/l)	Discharge	Water Quality
1	A1232	ISCOR steel works	27	1397	1965-1979	1965-1979
2	A1333	Klip Power Station	5	1579	1968-1979	1974-1979
3	A1631	Vaal Power Station	8	311	1974-1979	1974-1979
4	A5231	Meyerton sewage	0,4	536	1978-1979	1978-1979
5	A7531	Metalloys effluent	0,2	837	1975-1979	1975-1979
6	A7831	USCO effluent	1	554	1975-1979	1975-1979
7	A8131	USCO effluent	1	727	1975-1979	1975-1979
8	A8331	AECI effluent	6	708	1973-1979	1973-1979
9	B3331	ERPM gold mine	48	3998	1970-1979	1977-1979
10	B3431	Durban Roodepoort Deep gold mine	16	3062	1972-1979	1975-1979
11	B3531	East Daggafontein gold mine	Closed 1975		1970-1975	-
12	B3731	Grootvlei gold mine	15	1060	1967-1979	1978-1979
13	B4231	S.A. Lands gold mine	18	3183	1967-1979	1978-1979
14	B4331	Vlakfontein gold mine	Closed 1977		1970-1976	-
15	B4631	Sub Nigel gold mine	Closed 1972		1970-1972	-
16	B5231	Germiston (Rondebult) sewage	39	746	1966-1979	1966-1979
17	B5232	Germiston (Dekema) sewage	56	563	1966-1979	1966-1979
18	B5233	Germiston (Waterval) sewage	Opened 1979		1979	1979
19	B5331	Brakpan (Jan Smuts) sewage	11	726	1969-1979	1969-1979
20	B5431	Boksburg sewage	44	678	1968-1979	1971-1979
21	B5631	Benoni (Benoni works) sewage	15	675	1963-1979	1975-1979
22	B5632	Benoni (Rynfield) sewage	11	481	1967-1979	1975-1979
23	B5734	Springs (Ancor) sewage	Prior to 1979 all Springs effluent was delivered to SAPPI (flow line B8331)		1979	1979
24	B5735	Springs (McComb) sewage			1979	1979

Table A.3 - cont.

Point source			Mean 1977/78 values		Period of record	
Code No. (Fig. A.3)	Flow line[1] code	Description	Discharge (Ml/d)	TDS (mg/l)	Discharge	Water Quality
25	B5831	Nigel sewage	7	636	1973-1979	1973-1979
26	B5931	Heidelberg sewage	3	713	1964-1979	1975-1979
27	B6131	Johannesburg (Olifantsvlei) sewage	237	694	1965-1979	1965-1979
28	B6132	Johannesburg (Klipspruit) sewage	172	970	1965-1979	1965-1979
29	B6133	Johannesburg (Palmietfontein) sewage	Closed 1975		1972-1975	1973-1975
30	B6431	Daveyton sewage	8	601	1970-1979	1968-1979
31	B6433	Tsakane sewage	0,2	1477	1977-1979	1977-1979
32	B7931	Everite effluent	0,2	938	1976-1979	1977-1979
33	B8331	SAPPI effluent	32	1579	1966-1979	1966-1979
34	B8631	ERGO (works effluent)	5	3185	1978-1979	1978-1979
35	B8632	ERGO (tailings dam)	11	3082	1978-1979	1978-1979
Effluents discharged downstream of Vaal Barrage						
36	A1432	SASOL I effluent	58,5	812	1964-1979	1965-1979
37	A5431	Vanderbijlpark sewage	21,9	551	1966-1979	1963-1979

[1] computer reference code used in PWV project (Stewart et al., 1979)

Table A.4 Barrage cell mixing proportions obtained using the RWB supply regions method

Flow line code	RWB supply regions within which user is located						Barrage cell mixing proportions			
	1	2	3	4	5	6	34	41	52	0
A5231	60%	0	40%	0	0	0	0,17	0,37	0,21	0,23
A7531	100%	0	0	0	0	0	0,31	0,63	0,03	0,03
B5231	0	0	0	15%	85%	0	0,06	0,11	0,40	0,43
B5232	0	0	0	15%	85%	0	0,06	0,11	0,40	0,43
B5233	0	0	0	15%	85%	0	0,06	0,11	0,40	0,43
B5331	0	0	0	90%	10%	0	0,13	0,26	0,29	0,32
B5431	0	0	0	70%	30%	0	0,11	0,22	0,32	0,35
B5631	0	0	0	100%	0%	0	0,14	0,28	0,28	0,30
B5632	0	0	0	65%	35%	0	0,09	0,18	0,35	0,38
B5734	0	0	0	0	100%	0	0,04	0,08	0,42	0,46
B5735	0	0	0	0	1[illegible]	0	0,04	0,08	0,42	0,46
B5831	0	0	0	100%	0	0	0,14	0,28	0,28	0,30
B5931	0	0	0	100%	0	0	0,14	0,28	0,28	0,30
B6131	0	0	0	60%	0	40%	0,10	0,19	0,34	0,37
B6132	0	0	0	60%	0	40%	0,10	0,19	0,34	0,37
B6133	0	0	0	100%	0	0	0,14	0,28	0,28	0,30
B6431	0	0	0	100%	0	0	0,14	0,28	0,28	0,30
B6433	0	0	0	0	100%	0	0,04	0,08	0,42	0,46
B7931	0	0	0	0	0	100%	0,03	0,06	0,44	0,47
B8331	0	0	0	30%	70%	0	0,07	0,14	0,38	0,41
A5431	0	100%	0	0	0	0	0,10	0,19	0,34	0,37

The mixing proportions given in Table A.4 were then used to calculate monthly salt concentrations of water supplied to each user for the full period for which water quality data at the RWB Barrage abstraction points were available. All available monthly effluent return flow water quality data were then used to compute for each user the average increase in TDS concentration resulting from usage:

$$\Delta TDS = \frac{1}{N}\sum_{j=1}^{N}(CEFF_j - CSUP_j) \quad \text{.................... (A.12)}$$

where ΔTDS = average increase in TDS concentration (parameter CA D in program NACLØ9) (mg/l)

N = number of months for which concurrent water supply and effluent return flow water quality data are available

$CEFF_j$ = average effluent return flow salt concentration during month j (mg/l)

$CSUP_j$ = average water supply salt concentration during month j (mg/l)

The average addition of TDS was then combined with the calculated monthly water supply salt concentrations to predict the monthly effluent return-flow salt concentrations and thus to determine the standard error between predicted and observed monthly values. (The long term means must, of course, be identical because of the method used to calculate ΔT[illegible]). The average increases in TDS concentrations and the c[illegible]nding standard errors for each flow-line are given in [illegible] A.5.

The foregoing method of calculating mixing proportions and average TDS increases suffers from the following shortcomings:

(i) The period for which records of monthly supply TDS data in the six RWB regions were available was rather short (12 months);

(ii) The mixing proportions within each RWB region are not truly homogeneous; and

(iii) Many of the municipal areas do not fall entirely within a single RWB region. Although the mixing proportions were weighted according to the municipal areas situated within each region, the concentrations of population and industry are highly non-uniform and heterogeneous, thus weakening the basis of weighting.

Table A.5 Average increase in TDS concentration for each user

Flow line code	RWB water supply regions method		Optimization of mixing proportions method	
	Increase in TDS (mg/l)	Standard error (mg/l)	Increase in TDS (mg/l)	Standard error (mg/l)
A5231	53,1	51,5	-96,5	27,4
A7531	391,0	202,8	504,2	194,2
B5231	626,2	100,3	658,7	98,5
B5232	360,8	55,3	350,6	55,0
B5233	415,0[1]	-	420,5[1]	-
B5331	475,7	119,6	579,9	104,5
B5431	459,6	80,3	505,4	76,9
B5631	357,1	67,0	399,2	62,9
B5632	207,6	77,5	176,5	75,5
B5734	394,1[2]	-	411,0[2]	-
B5735	394,1[2]	-	411,0[2]	-
B5831	[illegible]07,6	121,3	427,2	120,9
B5931	31[illegible],8	66,7	323,2	66,5
B6131	318,1	89,3	344,9	88,0
B6132	4[illegible]4,7	88,5	447,5	88,4
B6133	459,8	94,3	422,2	91,5
B6431	351,1	[illegible]1,4	407,4	75,2
B6433	351,0[3]	-	407[3]	-
B7931	878[4]	-	890[4]	-
B8331	1847,9	350,9	1900,1	347,8
A5431	371,1	84,8	419,3	79,9

[1] The average TDS increase for the new Waterval sewage works was assumed to equal the flow-weighted average for the two older works (B5231 and B5232)

[2] The average TDS increase for the two Springs municipality sewage works was assumed to equal the flow-weighted average for all white municipalities in the southern PWV region

[3] The average TDS increase for the Tskane sewage works was assumed to be the same as that for the Daveyton works. (Both of these works service black townships and the absence of industrial effluent results in sewage characteristics which differ from those applicable to sewage from white municipalities).

[4] The average TDS increase for the Everite asbestos works was assumed to equal the flow-weighted average for all the major industries of the southern PWV region (i.e. A1232, A1333, A1432, A1631, A7531, A7831, A8131, A8331 and B8331).

It is recommended that a detailed study be embarked upon to calculate monthly salt concentrations supplied to each individual user. The report on the six RWB supply regions (Rand Water Board, 1978) was compiled using water quality analyses for a large number of service reservoirs in the PWV region and it is understood that these data are available for several years. A careful examination of the locations of the service reservoirs relative to the major users, the metered flows and the characteristics of the distribution network would be required to provide the basis for accurate calculation of month-by-month water supply qualities. The primary purpose of such a study would be to ascertain the change in TDS characteristics of the water supplied to each user. Valuable relationships such as the effect of water quality on water consumption (and on effluent discharge) could also be established.

The mixing characteristics of the distribution network are not likely to hold true for future conditions and will change with the growth of the system and with possible changes in management and planning policies. (For example, a decision to treat all water supplies at a centralized purification works would have the effect of making the water quality homogeneous, regardless of the characteristics of the distribution network). The relationships established between water supply and effluent return quality (and possibly also quantity) would be more nearly permanent (unless of course the research results lead to legislation forcing changes in existing industrial processes).

In order to make improved use of the available data the following method was adopted to compute mixing proportions and changes in salt concentrations:

A.3.3.2 Optimization method of establishing mixing proportions

In this method the ratio of the water supplied to each user from the RWB Vereeniging purification works to that supplied from Zuikerbosch works is optimized in such a manner as to minimize the standard error between observed and predicted monthly effluent TDS concentrations. The optimization procedure was as follows:

Firstly, the monthly salt concentrations at the two RWB purification works, $C_{Z,j}$ and $C_{V,j}$, were calculated using equations A.4 and A.5. Then, for each user of RWB water, a value was assumed for the proportion, P_Z, of water taken from the Zuikerbosch works. Monthly water supply concentrations were then calculated as :

$$CSUP_j = C_{Z,j}.P_Z + (1 - P_Z).\ C_{V,j} \qquad \text{(A.13)}$$

where $CSUP_j$, $C_{Z,j}$ and $C_{V,j}$ are as defined in section A.3.3.1.

Equation A.12 was then used to calculate ΔTDS, the average increase in TDS through usage. Monthly effluent TDS concentrations predicted using ΔTDS and the standard error between calculated and observed values were then calculated in the same manner as described in section A.3.3.1. Successive new estimates of P_Z were then made and an optimization procedure employed to converge upon the value of P_Z yielding the smallest standard error (i.e. the root mean square error).

The optimum values of P_Z and P_V ($= 1-P_Z$), the proportion from Vereeniging purification works, were then substituted for $P_{Z,i}$ and $P_{V,i}$ in equations A.6 to A.9 to obtain the corresponding Barrage cell mixing proportions.

The optimum mixing proportions derived in this way are given in Table A.6 while the increases in TDS and the standard errors are shown in Table A.5. In most instances the method yielded improved results, with the exception of those for flow line A5231 (see Table A.5) for which there was a negative increase in TDS. It is understood, however, that Meyerton municipality has

Table A.6 Barrage cell mixing proportions obtained using the optimization method

Flow line code	Barrage cell mixing proportions			
	34	41	52	0
A5231	0,29	0,59	0,06	0,06
A7531	0,18	0,37	0,22	0,23
B5231	0,01	0,02	0,47	0,50
B5232	0,07	0,14	0,38	0,41
B5233[1]	0,04	0,09	0,42	0,45
B5331	0,00	0,01	0,48	0,51
B5431	0,05	0,11	0,41	0,43
B5631	0,09	0,18	0,35	0,38
B5632	0,13	0,25	0,30	0,32
B5734[2]	0,00	0,01	0,48	0,51
B5735[2]	0,00	0,01	0,48	0,51
B5831	0,12	0,23	0,31	0,34
B5931	0,13	0,27	0,29	0,31
B6131	0,06	0,12	0,40	0,42
B6132	0,11	0,21	0,33	0,35
B6133	0,20	0,41	0,19	0,20
B6431	0,07	0,14	0,38	0,41
B6433[3]	0,04	0,08	0,42	0,46
B7931[3]	0,03	0,06	0,44	0,47
B8331	0,00	0,01	0,48	0,51
A5431	0,04	0,07	0,43	0,46

[1] Proportions for the new Waterval sewage works were calculated as flow-weighted averages of the proportions for the two older works (B5231 and B5232)

[2] Proportions for the two Springs sewage works were assumed equal to those used for SAPPI (B8331). (Prior to 1979 all Springs treated sewage was delivered to SAPPI).

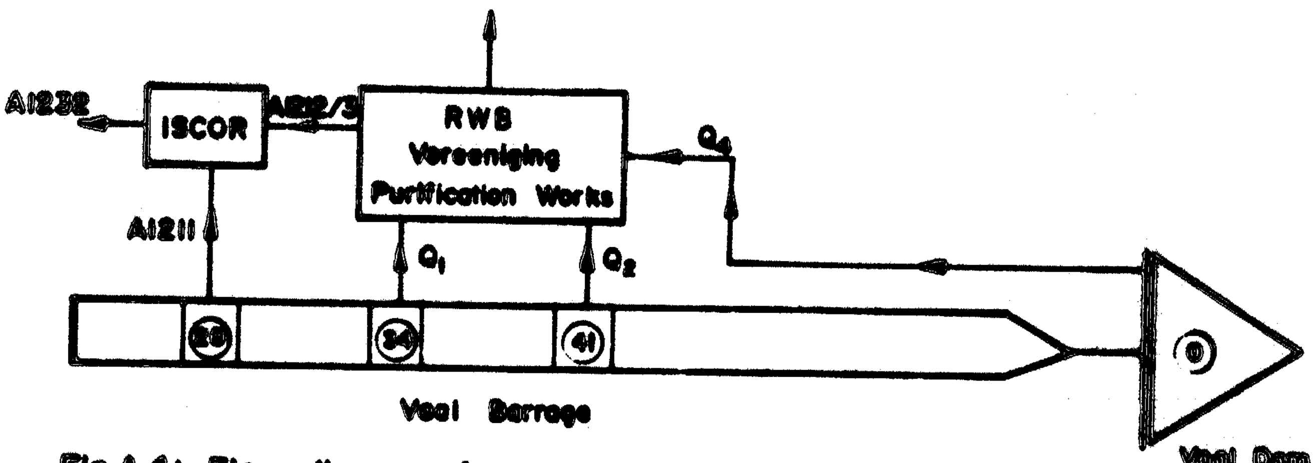
[3] The proportions given in Table A.4 have been used for these flow lines because the available data were inadequate.

experienced substantial seepage of groundwater into their newly laid sewers and this is dominating the still relatively small sewage discharges (see Table A.3). With this sole exception, the results derived from the optimization method took preference over those by the method outlined in section A.3.3.1.

A.3.3.3 <u>Industries consuming water not supplied by the RWB</u>

The calculations used to estimate mixing proportions for each of the industries operating their own pumps are now discussed.

a) <u>ISCOR steelworks</u> (flow line A1232)
Fig. A.4 shows the flow lines feeding the ISCOR works. ISCOR receives water abstracted from the ISCOR pump station, which draws water from Vaal Barrage cell No. 28 (flow line code No. A1211) and from the Vereeniging purification works (flow lines A1212 and A1213). The proportions of water from Barrage cells 34, 41 and O (Q_1, Q_2 and Q_4) making up the water treated at the RWB Vereeniging works during the year 1977/78 are given in Table A.7. The average discharges in flow lines A1211 and A1212/3 for the same period were 33,7 and 15,9 Ml/d respectively. Table A.8 gives the calculated quantities reaching ISCOR from cells 34, 41 and O, as well as the equivalent proportions.



<u>Fig.A.4: Flow diagram for water supplied to ISCOR</u>

experienced substantial seepage of groundwater into their newly laid sewers and this is dominating the still relatively small sewage discharges (see Table A.3). With this sole exception, the results derived from the optimization method took preference over those by the method outlined in section A.3.3.1.

A.3.3.3 <u>Industries consuming water not supplied by the RWB</u>

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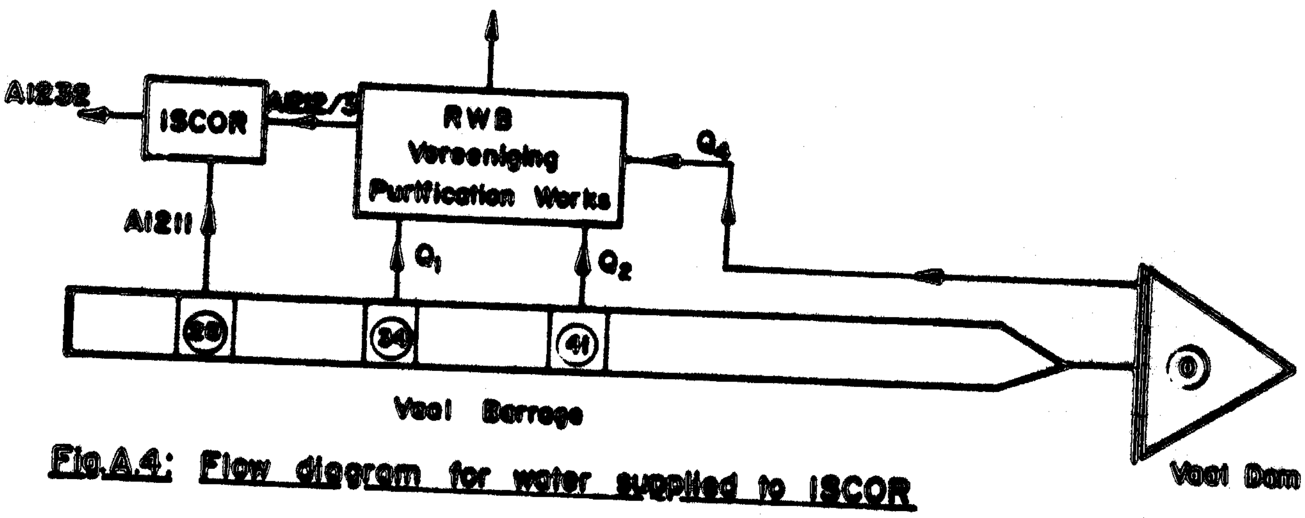
a) <u>ISCOR steelworks</u> (flow line A1232)

Fig. A.4 shows the flow lines feeding the ISCOR works. ISCOR receives water abstracted from the ISCOR pump station, which draws water from Vaal Barrage cell No. 28 (flow line code No. A1211) and from the Vereeniging purification works (flow lines A1212 and A1213). The proportions of water from Barrage cells 34, 41 and O (Q_1, Q_2 and Q_4) making up the water treated at the RWB Vereeniging works during the year 1977/78 are given in Table A.7. The average discharges in flow lines A1211 and A1212/3 for the same period were 33,7 and 15,9 Ml/d respectively. Table A.8 gives the calculated quantities reaching ISCOR from cells 28, 34, 41 and O, as well as the equivalent proportions.



<u>Fig.A.4: Flow diagram for water supplied to ISCOR</u>

Table A.7 Barrage cell proportions for RWB Vereeniging works (1977/78)

Cell number	34	41	0
Proportion	0.258	0,504	0,238

Table A.8 Discharges and cell proportions for water supplied to ISCOR

Cell number	28	34	41	0
Discharge (Ml/d) Proportion	33,7 0,68	4,1 0,08	8,0 0,16	3,8 0,08

b) Klip power station (flow line A1333)

As with ISCOR the Klip power station receives water from the RWB Vereeniging works (flow line A1313) as well as from their own pump station (flow line A1311, drawing on Barrage cell 44). The flow diagram is similar in form to Fig. A.4. The 1977/78 discharges of flow lines A1311 and A1313 (17,1 and 1,9 Ml/d respectively), together with the propo..ions for the RWB Vereeniging purification works (Table A.7), yield the cell proportions given in Table A.9.

Table A.9 Discharges and cell proportions for water supplied to Klip power station

Cell number	34	41	44	0
Discharge (Ml/d) Proportion	0,5 0,03	1,0 0,05	17,1 0,90	0,4 0,02

c) SASOL I works (flow line A1432)

Fig. A.5 is a flow chart for the SASOL I complex. The SASOL works receives part of its water supply from Sasolburg

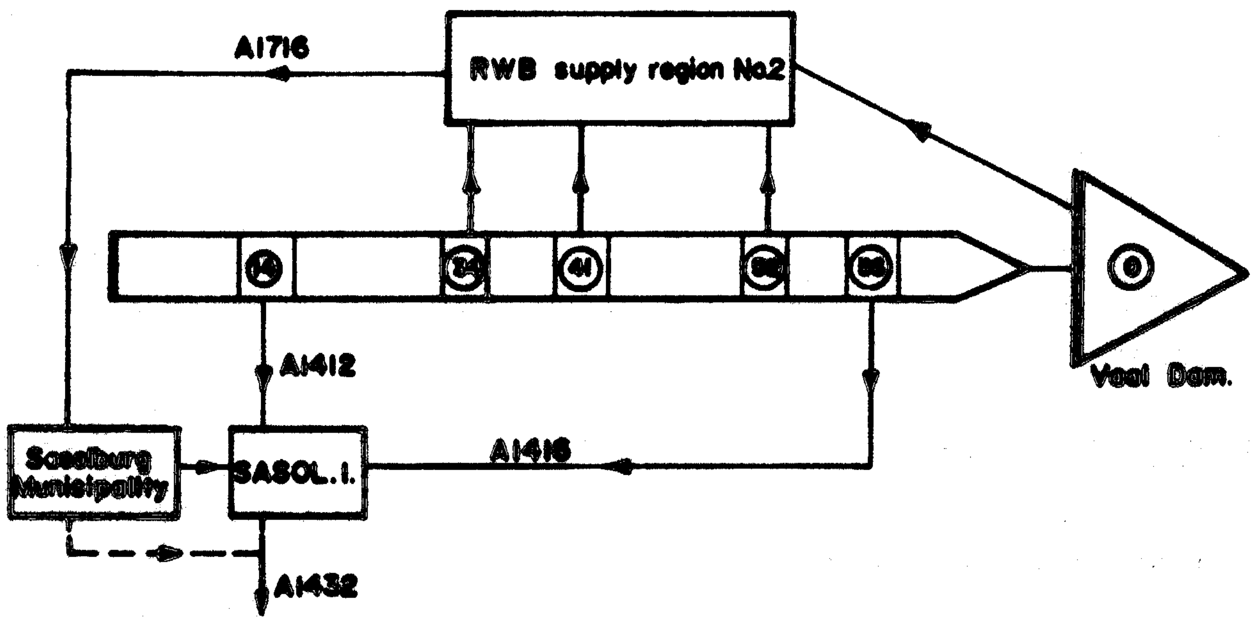


Fig. A.5: Flow diagram for water supplied to SASOL complex.

municipality, part from the SASOL intakes (flow line A1412 drawing on cell 14) and the remainder from cell 56 via the ESCOM Vaal Barrage intakes (flow line A1416). Sasolburg in turn receives its water from the RWB and is situated within RWB supply region 2. Sasolburg municipality and the SASOL works cannot be separated and are therefore treated as a single entity. The discharges of flow lines A1412, A1416 and A1716 (41,4, 21,5 and 32,1 Ml/d respectively) for 1976/77 were used in conjunction with the proportions for RWB region 2 of Table A.2 to calculate the discharges and cell proportions given in Table A.10.

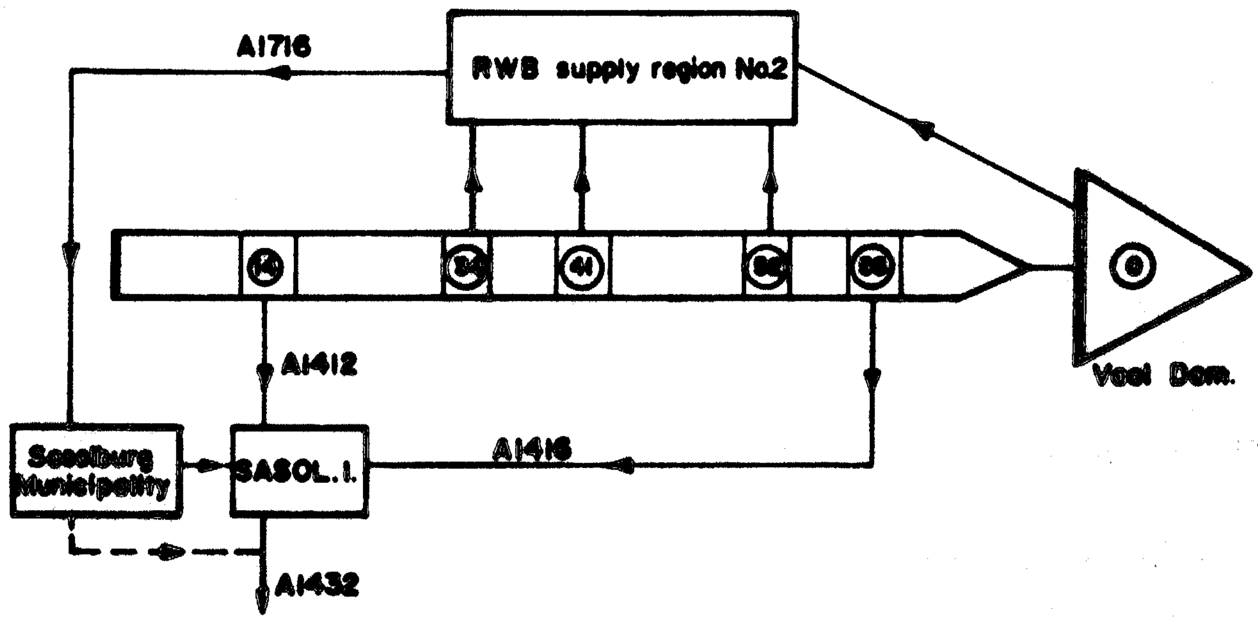


Fig. A.5: Flow diagram for water supplied to SASOL complex.

municipality, part from the SASOL intakes (flow line A1412 drawing on cell 14) and the remainder from cell 56 via the ESCOM Vaal Barrage intakes (flow line A1416). Sasolburg in turn receives its water from the RWB and is situated within RWB supply region 2. Sasolburg municipality and the SASOL works cannot be separated and are therefore treated as a single entity. The discharges of flow lines A1412, A1416 and A1716 (41,4, 21,5 and 32,1 Ml/d respectively) for 1976/77 were used in conjunction with the proportions for RWB region 2 of Table A.2 to calculate the discharges and cell proportions given in Table A.10.

Table A.10 Discharges and cell proportions for water supplied to the SASOL complex

Cell number	14	34	41	52	56	0
Discharge (Ml/d)	41,4	3,1	6,2	10,9	21,5	11,8
Proportion	0,44	0,03	0,07	0,11	0,23	0,12

Subroutine SUBFBK makes allowance for a maximum of five different cells, whereas Table A.10 contains six cells. The two smallest abstractions (from cells 34 and 41) are therefore aggregated into a single abstraction from cell 41 (with a proportion of 0,10).

d) Vaal power station (Flow line A1631)

Vaal power station receives all its water from the ESCOM pump station drawing on Barrage cell 56.

e) USCO works (Flow lines A7831 and A8131)

The Vaal Barrage intakes of the two USCO works are very close together (see Fig. 2.2) and the quantities abstracted are small compared with the quantities supplied by the RWB Vereeniging purification works. The error introduced by assuming the USCO Barrage abstraction points to be centred on cell 44 midway between the real abstraction points and assuming the water qualities supplied to the two works to be identical is therefore negligible. (Moreover, as Table A.3 shows, the effluent discharges from the two works are very small). With these assumptions the total inflows from cell 44 and from the RWB Vereeniging works become 0,3 and 2,9 Ml/d respectively. These quantities together with the values of Table A.7 yield the cell proportions given in Table A.11.

Table A.11 Discharges and cell proportions for water supplied to USCO works

Cell number	34	41	44	0
Discharge (Ml/d)	0,7	1,5	0,3	0,7
Proportion	0,22	0,47	0,09	0,22

Table A.10 Discharges and cell proportions for water supplied to the SASOL complex

Cell number	14	34	41	52	56	0
Discharge (Ml/d)	41,4	3,1	6,2	10,9	21,5	11,8
Proportion	0,44	0,03	0,07	0,11	0,23	0,12

Subroutine SUBFBK makes allowance for a maximum of five different cells, whereas Table A.10 contains six cells. The two smallest abstractions (from cells 34 and 41) are therefore aggregated into a single abstraction from cell 41 (with a proportion of 0,10).

d) Vaal power station (Flow line A1631)

Vaal power station receives all its water from the ESCOM pump station drawing on Barrage cell 56.

e) USCO works (Flow lines A7831 and A8131)

The Vaal Barrage intakes of the two USCO works are very close together (see Fig. 2.2) and the quantities abstracted are small compared with the quantities supplied by the RWB Vereeniging purification works. The error introduced by assuming the USCO Barrage abstraction points to be centred on cell 44 midway between the real abstraction points and assuming the water qualities supplied to the two works to be identical is therefore negligible. (Moreover, as Table A.3 shows, the effluent discharges from the two works are very small). With these assumptions the total inflows from cell 44 and from the RWB Vereeniging works become 0,3 and 2,9 Ml/d respectively. These quantities together with the values of Table A.7 yield the cell proportions given in Table A.11.

Table A.11 Discharges and cell proportions for water supplied to USCO works

Cell number	34	41	44	0
Discharge (Ml/d)	0,7	1,5	0,3	0,7
Proportion	0,22	0,47	0,09	0,22

f) AECI works (Flow line A8331)

The AECI works receives water from the RWB Vereeniging purification works. The cell proportions are therefore as given in Table A.7.

The cell proportions given in sections A.3.3.3 a) to f), together with observed monthly cell and effluent return-flow salt concentrations, were used to calculate the average increases in TDS given in Table A.12.

Table A.12 Average increases in TDS concentrations for users receiving water from suppliers other than RWB

Flow line	A1232	A1333	A1432	A1631[1]	A7831[1]	A8131[1]	A8331[1]
ΔTDS (mg/l)	949	836	494	220	120	304	277

[1] these values are based on sparse data and may be inaccurate

The flow weighted average increase in TDS concentration for the entire southern PWV region comes to 498 mg/l.

The cell proportions and increases in TDS for each user provided the basis for calculation of flow-weighted average values applicable to the aggregated effluent discharges within each of the 27 water supply sub-regions used in subroutine SUBFBK (not to be confused with the six RWB supply regions).

Table A.13 indicates which users discharge effluents into each water supply sub-region and gives the cell proportions flow-weighted according to the average effluent discharges shown in Table A.3.

As a final check the mixing proportions were used in conjunction with the 1977/78 demands of each user in order to calculate the quantity of water from each Barrage cell delivered to each user in the southern PWV region. These quantities were summated to yield the total quantities of water consumed in the southern PWV region abstracted from each Barrage cell. The equivalent quantities delivered to the northern PWV region were calculated by subtracting the southern PWV quantities from the observed 1977/78 Barrage abstractions.

Table A.13 Effluent point discharges located within each water supply sub-region

Supply sub-region	Effluent flow line codes	Cell mixing proportions in cell nos: 28	34	41	44	52	56	0	CADD (mg/1)
1	B5233,B6131,B6132	0	0,08	0,16	0	0,36	0	0,40	388
3	B5231,B5232,B5431,B6133	0	0,05	0,09	0	0,42	0	0,44	481
6	A1333,A5231,A7531	0	0,05	0,10	0,76	0,03	0	0,06	729
7	B6431	0	0,07	0,14	0	0,38	0	0,41	407
8	B5331,B5631,B5632,B6433	0	0,12	0,22	0	0,32	0	0,34	366
9	B8331	0	0,04	0,08	0	0,42	0	0,46	1490
10	B5734,B5735	0	0,04	0,08	0	0,42	0	0,46	366
13	B5831,B5931	0	0,14	0,28	0	0,28	0	0,30	397
22	A1232	0,68	0,08	0,16	0	0	0	0,08	949
25	A1631,A7831,A8131,A8331	0	0,12	0,23	0,01	0	0,53	0,11	241
26	A1432	0,44	0	0,10	0	0,11	0,23	0,12	494
27	A5431	0	0,10	0,19	0	0,34	0	0,37	282

The water volumes abstracted from each cell for the northern, southern and total PWV regions, together with equivalent mixing proportions are given in Table A.14.

Table A.14 Cell mixing proportions for entire PWV region - 1977/78

Cell number	Total PWV abstraction $m^3 x10^6$	proportion	southern PWV demand $m^3 x10^6$	proportion	northern PWV demand $m^3 x10^6$	proportion
14	15,4	0,021	18,6[1]	0,043	0	0
28	12,3	0,017	12,3	0,029	0	0
34	51,8	0,070	27,4	0,064	24,4	0,080
41	103,6	0,140	56,0	0,130	47,6	0,156
44	6,7	0,009	6,3	0,015	0	0
52	244,6	0,331	132,0	0,307	112,6	0,368
56	42,4	0,057	36,2[1]	0,084	0	0
0	262,7	0,355	141,7	0,329	120,9	0,396
total	739,5	1,000	430,6	1,000	305,5	0,413

[1] 1976/77 flow data were used to estimate mixing proportions for SASOL and the ESCOM power stations. In 1977/78, however, the proportion of SASOL demands met via the ESCOM pump station (cell 56) increased substantially.

Comparison of the mixing proportions of RWB water delivered to the southern and northern PWV catchments respectively from cells 34, 41, 52 and O would be misleading because the values for the southern catchment are distorted by virtue of abstractions from the other cells. Accordingly Table A.15 has been prepared to indicate the mix specifically of RWB water.

<u>Table A.15</u> <u>Cell mixing proportions for RWB water in the northern and southern PWV regions</u>

Region	Cell number			
	34	41	52	O
Southern PWV	0,077	0,157	0,369	0,397
Northern PWV	0,080	0,156	0,368	0,396
Whole	0,078	0,156	0,369	0,397

Table A.15 shows that the average quality of RWB water delivered to the northern PWV region is virtually identical to the average for the southern PWV region. This result, though plausible, cannot be confirmed, however, until the mixing proportions for the users of northern PWV regions have been estimated independently. (The values in Tables A.14 and A.15 for the northern catchment were arrived at by induction). If an analysis similar to that described in this section were to be made for each major user of the northern catchment (which represents 41% of the total 1977/78 PWV demand) the total calculated abstractions from each cell could be compared with the observed abstractions. The calculated mixing proportions for each user could then be adjusted to eliminate any error between observed and modelled total cell abstractions.

A.3.4 <u>Effluent discharge quantities (parameter QRET)</u>

Effluent discharges for the calendar years 1973 to 1980 and projections to 1990 and 2000 A.D. are given for each of the river reaches in Table A.16. Reaches not shown in Table A.16 do not have effluent inputs.

Table A.16 Annual average discharge rates into southern PWV tributary reaches (Ml/d)

Reach No.	Calendar year									
	1973	1974	1975	1976	1977	1978	1979	1980	1990	2000
1	258	267	321	355	337	383	370	405	674	1092
3	87	103	123	127	118	144	121	132	220	357
6	2	1	3	6	7	6	12	13	22	35
7	5	5	5	6	7	8	6	7	11	18
8	20	22	28	31	26	36	25	27	46	74
9	44	44	41	36	35	31	24	26	44	71
10	0	0	0	0	0	0	18	20	33	53
13	6	5	9	9	8	9	13	14	24	38
22	21	28	31	27	28	26	28	31	51	83
25	9	11	10	14	12	17	19	21	35	56
26	46	49	48	53	57	60	59	65	108	174
27	15	16	16	17	18	22	17	19	31	50

Effluent discharges for the period 1973 to 1979 are as recorded whereas those for 1980, 1990 and 2000 are estimates based on projected demands for the total southern PWV region (Herold, 1981b) on the assumption that the proportions of the total discharge derived from each supply sub-region remain the same as those observed in 1979.

The seasonal pattern for monthly discharges for each effluent point source was calculated using all available effluent return flow data. The flow weighted mean monthly discharges, expressed as percentages of the annual average discharges for each river reach (parameter SEASON), are given in Table A.17.

A.3.5 Mine pumpage

Mine effluent discharges in the southern PWV region are dominated by the highly saline water pumped from the mine workings. Small quantities of RWB water are used for domestic purposes and in the industrial processes, but these are inconsequential compared with mine pumpage. Part of the domestic effluent is in any case discharged to municipal sewers and is therefore already accounted for in section A.3.3. Table A.18 shows the mine pumpage flow lines discharging from each water supply sub-region.

Table A.17 Mean monthly effluent discharges as percentages of the annual average discharges

Supply sub-region	SEASON											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	106	108	107	104	100	93	96	96	99	94	99	98
3	105	110	115	108	99	98	96	97	93	90	95	94
6	98	98	107	101	101	82	108	103	94	88	108	113
7	116	116	104	101	93	88	93	93	92	96	103	104
8	113	124	114	114	100	93	89	88	88	88	93	96
9	103	99	98	102	100	101	99	99	99	104	99	98
10	113	124	114	114	100	93	89	88	88	88	93	96
13	118	130	126	116	103	87	88	79	86	83	85	95
22	105	101	92	100	91	97	101	100	101	100	108	106
25	105	101	92	100	91	97	101	100	101	100	108	106
26	100	100	100	100	100	100	100	100	100	100	100	100
27	100	100	100	100	100	100	100	100	100	100	100	100

Table A.18 Mine pumpage discharges located within each water supply sub-region

Supply sub-region	1	2	4	10	12	13
Mine pumpage flow lines	B3431	B3331	B4231 B8631[2] B8632[2]	B3731	B3831[1]	B4331[1] B4631[1]

[1] These mines have already been closed but are included as data for these flow lines were used in the verification run described in Chapter 3 for the period 1973/74 to 1978/79.

[2] The two discharges from the ERGO mine dump re-processing plant are regarded as being mine discharges as most of the water supply is S.A. Lands mine shaft water.

Hall (1980) made estimates of future mine pumpage rates and salt concentrations based on information obtained from the mining houses. Since these estimates were made the gold price has risen dramatically and the effect of increased prices is likely to be to prolong the lives of the gold mines. For this reason the decline in pumping rates estimated by Hall have been assumed to be delayed by 10 years. Hall's estimates have been further adjusted to bring his 1980 estimates in line with observed 1980 values which have since become available. The adjusted projections are given in Table A.19.

Table A.19 Projected mine pumpage rates and salinities

Flow line	Discharge (Ml/d)			TDS (mg/l)		
	1980	1990	2000	1980	1990	2000
B3331	41	41	41	4100	4500	4500
B3431	12	16	16	3000	3000	3000
B3731	11	11	0	2000	2000	-
B4231[1]	28	28	0	3600	3600	-
B8631/2[1]	7	7	0	3600	3600	-

[1] Approximately 60% of the water pumped from underground is delivered to ERGO (B8631/2) of which about half is discharged as effluent. The values shown in the table are the quantities discharged to stream.

Mine pumpage rates were assumed to remain constant during each year simulated. Observed annual average values were used for the verification run described in Chapter 3 (1973/74 to 1978/79).

A.4 Input data for subroutine SUBDAM

A.4.1 Reservoir geometry

Storage-area curves, reserve storages and storage capacities for each reservoir are to be found in HRU Report 4/81 (Herold, 1981b).

A.4.2 Rainfall and evaporation data

Details of the rainfall stations used to provide monthly rainfall data for each reservoir are given in Table A.6 of HRU Report 4/81. Mean monthly Symons pan evaporations were derived from the maps produced by Pitman (1973). These pan evaporations were converted to equivalent lake evaporations using the relationship suggested by Pitman (1973). Mean monthly gross lake evaporations for each reservoir are to be found in Table A.7 of HRU Report 4/81.

A.4.3 Reservoir demands and pumping rates

Annual reservoir demands for each reservoir and pumping rates applicable to transfers of water from the Tugela and Usutu catchments for the years 1980, 1990 and 2000 were estimated in the manner described in HRU Report 4/81 (Herold, 1981b). These values are summarised in Table A.20.

Table A.20 Projected annual reservoir demands and water imports

Reservoir	Demand ($m^3 x 10^6$)			Importation from other catchments ($m^3 x 10^6$)		
	1980	1990	2000	1980	1990	2000
Grootdraai Dam	34	207	274	0	100	100
Sterkfontein Dam	0	0	0	130	346	346
Vaal Dam	313	521	844	0	0	0
Welkom Dam	0	0	0	0	0	0
Vaal river between Welkom and Bloemhof	314	356	399	0	0	0
Bloemhof Dam	648	667	693	0	0	0

Mean monthly demands expressed as percentages of the total annual demand were calculated using all available RWB demand data. It was assumed that this seasonal pattern applies to the demands made on all reservoirs downstream of and including Vaal Dam. Most of the Grootdraai Dam demand is, however, used consumptively in power station cooling and the seasonal distribution of demands will therefore differ slightly from that used for the other reservoirs. For the sake of simplicity, however, it was assumed that the Grootdraai demands remain constant throughout the year. The mean monthly demands expressed as percentages of the annual total (parameter PMONTH) used for each reservoir are given in HRU Report No. 5/81 (Herold, 1981c).

A.4.4 Parameter RELMIN

The minimum allowable release from Vaal Barrage (RELMIN) was assumed to be 4 m^3/s.

A.4.5 Catchment runoffs and salt concentrations

The sources of the daily runoff data and the monthly runoff and salt concentration data used as input to the dam simulation model are discussed in section 2.4.