WATER RESEARCH COMMISSION

LONG TERM SALT BALANCE OF THE VAALHARTS IRRIGATION SCHEME

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REPORT TO THE WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND AND MOTIVATION

Vaalharts is the largest irrigation scheme in the Republic of South Africa. The Vaal River is the source of the water supply to the scheme. Since the commissioning of Vaalharts in the mid-thirties, the salinity of the supply water has deteriorated substantially due to large scale urban, industrial and mining developments in the Middle Vaal. A study of the Harts River carried out by Stewart Sviridov and Oliver in 1987 on behalf of the Department of Water Affairs (DWA) concluded that between 1935 and 1984 less than 20 percent of the salt contained in the water supplied to Vaalharts was released via return flows to the Harts River. This represents an overall accumulation of approximately 3 million tons of salt.

Implications for the Vaal and Orange River systems

Salinisation of the Vaal River has already led to serious water quality problems in the lower Vaal. The return of all of the salt contained in the irrigation water supplied to Vaalharts would have put an additional 100 000 tons of salt into the Lower Vaal each year, with serious economic consequences for downstream users. If this proves to be only a temporary phenomenon (i.e. lagged system response) then continued salinisation of the Middle Vaal could jeopardise all irrigation schemes downstream of the Vaal-Harts confluence. In this regard, even the Orange River is threatened, seeing as its dilution factor will be reduced by the expected eventual removal of a further 2200 million cubic metres of fresh water via the Lesotho Highlands Water Project.

Even if most of the unaccounted for salt has been permanently removed via percolation (through the calcrete layer that underlies the whole scheme) into deeper groundwater, it is likely that in future the salt removal rate will be reduced because of interception of drainage water by the recently installed sub-surface drains. Increased water allocations could also increase the leaching fraction, and hence the proportion of salt returned to the Harts River.

Key questions

The above considerations raise some important questions regarding the fate of the unaccounted for salt:

- Were the findings of the 1987 DWA study correct? (i.e. has most of the salt contained in the water supplied to Vaalharts been retained?)

- If so, what became of the salt?

- Has the salt been permanently removed from the surface drainage system, or has sub-surface storage merely delayed the response of the system to the sharp rise in the salinity of Vaal River water that commenced in the late seventies?

- Under what circumstances (if any) can the salt be expected to be returned to the surface drainage system?

- How will the recent provision of irrigation under-drains affect the proportion of salt removed?

- How will increased irrigation water allocations affect the salt removal?

The implications of continued salt inputs to the Vaalharts irrigation scheme warranted a research study aimed at answering the key questions posed above.

Expected benefits of study

Answers to the key questions set out above were expected to provide the following benefits:

- Place water resource managers in a better position to anticipate the consequences of upstream developments and timeously implement appropriate water quality management strategies.

- Provide a better understanding of the overall salt balance of the Vaalharts irrigation scheme. This will serve to improve the calibration of the hydro-salinity models currently used by the Department of Water Affairs and Forestry (DWAF) in planning and managing the water resources of the Vaal River system.

- Determine if a more comprehensive multi-disciplinary research project to study the circulation and storage of salt in the Vaalharts irrigation scheme is warranted.

- Highlight the need for appropriate steps to be taken to collect the data required to monitor the long term response of the system and provide the information required for the second phase of the study.

AIMS

The stated aims of this study were as follows:

- Quantify the long term historical macro-scale water and salt balance (in terms of both total dissolved salts (TDS) and its main ionic constituents) of the Vaalharts irrigation scheme to determine the extent of salt loss or accumulation.

- Analyze available flow and water quality records to quantify the effect of the sub-surface drains (the installation of which commenced in the mid-seventies) on irrigation return flow volumes, TDS loads and TDS composition.

- Study available agricultural, meteorological, hydrological, water quality, soils and geo-hydrological data to gain an understanding of the underlying hydro-salinity processes.

- Where necessary, propose and initiate additional monitoring and field investigations to supplement the available data.

The Water Research Commission decided on a two phase approach. The research reported on in this document is for the first phase, the primary purpose of which is to obtain an improved assessment of the situation and definition of the problem. The second phase was envisaged to involve an in-depth multi-disciplinary study of the processes taking place in the Vaalharts irrigation scheme. Commencement of the second phase is dependant on the findings of the first phase.

As the first phase is essentially a preliminary investigation, the methodology has been kept as simple as possible. As far as possible existing data was used, with little or no additional sampling, field experiments or new model development. The main tasks are outlined below.

TASKS UNDERTAKEN IN TERMS OF CONTRACT

- **Literature survey**

  A literature survey has been carried out to identify studies of a similar nature that have been carried out elsewhere. In particular, relevant reports on studies carried out on the Vaalharts irrigation scheme itself have been examined.

- **Macro-scale water and salt balance**

  The macro-scale water and salt balance was based on river monitoring in the Vaal and Harts Rivers and did not involve detailed studies of individual plots or irrigation blocks.

  Available hydrological, water quality, meteorological, water use and other relevant data were collected and entered into a project data base. Early flow and water quality records have been examined and patched using hydro-salinity models to estimate the water and salt loads supplied to and returned by the Vaalharts irrigation scheme. Computer software already developed in-house by the Consultants was used to check and patch deficient flow and water quality records. Existing hydro-salinity models were used to simulate the long term salt balance of the Vaalharts irrigation scheme.

- **Effect of sub-surface drains**

  Available data was analyzed in an attempt to detect the effect of the recent installation of extensive sub-surface drains on the global percentage return flow and salt export. Hydro-salinity modelling was used to eliminate the effect of long term hydrological fluctuations that tend to mask water quality trends.

- **Hypothesise processes**

  The results of the salt balance analyses were examined, together with relevant papers and reports and available agricultural, meteorological, water quality, soils and geohydrological data to gain an insight into the dominant processes controlling the storage and release of salt at Vaalharts. The most likely explanations for the apparent retention of salt at Vaalharts have been hypothesised. Cost-effective means of testing these hypotheses have been sought.

- **Monitoring proposals**

  Proposals have been made for additional monitoring and field experiments required to validate the main hypotheses put forward regarding the processes by which salts are being accumulated at Vaalharts.

CONCLUSIONS

The following conclusions can be drawn from the results of the study:

- **Parallels with other irrigation schemes**

  The history of civilisations, as well as better documented more recent cases, indicates that large irrigation schemes such as Vaalharts have the capacity to accumulate very large volumes of irrigation water in the groundwater. It can be deduced that the change in storage in the groundwater represents the potential to store large tonnages of salt.

  The history of the Indus Scheme in Pakistan (which was commissioned during the same decade as Vaalharts Irrigation Scheme), as well as that of Vaalharts itself, demonstrates that the raising of the groundwater table can take a number of decades. It follows that during this period both water and salt will be accumulated. This provides a plausible mechanism for the large accumulation of salt in Vaalharts estimated in a previous study.

- **Data deficiencies**

  - A surprisingly large amount of basic information regarding the historical development of the Vaalharts Irrigation Scheme (such as irrigated areas, volumes of water supplied, cropping patterns, etc.) appears to be unobtainable. This necessitated patching by means of interpolation and extrapolation.

  - The flow records for Spitskop Dam (C3R002), Espagsdrift weir (C3H007) and Mt. Rupert weir (C3H013) were found to be inaccurate. An investigation was carried out by the DWAF in Bloemfontein and a number of problems were identified with regard to the streamflow gauging operation. A report was compiled by them and sent to the DWAF in Pretoria who revised certain discharge table (DT) and streamflow data.

- **Hydro-salinity modelling**

  - The hydro-salinity water quality model WQT has been calibrated successfully for both the Upper Harts (i.e the catchment upstream of Taung weir) and Middle Harts catchments (i.e the catchment downstream of Taung weir - C3H003 up to Mt. Rupert weir - C3H013). The calibrated model was then used to simulate conditions up to the year 2030.

  - Owing to the inaccuracies in the flow gauging at key hydrological stations as well as the data deficiencies mentioned above, it was to be expected that the modelled values would not fit the observed values that well. The modelled values do, however, provide a reasonable first order approximation to the observed values.

- **Estimation of irrigation losses**

  - The annual return flows from the North Canal area to the Harts River for the period October 1976 to September 1991 were calculated from upstream and downstream river flow records and simulated monthly runoffs from the incremental catchment. The mean for this period came to $25x10^6m^3$ per annum which is about 11% of the annual supply to the North Canal area.

  - A simple crop water balance was carried out to calculate the annual total irrigation losses (i.e. return flow to the river plus deep percolation to groundwater storage). These were compared with similar estimates in earlier studies. In some instances, this exercise revealed wide discrepancies between the irrigation loss estimates arrived at using the different methods. All three methods appear to share the common weakness that none of them adequately account for the inter-relationship between the processes governing infiltration, surface runoff and soil moisture storage. The accuracy of all of the methods was also adversely affected by the coarse monthly computational time step.

  - Estimates of the annual amounts of water percolating to deep groundwater storage were made by subtracting the calculated annual return flows to the Harts River from the estimated total irrigation losses. These estimates were compared with those made by other researchers using four alternative methods of calculation. These alternative estimates of the mean annual deep percolation ranged between $33x10^6m^3$ and $63x10^6m^3$. This wide band of estimates is indicative of the inherent inaccuracy resulting from the uncertainties associated with this type of calculation. These alternative methods were employed to provide high and low estimates of possible deep percolation rates.

- **Change in groundwater storage in North Canal area**

  Two alternative hypotheses of the historical change in groundwater storage in the North Canal area were examined. The first was based on the assumption that the calcrete layer is sufficiently porous to permit percolation to the deeper groundwater table (GWT), which has been gradually filling over the years. The second supposed that there is no effective link between the perched water table above the calcrete layer and the underlying deep GWT.

  - Since the perched water table is relatively shallow, the second hypothesis appears to be incapable of explaining the long term retention of TDS in the North Canal area. Nor can it account for the difference between the calculated total irrigation loss and the return flow to the Harts River, even if the lowest estimate of the total irrigation loss is used.

  - The first hypothesis appears to be capable of explaining all of the main historical trends, provided the lower end of the range of estimated mean annual deep percolation estimates holds true (or the deep groundwater storage capacity is larger than that assumed). The implication of this set of assumptions is that the deep GWT has not yet completely filled. This hypothesis warrants further investigation to verify its validity.

- **Historical salt balance**

  - Model calibration results indicated that most of the TDS load returned to the Harts River comes from the North Canal area, with much smaller contributions from the Taung area and the West Canal area. Some 65% of the TDS load contained in the irrigation water supplied to the Vaalharts irrigation scheme appears to have been retained. This compares with the first order estimate of 80% retention (based on data available up to the end of September 1984) that was made by Stewart Sviridov & Oliver in their 1987 report to the DWAF which gave rise to this study. The difference between the two estimates can be explained partially by the additional data that has since become available, including the extremely wet 1987 hydrological year, and improved estimates of historical water supply prior to 1954. The errors in streamflow gauging which have been discovered during this study also contribute towards this 15% discrepancy.

  - The new estimate verifies the main finding of the earlier report, viz. that most of the TDS load in the irrigation water has been retained, holding the potential for future salinity problems. Such problems could arise when a balance is eventually attained between the incoming and outgoing TDS loads, resulting in increased export of TDS to the downstream river system.

- **Long term future salt balance**

  - Projections of the future TDS balance at Vaalharts were carried out using model simulations assuming continued loss of salts to the deep groundwater storage. Based on these assumptions Option 1 (the 1990 status quo option, which assumes no further irrigation development or change in water allocation), results in little change in the mean annual TDS load returned to the Harts River. For this option the deep groundwater is expected to have accumulated 60% of the applied TDS load by 2030, provided there are no water restrictions during this period (since the model projections assumed that the full irrigation demand is met). If the frequency and intensity of water restrictions during the next 40 years approximates that for the historical period, then a 65% TDS accumulation can be expected.

  - Option 2 (which takes account of new irrigation developments and increased water allocations that are already in the process of being implemented), is expected to increase the mean annual TDS load returned to the Harts River by about 10%. The increased water allocations have the effect of reducing the accumulated TDS load by the end of 2030 to 59% (since a larger proportion of the applied TDS load will have reached the Harts River).

  - Both of the above projections are based on the assumption that the deep groundwater has sufficient available storage capacity to continue to accumulate deep percolation. However, if at some point in time the available storage is exhausted, then a balance between the TDS load entering the irrigated lands and that leaving via return flow to the Harts River will begin to emerge. Although the TDS load already accumulated in the deep groundwater is not likely to return to the Harts River (or if it does return, the discharge rate will be too small to make a substantial impact on the TDS balance of the Harts River), a balance between supply and return flow TDS loads will result in a two- to three-fold increase in the mean annual TDS load returned to the Harts River. It is therefore important to establish when this very substantial increase in TDS export can be expected to occur and to evaluate the impact on the salinity regime of the downstream river system.

- **Comparison of TDS and chloride retention**

  For the period October 1975 to September 1991 the TDS retention was estimated at 57% of the applied irrigation load, while that for chloride was estimated at only 40%. The extended long term TDS retention of 65% is somewhat higher than that for the sixteen year period for which TDS and chloride could be compared. Hence in the long term the chloride retention can be expected to be about 46% (i.e 65 x 40 / 57). This implies that chemical transformations and adsorption processes could be removing a significant portion of the TDS load that has apparently been retained in the groundwater. Since chloride is a highly mobile ion that is unlikely to be removed by these processes, the results indicate that at least 70% of the observed net loss of TDS (i.e 46% of the TDS load in the supply water) is likely to have been to deep groundwater. This implies that up to 30% of the salt loss could be attributable to chemical transformations and adsorption processes, part of which may be a permanent loss from the water phase. However, this figure could well be less than 30% since the presence of the chloride ion in rainfall, or even the displacement of chloride from the original groundwater, may have altered the balance between TDS and chloride without actually removing other ions from the water. It is also unlikely that the irrigated soils can continue to remove salts indefinitely.

- **Effect of sub-surface drains**

  The effect of the sub-surface drains on irrigation return flows (in terms of both water and TDS load) has been totally obscured by wet and dry hydrological cycles and extraneous factors such as over irrigation during some periods, water restrictions and the plugging of drains during drought conditions. The drains appear to have had much less effect on return flows than have climatic fluctuations.

- **Hypothesis of processes**

  The main hypotheses are as follows:

  (i) The calcrete layer is sufficiently permeable in enough places to permit the percolation of water and salts to a deeper GWT. This is where most of the "lost" TDS load appears to have accumulated.

  (ii) This deep GWT may not yet have filled, but may do so at any time in the future (since we have little information regarding the remaining storage capacity and the rate of filling).

  (iii) The deep GWT's groundwater flow contribution to the Harts River is (at present) assumed to be small relative to that from the sub-surface drains and the perched water table above the calcrete layer.

(iv) When the deep GWT fills, a rough balance between the TDS load contained in the irrigation water supply and that in the return flow to the Harts River is expected to occur. The return flow will then increase substantially and the TDS load returned to the Harts River is likely to increase by a factor of two to three.

(v) Fallow lands, the unirrigated lands separating the irrigated areas from the Harts River and a transition area along the eastern, southern and, to a lesser extent, the northern boundary of the irrigation area are all likely to exhibit elevated GWTs and contribute to the evapotranspiration loss from the irrigated areas.

- **Future implications**

The accumulation of about two-thirds of the applied TDS load at Vaalharts implies that the salinity of the groundwater and that of the irrigation return flows is still a long way from reaching a state of dynamic equilibrium with the supply water salinity. Eventual filling of the available groundwater storage is expected to result in a state of equilibrium, with the mean annual TDS load returned to the Harts River matching that contained in the irrigation water. The system response to these changes will be complicated by the effect of the installation during the 1970's of irrigation sub-surface drains, which can be expected to intercept part of the water and salt load draining past the bottom of the crop root zone. This should serve to slow the rate at which salinity levels build up in the groundwater. However, it will also ensure that a larger proportion of the salt associated with the applied irrigation water will be returned directly to the Harts River. This implies a more rapid rise in return flow salt loads after the GWT fills, resulting in the new state of equilibrium being reached more quickly than would otherwise have been the case. The net result of the eventual increased TDS export on the downstream river system could be very serious indeed.

RECOMMENDATIONS

1. Investigation of the impact of increased salinity on the Vaal River.

There is an urgent need to determine the effect of increased salinisation of the Harts River on the Vaal River. The existing Lower Vaal River salinity model (Stewart Scott and BKS, 1992) should be used to simulate the effect on the Lower Vaal River (and the Orange River) of a doubling or trebling of the Vaalharts irrigation return flow TDS.

2. Improvement of the existing flow and water quality monitoring system

(i) **Spitskop Dam outflows:** Some difficulty was experienced due to the releases from Spitskop Dam not being metered and having to be estimated using downstream gauge C3H013 instead. Aside from being too far downstream, this gauge was found to be under-measuring due to its inadequate hydraulic properties and sub-surface flow under the gauging structure. It is therefore recommended that a continuous metering system be established at Spitskop Dam to measure releases and that the C3H013 gauging structure be reconstructed (possibly rebuilt in another location).

(ii) **Hydrological station C3H007:** A separate level recorder is required further upstream to improve the accuracy of flow measurement over the Ogee weir section. The Parshall flume can then be used to measure low flows up to 3.2 m^3/s and the Ogee weir for higher flows.

(iii) **Hydrological station C3H003:** Mistakes discovered in the early part of the observed flow record at station C3H003 should be corrected.

3. Implementation of new intensive monitoring

If the results of the pilot study recommended above indicate the likelihood of severe salinisation of the Lower Vaal River, then a monitoring system aimed at measuring the water supply volumes and TDS loads entering and leaving a representative portion of the North Canal area should be designed. The size of this portion of the north Canal area would have to be determined on a cost effective basis. This monitoring system should include the gauging of water levels in both the perched and the deeper GWTs. Geohydrological and geochemical surveys should be carried out to determine the storage capacity and porosity of each aquifer and to estimate flow directions and flow rates (both vertical and lateral), groundwater quality and groundwater abstraction via boreholes. The annual crop distribution and details of irrigation practices, including fertilizer and other chemical applications will need to be accurately recorded. A good spatial spread of meteorological stations is required. Regular soil analyses are also desirable.

4. Detailed study

Verification of the main hypotheses that motivated this study justifies the commencement of a detailed multi-disciplinary investigation to better quantify the uncertainties regarding groundwater storage states, groundwater quality and percolation rates and to better understand the processes governing the behaviour of the system. The main aim of this study should be to predict when the TDS loads returned to the Harts River are likely to increase and to what level they will rise. Secondary objectives should include evaluation of the impact on the downstream river system and the determination of the best management practices that could mitigate or delay these adverse effects.

5. Model adaptation and application

Critical to the attainment of the objectives of the detailed study is the development or acquisition of an improved irrigation model that hybridises the following:

(i) infiltration/surface runoff/soil moisture processes normally addressed by catchment models;

(ii) irrigation practices and advanced crop water balance modelling, including cross links with fallow land and down slope unirrigated pasture land;

(iii) groundwater modelling; and

(iv) soil chemistry modelling.

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ABSTRACT

Vaalharts is the largest irrigation scheme in South Africa. Large scale urban, industrial and mining developments in the Vaal River catchment have led to salinisation of the water supply to Vaalharts. This prompted a study of the overall water and salt balance of the scheme. A hydro-salinity simulation model was calibrated and used to patch gaps in the historical flow and water quality record and simulate the long term behaviour of the system. The results confirmed that Vaalharts is operating as a salt sink that has accumulated two-thirds of the total dissolved salts (TDS) load contained in the irrigation water since its commissioning in the late 1930's. It has been hypothesised that the gradual percolation of water from a perched water table above a semi-pervious calcrete layer to an underlying deeper groundwater storage is the main mechanism by which salts have been retained at Vaalharts. The sparse historical groundwater record lends support to this hypothesis. Eventual exceedance of the groundwater storage capacity is expected to result in the return of a much larger proportion of the irrigation water TDS load. This would increase the annual TDS load in the return flow to the Harts River by about 100 000 t, placing further pressure on the already severely salinised downstream river system. The effect of the installation of sub-surface drains in 40% of the irrigated lands during the 1970's and 1980's on TDS export from Vaalharts was found to be inconclusive. Longer term wet and dry climatic fluctuations and water restrictions were found to have a much stronger influence on the irrigation return flow volume and TDS load. Limited planned new irrigation developments and increased water allocations are expected to increase the TDS export to the downstream river system by 10%, until such time as Vaalharts' capacity to retain salts is exhausted. The findings of the preliminary study confirm that further investigation is required to quantify the groundwater retention capacity and determine the mechanisms controlling the timing of the release of salts to the surface drainage system. The impact on the downstream river system needs to be evaluated and the best means found for ameliorating adverse effects.

1. INTRODUCTION

1.1 PARALLELS WITH OTHER IRRIGATION SCHEMES

There are quite a number of examples all over the world of once fertile farmland becoming highly saline, waterlogged wasteland. Specific examples are as follows (Appleton, 1984):

1.1.1 In Pakistan, about 10 million ha out of a total of 15 million ha of irrigable land are estimated to be salinised, waterlogged or both, and the figure is growing at more than 100 ha per day.

1.1.2 In India, the amount of land devastated by water and salt has been estimated at between 6 and 10 million ha of the 43 million ha under irrigation.

1.1.3 More than half of Iraq's 3.6 million ha under irrigation is saline or waterlogged.

1.1.4 In the USA, 25 -35% of the irrigated land suffers from salinity.

Parallels can be drawn between the situation in Pakistan and the Vaalharts irrigation scheme in South Africa. Agriculture in Pakistan's Province of Sind depended almost entirely on the seasonal rise and fall of the Indus River until the Sukkur Barrage was built in 1932. This transformed 3.2 million ha of desert into fertile farmland but unfortunately no drainage system was installed. As a result, about 3.0 million ha have become highly saline, waterlogged wasteland. The largest drainage project ever attempted is expected to restore 0.6 million ha to fertile irrigable land (Wolfe, 1988). The Vaalharts irrigation scheme started in the same decade, also without a sub-surface drainage system. Severe salinity and waterlogging problems climaxing in the seventies resulted in an extensive drainage system being installed which alleviated the problem.

With regard to other irrigation schemes in South Africa, *ad hoc* investigations have been carried out by the Institute of Soil, Climate and Rainfall (formerly SIRI) on the request of farmers experiencing problems. Streutker (1982) summarised this information and found that 12% of the 101 400 ha area investigated had experienced waterlogging or salinisation problems in 1975, which was a year of above average rainfall. This percentage decreased to about 3% in 1980. Extrapolating this data to a total irrigated area of 885 000 ha and taking into account an estimate for 1985 (Du Plessis, Institute for Soil, Climate and Rainfall - 1986), it would appear that about 13% of the 850 000 ha under regular irrigation in South Africa is affected by waterlogging and/or salinisation.

Although water quality is deteriorating in South Africa due to urban, industrial, irrigation and other developments, the salinity of the surface water compares favourably with the rest of the world when compared with the 90th percentile value of about 2000 mg/l (320 Ms/m) found by the US Salinity Laboratory. This is, however, no reason to become complacent. The increasing demands on our limited water resources necessitate the more intensive use and re-use of water, which if unchecked, will cause increased salinisation. Figure 1.1 shows the suitability of South African surface waters for irrigation.

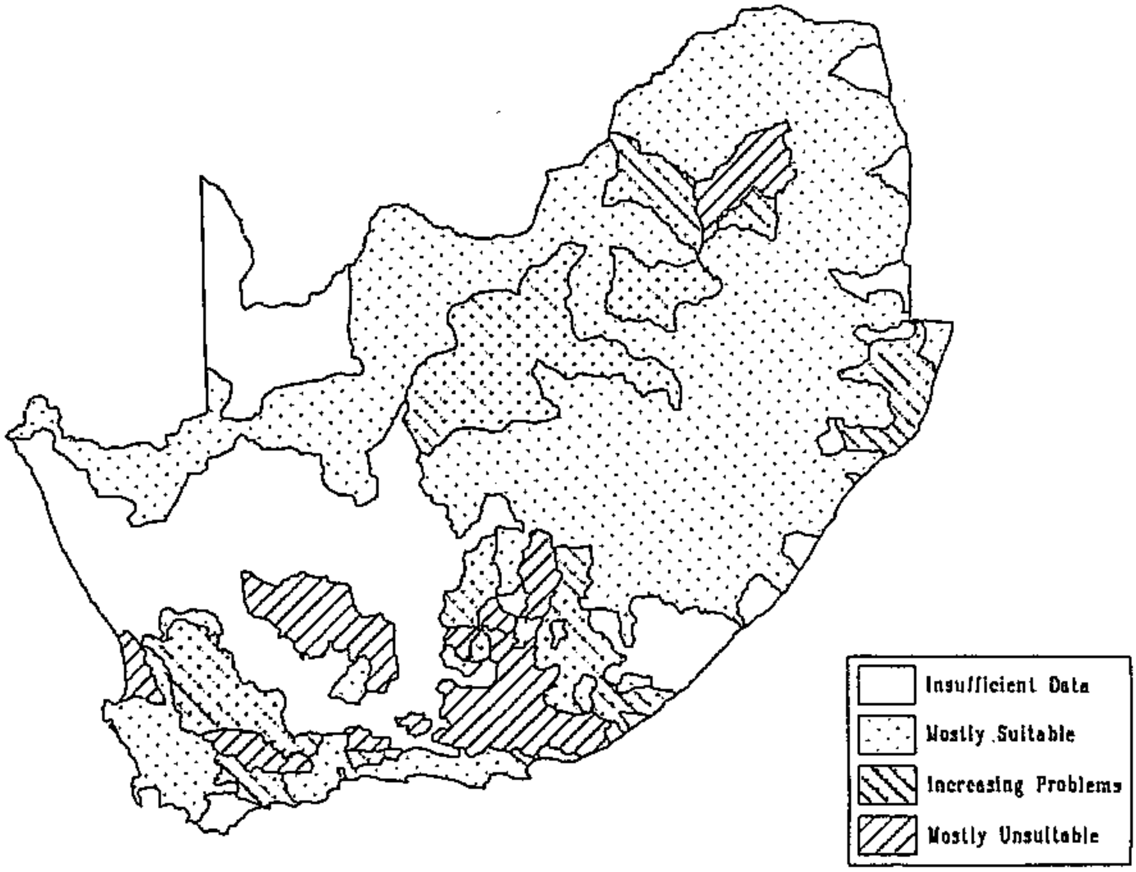

Figure 1.1 : Suitability of water for irrigation for the period 1979 to 1988 (H M du Plessis)

1.2 BRIEF HISTORY OF VAALHARTSIRRIGATION SCHEME

The history of the Vaalharts Scheme goes back to 1881-82 when the Irrigation Engineer of the Cape Province had the area surveyed with a view to irrigation and reported his findings to the Prime Minister of the Cape Colony - Cecil Rhodes. In a soil survey during 1932 to 1934, 36 000 ha of the total 74 000 ha was classified as irrigable (Van Garderen, Louw and Rosenstrauch, 1934). The Vaalharts Government Water Scheme was eventually started in 1933. The first plots were allocated in 1938 starting at Jan Kempdorp (North Canal area) and then moved northwards (Kriel, 1976). The North Canal development was completed in 1945 although improvements in the drainage system are still being undertaken. The West Canal area was developed in the 50's. The first plots were allocated in 1957 and 1958 and the last few in 1965 and 1966. The Barkly West Canal area also developed in the 50's. Prior to the sixties it is estimated that it took farmers about three years to develop their plots to the point where they were using their full allocations. Farmers were generally poor in this era and did not have the benefit of the sophisticated methods and machinery in use today. From the mid sixties onwards it is estimated that it took farmers about a year or less to develop their plots to full allocation usage (Visser, 1992).

Natural surface and sub-surface drainage was poor due to the flat gradient, typical soil profiles in the area and the presence of a relatively impermeable layer of calcrete at between 0 and 5 m depth. The groundwater table (GWT) during the period 1935 to 1940 was at about 24 m deep (Streutker, 1977). Other reports vary with regard to groundwater depth but it appears that no comprehensive system of borehole drilling was ever undertaken to determine GWT depth over the entire irrigation scheme. Over the years flood irrigation raised the GWT from about 24 m deep to about 1 m in the early seventies resulting in waterlogging and increased salinity in the root zone of crops (Streutker 1977, 1981). Above average rainfall experienced during 1974, 1975 and 1976 caused a severe loss in crop production (Streutker, 1971,1977). In some areas waterlogging occurred much earlier due to localised perched groundwater tables relatively close to the surface.

To overcome the waterlogging problem, a comprehensive system of about 240 sub-surface drainage systems were installed between 1976 and 1979. These drains successfully controlled the GWT and greatly improved crop production. In 1976, a total of almost 3000 ha of soil was saline or saline sodic to a depth of 0.3 m . At the end of 1977, about 1500 ha of saline soil remained and in 1980 there remained about 1000 ha of salt-affected soils (Streutker, 1981).

Since 1971, there have been improvements to irrigation canals, irrigation systems, external and internal drains with a resulting decrease in the leaching of salts. Leakage from irrigation canals has decreased because of regular maintenance and elimination of trees on the banks of canals. Two large buffer dams have been constructed to collect distribution losses. On each of about 560 plots the concrete lining of the dam, one main furrow and some lateral furrows has decreased the leakage of irrigation water. A high irrigation efficiency has been achieved by means of the correct manipulation of flow rate, length, width and slope of beds. (Streutker, 1977)

With the present scheme, irrigation water is diverted from the Vaalharts Weir between Christiana and Warrenton. The weir receives water released from Bloemhof Dam which in turn is augmented from the Vaal Dam. The Main Canal - 18.9 km bifurcates into the West Canal - 20.9 km and the North Canal - 60.4 km (refer to Figure 1 in Appendix A). Water from these two canals is conveyed into secondary and finally tertiary canals conveying water up to boundaries of each irrigation farm. The limited capacity of the Main Canal to meet peak water demand is the biggest stumbling block at present and it is intended to increase this capacity by means of a second canal. It has also been decided that the annual quota be simultaneously increased from 7700 m^3/ha to 9140 m^3/ha to correspond with similar irrigation schemes (Claasens, 1989).

1.3 GENERAL

The Vaalharts area lies between 1050 and 1150 m above sea-level. It is part of a semi-arid area with an average rainfall of 450 mm per year of which 80% falls during the summer months. The average maximum temperatures for January and June are 32°C and 18°C respectively while the average minimum temperatures for January and June are 16°C and 1°C respectively. Frost, hail and windstorms are experienced.

The Vaalharts Government Water Scheme is the largest in South Africa, with the total average annual value of the agricultural production in 1989/90 amounting to R61.7 million (Claasens, 1989).

1.4 NOTATION

At various times in the past the Department of Water Affairs and Forestry has been known as the Department of Water Affairs and the Department of Environment Affairs. In order to avoid confusion it has been referred to by its current name, the Department of Water Affairs and Forestry (or DWAF), throughout the text.

For consistency with computerised data, the decimal comma has been replaced by the decimal point.

1.5 DEFINITIONS OF KEYWORDS

The following terms have been defined to avoid any misunderstanding.

Irrigation return flow	-	That portion of the irrigation supply water and direct rainfall that is not used by the crop and which has the potential to end up in the Harts River. This water would comprise surface water runoff and water collected by sub-surface drains. It would not include that portion of the percolation to deep groundwater that contributes to a net increase in the long term groundwater storage.
Deep percolation	-	Water that infiltrates the soil but is not used by the crop and is also not collected by the drainage system. It seeps downwards through the permeable parts of the calcrete layer and builds up a deeper groundwater table. It is not included in the definition of irrigation return flow.
Total potential return flow	-	The sum of irrigation return flow and deep percolation.

1.6 ARCHIVING

All material collected for this study will be retained by the Consultant. All computerised data, information and reports will be stored on the Consultant's computer network. A tape backup of this information is carried out on a daily basis. Maps, reports etc. will be stored in the Consultant's archives. Any of this material can be retrieved as and when needed.

2. SITUATION ANALYSIS

2.1 AREA OF LAND UNDER IRRIGATION

2.1.1 Present

The Vaalharts Government Water Scheme is divided into the West Canal area comprising about 5000 ha of irrigated land and the North Canal area of about 24 000 ha. The latter area consists of blocks A to N each consisting of 1000 plots of 25 ha each. About 24 ha of each plot is under irrigation (Visser, 1992). The Taung irrigation scheme in Bophuthatswana (refer to Figure 2 in Appendix A) has an additional 3570 ha (Serfontein, 1992).

The split according to location (Refer to Figure 1 of Appendix A) is as follows (Visser, 1992):

(a) Mostly downstream of DWAF hydrological station C3H003 on the Harts River, the Taung irrigation scheme in Bophuthatswana comprises 3570 ha (1100 ha upstream of C3H003 and 2470 ha downstream).

(a) Between hydrological stations C3H003 and C3H007 (i.e North Canal area) - 24 000 ha.

(c) Between hydrological stations C3H007 and C3R002 - Spitskop Dam (i.e West Canal area) - 5000 ha.

(d) Downstream of hydrological station C3R002 - 1650 ha (of which about 100 ha is between stations C3R002 and C3H013).

(e) Downstream of hydrological station C9R001 - Vaalharts Weir (i.e irrigated from the canal running parallel to the right bank of the Vaal River towards Barkly West) - 2900 ha.

2.1.2 Historical

Table 2.1 shows the allocation records that we were able to obtain for the combined North and West Canal areas (as well as the Taung area up to 1981).

Table 2.2 gives a more detailed breakdown of the allocations for irrigation for the years 1976, 1980, 1984 and 1989.

TABLE 2.1
Allocation records (Durant, 1992)

Date	Allocation (ha)
1938+	381
1949 - July#	25 386
1950 - October	22 622
1952 - June	30 374
1953 - July	32 637
1954 - September	33 726
1955 - October	35 059
1956 - September	35 069
1961 - February	36 513
1964 - March	36 957
1967 - March	36 936
1969 - June	36 876
1971 - August	35 617
1981 - March*	31 743
1991 - December*	31 630

NOTES:

\+ On a site visit to the Vaalharts irrigation scheme it was mentioned that at the start of the scheme the Taung area began with approximately 1000 ha (Steyn, 1992). This conflicts with the total of only 381 ha for the entire area given in the table for 1938.

\# No data was available prior to 1949 apart from the first year 1938 (Kriel, 1976).

* It appears that the 1981 and 1991 allocations do not include an amount of 5319 ha which were called "free" allocations. This accounts for the apparent drop in the irrigated area from 1981 onwards. 5319 ha therefore has to be added to the 1981 and 1991 allocation figures to arrive at the true total allocation.

TABLE 2.2
Allocations for irrigation at Vaalharts Government Water Scheme
(Kriel, 1976 & Claasens, 1989)

Description	1976 (ha)	1980 (ha)	1984 (ha)	1989 (ha)
1. Rateable				
Vaalharts	29 469	29 112	29 113	29 416
Klipdam - Barkly	2 353	2 627	2 634	2 327
Sub-total	31 822	31 739	31 747	31 743
2. Non-rateable				
Taung area+	4 447	4 447	4 447	4 447
Department of Social Welfare (Ganspan)	300	300	300	300
Jan Kempdorp local authority	171	171	171	5
Vaalharts experimental farm	381	381	381	381
Poor Sisters of Nazareth	20	20	20	20
Miscellaneous State land	51	51	53	
Warrenton Prison farm				257
Special case (J.R Children's Home)*		103	103	17
Sub-total	5 370	5 370	5 373	5 427
Total allocated	37 192	37 212	37 222	37 171

NOTES: + The Taung allocation of 4447 ha is to be increased to 6424 after canal enlargement.

* This area is not formally scheduled

2.2 CROP DETAILS

2.2.1 General

Data for 1977 showed that the Vaalharts irrigation scheme provided 20% of South Africa's cotton, 7% of groundnuts and 4% of wheat. Other crops include lucerne, maize, sunflower, citrus, peas and other vegetables. Vineyards are also irrigated. The type of crops produced have not changed much over the years, although cotton production is now declining due to unfavourable market conditions. From studies on test areas, the following conclusions were drawn on the two crops which have been the most important, namely cotton and wheat (Streutker, 1971):

(a) Cotton

More cotton is produced in soil with a shallow GWT than a deeper GWT, provided that the GWT is not shallower than about 0.90 to 1.10 m. With nine irrigations per season, the yields for GWT's of 1.1, 1.7 and 2.3 m were 6.0, 4.2 and 3.0 t/ha respectively. With four irrigations, the yield is the same provided that the efficient cultivation practices are used. The total water usage was between 400 and 500 mm, depending on the depth of the GWT. On soil where the GWT was about 1.10 m deep, less irrigation water was required due to the fact that 300 mm of water could be drawn from the soil above the GWT. This in comparison to only 20 mm from the soil above the GWT where the GWT was at 2.5 m. There was no apparent difference in the quality of the cotton for different GWT levels. Using efficient cultivation practices, 0.6 to 1.0 t/ha more cotton was produced. A higher production was obtained where the GWT remained constant at 0.9 to 1.1 m depth. In the case where the GWT rose to within 0.3 m of the soil surface, the production of cotton was worse (Streutker, 1971).

(b) Wheat

With one to four irrigations per season, the yield for wheat was on average 0.8 t/ha more on soil with a GWT of 1.10 m than on soil with a GWT of 2.15 m. With a shallow GWT, the production with one and four irrigations was 4.0 t/ha, whereas for a deeper GWT it was 3.0 and 3.8 t/ha respectively. The total water use was between 450 and 500 mm depending on the depth of the GWT. About 240 mm of water was drawn from the soil above the GWT when the GWT was at about 1.10 m deep against 190 mm for a GWT of 1.60 m. Although the production was higher for a shallow GWT, the quality dropped from a class A to a class B. The highest quality wheat was obtained using only one irrigation. Using efficient cultivation practices, 1.4 t/ha more wheat was produced. As for cotton, the production of wheat on soil where the GWT was constant at 0.90 to 1.10 m deep was highest. Where the GWT rose to within 0.30 m of the ground surface, the nitrogen content of the wheat serial was lower (Streutker, 1971).

2.2.2 Areas under irrigation

The earliest data on record is for 1947. However, the areas under irrigation were not available. For this year only the crop production was available (Bornman, 1988):

Wheat	-	59 100 sacks
Lucerne	-	15 510 t
Groundnuts	-	100 000 kg
Potatoes	-	13 200 sacks
Tobacco	-	2000 kg

Detailed data on crops is only available from 1975 but prior to this the following crops were produced: groundnuts, wheat, lucerne, cotton and maize (Streutker, 1971).

Table 2.3 gives the area under each crop for the entire Vaalharts irrigation scheme since 1969. This data was obtained from different sources and for some years there is more than one set of data. The notes give details of where the data was obtained. Where there is no note, this data was obtained from the

Vaalharts Co-Op (Koen, 1992). This data is based on seed sales and therefore cannot be regarded as being as accurate as the other data. For the modelling process, an overview of all sources of irrigated areas was taken and therefore the areas given in Table 2.3 were not used exactly.

TABLE 2.3
Approximate area under each crop+ (ha)

Year	Wheat (W)#	Maize (S)	Ground -nuts (S)	Cotton (S)	Lucerne (S)	Vines (S)	Peas (W)	Oats (W)	Other	Total (S)	Total (W)	Grand Total
1969@	12087	8060	6562	No data	No data	71	749	590	1266	15959	13426	29385
1975*	19000	7000	11500	7200	1300	802	1047	4200	1088	28444	24693	53137
<u>1978</u>	11800	11600	8096	No data (6600)	&(2000)		? 16 (750)			28296	12550	40846
1979	12900	7900	13100	? 38 (6600)	(2000)		? 30 (750)			29600	13650	43250
1980*	14000	12000	17500	6000	2500	180	500		750	38930	14500	53430
1981	14100	11700	5300	6200	(2000)		500			25200	14600	39800
1982*	20000	16000	5000	7000	4000	220	1100		1500	33720	21100	54820
1983	5800	8200	4000	5100	(2000)		220			19300	6020	25320
1984	9000	1500	3900	3300	(2000)		660			10700	9660	20360
1985	11400	1900	4400	3500	(2000)		1500			11800	12900	24700
1986	15900	3662	4600	4000	(2000)		1960			14262	17860	32122
1987	12234	3852	4600	No data (3500)	(2000)		1700			13952	13934	27886
1988	15200	1050	4600	No data (3500)	(2000)		3500			11150	18700	29850
1989	No data											
1990	13000	5700	11400	3000	(2000)		2500			22100	15500	37600
1991$	12600	18400	8300	3000	4000	250	540		350	34300	13640	47440

NOTES:

+ Unless otherwise stated the data was obtained from the Vaalharts Co-Op (Koen, 1992). This data is based on seed sales and therefore cannot be regarded as being accurate. Alternative estimates have been used when available, as denoted by the following footnotes.

(S) and (W) denote summer and winter crops.

@ Data from the Agricultural Census 1968/69 (Department of Statistics, 1969). The Magisterial Districts of Hartswater and Warrenton (which includes Vaalharts Settlement B and very little other irrigation) were combined.

* Data from White Papers WP M-76 (Kriel, 1976), WP C-81 (Otto, 1981) and WP K-84 (Otto, 1984).

& Lucerne (shown in brackets) has been estimated.

? Areas for cotton and peas that appear to be unrealistic in terms of other data. For this data and where there was no data available, average areas have been determined as shown in brackets.

$ Data from the Department of Agriculture and Water Supply (Hamman, 1992).

Table 2.4 gives the production of crops for 1991.

TABLE 2.4
Production of crops in 1991 (Hamman, 1992)

Crop	Estimated average annual production (ton)
Wheat	60 894
Maize	63 321
Groundnuts	16 000
Cotton	6 000
Lucerne	70 000
Peas	1 100
Vines	2 400
Total	219 715

One of the results of the crop rotation irrigation method, based on areas given in White Papers (Otto, 1984), is that the total irrigated area (summer and winter) is larger than the scheduled area by a ratio of about 1.5.

The areas of crops under irrigation in the Republic of Bophuthatswana portion of the Vaalharts scheme are given in Table 2.5.

TABLE 2.5
Areas of crops under irrigation in Bophuthatswana (Serfontein, 1992)
(included in Table 2.3)

Crop	Area (ha)
Cotton	850
Groundnuts	1 650
Maize	110
Wheat (Winter)	2 100
Peas (Winter)	200
Lucerne	85
Sunflower	570
Total	5 565

2.2.3 Crop water requirements

A number of sources give estimates of monthly crop water requirements for Vaalharts (Ninham Shand Inc., 1985; Green, 1985; Loxton-Venn, 1985). Table 2.6 gives the monthly water requirements for the main groupings of crops as per Loxton-Venn (1985). While Green (1985) gives valuable detailed crop water requirement data that is an invaluable aid in the selection of crops and the planning of irrigation, this information could not be used in this study because the crops have been split into too many sub-varieties, for which overall crop areas could not be obtained for Vaalharts.

TABLE 2.6

Crop water requirements in mm (after Loxton-Venn, 1985)

Crop	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Wheat	157	-	-	-	-	-	-	+60	18	52	129	200	616
Maize	-	+60	45	133	162	132	60	-	-	-	-	-	592
Cotton	+60	48	113	185	142	35	28	-	-	-	-	-	611
Groundnuts	-	+60	45	147	82	40	37	-	-	-	-	-	411
Lucerne	157	192	192	174	125	77	38	26	18	30	52	95	1176
Potato	-	-	+60	66	92	114	105	-	-	-	-	-	437
Brassica	-	-	-	-	+60	31	58	60	34	-	-	-	243
Cucurbit	105	170	95	-	-	-	-	-	-	-	+60	63	493
Pea seed	-	-	-	-	-	-	+60	14	22	58	89	-	243

NOTE: + Pre-irrigation allowance

2.2.4 Irrigation systems

In the North Canal and West Canal areas, about 97% of the 29 063 ha is under flood irrigation. About 2.5% is under overhead spray irrigation and the remaining 0.5% is under drip irrigation. In the Taung area in Bophuthatswana, only about 10 ha of flood irrigation remains from 3570 ha, the rest having been upgraded to centre pivot irrigation (Serfontein, 1992 & Koen, 1992).

2.2.5 Fertilisers

Fertiliser use between February 1991 and March 1992 is given in Table 2.7. On average, the total use is between 10 000 and 20 000 tons per year.

The application rates of fertilisers depend on the soil type, crop type, irrigation methods (type, intensity and frequency), method of application of fertiliser (batches or mixed in while planting) and drainage.

Crops do not use 100 % of the applied fertiliser. The following components are regarded as increasing the soil salinity, namely: potassium, sulphates and chlorides. As a rough estimate, crops are thought to use the following percentages of these ions (Botha, 1992):

Potassium (K)	50 %
Sulphate (SO_4)	80 %
Chloride (Cl)	50 %

These percentages have been used to calculate the net effect of fertiliser application. It was calculated that 0.04 t/ha per annum will not be used by crops and will therefore increase the salinity of the soil (but by very little).

TABLE 2.7
Amounts of fertiliser presently being applied
(Koen, 1992 and Gerrit & Fick, 1992)

Type	Amount (t p.a.)
Ammonium sulphate $(NH_4)_2SO_4$ (72.7 % sulphate)	3 778
ASN - Ammonium sulphate nitrate 46% NH_4NO_3 and 54 % $(NH_4)_2SO_4$ (48 % sulphate)	2 727
LAN - Limestone ammonium nitrate mixture of $CaCO_3$ and NH_4NO_3	132
Urea $NH_2CO\text{-}NH_2$	484
2:3:4 (30) + Zn (2 parts nitrate 6.7 %, 3 parts phosfate 10 % and 4 parts potassium 13 %, 3.6 % sulphate and 8.3 % calcium, Zinc)	1 179
2:3:4 (30) as above without Zn	490
3:2:1 (25) + Zn (2 parts nitrate 12.5 %, 3 parts phosphate 8.3 % and 4 parts potassium 4.2 %, 9.7 % sulphate and 6.7 % calcium, Zinc)	2 826
3:2:1 (25) as above without Zn	588
Super phosphate $3Ca(H_2PO_4)_2H_2O$ + $7CaSO_4$ + HF (12 % sulphate)	1 566
Potassium chloride (50 % potassium, 50 % chloride)	433
MAP - Mono ammonium phosphate (1.1 % sulphate)	167
Saaifos (9.8 % sulphate)	37
Potassium sulphate K_2SO_4 (45 % potassium, 55 % sulphate)	10
2:3:2 (22) (2 parts nitrate 6.3 %, 3 parts phosphate 9.4 % and 4 parts potassium 6.3 %, 8.1 % sulphate and 12.6 % calcium, Zinc)	21
Limestone and gypsum	500
Total	14 938

2.3 DRAINAGE

2.3.1 General

The high infiltration rate of the sandy soil and the presence of the relatively impermeable underlying calcrete layer has resulted in waterlogging problems (refer to Figure 3 in Appendix A). With waterlogging, the water can no longer drain downwards resulting in rotting roots due to lack of oxygen. Waterlogging also causes increased salinity of the soil. These salts affect the osmotic process of the plant, i.e water and nutrients can no longer be absorbed as effectively. After heavy showers, crops are also drowned and erosion and general flood damage results. The problem was solved by the installation of a system of sub-surface drains. The groundwater slowly drains into the perforated pipes in this way leaching the dissolved salts out of the root zone. The groundwater table (GWT) therefore remains at an acceptable level. A system of branch drainage canals then collects seepage and storm water from the plots and carries it to the main drainage canals which discharge it in the Harts River (Otto, 1981).

The major drainage systems occur in the North and West Canal areas which are now virtually complete and cover about 40% of the combined area (refer to Figure 2, Appendix A). In the Taung area (i.e upstream of hydrological station C3H003), only about 50 ha needed to be drained because the area is not as flat as the North Canal area. The predominance of more efficient sprinkler irrigation in this area has also reduced the loss of irrigation water to the groundwater. The other areas, i.e downstream of Spitskop Dam and the area adjacent to the Vaal, have no artificial drainage (Visser, 1992).

2.3.2 Historical progression

Complaints about waterlogging were investigated between 1942 and 1967 on approximately 270 farms and the groundwater table was investigated in November 1972. In 1965 it was decided to investigate the possibilities of artificial drainage and a pilot sub-surface drainage system was installed on the plots 5K5, 6K5 and 7K5. Two types of drainage pipe (baked tile and perforated PVC pipe) and three types of filter material (fibre-glass film, fibre-glass sheet and river gravel-sand) were chosen. Above average rainfall was experienced during 1974, 1975 and 1976 and this caused severe waterlogging and salinisation on the West and North Canal areas. This situation was remedied between 1976 and 1979 by the installation of about 240 sub-surface drainage systems at a depth of 1.5 to 1.7 m. Immediately after the construction of the sub-surface drains, the high GWT dropped. It was found that it was possible to control the highest GWT after rain or irrigation at a level of about 0.2 m to 0.3 m above closely spaced tertiary drains, but at 0.6 m to 0.9m above widespread plot drains. Maintenance of the drains proved necessary to remove iron deposits and roots (Streutker, 1971, 1977 and 1982).

During 1983 to 1987 no drains were installed due to the drought conditions. In fact a lot of farmers plugged their drains to raise the water table. Since the 1988 floods, another 8 to 10% of the North Canal area has had drains installed. At present, there are just a few plots which are having waterlogging problems and require the installation of drains (Visser, 1992).

Table 2.8 indicates the improvement in internal plot drainage (Streutker, Mulder & Boer, 1982).

TABLE 2.8
Improvements in plot drainage from 1974/75 to 1991/92
(Otto, 1981; Hamman, 1992)

Year	Number of plots with sub-surface drainage	Area drained (ha)
1974/75	0	0
1975/76	36	900
1976/77	100	2 500
1977/78	104	2 600
1978/79	85	2 130
1979/80	55	1 430
1980/81	37	727
1981/82	(30)	748
1982/83	(12)	289
1983/84	(17)	434
1984/85	(4)	100
1985/86	(4)	100
1986/87	(1)	30
1987/88	0	0
1988/89	(3)	65
1989/90	(6)	157
1990/91	(9)	228
1991/92	(2)	38
Total	(505)	12 476

Note: 1. Otto (1981) provided data up to 1981/82 with the corresponding number of plots with drainage. Hamman (1992) provided data for the area drained over the period from 1975/76 to the present. There was a discrepancy in the areas drained in 1981/82 (Otto (1981) gave 376 ha). It was decided to use the data provided by Hamman (1992) for this year because this data was more up to date).

2. Figures in brackets were estimated using an average plot size of 25 ha.

2.3.3 Depth, spacing, diameter and slope of drains

The drainage system consists of three or four sub-surface drains per plot, of length 650 m, average depth 1.5 m and spaced approximately 100 m apart. The minimum depth of drains is 1.2 m . Crushed stone was used as a filter. The 70 mm diameter pipe proved to be more successful than 50 mm diameter pipe. The discharge of a drain of 650 m length subject to the highest GWT was 2.4 l/sec (Streutker, 1982).

The open drains are either parabolic or trapezoidal in cross-section and are usually concrete lined. (A very small percentage are grass lined.) Canal capacities are usually about 10 m^3/s depending on the gradient and storm water duty. The gradients are usually determined by the relative levels of the internal drains but figures of 1 in 300 to 1 in 500 are generally typical with a few reaches of 1 in 1000 (Kriel, 1976).

The drainage system is shown in Figure 2 (Appendix A).

2.3.4 Lining of irrigation dams

Up to September 1983, 832 out of a possible 1175 plots had already been provided with irrigation dams equipped with permanent linings in order to reduce losses through seepage and therefore to alleviate the drainage problem. Table 2.9 shows the progression with time.

TABLE 2.9
Total number of irrigation dams lined (Kriel, 1976; Otto, 1981 & 1984)

Year	No. of irrigation dams lined out of a total of 1175
1976	719
1980	780
1983	832

2.3.5 Maps

A comprehensive drainage map has been obtained from the Department of Water Affairs - Vaalharts (Visser, 1992). A map showing the Taung area with centre pivot irrigation details was obtained from Agricor (Steyn, 1992). The maps given in Figures 1 and 2 (see Appendix A) were obtained from Government White Papers (Otto, 1984).

2.4 FLOW DATA AND HISTORICAL WATER SUPPLY

2.4.1 Observed flow data

Reservoir records have been obtained for Vaalharts Weir (hydrological station C9R001) as well as Spitskop Dam (C3R002) (Gouveia & Modise, 1992). For Vaalharts Weir, reservoir records were available from the DWAF, Directorate:

Hydrology only from 1954. However, additional records were obtained back to 1941 (Pyke, 1992). Flow data was also obtained for flow gauging stations C3H003, C3H007 and C3H013 (Gouveia & Modise, 1992).

Large errors in the observed flow record for hydrological station C3H003 were discovered from 1926 to 1937. These were brought to the attention of the DWAF Directorate: Hydrology (Keuris & Swiegers, 1992). The same record had been obtained for a previous hydrological study of the Harts River and had been correct at that stage. (The error in the record was evidently introduced after the previous study had been completed when inappropriate discharge tables were applied to the original stage records. Apparently the original calculated flow records were not kept and after the error was detected there was no longer any means of determining which discharge tables and gauge zero corrections were applicable to different periods). The earlier version of the flow record, which was still available on the Consultant's computer files from the earlier study, was therefore used and brought up to date using the latest DWAF records.

Outflow data for Spitskop Dam (and hence inflow data which is calculated from outflow data) had to be based on the flow measured at the downstream weir, station C3H013, due to the fact that reservoir releases were not measured at Spitskop Dam prior to 1989. At the end of 1989, a differential flow pressure meter was installed in the outlet pipes at Spitskop Dam and releases have since been determined on a weekly basis (Visser, 1992). The C3H013 record has under-estimated the outflow from Spitskop Dam. This under-estimation is attributable to ungauged seepage under the weir, irrigation abstractions (approximately 100 ha between Spitskop Dam and the weir) and an incorrect discharge table (DT) at station C3H013. At the request of the study team, the flow records for stations C3H007, C3H013 and Spitskop Dam were revised by the DWAF following a site investigation.

There are also three operational flow gauging weirs which do not have official gauge numbers. One is a sharp/broad crested weir with an OTT recorder located at Lloyd on the Lower Harts River about 400 m downstream of the bridge on the Barkly West road. This weir has a capacity of about 5-6 m^3/s and is estimated by the DWAF to be accurate to within 5%. It was washed away during the 1988 floods but was later re-built. Flow records for this weir are available for only the last two years. The other two operational weirs are the Scmidtsdrift weir, located downstream of the Vaal - Harts confluence, and a weir at the Sydney-on-Vaal bridge, upstream of Delportshoop (Visser, 1992).

Flow gauge evaluations for hydrological stations C3H003, C3H007 and C3H013 were obtained from the DWAF (Keuris & Swiegers, 1992; Van Bosch, 1992 and Du Plessis, 1992). Further details on gauges can be found in the site visit notes. Photographs of gauging sites were also taken during a site visit. (Refer to Appendix C for the C3H007 site survey, site notes, EC readings taken on site and photographs.)

2.4.2 Urban and industrial abstractions

Urban and industrial use from the Vaalharts canals occurs at Warrenton, Pampierstad, Taung, Pudimoe, Vryburg, Jan Kempdorp and Hartswater. A purification works at the end of Bophuthatswana's canal at Pudimoe supplies Pudimoe and Taung and delivers water via a pipeline to Vryburg (RSA). Jan Kempdorp, Hartswater and Pampierstad are supplied from the RSA's canal (Visser, 1992).

An annual total of $16.53 \times 10^6 m^3$ of water is required for domestic and industrial purposes. A breakdown of this water use is given in Table 2.10.

TABLE 2.10
Allocations for domestic and industrial purposes (Claasens, 1989)

Consumers	**Annual allocation (10^6 m^3)**
BOPHUTHATSWANA:	
Pampierstad	1.80
Pudimoe	1.28
Taung	1.02
Magogong	0.37
Sub-total	4.47
RSA:	
Warrenton	3.57
Vryburg	3.10
Hartswater	0.95
Jan Kempdorp	0.88
Other smaller consumers	3.55
Sub-total	12.05
Grand total	16.53

2.4.3 Historical changes in water allocation

The capacities of the Main Canal, North Canal and West Canal are 27, 22.5 and 4 m^3/s respectively. The respective lengths are 18.9, 60.4 and 20.9 km. The maximum delivery rate to Bophuthatswana is 3.2 m^3/s (if the demand in RSA is low) and 2.4 m^3/s (for the maximum demand in RSA). The North Canal capacity of 22.5 m^3/s includes Bophuthatswana's 2.4 m^3/s (Visser, 1992).

The annual allocation for RSA farmers increased in April 1990 from 770 to 914 mm (7700 m^3/ha to 9140 m^3/ha). This allocation of 9143 m^3/ha will, however, only be utilised when the new canal from the Vaalharts Weir has been completed. Bophuthatswana's annual allocation is fixed at 7700 m^3/ha plus 10% distribution losses on an area of 6424 ha which is equivalent to 54.41×10^6 m^3/annum. However, only 37.7×10^6 m^3 per annum can be supplied by the existing canal system and this is only sufficient for the irrigation of 4447 ha at a quota of 7700 m^3/ha/annum plus 10% distribution losses. Enlargement of the existing canal scheme for the Vaalharts area will thus enable the Taung area to fully utilise its rightful allocation (Claasens, 1989).

According to the White Paper W.P.C-81 (Otto, 1981), only about 80% of the total quota (or 179 x 10^6 m^3) of the North and West canal areas is supplied annually. (The under-utilisation of quotas is attributable to the inadequate capacity of the irrigation canals.) This is equivalent to an annual supply of only 6160 m^3/ha for a scheduled area of 29 112 ha (1981). This appears to be somewhat low compared with the Vaalharts Weir reservoir records, which show annual abstractions of the order of 333x$10^6$$m^3$ (average for 1980 to 1982). However, irrigation use in Bophuthatswana, the Barkly West area and towns also have to be taken into account. The abstractions at Vaalharts Weir also include canal losses. Appendix B1 gives the supply of irrigation water and rainfall during summer and winter for the North Canal area.

At present, a new canal is being constructed to run in parallel with the Main Canal (to be completed in 1993/94) which will increase the combined capacity to about 48 m^3/s. The North Canal will then be able to deliver about 39 m^3/s and the West Canal about 6.5 - 7.0 m^3/s. This proposed system will be designed for a peak supply rate over the week of 7 mm/day in an irrigation week of 5 days per week. This canal service over 7 days is equivalent to 9.8 mm/day. This is the maximum crop demand during the peak four to six week periods September to October (winter crop) and January (before summer rains).

In addition to the main Vaalharts irrigation located adjacent to the Harts River there is the Klipdam - Barkly West canal which runs parallel to the Vaal River towards Barkly West. This 350 km long canal has a capacity of about 2 m^3/s and irrigates an area of about 2900 ha. It is an automatic system, supplying 11 855 m^3/ha/annum over a 250 day period. This canal is, however, being closed down and water will be supplied from the lower Vaal River instead (Visser, 1992).

2.4.4 Irrigation return flow

The irrigation return flow for the North Canal area is substantially higher than that for the West Canal area owing to the fact that the North Canal irrigation area lies much closer to the river and the volumes of irrigation water used are much higher. There are also pans in the area between the West Canal irrigation area and the Harts River which appear to evaporate most of the return flow.

Irrigation return flow plays a significant role in the salinisation of rivers. During the periods 1959 - 1966 and 1967 - 1970, the calculated mean annual irrigation return flows to the Harts River were estimated at 24% and 11% (respectively) of the gross water supply (Streutker, 1977). More recent return flows are of the order of 10%. Of the factors determining salinisation of rivers as a result of irrigation, irrigation water salinity, leaching fraction and evapo-transpirational requirement of the crop were found to be the most important in determining the salt load draining from irrigated land.

Maximum return flows occur from mid September to the end of October. The salinity of these return flows is generally lower with higher return flow volumes (Visser, 1993).

The Vaalharts North Canal area was used in a study (Ninham Shand, 1985) to compare return flow volumes and salt loads. Table 2.11 gives a comparison of deep percolation estimates using different techniques.

TABLE 2.11

Comparison between deep percolation# estimates by different techniques for the North Canal area (Ninham Shand, 1985)

Hydrological year	Deep percolation ($10^6 m^3$)			
	Crop water balance (Ninham Shand)	ACRU daily soil water model	Projected drain outflows*	Streutker estimates+
1975	7.6	62.6	-	-
1976	8.6	26.3	-	-
1977	16.4	28.9	-	30.0
1978	8.1	15.9	-	27.0
1979	16.5	29.4	-	27.0
1980	15.0	39.1	34.0	-
1981	17.8	28.9	21.0	-
1982	3.5	-	16.7	-

NOTES:

* Missing data linearly interpolated.

\+ Calculated unpublished data with suppositions (sub-surface drain discharge calculated during a period of no rainfall).

\# Ninham Shand's definition of "deep percolation" refers to water leaving the root zone in actual irrigated fields.

Table 2.12 gives comparisons of total potential return flow estimates (Ninham Shand, 1985).

TABLE 2.12
Comparison between total potential return flow estimates by different techniques for the North Canal area

Hydrological year	Total potential return flow ($10^6 m^3$)		
	Crop water balance (Ninham Shand)	* Streutker estimates (unpublished data)	River channel mass balance
1977	50.4	51	-
1978	59.2	44	-
1979	86.2	45	-
Mean annual (years included)	55.4 (1974-1979)	47 (1977-1979)	45.0-48.5 (1974-1979)

Note: * Drain discharge plus irrigation tail end losses during periods of no rainfall

It should be noted that not all of the figures given in Table 2.12 are directly comparable. For example the NSI crop water balance volumes include both return flow to the river and possible percolation to deep storage, whereas the river channel mass balance accounts only for return flows to the river. It is not clear what components the Streutker estimates include due to the fact that NSI quoted from unpublished Streutker data.

Table 2.13 gives estimates of return flow salt loads associated with deep percolation and loads associated with total return flows. There was no water quality data for several months over the period 1975 to 1980. Only one of the six years in the period 1975 to 1980 has been reproduced from the full table given by Ninham Shand (1985).

TABLE 2.13
Deep percolate TDS concentrations and salt loads as estimated with the ACRU model combined with the Oster and Rhoades model, as well as total return flow salt loads by river channel mass balance for the 1977 hydrological year.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
LF	0.01	0.04	0.05	0	0.12	0	0.52	0	0.02	0.32	0.29	0.05
TDS	3300	3500	3500	0	1700	0	600	0	3500	800	950	3200
DP flow	0.1	0.9	1.7	0	2.9	0	11.9	0	0.3	2.7	5.6	1.2
DP load	330	3150	5950	0	4930	0	7140	0	1050	2160	5310	3840
RMB load	-	-	-	-	-	-	-	3123	3292	3321	3986	-

NOTES:
1. LF - leaching fraction (ACRU) = deep percolation/(irrigation + effective rain)
2. TDS - total dissolved solids of deep percolate (mg/l)
3. DP flow - deep percolate ($10^6 m^3$)
4. DP load - deep percolate salt load (tons)
5. RMB load - total return flow salt load by river channel mass balance (tons)

2.4.5 Evaporation

The mean annual A-pan evaporation is 2600 mm (based on the data for evaporation station 2757/2450 - Jan Kempdorp). Refer to Appendix J for mean monthly potential lake evaporation values. (The mean monthly lake evaporation values from October to September are given in the last row of the reservoir (RV) sub-model input data files).

2.5 HISTORICAL WATER QUALITY DATA AND SALT BALANCE

The latest data for Vaalharts Weir (C9R001) was obtained. In an attempt to supplement the Vaalharts weir water quality record, an approach was made to Eskom to obtain historical water quality records for the Vaal River water supply to Vierfontein Power Station (which was closed down a couple of years ago) but no such records could be traced (Goosen, 1992). Data has also been obtained for the gauges C3R001, C3H003, C3H007, C3R002, C3H013, C9R002 and C9H010 (Schutte, 1992). There is no water quality data available for the operational weir at Lloyd, other than a single field electrical conductivity (EC) reading taken during a site visit. (Full details of all EC readings taken during the site visit are given in Appendix C).

A salt balance carried out by Streutker (1977) for the North Canal area gave the following mean annual reults for the years 1959 to 1966:

Salt in irrigation water	= 40 924 t (V = 142.1, C = 288)
Salt in fertilisers	= 8 184 t
Salt in drainage water	= 7 322 t (V = 10.4, C = 704)
Salt removed by plants	= 6 480 t

Where V = water volume (million cubic metres) and C = TDS concentration (mg/l).

This implies an annual TDS accumulation of 7322 + 6480 - 40 924 - 8184 = 35 306 tons.

Stewart Sviridov & Oliver (1987) estimated that between 1935 and 1984 the TDS load returned to the Harts River was less than 20% of the TDS load contained in the irrigation water supplied to Vaalharts, ignoring the net effect of the salt input via fertiliser application and that removed by plants. This compares closely with Streutker's estimates for the period 1959 to 1966, which give an equivalent salt return flow of 18% (expressed as a percentage of the TDS load in the irrigation supply water).

2.6 SOILS DATA

2.6.1 Maps

Figure 3 (Appendix A) shows three different types of soil classification for the North Canal area (Streutker, 1977). The 1:250 000 Land Type Series maps also provide soil classification details (Dept. Agricultural Technical Services, 1978).

The Institute for Soil, Climate and Water have detailed soils maps drawn up during 1932 to 1934 (Schoeman, 1992). There are 24 linen maps in total (scale 1:6000), depicting the distribution of the ten soil types that were distinguished. The ten soil types are as follows:

1	Sandy to sandy loam B
2	Sandy to Sandy loam on lime
3	Sandy to sandy loam on rock
4	Sandy loam to clay loam B
5	Sandy loam to clay loam on lime
6	Sandy loam to clay loam on rock
7	Alluvial soil
8	Pan to vlei formation
9	Rock outcrops or stone strewn
10	Rock and limestone outcrops, shallow definitely non-irrigable

An intensive survey was carried out on 7000 test holes from 1932 to 1934. Van Garderen and Rosenstrauch (1936) give the depth to different layers of various material for each test hole. Van Garderen and Rosenstrauch divided the soil/rock profile into the following material types:

Ca	Small amounts of calcrete or calcrete powder with soil
L_0	Very soft calcrete with or without soil
L_1	Fairly hard calcrete
L_2	Hard calcrete
L_3	Impenetrable calcrete
B_1	Stones with soil
$R_{1 \text{ to } 3}$	Rock with varying degrees of resistance

2.6.2 Soil depths

Table 2.14 gives an indication of the depth of soil (refer also to Figure 3, Appendix A.)

TABLE 2.14
Percentage of area subject to certain soil depths (Hamman, 1992)

Soil Depth (m)	Percentage of the area of the Vaalharts Irrigation Scheme
< 0.9	12.8
0.9 to 1.2	10.9
1.2 to 1.8	15.4
> 1.8	60.9

2.6.3 Soil types

Soils in the Vaalharts area can be classified as being of two main types, namely: the Managano series of the Hutton soil form and Clovelly/Sunbury. The typical soil profile comprises an orthic A-horison on a red apedal B-horison underlain by hard rock. Due to a high percentage of fine sand this soil has a tendency to become dense which can seriously affect root development (Kriel, 1976).

The soil is a class 3 irrigable soil (according to the USDA classification system), because of the low water holding capacity, low fertility, high bulk density and limited depth (Streutker, 1977).

The soil is mainly a loamy fine-grained sand with an average composition of 8% clay, 2% silt, 68% fine sand of between 0.2 and 0.07 mm and 22% of coarse and medium sand of between 1.0 and 0.2 mm. On about 10 to 20% of the area, there is a sandy, loamy soil with 25% clay, 2% silt, 55% fine sand (0.2 to 0.07 mm) and 18% medium and coarse sand (Streutker, 1971).

Table 2.15 gives values for soil water constants for these two types of soil.

Improved cultivation practices whereby cotton seeds were planted directly above the deep ridged furrow improved the soil for cultivation (Streutker, 1971).

TABLE 2.15
Values for soil water constants (Ninham Shand, 1985)

Soil type	Hutton/Mangano	Clovelly/Sunbury
Clay distribution model	1b	1a
Texture	Sandy loam	Loamy sand
Field capacity - A horizon (mm/m)	180	158

Soil type	Hutton/Mangano	Clovelly/Sunbury
Field capacity - B horizon (mm/m)	201	171
Wilting point - A horizon (mm/m)	83	64
Wilting point - B horizon (mm/m)	91	65
Porosity value (mm/m)	412	401

2.6.4 Depth to calcrete layer

The depth to the calcrete layer can vary from only a few centimetres (near the Harts River where the sand disappears) to about 12 m in some places near Ventersdorprant. On average, it is generally found between 0 and 5 m depth. In the southern part of the North Canal area (roughly from Jan Kempdorp to about half of the way to Hartswater) it is about 1.5 to 1.6 m deep whereas in the northern part it is about 2.5 m deep. Further east it ranges from about 2 to 2.5 m deep.

2.7 GEOLOGICAL AND GEOHYDROLOGICAL DATA

The geological formation is as follows: sand, calcrete, weathered Dwyka (clay), Dwyka and Ventersdorp lava (refer to Figure 4, Appendix A (Temperley, 1977))

In an attempt to get a clear understanding of the geology of the Vaalharts area, numerous reports on borehole analyses and associated geology were studied. Unfortunately, most of the borehole testing took place between July 1973 and April 1975 with the result that few comparisons against the late 1930's could be made. It was only possible to discover one report (Paver & Dicker, 1939) that dealt with borehole analysis (to a significant depth) prior to the commencement of the irrigation scheme. The greater part of this work consisted of electrical resistivity measurements in order to select borehole sites for the determination of water depth. It is mentioned that water was struck at a few existing boreholes at depths of approximately 30 m and that others were dry even down to 100 m (Gombar, 1974; Gombar & Erasmus, 1976). It appears that, although sites were selected, no further boreholes were sunk until the seventies. A number of reports (Botha, 1973; Vegter & Combar, 1974; Gombar, 1974; Gombar & Erasmus, 1976) cover the borehole testing carried out in the seventies. A total of 87 boreholes were sunk by the Department of Water Affairs on the recommendations of Geological Survey between 1973 and 1975. These boreholes varied in depth from 8 to 80 m and were limited to the southerly irrigation area between irrigation blocks A and H. Groundwater contour maps were drawn up. From the borehole results, it appeared that the groundwater was contained in a sandy, gravelly layer above the calcrete. Borehole yields were seen to be directly proportional to the thickness of this sandy, gravelly layer while little or no water was found below this layer.

The calcrete layer consists of impermeable rock as well as permeable soft, spongy material (Streutker, 1971; Streutker, 1977; Temperley, 1967). As a result of this inconsistency in the calcrete material and after studying reports on borehole analysis and associated geology it appears that a perched water table exists in certain areas. To substantiate this, the first cases of waterlogging occurred in 1942, yet there are no analyses (in the late thirties) where the GWT was reported as being higher than 24 m. It is obviously impossible for this vast soil volume to have filled with water in just a few years. Another report states that the calcrete layer reduced the effective depth of the groundwater reservoir to between 0 and 5 m (Streutker, 1971).

Some interesting observations were provided by Temperley (1967), who stated that the calcrete had developed as a result of the calcification of any one of three other formations of the pervious zone (Kalahari sand overlying calcrete overlying old alluvial gravel overlying weathered bedrock) and so may occur at any level and may vary in thickness from about 75 mm to about 15 m. The permeability of the four formations is very limited and variable both horizontally and vertically. Thus the Kalahari sand becomes locally loamy or clayey, the calcrete varies from impermeable rock to permeable soft or spongy material, the old alluvial gravels are permeable only where they have escaped cementation by calcrete while the weathered bedrock is only permeable where it does not consist of clay. The 15 m thick "permeable" zone is therefore highly obstructed with impermeable material, the distribution of which is highly irregular. The distribution of soil deterioration patches on the surface indicates that the downslope rise of calcrete or bedrock towards the soil surface is the most potent factor obstructing downslope movement of groundwater in the permeable zone (refer to Figure 5, Appendix A).

It therefore appears that there are areas where the calcrete is impermeable and a perched water table exists and other areas where the calcrete layer is pervious (Temperley) and the GWT could well have risen from about 24 m up to about 1 m. Streutker (1977) states that in 1935-1940, the GWT was at about 24 m. Irrigation and the effect of the calcrete layer caused the GWT to rise and in 1972, 67% of the area had a GWT within 1.2 m of the surface. Groundwater contour maps (Gombar & Erasmus, 1976) show the area having a GWT less than 1.2 m from the surface and the area around Hartswater and between Hartswater and the Harts River with a deeper GWT. The GWT varies by about 0.5 m between summer and winter.

It was noticed that following pumping of water out of boreholes, the water level rose again quicker than theoretically predicted. A water balance was carried out and an evapotranspiration volume as well as a storage volume were calculated. Flows were estimated by using an infiltration rate and multiplying by a length of 48 km and a certain groundwater gradient. The infiltration rate was proportional to the thickness of the layer of material containing the groundwater. The thickness of the sandy, gravelly layer was estimated at 9.3 m and the average water content of this material was taken as 12.4%. Certain figures were, however, based on just two boreholes and the calculated results could vary quite considerably. From the evapotranspiration volume, the mass of total dissolved solids were estimated. Finally, it was determined that the GWT could be controlled by pumping water out of boreholes (Gombar, 1974; Gombar & Erasmus, 1976).

Table 2.16 gives an indication of the GWT as determined in 1974.

TABLE 2.16
Percentage of area subject to certain GWT depths (Hamman, 1992)

Depth of GWT (m)	Percentage of the Vaalharts Irrigation Scheme area
< 0.6	4.4
0.6 to 0.9	24.2
0.9 to 1.2	19.0
> 1.2	52.0

Recent water quality analyses of a number of boreholes in the Vaalharts area were obtained (Hamman, 1992).

There are two dolerite intrusions stretching north-south. The eastern intrusion is a dolerite plate with its slope becoming more level towards the west. The western intrusion is a wavy plate with an irregular slope. It was stated by Paver and Dicker (1939) that Dwyka shale was found only in the vicinity of the Harts River and acted as a barrier which prevented groundwater from flowing to the Harts River. From river gauging, however, it appears that groundwater definitely does seep back to the Harts River.

2.8 TAUNG DAM

Taung Dam is of little interest from the point of view of estimating the long term salt balance of the Vaalharts irrigation scheme since it has not yet been completed. However, once completed this dam, and the additional irrigation that it will support, will affect the future salinity regime. For this reason data pertaining to Taung Dam has been gathered (Serfontein, 1992).

2.8.1 Storage/area data

The design active capacity is $45x10^6m^3$ with a total capacity (including silt capacity) of $66x10^6m^3$. The dead storage was taken as 5% of the full storage capacity (FSC).

2.8.2 Allocations

An additional irrigation area of approximately 1700 ha will be supported by Taung Dam depending on the crop types to be produced.

The following water allocations from the Vaalharts North Canal exist in respect of both primary and irrigation water:

Primary water (domestic)	:	$3.76x10^6m^3$/annum
Irrigation water	:	$54.41x10^6m^3$/annum

The figure of $3.76x10^6m^3$ for primary use is smaller than the $4.47x10^6m^3$ (see Table 2.10) that was initially envisaged in White Paper W.P.M-76 (Claasens, 1989). The Vaalharts North Canal has the capacity to supply the present allocation of $54.41x10^6$ m^3/annum to Bophuthatswana on an average annual basis. However, the canal has been unable to supply even the current peak demands as the capacity of the canal on the RSA side of the border is only 3.3 m^3/s. The RSA Department of Water Affairs has agreed to enlarge the main supply canal to Taung to provide the allocated $58.17x10^6m^3$/annum at the border with Bophuthatswana at a peak demand flow rate of 5.1 m^3/s.

2.8.3 Date of closure and commissioning date

The planned river closure date for Taung Dam was October 1992 and the commissioning date was April 1993.

3. DATA CONVERSION AND PATCHING

3.1 Observed daily flow

Daily flow records for hydrological stations C3H003, C3H007, C3H013 and C3R002 were obtained from the DWAF (Gouveia & Modise, 1992) and were converted to the appropriate daily format using the program FORMWQS. If a daily flow value had a DWAF error code of one (gauge height exceeded) or three (gauge height exceeded and missing data) , then the value was set to a negative. In this case the value was not used by any other program but was retained for possible manual analysis. If a daily flow had an error code of two (missing data), four (entire day missing) or a five (no discharge table) then the daily value was taken as missing. Missing values are denoted in the data files as "-1"entries, which are recognised by the computer models and data processing software used in the study.

3.2 Observed monthly flow

Daily flow records for stations C3H003, C3H007 and C3H013 were converted to the appropriate monthly format using the program CONVERT6.

Observed monthly inflows to C3R002 were based on the water balance reservoir records obtained from the DWAF (Gouveia & Modise, 1992). Spillage from this dam is based on spillway records. Releases from the dam via the outlet pipes were not measured prior to April 1990. The downstream gauge C3H013 was used for this earlier period. An initial attempt was made to estimate return flows by using the flow records at gauges C3H003, C3H007 and C3H013 together with Spitskop Dam (C3R002). The following method was used: Firstly, low flows ($< 3 \times 10^6$ m^3) were identified in the C3H003 observed flow record, then records were determined for the difference in observed flows for C3H003 and C3H007 as well as C3H003 and C3R002 for the low flow months (the former method was used by Streutker, 1971 for periods of no rainfall). Data for months with higher flows at C3H003 were ignored since during wet conditions the incremental catchment runoff would adversely affect the accuracy of the calculations. From these incremental observed flow records the simulated incremental catchment runoffs were subtracted.

The anomaly was noticed when comparing the two records, that in most months the return flow for the incremental catchment between C3H003 and C3H007 was larger than that for the incremental catchment between C3H003 and C3R002. Furthermore, it was noticed that in some months the flow into Spitskop Dam was about 1×10^6 m^3 less than that at C3H007. This was contrary to expectation and the situation was investigated more thoroughly. It was established that there were some irrigation abstractions from the Harts River by farmers with special permits. However, the abstractions between C3H007 and Spitskop Dam (gauge C3R002) were far too small to account for the difference in incremental return flows. Inaccuracy in the C3R002 observed inflow was expected because the inflow record was calculated from the reservoir water balance. However, the consistent nature of the observed anomaly between the C3H007 and C3R002 records indicated a serious gauging error. This prompted an investigation to isolate the cause of the inconsistency. Following considerable discussion with the DWAF in Vaalharts and Pretoria, it was decided to carry out a site investigation of the gauges C3H007, C3H013 and upstream and downstream of Spitskop Dam. This investigation was carried out by the DWAF OFS Regional Office (Van Bosch, 1993), who discovered the following:

- About 0.121 m^3/s is abstracted for irrigation by farmers between Spitskop Dam and gauge C3H013.

- There is leakage under the weir at C3H013 (about 0.069 m^3/s).

- The discharge table (DT) for station C3H013 is not accurate (it under-estimates by approximately 15% at low flows).

These three problems are cumulative and amount to an over-estimate of about $1x10^6m^3$ per month. In the first two cases, the flow data at C3H013 can be corrected simply by adding the estimated losses. Because of the non-linearity of flow versus gauge height, the third error had to be addressed by reconstructing the flow record using a new DT. Consequently in November 1992, the DWAF were requested to update the DT and daily flow record for station C3H013 to permit updating of the reservoir record for Spitskop Dam. The new DT was received in February 1993 and the outflow record for Spitskop Dam was reconstructed taking into account of the following factors:

- Reasonably accurate measured releases via the outflow pipes are available from April 1990. The DWAF Vaalharts have kept weekly records of releases since April 1990. Release volumes are calculated every Thursday from irrigator's demands. In the order of 1.5 m^3/s is then released for a period ranging from 24 to 36 hours followed by about 0.5 m^3/s for a period of about 3 days. Releases are stopped over Thursday and Friday (maintenance is then carried out if required) and are then started again on Saturday.

- When the dam is spilling the outflow pipes are usually closed and therefore daily spillage over the spillway is the only outflow. (D. Visser, 1993)

- The revised DT at C3H013 appears to be unreliable for flows higher than 2.3 m^3/s (the highest discharge that was measured by current metering during compilation of the DT). Therefore more reliable dam spillway records will be used where possible.

- The leakage under the weir is assumed to be a constant 0.09 m^3/s (J. van Bosch, 1993).

- Measured irrigation abstractions between Spitskop Dam and C3H013 are only available since April 1989 when DWAF Vaalharts took over control of the water meters (D. Visser, 1993). Prior to this, water meters were not maintained and as a result no accurate data is available.

- The WRSM90 model (Stewart Scott, 1991) was used to create an irrigation abstraction record for the period prior to April 1989 based on the area of irrigation between Spitskop Dam and C3H013. This area amounts to approximately 100 hectares. Appendix J-6 gives the model parameter data used and Appendix G-5 gives the simulated monthly irrigation abstractions.

The following method for determining the combined spill and compensation from Spitskop Dam has been used to take account of the above mentioned factors:

(a) Releases from Spitskop Dam from April 1990 were assumed equal to the monthly outflows measured at the outlet pipes.

(b) When the dam was spilling the assumption was made that the outflow pipes were closed and therefore daily spillage over the spillway is the only outflow.

(c) For the period prior to April 1990, when there was no spillage, the C3H013 record (based on the new DT and including estimated leakage) was added to the estimated irrigation abstraction between the dam and C3H013 (as per Appendix G-5).

(d) In instances where the dry weather daily release from Spitskop Dam calculated in (c) above exceeded 1.5 m^3/s, a check was carried out to determine if the monthly runoff from the incremental catchment (as simulated by the WRSM90 model) was substantial (taken as $> 0.5x10^6m^3$). In such instances the flow was limited to 1.5 m^3/s whereas if the simulated monthly incremental runoff was less than 0.5×10^6 m^3 then the daily flow at C3H013 was accepted as the outflow from the dam. This rule was adopted since there is little need to release more than 1.5 m^3/s to satisfy downstream demands.

(e) When there was spillage from the dam and daily flow at C3H013 exceeded 2.3 m^3/s then daily spillway data was used. At lower discharges the daily flow at C3H013 plus irrigation abstractions were used (this is because at low discharges the spillway record is considered less accurate than that at C3H013) but at flows above 2.3 m^3/s the accuracy of C3H013 is dubious.

(f) Where there was spillage over the spillway of less than 2.3 m^3/s, then daily flow at C3H013 plus irrigation was used. In instances when this rule conflicts with rule (e), then the spillway record was taken unless it was lower than 0.1 m^3/s (probably just waves slopping over the crest). Exceptions to this general rule had to be applied for certain periods prior to 1983 when there was strong evidence suggesting that water was released via the outlet pipes when the dam was spilling small amounts of water (i.e. assumption (b) was violated). In such instances the C3H013 record was used in preference to the spillway record, since the spillway record does not include the ungauged pipe releases.

(g) During periods when there was a break in the spillway record, such as after the February 1988 floods, then daily flow at C3H013 was used irrespective of the flow magnitude. Irrigation was added as before.

(h) If there was no daily flow record for a specific day during low flow periods when a uniform flow pattern could be expected, then the missing day's flow was interpolated. Interpolation was not attempted to patch long gaps in the record or during periods of high flow when rapid changes in discharge could be expected. For example, no attempt was made to patch the record over the period when flooding washed part of the dam wall away and there was missing data in the daily flow at C3H013.

Following the site investigation, station C3H007 was also found to be unreliable. This station has a compound structure consisting of a Parshall flume and Ogee spillway. The measuring device is located in the throat of the Parshall flume where there is already an appreciable velocity resulting in a water level that is lower than that in the pool upstream of the Ogee spillway (refer to the plan of the weir in Appendix C-1). This means that the DT for flows above 3.2 m^3/s (the discharge above which flow over the Ogee spillway should commence), will be subject to considerable error. It was therefore decided to only use flows within the range of the Parshall flume's DT (i.e up to 3.2 m^3/s). The differences in the original and revised DT's up to flows of 3.2 m^3/s were very small and it was therefore decided to use the original DT but only for flows not exceeding 3.2 m^3/s.

3.3 Observed water quality

Water quality data was obtained from the DWAF (Schutte, 1992) and converted to the appropriate format using the program XQUAL which extracted daily EC (Electrical Conductivity), TDS (Total Dissolved Salts) and Cl (Chlorides). A moving regression program MOVREG was used to patch the EC, TDS and Cl records with flow. The observed EC and Cl records were then anchored with the above regressed EC and Cl records using the program ANCHOR. Plots were obtained of flow, EC, EC regressed, and EC anchored for the purpose of eliminating outliers (bad data). Ratios of TDS to EC were then determined using the program DAYDIV and these were transformed to regressed, anchored ratios using programs MOVREG and ANCHOR. TDS records were then determined using the program DAYLOAD which converted the above ratios to TDS values. Plots were again obtained and analyzed for irregularities. The daily EC, TDS and Cl records were then converted to monthly flow-weighted records using the program DAYMONWT. The program XQUAL was used to convert monthly water quality data from the DWAF to the appropriate format for use in the REPLACE program. Finally the REPLACE program was used to eliminate any values obtained using DAYMONWT where there is less than one water quality value in a month. A final manual analysis was carried out to eliminate any suspect values.

The relatively low EC value measured in some of the drainage canals during the site visit indicated that the flow was mainly end spillage of irrigation supply water. This may, however, not be the normal situation. In view of the fact that the return flow is of the order of 10%, this implies that salt is being retained in the soil (refer to Appendix C).

4. NATURALISATIONOF HYDROLOGY

4.1 RAINFALLDATA

Rainfall data up to 1989 was obtained from the CCWR. This was updated to the end of September 1991 using data provided by the Weather Bureau (De Villiers, 1992). Nearby stations were used to patch missing values using the programs PATCHMP and HDYP08. The following average monthly rainfall files (see Appendix E) were constructed from the data for individual rainfall stations:

MPSCHWI.RAN - Rainfall station 0397/581 (at Schweizer Reneke Dam).

V-H.RAN - Rainfall stations 0359/808 and 0361/295.

MPSPITS.RAN - Rainfall station 0359/808 (at the dam).

C3R02.RAN - Rainfall stations 0359/304, 0359/352, 0359/808, 0324/135, 0360/512,0361/295,0395/822,0395/855,0396/271,0396/284, 0396/813,0396/853,0431/508,0432/196,0432/387,0432/530, 0432/700, 0433/115 and 0433/494.

C3M03.RAN - Rainfall stations 0434/431, 0434/699, 0434/888, 0435/36, 0435/735,0471/259,0471/490,0472/135,0472/175,0472/281, 0509/78, 0397/784, 0433/494, 0433/791, 0433/804, 0434/228, 0434/359, 0397/581, 0360/512, 0361/61, 0398/177, 0396/813 and 0396/853.

4.2 NATURALISATION

Irrigation return flows have a major influence on the hydrology of the Harts River. It is therefore essential to remove the influence of these return flows from the flow record to arrive at a virgin (or "naturalised") catchment runoff record. These naturalised data files are required as input to the hydro-salinity models. Monthly catchment runoff records were naturalised for the period October 1923 to September 1991.

The monthly values contained in the naturalised catchment runoff files (refer to Appendix F) were obtained using the following equations:

During the period for which observed flow records are available:

$$NAT = OBS - (SIM - VRG) \qquad (4.1)$$

where:

OBS = observed monthly flow at catchment outlet.

VRG = simulated virgin flow record (ignoring all man made influences obtained using the Pitman (WRSM90) model).

SIM	=	simulated historical record. Obtained by running the WQT model with the simulated virgin flow record as input and the historical levels of abstractions and irrigation development.

In equation (4.1) the term (SIM - VRG) represents the estimated net influence of catchment development (i.e. it is effectively the sum of all man made discharges to the river, such as irrigation return flows, minus the sum of all abstractions).

During periods for which no historical flow records are available the naturalised flow was taken as:

NAT = VRG .... (4.2)

4.2.1 Upper Harts catchment

In the case of the Harts River upstream of Taung weir (station C3H003), equation (4.1) was applied as follows to calculate the naturalised monthly catchment runoffs for the entire period from October 1923 to September 1991:

C3M03AKB.NAT = C3M03Q.OBS + UHRQ5.VRG - UHRTQ9T.SIM ...... (4.3)

where:

C3M03AKB.NAT	= naturalised flow at gauge C3H003 (see Appendix F1)
C3M03Q.OBS	= observed flow at gauge C3H003 (see Appendix H1)
UHRQ5.VRG	= simulated virgin flow at gauge C3H003
UHRTQ9T.SIM	= simulated historical flow at gauge C3H003

The Pitman (WRSM90) model parameter data files used to simulate virgin conditions are given in Appendix J1. The WQT model parameter values used to simulate the historical conditions are given in Appendix J3.

4.2.2 Middle Harts catchment

The naturalised monthly catchment runoffs from the incremental catchment between Taung (station C3H003) and Spitskop Dam (station C3R002) were determined as follows:

For the period from 1974 onwards:

C3R002AK.NAT = C3R002.OBS + MHCR8.VRG - MHRTQ17T.SIM ...... (4.4)

where:

C3R002AK.NAT	= naturalised runoff from Spitskop Dam incrememntal catchment (see Appendix F2)
C3R002.OBS	= observed inflow to Spitskop Dam (see Appendix H3)
MHCR8.VRG	= simulated virgin flow at Spitskop Dam
MHRTQ17T.SIM	= simulated historical flow at Spitskop Dam

For the period prior to 1974:

C3R002AK.NAT = MHCR8.VRG . . . . (4.5)

The Pitman (WRSM90) model parameter data files used to simulate virgin conditions are given in Appendix J2. The WQT model parameter values used to simulate the historical conditions are given in Appendix J5.

4.2.3 Catchment between Spitskop Dam and Mt Rupert weir

A different approach was adopted to determine the naturalised monthly runoffs from the small incremental catchment between Spitskop Dam (station C3R002) and Mt Rupert weir (station C3H013). This modified approach was used since estimates of the irrigation abstraction between these two stations had already been made in order to patch the Spitskop Dam outflow record.

The following equation was used for periods for which flow records are available (i.e. from 1967 onwards):

C3H013AK.NAT = C3H013.OBS - C3R002.FLW + HARTDSP.ABS . . . . (4.6)

where:

C3H013AK.NAT = naturalised runoff from C3H013 incremental catchment (see Appendix F3)
C3H013.OBS = observed flow at gauge C3H013 (see Appendix H6)
C3R002.FLW = outflow (spill and compensation) from Spitskop Dam (see Appendix H5)
HARTDSP.ABS = estimated abstraction between Spitskop Dam and C3H013 (see Appendix G5)

Simulated virgin catchment runoffs were used for the period prior to the commencement of observed flow records (i.e. prior to 1967):

C3H013AK.NAT = MHCR10.VRG . . . . (4.7)

where:

MHCR10.VRG = simulated virgin runoff from C3H013 incremental catchment

Equation (4.7) was also used in place of equation (4.6) during the period after 1967 in instances when the following circumstances arose:

(i) records for either C3H013.OBS or C3R002.FLW were missing;

or

(ii) if C3H013.OBS < C3R002.FLW.

The Pitman (WRSM90) model parameter data files used to simulate virgin conditions are given in Appendix J2.

It will be seen from equation (4.1) that naturalisation of the observed record relies on the estimate of irrigation return flows obtained from simulation using the hydro-salinity model (WQT). However, the irrigation return flow factor (calibration parameter value RRLF in model WQT), which determines the irrigation return flow volume, also has a strong influence on the simulated water quality in the irrigation return flows. During the calibration of model WQT, the parameter RRLF needs to be adjusted to achieve a good fit between modelled and observed TDS concentrations observed at key points in the Harts River. Once this occurs, the naturalised data file is no longer valid, since the assumption regarding irrigation return flows used to construct it have changed. It then becomes necessary to revise the estimate of the naturalised monthly catchment runoffs. This in turn affects the model calibration. Hence an iterative process develops between model calibration and naturalisation of the hydrological record. In practice, it was found that after two or three iterations there was no longer any significant effect on the results. Chapter 5, dealing with the water quality model calibration, describes this iterative process.

5. CALIBRATIONOF HYDRO-SALINITYMODEL

The monthly time step Hydro-salinity Calibration Model is described in the DWAF Reports P C000/00/7086, Volume A (Stewart Sviridov & Oliver and BKS Inc., 1987) and P C000/00/9390 (Stewart Sviridov & Oliver, 1991). It is written in FORTRAN and runs on any IBM or fully compatible PC (Personal Computer).

The Hydro-salinity Calibration Model is primarily a calibration tool. Only relatively simple options can be simulated with it. DWAF report P C000/00/9490 (Stewart Sviridov & Oliver, 1990) can give the reader a detailed explanation of the methodology and the sensitivity of the simulation results to the calibration parameters of the model.

The study was divided into the Upper Harts (upstream of Taung weir, C3H003) and the Middle Harts (downstream of Taung) areas. The following procedure was adopted in the calibration:

(a) An initial choice of the calibration parameters was made based on a previous report "Orange River System Analysis, Lower Vaal River sub-system, Hydro-salinity model calibration" (Stewart Sviridov & Oliver and BKS, 1992) as well as modelling experience gained from adjacent catchments.

(b) Create a file containing a first estimate of the naturalised monthly runoffs from each catchment using the WRSM90 model (see equation (4.2) of Chapter 4).

(c) Run the hydro-salinity model WQT using the data files of estimated monthly naturalised catchment runoffs derived from step (b) as input.

(d) Create a new data file containing revised estimates of the naturalised monthly catchment runoffs using the procedures described in section 4.2 .

(e) Run model WQT again using the revised naturalised catchment runoff data file. Adjust the dependent initial catchment salt storage parameters and re-run WQT until a reasonable balance is obtained between the specified starting storages and the simulated ending TDS storages.

(f) Compare modelled and observed monthly flows, salt concentrations and loads at all possible observation points. This is done both by examining statistics and by observing screen plots. Adjust the catchment salt washoff model and the irrigation sub-model parameter values within reasonable limits to improve the fit between modelled and observed monthly flows, TDS concentrations and TDS loads. In this regard the irrigation sub-model's return flow factor, RRLF, is of particular importance for the incremental Spitskop Dam catchment.

(g) Once a good fit between modelled and observed monthly values has been obtained, return to step (c) and repeat the procedure until finally the naturalised data file has been determined from the final choice of parameters, the starting and end salt storages are in balance and the fit between modelled and observed flow, TDS concentrations and TDS loads is as close as possible.

The re-naturalising procedure (i.e. the repetition of steps (c) to (g)) is only required if any calibration parameters affecting flow are modified. These are the initial groundwater interflow, minimum groundwater flow, interflow decay factor, proportion interflow and proportion infiltration in the salt washoff sub-model and the return flow factors in the irrigation sub-model. If any of the calibration parameters in either the catchment salt washoff sub-model or the irrigation sub-model are changed, then the starting and ending salt storages have to be re-balanced.

5.1 UPPER HARTS SUB-SYSTEM

The Upper Harts River sub-system (Refer to Figure 5.1) consists of two channel reaches, one upstream of Schweizer Reneke Dam (also known as Wentzel Dam) and the second downstream of it. The Schweizer Reneke Dam has an irrigation sub-model attached which conveys return flow to the downstream channel reach mentioned above. Urban abstractions from Schweizer Reneke Dam have been accounted for.

In the catchment salt washoff sub-model, the effective area was used (i.e. the total catchment area less any 'dead' or flat areas not contributing to runoff). The effective catchment areas were derived from Middleton *et. al.* (1981).

Other model parameter values were obtained by adjustment during calibration.

The split between the catchment runoff entering channel reaches CR1 and CR3 was determined according to effective catchment areas.

In order to simplify the system, small irrigation abstractions upstream of the Schweizer Reneke Dam were included in irrigation sub-model RR4. The irrigation method is flood irrigation, with an assumed efficiency of 0.65 (Loxton-Venn, 1985).

That portion of the Vaalharts scheme that is located upstream of gauge C3H003 is accounted for by irrigation sub-model RR5. The water supply to irrigation sub-model RR5 was routed through a dummy reservoir (RV6). The file of specified monthly TDS concentrations in the supplied irrigation water (file C9R01TDS.MOR) was obtained from water quality records at Vaalharts weir, supplemented with those at Bloemhof Dam and simulated output from a model set up for the Vaal River system. This input data file is given in Appendix I1. The irrigation sub-model structure was modified to include historical changes in return flow percentage and efficiency which occurred in this area due to conversion from earlier flood irrigation to sprinkler, centre-pivot and drip irrigation, all of which have different irrigation efficiencies and return flow factors. There was no irrigation upstream of C3H003 prior to 1976.

Model parameter data files are given in Appendix J3. Summaries of the calibrated model parameter values are given in Appendix K.

Graphs of modelled and observed discharge, TDS concentration and TDS load can be found in Appendix M. Calibration statistics are given in Appendix L1.

The fit obtained between modelled and observed monthly TDS loads is very good (although the period of comparison was rather short). However that for TDS concentrations is not as good. The relatively poor fit for TDS concentrations is attributable to differences that occur during low flow conditions. This result is to be expected, since in a semi-arid catchment the flow virtually ceases during dry weather. During such conditions it is impossible to simulate TDS concentrations with any degree of precision. However such errors are of little consequence to the study as the associated salt loads during dry weather are very small and will have little effect on the overall catchment TDS balance.

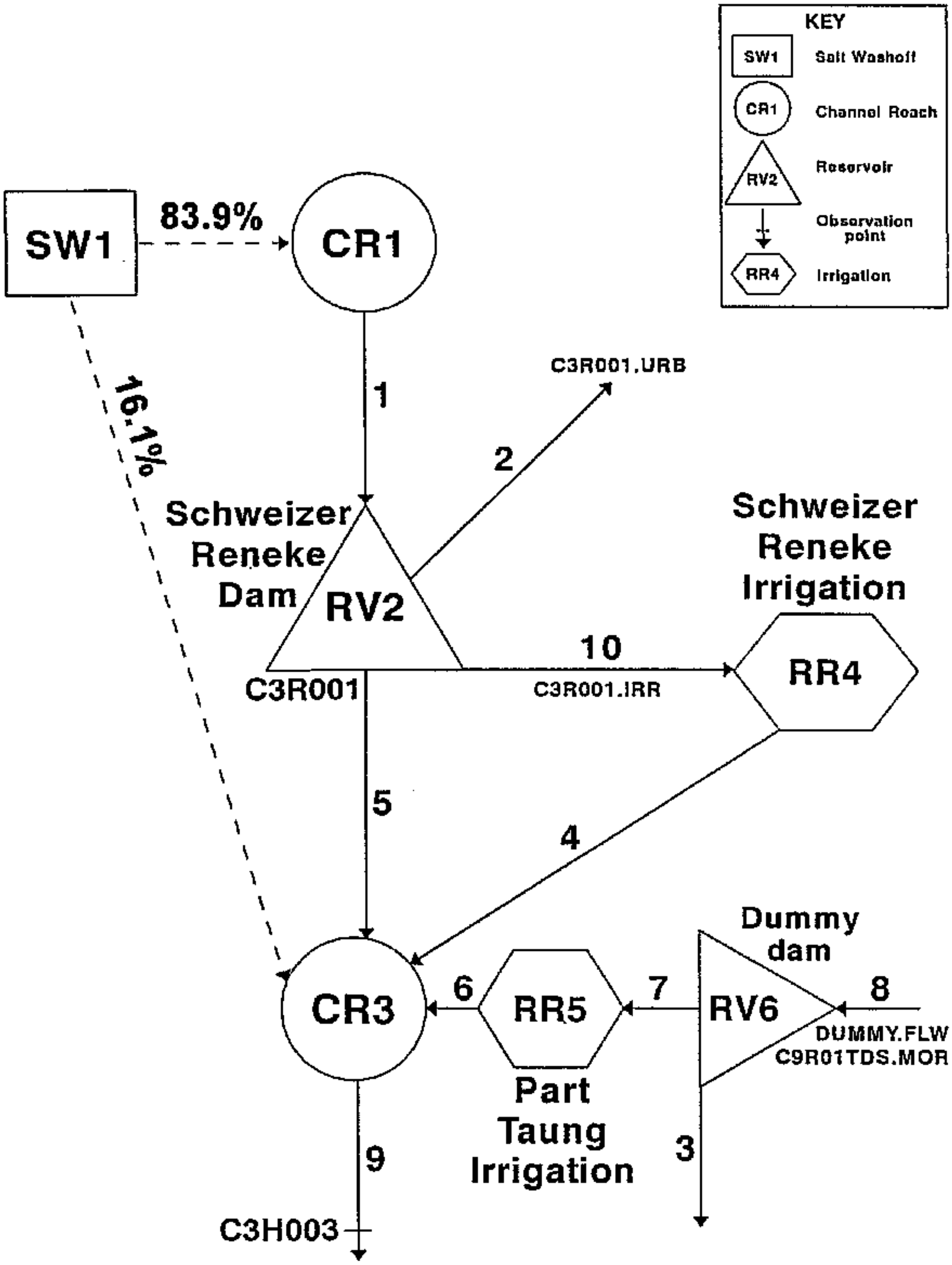

Figure 5.1 : System configuration for the Upper Harts River sub-catchment

5.2 MIDDLE HARTS SUB-SYSTEM

The Middle Harts River sub-system (Refer to Figure 5.2) is more complex than the Upper Harts sub-system in that it contains the North and West Canal irrigation areas and the three gauges C3H007, C3R002 and C3H013. Two salt washoff sub-models were required and effective catchment areas were again used.

Irrigation sub-model RR11 comprises the North Canal irrigation area as well as the Taung area downstream of gauge C3H003.

Sub-model RR12 consists of the West Canal irrigation area. Dummy reservoirs were used again to balance the water supply. The inflows to these dummy reservoirs were determined by taking the overall water supply from the Main Canal, subtracting that required for the Upper Harts (as derived from the modelling of the Upper Harts sub-system) and then dividing it between RR11 and RR12 according to their respective irrigation areas.

Junction nodes have been included to cater for small irrigation abstractions from the Harts River for three different regions.

The first step involved the calibration of the return flows from the two irrigation sub-models RR11 and RR12. Observed return flows were determined for both the North Canal area and the West Canal area. For the North Canal area, the return flow was determined as follows:

C3R007.RET = C3H007.OBS - C3M03Q.OBS - C3H007.INF .... (5.1)

where :

C3H007.RET	=	return flow for the North Canal area
C3H007.OBS	=	observed flow at station C3H007 (see Appendix H2)
C3M03Q.OBS	=	observed flow at station C3H003 (see Appendix H1)
C3H007.INF	=	incremental inflow (determined using the WRSM90 model) for the C3H007 sub-catchment.

Finally the return flow file C3H007L3.RET (see Appendix H9) was determined by eliminating certain monthly flows when the occurrence of any of the following conditions cast doubts on the accuracy of the calculation using equation (5.1):

(a) Flow at C3H007 > DT limit of 3.2 m^3/s (which implies that the flow gauging is inaccurate).

(b) Flow at C3H003 > $3x10^6 m^3$ for the month. (When the flow at the upstream station is high, small errors in the estimation of river flows can result in large percentage errors in the return flow calculated using equation (5.1)).

(c) Incremental flow between stations C3H003 and C3H007 high relative to the calculated return flow (which implies that small errors in the estimated catchment runoff can result in large percentage errors in the calculated return flow).

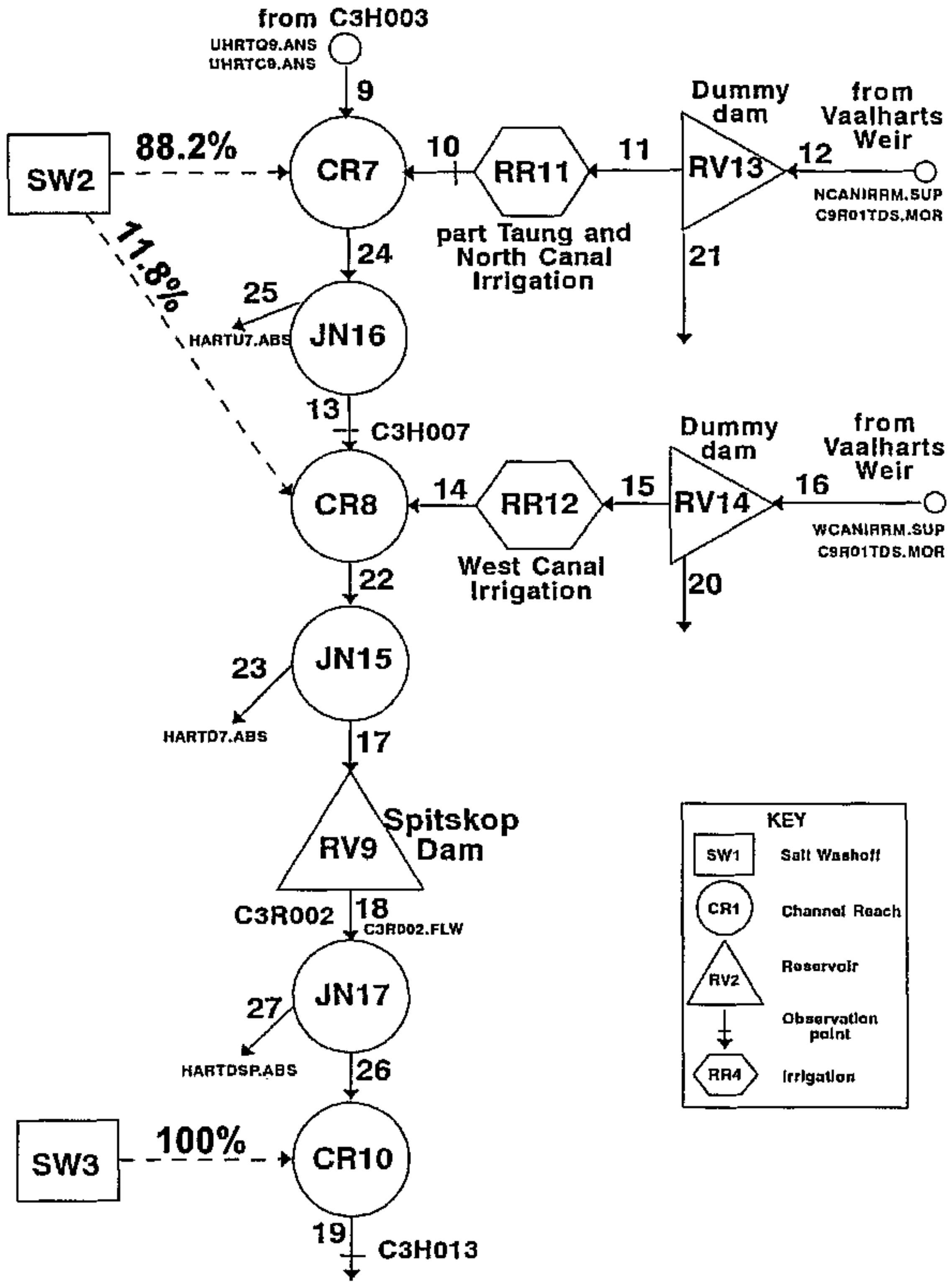

Figure 5.2 : System configuration for the Middle Harts River sub-catchment

The low DT for weir C3H007 meant in effect that irrigation return flows could only be calculated during relatively dry months. As a result the return flows for most of the months November to May could not be calculated (see Appendix H9).

For the West Canal area, the return flow factor was taken to be zero due to the following factors:

(a) The West Canal is about 15 km away from the Harts River on average and there are several pans which evaporate water that could otherwise have been returned to the Harts River.

(b) The same procedure used to calculate the return flow between C3H003 and C3H007 was used to estimate the return flow from the entire area between C3H003 and C3R002 (i.e. the inflow file for Spitskop Dam was used in place of file C3H007.OBS and the runoff for the entire Spitskop Dam catchment in place of file C3H007.INF in equation (5.1)). This yielded return flows that were *lower* (although to a negligible degree) than those given in file C3H007.RET. This indicates losses in the West Canal area rather than gains due to return flow.

The WQT model parameter data files are given in Appendix J7. Summaries of the calibrated model parameter values are given in Appendix K.

Following calibration of the irrigation sub-models, the Middle Harts system as a whole was calibrated. There are three points where observed flow and water quality exist, namely: C3H007, C3R002 and C3H013. Due to the problems experienced with the streamflow records (as discussed in Chapter 3), a considerable effort was made to use only meaningful data in the observed flow files and demand files incorporated into the hydro-salinity modelling process. Statistics and plots were examined for the above mentioned three gauges as well as for the irrigation sub-model RR11 to ensure as close a fit between modelled and observed values as possible.

Graphs of modelled and observed discharge, TDS concentration and TDS load can be found in Appendix M. Calibration statistics are given in Appendix L.

For the irrigation sub-model RR11, only the flow was calibrated because there was no observed TDS concentration. The WQT program was modified so that growth in return flow and efficiency could be incorporated into the irrigation sub-model. This was required for the North Canal area because the farmers installed drains in the period from 1976 to 1979 and then, due to the drought, plugged these drains between 1983 and 1986. The plot of observed flow does not indicate much growth in return flow over the period when the drains were installed. This is possibly due to secondary effects such as reduced rainfall, efficiency of these drains etc. When the drains were plugged, however, there is a very distinct drop in return flow which was successfully modelled. The modelled TDS concentrations dropped quite sharply after the flood events in 1975 and 1988 which was to be expected. Overall the fit between modelled and observed flows was fairly good which is verified by the statistics for route 10. The average irrigation return flows for the months June to October inclusive for hydrological years 1952 to 1990 is shown in Figure 8.1 (refer to Chapter 8). The return flows for full years could not be compared because most of the observed data for the wetter months was missing due to the inadequate flow gauging range flow gauging station C3H007.

For the West Canal area (RR12), no observed data existed and modelled flows were negligible except for the flood events in 1975 and 1988. TDS concentrations for return flows from the West Canal area were of the order of twice the magnitude of those from the North Canal area. This is due to the fact that the return flows in the West Canal are much reduced.

At station C3H007, observed flow data exists from 1952 while observed TDS concentrations are available from 1972. The plots and statistics showed a fairly close fit between modelled and observed monthly values. Modelled TDS concentrations were generally lower than those observed from 1976 to 1980 but were generally higher from 1980 to 1990. Unfortunately, meaningful comparison between monthly TDS loads is impossible due to the low DT limit of flow gauging station C3H007.

The fit achieved between the modelled and observed monthly TDS loads at station C3R002 was very good. The modelled TDS concentrations at station C3R002 did not fit as well. However, the fit between modelled and observed loads was considered to be of more importance than that of the TDS concentrations since the objective of the study was to determine the overall salt balance of the Vaalharts irrigation scheme.

Meaningful comparison of modelled and observed monthly TDS loads at station C3H013 is impossible due to the low DT limit of the weir. The modelled and observed TDS concentrations are reasonably well correlated at this station, although the modelled mean is higher than that observed.

Owing to the inaccuracies in the flow gauging at all three stations, it was to be expected that the modelled TDS concentrations would not fit the observed values particularly well, especially during low flow conditions. However, the good fit achieved between modelled and observed TDS loads at the two most important stations (C3H003 and C3R002) means that the model is well able to fulfil its primary task of patching the historical water quality record to facilitate calculation of the long term TDS export from the Vaalharts irrigation scheme.

6. WATERBALANCE

The large difference between the TDS load in the irrigation water supplied to Vaalharts and that returned to the Harts River (see section 2.5) requires a mechanism for the removal of salt. Since the area is semi-arid, the gradual raising of the groundwater table (GWT) due to percolation below the irrigated crop root zone could provide a plausible explanation. This hypothesis is strengthened by the early borehole records that indicated a relatively deep GWT prior to the commencement of irrigation, which has since risen to within one or two metres of the surface in many parts of the irrigated area (see section 2.7). Accumulation of the unaccounted for salt in a deep groundwater storage requires a corresponding accumulation of water. For this reason the water balance of the North Canal area has been examined to determine if the annual percolation of water to the deep groundwater storage is consistent with the hypothesis of a gradually filling groundwater storage.

6.1 CROP WATERBALANCE

The North canal area was divided into two distinct portions for the purpose of carrying out a crop water balance. The first area comprises the land actually under irrigation. The second land type comprises small portions of fallow land interspersed between irrigated plots and veld areas located between the irrigated land and the Harts River, part of which is irrigated using return flow from the scheduled irrigation areas. The crop water balances for these two land types are dealt with in the following sections.

6.1.1 Scheduled irrigated areas

The following equation was used to describe the crop water balance:

LOSS $= A + B$ .... (6.1)

where:

LOSS = total volume of water not used by the crop ($10^6 m^3$)

Term A of equation (6.1) was calculated as:

A $= FEFF \cdot SUPP + RAIN - ETC$ .... (6.2)

where:

FEFF = irrigation efficiency factor (=0.68, according to Loxton Venn (1985))

SUPP = water supply reaching North Canal area ($10^6 m^3$)

RAIN = rainfall on irrigated area, calculated from rainfall file V-H.RAN (Appendix E2), a mean annual precipitation (MAP) of 550 mm and an irrigated area of 240 km^2 ($10^6 m^3$)

ETC = total evapotranspiration based on areas under each crop type (Table 2.3), relevant crop factors (Table 2.6) and A pan evaporation data ($10^6 m^3$)

The water supply reaching the North Canal area, SUPP, was calculated as:

$$SUPP = 0.83 \cdot \{0.886 \cdot (Q_{abs} - Q_{towns} - Q_{canal\ losses}) - Q_{Bop.\ sim.}\} \quad \ldots\ldots \quad (6.3)$$

where:

0.83 = proportion of the total North and West canal irrigation area covered by the North Canal irrigation area

0.886 = proportion of the total irrigation area covered by the North and West canal irrigation areas, including the Bophuthatswana area (the remaining 0.114 is the proportion attributed to the Barkly West area supplied via the Barkly West canal)

Q_{abs} = total abstraction from Vaalharts Weir for irrigation and urban use (from reservoir records and the DWAF Vaalharts)

Q_{towns} = use by Hartswater, Jan Kempdorp, Pampierstad and Vryburg (Stewart Sviridov & Oliver, 1987) and (DWAF, 1988)

$Q_{canal\ losses}$ = main canal evaporation and seepage losses between Vaalharts Weir and the North Canal irrigation area. Evaporation losses were based on a canal width of 10 m, a length of 40 km (from Vaalharts Weir to Jan Kempdorp), a mean annual evaporation of 1896 mm and a mean annual rainfall of 446 mm. Seepage losses were determined using the estimate of 10 l/s/km (K Van Deventer, 1994).

$Q_{Bop.\ sim.}$ = irrigation water supply to the Bophuthatswana area around Taung (model simulation estimates as per Chapters 4 and 5).

Certain of the monthly losses calculated using equation (6.1) were negative. This is to be expected with a simple crop water balance determined on a monthly basis when changes in soil water storage are ignored. It was decided to re-distribute these negative values to either (or both) the preceding or succeeding month, provided they had positive values. Any remaining negative values were replaced with zeroes. This re-distribution is a crude means of representing the carry over effect, whereby over-irrigation or heavy rainfall in one month could result in a lower irrigation demand in the following month, or where under-supply of irrigation water in one month may result in a higher than theoretical demand in the following month. In some instances the negative monthly values persisted for two or more months in succession. In such instances the carry-over period is too long to be accounted for by changes in soil water storage. This implies inaccuracies in some or all of the following:- crop areas, crop factors, irrigation efficiency and the estimation of supply volumes. Long periods of negative calculated losses could also result from failure to satisfy the crop demand (for example, during periods of water restriction or due to canal capacities being inadequate to meet peak crop demands). In such instances the negative values were simply set to zero.

The resulting losses calculated using equation (6.1) and adjusted using the method described above comprise surface runoff, reject and tailwater and drainage below the root zone. The root zone drainage can be lost to sub-surface drains and percolation to the groundwater. Part of that portion of the drainage entering the groundwater can enter the natural surface drainage system via groundwater flow. The remainder can contribute to a change in the groundwater storage and can also possibly percolate to deeper groundwater storage (for example, from a perched water table through the more permeable portions of the calcrete layer to deeper groundwater that is not likely to contribute flow to the Harts River).

Term B of equation (6.1) was calculated as:

$$B = A' + (1. - FEFF) \cdot SUPP \quad \ldots\ldots\ldots \quad (6.4)$$

where:

A' = term A (given by equation 6.2) after adjustment of negative monthly values as described above.

Equation (6.4) accounts for the irrigation supply water that was not available to the crop due to the supply water efficiency being less than 100%.

6.1.2 Other areas

It was recognised that in much of the North Canal area the irrigated lands are separated from the Harts River by a veld area, some of which is irrigated using return flow from the scheduled irrigation areas. Even where this veld area is not directly irrigated, seepage from the irrigated areas could become available to natural grasses, thereby providing a means for further evapotranspiration loss. An attempt was made to account for this secondary use of losses from the Vaalharts scheme to improve the estimation of the overall losses.

Table 6.1 gives the crop factors chosen for the down-slope veld area.

TABLE 6.1
Crop factors for veld

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Crop factor	0.40	0.45	0.45	0.45	0.45	0.45	0.40	0.35	0.25	0.25	0.25	0.35

The veld area (71.9 km^2) was determined by planimetering the total North Canal irrigation area, including the area between the irrigated lands and the Harts River, and subtracting the scheduled area. It was assumed that the area taken up by roads and homesteads would be negligible.

The overall monthly losses (including those from the veld area) were then determined using a procedure similar to that described in section 6.1.1. In the case of equation (6.2) the monthly crop factors for veld (see Table 6.1) were used in place of those for the crops grown on the scheduled areas to calculate the monthly crop demands. The supply water (SUPP in equation (6.2)) was set equal to the irrigation loss from the scheduled area (LOSS in equation (6.1)). A relatively low irrigation efficiency factor of 0.5 has been assigned to this veld area to account for a portion of the return flow bypassing this area.

6.1.3 Comparison of losses

The resulting net overall monthly losses for the North Canal area are given in Appendix H11. (Annual totals for hydrological years 1975 to 1990 are also given in the second column of Table 6.3.)

The overall losses (including canal losses) thus calculated represent the total potential return flow from the North Canal area. However, all of this water may not have reached the Harts River, since some may have contributed to a gain in groundwater storage (both local and more widespread).

Table 6.2 gives comparisons of the calculated overall losses (total potential return flow) against two other sets of figures determined in another study (Ninham Shand, 1985).

TABLE 6.2

Comparisons of total potential return flow (10^6m^3)

Year	From crop water balance as per Ninham Shand (1985)	Streutker (Ninham Shand, 1985)	Crop water balance (this report)
1977	50.4	51	102
1978	59.2	44	73
1979	86.2	45	81

The annual values calculated using the method described above give higher estimates of the losses than those made by Ninham Shand and Streutker. The difference is particularly large for 1977. The reason for this is that 1977 was a year of high rainfall. The potential return flow of $102x10^6m^3$ calculated in this report includes a larger estimate of runoff than do the other two methods. For example, Ninham Shand (1985) used an estimate of the effective rainfall, instead of the actual rainfall, in their water balance calculations. This approach was rejected since it does not answer the question of what became of the difference between the actual (measured) rainfall and the effective rainfall. Obviously it must either have infiltrated and drained past the root zone, or left as surface runoff. In either event it should be available to form part of the theoretical potential return flow. (The concept of effective rainfall is more appropriate in determining the irrigation requirement. It is not appropriate for a water balance, where *all* of the water has to be accounted for.)

The main weakness of the Ninham Shand method and that used in this report lies in the estimation of surface runoff due to rainfall. In the case of the method described in this report the implicit assumption is that crop evapotranspiration is the only means by which water can be evaporated. However, during heavy rainfall events (and even during irrigation applications) temporary saturation of the soil near the surface can give rise to full potential lake evaporation, which is generally higher than the monthly crop demand. The method is therefore likely to over-estimate the potential irrigation return flow. Better results might have been obtained by (a) employing a more detailed model that takes account of hydrological processes governing surface runoff, infiltration and soil moisture storage state and (b) carrying out the calculations at a finer (daily) computational time step. Since the development of such a detailed model was clearly beyond the scope of the current study, the method described was used to obtain a first order approximation of the potential return flow.

6.2 IRRIGATION RETURN FLOW TO THE HARTS RIVER

Section 5.2 describes the method used to estimate the actual monthly irrigation return flows from the North Canal area to the Harts River by comparing the flow record of hydrological station C3H003 (upstream of the North Canal area) with that of station C3H007 (downstream of the North Canal area). The results are given in Appendix H9.

The irrigation return flow could be calculated with reasonable accuracy only during low flow periods, when the natural catchment runoff from the semi-arid incremental catchment can be expected to be small relative to the return flow. Unfortunately the low limit for accurate flow gauging at hydrological station C3H007 meant that the return flows for only a small number of individual months could be calculated using this method. Not one year had a complete record (the closest being the 1978 hydrological year, for which 11 months could be obtained). The flow at C3H007 for the missing month of the 1978 hydrological year (February 1979) was approximated using the value contained in Appendix H2 (i.e. by accepting the flow estimate for the doubtful range of the weir's DT). This yielded an annual return flow for the 1978 hydrological year of $35.9 \times 10^6 m^3$. However, this cannot be used to estimate the long term irrigation return flow because 1978 was an exceptionally dry year (rainfall 80% of MAP) and is therefore not representative of average conditions.

An alternative method of estimating the irrigation return flow from the North Canal area was attempted by carrying out a similar calculation using the Spitskop Dam inflow record in place of that for station C3H007. In this instance a larger catchment was used to calculate the naturalised incremental runoff (i.e. the naturalised runoff data file given in Appendix F2). This method is of little use for calculating monthly return flows, since the inflows to Spitskop Dam had to be calculated from the dam's estimated net evaporation, change in storage and outflow records. In such a calculation small errors in the monthly change in storage can result in a relatively large error in the estimated monthly inflow, especially during dry weather conditions. However, these month by month errors tend to automatically result in corresponding compensating errors in the long term. The annual totals (except during extreme dry years) and the long term mean should therefore be reasonably represented.

The third column of Table 6.3 gives the calculated annual irrigation return flows to the Harts River obtained by this method.

The average annual values are given in Table 6.3 for all 16 years from 1975 to 1990, and for the reduced sample of 14 years after eliminating the 1975 and 1987 hydrological years. The latter estimate is considered a more reliable representation of the long term means since the floods that occurred in both 1975 and 1987 were extreme events. (Under such conditions of extreme high natural catchment runoff, the calculation of the return flow by subtraction of large flood discharges estimated at weirs can result in highly inaccurate estimates, since flow gauging has a wide margin of error at high river stages.)

Table 6.3
Calculated annual return flows from the North Canal area to Harts River ($10^6 m^3$)

Year	Calculated total irrigation losses	Calculated return flow	Difference
1975	(100)	(49)	(51)
1976	101	42	59
1977	102	45	57
1978	73	43	30
1979	81	41	40
1980	54	40	14
1981	104	42	62
1982	51	8	43
1983	67	5	62
1984	91	5	86
1985	81	6	75
1986	45	5	40
1987	(238)	(7)	(231)
1988	175	45	130
1989	106	25	81
1990	105	5	100
Average (all years)	(98)	(26)	(72)
Average (all years except 1975 and 1987)	88	25	63

6.3 NET LOSS TO GROUNDWATER

The last column of Table 6.3 was calculated by subtracting the estimated return flow to the Harts River (see section 6.2 above) from the calculated total irrigation losses (see section 6.1). This difference represents the unaccounted for portion of the irrigation loss that could potentially have been lost to groundwater storage. However, it must be stressed that this is probably an over-estimate, since at least part of the unaccounted irrigation loss is likely to have been lost to additional evaporation from wet soil surfaces when the potential lake evaporation exceeded the theoretical crop water demand.

The estimated potential groundwater losses to deep storage given in Table 6.3 were compared for the period 1977 to 1979 with the deep percolation estimate determined by subtracting the calculated return flow (from Table 6.3) from the Ninham Shand estimate of total potential return flow given in Table 2.12. This comparison (for the period 1977 to 1979) was as follows:

Average deep percolation (from Table 6.3) = $42x10^6m^3$
Average potential return (from Table 2.12) flow less calculated return flow (from Table 6.3) = $22.2x10^6m^3$. The Ninham Shand value for deep percolation is therefore 53% of that determined in this report.

The estimates made by Ninham Shand represent the lower estimate of deep percolation. Much of the difference between the high and low estimates lies in the handling of effective rainfall. In the case of the high estimate presented in this report, the assumption is that all of the non-effective rainfall and irrigation supply water is available for deep percolation. The low estimate appears to be based on the implicit assumption that the non-effective rainfall is all evaporated.

Since the alternative estimates cover relatively short periods, the estimate of the long term mean annual deep percolation based on Table 6.3 (i.e. $63x10^6m^3$ p.a.) was simply scaled by the percentage obtained for Ninham Shand. On this basis the estimated mean annual deep percolation varies between high and low values of $63x10^6m^3$ and $33x10^6m^3$. This wide band of estimates is indicative of the inherent inaccuracy resulting from the uncertainties associated with this type of calculation.

6.4 GROUNDWATER STORAGE WATER BALANCE

The groundwater storage water balance is based on the continuity equation:

INFLOW - OUTFLOW = CHANGE IN STORAGE .... (6.5)

The estimates of deep percolation made in Section 6.3 give an indication of the net rate of input of water to the groundwater via percolation (i.e. an input rate of the order of $33x10^6m^3$ to $63x10^6m^3$ p.a.). The method used to estimate the net deep percolation already implicitly accounts for any groundwater contribution to the surface flow in the Harts River. Therefore, provided there are no other significant means of water loss from the groundwater, the estimated net deep percolation should represent the left hand side of equation (6.5), and approximate the rate at which the groundwater storage is increasing.

The next step was to compare the range of estimates of the rate of accumulation of water in the groundwater with an estimation of the change in groundwater storage that has taken place since the North Canal area was brought under irrigation. Calculation of the increase in the groundwater storage requires estimation of the following parameters:

(i) the initial depth to the groundwater table (GWT), and changes thereafter;

(ii) the original and present connectivity between the old perched water table and the deeper GWT;

(iii) the average porosity of the soil and rock located between the level of the original and present water tables;

(iv) the extent to which the hump in the GWT has spread laterally beyond the boundaries of the irrigated area.

6.4.1 Changes in groundwater table

According to Streutker (1977), during the period 1935-1940 the GWT was at a depth of about 24 m, rising to within 1.2 m of the surface by 1972. However, Paver and Dicker (1939), reported that a few existing boreholes that they examined in the 1930s to determine the groundwater depth struck water at approximately 30 m, while some were dry down to 100 m. This implies a somewhat deeper GWT, of at least 30 m. Since Paver and Dicker's report is the only one to have examined early data for boreholes of significant depth, a depth of 30 m has been accepted as the initial groundwater depth. On this basis the groundwater depth has been assumed to rise by approximately 29 m since the commissioning of the Vaalharts Government Water Scheme (GWS).

6.4.2 Continuity of groundwater

There is evidence to suppose that there was originally a perched water table above the calcrete layer, which according to Streutker (1971) reduces the effective depth of the groundwater reservoir to 0 to 5 m. The occurrence of waterlogging in portions of the Vaalharts GWS as early as 1942 (only four years after the commencement of irrigation) is a clear indication of a local perched GWT, since it is impossible for less than one metre of irrigation application to have raised the GWT by 29 m in so short a time. What is not clear is whether or not the deeper GWT has as yet risen sufficiently to merge with and form a continuum with the original perched GWT.

The two extreme assumptions that can be made regarding the increase in the GWT are as follows:

(i) Assumption (a) : Assuming that a single continuous groundwater body has been developed (i.e. percolation through the more porus portions of the calcrete layer has eventually filled the deeper GWT) gives an estimated gain in the GWT of 29 m.

(ii) Assumption (b) : Assuming virtually no percolation to the deeper GWT (i.e. the calcrete layer is effectively impermeable) implies that the gain in groundwater storage has been confined to the perched water table above the calcrete layer. The literature is somewhat contradictory on just how deep the upper pervious layer actually is. According to Streutker (1971) the effective depth of the groundwater reservoir is between 0 and 5 m. However, Temperley (1967) reported a permeable zone up to 15 m thick, while Gombar and Erasmus estimated the thickness of a sandy-gravelly aquifer to be 9.3 m (Gombar, 1974; Gombar & Erasmus, 1976). Hence the rise in the water table could be anywhere between 2.5 and 15 m.

The truth could lie anywhere between these two extreme assumptions, with a continuous GWT in some areas and an independent perched water table in other areas. The irregular nature of the calcrete layer, the presence of two major dolerite intrusions and Dwyka shales forming an impermeable layer near the Harts River all tend to support this hypothesis.

The two extreme estimates of the gain in the GWT therefore range between a low of only 2.5 m and a high of 29 m.

6.4.3 Average porosity

The average porosity of the soil and rock in that portion of the geological profile that was filled since irrigation commenced is an important factor in determining the increase in water storage.

Temperley (1967) indicated the following geological profile: Kalahari Sand overlying calcrete overlying old alluvial gravel overlying weathered bedrock. The porosity of each of these layers can be expected to vary markedly. Based on often scanty information, an attempt has been made to make a first order estimate of the depth and porosity of each of these layers.

(a) Kalahari Sands: Table 2.16 gives the average porosity of the surface soils as about 0.4 . The average depth of these soils has been taken as about 2.5 m (since the depth to the calcrete layer was reported to vary on average between about 0 and 5 m). Since the groundwater table reached only as far as about 1.2 m below the surface by the early seventies, the rise of the groundwater through the lower portion of the soil profile could account for an addition of water to the groundwater of only 0.5 m (i.e. {2.5 - 1.2}·0.4).

(b) Calcrete layer: No information could be found regarding the average porosity of this layer, which appears to vary from being completely impermeable rock to permeable soft or spongy material. The porosity of the impermeable areas is irrelevant, since water would have no access to the pores. The only means of water storage in this zone would be in cracks and fissures, representing (say) 1% of the rock mass. In the permeable portions the porosity could be similar to that of the overlying soils. Assuming a 50:50 split between permeable and impermeable calcrete and an average layer thickness of 7.5 m (based on Temperley's estimate of the thickness varying between 0 and 15m) gives a potential water storage of 1.6 m. It must be stressed that this estimate is little better than a guess.

(c) Old alluvial gravel: Gombar and Erasmus reported the average water content of the sandy-gravelly layer to be 12.4%, with an average depth of 9.3 m. This implies a water storage capacity in this zone of approximately 1.2 m.

(d) Weathered bedrock: The remaining 9.6 m down to the assumed original depth of the GWT is assumed to comprise weathered bedrock. No information could be obtained regarding the porosity of this part of the profile. However, the simplifying assumption has been made that the porosity varies linearly from 0.2 at the bottom of the calcrete layer (i.e. similar to that of the calcrete layer) to zero at 29 m depth. This is based on the assumption that the degree of weathering of the bedrock decreases with increasing depth, tending towards fresh rock at the bottom of the profile. Since the underlying rock comprises mainly impermeable Dwyka shale and Tillite, it has been assumed to be virtually impermeable. Hence the assumed water storage capacity has been estimated as 1.0 m (i.e. $\frac{1}{2}\{0.2 + 0\} \cdot 9.6$).

Hence, for Assumption (a), i.e. assuming that the GWT has risen from a depth of 29 m to 1.2 m, the groundwater would have accumulated a further 4.3 m of water. In the case of Assumption (b), i.e. assuming no percolation to deeper groundwater from the perched water table, only 0.5 m of water would have been accumulated.

6.4.4 Aerial extent of influence of irrigation on groundwater

The scheduled area of the North Canal area is 240 km^2 (i.e. 24 000 ha). However, a further 72 km^2 of unirrigated land is either interspersed with irrigated lands or lies between the irrigated lands and the Harts River to the west. Since all of this land is either surrounded by irrigated lands, or immediately down-slope of them, it is logical to assume that the groundwater hump caused by irrigation extends over this entire area (i.e. 312 km^2).

In addition, the elevated GWT will have spread beyond the northern, eastern, and southern boundaries of the North Canal area.

It can be expected that the northerly advection of the groundwater would have been severely restricted by the presence of the irrigated lands in Bophuthatswana, which reach to the northern boundary of the North Canal area. Since the water table should also have risen in the Bophuthatswana area, the potential for groundwater flow in a northerly direction should be low. Moreover, since the elevation of the ground surface gradually falls from north to south in the direction of flow of the Harts River, the local 28 m rise in the GWT, even if it attained a horizontal profile extending in a northerly direction from the northern boundary of the North Canal area, would soon intersect the natural GWT, which can be expected to remain a relatively constant depth below the natural ground surface. For these reasons the possible extension of the groundwater hump beyond the northern boundary of the irrigated area has been ignored.

The southwards flow of water from the elevated GWT has been largely accounted for by the 72 km^2 assumed to be affected by the westward extension of the GWT towards the Harts River. This is because the southern boundary does not run from east to west, but rather is skewed in a north-west to south-east direction. Much of the land to the south-west of this boundary between the irrigated lands and the Harts River was included in the 72 km^2 of land that was assumed to have a GWT at a similar elevation to that under the scheduled North Canal area. The elevated GWT further to the south caused by the irrigation of the West Canal area would also tend to limit the southwards migration of groundwater from the North Canal area. For these reasons the southwards movement of groundwater from the North Canal area has also been ignored.

Along the eastern fringe of the North Canal area a 28 m rise in the GWT could be expected to cause a rise in the water table towards the east. However, once the groundwater in the transition zone reached a state of equilibrium with the old natural GWT, little further movement of the groundwater in an easterly direction should have occurred (since the natural direction of flow should be from east to west, in accordance with the fall of the ground surface). According to Temperly (1967) there is a 1% fall in the ground surface from east to west in the vicinity of the eastern boundary of the North Canal area (see Fig. 5, Appendix A). Hence, assuming that the original natural GWT followed roughly parallel to the ground surface, a horizontal eastward extension of the 28 m rise in the GWT (after attaining static equilibrium under the action of gravity) would intersect the natural GWT some 2.8 km to the east of the North Canal irrigated area. The depth of the rise in the GWT in this transition zone could be expected to vary approximately linearly between 28 m at the eastern edge of the irrigated land to zero 2.8 km further east. Since this boundary extends roughly 35 km from north to south, the affected area should be about 98 km^2, but with an average depth only about half that under the irrigated area. Changes in the geology near the eastern edge of the North Canal area may affect this calculation, and would almost certainly affect the estimated porosity at different depths. However, the simplifying assumption has been made that this zone has provided a further 49 km^2 of groundwater storage to the same effective depth as for the North Canal area.

The total affected area is therefore taken as 361 km^2 ($240+72+49 = 361\ km^2$). Filling of the entire soil/rock profile to within 1.2 m of the surface would therefore represent an increase in water storage of about $1552 \times 10^6 m^3$.

6.4.5 Evaluation of plausible water balance scenarios

(a) Scenario 1 : Low deep percolation combined with continuity between old perched and deep GWTs

This scenario assumes a potential total increase in groundwater storage of $1552x10^6m^3$ and a net rate of increase in storage of $33x10^6m^3$ per annum. This would imply that complete filling of the available groundwater storage would require 47 years. The conclusion would then be that the GWT has not quite filled up and there is still a discontinuity between the perched and deeper water tables. If this is the case then the groundwater could be expected to continue to accumulate both water and salts for only a few more years. Thereafter the percentage return flow to the Harts River could be expected to increase substantially and a balance between the TDS load contained in the applied irrigation water and that in the return flow will be attained. The salinity in the Harts River, and hence in the lower Vaal River, would then deteriorate sharply. In view of the variation in the soil depth and permeability, the geology and the history of irrigation practice, it is possible that in portions of the irrigated area the deep groundwater storage has already filled.

This scenario is plausible, since it would explain why historically and at present the return flow TDS load is considerably less than that contained in the irrigation supply water. It is also consistent with the calculated positive net deep percolation that has continued to occur since the mid-seventies. If correct, this scenario would imply that the installation of sub-surface drains in the early seventies was necessitated primarily by the exceptionally wet conditions, which caused a temporary imbalance between the water input to the perched water table and the rate at which it is percolating through the permeable portions of the calcrete layer to the deeper GWT.

(b) <u>Scenario 2 : High deep percolation combined with continuity between old perched and deep GWTs</u>

This scenario assumes a potential total increase in groundwater storage of $1552x10^6m^3$ and a net rate of increase in storage of $63x10^6m^3$ per annum. This would imply that the available groundwater storage would have been filled within 25 years. Given that the annual water supply to the North Canal area was lower in the first few years of operation (see Appendix H7), this would have resulted in complete filling of the available groundwater storage by the early to mid seventies.

This would be consistent with the severe waterlogging conditions that occurred in the early seventies. However, it fails to provide an adequate explanation for the fact that the TDS load in the return flow between then and now has remained substantially lower than that in the applied irrigation supply water. It also fails to explain why the calculated crop water balances carried out using a number of different methods all show continued irrigation losses that exceed the observed return flow to the Harts River. A positive deep percolation cannot continue unless the water has a place to which it can go. Since it is not to the river, and the absence of waterlogging after the installation of the drains rules out increased evaporation from saturated lands, the excess water must still be accumulating in the groundwater.

(c) Scenario 3 : Isolated perched GWT

This scenario assumes a potential total increase in groundwater storage of only $181x10^6m^3$. If combined with the assumption of a low net deep percolation rate of $33x10^6m^3$ per annum it would imply that at the current rate of increase, complete filling of the available storage would have occurred within about 5 years. Even allowing for the fact that the annual irrigation supply was relatively low during the first few years of operation, severe and widespread waterlogging could have been expected to occur long before the seventies. Since this did not happen until the early seventies (when drains had to be installed), the plausibility of this scenario is in doubt. This option also fails to account for the calculated net deep percolation since the time when the GWT could have been expected to have reached its ultimate level and the lack of balance between the applied and returned TDS loads. Application of the assumption of the highest estimated deep percolation rate ($63x10^6m^3$ p.a.) renders this scenario even less tenable. The logical conclusion is that Scenario 3 is implausible and that there must be a means by which a substantial amount of the excess water can penetrate pervious portions of the calcrete layer and reach the deep groundwater.

The true situation probably lies somewhere between scenarios (a) and (b) but closer to (a), i.e. that the calcrete layer is sufficiently permeable to permit the build up of the deep water table, and the filling of the deeper water table is not yet complete. This does not necessarily verify the estimates made of the available groundwater storage or the net deep percolation rate (both of which are subject to a wide margin of error). But it does imply that the ratio between the storage capacity and the net recharge rate is likely to be such that the available storage has not yet been filled. When this does occur, the amount of water and the TDS load returned to the Harts River is expected to increase substantially. This points to the need to better estimate both the rate of increase and the remaining available storage. The extent to which water can be leaving the system by other means (such as groundwater flow spreading further beyond the boundaries of the irrigated areas) also needs to be examined.

7. LONG TERM SALT BALANCE

7.1 MODEL SIMULATIONS

The hydro-salinity model WQTS was used to simulate scenarios of the long term TDS balance of the irrigated areas. The model calibration parameter values obtained in Chapter 5 were used. For these simulations the Upper and Middle Harts sub-systems were combined into one system. The system was simulated from October 1991 to 2030, using as input several different historical hydrological and meteorological sequences observed from 1923 to 1990. Starting salt concentrations for the pervious zone and the groundwater zone in the salt washoff sub-models were set to the values obtained for the last month in the calibration period (i.e September 1991) obtained from the model calibration answer files. For the irrigation sub-models, starting salt concentrations for the upper and lower soil zones had to be obtained in a similar manner. Starting reservoir storages and concentrations were obtained in the same manner. The supply water TDS concentration was assumed constant for the purposes of these projections and was taken as the average observed at Vaalharts weir between 1982 and 1991.

Each of the future years from 1991 to 2030 was represented by each of the historical hydrological years from 1923 to 1990, at the same time preserving the sequence of the historical hydrology by simulating 108 hydrological sequences, varying in length from 1 to 40 years. The first run was initialised with the storage states as simulated at the end of the model calibration period and projected forward one year, using the observed hydrological input for 1990. The second run projected forward two years from the identical starting conditions, this time using the observed historical hydrology for 1989 and 1990 to represent 1991 and 1992 conditions respectively. In the same manner the starting position in the historical hydrological record was decremented by one year, with the corresponding forecast period being increased by one year, for the third to the fortieth run, by which time the forecast period spanned the entire period from 1991 to 2030, using the historical hydrology for the period 1951 to 1990 as input to the model. The starting position in the historical hydrological sequence continued to be decremented by one year for successive runs. However, each of the simulations from run 41 to 68 remained forty years long, each starting with 1991 conditions and ending with projected 2030 conditions. After run 68, the mean storage states as at the end of 1991 were calculated from the results of the first 68 simulations. Run 69 then commenced at 1992 and ended at 2030, using the mean end of 1991 storage states derived from the preceding 68 runs as the starting condition. The starting point in the historical hydrological input remained at 1923 and ended in 1961. For the remaining 39 runs the starting point in the historical hydrological sequence remained at 1923, but the length of each successive run was reduced by one year and the starting storage states were approximated by calculating the means of the simulated storage states for the end of demand year immediately preceding the starting year derived from the previous 68 runs. Hence by end of this process, simulation no. 108 was only one year long, representing 2030 conditions and using the historical 1923 hydrological data as input to the model.

Once all of these sequences had been simulated, it was possible to construct smoothed projections of average annual return flow volumes or average annual TDS concentrations simply by calculating the means of the simulated values corresponding to hydrological years 1923 to 1990 for each future demand year. In the same way it was also possible to derive representative duration curves (i.e. cumulative frequency curves) of monthly flows, TDS concentrations or TDS loads for any selected demand year taking account of all of the historical hydrology from 1923 to 1990.

Two options were considered:

(i) Option 1: the present canal capacities (1990 conditions prior to increased allocations);

and

(ii) Option 2: the future situation, where both the Bophuthatswana and North and West Canal irrigation areas will receive a higher water allocation. Although the Bophuthatswana irrigation area is to increase, the main reason for the construction of the new canal is to increase the allocation of water to the existing Bophuthatswana and the North and West Canal areas. The North and West Canal irrigation areas are not expected to increase (Van Rooyen, 1993). Aside from the scheduling of small amounts of additional land that is currently in the pipeline, it is unlikely that there will be any further increase in the scheduled area owing to the fact that it would not be economically viable to upgrade the secondary and tertiary canal systems.

The assumed irrigation water allocations and irrigated areas for these two options were as follows:

For irrigation sub-model RR5 (Taung area upstream of C3H003),

Option 1 = 9.33×10^6 m^3 for an area of 1100 ha.
Option 2 = 13.46×10^6 m^3 for an area of 1589 ha.

For sub-model RR11 (North Canal area and Taung area downstream of C3H003),

Option 1 = 209.50×10^6 m^3 for an area of 26 870 ha.
Option 2 = 255.99×10^6 m^3 for an area of 28 358 ha.

For sub-model RR12 (West Canal area),

Option 1 = 38.50×10^6 m^3 for an area of 5000 ha.
Option 2 = 45.70×10^6 m^3 for an area of 5000 ha.

Since the model was calibrated using observed historical flow and water quality data, the underlying assumption for both options was that the irrigated lands would continue to accumulate salt as before.

The output from the simulation program WQTS was used as input to program RANKDM to produce duration curves of monthly irrigation return flow discharge and TDS. These duration curves are shown in Appendices D1 to D12 .

7.1.1 Taung area upstream of station C3H003

Appendix D1 shows the simulated monthly flow duration curve for the return flow from the irrigation area upstream of station C3H003 (via flow route 6 in

Figure 5.1) for the year 2010. For this irrigation area, both options had the same water allocation per unit area. Hence the only difference between the two options was a larger irrigated area, resulting in proportionally larger flows. Since the same application rate and return flow factors apply to both options, the simulated TDS concentrations of the return flow to the Harts River was identical for both options.

Appendix D2 shows the monthly TDS concentration duration curves for 10-yearly intervals with the concentrations increasing into the future. The gradual increase in the simulated TDS concentrations results from the relatively low return flow factor that had to be calibrated for this irrigation module. This is consistent with the higher efficiency achieved with centre pivot overhead spray irrigation. The simulations indicate that the salinity of these irrigated lands will reach a plateau after about 2020.

7.1.2 North Canal area

For the North Canal area, the simulated return flow (via flow route 10 in Figure 5.2) for Option 2 is larger than that for Option 1 owing to increases in both the water allocation per hectare and the increased scheduled area (refer to Appendix D3).

Appendix D4 shows that the TDS concentrations in the return flow from the North Canal area for Option 1 have been simulated as improving rapidly between 1991 and 2000, after which they stabilise. The simulated TDS concentrations for Option 2 (which have not been plotted) behave in a similar manner. This unusual result is attributable to the fact that the period at the end of the model calibration period was exceptionally dry, with low return flows. As a result salt was simulated to have accumulated in the soils of the irrigated lands. Since the model projections commenced with these elevated salt storages as starting conditions, the model simulated the flushing of this excess salt. Thereafter the simulated salinity of the soil zone rapidly reached a state of equilibrium with the assumed constant salinity of irrigation water. However, it must be stressed that these simulation results are based on the assumption that salt will continue to be transported to the deeper groundwater storage, from which there is assumed to be no return flow to the Harts River (see Scenario 1 of Section 6.4.5). Since this is not likely to continue indefinitely, a stage could easily be reached when the lower groundwater storage is completely filled. At that point in time (which cannot be predicted from the scanty information available) a large increase in the salt load entering the Harts River can be anticipated.

Simulated TDS concentrations for Options 1 and 2 are compared for the year 2010 in Appendix D5. This plot shows that Option 2 would result in an increase in the TDS concentration of the return flow water to the Harts River. This increase in the simulated return flow TDS concentration came about because a large proportion of the increased water allocation was used up in satisfying the crop demand, which was not fully satisfied in Option 1. Hence the simulated increase in water supply was proportionally larger than the increase in the return flow volume.

7.1.3 West Canal area

For the West Canal area, the return flow factor was set as zero since there appears to be little, if any, observed return flow to the Harts River (via flow route 14 in Figure 5.2). This is attributable to the large distance separating most of the West Canal area from the Harts River and the presence of wetlands and pans downstream of the irrigated area that are reported to spill only during exceptionally wet weather. The assumption was made that this would remain unchanged after the increase in water allocation for Option 2. A return flow factor of zero means that the model simulates a return flow only when there is sufficient rainfall to produce runoff from the natural catchment. Since Option 2 does not change the area of land under irrigation, these model assumptions result in virtually no difference in flow between options 1 and 2 (as shown in Appendix D6).

The low effective return flow from the West Canal area simulated using these assumptions results in a very long lag time before a state of equilibrium can be attained between the supply water TDS concentration and that of the return flow water. This leads to a simulated increase in TDS concentration throughout the simulation period (see Appendix D7), with the exception of the period between 1991 and 2000, when the simulated TDS concentrations first dropped while some of the TDS load accumulated during the dry period of the last decade or so of the historical period was flushed.

Appendix D8 shows the simulated year 2010 TDS concentrations in the return flow from the West Canal area for Option 2 to be higher than those for Option 1. This is attributable to the simulated return flow volume being similar for both options, while the water supply (and hence applied TDS load) is higher for Option 2.

7.1.4 Total Vaalharts area

Duration curves of the simulated total return flow from the Vaalharts irrigation area (i.e. Bophuthatswana, North Canal and West Canal combined) for Options 1 and 2 are compared in Appendix D9. The simulated return flow for Option 2 can be seen to be larger than that for Option 1. This is primarily due to the increased allocation and larger irrigated area in the case of Option 2.

Comparison of Appendix D10 with Appendix D4 shows that for Option 1 the trend of projected simulated TDS concentrations in the total return flow is similar to that for the North Canal area (see Section 7.1.2 above). This is because the return flow contributions from the Bophuthatswana and West Canal areas are much smaller than that from the North Canal area.

Appendix D11 shows that the simulated year 2010 return flow TDS concentrations for Option 2 are higher than those for Option 1. This again is similar to the results for the dominant North Canal area.

Appendix D12 gives duration curves of simulated monthly TDS loads returned to the Harts River for 2010 conditions for Options 1 and 2. The simulated

TDS load for Option 2 is higher than that for Option 1, the median being about 10% higher.

Appendix D15 shows the projected exceedance of return flow TDS concentration (average for the total irrigation area) for Option 1 for various percentiles over the period 1991 to 2030. After an initial dip to the year 2000, the simulated percentile values remain fairly constant towards the year 2030, except for the 1% and 5% percentile values, which show an increasing trend. Option 2 gave similar results.

7.1.5 Accumulation of TDS at Vaalharts

Appendix D13 shows the comparison between the simulated cumulative total supply and return flow TDS load since the commissioning of the Vaalharts irrigation scheme. The historical loads (prior to the 1991 hydrological year) were taken from output from the model calibration run. Those from 1991 to 2030 were taken from the model simulation results for Option 1. This was done by calculating the means of the simulated annual return flows for all of the hydrological scenarios that were simulated. The graph shows a steady increase in accumulated load (darkly shaded).

By the end of the 1990 hydrological year the simulated accumulation of TDS at Vaalharts amounted to about 65% of the TDS load contained in the applied irrigation water. This is somewhat lower than the 80% salt retention estimated by Stewart Sviridov and Oliver (1987). The reasons for the current lower estimate of retention include:

(i) The historical record used in the 1987 study was shorter than that used in the current study. In particular, it did not include the massive 1988 flood, which was much higher than anything observed before.

(ii) The less detailed earlier study did not permit the gathering of obscure records of water supply to Vaalharts during the earlier years. The simplifying assumption that the scheme was fully developed from the mid-thirties led to over-estimation of the TDS input during the earlier years. This in turn increased the estimated salt retention.

(iii) By the end of the longer record used in the current analysis the sub-surface drains had been in place for longer than was the case when the earlier evaluation was carried out.

Despite the lower estimate of the proportion of the applied TDS load retained in the irrigated lands, the new estimate of 65% remains very substantial. Any change in the conditions causing two-thirds of the incoming TDS load to be retained (such as the filling up of the available groundwater storage) would have a large impact on the salinity regime of the Harts River and the downstream portion of the Lower Vaal River.

Assuming no change in the conditions controlling the retention of TDS, the model simulations indicate that the accumulated TDS load will be nearing 4 million tons by the year 2030.

A similar trend was simulated for Option 2 (refer to Appendix D14).

7.2 COMPARISON OF TDS AND CHLORIDE LOAD RETENTION

The possibility that part of the TDS load retention has been due to chemical alteration (for example, precipitation of salts that are near their saturation limits) or the adsorption of certain ions into soil particles was investigated. This was done by expressing the TDS load retained in the irrigated lands as a percentage of the TDS load in the irrigation supply water and comparing it with the corresponding percentage chloride retention during the 16-year period from October 1975 to September 1991.

Chloride was chosen for comparison with TDS since it is known to be one of the most mobile ions that is the least likely to be precipitated or otherwise chemically removed. The period from the 1975 to the 1990 hydrological year was chosen because prior to the commissioning of Spitskop Dam in 1975 it was not possible to directly calculate the TDS or chloride export from the incremental catchment.

For this exercise, missing TDS data was patched using simulated values. The following equation was used to calculate the percentage retention of TDS:

$$PRET = \{LSUP - (LC3R002 + L2 - L1 - LC3H003 - LCAT)\} \cdot 100/LSUP \quad \ldots. \quad (7.1)$$

where :

PRET	=	percentage of TDS load in irrigation water retained
LSUP	=	TDS supply load to North and West Canal irrigation areas
LC3R002	=	TDS load discharged from Spitskop Dam
L2	=	TDS load in Spitskop Dam at the end of September 1991
L1	=	TDS load in Spitskop Dam at the start of October 1975
LC3H003	=	TDS load passing station C3H003
LCAT	=	TDS export from incremental catchment simulated using salt washoff sub-model SW2.

It was found that during this period about 57% of the TDS load in the supply water was retained. This is lower than the longer term estimated percentage retention since the commissioning of the irrigation scheme (65%) because this period contained two exceptionally large floods (in the 1975 and 1987 hydrological years) that were unparalleled in the earlier record. During such unusually wet conditions a higher than normal degree of flushing of salts from irrigated lands can be expected.

The percentage chloride retention was calculated using a similar equation. However, in this instance LCAT had to be estimated by applying a factor of 0.15 (based on the average chloride to TDS ratio at station C3H003 for the period 1975 to 1990) to the simulated incremental catchment TDS washoff load. Where patching was required for any other missing monthly chloride loads, the corresponding monthly TDS loads were also multiplied by the factor 0.15 . About 40% of the chloride load was estimated to be retained over the period 1975 to 1990. The lower percentage retention of chloride (compared with TDS) implies that some constituents of the TDS have been retained at a faster rate than has chloride, possibly through precipitation of insoluble salts or adsorption into soil particles. Ion exchange processes may also have played a role. This could mean that part of the retained TDS load has been removed by chemical and adsorption processes in the soil and may not have moved into a deeper groundwater storage. The permanence of this salt removal process depends on a number of factors. However, irrespective of how reversible the chemical and adsorptive processes may be, the retention of 40% of the chloride load implies a substantial percolation of salt to a deeper groundwater storage (or to some other relatively inaccessible part of the groundwater). This basically gives an upper limit of TDS retention of 65% and a lower limit of 40%.

8. EFFECT OF THE SUB-SURFACE DRAINS

One of the objectives of the study was to attempt to determine the long term effect of the sub-surface drains that were installed during the seventies on the retention of TDS in the irrigated lands.

Certain data was received from the DWAF Vaalharts on releases from the ends of canals to the drainage system. This data covered the period April 1988 to March 1992 for the following monitoring points, 4/5 TE, 6 to 14 TE, 15/16 TE, 24/25 TE and 26/27 TE. Some of these points were identified on the drainage map. Unfortunately, this data only covered overspills and did not include irrigation return flow or stormwater. As no other data was available, it was not possible to carry out a detailed analysis on the effect of the drains.

In order to gain some insight into the effect of the drains, a graphical analysis was carried out to calculate the irrigation return flows from the North Canal area to the Harts River for the period 1952 to 1990, based on the flow records at hydrological stations C3H003 and C3H007. The monthly return flows were calculated using the method described in Section 5.2, using equation (5.1). Unfortunately, since the DT of station C3H007 is unreliable above 3.2 m^3/s, this analysis could only be carried out for the dry months June to October (inclusive). Two curves were plotted over the period 1952 to 1990 (refer to Figure 8.1). Firstly, the averages of all the non-zero irrigation return flows (using the return flow data file C3H003L3.RET given in Appendix H9) were plotted. Secondly, the irrigation return flows as a percentage of supply were superimposed.

Most of the drains were installed between 1976 and 1979. However, Fig. 8.1 shows little discernable increase in the magnitude of the irrigation return flow or the percentage return flow during this period. The wet conditions prevalent during the early to mid 1970s appears to have had a larger impact on return flows than have the drains. However, the fact that the percentage return flow remained at the same high level until the 1980 hydrological year, after the end of the wet period, is probably indicative of the effect of the drains. Thereafter the dry conditions and water restrictions that occurred during the 1980's drought completely masked the effect of the drains. In point of fact during the last few years of the drought farmers were known to plug their drains in order to raise the water table in an attempt to counteract the curtailment of their water supply during the period of water restriction. The high return flow during the 1987 hydrological year is attributable to the large flood of February/March 1988 (which breached Spitskop Dam). However, the relatively high percentage return flow during the drier last few years of the record could well indicate the effect of the drains.

It is of interest to observe that during the wet 1950s, when there were no drains, the percentage return flow was significantly higher than at any time since the drains were installed. This appears to imply that wet and dry hydrological cycles have a bigger impact on irrigation return flows than the sub-surface drains (although over-irrigation may also have played a role). This observation is supported indirectly by the small amount of water that was seen to be entering the main drainage canals via sub-surface drains during the field trip of 5/6 October 1992. Based on in situ EC measurements and visual inspection a large proportion of the return flow in the main drains appeared to comprise tailwater, rather than sub-surface seepage.

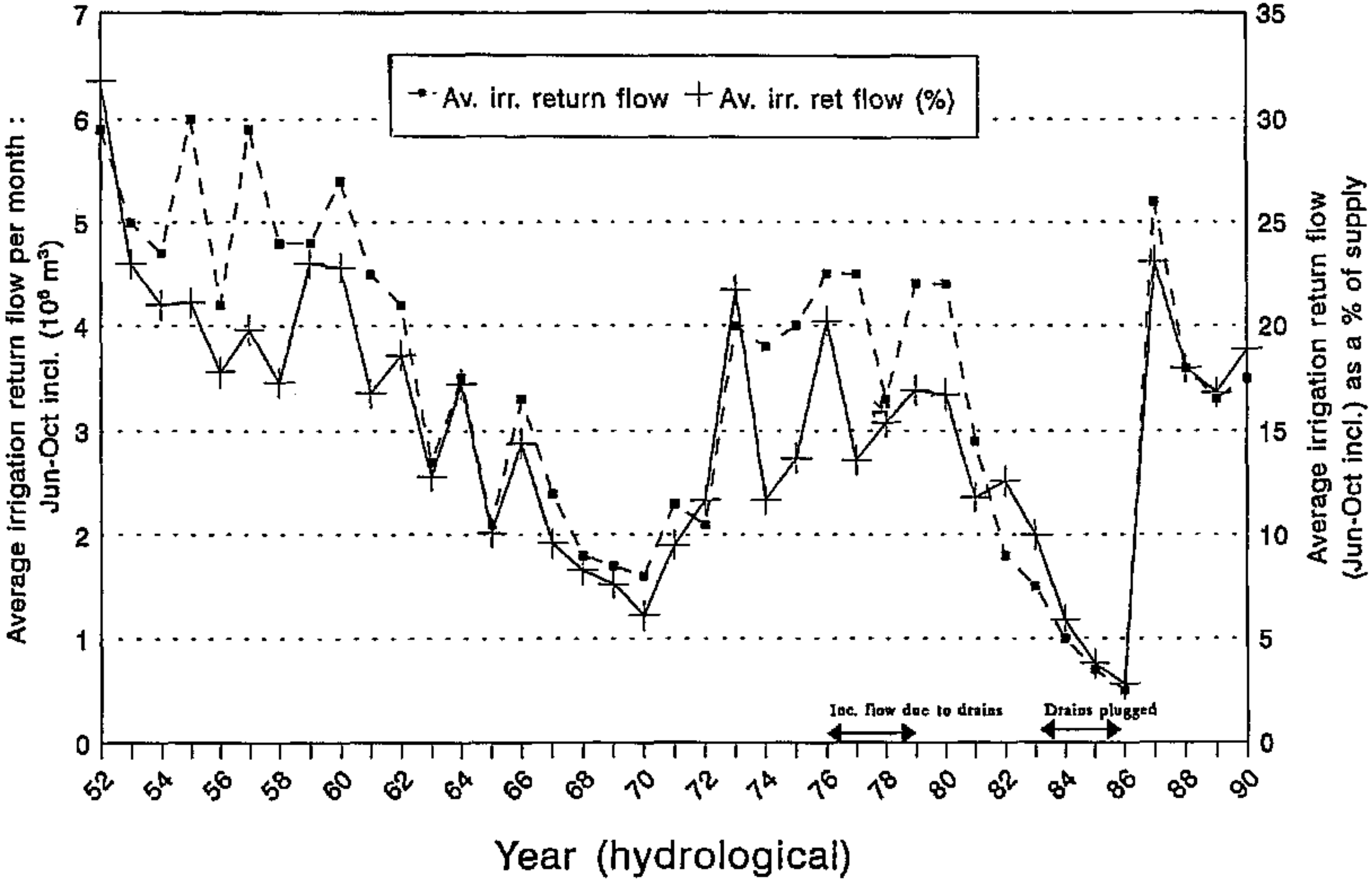

Figure 8.1 : Irrigation return flow to the Harts River from North Canal area

9. HYPOTHESIS OF PROCESSES

The various processes taking place in the Vaalharts irrigation scheme have been hypothesised. In Figure 9.1, the various flows have been graphically depicted for the Vaalharts irrigation scheme (which will be similar to most irrigation schemes). To briefly summarise the sketch, a dam supplies water to a canal which conveys water to the irrigation area. The supply water is restricted by allocation, availability and canal capacity. Secondary and tertiary canals then distribute this water to the various plots and farm dams. A certain proportion of this supply water will be lost prior to reaching the irrigation area due to evaporation and seepage from the canals. The farm dams will also be subject to evaporation and seepage. Water is also received via rainfall. This total water supply will be divided up into evaporation, surface runoff, infiltration into the soil to be used by the crop (evapotranspiration), lateral seepage towards the veld transport zone and deep percolation into the groundwater. Some of the irrigated area is fallow and will not be irrigated directly.

The drains, which were installed to maintain the water level below the crop root zone intercept a certain amount of groundwater. This water is collected by drainage canals and directed towards the Harts River. These drainage canals also collect upstream catchment runoff which is conveyed over the main supply canal by super passages. The drainage water, together with seepage, flows through a veld area towards river. Not all this water will reach the river since some will be lost to evaporation or re-used to irrigate pasture land within the veld area. The remaining water will reach the river, which will also be subject to evaporation and seepage losses.

Drainage below the root zone of the soil that is not intercepted by the sub-surface drains will enter the groundwater (which may comprise both an upper perched water table and a deeper water table). From the perched water table, part of the water and its associated solutes can gradually flow laterally towards either the river or the nearest main drain. The remainder could percolate through permeable portions of the strata immediately below the perched water table, resulting in a gradual filling of the deeper water table. Once the lower water table is filled there would be a rapid increase in the rate at which water discharges towards the river via direct seepage and the sub-surface drains. Whereas before a substantial proportion of the TDS load contained in the irrigation water would have been trapped in the deeper groundwater zone, from then onwards a rough balance would be maintained between the TDS loads entering via the irrigation water and returning to the river. This would result in increased salinisation of the river. In the absence of adequate drainage (either natural or artificial), the cessation (or severe reduction) of the loss of surplus water to the deeper groundwater would result in waterlogging.
1
If the flow of the lower groundwater towards the Harts River is unimpeded, then over a long period of time the accumulated TDS load could begin to return to the surface water. However, in the case of the Vaalharts irrigation scheme, if any such pathways do exist, the permeability of the Dwyka shale and Tillite is likely to be so low as to restrict the flow rate to such an extent that the contribution to the TDS loading of the Harts River will be small compared with the direct drainage from the upper zone.

Another process that could play a role is the lateral movement of water (and its associated TDS load) beyond the boundaries of the irrigated area, thereby effectively increasing aerial extent of the groundwater reservoir.

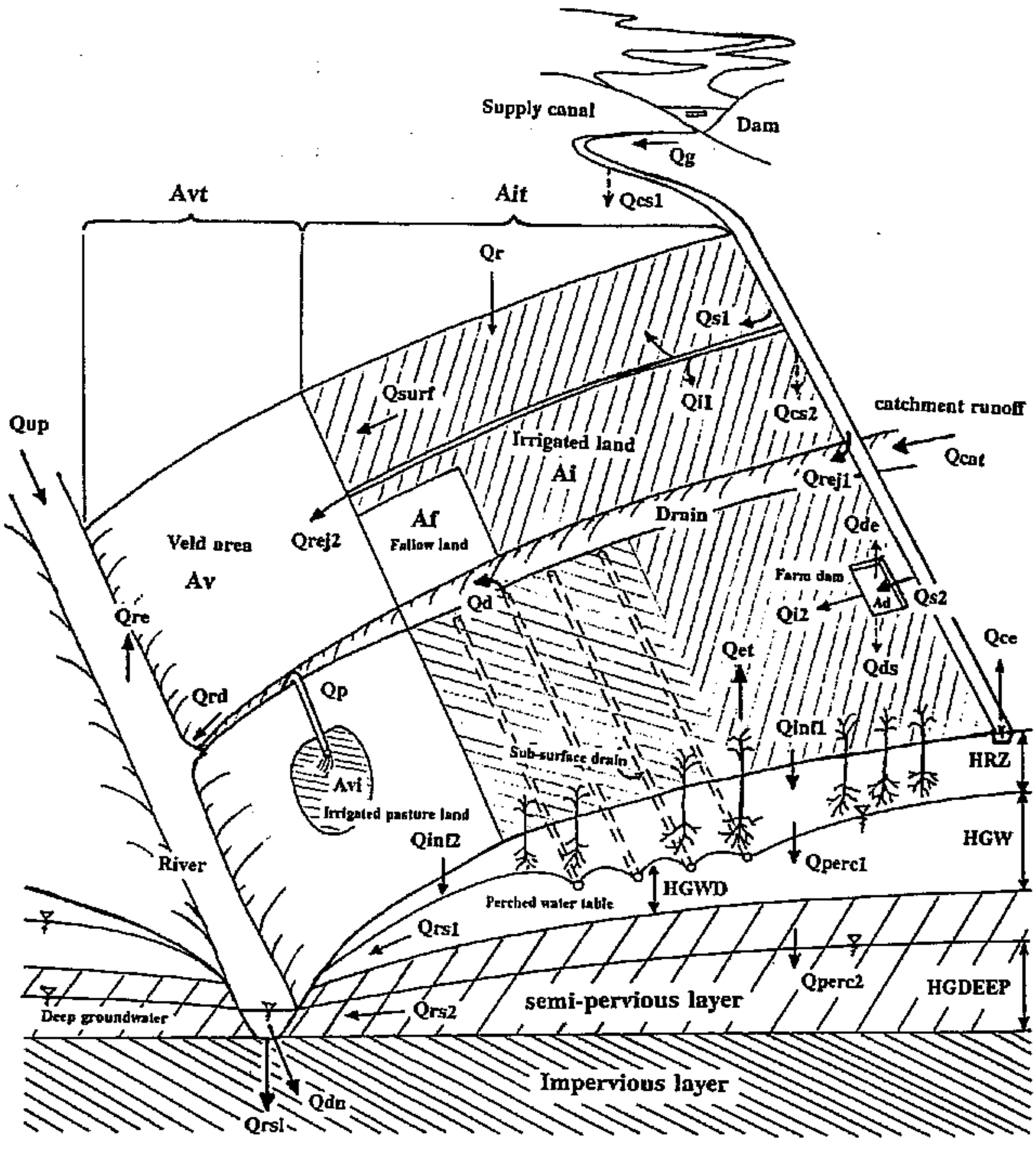

Figure 9.1 : Hypothesised flow processes in the Vaalharts irrigation area

The following is a description of the terms used in Figure 9.1 .

Ait	= Total irrigation area (= Ai + Af + Ad)
Ai	= Irrigated area
Af	= Fallow land area (temporary fallow area)
Ad	= Full surface area of farm dams
Avt	= Total downstream veld area (= Avi + Av)
Av	= Veld area
Avi	= Pasture land area in transport zone irrigated from reject water
Qp	= Water pumped from drains for re-use on lands in transport zone
Qd	= Sub-surface flow to drains
Qg	= Gross canal supply
Qr	= Rainfall
Qs1	= Canal supply to field edge
Qs2	= Canal supply to farm dam
Qce	= Canal evaporation
Qcs1	= Canal seepage loss remote from irrigation area
Qcs2	= Canal seepage loss in irrigated area
Qi1	= Direct irrigation from supply canal
Qi2	= Irrigation supply from farm dams
Qcat	= Storm water runoff from upstream catchment (passed through main drains)
Qsurf	= Surface water runoff
Qup	= Upstream flow in river
Qdn	= Downstream flow in river
Qde	= Evaporation from farm dams
Qds	= Seepage from farm dams
Qrej1	= Reject water direct to drains
Qrej2	= Reject water to veld/pasture land
Qrd	= Return flow to river via drains
Qrs1	= Return flow to river via seepage from perched ground water table
Qrs2	= Return flow to river via seepage from deep ground water
Qperc1	= Percolation to perched groundwater
Qperc2	= Percolation to deep groundwater
Qinf1	= Infiltration in irrigated area
Qinf2	= Infiltration in downstream transport zone
Qet	= Evapotranspiration loss
Qre	= Evaporation from river
Qrsl	= Seepage loss from river
HRZ	= Root zone storage capacity
HGW	= Groundwater storage above perched water table
HGWD	= Groundwater storage in drained areas
HGDEEP	= Deep groundwater storage

The present irrigation sub-model in the WQT program is inadequate in many respects and cannot effectively model the situation shown in Figure 9.1 . There are various models in South Africa which model groundwater, soil chemistry etc. but none are compatible with the WQT model. In order to model the Vaalharts irrigation scheme (and other similar schemes) as closely as possible, an irrigation sub-model should be adapted as follows:

(i) The monthly rainfall should be disaggregated into smaller time steps based on the irrigation frequency and the irrigation duration. The interception loss would be apportioned to each time step according to the rainfall intensity during the time step.

(ii) A surface water balance using assumptions similar to those used in catchment hydrological models should be allowed for, taking account of the frequency distribution of catchment absorption and the relationship between infiltration rate and soil moisture storage.

(iii) Allowance needs to be made for increased evapotranspiration from the soil moisture, tending towards full lake evaporation as the storage approaches saturation.

(iv) The scheduling of irrigations needs to be taken into account in conjunction with the temporal distribution of rainfall when simulating infiltration, direct surface runoff and tailwater discharge.

(v) Allowance needs to be made for a variable groundwater table that reduces the unsaturated soil depth as it rises and increases it again as the groundwater level falls. Algorithms for handling the effect of installing sub-surface drains need to be included.

(vi) The possibility of deep percolation below a perched water table needs to be included.

(vii) The lateral transport of water and salt in the groundwater towards the river needs to be dealt with. The lag effect could be modelled by means of a series of cells.

(viii) Provision needs to be made for the gradual filling of a deep groundwater table and the cessation (or reduction) of deep percolation to this zone once it has filled.

(ix) Algorithms for simulating the water and salt balance of fallow land and land located down slope of the irrigated area need to be included.

(x) Processes whereby salts can be removed by chemical processes, adsorption and crop uptake need to be taken into account.

(xi) Losses from farm dams and distribution canals in terms of evaporation and seepage should be taken into account.

In addition to developing an improved irrigation model, the need exists to design and set up monitoring systems and field studies to test the hypotheses and successfully calibrate the models for the Vaalharts irrigation scheme. This will require a multi-disciplinary approach involving hydrologists, geohydrologists, and irrigation experts.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

10.1.1 Parallels with other irrigation schemes

The history of civilisations, as well as better documented more recent cases, indicates that large irrigation schemes such as Vaalharts have the capacity to accumulate very large volumes of irrigation water in the groundwater. It can be deduced that the change in storage in the groundwater represents the potential to store large tonnages of salt.

The history of the Indus Scheme in Pakistan (which was commissioned during the same decade as the Vaalharts irrigation scheme), as well as that of Vaalharts itself, demonstrates that the raising of the groundwater table can take a number of decades. It follows that during this period both water and salt will be accumulated. This provides a plausible mechanism for the large accumulation of salt in Vaalharts estimated by Herold and Muller (Stewart Sviridov & Oliver, 1987) and in the current study.

10.1.2 Data collection

Although every effort has been made to collect all data pertaining to this study, certain data has been unobtainable. Missing data on crops, areas under irrigation etc. had to be interpolated or extrapolated. Missing water supply quality data prior to the early seventies was simulated using the Vaal River model.

The flow records for Spitskop Dam (C3R002), Espagsdrift weir (C3H007) and Mt. Rupert weir (C3H013) were found to be inaccurate. An investigation was carried out by the DWAF OFS Regional Office confirmed that there were a number of problems with regard to the streamflow gauging at these stations. A report was compiled by them and sent to the DWAF head office who revised certain DT and streamflow data.

10.1.3 Hydro-salinity modelling

The hydro-salinity water quality model WQT has been calibrated successfully for both the Upper Harts (i.e upstream of Taung weir) and Middle Harts (i.e between Taung weir - C3H003 and Mt. Rupert weir - C3H013) catchments. The calibrated model was then used to simulate conditions up to the year 2030 (refer to Chapter 8).

Owing to the inaccuracies in the flow gauging at key hydrological stations and data deficiencies (see Section 10.1.2 above), it was to be expected that the modelled values would not fit the observed values that well. The modelled values do, however, provide a reasonable first order approximation to the observed values. A detailed discussion of the fit between observed and modelled values is given in Chapter 5.

10.1.4 Estimation of irrigation losses

The annual return flows from the North Canal area to the Harts River for the period October 1976 to September 1991 were calculated from upstream and downstream river flow records and simulated monthly runoffs from the incremental catchment. The mean for this period came to $25x10^6m^3$ per annum which is about 11 % of the annual supply to the North Canal area.

A simple crop water balance was carried out to calculate the annual total irrigation losses (i.e. return flow to the river plus deep percolation to groundwater storage). These were compared with similar estimates made by Streutker and Ninham Shand Inc. In some instances, this exercise revealed wide discrepancies between the irrigation loss estimates arrived at using the different methods. All three methods appear to share the common weakness that none of them adequately account for the inter-relationship between the processes governing infiltration, surface runoff and soil moisture storage. The accuracy of all of the methods was also adversely affected by the coarse monthly computational time step.

Estimates of the annual amounts of water percolating to deep groundwater storage were made by subtracting the calculated annual return flows to the Harts River from the estimated total irrigation losses. These estimates were compared with those made by other researchers using four alternative methods of calculation. These alternative estimates of the mean annual deep percolation ranged between $33x10^6m^3$ and $63x10^6m^3$. This wide band of estimates is indicative of the inherent inaccuracy resulting from the uncertainties associated with this type of calculation. These alternative methods were employed to provide high and low estimates of possible deep percolation rates.

10.1.5 Change in groundwater storage in North Canal area

Two alternative hypotheses of the historical change in groundwater storage in the North Canal area were examined. The first was based on the assumption that the calcrete layer is sufficiently porous to permit percolation to the deeper GWT, which has been gradually filling over the years. The second supposed that there is no effective link between the perched water table above the calcrete layer and the underlying deep groundwater table (GWT).

Since the perched water table is relatively shallow, the second hypothesis appears to be incapable of explaining the long term retention of TDS in the North Canal area. Nor can it account for the loss of the difference between the calculated total irrigation loss and the return flow to the Harts River, even if the lowest estimate of the total irrigation loss is used.

The first hypothesis appears to be capable of explaining all of the main historical trends, provided the lower end of the range of estimated mean annual deep percolation estimates holds true (or the deep groundwater storage capacity is larger than that assumed. The implication of this set of assumptions is that the deep GWT has not yet completely filled. This hypothesis warrants further investigation to verify its validity.

10.1.6 Historical salt balance

Model calibration results indicated that most of the TDS load returned to the Harts River comes from the North Canal area, with much smaller contributions from the Taung area and the West Canal area. Some 65% of the TDS load contained in the irrigation water supplied to the Vaalharts irrigation scheme appears to have been retained. This compares with Herold and Muller's first order estimate of 80% retention, based on data available up to the end of September 1984 (Stewart Sviridov & Oliver, 1987). The difference between the two estimates can be explained partially by the additional data that has since become available, including the extremely wet 1987 hydrological year, and improved estimates of historical water supply prior to 1954. The errors in streamflow gauging which have been discovered during this study would also contribute towards this 15% discrepancy.

The new estimate verifies the main finding of Herold and Muller, viz. that most of the TDS load in the irrigation water has been retained, holding the potential for future salinity problems. Such problems could arise when a balance is eventually attained between the incoming and outgoing TDS loads, resulting in increased export of TDS to the downstream river system.

10.1.7 Long term future salt balance

Projections of the future TDS balance at Vaalharts were carried out using model simulations assuming continued loss of salts to the deep groundwater storage. Based on these assumptions Option 1 (the 1990 status quo option, which assumes no further irrigation development or change in water allocation), results in little change in the mean annual TDS load returned to the Harts River. For this option the deep groundwater is expected to have accumulated 60% of the applied TDS load by 2030, provided there are no water restrictions during this period (since the model projections assumed that the full irrigation demand is met). If the frequency and intensity of water restrictions during the next 40 years approximates that for the historical period, then a 65% TDS accumulation can be expected.

Option 2 (which takes account of new irrigation developments and increased water allocations that are already in the process of being implemented), is expected to increase the mean annual TDS load returned to the Harts River by about 10%. The increased water allocations have the effect of reducing the accumulated TDS load by the end of 2030 to 59% (since a larger proportion of the applied TDS load will have reached the Harts River).

Both of the above projections are based on the assumption that the deep groundwater has sufficient available storage capacity to continue to accumulate deep percolation. However, if at some point in time the available storage is exhausted, then a balance between the TDS load entering the irrigated lands and that leaving via return flow to the Harts River will begin to emerge. Although the TDS load already accumulated in the deep groundwater is not likely to return to the Harts River (or if it does return, the discharge rate will be too small to make a substantial impact on the TDS balance of the Harts River), a balance between supply and return flow TDS loads will result in a two- to three-fold increase in the mean annual TDS load returned to the Harts River. It is therefore important to establish when this can be expected to occur and to evaluate the likely impact on the salinity regime of the downstream river system.

10.1.8 Comparison of TDS and chloride retention

For the period October 1975 to September 1991 the TDS retention was estimated at 57% of the applied irrigation load, while that for chloride was estimated at only 40%. The extended long term TDS retention of 65% is somewhat higher than that for the sixteen year period for which TDS and chloride could be compared. Hence in the long term the chloride retention can be expected to be about 46% (i.e 65 x 40/57). This implies that chemical transformations and adsorption processes could be removing a significant portion of the TDS load that has apparently been retained in the groundwater. Since chloride is a highly mobile ion that is unlikely to be removed by these processes, the results indicate that at least 70% of the observed net loss of TDS (i.e 46% of the TDS load in the supply water) is likely to have been to deep groundwater. This implies that up to 30% of the salt loss could be attributable to chemical transformations and adsorption processes, part of which may be a permanent loss from the water phase. However, this figure could well be less than 30% since the presence of the chloride ion in rainfall, or the displacement of chloride from the original groundwater, may have altered the balance between TDS and chloride without actually removing other ions from the water. It is also unlikely that the irrigated soils can continue to remove salts indefinitely.

10.1.9 Effect of sub-surface drains

The effect of the sub-surface drains on irrigation return flows (in terms of both water and TDS load) has been totally obscured by wet and dry hydrological cycles and extraneous factors such as over irrigation during some periods, water restrictions and the plugging of drains during drought conditions. The drains appear to have had much less effect on return flows than have climatic fluctuations.

10.1.10 Hypothesis of processes

The main hypotheses are as follows:

(i) The calcrete layer is sufficiently permeable in enough places to permit the percolation of water and salts to a deeper GWT. This is where most of the "lost" TDS load appears to have accumulated.

(ii) This deep GWT may not yet have filled, but may do so at any time in the future (since we have little information regarding the remaining storage capacity and the rate of filling).

(iii) The deep GWT's groundwater flow contribution to the Harts River is (at present) assumed to be small relative to that from the sub-surface drains and the perched water table above the calcrete layer.

(iv) When the deep GWT fills, a rough balance between the TDS load contained in the irrigation water supply and that in the return flow to the Harts River is expected to occur. The return flow will then increase substantially and the TDS load returned to the Harts River is likely to increase by a factor of two to three.

(v) Fallow lands, the unirrigated lands separating the irrigated areas from the Harts River and a transition area along the eastern, southern and, to a lesser extent, the northern boundary of the irrigation area are all likely to exhibit elevated GWTs and contribute to the evapotranspiration loss from the irrigated areas.

A fuller description of the processes that need to be taken into account when modelling the system are given in Chapter 9.

10.1.11 Future implications

The accumulation of about two-thirds of the applied TDS load at Vaalharts implies that the salinity of the groundwater and that of the irrigation return flows is still a long way from reaching a state of dynamic equilibrium with the supply water salinity. Eventual filling of the available groundwater storage is expected to result in a state of equilibrium, with the mean annual TDS load returned to the Harts River matching that contained in the irrigation water. The system response to these changes will be complicated by the effect of the installation during the 1970's of irrigation sub-surface drains, which can be expected to intercept part of the water and salt load draining past the bottom of the crop root zone. This should serve to slow the rate at which salinity levels build up in the groundwater. However, it will also ensure that a larger proportion of the salt associated with the applied irrigation water will be returned directly to the Harts River. This implies a more rapid rise in return flow salt loads after the GWT fills, resulting in the new state of equilibrium being reached more quickly than would otherwise have been the case. The net result of the eventual increased TDS export on the downstream river system could be very serious indeed.

10.2 RECOMMENDATIONS

10.2.1 Investigation of the impact of increased salinity on the Vaal River.

There is an urgent need to determine the effect of increased salinity of the Harts River on the Vaal River. The existing Lower Vaal River salinity model (Stewart Scott and BKS, 1992) should be used to simulate the effect on the Lower Vaal River (and the lower Orange River) of a doubling or trebling of the Vaalharts irrigation return flow TDS.

10.2.2 Improvement of the existing flow and water quality monitoring system

(i) **Spitskop Dam releases:** Some difficulty was experienced due to the outflows at Spitskop Dam not being metered and having to be estimated using downstream gauge C3H013 instead. Aside from being too far downstream, this gauge was found to be under-measuring due to its inadequate hydraulic properties and sub-surface flow under the gauging structure. It is therefore recommended that a continuous metering system be established at Spitskop Dam to measure releases and that the C3H013 gauging structure be reconstructed (possibly rebuilt in another location).

(ii) **Hydrological station C3H007:** A separate level recorder is required further upstream to improve the accuracy of flow measurement over the Ogee spillway section. The Parshall flume can then be used to measure flows up to 3.2 m^3/s and the Ogee spillway for higher flows.

(iii) **Hydrological station C3H003:** The mistakes discovered in the early part of the C3H003 observed flow record as stated in section 2.4.1 should be corrected.

10.2.3 Implementation of new intensive monitoring

If the results of the pilot study recommended in section 10.2.1 indicate the likelihood of severe salinisation of the Lower Vaal River, then a monitoring system aimed at measuring the water supply volumes and TDS loads entering and leaving a representative portion of the North Canal area should be designed. The size of this portion of the north Canal area would have to be determined on a cost effective basis. This monitoring system should include the gauging of water levels in both the perched and the deeper GWTs. Geohydrological and geochemical surveys should be carried out to determine the storage capacity and porosity of each aquifer and to estimate flow directions and flow rates (both vertical and lateral), groundwater quality and groundwater abstraction via boreholes. The annual crop distribution and details of irrigation practices, including fertilizer and other chemical applications will need to be accurately recorded. A good spatial spread of meteorological stations is required. Regular soil analyses are also desirable.

10.2.4 Detailed study

Verification of the main hypotheses that motivated this study justifies the commencement of detailed a multi-disciplinary investigation to better quantify the uncertainties regarding groundwater storage states, groundwater quality and percolation rates and to better understand the processes governing the behaviour of the system. The main aim of this study should be to predict when the TDS loads returned to the Harts River are likely to increase and to what level they will rise. Secondary objectives should include evaluation of the impact on the downstream river system and the determination of the best management practices that could mitigate or delay these adverse effects.

10.2.5 Model adaptation and application

Critical to the attainment of the objectives of the detailed study is the development or acquisition of an improved irrigation model that hybridises the following:

(i) infiltration/surface runoff/soil moisture processes normally addressed by catchment models;

(ii) irrigation practices and advanced crop water balance modelling, including cross links with fallow land and down slope unirrigated pasture land;

(iii) groundwater modelling; and

(iv) soil chemistry modelling.

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APPENDIX A

MAPS AND DIAGRAMS

Figure **Page**

A.1

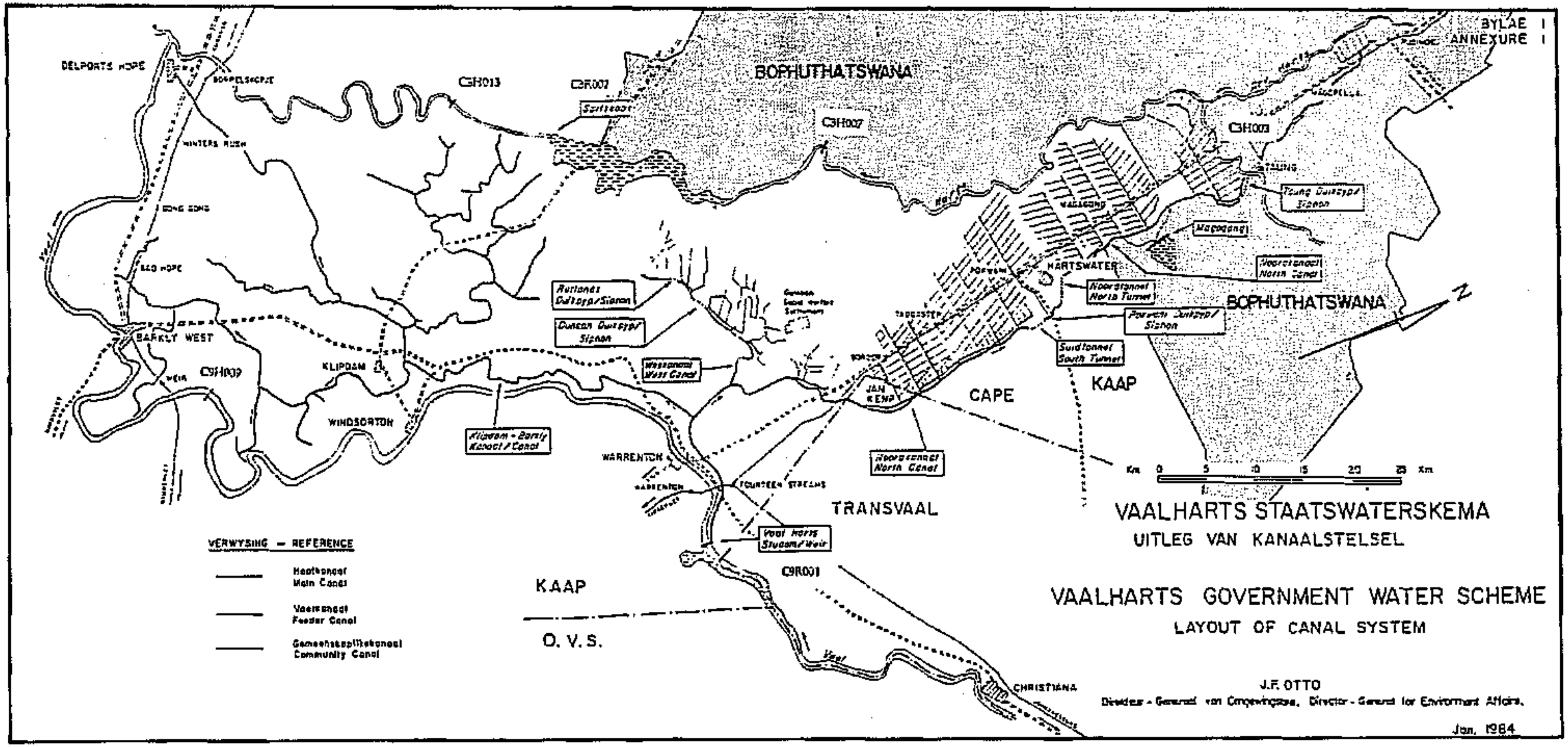

Figure A1 : **Vaalharts Government Water Scheme: Layout of canal system (excerpt from Government White Paper W.P. K-84)** **Figure A1**

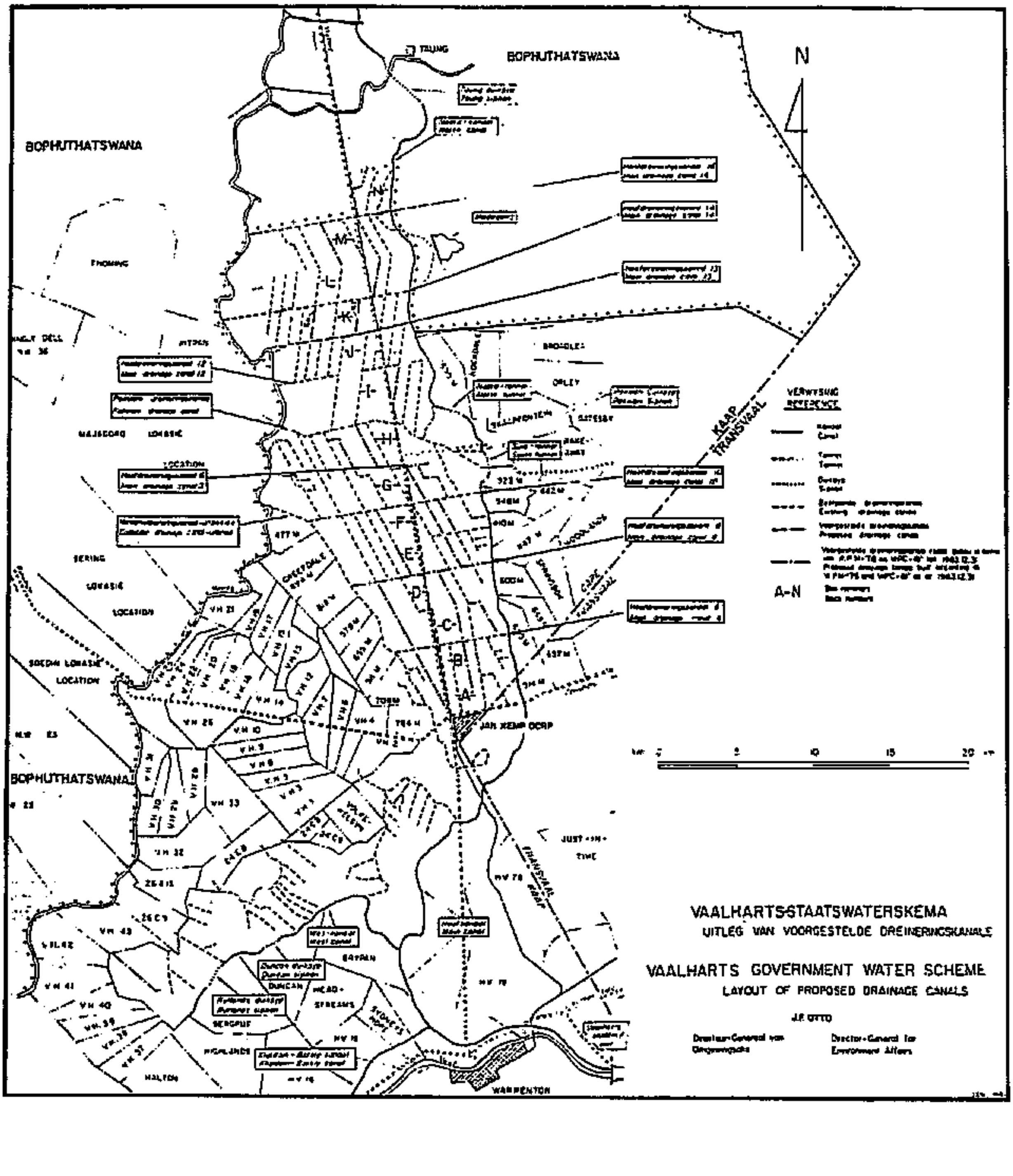

Figure A2 : **Vaalharts Government Water Scheme: Layout of proposed drainage canals (excerpt from Government White Paper W.P. K-84)**

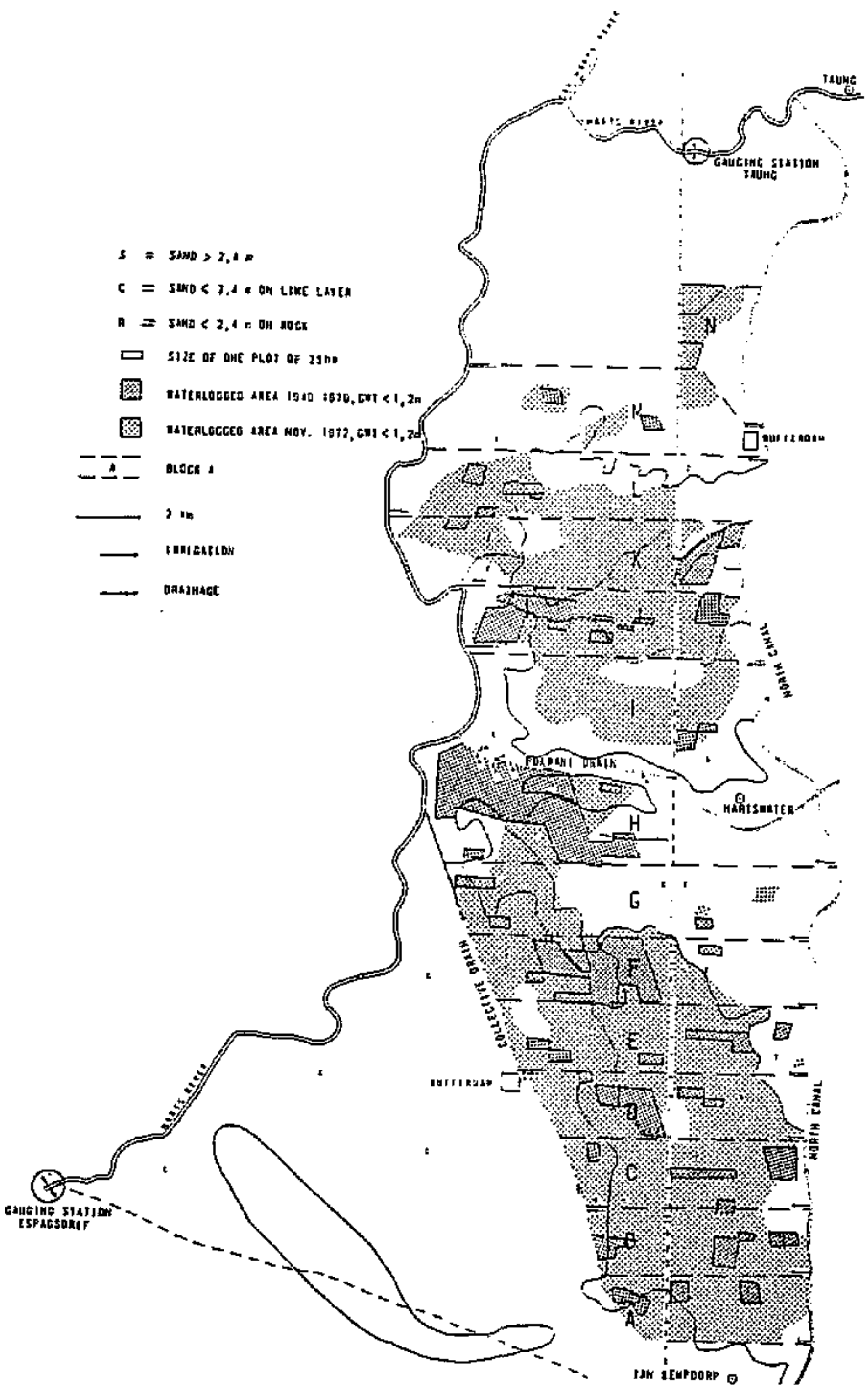

Figure A3 : Waterlogging and different soil types in the North Canal area (after Streutker, 1977)

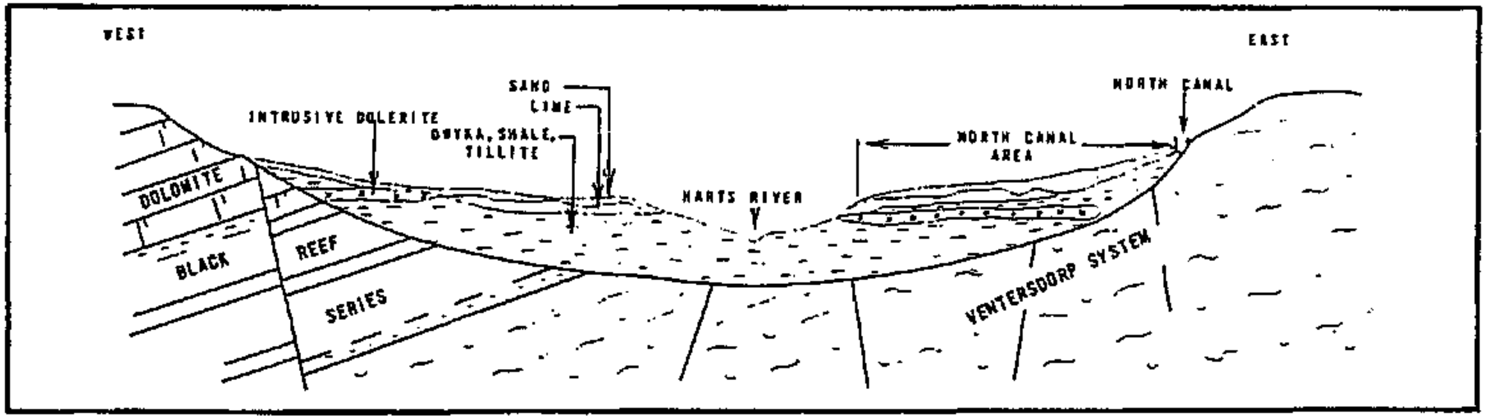

Figure A4 : **A geological profile of the Harts River Valley (after Temperley, 1967)**

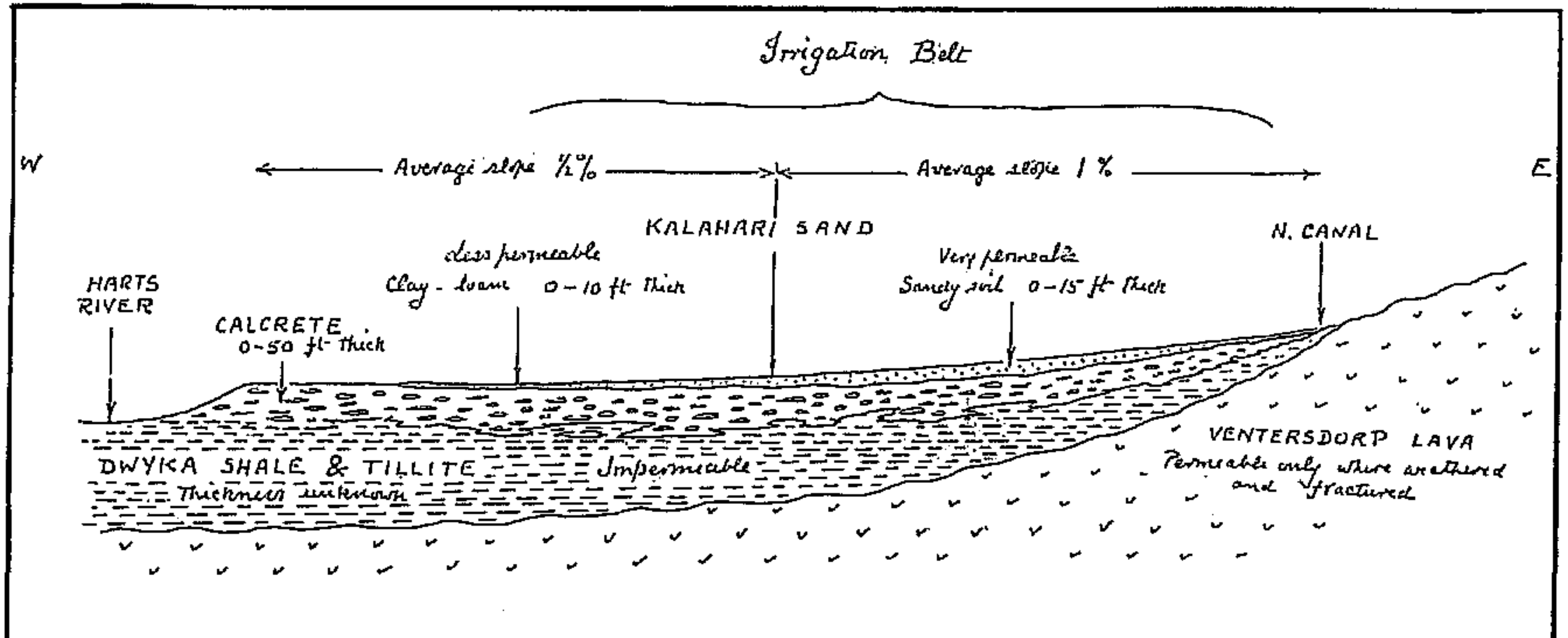

Fig. 5. Geological section across the North Canal area of the Vaal-Harts Irrigation Settlement. Generalized and largely inferred. Residual and alluvial deposits omitted.

Figure A5 : **A geological section across the North Canal area (after Temeperley, 1967)**

APPENDIX B

TABLES OF WATER SUPPLY AND WATER QUALITY

Table **Page**

Table B1 : Supply of irrigation water for period 1959 - 1969 (after Streutker, 1977)

TABLE 1

SUPPLY OF IRRIGATION WATER (× 10^6 m^3)AND RAINFALL (mm) *DURING THE WINTER SEASON* (1 MAY – 1 NOVEMBER) TO WHEAT ON 50% OF THE NORTH CANAL AREA, or 12 000 ha.

Year	Gross water supply		Irr. wasted water & drain water	Drain water	Irr. wasted water	Nett. water supply to farm sluices	Rain
	Demand	Additional					
1959	88,4	12,0	29,0	5,2	23,8	77,4	57
1960	79,9	11,0	28,0	5,7	22,3	68,6	47
1961	78,3	12,9	28,0	5,2	22.8	68,4	74
1962	88,0	13,2	21,8	5,2	16,6	84,6	6
1963	79,2	9.5	24,9	5,2	19.7	69,0	57
1964	71,0	8,5	16,1	4,7	11,4	68,1	74
1965	84,1	10,1	21,3	4,7	16,6	77,5	13
Average '59–'66	81,3	11,1	—	—	19,0	73,4	—
1966	60.5	7,3	10,9	4,7	6,2	61,5	8
1967	72,5	8.6	10,9	4,7	6,2	74,9	112
1968	84,0	10.0	10,9	4,1	6,0	87,2	72
1969	59,0	7,1	8,8	4,1	4,7	61,4	157
Average '66–'69	69,0	8,3	—	—	6,0	71,3	—

TABLE 2

SUPPLY OF IRRIGATION WATER (× 10^6 m^3) AND RAINFALL (mm) *DURING THE SUMMER SEASON* (1 NOVEMBER – 1 MAY) ON 75% OF THE NORTH CANAL AREA, OR 18 000 HA[1]

Year	Gross water supply		Irr. wasted water & drain water	Drain water	Irr. wasted water	Nett water supply to farm sluices	Rain
	Demand	Additional					
'59/'60	57.0	7.9	20,7	5,2	15.6	49,4	406
'60/'61	57,6	13,3	19,2	5,7	13,5	57.5	401
'61/'62	75,3	11,3	19.2	5,2	14.0	72,5	357
'62/'63	43.9	5.3	17,6	5,2	12.4	36,7	528
'63/'64	86,1	10.4	17,6	5.2	12.4	84.1	265
'64/'65	93.6	11.9	14,5	4.7	9.8	101.7	185
'65/'66	77,1	9.2	11,9	4.7	7,3	79.1	271
Average '59 – '66	70,9	9,9	—	—	12,1	68,7	—
'66/'67	27,7[2]	3.3	10,4	3,6	6,7	24.3	473
'67/'68	88.5	10.6	8,8	3.6	5.2[3]	93.9	205
'68/'69	72.9	8,7	7,8	3,6	4.1	77.5	240
'69/'70	80,1	10,5	7,8	3,1	4,7[3]	94.0	93
Average '67 – '70	83,1	9,9	—	—	4,6	88,4	—

1. Because of 25% annual double cropping of 24 000 ha;
2. Because of a decrease of the water quota not many summer crops were planted in Oct. '66; this figure is omitted from the average;
3. Irrigation wasted water was partly collected by new large buffer dams.

Table B2 : Chemical analyses of water from different sources at Vaalharts (after Streutker, 1977)

TABLE 3

CHEMICAL ANALYSES OF WATER FROM DIFFERENT SOURCES AT VAALHARTS

Water Source	Date	Remarks	pH	Eℓ. Cond. mS/m	Na^{+}	K^{+}	Ca^{++}	Mg^{++} me/ℓ	HCO_3^{-}	$Cℓ^{-}$	$SO_4^{=}$
Vaal River	2.12.1964		8,0	36,0	1,1	—	1,8	1,4	2,0	0,8	1,7
Vaal River	17.7.1970		7,1	60,0	1,5	0,2	1,3	1,6	2,9	0,6	1,1
North Canal	Aug. 1945		7,5	41,0	0,9	—	1,4	2,4	2,6	0,3	0,8
North Canal	Oct. 1949		8,1	46,1	1,0	—	1,4	1,2	2,7	0,3	0,5
North Canal	1958 – 1959		—	29,0	0,8	0,1	1,3	0,9	2,0	0,4	0,8
North Canal	13.8.1970		7,8	40,0	1,2	0,1	1,4	1,5	2,2	1,0	1,5
High GWT	6B4 1945		7,0	77,3	3,2	—	1,6	2,6	3,3	1,1	3,0
(in sandy soil)	6B4 1970		7,0	84,5	3,4	0,1	2,3	2,6	2,2	2,6	3,9
	5G15 1945		6,9	34,3	1,0	—	1,2	1,7	2,1	0,7	1,0
	5G15-1970		7,5	96,0	3,0	—	1,7	3,4	3,0	1,6	3,8
	6K5 1969	Average of 2 samples	—	20,0	7,0	0,2	6,6*	—	5,9	2,3	5,5
High GWT	6K5 1969	Average of 4 samples	—	350,0	17,4	0,5	21,4*	—	9,2	20,3	10,3
(on calcrete)	2K4 1970	Average of 4 samples	—	180,0	6,2	0,3	13,0*	—	16,2	2,0	1,6
Open ground	5K5 1958 – 1959		7,8	152,0	6,3	0,4	4,0	4,7	7,3	5,0	3,2
drains	1J13 1958 – 1959		7,7	370,0	10,1	0,5	12,1	12,3	4,4	26,5	5,0
Concrete lined drains	July – Aug. 1970	Average of 14 drains	8,0	113,0	4,0	0,1	2,8	4,2	5,0	1,5	4,6
Harts River at Taung	2.6.1969	Stórmwáter 158 ℓ/s	8,3	24,0	0,7	0,1	1,8*	—	2,0	0,5	0,0
	30.6.1969	Normal flow 48 ℓ/s	—	92,0	3,6	0,1	5,8*	—	6,2	1,1	2,2
	25.7.1969	Normal flow 82 ℓ/s	—	100,0	4,4	0,1	5,8*	—	5,8	1,5	2,8
	25.8.1969	Normal flow 79 ℓ/s	8,0	102,0	5,4	0,1	6,2*	—	6,0	2,2	3,5
	2.9.1969	Normal flow 62 ℓ/s	8,2	112,0	5,6	0,1	6,3*	—	6,3	2,3	3,7
Harts River at	2.6.1969	Normal flow 849 ℓ/s	—	61,0	2,4	0,1	3,6*	—	2,2	2,1	1,6
Espagsdrif	30.6.1969	Storm water 1188 ℓ/s	—	98,0	4,1	0,1	5,6*	—	3,2	3,2	3,1
	28.7.1969	Normal flow 906 ℓ/s	—	119,0	5,4	0,2	6,3*	—	3,2	4,7	3,5
	25.8.1969	Irr. off-period 232 ℓ/s	9,5	112,0	5,6	0,1	4,6*	—	2,4	4,0	4,1
	22.9.1969	Normal flow 453 ℓ/s	8,1	125,0	6,1	0,1	6,0*	—	3,9	4,6	4,6

*Ca^{++} + Mg^{++}

APPENDIX C

SITE VISIT NOTES, EC MEASUREMENTS AND PHOTOGRAPHS

C1 : NOTES ON THE SITE VISIT ON 5-6 OCTOBER 1992

DAY 1

Present:		
	Mr. Meiring du Plessis	(Water Research Commission)
	Dr. Peter Reid	(Water Research Commission)
	Dr. Arend Streutker	(Dept. Agriculture and Water Supply)
	Dr. Chris Herold	(Stewart Scott Inc.)
	Mr. Allan Bailey	(Stewart Scott Inc.)
	Mr. Dries Visser	(Dept. Water Affairs - Vaalharts)
	Mr. Japie Momberg	(Dept. Water Affairs - Vaalharts)
	Mr. Jan Minnie	(Dept. Water Affairs - Vaalharts)
	Mr. Stanley Southwood	(Eksteen, Van Der Walt & Nissan/ farmer)
	Mr. Sydney Visser	(Vaalharts Co-Op.)

Brief discussions were held at the DWAF offices in Jan Kempdorp before travelling to Taung. The gauge C3H003 was inspected and photographed. It was noted that the 1988 floods had caused severe damage to the road bridge. The DWAF stated that during the 1988 flood the peak water level was up to the bottom of the recording box. Adjacent to the right bank of the present river course, the 1988 floods had eroded a second channel. C3H003 appears to be a reasonable flow gauging structure, although the long broad crest is not ideal for measuring low flows. A full weir evaluation is to be obtained.

It was thought that the 1976 floods were the worst on record at this gauge but later in the day Mr Southwood mentioned that a higher stage had been recorded in March 1929.

A check on records after completion of the site visit showed the following:

Date	Volume (10^6 m^3/month)	Flood peak (m^3/s)	Peak height for the month (m)
05/03/1929	28.598	222.610	7.315
19/01/1976	237.258	* 298.600	5.802
21/02/1988	19.336	* 298.600	6.000

Note: * Since the flood peak of 298.6 m^3/s is given in the DWAF monthly data file for different gauge heights, it appears that this flow is the limit of the DT.

The fact that a 7.3 m water level gave a 222.6 m^3/s flood peak in 1929, whereas a 5.8 m water level gave an estimated flood peak of over 298 m^3/s in 1976 indicates that the datum level of the weir may have been changed at some point in time. Alternatively the weir structure itself may have been altered. There appears to be some conflict between the earlier and later records. The DWAF later confirmed that there are errors in the record over the period 1926 to 1937.

Discussions were held with Mr Dries Steyn in the Agricor offices. He provided a detailed map of the Taung Irrigation Scheme. He stated that irrigation began at the time that the North Canal area was developed (i.e. ≈1940) with about 1000 ha under flood irrigation. This was in the Mokassa region downstream of C3H003. This scheme was not very successful and was eventually changed to hand-moved sprinklers. From about 1978 onwards, other areas upstream and downstream of C3H003 developed, almost all of which was centre pivot irrigation. The present total is 3570 ha. The 1000 ha in the Mokassa region has remained fairly constant over the years. There was no irrigation upstream of C3H003 prior to 1978.

There are about 70 centre pivots in total. These include 40, 20 and 10 hectare pivots. There are three balancing dams of size 600 m by 200 m with depths of 3, 4 and 6 m respectively. Irrigation is continuous but declines at the weekends in the Mokassa region where the sprinklers are hand-moved. Taung Dam will provide water for an additional 1500 ha and will also provide industrial needs.

EC readings were taken at several locations. The highest EC reading in the Taung area was 549 mS/m which was in a grass drain in the Mokassa region. It was noticed that irrigation water consistently measured ≈105 mS/m (later verified at Vaalharts weir). From the DWAF records, it was noted that the most recent readings to hand for Vaalharts weir gave 61.7 mS/m (31 October 1991) and at Bloemhof Dam gave 64.0 mS/m (16 October 1991). Therefore a significant increase in EC occurred at Vaalharts weir over the preceding 12 month period. (The hand held EC meter was checked before and after the site visit and was found to be measuring within the prescribed limits).

Taung Dam was not visited since it was reported that there was no flow in the Harts River at that time. (Taung Dam was still under construction and river closure had not yet taken place. Hence there would also not have been any water in the dam basin.)

Mr Stanley Southwood joined the party for lunch at Hartswater and Mr Sidney Visser thereafter. In the afternoon the North Canal area was visited, where numerous EC readings were taken. It was noted that surface runoff in some areas was quite significant in that excess water sometimes merged with drainage water near the ends of drainage canals resulting in diluted (lower) EC values. EC values were found to lie mainly in the range 150 to 200 mS/m, depending on the dilution with irrigation water. A relatively high value of 290 mS/m was measured at a sub-surface drainage pipe outlet into drain 13. Since the EC of the water in drain 13 near this point measured only 150 mS/m, it can be concluded that a large proportion of the water in the drain comprised irrigation tail water and reject water. (The EC of the irrigation water was measured at 105 mS/m).

Wheat appeared to be flourishing on most farms, cotton has declined drastically due to low prices, the cultivation of vines appears to be increasing and some farmers are experimenting with new crops (eg. paprika).

Mr Sydney Visser offered to assist with some further data on fertiliser use.

The afternoon's program ended with a pleasant tea time at Mr Stanley Southwood's farm at Tadcaster (farm 2D9). Hand-moved sprinkler irrigation is used on this farm. Mr Southwood provided valuable insights into farming practices at Vaalharts.

DAY 2

Present:	Mr. Meiring du Plessis	(Water Research Commission)
	Dr. Peter Reid	(Water Research Commission)
	Dr. Arend Streutker	(Dept. Agriculture and Water Supply)
	Dr. Chris Herold	(Stewart Scott Inc.)
	Mr. Allan Bailey	(Stewart Scott Inc.)
	Mr. Koos Potgieter	(Dept. Water Affairs - Vaalharts)
	Mr. Jan Minnie	(Dept. Water Affairs - Vaalharts)

The days itinerary commenced at the DWAF offices. It was noticed that Mr. Jan Minnie had a wall map indicating Parshall flumes on several drains. He indicated that about five years of flow data was available for these flumes and agreed to make the monthly flow data available. Irrigation abstractions from the North and West Canals for the last few years were also obtained from him.

Flow gauging station C3H007 (Espagsdrift weir), Spitskop Dam, C3H013 (Mt. Rupert weir) and the operational flow gauging weir at Lloyd on the lower Harts River were all inspected, taking EC readings along the way.

Flow gauging station C3H007 comprises a low flow Parshall flume on the left bank with a Ogee crest weir section extending from the upstream end of its right wing wall to the right bank of the river. It was noticed that the water level recorder and gauge plates are positioned in the Parshall flume downstream of the crest of the Ogee crested weir. Since the flow velocity in the flume at this point is already appreciable, the velocity head will result in a significant drop in the water level recorded at this point relative to that of the pool upstream of the Ogee weir section. This can be expected to result in substantial under estimation of the discharge over the Ogee weir section.

At Spitskop Dam it was noted that the section of the dam which was washed away in the 1988 floods has been replaced by an additional spillway section thus increasing the spillway capacity.

It was observed that C3H013 can not be regarded as a reliable flow gauging station because of a sharp bend in the river immediately upstream of the weir and the presence of rocks near the weir. The hydraulic properties of the structure itself are not conducive to accurate flow gauging. Substantial seepage under the weir was also noticed.

The EC in various drains in the West Canal area was measured. The EC range was much the same as observed the previous day in North Canal area drains, with the exception of one higher value of 260 mS/m adjacent to farm 27E10. Some flows and water levels at drains and weirs were also estimated or noted. Mention was made of a series of pans (roughly in a line from Jan Kempdorp to Espagsdrift), which only in times of exceptional flood flow from one to the other. Ganspan is the largest of these and is thought to act as a sink most of the time.

Finally, Vaalharts weir was visited. The EC in the main canal was measured at 106 mS/m. The canal was flowing full. A new canal is under construction from the same take-off point which will increase the flow to the Vaalharts area from 29 m^3/s to about 49 m^3/s.

C2 : SITE EC MEASUREMENTS

No.	Description and comment	EC$^+$ (mS/m)	Temp. (°C)
DAY 1 : 5 OCTOBER 1992			
1	Harts River at C3H003 (downstream of weir)	127	21.5
2	3 year old grass drainage canal near Mokassa (point 2 on Taung drg. 8107/100*)	546	19.0
3	Concrete canal (point 3 on drg. 8107/100) - constructed 1979: - Outlet pipe (appeared to be from experimental farm) - Bottom of canal downstream of outlet pipe - 10 m upstream in bottom of canal	198 198 155	18.6 19.5 25.0
4	Harts River (upstream of concrete drainage canal, point 4 on drg. 8107/100)	191	24.4
5	End of concrete drainage canal near Harts River (point 5 on drg. 8107/100)	229	28.5
6	Experimental farm in the Mokassa area - drainage water may have been partially diluted since the drains were blasted out with irrigation water during the previous week): - Manhole (near farm buildings) - Tap (borehole water) - Manhole (bottom corner of farm)	122 141 197	18.8 - 18.7
7	Dry Harts River	177	30.4
8	North Canal drain 13 (drainage block K13): - Sub-surface drainage pipe entering canal - Bottom of canal - Nearby irrigation canal	291 150 105	18.2 29.2 25.1
9	- Downstream of junction of drains 13 and 14 - Drain 13 - Drain 14	144 144 177	27.2 27.1 31.9
10	Harts River (near junction of drain 13 and 14)	162	25.2
11	Pokwani drain: - Downstream of drain H1 (flow ≈0.25 m^3/s) - Side drain H1	165 181	29.6 30.4
12	S. Visser's farm 2G10: - Irrigation canal - Drainage canal	106 204	23.2 17.2

No.	Description and comment	EC+ (mS/m)	Temp. (°C)
13	Farm 2F13 (last drain before undrained area - unscheduled) Irrigation canal	169 102	19.7 25.8
14	Farm 1C8 - irrigation canal	106	21.9
15	Main drain 8, farm 1E6	154	24.1
16	Grass drain for farms 2E7 to 6E7 (Depth of V-notch = 155 mm, i.e. flow ≈0.013 m^3/s. Drains 6 plots (50% irrigated, i.e. ≈75 ha total)	198	18
DAY 2 : 6 OCTOBER 1992			
17	Drain Q (junction of P, Q and R drains ≈20 m wide)	160	21.4
18	Harts River at C3H007 (diluted with flood irrigation tail water since EC so low and no flow upstream of Taung)	149	20.8
19	Drain 24C and 24D	144	23.9
20	Drain 26B and 26C: - Bottom of canal upstream of drain - Sub-surface drain entering canal - Downstream in canal	 176 168 176	 24.3 19.6 23.9
21	Farm 27E10	260	23.1
22	Farm 4H37 - 40 (irrigation canal)	105	25.1
23	Spitskop Dam (flow from outlet pipe ≈2 m^3/s)	173	21.6
24	Harts at C3H013 (water level ≈350 mm)	174	21.6
25	Harts at Lloyd operational weir (water level ≈40 mm , flow ≈0.25 m^3/s)	209	22.5
26	Vaalharts weir C9R001 (irrigation canal)	106	20.7

Notes: + Electrical conductivity corrected to 20°C.

* This drawing was obtained from Mr D. Steyn of Agricor. Another drawing (General Layout 26021/50) of the drainage system was obtained from the DWAF. These drawings are too large to reproduce in the report.

C3 : SITE PHOTOGRAPHS

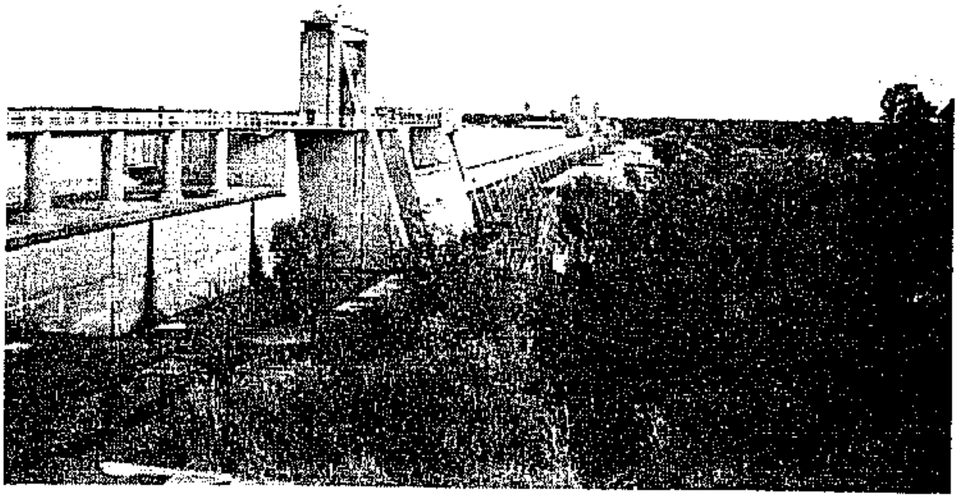

Photo 1 - Vaalharts Weir 6/10/92

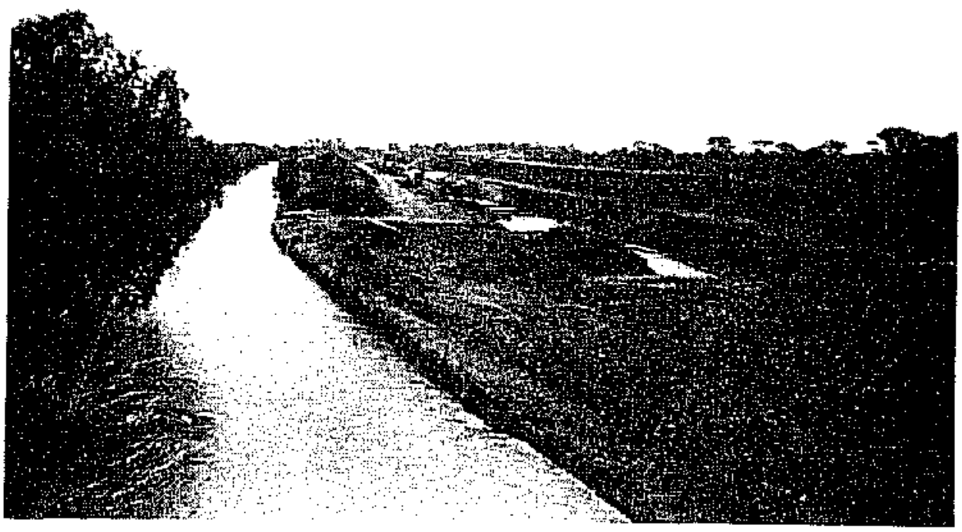

Photo 2 - New canal under construction at Vaalharts Weir 6/10/92

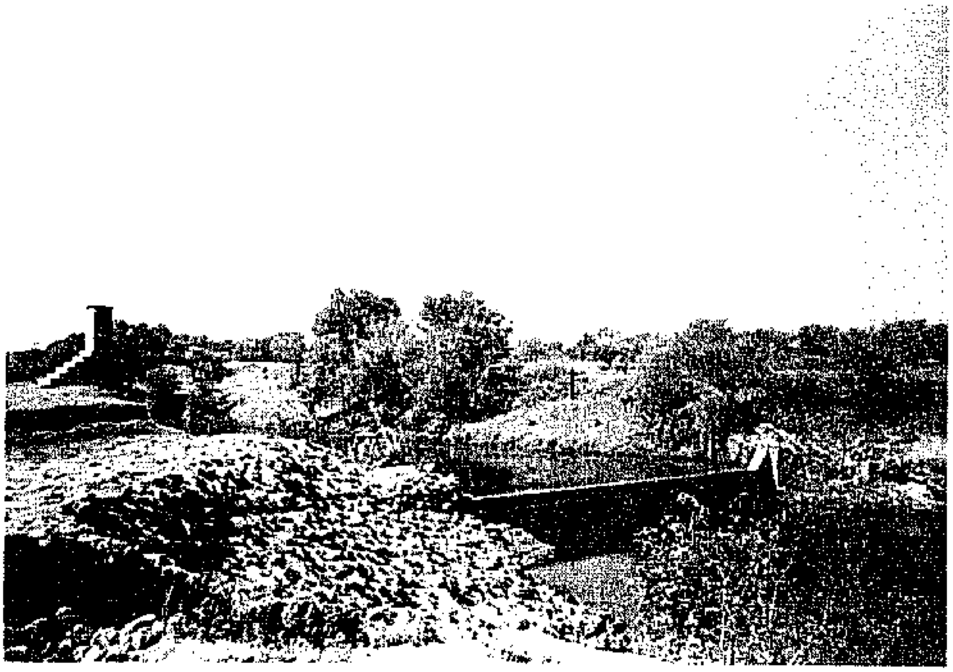

Photo 3 - C3H003 at Taung looking upstream 5/10/92

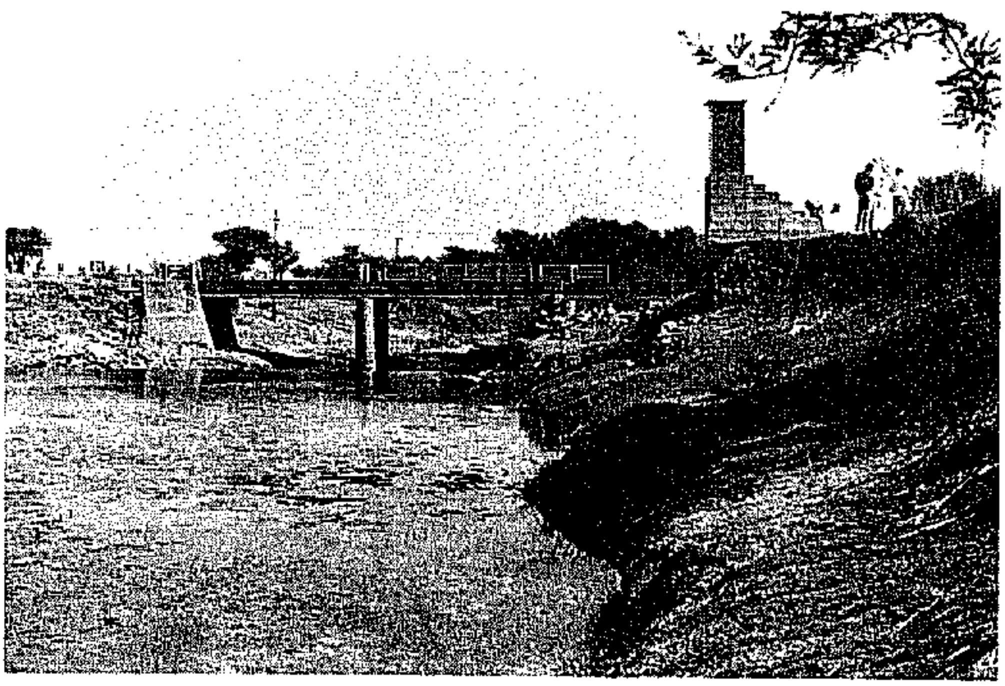

Photo 4 - C3H003 at Taung looking downstream 5/10/92 (Note erosion of the right bank and damage to the bridge caused by the 1988 floods)

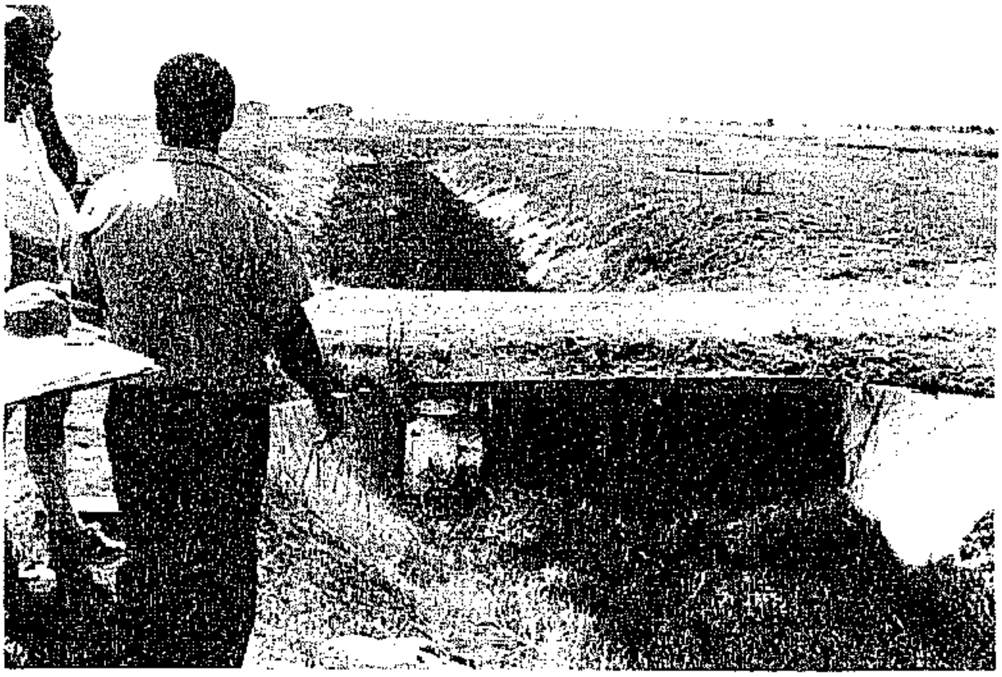

Photo 5 - Grass drainage canal near Mokassa in the Taung area 5/10/92

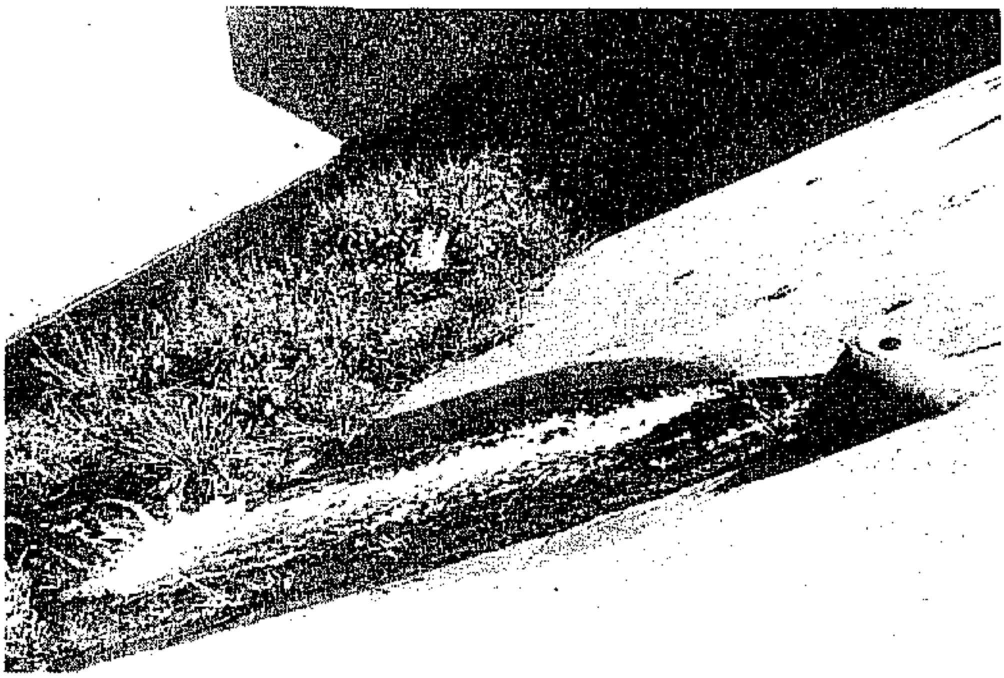

Photo 6 - Outlet pipe from the experimental farm into drainage canal in the Taung area 5/10/92

Photo 7 - Drainage canal in the Taung area (Note seepage from bottom line of holes whereas no seepage from upper line of holes)

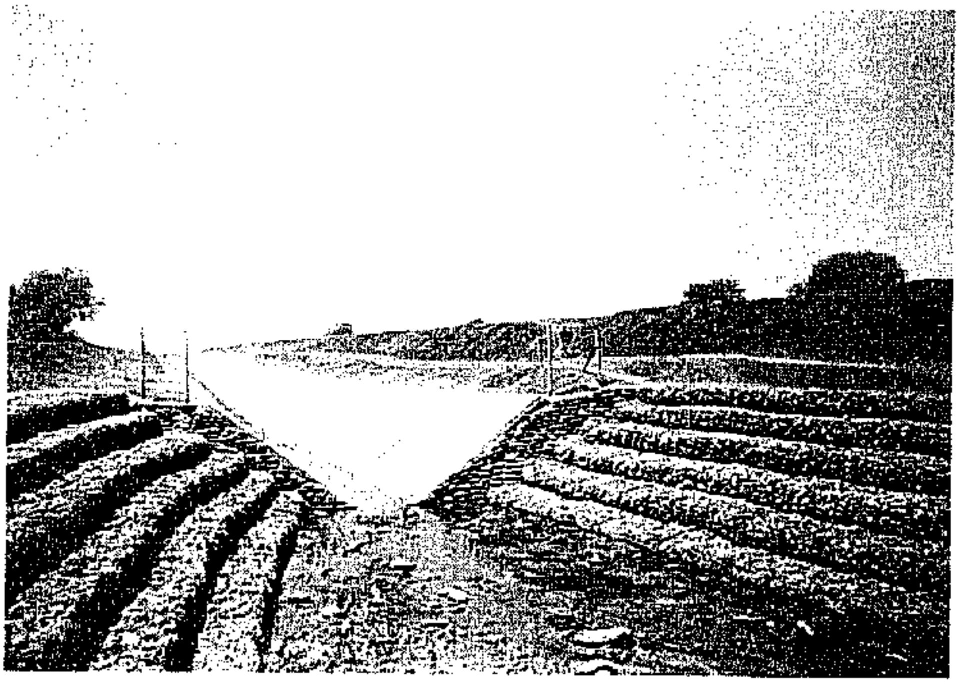

Photo 8 - End of concrete canal flowing into Harts River in the Taung area 5/10/92

Photo 9 - Harts River just upstream of canal shown in photo 8 5/10/92

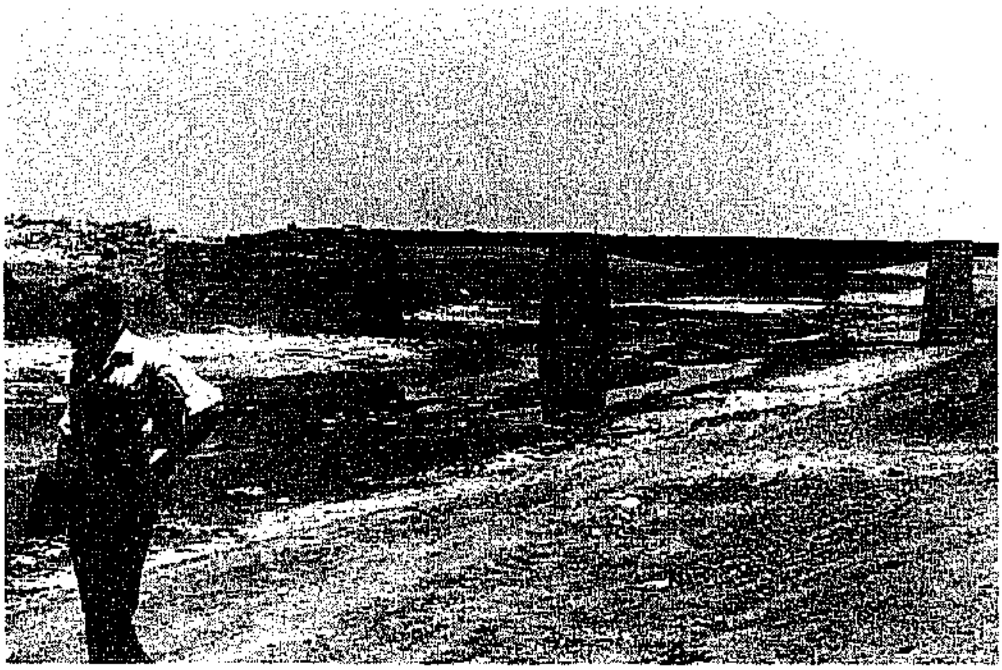

Photo 10 - Dry Harts River 5/10/92

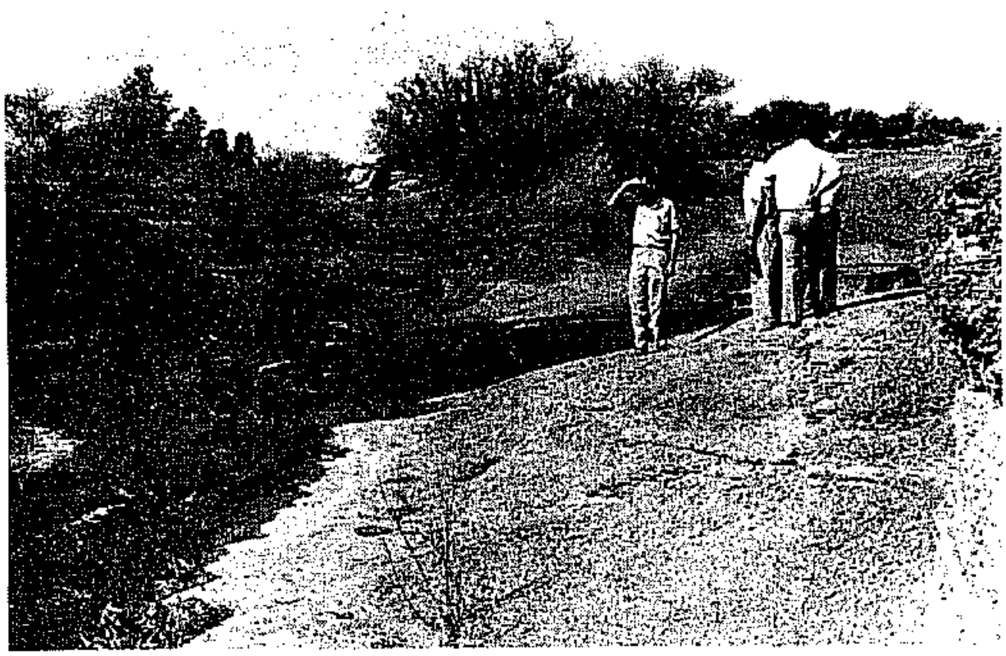

Photo 11 - Downstream of drains 13 and 14 in the North Canal area 5/10/92

Photo 12 - Side drain H1 into Pokwani drain in the North Canal area 5/10/92

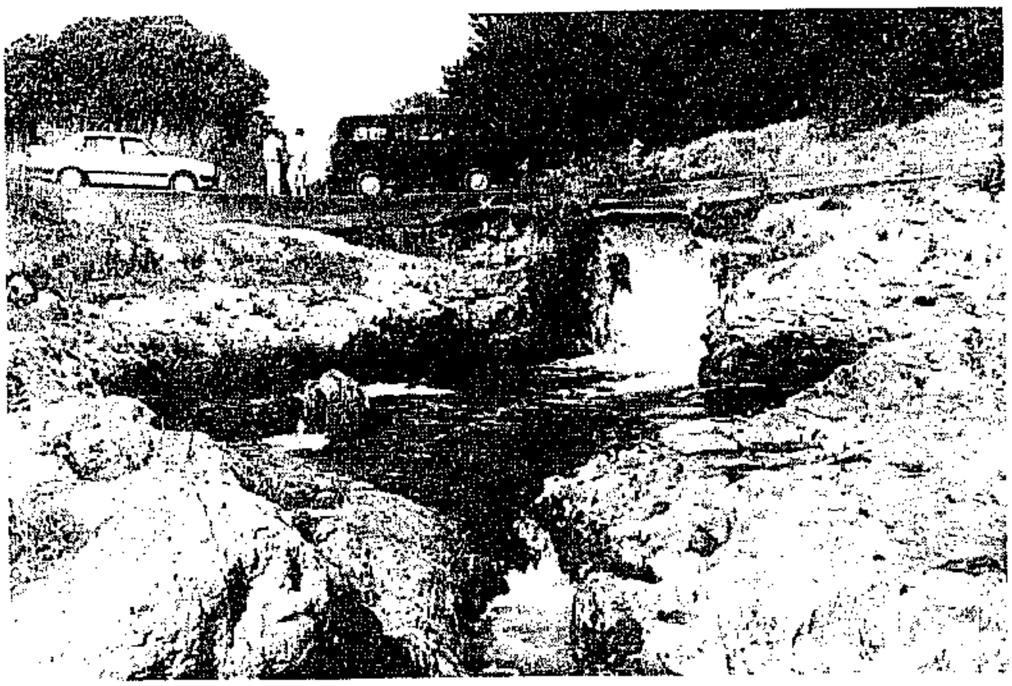

Photo 13 - Pokwani drain just downstream of photo 12 5/10/92

Photo 14 - Typical drainage canal in West Canal area 6/10/92 (although most other drains were dry)

Photo 15 - V-notch weir in drain near farm AG10 6/10/92

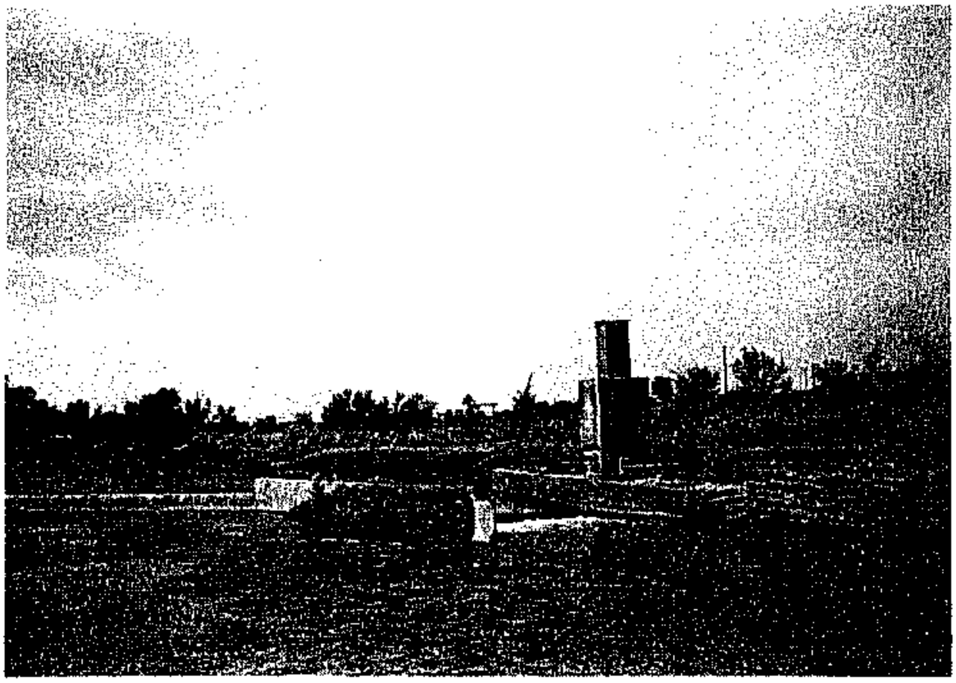

Photo 16 - Weir C3H007 at Espagsdrift 6/10/92

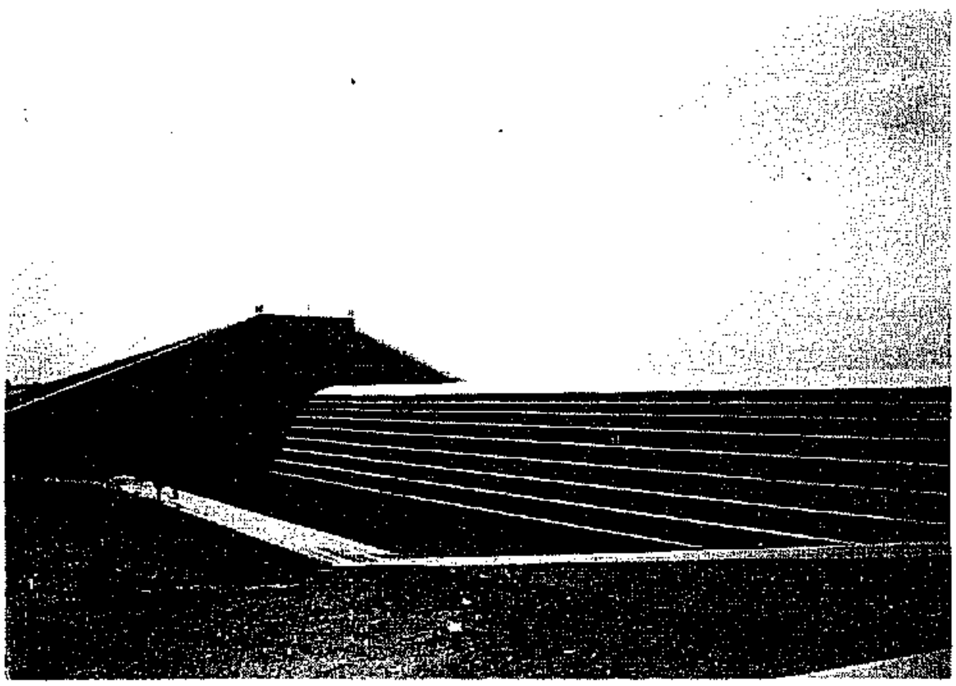

Photo 17 - New spillway at Spitskop Dam replacing part of the wall washed away in the 1988 floods 6/10/92

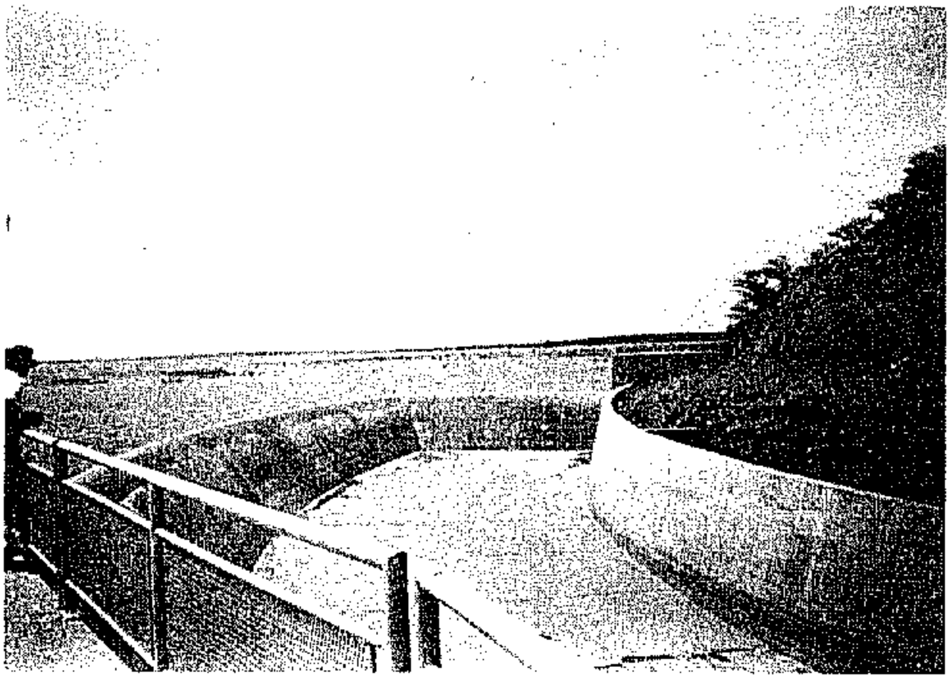

Photo 18 - Old spillway at Spitskop Dam 6/10/92

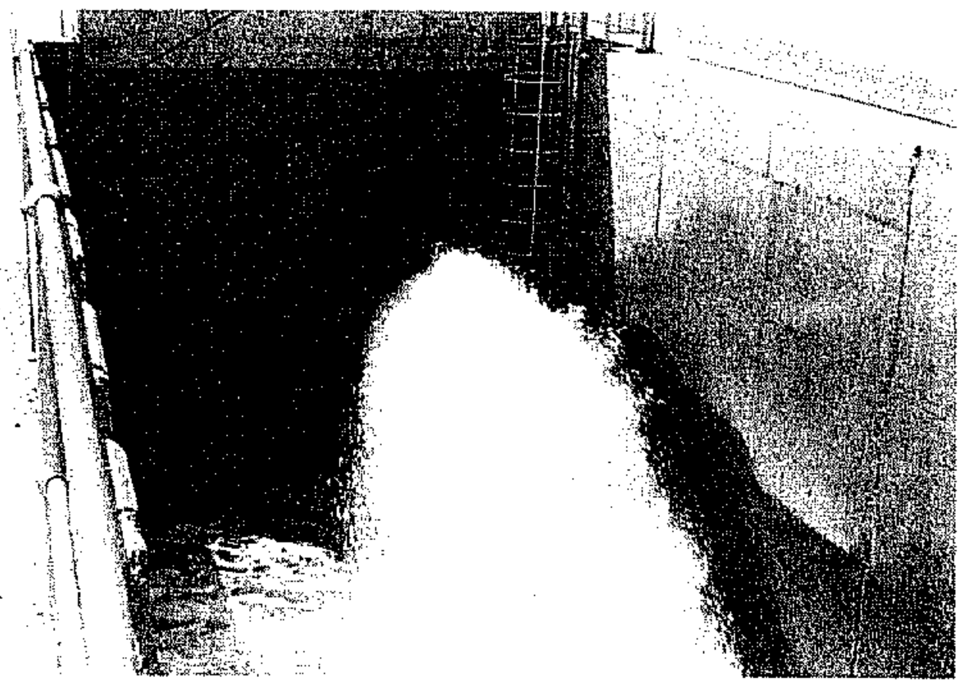

Photo 19 - Outflow pipes from Spitskop Dam 6/10/92

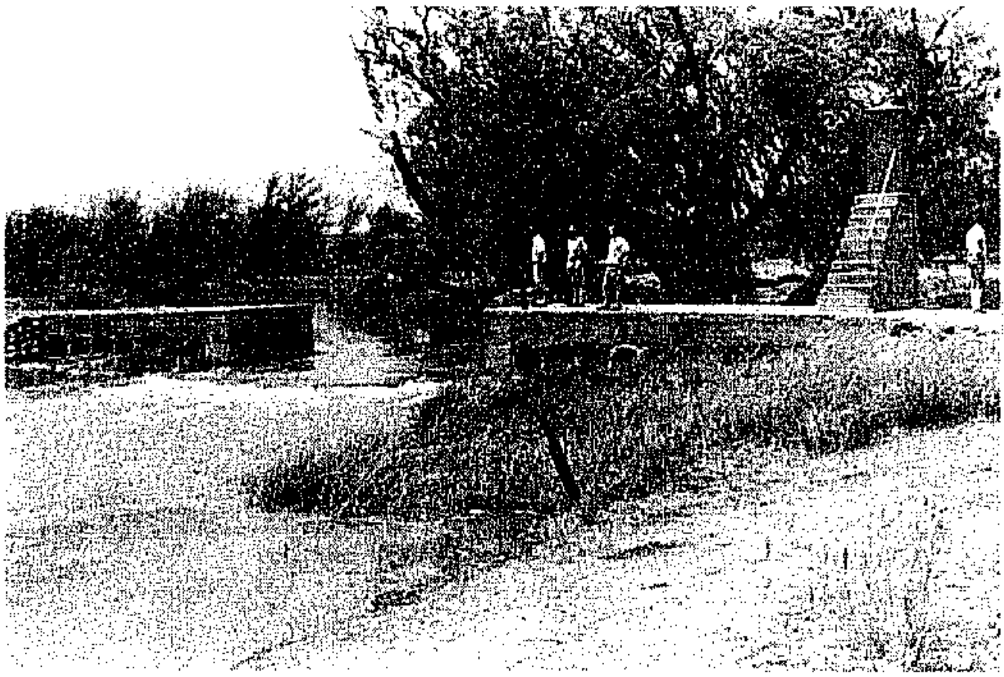

Photo 20 - Weir C3H013 at Mt. Rupert 6/10/92

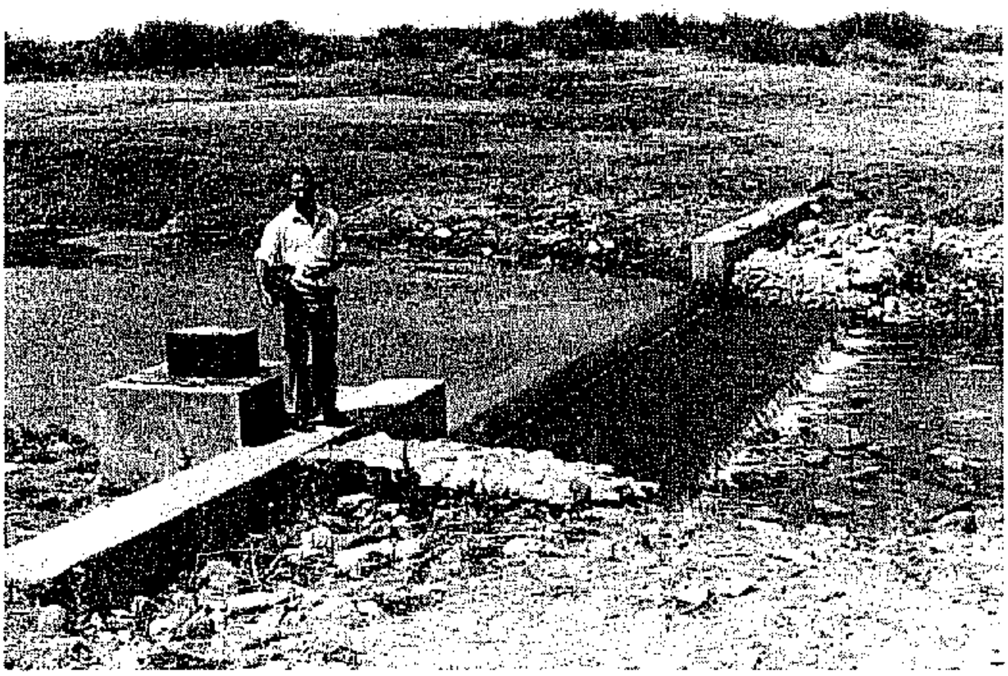

Photo 21 - Operational gauge on Harts River at Lloyd 6/10/92

APPENDIX D

PLOTS OF FLOW, TDS CONCENTRATION AND LOAD

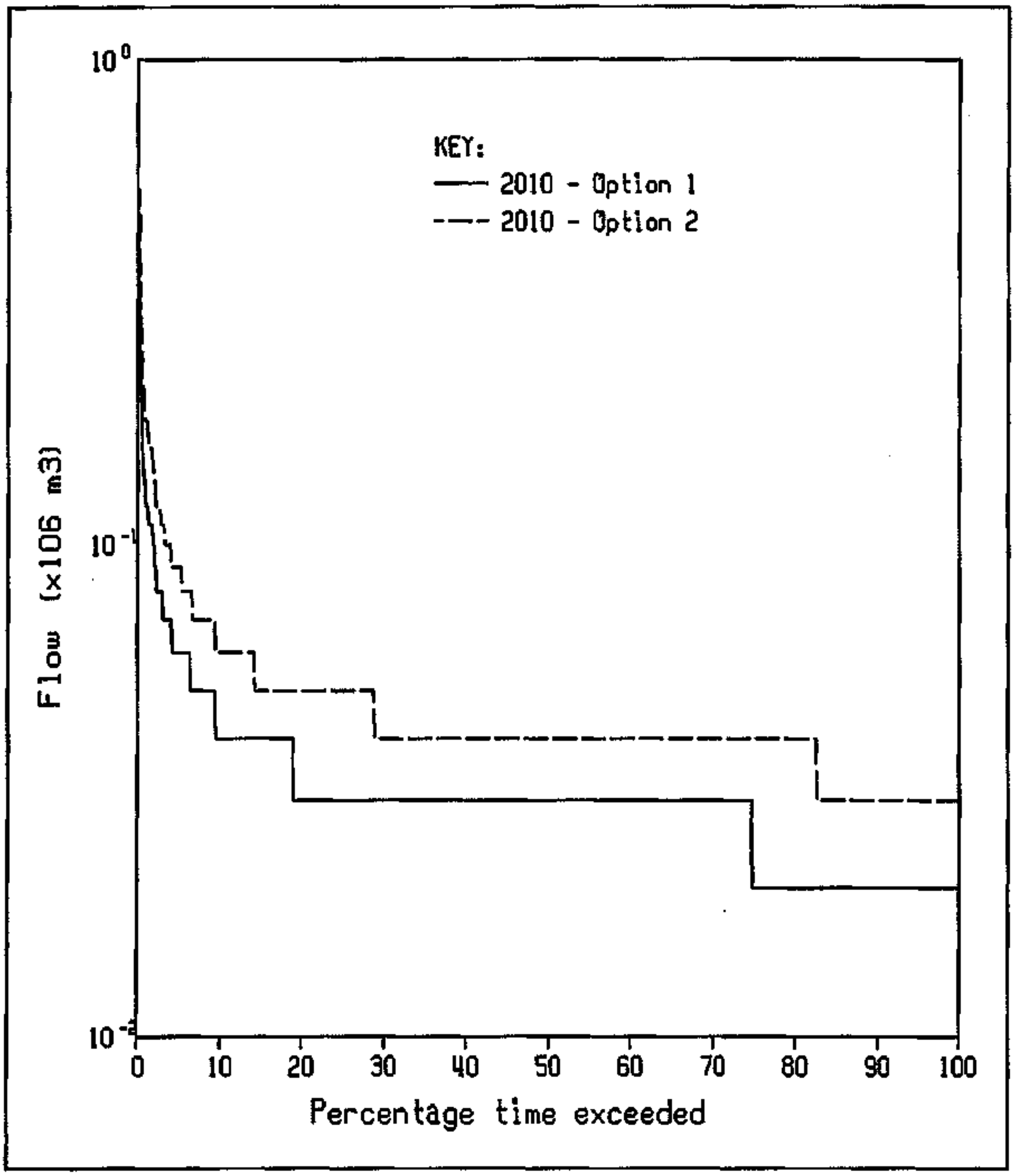

Figure D1 : Monthly flow duration curves for route 6 - Options 1 and 2

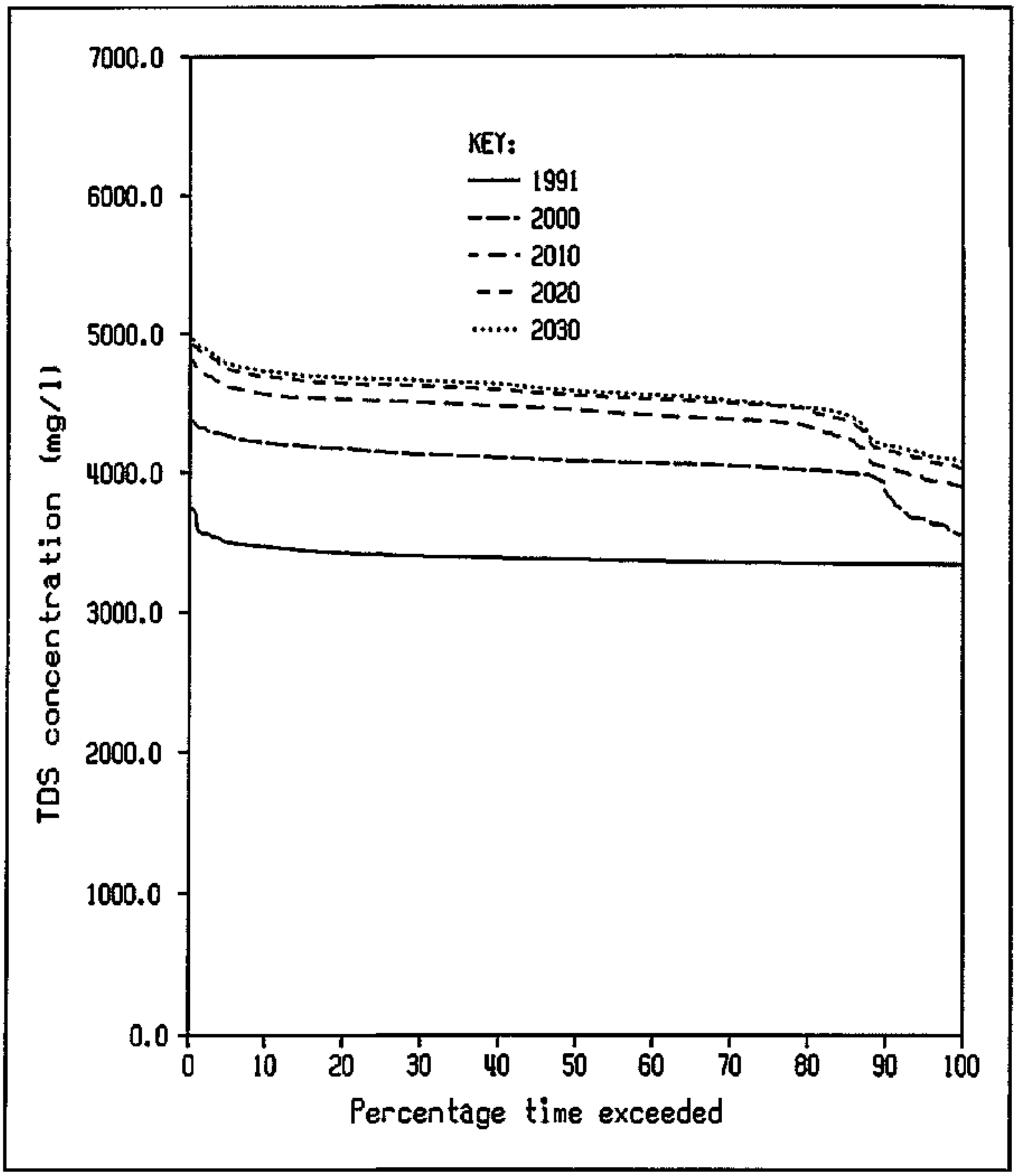

Figure D2 : Monthly TDS concentration duration curves for route 6 - Options 1 and 2

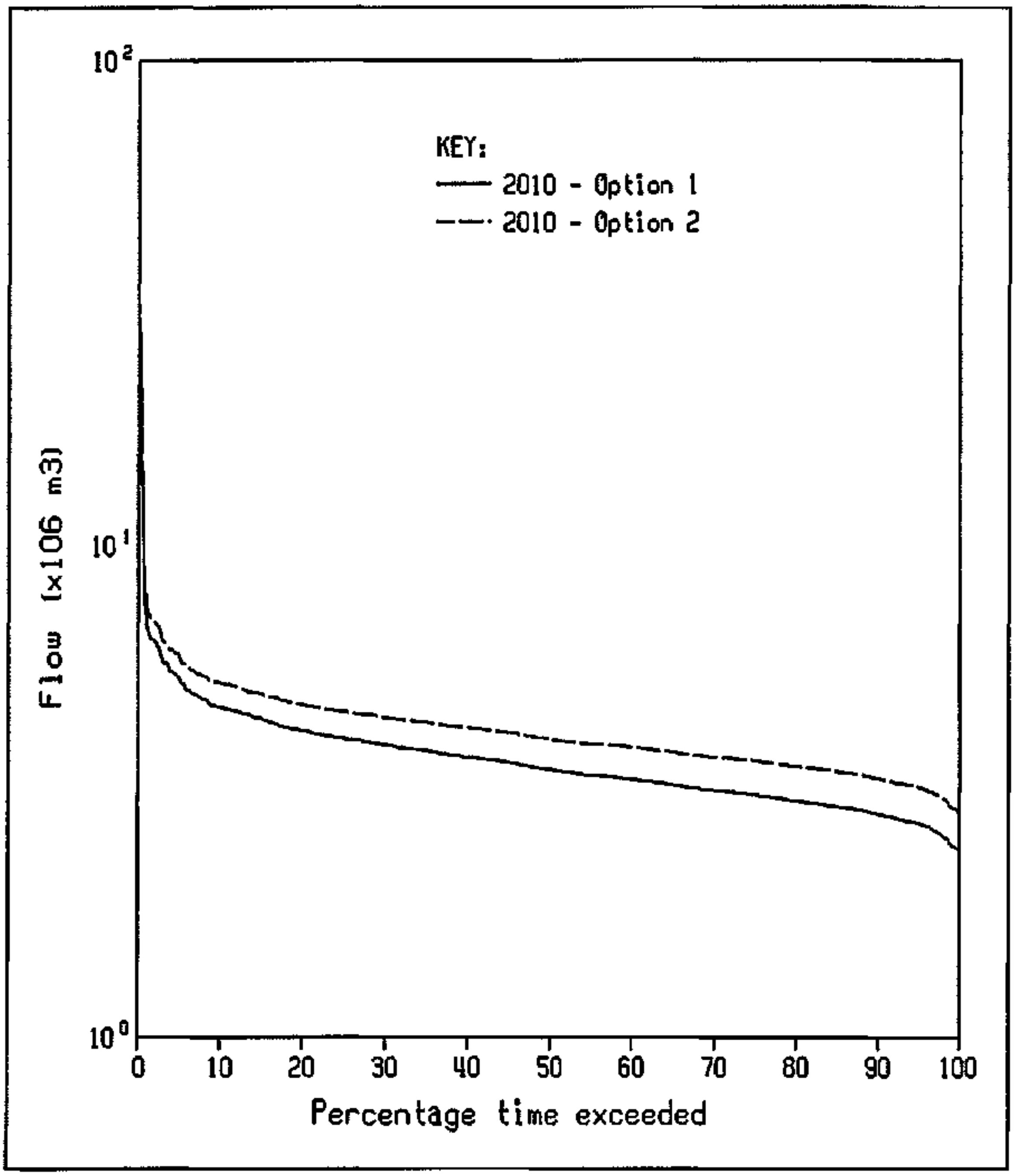

Figure D3 : Monthly flow duration curves for route 11 - Options 1 and 2

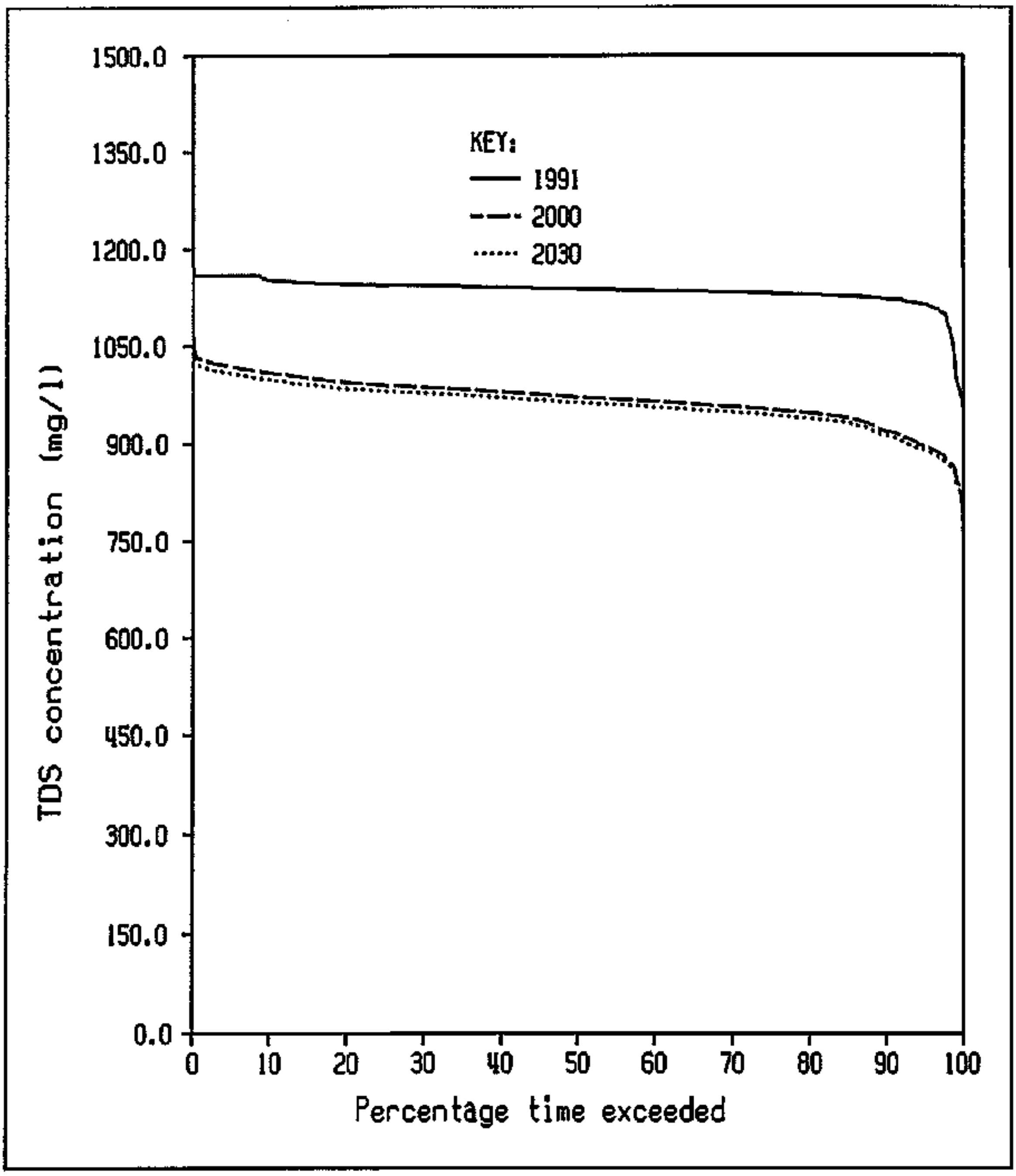

Figure D4 : Monthly TDS concentration duration curves for route 11 - Option 1

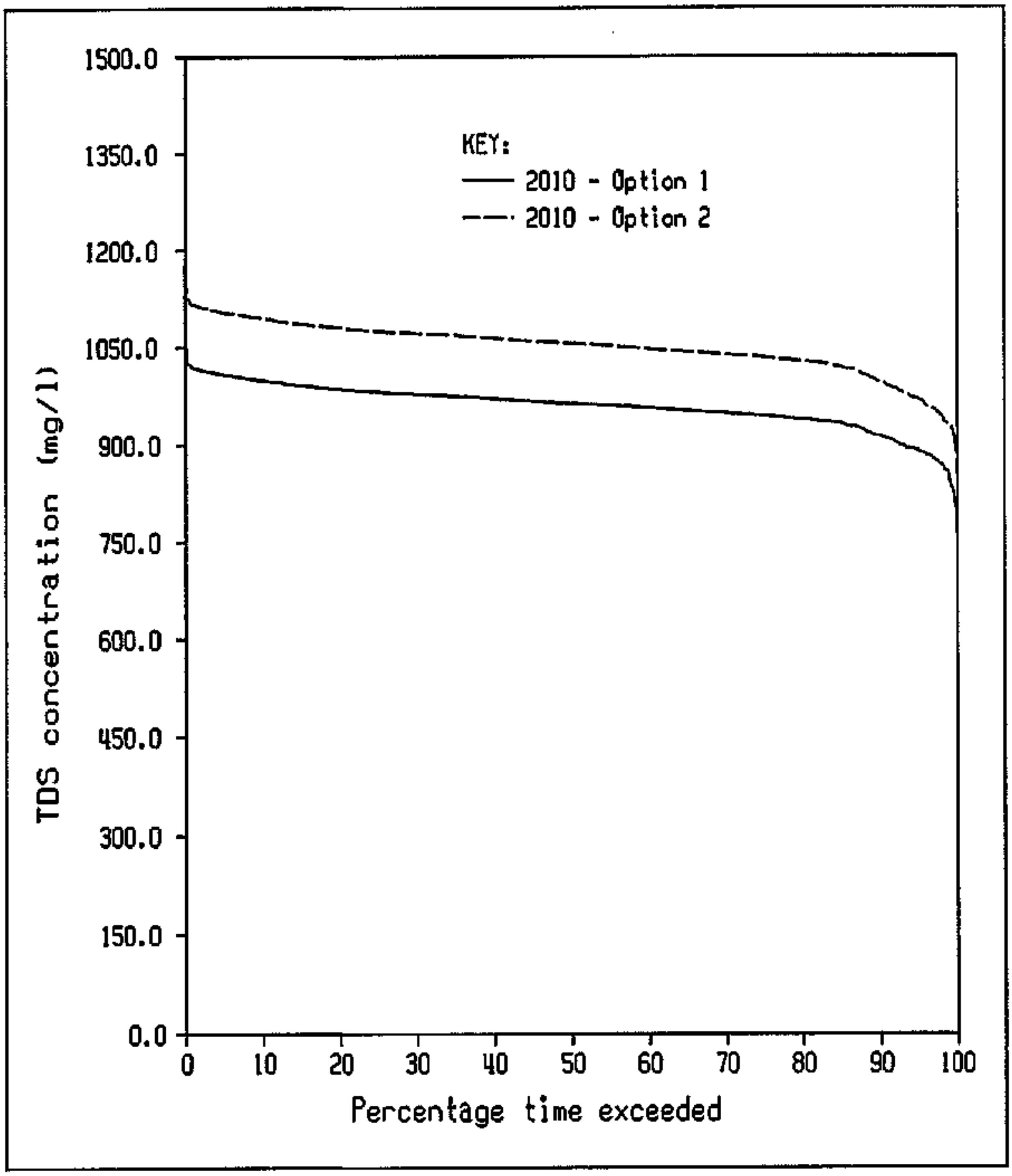

Figure D5 : Monthly TDS concentration duration curve for route 11 - Options 1 and 2

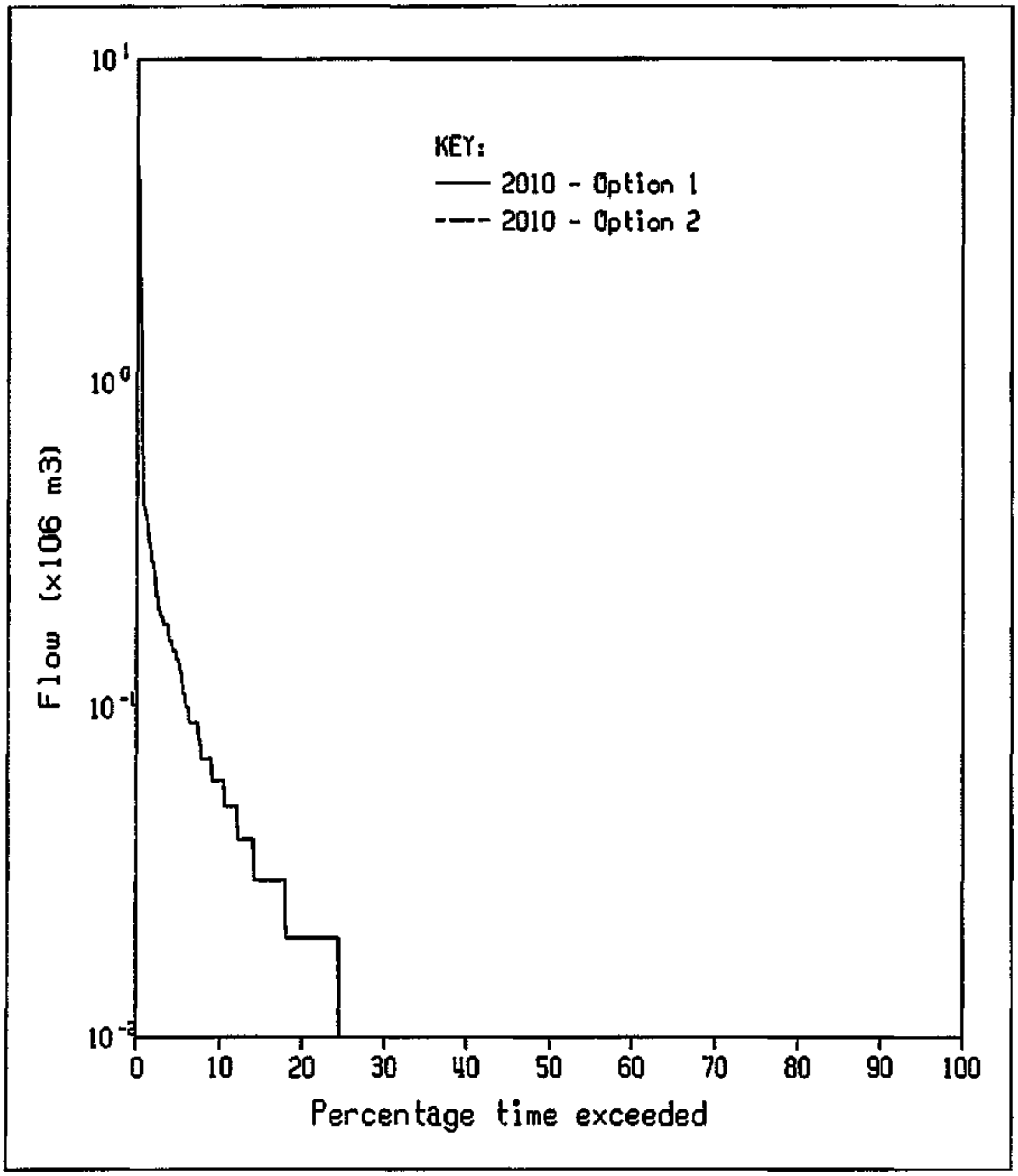

Figure D6 : Monthly flow duration curve for route 15 - Options 1 and 2

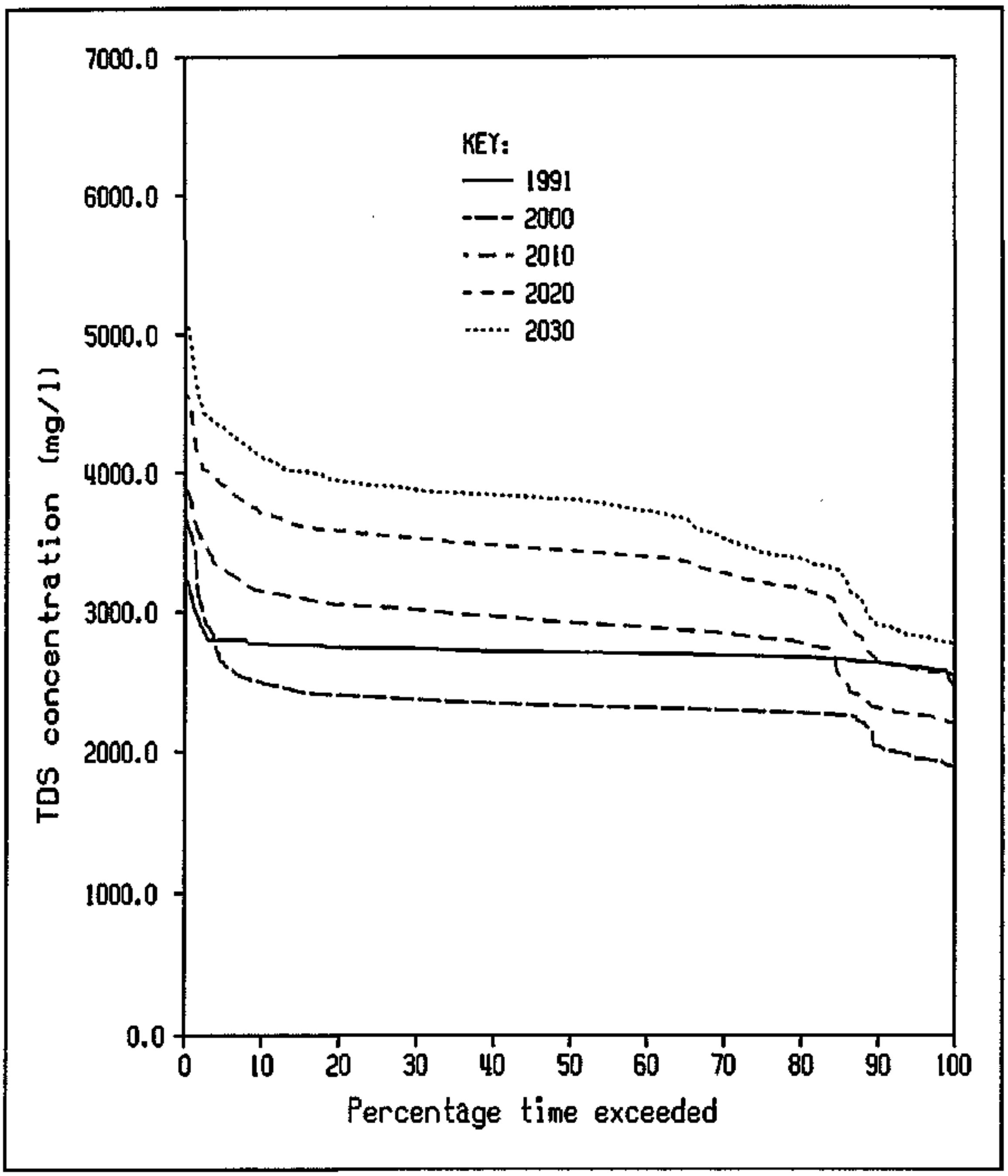

Figure D7 : Monthly TDS concentration duration curves for route 15 - Option 1

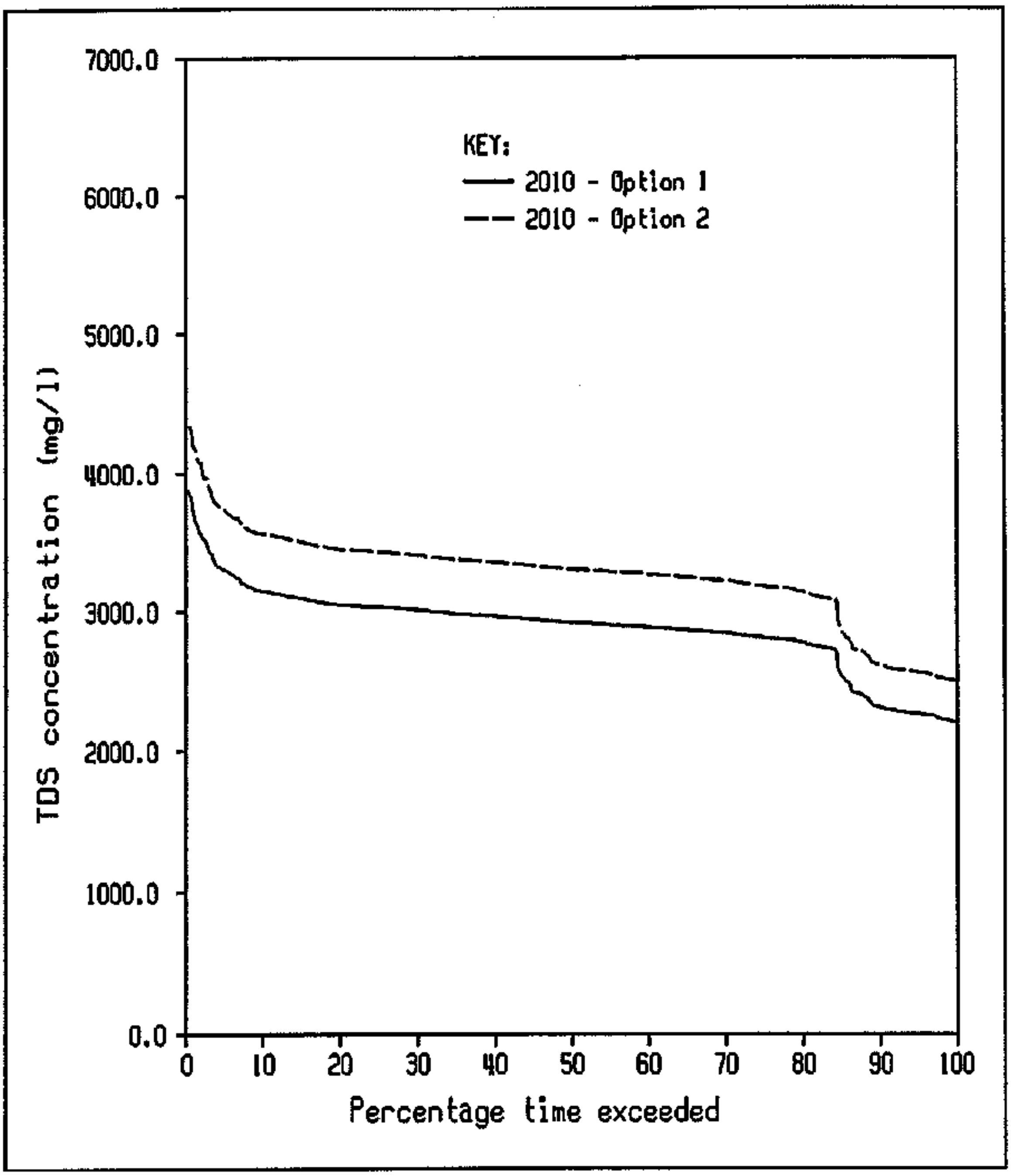

Figure D8 : Monthly TDS concentration duration curves for route 15 - Options 1 and 2

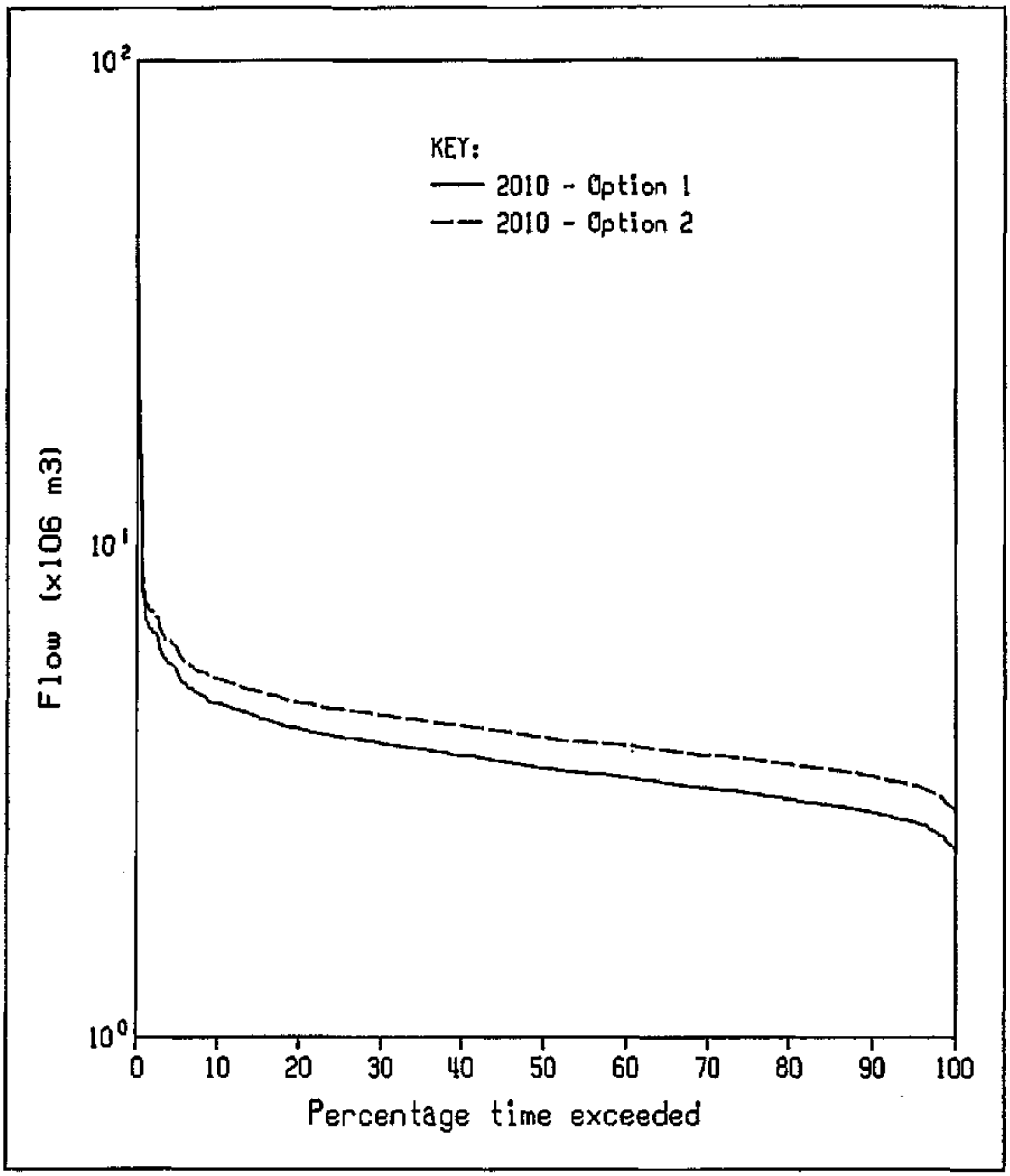

Figure D9 : Monthly total return flows - Options 1 and 2

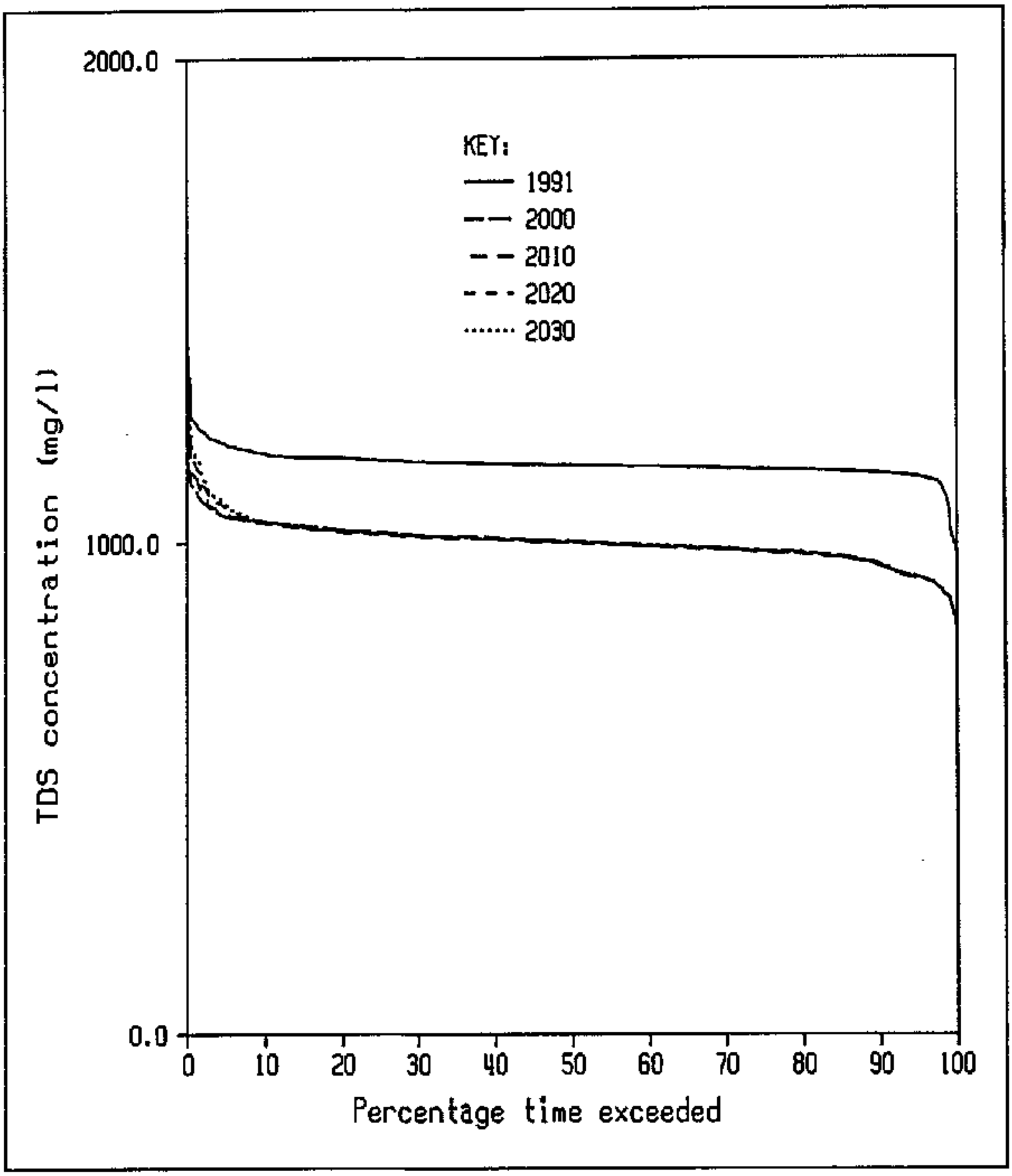

Figure D10 : Total return flow monthly TDS concentration duration curves - Option 1

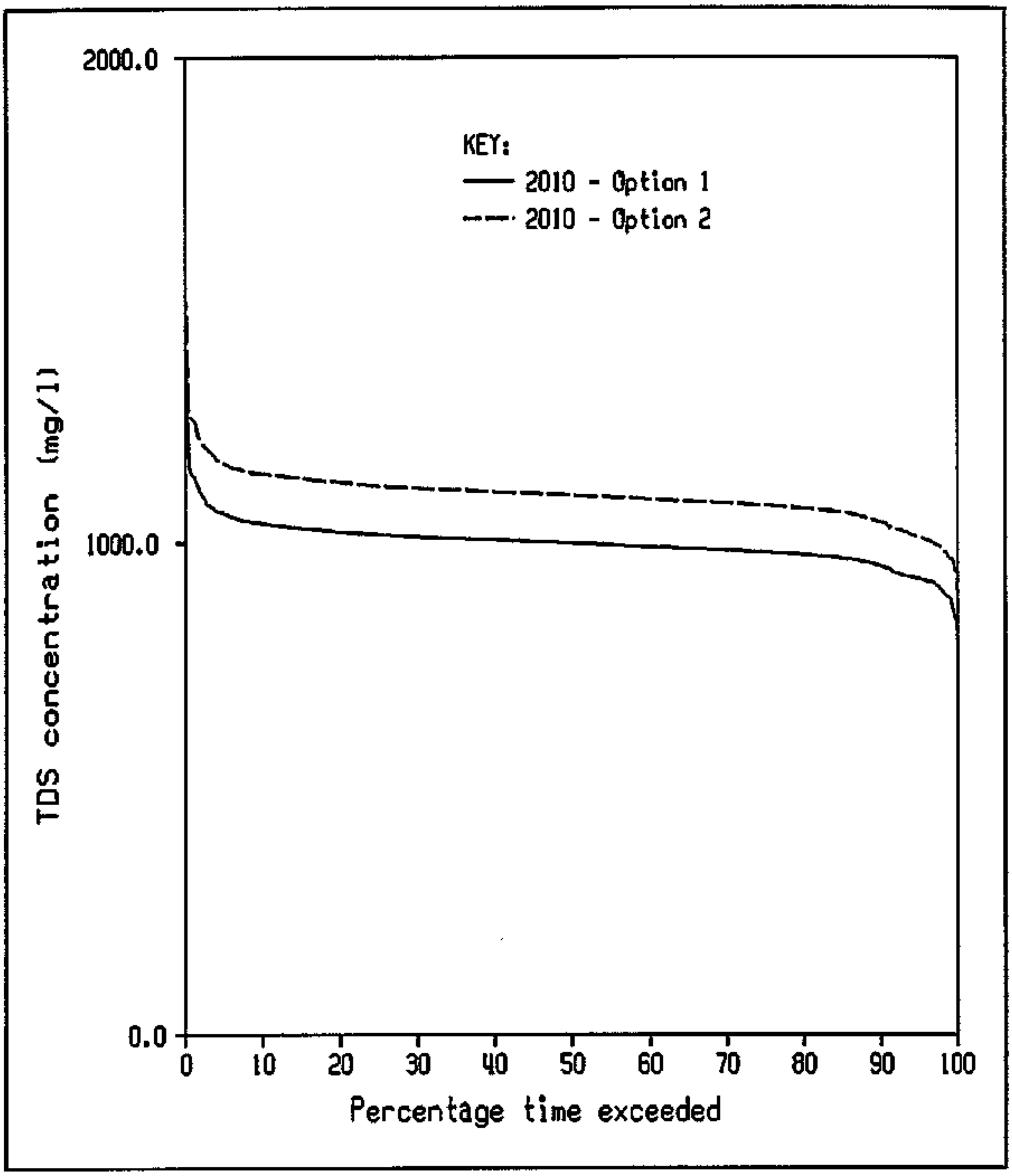

Figure D11 : Total return flow monthly TDS concentration duration curves - Options 1 and 2

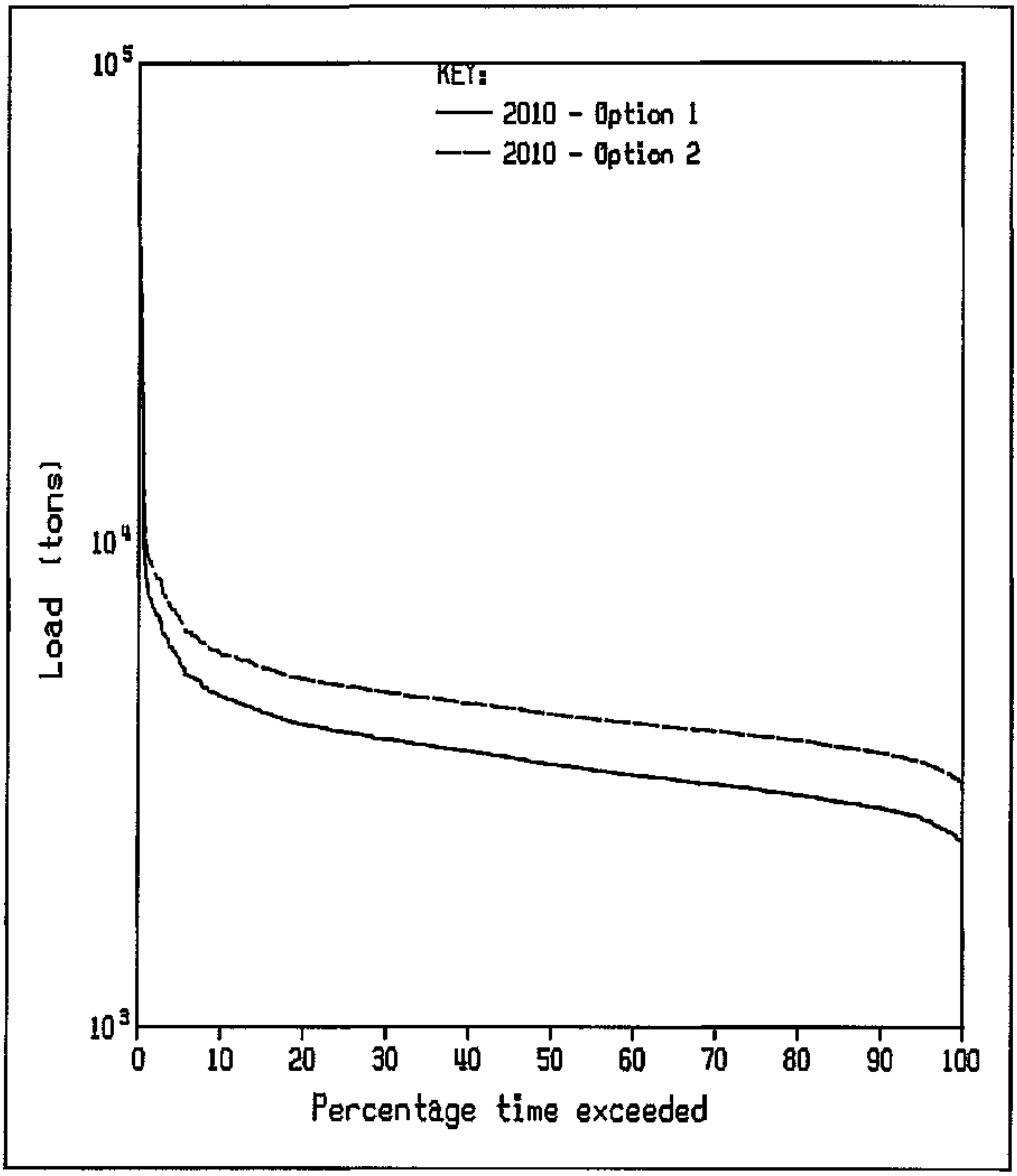

Figure D12 : Total return flow monthly TDS load duration curves - Options 1 and 2

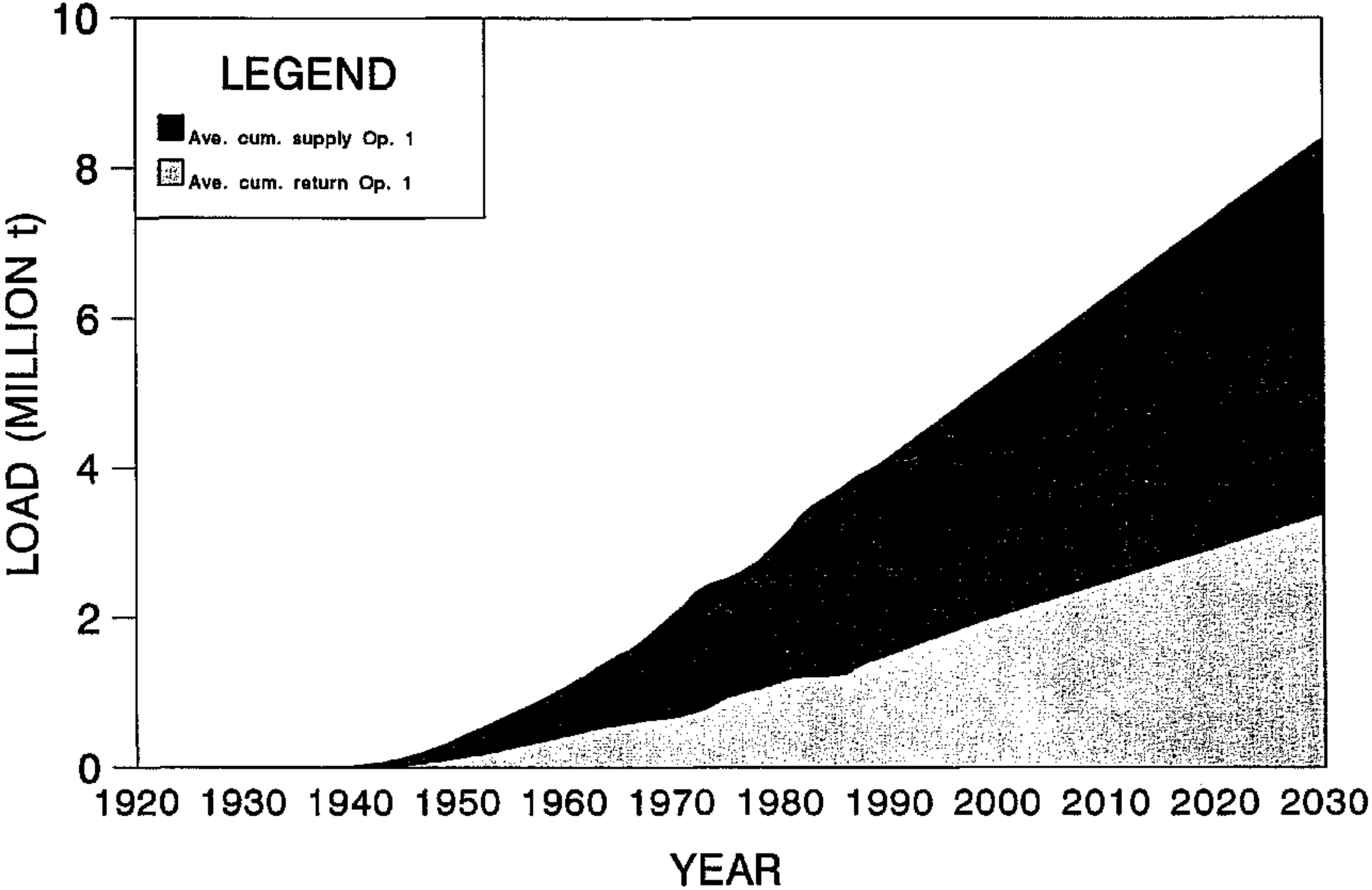

Figure D13 : Comparison between total (cumulative) supply and return flow TDS load - Option 1

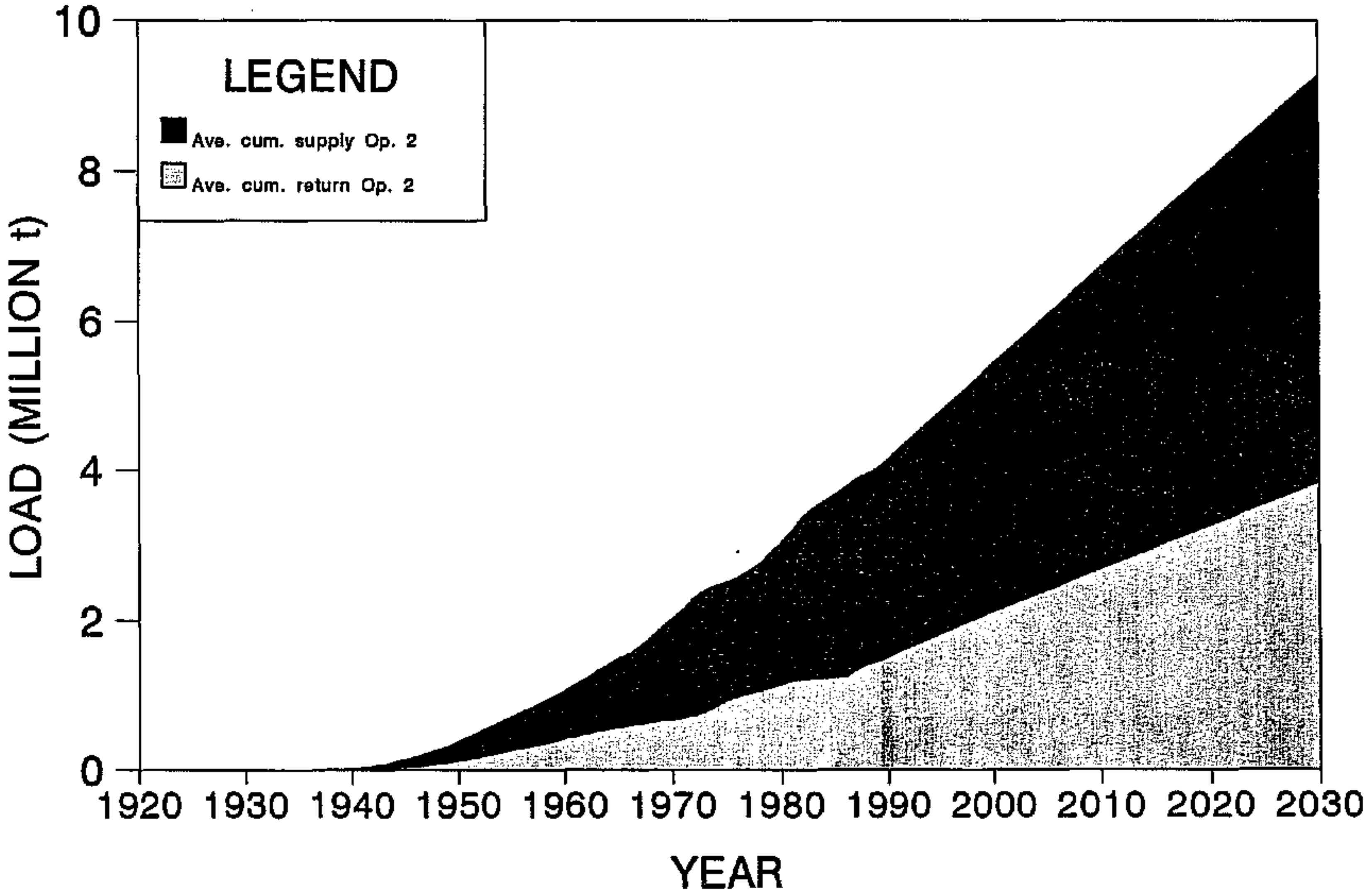

Figure D14 : Comparison between total (cumulative) supply and return flow TDS load - option 2

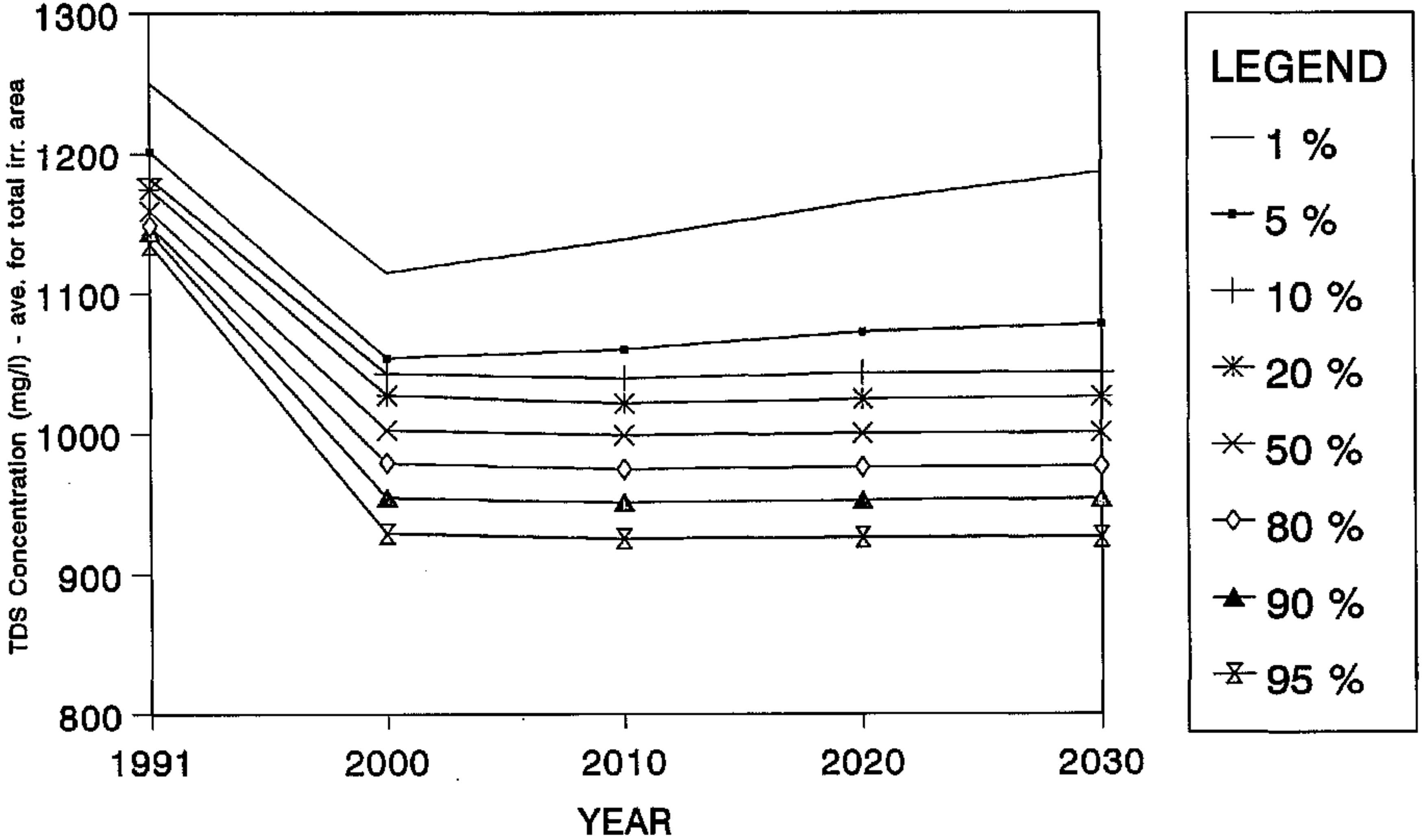

Figure D15 : Exceedance of return flow TDS concentration - Option 1

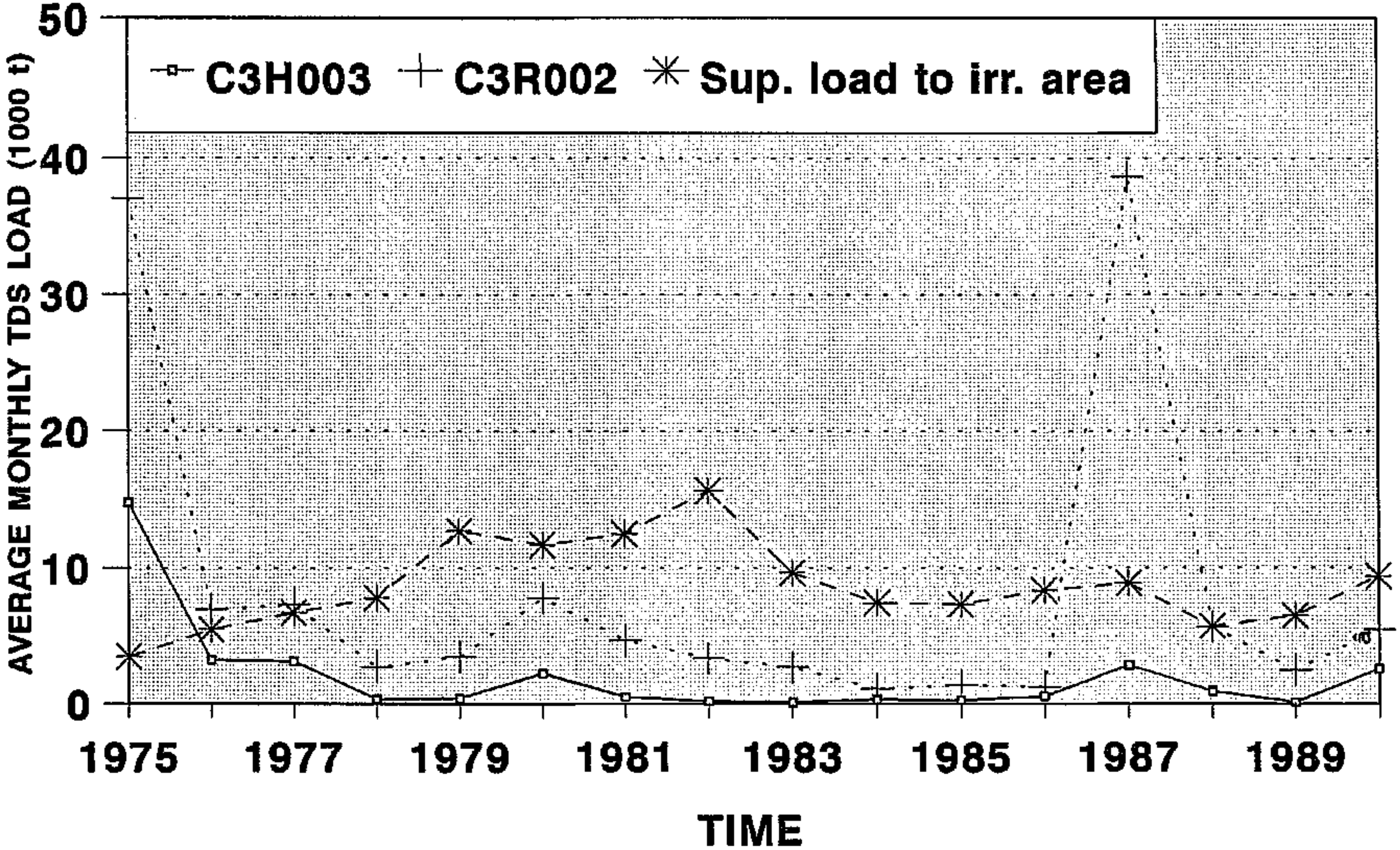

Figure D16 : Monthly TDS loads in irrigation supply to North and West Canal areas and in Harts River at stations C3H003 and C3R002

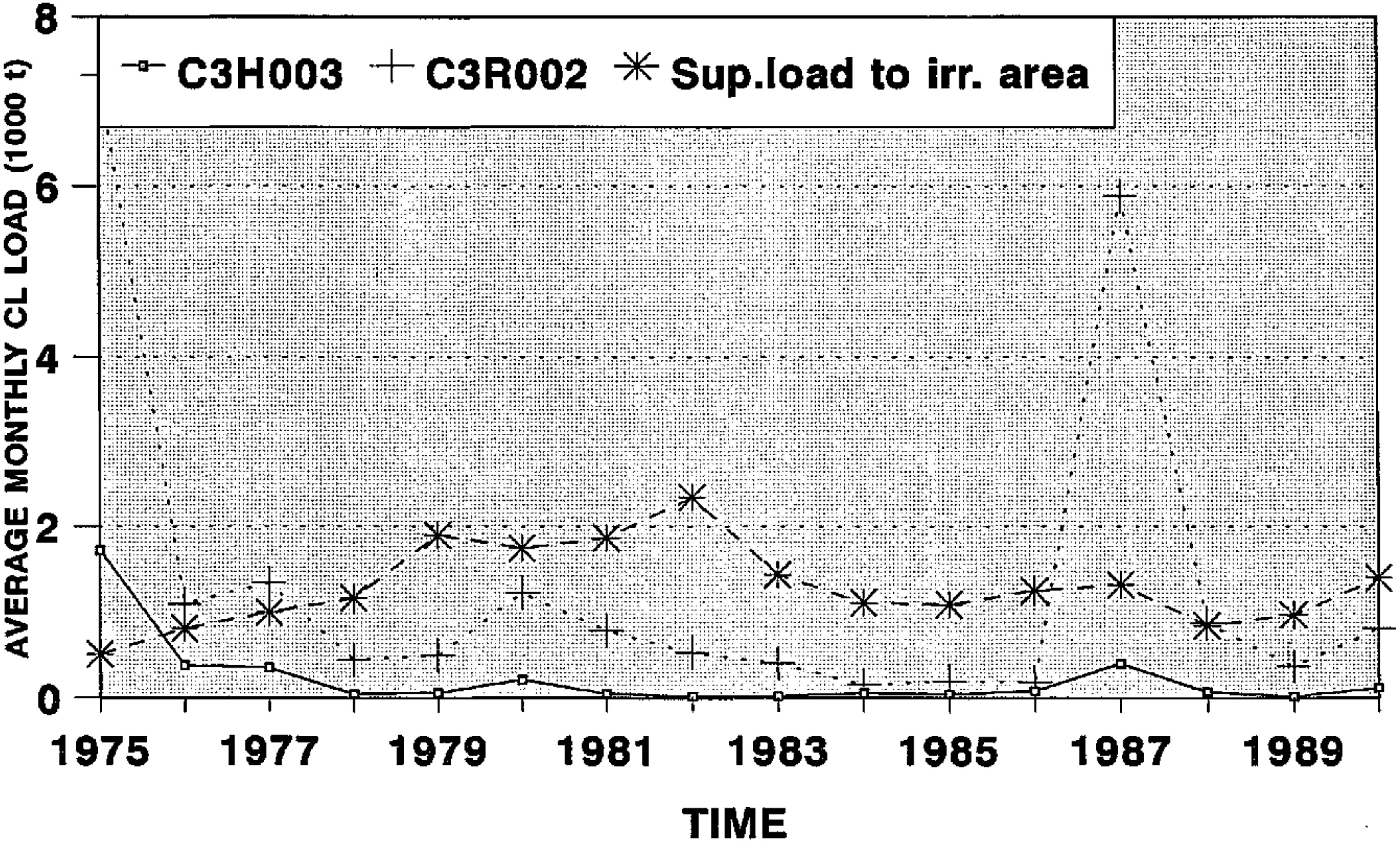

Figure D17 : Monthly chloride loads in irrigation supply to North and West Canal areas and in Harts River at stations C3H003 and C3R002

APPENDIX E

RAINFALL DATA FILES

File **Page**

File E1 : MPSCHWI.RAN (Rainfall on Schweizer Reneke Dam)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1923	1.97	15.83	2.12	7.47	4.22	16.48	3.07	6.28	0.00	0.00	0.12	10.73
1924	4.94	18.16	19.99	15.73	12.84	46.49	18.38	8.63	0.45	0.14	0.18	3.57
1925	0.47	3.51	1.64	6.19	6.99	13.61	5.43	1.58	0.00	0.00	0.00	2.45
1926	9.80	6.34	20.29	10.11	2.93	23.29	0.72	0.00	0.00	3.45	0.12	0.00
1927	5.43	1.30	13.59	26.03	13.80	26.70	10.20	0.33	0.46	0.00	1.30	0.54
1928	5.48	9.15	5.83	14.04	4.11	13.76	6.10	3.52	1.97	6.78	1.93	9.41
1929	1.18	12.55	19.53	22.54	8.45	18.28	6.40	1.06	0.30	0.05	0.64	0.00
1930	5.83	9.90	9.13	24.14	19.46	14.43	16.33	0.00	0.00	0.07	0.00	0.09
1931	12.32	16.33	2.67	5.05	17.01	22.78	3.38	0.00	0.65	0.00	0.00	4.36
1932	6.86	11.55	21.48	3.75	12.64	2.70	6.66	0.00	0.51	0.00	0.00	0.31
1933	1.41	18.68	20.60	28.88	21.59	8.42	26.75	14.31	2.03	0.88	0.94	0.84
1934	3.48	21.85	14.52	3.58	10.57	22.67	11.08	2.81	0.57	0.10	0.27	2.70
1935	0.94	7.33	29.02	15.71	18.31	33.24	2.54	11.82	0.00	0.00	0.00	0.27
1936	0.61	21.42	4.89	28.81	18.10	10.87	6.61	1.35	0.00	0.00	0.00	0.74
1937	0.41	4.89	19.15	11.71	15.61	5.94	6.72	2.81	1.86	0.31	0.20	0.00
1938	12.70	7.02	12.06	22.16	16.55	12.64	0.47	5.26	0.20	10.77	8.42	2.76
1939	17.69	12.27	9.67	10.61	10.03	24.25	9.89	2.09	0.20	0.00	0.00	5.47
1940	0.61	4.32	14.62	46.24	21.89	4.26	10.10	0.00	0.00	0.00	0.27	1.09
1941	1.56	1.56	4.69	18.00	18.78	20.34	8.01	0.00	0.00	0.00	3.44	0.98
1942	18.62	3.07	31.82	13.78	9.93	18.17	31.01	8.74	0.00	4.89	14.77	1.31
1943	4.79	23.14	32.52	8.58	31.37	8.74	1.31	2.81	6.45	0.00	0.00	7.13
1944	13.37	12.84	2.87	16.92	10.87	49.38	2.91	0.51	0.00	0.61	0.00	0.00
1945	4.79	11.65	6.39	29.02	11.14	27.42	2.33	3.44	0.00	0.00	0.00	0.20
1946	5.88	11.18	8.89	16.28	13.68	9.11	18.72	2.23	0.00	0.00	0.00	1.72
1947	4.79	10.87	20.50	22.47	14.09	21.54	10.77	1.25	0.00	0.00	0.00	0.00
1948	13.58	13.31	1.99	5.61	6.29	6.92	2.87	1.45	1.35	0.00	0.00	0.00
1949	4.69	5.88	24.08	6.08	11.71	30.37	18.31	23.00	5.51	0.00	4.79	0.00
1950	1.04	3.07	25.80	10.87	8.85	12.80	8.56	7.29	3.11	1.62	0.57	0.00
1951	15.44	0.00	7.70	7.43	16.55	5.57	4.36	0.00	1.56	4.48	0.00	2.50
1952	6.45	12.39	10.22	6.55	20.03	10.03	10.32	1.58	0.00	0.00	0.31	0.00
1953	8.50	9.79	8.48	20.83	14.75	10.34	7.58	0.41	0.39	0.00	0.00	0.51
1954	0.00	4.05	19.78	26.42	35.08	5.22	7.58	2.25	4.40	0.00	0.00	0.00
1955	3.48	4.51	20.50	14.01	49.05	48.74	0.00	7.47	0.00	0.00	0.06	4.20
1956	3.17	13.21	15.15	14.68	15.20	8.40	6.66	0.00	14.54	1.02	1.54	19.91
1957	7.07	11.78	12.59	25.70	7.88	16.38	11.06	0.51	0.00	0.00	0.00	6.76
1958	2.42	7.00	17.00	14.03	12.39	0.00	7.37	4.92	0.51	2.87	0.00	0.00
1959	5.22	7.58	17.20	4.05	15.69	3.69	12.49	0.00	0.00	1.84	2.36	0.00
1960	2.25	5.22	19.97	5.02	12.43	11.96	24.27	2.15	4.40	3.28	0.00	0.00
1961	0.00	27.24	1.43	13.95	11.26	20.23	10.65	0.00	0.00	0.00	0.00	0.00
1962	5.63	19.46	17.92	54.80	3.28	9.52	22.42	1.95	2.76	0.00	0.00	0.00
1963	2.36	13.82	4.71	14.03	8.81	11.16	1.23	0.00	0.00	0.00	0.00	0.00
1964	10.44	3.89	10.34	20.07	5.63	2.46	6.66	0.00	1.54	1.23	0.00	2.15
1965	0.00	16.90	1.43	28.06	25.70	3.79	9.63	0.00	3.07	0.00	0.00	3.28
1966	9.42	2.15	7.88	40.75	27.24	18.74	13.31	10.85	0.00	0.00	1.23	2.87
1967	2.25	19.05	0.61	4.51	0.00	30.66	16.59	13.93	0.00	0.00	0.00	0.00
1968	2.66	9.01	18.84	8.70	12.29	12.14	3.28	25.29	0.00	0.00	0.00	0.00
1969	10.03	2.25	8.29	7.17	11.57	5.02	1.54	0.00	6.55	3.28	0.00	2.36
1970	0.82	6.86	7.88	19.86	9.01	8.40	12.59	8.29	0.00	0.00	0.00	0.00
1971	18.64	1.23	7.78	30.62	18.84	33.03	9.44	0.00	2.25	0.00	0.00	0.00
1972	1.84	5.53	6.96	7.47	18.33	9.01	24.17	0.00	0.00	0.51	1.02	12.70
1973	3.99	15.77	17.82	47.72	16.36	31.11	10.59	1.13	0.00	0.00	3.48	1.13
1974	1.29	27.09	7.78	34.30	24.27	29.49	10.92	2.76	2.87	0.51	0.00	0.00
1975	6.04	13.11	28.40	55.11	16.18	32.34	8.09	10.94	1.23	0.00	0.00	6.76
1976	24.45	13.31	17.10	16.28	16.49	30.62	3.99	0.00	0.00	0.00	0.00	8.07
1977	10.34	24.78	12.84	5.30	23.80	33.11	17.65	0.00	1.84	0.00	2.81	1.33
1978	4.75	5.69	14.01	8.19	6.35	3.17	8.91	2.31	0.00	0.27	14.54	0.00
1979	7.47	8.50	11.73	6.76	19.99	2.76	4.61	0.00	0.00	0.00	0.00	8.91
1980	0.33	43.29	18.17	17.76	13.17	14.03	2.81	1.02	1.64	0.00	6.86	4.81
1981	6.37	9.05	15.15	22.67	13.93	14.66	12.02	0.00	1.02	3.89	0.00	0.00
1982	17.41	13.11	9.40	9.67	2.97	5.24	1.06	4.05	4.71	3.93	0.00	0.00
1983	8.95	4.87	19.66	10.61	6.14	16.42	1.74	4.71	3.79	2.46	2.42	0.00
1984	35.55	7.25	6.00	30.72	13.66	17.00	0.61	0.20	0.00	0.00	0.00	1.58
1985	13.80	4.81	9.52	20.21	13.62	8.29	4.30	0.00	0.72	0.00	3.99	4.03
1986	24.98	37.07	5.63	8.27	12.37	7.27	1.64	0.00	0.00	0.72	0.72	19.97
1987	3.69	4.10	38.11	8.81	54.27	24.84	10.89	2.25	1.27	0.00	0.00	3.34
1988	23.71	8.48	11.26	31.72	28.22	12.29	12.53	4.40	0.00	0.00	0.16	0.00
1989	1.43	6.86	6.27	6.55	10.55	16.49	17.51	0.00	0.10	0.00	0.14	1.74
1990	1.43	1.21	16.35	36.58	19.67	30.64	0.00	0.00	0.00	0.00	0.00	11.37

File E2 : V-H.RAN (Average rainfall on incremental catchment between C3H003 and C3R002)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1923	2.01	8.99	0.64	13.79	9.86	20.38	8.12	4.10	0.00	0.00	0.00	3.52
1924	9.23	12.80	37.08	11.36	18.10	35.06	28.31	19.92	0.00	0.00	0.00	5.23
1925	1.12	1.91	6.36	10.80	5.66	36.19	7.98	2.81	0.04	2.66	0.00	0.43
1926	15.73	9.77	20.19	9.42	6.32	17.24	5.15	0.06	0.00	3.37	0.49	0.17
1927	3.72	7.03	12.90	21.22	17.28	20.35	9.29	0.04	0.00	0.00	2.32	0.70
1928	2.88	8.46	6.96	17.67	5.28	37.05	6.44	2.39	4.01	1.75	7.78	21.30
1929	3.28	8.79	20.66	10.37	13.25	9.34	4.00	0.74	0.04	0.00	0.62	0.00
1930	5.08	4.66	10.50	23.94	21.35	22.66	16.45	0.00	0.27	0.86	0.00	0.00
1931	12.68	28.14	3.70	10.97	23.61	18.63	5.23	0.30	0.24	0.00	0.00	9.83
1932	2.04	11.40	13.97	7.51	8.36	7.86	6.29	0.00	0.47	0.00	0.00	0.28
1933	0.56	12.84	18.58	29.62	24.91	14.19	20.13	12.26	0.24	1.76	0.27	0.00
1934	6.98	30.13	14.91	7.28	18.28	16.43	13.80	7.41	1.64	0.00	0.11	0.43
1935	0.39	3.33	17.26	15.79	16.72	39.36	4.22	10.12	0.13	0.00	0.00	7.02
1936	1.47	22.52	3.73	41.47	21.00	8.20	9.35	1.95	0.00	0.00	0.00	0.00
1937	0.71	2.26	19.39	12.15	20.33	7.88	1.69	0.59	2.16	0.21	0.19	0.24
1938	12.03	12.00	21.97	26.95	16.31	18.08	0.70	3.09	0.13	14.41	5.26	0.10
1939	27.85	13.44	6.56	12.56	9.67	30.36	6.04	2.52	0.18	0.22	0.00	3.38
1940	6.70	5.92	28.38	16.53	29.10	8.35	6.41	0.00	0.56	0.02	0.02	0.47
1941	6.99	0.00	7.94	7.41	19.71	18.38	12.58	2.33	0.02	0.06	11.27	0.06
1942	25.90	2.81	27.16	16.25	18.33	13.64	26.50	14.36	0.00	2.10	22.11	0.88
1943	3.67	19.45	18.91	22.91	19.83	11.90	1.79	2.72	15.18	0.00	0.00	4.08
1944	5.80	5.82	2.02	22.22	7.14	25.86	4.70	0.37	0.00	0.11	0.00	0.00
1945	0.15	4.70	1.45	28.70	13.06	22.32	4.30	6.01	0.00	0.52	0.00	0.46
1946	7.73	10.31	7.05	6.01	5.21	15.88	13.10	1.55	3.09	0.06	0.59	7.31
1947	3.94	10.74	27.59	11.15	14.89	33.62	8.45	0.22	0.00	0.00	0.00	0.00
1948	1.51	14.81	2.78	8.00	4.94	14.78	1.35	0.13	4.46	0.45	1.26	0.15
1949	0.87	4.45	17.60	11.61	12.24	22.94	23.67	15.33	1.73	0.45	13.15	2.19
1950	1.85	3.01	42.96	14.40	9.12	16.71	9.44	6.85	0.00	0.13	0.24	0.52
1951	8.15	3.17	5.52	7.02	16.70	9.12	4.02	0.88	0.68	7.15	0.29	1.50
1952	9.36	11.56	8.21	5.16	18.41	6.69	16.54	0.51	0.00	0.00	0.46	0.00
1953	10.71	5.24	22.19	14.14	13.52	17.18	7.40	0.19	0.86	0.05	0.47	3.47
1954	0.18	4.69	11.30	39.87	33.90	7.37	10.40	1.76	5.37	0.56	0.00	0.00
1955	1.16	15.64	30.22	6.27	26.93	44.83	0.00	2.14	0.00	0.00	0.00	3.59
1956	6.04	14.59	10.20	12.14	11.86	12.60	12.06	0.09	17.64	4.16	3.96	21.72
1957	6.85	8.55	22.25	20.09	9.72	13.07	7.50	3.87	0.00	0.00	0.00	1.44
1958	3.87	6.10	28.10	16.75	11.20	3.69	7.27	4.39	0.52	2.32	0.00	0.00
1959	4.09	9.15	22.92	8.25	23.95	17.44	22.00	0.78	1.42	0.45	5.39	0.00
1960	2.31	13.72	12.51	14.08	15.54	21.53	19.48	3.25	7.91	9.34	0.07	0.00
1961	0.00	28.42	4.80	2.00	18.16	18.08	9.30	0.00	0.00	0.00	0.00	0.40
1962	2.47	26.26	17.77	47.88	4.10	16.24	19.32	4.93	1.84	1.47	0.00	0.00
1963	6.36	27.22	7.89	2.41	5.56	16.24	1.42	0.00	2.78	0.00	0.10	0.00
1964	12.13	0.95	14.78	18.00	7.00	3.28	4.39	0.00	0.10	1.48	0.37	0.00
1965	0.00	12.65	1.54	16.31	16.29	2.08	5.33	0.00	1.01	0.00	0.00	0.00
1966	1.60	10.15	6.66	39.45	22.50	12.20	24.90	15.35	0.00	0.00	0.83	0.00
1967	5.08	7.77	6.71	8.29	3.52	13.52	9.14	11.70	0.00	0.64	0.00	0.00
1968	7.20	3.06	18.06	6.58	18.92	7.52	6.27	7.93	0.00	0.30	1.57	0.11
1969	17.70	0.78	4.75	4.24	7.64	7.45	8.78	6.20	5.07	1.95	0.54	0.67
1970	3.74	3.23	12.25	14.88	10.19	7.59	9.33	6.91	0.11	0.00	0.00	0.00
1971	8.30	11.92	20.38	25.61	19.98	32.97	8.08	0.00	0.00	0.00	0.00	0.00
1972	5.31	3.70	2.09	5.49	26.70	11.89	11.16	0.00	0.00	0.69	0.01	11.53
1973	2.50	11.62	18.22	55.02	14.51	37.58	15.72	5.41	0.00	0.00	5.15	2.05
1974	5.90	16.51	16.79	43.21	23.84	23.17	11.76	0.46	1.38	1.33	0.00	3.31
1975	6.99	11.63	27.04	48.09	16.64	31.85	7.94	2.07	1.54	0.00	0.00	8.69
1976	11.77	8.54	15.82	16.37	29.78	37.98	5.31	0.00	0.00	0.00	0.24	14.46
1977	0.22	10.93	6.71	5.57	14.43	43.66	12.24	0.00	0.00	0.00	0.00	6.34
1978	10.00	3.37	6.14	24.24	3.64	8.68	9.42	1.49	0.17	3.02	9.77	0.33
1979	4.82	12.66	4.03	4.93	26.40	11.58	3.47	0.92	0.00	0.00	1.48	13.23
1980	4.62	28.06	6.65	27.22	20.20	12.64	3.54	1.03	0.00	0.00	5.71	0.00
1981	7.85	11.67	18.67	7.98	6.34	9.90	13.98	0.00	0.81	1.92	0.00	0.00
1982	8.75	13.70	11.05	13.12	4.24	6.46	0.56	2.38	3.31	4.27	0.00	1.12
1983	20.91	16.72	16.62	5.67	7.43	23.72	2.61	4.67	0.73	1.65	0.00	0.00
1984	17.10	15.24	0.78	9.58	15.28	10.97	0.00	0.63	0.17	0.00	0.00	1.56
1985	15.93	8.79	21.02	21.73	12.30	3.94	2.60	0.00	2.30	0.00	2.78	6.14
1986	4.85	19.70	2.96	11.81	12.60	9.30	6.13	0.00	0.00	0.94	1.60	15.46
1987	3.47	4.90	11.72	5.84	72.21	31.59	24.43	0.61	1.51	0.00	0.00	8.81
1988	17.93	10.08	17.71	33.14	19.65	9.69	15.80	4.80	0.00	0.00	0.00	0.00
1989	0.03	5.86	10.45	8.13	13.52	10.02	15.20	0.22	1.22	0.36	0.88	2.05
1990	0.00	1.99	7.25	41.24	11.15	19.04	0.00	0.00	7.35	0.11	0.00	3.97

File E3 : MPSPITS.RAN (Rainfall on Spitskop Dam)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1923	1.03	10.41	0.56	15.83	8.32	21.89	6.14	2.62	0.00	0.00	0.00	1.55
1924	2.89	8.21	47.30	16.55	26.19	32.25	23.37	27.63	0.00	0.00	0.00	5.02
1925	0.56	2.11	5.65	20.09	0.00	59.50	8.45	5.25	0.00	6.14	0.00	0.00
1926	7.85	4.91	20.59	4.28	8.86	13.68	6.41	0.00	0.00	1.82	0.81	0.00
1927	6.06	10.70	13.99	21.60	10.32	19.26	8.07	0.00	0.00	0.00	3.03	1.30
1928	2.56	4.42	5.63	10.36	9.17	27.49	6.77	3.07	0.92	0.00	13.12	23.97
1929	1.14	6.01	21.91	10.99	17.11	9.40	3.23	1.14	0.00	0.00	0.00	0.00
1930	9.26	4.58	14.08	18.73	20.21	39.58	16.06	0.00	0.81	1.41	0.00	0.00
1931	10.07	29.56	1.55	13.01	29.94	24.89	6.39	0.56	0.00	0.00	0.00	7.13
1932	1.44	9.22	14.13	6.12	8.43	10.76	9.24	0.00	0.96	0.00	0.00	0.00
1933	0.00	10.29	19.33	39.58	22.34	16.39	19.96	16.06	0.29	0.00	0.40	0.00
1934	8.66	30.12	19.51	13.01	21.64	11.89	10.20	8.32	0.45	0.00	0.34	0.40
1935	0.74	4.66	15.52	16.86	12.09	59.52	6.21	11.98	0.40	0.00	0.00	13.79
1936	2.44	15.86	4.98	37.27	25.12	7.58	11.03	4.10	0.00	0.00	0.00	0.00
1937	0.92	3.88	11.39	10.45	20.23	3.09	0.92	0.85	2.33	0.63	0.56	0.00
1938	10.68	10.94	30.66	37.09	16.93	23.75	1.37	3.18	0.00	16.06	4.55	0.29
1939	30.77	6.59	6.80	15.81	9.98	22.67	4.73	2.06	0.00	0.45	0.00	5.29
1940	7.40	6.50	27.70	25.05	23.48	9.46	8.48	0.00	0.00	0.00	0.00	0.56
1941	6.95	0.00	6.66	3.23	23.48	21.73	10.99	3.41	0.00	0.00	5.70	0.00
1942	32.00	3.83	35.93	13.01	22.58	10.45	21.24	11.35	0.00	3.99	32.18	0.00
1943	4.04	19.20	16.93	23.70	9.24	11.98	0.74	2.29	15.56	0.00	0.00	2.92
1944	4.37	2.51	0.96	29.04	6.19	17.65	8.66	0.56	0.00	0.00	0.00	0.00
1945	0.45	1.53	2.67	19.89	17.92	24.85	8.45	8.10	0.00	1.55	0.00	0.22
1946	8.48	6.17	6.66	7.09	3.77	13.90	9.28	2.51	4.84	0.18	1.37	8.54
1947	3.72	10.41	22.67	11.84	18.70	35.66	9.69	0.00	0.00	0.00	0.00	0.00
1948	1.32	13.39	2.38	11.28	2.69	13.21	2.69	0.00	5.29	0.29	1.48	0.45
1949	1.19	1.70	15.47	13.75	18.68	34.02	21.26	9.37	1.44	0.00	15.14	2.38
1950	3.48	3.43	25.41	17.99	14.40	15.95	10.09	5.47	0.00	0.40	0.00	0.34
1951	6.57	4.66	8.86	5.74	15.50	3.92	4.51	1.66	2.04	6.21	0.36	1.88
1952	7.69	6.32	9.24	3.59	19.42	8.23	21.17	0.38	0.00	0.00	1.37	0.00
1953	16.17	3.83	31.91	8.54	14.69	24.49	6.95	0.56	2.58	0.16	1.41	5.27
1954	0.00	0.67	8.01	35.77	27.02	6.44	9.19	2.47	3.97	1.68	0.00	0.00
1955	1.46	16.26	25.54	5.05	20.97	54.16	0.00	6.21	0.00	0.00	0.00	2.35
1956	9.64	11.01	17.16	13.48	11.10	16.71	13.90	0.27	20.52	6.06	5.16	12.67
1957	9.17	6.97	23.26	33.08	14.91	19.69	5.05	5.61	0.00	0.00	0.00	0.00
1958	4.93	4.04	21.08	14.91	18.17	4.04	3.99	3.36	0.00	2.02	0.00	0.00
1959	7.51	12.67	29.51	10.32	28.24	7.24	19.67	2.02	0.00	1.01	2.40	0.00
1960	6.28	10.76	14.35	10.99	7.85	23.93	15.05	6.39	7.06	11.33	0.00	0.00
1961	0.00	31.11	1.91	1.91	18.55	12.13	7.51	0.00	0.00	0.00	0.00	0.00
1962	1.46	31.96	16.37	60.57	2.80	12.22	16.71	5.09	0.00	1.46	0.00	0.00
1963	4.15	19.62	1.93	0.00	5.49	17.49	2.35	0.00	3.81	0.00	0.00	0.00
1964	8.41	0.90	15.25	11.93	13.30	6.06	6.28	0.00	0.00	1.79	1.12	0.00
1965	0.00	15.18	0.00	24.83	16.60	0.00	9.08	0.00	2.47	0.00	0.00	0.00
1966	0.90	5.70	0.00	28.17	33.98	13.66	24.33	17.72	0.00	0.00	0.00	0.00
1967	7.18	6.64	0.00	12.18	0.00	5.27	4.93	8.79	0.00	0.00	0.00	0.00
1968	12.90	0.00	14.13	10.56	9.69	6.28	0.00	0.00	0.00	0.00	2.40	0.22
1969	12.78	1.57	11.01	4.91	10.65	6.17	15.36	6.62	3.18	0.00	0.00	2.02
1970	4.49	0.00	8.07	21.87	0.00	0.00	16.82	0.00	0.00	0.00	0.00	0.00
1971	7.85	9.04	14.69	33.33	12.33	13.23	7.85	0.00	0.00	0.00	0.00	0.00
1972	3.14	2.24	3.16	1.21	24.56	22.54	10.99	0.00	0.00	0.02	0.02	1.01
1973	1.01	11.44	22.22	81.52	13.23	55.28	17.49	8.63	0.00	0.00	6.62	1.46
1974	9.53	11.89	8.41	25.45	19.74	28.37	21.08	0.00	0.00	0.00	0.00	0.00
1975	0.90	9.76	35.88	53.38	23.32	35.66	14.13	1.35	0.00	0.00	0.00	3.14
1976	9.53	5.94	9.87	19.40	46.54	44.85	8.07	0.00	0.00	0.00	0.22	11.71
1977	0.00	8.07	8.12	0.00	11.66	51.47	0.00	0.00	0.00	0.00	0.00	12.45
1978	10.76	5.16	6.28	17.94	10.99	5.83	5.49	3.59	0.00	1.35	21.08	4.49
1979	6.19	9.02	9.31	6.64	32.16	17.11	2.13	0.00	0.00	0.00	1.35	12.67
1980	0.00	6.84	0.00	31.13	10.99	9.64	5.49	0.00	0.00	0.00	7.98	0.00
1981	7.06	5.16	23.44	4.71	8.25	7.96	17.16	0.00	0.45	1.68	0.00	0.00
1982	4.58	8.75	0.00	9.87	9.42	6.95	1.68	0.00	3.36	3.36	0.00	3.36
1983	28.26	13.57	15.65	6.50	5.05	27.70	2.69	4.15	1.46	0.00	0.00	0.00
1984	10.76	17.60	1.57	15.92	12.90	12.78	0.00	0.00	0.00	0.00	0.00	2.47
1985	15.90	6.39	14.44	18.68	9.49	2.69	1.01	0.00	3.05	0.00	2.24	4.93
1986	5.38	14.80	0.00	7.51	12.00	8.41	7.18	0.00	0.00	0.00	0.00	16.15
1987	5.83	5.83	14.62	2.80	65.37	18.52	26.80	0.00	1.35	0.00	0.00	4.93
1988	7.96	12.45	17.04	33.86	14.58	11.66	25.27	2.02	0.00	0.00	0.00	0.00
1989	0.00	6.62	10.09	9.19	11.21	11.89	14.13	0.45	1.12	0.00	0.00	0.90
1990	0.00	0.22	7.74	40.49	13.34	6.50	0.00	0.00	11.88	0.22	0.00	2.80

File E4 : C3R02.RAN (Average rainfall on Spitskop Dam catchment)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1923	2.38	15.56	3.78	11.08	5.60	25.79	7.45	5.92	0.00	0.00	0.00	7.14
1924	6.29	15.06	27.10	13.02	14.57	35.90	24.38	17.58	0.17	0.03	0.10	5.39
1925	0.94	1.57	4.52	6.91	4.92	25.42	9.45	3.80	0.43	0.89	0.00	2.00
1926	10.65	10.51	18.45	10.40	7.17	23.40	5.00	0.01	0.00	3.07	0.90	0.08
1927	4.17	4.06	11.63	22.76	18.65	26.14	9.39	0.25	0.15	0.00	1.81	0.43
1928	3.58	11.88	9.39	15.65	4.90	25.26	6.51	4.40	2.40	2.75	5.79	11.81
1929	2.07	13.19	17.52	13.23	12.20	10.25	7.06	0.66	0.17	0.00	0.99	0.00
1930	5.51	8.75	10.41	33.01	15.98	15.17	16.83	0.00	0.06	0.18	0.00	0.00
1931	12.28	19.99	4.11	6.55	22.98	20.73	4.54	0.09	0.21	0.00	0.00	8.02
1932	4.43	9.89	15.92	9.58	10.48	5.32	5.66	0.24	0.44	0.00	0.00	0.15
1933	0.32	10.21	18.16	26.37	21.54	11.60	12.06	11.73	1.14	0.51	1.00	0.22
1934	8.22	28.63	16.05	5.85	15.33	16.98	11.77	4.36	1.47	0.01	0.02	0.86
1935	2.13	6.66	14.40	20.20	23.62	38.32	2.34	9.71	0.14	0.00	0.00	4.58
1936	2.56	23.53	5.31	31.63	23.81	9.11	8.25	1.21	0.00	0.00	0.02	1.48
1937	1.11	1.62	18.58	15.81	18.02	5.06	3.94	1.23	0.90	0.48	0.27	0.04
1938	7.39	5.36	19.04	26.31	21.19	16.37	0.57	3.01	1.51	10.53	4.37	0.49
1939	16.49	12.90	5.77	11.40	7.59	23.15	8.49	2.11	0.03	0.06	0.02	4.74
1940	3.47	4.85	19.42	27.45	23.67	4.49	6.05	0.64	0.10	0.01	0.08	0.27
1941	5.30	0.00	5.94	8.40	20.02	17.74	13.26	1.26	0.00	0.11	5.72	0.52
1942	19.13	2.93	29.46	13.55	10.68	10.69	33.19	9.46	0.00	2.62	15.89	2.03
1943	5.53	20.23	22.67	16.86	30.59	10.10	0.94	2.82	14.99	0.00	0.00	4.93
1944	12.26	9.40	2.10	17.03	9.69	34.57	4.99	0.25	0.00	0.74	0.00	0.01
1945	3.96	9.30	4.94	26.92	15.03	26.87	4.44	3.37	0.00	0.12	0.00	0.20
1946	6.52	7.66	7.80	7.71	9.47	17.10	14.22	2.34	1.17	0.03	0.48	3.89
1947	7.46	11.48	20.32	15.90	15.20	32.58	11.04	0.80	0.00	0.00	0.00	0.01
1948	8.39	16.82	2.84	12.10	8.28	12.49	0.75	0.62	3.84	0.53	0.39	0.06
1949	3.40	6.32	21.71	11.40	19.34	21.99	23.56	21.46	4.92	0.24	13.06	0.58
1950	1.37	3.78	40.77	15.88	12.72	13.55	11.92	9.95	0.51	0.33	0.22	0.36
1951	16.57	1.42	4.37	8.52	16.45	9.27	1.37	0.52	0.82	6.16	0.41	0.76
1952	7.24	9.89	11.95	7.57	25.18	8.93	17.28	1.09	0.00	0.00	0.36	0.00
1953	7.79	6.35	19.87	14.65	15.98	13.65	7.43	3.19	0.99	0.01	0.09	1.87
1954	0.06	3.37	19.10	30.02	23.18	8.00	7.42	2.23	5.23	0.31	0.00	0.12
1955	4.27	11.22	23.65	9.17	31.93	38.67	0.90	4.06	0.86	0.00	0.00	2.25
1956	4.82	13.59	12.10	14.70	11.37	11.12	7.06	1.04	16.24	2.24	2.87	18.51
1957	11.08	7.19	20.20	25.10	12.64	11.39	9.27	2.44	0.00	0.00	0.00	3.02
1958	2.94	8.65	24.74	19.80	15.72	4.20	6.83	7.77	0.43	2.31	0.00	0.00
1959	4.76	7.97	15.58	12.62	22.10	11.78	15.86	0.81	1.07	1.17	5.48	0.01
1960	3.32	11.14	15.48	9.71	13.04	22.43	23.80	3.03	6.42	10.02	0.15	0.04
1961	0.00	25.34	6.02	7.83	15.55	16.47	8.50	0.00	0.00	0.00	0.06	0.32
1962	2.95	25.27	14.21	36.60	3.77	14.83	15.48	5.36	3.84	0.82	0.00	0.01
1963	5.49	22.52	8.15	5.25	5.90	17.05	2.42	0.22	2.14	0.00	0.14	0.00
1964	12.26	3.16	11.28	17.36	8.14	3.28	6.88	0.00	0.53	1.29	0.09	0.55
1965	0.37	10.88	1.20	17.83	17.88	1.55	5.01	0.00	1.24	0.00	0.00	1.71
1966	3.49	6.20	8.59	41.17	18.84	11.86	22.69	12.33	0.00	0.00	2.19	0.58
1967	5.28	10.46	6.83	6.82	5.19	21.62	11.76	13.13	0.36	0.38	0.31	0.00
1968	6.25	5.67	14.74	6.80	20.03	11.77	10.02	9.27	0.19	0.50	0.98	0.20
1969	13.11	2.01	6.08	10.51	10.94	5.82	6.37	3.98	4.80	1.62	0.53	1.01
1970	3.61	5.07	18.24	26.17	15.81	10.87	11.29	9.17	0.04	0.27	0.00	0.61
1971	10.60	9.30	19.03	37.92	17.12	37.92	7.09	0.26	0.75	0.00	0.00	0.00
1972	3.10	6.00	2.28	6.96	24.64	12.78	13.45	0.01	0.00	0.29	0.15	11.66
1973	3.39	14.93	20.88	39.46	25.26	39.37	15.24	4.48	0.03	0.00	4.63	1.15
1974	2.92	17.87	11.76	36.87	25.02	29.18	12.57	2.74	2.09	0.57	0.08	0.82
1975	5.38	12.33	31.47	48.44	19.34	29.32	9.02	5.15	2.17	0.02	0.00	7.42
1976	15.37	5.86	15.33	21.50	23.26	28.93	8.10	0.49	0.00	0.00	0.26	11.29
1977	3.81	17.02	8.10	17.30	12.14	25.68	17.10	0.21	0.12	0.17	1.54	2.21
1978	7.80	4.13	7.34	20.18	8.95	3.39	7.66	2.27	0.24	0.88	13.76	0.77
1979	8.32	13.87	6.24	10.39	20.02	8.09	4.26	0.48	0.00	0.00	0.55	9.35
1980	1.89	27.72	9.82	25.62	19.68	11.88	2.27	0.72	1.21	0.00	6.53	0.00
1981	4.42	13.91	22.16	7.92	6.00	10.72	11.06	0.00	1.04	2.72	0.00	0.00
1982	12.39	7.32	10.11	14.50	3.17	7.01	0.78	4.44	4.50	2.77	0.00	0.66
1983	9.94	11.35	17.38	4.39	2.93	17.94	2.37	3.91	3.38	0.68	1.34	0.00
1984	16.01	10.08	2.47	10.36	19.92	12.56	0.17	0.30	0.07	0.00	0.00	1.26
1985	15.00	11.18	14.91	20.14	8.50	6.60	4.38	0.00	1.83	0.00	2.94	4.84
1986	9.78	25.67	5.92	7.77	15.01	10.05	4.11	0.00	0.00	1.25	1.42	15.91
1987	3.38	5.66	13.27	4.99	74.96	30.19	21.51	0.79	1.18	0.00	0.00	6.55
1988	18.17	8.71	18.33	34.71	23.34	10.58	15.74	3.43	0.15	0.00	0.00	0.00
1989	0.57	5.46	7.00	10.72	17.06	10.57	17.97	0.83	0.65	0.15	0.49	1.05
1990	0.36	1.27	11.91	44.00	14.36	22.66	0.00	0.00	7.31	0.04	0.00	5.23

File E5 : C3M03.RAN (Average rainfall on catchment upstream of C3H003)

Year		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
C3M03	23	3.18	12.21	3.95	8.39	5.98	20.35	2.32	5.09	0.00	0.00	0.12	7.24
C3M03	24	6.32	18.15	20.49	12.15	17.00	41.44	18.06	9.86	1.00	0.28	0.32	3.97
C3M03	25	1.16	6.92	3.20	7.99	7.51	14.68	6.30	2.45	0.11	0.61	0.00	2.83
C3M03	26	8.72	9.17	21.22	12.45	7.34	27.48	2.90	0.27	0.00	3.07	0.10	0.01
C3M03	27	7.83	2.74	11.03	26.36	17.04	20.80	6.23	0.19	0.32	0.00	1.43	1.46
C3M03	28	6.21	19.82	7.71	17.24	6.11	19.14	7.38	5.15	2.63	4.89	1.54	10.33
C3M03	29	5.95	17.78	15.02	19.47	11.23	15.96	5.26	1.24	0.20	0.03	0.64	0.04
C3M03	30	4.86	7.99	9.28	23.05	14.16	9.67	14.20	0.00	0.00	0.05	0.00	0.02
C3M03	31	6.87	17.65	5.08	5.87	18.42	16.36	5.20	0.49	0.60	0.00	0.01	2.41
C3M03	32	5.63	10.45	18.02	7.08	10.85	5.85	5.11	0.44	0.33	0.00	0.00	0.30
C3M03	33	1.04	13.79	20.57	37.77	16.28	11.44	9.50	10.94	1.16	0.22	1.99	1.01
C3M03	34	9.77	28.10	13.50	4.56	10.93	22.23	9.06	2.13	0.40	0.01	0.08	1.18
C3M03	35	2.46	6.19	16.28	19.77	20.01	27.81	2.00	8.94	0.01	0.00	0.00	0.44
C3M03	36	4.14	24.09	7.16	25.52	18.50	6.43	5.73	0.78	0.00	0.00	0.00	0.54
C3M03	37	2.38	3.48	22.86	14.19	12.21	4.70	9.23	1.17	1.49	0.22	1.49	0.18
C3M03	38	10.81	4.52	15.19	23.95	23.83	15.56	0.83	5.40	0.57	9.17	4.43	1.28
C3M03	39	8.86	16.66	8.56	14.92	9.86	22.59	5.80	2.24	0.20	0.00	0.21	7.34
C3M03	40	2.32	5.96	22.15	22.48	21.23	3.81	5.21	0.00	0.00	0.02	0.02	0.98
C3M03	41	6.06	0.61	8.99	13.87	15.57	15.05	7.98	0.84	0.06	0.01	3.28	0.87
C3M03	42	14.36	5.27	28.37	14.51	7.08	15.40	30.00	6.53	0.00	1.75	9.32	7.04
C3M03	43	12.20	20.57	27.04	16.79	39.43	8.46	0.66	1.91	13.88	0.00	0.00	6.85
C3M03	44	11.97	12.44	1.60	12.67	10.27	34.37	4.04	0.41	0.03	0.64	0.00	0.00
C3M03	45	3.47	8.96	5.79	20.84	15.41	25.90	3.09	3.03	0.00	0.00	0.00	0.27
C3M03	46	6.08	10.30	7.25	16.32	12.49	14.91	12.85	1.27	0.13	0.01	0.00	2.07
C3M03	47	5.64	9.39	23.17	19.40	13.65	23.97	10.70	2.11	0.00	0.02	0.00	0.15
C3M03	48	6.54	15.94	2.74	14.31	9.06	11.10	1.72	1.08	3.12	0.34	0.10	0.06
C3M03	49	4.30	6.54	24.17	13.40	10.76	23.94	17.47	21.03	4.31	0.48	3.92	0.99
C3M03	50	3.97	3.61	30.25	14.90	13.49	12.51	16.24	10.13	0.84	1.00	1.00	0.32
C3M03	51	16.87	1.59	6.54	11.50	19.20	9.46	2.56	1.12	0.97	5.13	0.04	0.43
C3M03	52	10.42	15.87	14.35	6.93	24.74	13.13	10.05	1.04	0.00	0.00	0.22	0.00
C3M03	53	9.86	12.13	14.85	18.15	16.46	14.02	9.75	2.06	1.86	0.00	0.00	2.36
C3M03	54	0.74	6.37	16.68	27.51	28.96	8.70	7.04	4.03	2.54	0.01	0.00	0.10
C3M03	55	8.84	9.48	22.32	12.53	36.25	32.05	0.95	7.91	0.00	0.00	0.00	2.86
C3M03	56	7.25	14.74	19.56	20.50	14.97	14.98	3.61	1.53	11.92	3.02	2.39	15.45
C3M03	57	14.40	11.81	16.43	25.41	13.54	12.03	10.45	0.60	0.00	0.00	0.00	4.45
C3M03	58	3.96	17.92	22.70	15.57	12.60	6.04	9.83	5.93	0.63	3.31	0.00	0.00
C3M03	59	6.40	8.49	15.20	11.51	18.80	12.57	13.97	0.28	1.14	1.50	4.27	0.30
C3M03	60	4.16	12.86	22.43	8.26	13.97	18.80	22.56	4.53	5.62	3.64	0.06	0.02
C3M03	61	0.30	25.33	6.09	9.91	18.41	14.00	13.83	0.31	0.01	0.00	0.42	0.48
C3M03	62	4.41	21.81	14.20	29.92	5.03	12.20	13.93	5.29	6.10	0.03	0.00	0.03
C3M03	63	8.31	18.44	6.78	10.48	7.19	11.25	3.08	0.26	0.56	0.03	0.09	0.00
C3M03	64	13.30	4.07	14.62	20.78	4.18	1.82	9.07	0.13	0.54	1.97	0.02	1.12
C3M03	65	0.70	14.40	3.47	19.72	24.90	2.78	6.01	0.28	4.59	0.00	0.00	1.43
C3M03	66	7.26	5.24	14.38	44.69	19.90	16.31	23.59	8.40	0.08	0.00	0.88	1.73
C3M03	67	4.71	16.31	7.79	9.68	3.95	24.70	14.30	11.66	0.90	0.30	1.17	0.25
C3M03	68	2.84	10.76	20.20	6.98	15.53	16.54	12.05	14.85	0.08	0.27	0.24	0.73
C3M03	69	11.30	5.25	9.08	14.85	9.43	5.79	3.44	1.58	2.73	2.34	0.19	3.85
C3M03	70	3.67	9.38	15.64	21.93	13.97	11.48	16.19	4.34	0.60	0.20	0.00	2.66
C3M03	71	10.33	13.14	19.78	34.15	18.96	24.31	5.27	0.53	1.53	0.00	0.02	0.04
C3M03	72	3.31	6.87	3.09	10.15	20.06	9.92	13.94	0.18	0.00	0.15	0.78	14.95
C3M03	73	3.58	14.49	17.45	35.95	15.88	25.37	15.68	0.52	0.00	0.00	0.87	1.71
C3M03	74	2.09	15.07	16.82	40.74	17.90	24.54	17.58	3.31	1.54	0.11	0.73	0.70
C3M03	75	5.77	11.96	28.71	45.11	19.40	21.26	8.31	4.28	0.73	0.00	0.34	5.59
C3M03	76	18.61	12.11	15.34	20.56	16.54	26.36	6.53	0.25	0.00	0.00	0.03	10.08
C3M03	77	7.39	18.76	9.28	21.29	17.71	18.95	20.77	0.09	0.29	0.03	3.75	1.28
C3M03	78	8.57	5.77	8.86	18.24	10.06	3.59	6.08	3.90	0.06	0.43	13.67	2.74
C3M03	79	9.32	15.01	11.92	15.51	16.39	5.96	3.21	0.68	0.00	0.00	0.12	7.10
C3M03	80	2.04	30.58	10.62	32.27	19.06	19.04	3.06	0.50	1.07	0.00	5.60	1.23
C3M03	81	6.29	12.24	19.72	15.27	5.68	12.33	15.41	0.12	0.19	4.40	0.00	0.10
C3M03	82	17.03	7.30	9.80	11.85	7.28	5.32	2.13	6.59	6.18	4.28	0.02	0.03
C3M03	83	6.73	6.69	13.28	5.36	3.93	14.26	1.71	4.01	3.01	0.89	2.93	0.35
C3M03	84	14.10	6.50	8.19	13.64	15.08	16.75	0.59	0.24	1.53	0.00	0.10	0.20
C3M03	85	14.02	5.16	11.87	20.41	10.72	11.31	5.91	0.21	1.73	0.00	2.65	4.34
C3M03	86	14.96	25.43	10.23	10.12	14.00	11.08	1.49	0.00	0.00	0.33	1.07	14.74
C3M03	87	6.10	5.39	16.51	8.49	39.62	28.68	11.50	1.52	0.76	0.08	0.11	4.11
C3M03	88	19.97	8.74	18.97	21.73	32.46	12.24	12.32	7.29	0.73	0.00	0.39	0.00
C3M03	89	3.19	16.19	13.23	9.44	14.11	16.60	16.93	0.27	0.08	0.65	0.13	0.68
C3M03	90	4.33	2.29	9.60	37.47	12.52	17.50	0.00	0.32	4.92	0.05	0.06	9.47

APPENDIX F

NATURALISED FLOW DATA FILES

File **Page**

File F1 : C3M03AKB.NAT - Naturalised catchment runoff for the Upper Harts (SW1 sub-model)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.05	6.75	.41	.90	5.24	16.13	.81	.52	.07	.05	.06	1.39	32.38
1924	1.53	6.39	17.59	1.98	6.06	35.77	10.26	13.69	1.05	.05	.06	.06	94.49
1925	.10	.15	.13	.11	.07	3.03	2.33	.06	.07	.04	.06	.06	6.21
1926	.49	1.86	4.63	4.97	3.76	3.35	.08	.07	.07	.03	.06	.06	19.43
1927	.41	.05	7.56	10.71	2.71	12.11	5.37	.07	.07	.05	.05	.06	39.22
1928	.05	2.67	1.48	3.66	.12	31.08	1.07	.06	.07	.04	.03	8.83	49.16
1929	.15	.17	3.99	2.26	.38	.41	.23	.07	.07	.05	.06	.05	7.89
1930	.04	1.01	2.51	4.47	6.33	19.24	13.61	.07	.07	.05	.06	.05	47.51
1931	7.03	15.38	.14	4.07	6.24	8.37	.08	.07	.07	.05	.06	.49	42.05
1932	.04	.77	2.81	.70	8.08	.79	2.72	.03	.03	.04	.04	.03	16.08
1933	.03	1.08	13.02	58.88	33.32	2.10	8.04	.02	.07	.04	.06	.08	116.74
1934	.55	16.42	7.30	1.12	.02	2.93	4.21	.06	.11	.08	.07	.06	32.93
1935	.05	.93	3.57	6.88	10.43	15.33	6.70	1.92	.39	.14	.11	.04	46.49
1936	.06	66.60	.96	30.94	6.69	.68	.95	.07	.06	.05	.00	.04	107.10
1937	.02	.02	10.25	1.08	1.11	.79	.16	.10	.05	.00	.00	.00	13.58
1938	.22	.19	1.85	4.59	9.90	5.91	1.17	.14	.10	.59	.16	.03	24.85
1939	3.74	7.78	1.30	.85	.54	3.04	.51	.19	.09	.00	.00	.03	18.07
1940	.44	.04	5.62	4.76	27.34	.87	.16	.07	.01	.00	.04	.00	39.35
1941	.05	.22	1.99	3.51	6.79	5.30	2.19	.33	.29	.13	1.59	.25	22.64
1942	9.55	3.69	14.45	2.56	1.13	2.19	12.75	15.40	.50	.24	2.65	14.99	80.10
1943	.74	3.98	19.49	6.20	130.98	4.01	.86	.35	1.90	1.20	.52	1.30	171.53
1944	2.04	1.25	.39	2.02	.78	10.04	1.41	1.04	.70	.32	.25	.31	20.55
1945	.18	.43	.10	11.97	3.30	12.76	.82	.43	.12	.09	.09	.08	30.37
1946	.64	12.78	1.70	3.10	1.69	5.91	1.92	.91	.14	.03	.00	.06	28.88
1947	1.05	4.95	8.14	5.78	7.58	20.73	1.58	.38	.15	.11	.09	.07	50.61
1948	.17	6.67	1.08	1.48	2.84	2.92	.22	.10	.19	.05	.05	.07	15.84
1949	.09	.03	7.02	2.92	3.67	9.70	4.21	20.22	1.20	.67	.41	2.01	52.15
1950	.16	.10	10.49	4.91	1.09	2.66	.88	.97	.40	.23	.40	.19	22.48
1951	1.84	1.35	1.36	.75	5.00	1.01	2.15	.07	.16	.18	.20	.12	14.19
1952	3.54	4.90	1.61	2.42	12.03	1.02	2.90	.47	.15	.08	.07	.05	29.24
1953	.84	.76	3.62	11.59	3.93	6.33	.79	1.13	.10	.09	.07	.06	29.31
1954	.05	.42	5.66	22.23	63.21	1.50	2.18	.18	.12	.10	.09	.07	95.81
1955	.14	1.78	3.06	4.30	6.77	37.69	3.50	.28	.39	.34	.47	.52	59.24
1956	.73	4.80	1.94	.56	.79	.46	.42	.14	.42	.28	.15	3.33	14.02
1957	.00	.55	.59	2.01	.29	.56	.45	.23	.09	.02	.06	.05	4.90
1958	.05	2.64	4.26	.55	.60	.42	.24	.15	.08	.08	.08	.07	9.22
1959	.06	.10	6.29	1.01	9.47	8.03	1.74	.32	.12	.09	.34	.08	27.65
1960	.37	2.85	3.64	3.47	.75	6.37	20.92	.32	.29	.16	.19	.14	39.47
1961	.10	6.58	2.68	1.19	3.06	2.58	.88	.39	.12	.09	.07	.06	17.80
1962	.04	7.53	1.62	11.72	.54	.61	3.18	.84	.15	.07	.05	.00	26.35
1963	.02	8.04	1.35	.70	.16	1.15	.22	.04	.04	.04	.04	.03	11.83
1964	3.99	1.22	3.71	22.70	2.13	.09	.13	.08	.04	.00	.03	.02	34.14
1965	.00	1.30	.69	19.33	29.71	16.09	.48	.05	.06	.00	.00	.00	67.71
1966	.05	1.94	6.28	27.87	52.17	22.75	13.83	6.63	2.66	.17	.16	.08	134.59
1967	.04	2.90	1.42	1.27	.20	18.04	1.97	4.49	.67	.48	.39	.34	32.21
1968	.39	.59	5.47	.71	4.31	2.75	1.04	2.76	.61	.40	.31	.20	19.54
1969	1.82	.44	.33	1.71	1.04	.65	.25	8.92	.38	.35	.34	.27	16.50
1970	.38	.67	2.69	8.53	3.35	1.91	1.16	1.69	.38	.32	.39	.28	21.75
1971	1.96	3.16	5.07	23.43	6.39	24.31	3.42	1.13	.78	.68	.41	.38	71.12
1972	.41	.31	.29	.45	4.36	.82	1.60	.41	.23	.62	.39	2.10	11.99
1973	1.00	.72	1.47	12.36	27.19	32.03	78.41	18.45	1.60	.95	.92	.66	175.76
1974	.29	4.35	1.11	14.31	35.62	51.87	51.94	26.58	5.30	3.17	1.57	1.06	197.17
1975	.71	1.14	7.30	236.82	90.56	126.00	30.18	34.68	6.37	3.78	2.40	1.53	541.47
1976	18.81	6.08	1.96	1.56	20.63	33.15	8.35	2.75	1.51	1.18	.84	1.32	98.14
1977	1.64	2.31	3.64	5.55	23.66	15.05	47.01	7.87	3.08	2.40	1.59	1.98	115.78
1978	.63	.20	.69	2.90	1.72	.57	.46	.21	.36	.59	1.49	.84	10.66
1979	1.25	1.93	1.23	.83	2.56	2.90	.21	.37	.37	.54	.53	.44	13.16
1980	.62	6.02	10.24	6.83	52.83	12.99	8.69	2.00	1.14	.83	.42	.15	102.76
1981	1.64	1.64	2.27	1.32	1.61	1.68	.20	.64	.00	1.00	.80	.34	13.14
1982	2.92	1.61	3.42	1.37	.30	.28	.03	.03	.05	.09	.09	.08	10.27
1983	.09	.91	1.85	.88	.78	4.31	.80	.05	.05	.06	.06	.06	9.90
1984	4.04	4.94	.20	1.40	4.70	3.18	.47	.13	.06	.05	.05	.04	19.26
1985	1.09	1.05	1.30	4.59	6.35	.61	.25	.06	.05	.05	.05	.05	15.50
1986	1.63	15.82	1.15	.52	1.66	.81	.29	.05	.04	.04	.04	1.79	23.84
1987	1.24	.30	2.81	1.42	78.52	61.63	13.03	.84	.32	.79	.30	.59	161.79
1988	4.14	1.25	1.08	10.81	18.12	10.46	1.66	3.50	.85	.66	.23	.18	52.94
1989	.32	2.02	.69	.99	1.56	.63	.29	.32	.18	.18	.14	.09	7.41
1990	.09	.06	.20	64.60	31.11	4.48	.73	.25	.16	.18	.17	.26	102.29
AVERAGE	1.30	3.96	3.77	10.66	13.20	11.12	5.76	2.75	.55	.38	.34	.74	54.54

File F2 : C3R002AKB.NAT - Naturalised catchment runoff for the Middle Harts (SW3 sub-model)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	1.22	.57	.18	.08	11.49	5.40	.10	.00	.00	.00	.00	19.04
1924	.00	1.04	14.47	7.05	1.22	41.00	28.23	6.88	1.13	.02	.00	.00	101.04
1925	.00	.00	.00	.00	.00	10.85	5.14	.12	.00	.00	.00	.00	16.11
1926	.13	.18	2.82	1.41	.08	7.75	3.64	.07	.00	.00	.00	.00	16.08
1927	.00	.00	.23	7.01	6.15	13.55	5.77	.13	.00	.00	.00	.00	32.84
1928	.00	.27	.17	1.28	.59	10.59	4.97	.09	.00	.00	.00	.26	18.22
1929	.12	.51	2.41	1.54	.58	.25	.05	.00	.00	.00	.00	.00	5.46
1930	.00	.02	.12	29.81	15.37	2.00	2.32	.85	.02	.00	.00	.00	50.51
1931	.33	4.72	1.86	.04	7.18	8.02	2.24	.04	.00	.00	.00	.01	23.84
1932	.00	.07	1.41	.70	.15	.05	.00	.00	.00	.00	.00	.00	2.38
1933	.00	.09	2.62	13.76	11.39	2.91	.46	.39	.12	.00	.00	.00	31.74
1934	.01	17.33	9.57	.83	1.15	2.41	1.15	.14	.00	.00	.00	.00	32.59
1935	.00	.00	.82	4.53	10.00	55.27	24.23	.52	.04	.00	.00	.00	95.41
1936	.00	7.92	3.72	25.43	20.23	4.17	.11	.01	.00	.00	.00	.00	61.59
1937	.00	.00	2.86	2.67	3.13	1.18	.02	.00	.00	.00	.00	.00	9.86
1938	.00	.00	3.19	13.94	10.97	4.08	.79	.01	.00	.12	.06	.00	33.16
1939	1.63	1.21	.22	.21	.10	7.41	3.50	.07	.00	.00	.00	.00	14.35
1940	.00	.00	3.48	16.35	15.06	3.94	.08	.00	.00	.00	.00	.00	38.91
1941	.00	.00	.00	.02	3.99	4.18	1.64	.27	.01	.00	.00	.00	10.11
1942	3.26	1.53	19.38	9.67	.58	.20	30.44	14.31	.29	.01	1.36	.64	81.67
1943	.01	4.17	8.75	5.04	23.26	10.59	.24	.00	1.01	.47	.01	.00	53.55
1944	.33	.20	.03	1.90	.96	35.37	16.59	.32	.01	.00	.00	.00	55.71
1945	.00	.04	.02	13.62	7.42	14.13	6.36	.12	.00	.00	.00	.00	41.71
1946	.00	.00	.01	.01	.05	1.96	1.68	.38	.01	.00	.00	.00	4.10
1947	.00	.22	4.36	3.36	1.76	28.86	13.48	.33	.01	.00	.00	.00	52.38
1948	.01	1.80	.84	.32	.15	.38	.17	.00	.00	.00	.00	.00	3.67
1949	.00	.00	5.66	2.86	3.57	7.58	10.80	9.18	2.60	.05	.48	.22	43.00
1950	.00	.00	64.27	31.53	1.62	.80	.55	.21	.04	.00	.00	.00	99.02
1951	1.67	.78	.01	.02	1.62	.80	.03	.00	.00	.00	.00	.00	4.93
1952	.00	.07	.31	.14	10.44	4.93	2.15	.96	.02	.00	.00	.00	19.02
1953	.01	.00	3.86	2.71	1.85	1.28	.30	.01	.00	.00	.00	.00	10.02
1954	.00	.00	3.24	22.32	17.24	3.69	.08	.00	.00	.00	.00	.00	46.57
1955	.00	.19	8.18	3.84	26.37	65.51	25.20	.48	.01	.00	.00	.00	129.78
1956	.00	.60	.58	1.06	.63	.28	.08	.00	1.51	.71	.01	2.81	8.27
1957	1.49	.11	4.15	12.25	5.27	.48	.14	.02	.00	.00	.00	.00	23.91
1958	.00	.02	9.73	8.36	3.16	.64	.01	.01	.00	.00	.00	.00	21.93
1959	.00	.01	1.23	.97	6.30	3.12	1.52	.64	.01	.00	.00	.00	13.80
1960	.00	.18	1.27	.62	.51	6.72	11.36	3.96	.08	.08	.04	.00	24.82
1961	.00	10.71	5.03	.10	1.22	2.19	.79	.02	.00	.00	.00	.00	20.06
1962	.00	10.59	5.74	44.01	20.46	1.35	1.65	.57	.01	.00	.00	.00	84.38
1963	.00	6.60	3.11	.06	.00	1.91	.90	.02	.00	.00	.00	.00	12.60
1964	.33	.15	.19	2.17	.99	.02	.00	.00	.00	.00	.00	.00	3.85
1965	.00	.15	.07	2.36	3.50	1.15	.02	.00	.00	.00	.00	.00	7.25
1966	.00	.00	.02	66.55	34.29	2.29	6.98	3.54	.22	.00	.00	.00	113.89
1967	.00	.11	.05	.00	.00	5.56	2.86	.66	.23	.00	.00	.00	9.47
1968	.00	.00	.93	.44	4.00	2.13	.24	.08	.02	.00	.00	.00	7.84
1969	.49	.23	.00	.12	.21	.07	.00	.00	.00	.00	.00	.00	1.12
1970	.00	.00	2.62	13.41	7.07	.88	.28	.13	.02	.00	.00	.00	24.41
1971	.12	.10	3.20	51.03	25.24	50.90	23.29	.44	.01	.00	.00	.00	154.33
1972	.00	.00	.00	.00	9.57	4.91	.85	.27	.01	.00	.00	.24	15.85
1973	.11	.99	5.25	59.44	37.47	62.19	27.84	1.03	.02	.00	.00	.00	194.34
1974	.00	2.39	1.37	44.88	31.19	23.83	9.24	.35	.01	2.72	2.72	.65	119.35
1975	.00	.06	8.05	221.19	106.52	253.24	28.99	8.46	4.10	4.11	.00	3.49	638.21
1976	.00	.27	.00	1.43	.00	43.82	1.87	.00	.95	1.44	1.60	2.79	54.17
1977	1.90	.00	.44	.70	.00	4.46	13.15	.00	1.18	1.09	5.28	1.59	29.79
1978	.26	1.65	.00	.00	.82	2.78	.10	.00	.00	.00	.00	.00	5.61
1979	.26	.82	.00	.00	.50	2.53	.00	.00	.38	1.62	1.91	1.63	9.65
1980	2.93	.00	1.63	.00	29.71	9.15	8.02	.00	.98	1.06	2.44	2.75	58.67
1981	1.32	4.61	1.69	.00	.00	.00	.00	.00	.00	.27	.72	.23	8.84
1982	3.08	2.63	4.76	3.07	2.71	2.89	.86	.39	.91	.70	.83	1.59	24.42
1983	2.60	5.60	7.29	5.23	5.39	.00	3.79	.00	.80	.52	.32	.39	31.93
1984	.87	.47	.97	.00	2.06	5.81	.06	.74	.73	.35	.55	.10	12.71
1985	2.10	1.58	2.26	.33	2.22	.00	.00	.00	.00	.03	.29	1.52	10.33
1986	.10	9.46	.07	.18	.10	.00	.08	.00	.17	.00	.00	1.45	11.61
1987	.00	.00	8.81	.00	735.07	366.21	21.62	2.50	4.90	3.98	4.39	5.29	1152.77
1988	.53	.00	.00	28.62	2.19	9.23	.00	2.45	.20	.00	.26	.51	43.99
1989	.00	.00	.00	.00	.81	.00	.00	.00	.00	.00	2.43	.00	3.24
1990	.00	.00	1.00	.00	22.86	14.37	.00	.00	.39	.00	1.55	1.00	41.17
AVERAGE	.38	1.52	3.69	11.66	19.21	18.42	5.36	.92	.34	.28	.40	.43	62.60

File F3 : C3H013AKB.NAT - Naturalised catchment runoff for the Middle Harts (SW2 sub-model)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.09	.04	.01	.01	.89	.42	.01	.00	.00	.00	.00	1.47
1924	.00	.08	1.12	.54	.09	3.17	2.18	.53	.09	.00	.00	.00	7.80
1925	.00	.00	.00	.00	.00	.84	.40	.01	.00	.00	.00	.00	1.25
1926	.01	.01	.22	.11	.01	.60	.28	.01	.00	.00	.00	.00	1.25
1927	.00	.00	.02	.54	.48	1.05	.45	.01	.00	.00	.00	.00	2.55
1928	.00	.02	.01	.10	.05	.82	.38	.01	.00	.00	.00	.02	1.41
1929	.01	.04	.19	.12	.04	.02	.00	.00	.00	.00	.00	.00	.42
1930	.00	.00	.01	2.30	1.19	.15	.18	.07	.00	.00	.00	.00	3.90
1931	.03	.32	.14	.00	.56	.62	.17	.00	.00	.00	.00	.00	1.84
1932	.00	.01	.11	.05	.01	.00	.00	.00	.00	.00	.00	.00	.18
1933	.00	.01	.20	1.06	.88	.23	.04	.03	.01	.00	.00	.00	2.46
1934	.00	1.34	.74	.06	.09	.19	.09	.01	.00	.00	.00	.00	2.52
1935	.00	.00	.06	.35	.77	4.27	1.87	.04	.00	.00	.00	.00	7.36
1936	.00	.61	.29	1.97	1.56	.32	.01	.00	.00	.00	.00	.00	4.76
1937	.00	.00	.22	.21	.24	.09	.00	.00	.00	.00	.00	.00	.76
1938	.00	.00	.25	1.08	.85	.32	.06	.00	.00	.01	.00	.00	2.57
1939	.13	.09	.02	.02	.01	.57	.27	.01	.00	.00	.00	.00	1.12
1940	.00	.00	.27	1.26	1.16	.30	.01	.00	.00	.00	.00	.00	3.00
1941	.00	.00	.00	.00	.31	.32	.13	.02	.00	.00	.00	.00	.78
1942	.25	.12	1.50	.75	.04	.02	2.35	1.11	.02	.00	.11	.05	6.32
1943	.00	.32	.68	.39	1.80	.82	.02	.00	.08	.04	.00	.00	4.15
1944	.03	.02	.00	.15	.07	2.73	1.28	.02	.00	.00	.00	.00	4.30
1945	.00	.00	.00	1.05	.57	1.09	.49	.01	.00	.00	.00	.00	3.21
1946	.00	.00	.00	.00	.00	.15	.13	.03	.00	.00	.00	.00	.31
1947	.00	.02	.34	.26	.14	2.23	1.04	.03	.00	.00	.00	.00	4.06
1948	.00	.14	.07	.02	.01	.03	.01	.00	.00	.00	.00	.00	.28
1949	.00	.00	.44	.22	.28	.59	.83	.71	.20	.00	.04	.02	3.33
1950	.00	.00	4.97	2.44	.13	.06	.04	.02	.00	.00	.00	.00	7.66
1951	.13	.06	.00	.00	.13	.06	.00	.00	.00	.00	.00	.00	.38
1952	.00	.01	.02	.01	.81	.38	.17	.07	.00	.00	.00	.00	1.47
1953	.00	.00	.30	.21	.14	.10	.02	.00	.00	.00	.00	.00	.77
1954	.00	.00	.25	1.73	1.33	.29	.01	.00	.00	.00	.00	.00	3.61
1955	.00	.01	.63	.30	2.04	5.06	1.95	.04	.00	.00	.00	.00	10.03
1956	.00	.05	.05	.08	.05	.02	.01	.00	.12	.05	.00	.22	.65
1957	.12	.01	.32	.95	.41	.04	.01	.00	.00	.00	.00	.00	1.86
1958	.00	.00	.75	.65	.24	.05	.00	.00	.00	.00	.00	.00	1.69
1959	.00	.00	.10	.07	.49	.24	.12	.05	.00	.00	.00	.00	1.07
1960	.00	.01	.10	.05	.04	.52	.88	.31	.01	.01	.00	.00	1.93
1961	.00	.83	.39	.01	.09	.17	.06	.00	.00	.00	.00	.00	1.55
1962	.00	.82	.44	3.40	1.58	.10	.13	.04	.00	.00	.00	.00	6.51
1963	.00	.51	.24	.00	.00	.15	.07	.00	.00	.00	.00	.00	.97
1964	.03	.01	.02	.17	.08	.00	.00	.00	.00	.00	.00	.00	.31
1965	.00	.01	.01	.18	.27	.09	.00	.00	.00	.00	.00	.00	.56
1966	.00	.00	.00	5.14	2.65	.18	.54	.27	.02	.00	.00	.00	8.80
1967	.00	.01	.00	.00	.00	.43	.22	.05	.02	.00	.00	.00	.73
1968	.00	.00	.07	.03	.31	.16	.02	.01	.00	.00	.00	.00	.60
1969	.04	.02	.00	.01	.02	.01	.00	.00	.00	.00	.00	.00	.10
1970	.00	.00	.20	1.04	.55	.07	.02	.01	.00	.00	.00	.00	1.89
1971	.01	.01	.25	3.95	1.95	3.93	1.80	.03	.00	.00	.00	.00	11.93
1972	.00	.00	.00	.00	.74	.38	.07	.02	.00	.00	.00	.02	1.23
1973	.01	.08	.41	4.59	2.90	4.81	2.15	.08	.00	.00	.00	.00	15.03
1974	.00	.18	.11	3.47	2.41	1.84	.71	.03	.00	.00	.00	.00	8.75
1975	.09	.03	2.20	10.00	4.55	1.67	.01	.00	.00	.00	.00	.00	18.55
1976	.01	.04	.00	.00	.78	1.67	.66	1.33	.00	.00	.00	.00	4.49
1977	.00	.00	.00	.00	.10	.89	.56	.08	.00	.00	.00	.00	1.63
1978	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02	.02
1979	.00	.00	.02	.00	.31	.00	.00	.00	.00	.00	.00	.00	.33
1980	.00	2.28	.56	.88	.69	.16	.01	.00	.00	.00	.00	.00	4.58
1981	.00	.05	.00	.23	.00	.00	.00	.00	.00	.00	.00	.00	.28
1982	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1983	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1984	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1985	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1986	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1987	.00	.00	.00	.00	56.85	28.34	1.70	.22	.00	.00	.00	.00	87.11
1988	.00	.00	.21	2.87	1.90	.31	.11	.05	.00	.00	.00	.00	5.45
1989	.00	.00	.00	.00	.00	.00	.48	.09	.12	.39	.37	.52	1.97
1990	.00	.20	.02	6.52	3.12	.61	.03	.42	.08	.61	.83	1.05	13.49
AVERAGE	.01	.12	.29	.91	1.45	1.11	.38	.09	.01	.02	.02	.03	4.43

APPENDIX G

ABSTRACTION DATA FILES

File G1 : C3R001.URB - Urban abstraction from Schweizer Reneke Dam

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1938	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.02	.01	.22
1939	.02	.02	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.23
1940	.01	.02	.02	.02	.02	.02	.02	.02	.04	.02	.02	.02	.25
1941	.05	.04	.02	.02	.02	.02	.02	.02	.02	.01	.05	.02	.31
1942	.02	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.23
1943	.04	.05	.02	.02	.02	.02	.02	.02	.02	.02	.01	.02	.28
1944	.01	.02	.02	.01	.02	.02	.02	.02	.02	.02	.02	.02	.22
1945	.02	.01	.01	.02	.02	.02	.01	.02	.01	.02	.02	.02	.20
1946	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1947	.02	.02	.01	.02	.02	.01	.02	.02	.02	.01	.03	.01	.21
1948	.02	.02	.02	.02	.01	.02	.02	.02	.01	.02	.02	.02	.22
1949	.02	.02	.02	.02	.02	.02	.02	.02	.01	.01	.02	.03	.23
1950	.03	.02	.01	.01	.01	.02	.02	.01	.01	.02	.02	.02	.20
1951	.02	.03	.03	.02	.03	.03	.02	.03	.02	.01	.02	.02	.28
1952	.03	.02	.02	.03	.02	.03	.02	.02	.02	.02	.02	.02	.27
1953	.03	.03	.02	.03	.02	.02	.02	.02	.04	.03	.02	.03	.31
1954	.03	.03	.03	.03	.01	.03	.02	.03	.02	.02	.03	.02	.30
1955	.03	.03	.03	.03	.03	.02	.02	.02	.02	.01	.02	.02	.28
1956	.03	.04	.02	.03	.02	.02	.03	.03	.02	.01	.02	.02	.29
1957	.02	.03	.02	.02	.02	.03	.04	.04	.03	.04	.01	.01	.31
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02	.02	.04
1959	.02	.02	.02	.02	.02	.02	.02	.02	.00	.00	.02	.02	.20
1960	.02	.02	.02	.02	.02	.02	.02	.02	.00	.00	.02	.02	.20
1961	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.01	.02	.23
1962	.02	.02	.02	.02	.02	.02	.01	.01	.01	.02	.02	.02	.21
1963	.03	.03	.03	.03	.03	.02	.03	.02	.02	.02	.02	.03	.31
1964	.02	.02	.03	.03	.02	.02	.01	.02	.01	.01	.02	.02	.23
1965	.02	.02	.04	.01	.01	.03	.02	.02	.01	.02	.02	.03	.25
1966	.03	.02	.02	.02	.02	.02	.01	.02	.02	.02	.04	.03	.27
1967	.03	.02	.03	.03	.04	.02	.02	.02	.01	.02	.03	.03	.30
1968	.03	.06	.02	.03	.02	.02	.03	.02	.02	.02	.02	.02	.31
1969	.03	.03	.03	.05	.03	.04	.03	.03	.02	.02	.02	.02	.35
1970	.03	.03	.03	.03	.09	.09	.09	.02	.03	.02	.03	.04	.53
1971	.02	.03	.04	.02	.04	.02	.02	.04	.04	.02	.04	.04	.37
1972	.05	.06	.03	.05	.02	.04	.03	.03	.02	.02	.04	.04	.43
1973	.04	.04	.05	.02	.03	.02	.02	.04	.03	.03	.04	.04	.40
1974	.06	.02	.05	.04	.03	.03	.03	.02	.01	.03	.03	.05	.40
1975	.06	.04	.05	.02	.03	.03	.02	.03	.02	.03	.05	.04	.42
1976	.04	.05	.05	.06	.03	.04	.04	.02	.04	.04	.04	.00	.45
1977	.00	.06	.05	.05	.04	.01	.02	.03	.03	.03	.04	.06	.42
1978	.04	.06	.05	.06	.05	.05	.05	.03	.03	.03	.04	.04	.53
1979	.05	.06	.05	.06	.05	.04	.04	.03	.00	.00	.00	.00	.38
1980	.00	.00	.04	.06	.04	.04	.04	.04	.03	.04	.04	.05	.42
1981	.06	.05	.05	.00	.00	.04	.04	.01	.04	.04	.05	.06	.44
1982	.06	.05	.06	.09	.05	.04	.03	.02	.01	.02	.01	.02	.46
1983	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01
1984	.00	.00	.02	.02	.03	.03	.04	.04	.03	.03	.04	.05	.33
1985	.04	.06	.05	.05	.04	.04	.03	.03	.02	.03	.03	.03	.45
1986	.04	.04	.07	.08	.05	.06	.06	.06	.04	.04	.05	.04	.63
1987	.07	.08	.06	.07	.05	.04	.05	.05	.04	.05	.06	.06	.68
1988	.05	.06	.06	.06	.04	.06	.05	.04	.05	.05	.06	.08	.66
1989	.08	.07	.08	.08	.05	.05	.04	.04	.04	.05	.04	.02	.64
1990	.06	.07	.05	.03	.05	.05	.05	.05	.05	.05	.05	.05	.61
AVERAGE	.03	.03	.03	.03	.03	.03	.03	.03	.02	.02	.03	.03	.33

File G2: C3R001.IRR - Irrgation abstraction from Schweizer Reneke Dam

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.02	.05	.03	.06	.05	.21
1935	.08	.10	.04	.08	.09	.00	.01	.04	.10	.21	.20	.32	1.27
1936	.37	.15	.13	.00	.00	.05	.00	.18	.22	.23	.38	.27	1.98
1937	.42	.42	.00	.03	.00	.06	.04	.31	.24	.29	.39	.43	2.63
1938	.41	.07	.10	.00	.00	.00	.07	.27	.35	.10	.08	.51	1.96
1939	.19	.23	.26	.23	.20	.06	.09	.13	.48	.42	.40	.39	3.08
1940	.42	.16	.01	.04	.00	.00	.00	.39	.42	.45	.23	.43	2.55
1941	.45	.31	.19	.27	.11	.00	.00	.00	.26	.20	.09	.32	2.20
1942	.00	.30	.00	.00	.15	.00	.00	.00	.00	.29	.21	.07	1.02
1943	.48	.02	.00	.00	.00	.00	.00	.17	.04	.18	.25	.23	1.37
1944	.27	.00	.20	.18	.05	.00	.34	.06	.07	.14	.17	.29	1.77
1945	.36	.18	.14	.08	.06	.00	.01	.16	.33	.09	.10	.27	1.78
1946	.32	.13	.13	.07	.13	.53	.17	.14	.21	.28	.44	.17	2.72
1947	.30	.09	.08	.08	.02	.03	.14	.04	.18	.20	.23	.26	1.65
1948	.15	.13	.34	.21	.16	.14	.25	.15	.09	.14	.13	.00	1.89
1949	.00	.00	.00	.18	.12	.04	.00	.00	.00	.14	.25	.21	.94
1950	.23	.29	.07	.00	.12	.05	.03	.04	.03	.07	.17	.18	1.28
1951	.08	.24	.18	.21	.12	.11	.15	.09	.07	.04	.11	.09	1.49
1952	.26	.02	.14	.26	.00	.07	.04	.17	.10	.04	.19	.18	1.47
1953	.08	.08	.29	.04	.01	.08	.10	.03	.10	.04	.11	.14	1.10
1954	.15	.12	.12	.08	.00	.02	.18	.08	.02	.13	.08	.12	1.10
1955	.15	.09	.01	.07	.07	.00	.00	.01	.05	.04	.06	.06	.61
1956	.09	.03	.04	.04	.14	.03	.09	.05	.01	.02	.05	.05	.64
1957	.04	.03	.05	.00	.00	.15	.17	.23	.25	.28	.08	.11	1.39
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1959	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1960	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1961	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1962	.00	.00	.00	.00	.00	.00	.00	.08	.27	.32	.37	.54	1.58
1963	.58	.21	.18	.19	.11	.00	.00	.00	.00	.00	.00	.00	1.27
1964	.00	.07	.00	.05	.41	.09	.24	.32	.24	.24	.28	.36	2.30
1965	.56	.07	.31	.27	.00	.19	.31	.41	.22	.56	.62	.59	4.11
1966	.40	.42	.35	.22	.00	.01	.00	.20	.19	.37	.24	.41	2.81
1967	.41	.29	.28	.34	.03	.00	.00	.00	.02	.12	.09	.14	1.72
1968	.21	.14	.05	.02	.03	.05	.04	.04	.08	.11	.47	.47	1.71
1969	.22	.22	.22	.22	.22	.22	.22	.22	.00	.00	.00	.00	1.76
1970	.00	.00	.00	.19	.19	.19	.19	.19	.19	.19	.19	.19	1.71
1971	.30	.30	.30	.30	.30	.30	.00	.00	.00	.00	.00	.00	1.80
1972	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1973	.02	.09	.00	.05	.03	.02	.00	.05	.01	.04	.01	.05	.37
1974	.08	.03	.00	.00	.00	.00	.00	.00	.06	.01	.00	.08	.26
1975	.16	.11	.02	.00	.00	.00	.00	.00	.00	.00	.00	.00	.29
1976	.00	.03	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.03
1977	.00	.12	.06	.20	.10	.00	.00	.00	.00	.05	.13	.18	.84
1978	.16	.18	.09	.12	.21	.17	.02	.01	.04	.00	.00	.00	1.00
1979	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1980	.00	.00	.00	.00	.00	.00	.08	.00	.00	.00	.01	.00	.09
1981	.00	.06	.00	.08	.10	.09	.00	.96	.67	.56	.39	.00	2.91
1982	.20	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.20
1983	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1984	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1985	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1986	.00	.00	.09	.09	.00	.15	.09	.15	.08	.00	.00	.00	.65
1987	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.19	.21	.40
1988	.08	.15	.16	.00	.00	.00	.00	.00	.00	.00	.00	.00	.39
1989	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1990	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
AVERAGE	.15	.10	.08	.08	.06	.05	.05	.10	.10	.12	.13	.15	1.18

File G3 : HARTU7.ABS - Irrigation abstraction from Harts River upstream of C3H007

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1938	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1939	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1940	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1941	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1942	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1943	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1944	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1945	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1946	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1947	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1948	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1949	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1950	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1951	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1952	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1953	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1954	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1955	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1956	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1957	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1959	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1960	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1961	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1962	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1963	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1964	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1965	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1966	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1967	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1968	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1969	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1970	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1971	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1972	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1973	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1974	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1975	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1976	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1977	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1978	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1979	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1980	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1981	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1982	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1983	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1984	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1985	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1986	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1987	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1988	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1989	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
1990	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12
AVERAGE	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.12

File G4: HARTD7.ABS - Irrigation abstraction from Harts River downstream of C3H007

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1938	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1939	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1940	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1941	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1942	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1943	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1944	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1945	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1946	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1947	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1948	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1949	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1950	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1951	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1952	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1953	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1954	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1955	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1956	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1957	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1959	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1960	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1961	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1962	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1963	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1964	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1965	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1966	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1967	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1968	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1969	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1970	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1971	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1972	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1973	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1974	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1975	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1976	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1977	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1978	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1979	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1980	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1981	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1982	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1983	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1984	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1985	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1986	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1987	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1988	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1989	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
1990	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24
AVERAGE	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.24

File G5 : HARTDSP.ABS - Irrigation abstraction between Spitskop Dam and C3H013

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1938	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1939	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1940	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1941	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1942	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1943	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1944	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1945	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1946	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1947	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1948	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1949	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1950	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1951	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1952	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1953	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1954	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1955	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1956	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1957	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1959	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1960	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1961	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1962	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1963	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1964	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1965	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1966	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1967	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1968	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1969	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1970	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1971	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1972	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1973	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1974	.00	.00	.00	.00	.00	.00	.00	.00	.03	.03	.07	.08	.21
1975	.11	.09	.01	.00	.01	.00	.01	.03	.03	.03	.07	.08	.47
1976	.08	.10	.09	.05	.00	.00	.02	.03	.03	.03	.06	.05	.54
1977	.11	.09	.10	.11	.04	.00	.04	.03	.03	.03	.07	.05	.70
1978	.07	.10	.10	.06	.04	.04	.03	.03	.03	.03	.00	.07	.60
1979	.09	.09	.09	.09	.00	.02	.04	.03	.03	.03	.06	.05	.62
1980	.11	.09	.12	.02	.04	.03	.03	.03	.03	.03	.04	.09	.66
1981	.09	.10	.05	.10	.05	.04	.00	.03	.03	.03	.07	.09	.68
1982	.09	.09	.12	.08	.04	.04	.04	.03	.02	.03	.07	.08	.73
1983	.02	.07	.08	.09	.05	.00	.03	.03	.02	.03	.07	.09	.58
1984	.07	.06	.12	.06	.04	.03	.04	.03	.03	.03	.07	.08	.66
1985	.06	.10	.08	.06	.04	.05	.04	.03	.02	.03	.06	.07	.64
1986	.09	.07	.12	.09	.04	.04	.02	.03	.03	.03	.07	.04	.67
1987	.09	.10	.08	.10	.00	.01	.00	.03	.02	.03	.07	.07	.60
1988	.08	.08	.07	.01	.03	.03	.01	.00	.01	.03	.03	.06	.44
1989	.06	.04	.02	.04	.03	.02	.01	.02	.02	.04	.09	.12	.51
1990	.05	.13	.06	.07	.00	.00	.00	.02	.00	.03	.09	.05	.50
AVERAGE	.08	.09	.08	.06	.03	.02	.02	.03	.02	.03	.06	.07	.60

APPENDIX H

STREAMFLOW DATA FILES

File H1 : C3M03Q.OBS - Observed flow at C3H003

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	6.63	.26	.82	5.20	16.09	.74	.46	.00	.00	.00	1.32	31.52
1924	1.47	6.29	17.59	1.88	6.04	35.77	10.26	13.69	.98	.00	.00	.00	93.97
1925	.00	.00	.00	.00	.00	3.03	2.26	.00	.00	.00	.00	.00	5.29
1926	.45	1.75	4.56	4.86	3.69	3.30	.00	.00	.00	.00	.00	.00	18.61
1927	.33	.00	7.46	10.65	2.69	12.07	5.30	.00	.00	.00	.00	.00	38.50
1928	.00	2.55	1.36	3.58	.04	31.08	.99	.00	.02	.00	.00	8.83	48.45
1929	.06	.05	3.93	2.15	.34	.32	.14	.00	.00	.00	.00	.00	6.99
1930	.00	.94	2.40	4.42	6.33	19.21	13.58	.00	.00	.00	.00	.00	46.88
1931	6.98	15.35	.00	4.01	6.24	8.32	.00	.00	.00	.00	.00	.45	41.35
1932	.00	.66	2.72	.58	8.02	.70	2.69	.00	.00	.00	.00	.00	15.37
1933	.00	.98	12.95	58.86	33.32	2.03	8.02	.00	.00	.00	.00	.00	116.16
1934	.48	16.40	7.21	1.00	.00	2.87	4.16	.00	.00	.00	.00	.00	32.12
1935	.00	.90	3.46	6.72	3.00	15.02	6.29	1.77	.18	.00	.00	.00	37.34
1936	.00	63.77	.15	30.77	6.59	.24	.82	.00	.00	.00	.00	.00	102.34
1937	.00	.00	5.75	.51	.97	.45	.00	.00	.00	.00	.00	.00	7.68
1938	.00	.00	.25	1.70	9.74	5.57	.63	.00	.00	.46	.00	.00	18.35
1939	3.67	5.28	.13	.06	.05	2.87	.13	.00	.07	.01	.00	.02	12.29
1940	.44	.00	1.15	4.72	27.29	.35	.00	.00	.00	.00	.00	.00	33.95
1941	.09	.19	1.88	2.36	4.58	2.94	1.38	.22	.21	.06	1.54	.19	15.64
1942	8.34	2.98	12.96	2.05	.73	1.91	12.86	15.24	.16	.00	2.47	14.74	74.44
1943	.10	2.65	19.28	5.64	131.06	3.58	.41	.17	1.43	.72	.36	1.17	166.57
1944	1.45	.27	.00	1.30	.20	9.71	.66	.64	.56	.22	.17	.25	15.43
1945	.13	.30	.03	8.36	2.98	12.66	.40	.15	.00	.00	.02	.02	25.05
1946	.60	12.51	1.55	.83	.02	4.76	1.63	.46	.04	.01	.03	.00	22.44
1947	1.00	4.79	4.69	5.31	7.35	20.55	1.17	.00	.00	.00	.00	.00	44.86
1948	.12	4.65	.02	.18	2.13	2.49	.01	.06	.15	.00	.00	.03	9.84
1949	.05	.00	3.54	2.09	3.30	9.61	4.12	20.29	.97	.25	.17	1.78	46.17
1950	.00	.00	8.10	4.36	.67	2.26	.55	.72	.10	.06	.26	.09	17.17
1951	.29	.31	1.28	.27	3.76	.40	1.98	.02	.11	.13	.14	.06	8.75
1952	3.24	2.80	.20	1.70	11.72	.51	2.62	.26	.05	.00	.00	.00	23.10
1953	.62	.04	1.93	10.10	3.72	5.87	.37	.94	.00	.00	.00	.00	23.59
1954	.00	.39	3.20	21.08	63.38	.96	1.76	.04	.00	.00	.00	.00	90.81
1955	.00	1.56	.30	3.67	7.06	37.96	3.03	.03	.00	.00	.00	.00	53.61
1956	.02	4.22	1.38	.00	.45	.00	.00	.00	.14	.00	.00	2.89	9.10
1957	.68	.00	.10	1.74	.00	.12	.02	.00	.00	.00	.00	.00	2.66
1958	.00	.02	3.92	.13	.40	.00	.00	.00	.00	.00	.00	.00	4.47
1959	.00	.00	4.65	.11	9.34	7.61	1.58	.00	.00	.00	.26	.00	23.55
1960	.31	2.04	2.39	2.90	.55	6.07	20.90	.04	.10	.00	.00	.00	35.30
1961	.00	5.54	2.01	.82	2.79	2.38	.64	.07	.00	.00	.00	.00	14.25
1962	.00	5.99	1.23	11.90	.17	.26	3.15	.50	.01	.00	.00	.00	23.21
1963	.05	4.52	.56	.36	.00	.74	.00	.00	.00	.00	.00	.00	6.23
1964	3.10	.73	2.32	21.90	1.39	.00	.00	.00	.00	.00	.00	.00	29.44
1965	.00	.00	.00	15.70	29.70	15.40	.27	.00	.00	.00	.00	.00	61.07
1966	.00	1.90	4.97	23.50	52.20	22.50	13.70	6.33	2.22	.04	.00	.00	127.36
1967	.00	.62	.25	1.04	.10	16.70	1.81	4.40	.36	.29	.24	.23	26.04
1968	.31	.23	3.32	.12	4.09	2.34	.64	2.77	.23	.20	.21	.18	14.64
1969	1.44	.19	.18	.14	.20	.54	.22	8.89	.34	.30	.29	.22	12.95
1970	.33	.51	.77	5.79	2.82	1.25	.69	1.33	.23	.21	.29	.20	14.42
1971	1.70	2.19	2.64	23.00	6.03	24.20	3.17	.81	.63	.57	.32	.31	65.57
1972	.36	.27	.26	.22	1.97	.42	1.53	.08	.13	.54	.32	1.28	7.38
1973	.42	.16	1.05	12.40	27.00	32.00	78.20	18.10	1.36	.79	.80	.57	172.85
1974	.23	2.78	.55	14.20	35.60	51.80	51.70	26.30	5.00	2.96	1.42	.95	193.49
1975	.63	.53	5.88	237.00	90.40	126.00	29.90	34.50	6.17	3.63	2.28	1.44	538.36
1976	17.70	5.52	1.51	1.10	20.50	33.12	7.98	2.43	1.37	1.08	.76	1.07	94.14
1977	1.46	1.06	3.05	4.73	23.50	15.10	46.90	7.56	2.82	2.25	1.47	1.89	111.79
1978	.49	.11	.57	.85	1.18	.41	.42	.17	.31	.54	.51	.27	5.83
1979	1.02	.97	.70	.24	2.48	2.46	.13	.32	.33	.50	.49	.40	10.04
1980	.58	4.53	9.82	6.48	52.67	12.70	8.25	1.81	1.03	.74	.34	.08	99.03
1981	1.58	.99	.81	.93	1.33	1.29	.00	.00	.00	1.16	.82	.27	9.18
1982	.27	.70	3.17	.76	.01	.24	.01	.00	.00	.01	.00	.00	5.17
1983	.04	.86	.97	.41	.75	3.16	.17	.00	.00	.00	.00	.00	6.36
1984	2.92	4.33	.10	.36	4.18	2.91	.05	.04	.00	.00	.00	.00	14.89
1985	.00	.43	.78	3.82	6.15	.19	.00	.00	.00	.00	.00	.00	11.37
1986	.22	15.69	.41	.00	1.28	.23	.05	.00	.00	.00	.00	.44	18.32
1987	.51	.22	2.14	.83	78.91	61.56	12.87	.56	.06	.61	.16	.50	158.93
1988	2.84	.54	.43	10.67	18.16	10.10	1.47	3.27	.65	.51	.11	.09	48.84
1989	.26	.11	.07	.37	1.31	.33	.17	.00	.02	.07	.05	.02	2.78
1990	.04	.02	.03	62.54	30.98	4.42	.30	.12	.09	.11	.10	.06	98.81
AVERAGE	1.02	3.29	2.84	9.91	12.81	10.79	5.53	2.58	.42	.28	.24	.62	50.33

File H2 : C3H007.OBS - Observed flow at C3H007

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	5.32	6.48	4.96	6.03	7.93	30.72
1953	7.48	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	5.29	5.54	4.15	4.42	4.50	31.38
1954	3.71	4.58	-1.00	-1.00	-1.00	5.92	-1.00	6.13	4.99	3.05	5.21	5.01	38.60
1955	5.04	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	7.88	6.91	4.63	5.55	6.52	36.53
1956	3.42	-1.00	-1.00	6.12	-1.00	-1.00	4.45	4.95	-1.00	4.35	4.85	-1.00	28.14
1957	7.48	-1.00	-1.00	-1.00	-1.00	6.19	-1.00	-1.00	-1.00	4.83	6.45	6.69	31.64
1958	4.52	-1.00	-1.00	-1.00	-1.00	4.79	4.49	4.32	4.89	4.52	5.43	5.29	38.25
1959	4.32	3.46	-1.00	-1.00	-1.00	-1.00	-1.00	4.88	6.20	4.30	-1.00	-1.00	23.16
1960	5.13	-1.00	7.12	-1.00	-1.00	-1.00	-1.00	6.43	6.95	5.94	5.15	4.46	41.18
1961	4.18	-1.00	-1.00	3.51	-1.00	-1.00	-1.00	2.93	6.49	4.34	-1.00	-1.00	21.45
1962	3.21	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.96	4.02	5.72	4.95	4.24	26.10
1963	-1.00	-1.00	-1.00	3.28	3.27	5.31	2.42	2.35	2.95	2.38	2.94	2.83	27.73
1964	-1.00	2.82	5.03	-1.00	-1.00	3.63	2.90	3.13	3.81	3.67	3.47	-1.00	28.46
1965	3.87	4.02	1.79	-1.00	-1.00	-1.00	2.78	1.83	2.11	1.30	1.64	1.63	20.97
1966	1.83	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.98	3.96	3.59	13.36
1967	2.96	4.46	1.67	-1.00	1.48	-1.00	4.54	-1.00	3.79	2.30	2.35	1.79	25.34
1968	2.98	1.71	-1.00	1.54	-1.00	-1.00	2.57	-1.00	2.22	1.93	1.37	1.39	15.71
1969	-1.00	1.23	1.98	1.07	1.46	-1.00	1.01	-1.00	2.23	2.17	1.74	1.61	14.50
1970	2.07	-1.00	2.38	-1.00	-1.00	3.72	-1.00	4.28	1.72	1.73	1.91	1.82	19.63
1971	2.83	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2.78	2.99	3.04	2.59	2.22	16.45
1972	2.43	1.63	1.59	2.36	-1.00	3.24	-1.00	1.54	2.42	3.08	2.51	-1.00	20.80
1973	3.47	1.76	3.32	-1.00	-1.00	-1.00	-1.00	-1.00	5.87	5.70	4.78	4.08	28.98
1974	3.40	-1.00	4.52	-1.00	-1.00	-1.00	-1.00	-1.00	10.62	7.47	5.47	5.14	36.62
1975	4.16	3.33	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	7.56	5.92	20.97
1976	-1.00	-1.00	5.05	5.33	-1.00	-1.00	-1.00	5.33	4.85	5.60	5.29	6.84	38.29
1977	6.20	4.73	6.81	-1.00	-1.00	-1.00	-1.00	-1.00	6.95	6.00	5.84	5.68	42.21
1978	4.80	3.08	4.19	4.77	5.23	3.72	3.29	2.64	3.54	4.11	4.12	3.81	47.30
1979	4.70	-1.00	4.52	2.83	-1.00	-1.00	3.16	-1.00	3.59	5.17	5.08	5.37	34.42
1980	5.35	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.01	4.61	4.53	5.13	5.72	29.35
1981	5.34	-1.00	6.64	4.26	5.12	5.01	2.81	1.15	3.46	4.85	4.48	3.84	46.96
1982	4.59	4.48	-1.00	4.39	2.70	3.43	1.04	.83	1.30	1.39	1.27	1.85	27.27
1983	4.02	-1.00	-1.00	-1.00	7.45	-1.00	-1.00	.84	1.17	.83	.95	1.13	16.39
1984	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	.85	1.15	1.01	.91	.97	1.08	5.97
1985	1.93	2.24	3.18	-1.00	-1.00	1.80	.58	.45	.53	.67	.85	-1.00	12.23
1986	1.22	-1.00	1.51	.73	2.06	1.19	.72	.39	.50	.50	.59	2.69	12.10
1987	2.11	1.75	-1.00	1.84	-1.00	-1.00	-1.00	7.03	5.68	5.20	5.08	6.05	34.74
1988	-1.00	4.31	5.40	-1.00	-1.00	-1.00	4.93	8.51	4.02	4.02	4.04	3.71	38.94
1989	3.15	2.72	3.02	3.21	-1.00	3.09	2.69	1.66	2.77	4.67	5.36	3.44	35.78
1990	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.82	2.36	4.04	-1.00	-1.00	4.52	14.74
1991	5.77	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	5.77
AVERAGE	3.99	3.08	3.87	3.23	3.60	3.93	2.73	3.60	4.03	3.73	3.87	4.01	26.98

File H3 : C3R002.OBS - Observed inflow to Spitskop Dam

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1972	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1973	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1974	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	9.00	7.22	4.53	20.75
1975	3.73	4.58	19.57	463.39	202.09	384.09	63.45	46.75	13.60	10.93	4.97	8.07	1225.22
1976	20.61	9.96	3.63	6.91	23.36	81.99	14.71	4.17	5.81	5.84	5.45	7.49	189.93
1977	7.06	5.03	7.68	9.39	26.52	23.81	64.85	11.26	7.91	6.91	9.99	6.57	186.98
1978	5.05	5.70	3.91	6.00	6.20	6.57	3.89	3.40	3.15	2.73	3.94	3.81	54.35
1979	4.70	6.19	4.57	2.71	7.34	9.35	3.58	3.21	3.72	5.10	5.24	5.25	60.96
1980	6.88	3.08	16.18	9.81	87.46	26.66	20.40	5.26	5.13	4.80	5.79	6.07	197.52
1981	5.86	9.63	7.85	3.73	5.41	5.35	3.31	2.62	3.77	4.44	4.56	3.81	60.34
1982	4.53	4.41	8.32	4.57	3.40	3.57	1.49	.94	1.44	1.26	1.39	2.14	37.46
1983	3.21	6.35	8.37	6.17	6.38	3.80	4.79	.39	1.25	.99	.80	.90	43.40
1984	3.74	5.57	1.55	.75	7.02	9.15	.48	1.05	1.04	.69	.91	.52	32.47
1985	2.80	2.29	3.46	5.19	8.94	.59	.38	.18	.32	.45	.73	2.01	27.34
1986	.87	25.71	.97	.60	1.78	.58	.51	.17	.59	.31	.37	2.29	34.75
1987	.89	.60	11.78	.86	814.72	428.59	35.31	3.86	5.68	5.20	5.08	6.05	1318.62
1988	8.45	2.27	4.51	43.79	24.97	23.55	5.26	9.55	4.22	3.59	3.48	3.70	137.34
1989	2.53	2.19	2.42	1.81	4.85	2.77	1.41	1.60	1.64	2.52	4.98	2.45	31.17
1990	2.06	1.30	4.27	38.56	57.56	22.14	3.05	1.78	3.19	2.67	4.34	3.94	144.86
AVERAGE	5.19	5.93	6.82	37.76	80.50	64.53	14.18	6.01	3.90	3.97	4.07	4.09	223.73

File H4 : C3R002DI.OBS - Observed outflow from Spitskop Dam

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1972	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1973	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1974	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	12.29	10.55	9.81	32.65
1975	6.52	9.52	3.90	425.76	216.80	375.77	71.74	46.70	11.04	10.03	2.79	8.16	1188.73
1976	15.90	5.48	4.31	3.71	14.13	82.38	12.25	4.47	3.80	3.90	3.87	3.70	157.90
1977	3.49	2.64	2.80	2.60	21.48	20.63	63.47	10.00	6.00	5.00	8.55	3.37	150.03
1978	3.98	3.89	3.59	3.09	3.23	3.55	2.84	2.31	2.36	1.80	4.24	-1.00	34.88
1979	-1.00	5.24	3.81	3.17	2.69	1.87	1.71	1.81	1.82	3.13	2.63	5.38	33.26
1980	11.05	3.70	4.00	3.99	56.24	24.09	19.03	4.99	3.41	3.13	3.71	5.65	142.99
1981	15.32	14.95	3.02	11.25	4.86	3.60	3.82	2.84	2.06	2.46	2.38	4.18	70.74
1982	4.20	4.36	4.10	3.35	3.02	3.36	2.13	1.63	.54	.61	1.69	2.56	31.55
1983	3.65	5.36	9.40	5.61	5.90	2.13	.38	.27	.69	.60	1.10	1.30	36.39
1984	1.78	1.97	1.54	2.27	1.72	.69	1.50	.75	.67	1.05	1.30	1.80	17.04
1985	2.95	1.61	1.49	2.07	1.85	2.14	.74	.32	.44	.76	.64	1.28	16.29
1986	.91	.89	2.34	2.40	1.98	2.46	.74	.65	.41	.84	1.00	.84	15.46
1987	1.55	2.03	1.09	1.88	-1.00	-1.00	-1.00	-1.00	4.84	3.75	4.29	4.57	24.00
1988	5.20	6.13	3.84	39.14	7.61	21.90	8.54	8.89	4.45	1.73	1.76	2.04	111.23
1989	2.54	2.51	1.87	1.97	1.95	2.03	.85	.71	.72	.85	1.10	1.36	18.46
1990	3.11	2.60	1.49	2.49	39.78	21.77	2.80	1.02	.67	.95	.86	.97	78.51
AVERAGE	5.48	4.55	3.29	32.17	25.55	37.89	12.84	5.82	2.74	3.11	3.09	3.56	127.07

File H5 : C3R002.FLW - Patched outflow from Spitskop Dam

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1938	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1939	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1940	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1941	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1942	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1943	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1944	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1945	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1946	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1947	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1948	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1949	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1950	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1951	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1952	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1953	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1954	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1955	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1956	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1957	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1958	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1959	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1960	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1961	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1962	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1963	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1964	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1965	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1966	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1967	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1968	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1969	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1970	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1971	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1972	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1973	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1974	.00	.00	.00	.00	.00	.00	.00	.00	.00	12.29	10.55	9.81	32.65
1975	6.52	9.52	3.90	425.76	216.80	375.77	71.74	46.70	11.04	10.03	2.79	8.16	1188.73
1976	15.90	5.48	4.31	3.71	14.13	82.38	12.25	4.47	3.80	3.90	3.87	3.70	157.90
1977	3.49	2.64	2.80	2.60	21.48	20.63	63.47	10.00	6.00	5.00	8.55	3.37	150.03
1978	3.98	3.89	3.59	3.09	3.23	3.55	2.84	2.31	2.36	1.80	4.24	6.71	41.59
1979	4.92	5.24	3.81	3.17	2.69	1.87	1.71	1.81	1.82	3.13	2.63	5.38	38.18
1980	11.05	3.70	4.00	3.99	56.24	24.09	19.03	4.99	3.41	3.13	3.71	5.65	142.99
1981	15.32	14.95	3.02	11.25	4.86	3.60	3.82	2.84	2.06	2.46	2.38	4.18	70.74
1982	4.20	4.36	4.10	3.35	3.02	3.36	2.13	1.63	.54	.61	1.69	2.56	31.55
1983	3.65	5.36	9.40	5.61	5.90	2.13	.38	.27	.69	.60	1.10	1.30	36.39
1984	1.78	1.97	1.54	2.27	1.72	.69	1.50	.75	.67	1.05	1.30	1.80	17.04
1985	2.95	1.61	1.49	2.07	1.85	2.14	.74	.32	.44	.76	.64	1.28	16.29
1986	.91	.89	2.34	2.40	1.98	2.46	.74	.65	.41	.84	1.00	.84	15.46
1987	1.55	2.03	1.09	1.88	861.29	428.51	35.28	3.75	4.84	3.75	4.29	4.57	1352.83
1988	5.20	6.13	3.84	39.14	7.61	21.90	8.54	8.89	4.45	1.73	1.76	2.04	111.23
1989	2.54	2.51	1.87	1.97	1.95	2.03	.85	.71	.72	.85	1.10	1.36	18.46
1990	3.11	2.60	1.49	2.49	39.78	21.77	2.80	1.02	.67	.95	.86	.97	78.51
AVERAGE	1.28	1.07	.77	7.57	18.30	14.66	3.35	1.34	.65	.78	.77	.94	205.92

File H6 : C3H013.OBS - Observed flow at C3H013

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	3.01	1.17	-1.00	4.23	-1.00	3.16	1.62	1.46	1.14	15.79
1968	1.69	1.04	5.60	1.22	4.24	-1.00	3.03	5.37	1.89	1.32	1.13	.91	27.44
1969	3.74	.96	1.24	1.22	-1.00	2.88	1.19	4.15	1.71	1.85	1.31	1.08	21.33
1970	1.58	1.79	2.47	-1.00	-1.00	3.24	4.10	4.19	1.72	1.40	1.78	1.74	24.01
1971	2.16	2.70	-1.00	-1.00	-1.00	-1.00	-1.00	3.18	2.88	3.19	2.28	1.90	18.29
1972	1.90	1.55	1.15	2.19	-1.00	4.03	4.60	2.10	2.80	3.21	2.69	2.41	28.63
1973	3.84	-1.00	3.27	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	5.67	5.84	4.50	23.12
1974	3.85	4.87	5.00	3.48	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	17.20
1975	-1.00	-1.00	6.09	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	6.09
1976	-1.00	-1.00	4.22	3.66	-1.00	-1.00	-1.00	5.77	3.77	3.87	3.81	3.65	28.75
1977	3.38	2.55	2.70	2.49	-1.00	-1.00	-1.00	-1.00	5.07	4.78	4.19	3.32	28.48
1978	3.91	3.79	3.49	3.03	3.19	3.51	-1.00	2.28	2.33	-1.00	4.24	-1.00	29.77
1979	-1.00	5.15	-1.00	3.08	-1.00	1.85	1.67	1.78	1.79	3.10	2.57	5.33	26.32
1980	-1.00	5.89	-1.00	-1.00	-1.00	-1.00	-1.00	3.91	3.38	3.10	3.67	5.56	25.51
1981	-1.00	-1.00	2.97	-1.00	-1.00	3.56	3.82	2.81	2.03	2.43	2.31	4.09	24.02
1982	4.11	4.27	3.98	3.27	2.98	3.32	2.09	1.60	.52	.58	1.62	2.48	30.82
1983	3.63	5.29	9.32	5.52	5.85	2.13	.35	.24	.67	.57	1.03	1.21	35.81
1984	1.71	1.91	1.42	2.21	1.68	.66	1.46	.72	.64	1.02	1.23	1.72	16.38
1985	2.89	1.51	1.41	2.01	1.81	2.09	.70	.29	.42	.73	.58	1.21	15.65
1986	.82	.82	2.22	2.31	1.94	2.42	.72	.62	.38	.81	.93	.80	14.79
1987	1.46	1.93	1.01	1.78	-1.00	-1.00	-1.00	-1.00	4.82	3.72	4.22	4.50	23.44
1988	5.12	6.05	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.44	1.70	1.73	1.98	21.02
1989	-1.00	2.37	1.85	1.93	1.92	2.01	1.32	.62	.82	1.20	1.38	1.76	17.18
1990	3.04	2.67	-1.00	-1.00	-1.00	-1.00	2.83	1.42	.75	1.53	1.60	1.97	15.81
1991	2.23	2.10	2.46	3.71	3.74	2.45	1.83	1.55	1.28	1.30	1.82	-1.00	24.47
AVERAGE	2.84	2.96	3.26	2.71	2.85	2.63	2.26	2.37	2.15	2.21	2.32	2.54	22.40

File H7 : NCANIRRM.SUP - Irrigation supply to the North Canal area

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1938	1.69	1.02	1.00	1.46	1.09	.93	.43	.57	.81	.69	1.22	1.51	12.42
1939	4.07	2.46	2.39	3.49	2.62	2.23	1.04	1.36	1.95	1.65	2.94	3.62	29.82
1940	6.44	3.90	3.80	5.53	4.17	3.55	1.66	2.16	3.09	2.62	4.67	5.72	47.31
1941	8.82	5.33	5.19	7.57	5.71	4.85	2.27	2.95	4.22	3.59	6.38	7.84	64.72
1942	11.19	6.77	6.59	9.61	7.24	6.16	2.87	3.75	5.37	4.56	8.11	9.95	82.17
1943	13.57	8.21	7.99	11.65	8.77	7.47	3.48	4.54	6.50	5.52	9.82	12.06	99.58
1944	16.28	9.85	9.59	13.97	10.53	8.96	4.18	5.45	7.80	6.62	11.79	14.47	119.49
1945	19.12	11.29	11.95	16.37	12.34	10.47	5.47	6.32	9.23	8.52	13.52	17.33	141.93
1946	21.56	12.72	13.47	18.45	13.91	11.81	6.17	7.12	10.41	9.61	15.24	19.54	160.01
1947	23.99	14.16	15.00	20.53	15.47	13.14	6.87	7.92	11.58	10.69	16.97	21.75	178.07
1948	26.42	15.60	16.52	22.62	17.05	14.47	7.56	8.72	12.76	11.78	18.68	23.95	196.13
1949	28.86	17.03	18.04	24.70	18.62	15.81	8.26	9.53	13.93	12.87	20.41	26.16	214.22
1950	29.90	17.65	18.69	25.59	19.29	16.38	8.56	9.87	14.43	13.33	21.14	27.11	221.94
1951	31.29	18.47	19.56	25.95	20.19	17.14	8.96	10.33	15.11	13.95	22.12	28.37	231.44
1952	32.33	19.09	20.21	27.67	20.87	17.72	9.25	10.68	15.61	14.42	22.87	29.31	240.03
1953	33.72	19.91	21.08	28.87	21.76	18.47	9.65	11.14	16.28	15.03	23.85	30.57	250.33
1954	34.77	20.52	21.73	29.76	22.43	19.05	9.95	11.48	16.78	15.50	24.58	31.52	258.07
1955	41.47	21.13	11.37	28.00	21.17	5.83	15.07	26.93	18.78	17.21	33.72	32.18	272.86
1956	40.87	21.74	20.30	37.91	23.59	17.81	9.99	28.32	15.89	4.68	20.39	20.67	262.16
1957	30.39	30.83	23.73	11.45	26.88	22.98	12.22	21.85	24.16	17.31	34.73	36.58	293.11
1958	45.42	23.67	22.41	27.35	15.45	26.23	28.20	12.35	18.78	17.77	34.18	38.42	310.23
1959	39.23	24.27	17.58	32.17	18.79	17.83	13.20	11.92	22.52	9.90	30.14	35.62	273.17
1960	36.78	24.80	26.22	26.07	33.83	21.10	9.79	16.32	10.44	16.91	21.46	33.03	276.75
1961	44.38	19.96	23.64	41.63	17.92	24.12	14.77	20.96	20.62	21.45	34.46	43.66	327.57
1962	36.23	12.27	17.17	13.28	16.51	25.51	4.31	11.67	12.93	14.20	24.19	36.22	224.49
1963	44.69	14.62	21.11	49.37	34.74	30.77	18.96	19.48	17.40	11.71	24.10	32.50	319.45
1964	22.12	31.28	28.23	26.41	37.25	40.32	16.42	20.67	15.12	17.13	28.29	36.67	319.91
1965	33.97	19.84	28.53	34.42	10.72	37.34	16.32	18.33	15.69	10.97	24.19	22.36	272.68
1966	21.98	5.10	15.03	22.34	3.79	16.67	5.01	17.79	4.00	16.81	21.65	31.47	181.64
1967	35.29	16.12	26.94	39.27	40.96	18.49	9.13	14.04	16.27	14.04	23.67	36.31	290.53
1968	35.37	27.47	18.43	38.69	28.29	11.53	8.97	8.17	9.86	14.56	18.86	29.39	249.59
1969	22.58	21.82	35.27	42.33	33.12	29.12	16.29	9.87	20.82	7.34	26.21	35.24	300.01
1970	33.77	20.93	22.86	13.43	15.22	35.17	8.16	6.87	18.91	12.82	27.65	37.32	253.11
1971	30.26	21.49	26.28	19.42	35.75	14.71	5.72	7.05	20.32	17.87	25.40	33.02	257.29
1972	36.81	26.20	35.45	44.85	18.37	22.32	6.43	12.32	20.13	8.85	11.81	25.64	269.18
1973	31.69	22.52	16.53	16.30	4.27	1.86	1.05	1.14	10.22	16.37	10.47	23.45	155.87
1974	38.30	9.23	22.75	33.50	13.52	2.48	8.03	4.82	13.97	17.02	22.64	36.49	222.75
1975	43.66	16.97	9.06	3.73	9.74	3.47	4.95	4.38	12.35	14.87	21.68	32.05	176.91
1976	20.41	22.47	26.72	27.40	13.39	6.61	6.78	8.90	19.78	17.68	25.38	26.37	221.89
1977	35.71	27.11	18.96	27.58	19.22	13.56	2.82	6.01	18.04	16.45	28.31	28.30	242.07
1978	38.65	24.07	27.02	28.99	21.32	27.10	10.21	7.31	17.83	17.07	17.91	29.80	267.28
1979	38.75	10.76	30.59	46.39	38.39	5.09	11.90	10.59	21.87	23.27	27.09	32.12	296.81
1980	38.48	17.03	22.57	30.24	9.06	12.20	11.97	6.78	20.52	21.18	19.57	32.17	241.77
1981	43.28	26.63	12.33	42.76	39.46	26.66	5.57	8.67	21.37	17.11	28.81	39.76	312.41
1982	36.22	22.26	19.49	39.85	36.33	29.02	6.60	5.22	8.07	6.92	11.33	18.08	239.39
1983	16.53	17.17	7.66	21.18	31.53	13.65	2.13	3.72	14.54	10.76	19.97	24.29	183.13
1984	23.97	17.85	10.75	25.46	9.99	6.01	4.84	5.05	16.22	12.59	25.05	25.61	183.39
1985	32.39	9.24	7.54	17.60	9.55	10.36	8.49	9.40	13.26	12.30	20.82	21.23	172.18
1986	24.99	4.51	16.12	16.36	14.27	17.19	8.51	9.02	17.54	16.63	20.03	22.50	187.67
1987	35.04	25.52	27.70	37.41	25.72	5.97	1.81	4.72	18.49	16.56	32.57	27.56	259.07
1988	24.88	18.52	13.52	9.32	21.33	23.30	8.12	3.67	13.92	13.82	17.90	34.24	202.54
1989	31.97	26.21	16.54	21.14	17.86	19.14	4.93	4.45	16.78	13.32	25.53	25.83	223.70
1990	42.01	19.79	20.16	18.76	9.45	12.72	11.83	11.48	12.79	20.30	19.59	31.37	230.25
AVERAGE	23.13	13.61	14.11	19.21	14.69	12.39	6.41	7.56	11.12	10.10	16.24	20.86	217.37

File H8: WCANIRRM.SUP - Irrigation supply to the West Canal area

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	-1.00
1938	.34	.20	.20	.29	.22	.19	.09	.11	.16	.14	.24	.30	2.48
1939	.81	.49	.48	.70	.52	.45	.21	.27	.39	.33	.59	.72	5.96
1940	1.29	.78	.76	1.11	.83	.71	.33	.43	.62	.52	.93	1.14	9.45
1941	1.76	1.07	1.04	1.51	1.14	.97	.45	.59	.84	.72	1.28	1.57	12.94
1942	2.24	1.35	1.32	1.92	1.45	1.23	.57	.75	1.07	.91	1.62	1.99	16.42
1943	2.71	1.64	1.60	2.33	1.75	1.49	.70	.91	1.30	1.10	1.96	2.41	19.90
1944	3.26	1.97	1.92	2.79	2.11	1.79	.84	1.09	1.56	1.32	2.36	2.89	23.90
1945	3.82	2.26	2.39	3.27	2.47	2.09	1.09	1.26	1.85	1.70	2.70	3.47	28.37
1946	4.31	2.54	2.69	3.69	2.78	2.36	1.23	1.42	2.08	1.92	3.05	3.91	31.98
1947	4.80	2.83	3.00	4.11	3.09	2.63	1.37	1.58	2.32	2.14	3.39	4.35	35.61
1948	5.28	3.12	3.30	4.52	3.41	2.89	1.51	1.74	2.55	2.36	3.74	4.79	39.21
1949	5.77	3.41	3.61	4.94	3.72	3.16	1.65	1.91	2.79	2.57	4.08	5.23	42.84
1950	5.98	3.53	3.74	5.12	3.86	3.28	1.71	1.97	2.89	2.67	4.23	5.42	44.40
1951	6.26	3.69	3.91	5.19	4.04	3.43	1.79	2.07	3.02	2.79	4.42	5.67	46.28
1952	6.47	3.82	4.04	5.53	4.17	3.54	1.85	2.14	3.12	2.88	4.57	5.86	47.99
1953	6.74	3.98	4.22	5.77	4.35	3.69	1.93	2.23	3.26	3.01	4.77	6.11	50.06
1954	6.95	4.10	4.35	5.95	4.49	3.81	1.99	2.30	3.36	3.10	4.92	6.30	51.62
1955	8.29	4.23	2.27	5.60	4.23	1.17	3.01	5.39	3.76	3.44	6.74	6.44	54.57
1956	8.17	4.35	4.06	7.58	4.72	3.56	2.00	5.66	3.18	.94	4.08	4.13	52.43
1957	6.08	6.17	4.75	2.29	5.38	4.60	2.44	4.37	4.83	3.46	6.95	7.32	58.64
1958	9.08	4.73	4.48	5.47	3.09	5.25	5.64	2.47	3.76	3.55	6.84	7.68	62.04
1959	7.85	4.85	3.52	6.43	3.76	3.57	2.64	2.38	4.50	1.98	6.03	7.12	54.63
1960	7.36	4.96	5.24	5.21	6.77	4.22	1.96	3.26	2.09	3.38	4.29	6.61	55.35
1961	8.88	3.99	4.73	8.33	3.58	4.82	2.95	4.19	4.12	4.29	6.89	8.73	65.50
1962	7.25	2.45	3.43	2.66	3.30	5.10	.86	2.33	2.59	2.84	4.84	7.24	44.89
1963	8.94	2.92	4.22	9.87	6.95	6.15	3.79	3.90	3.48	2.34	4.82	6.50	63.88
1964	4.42	6.26	5.65	5.28	7.45	8.06	3.28	4.13	3.02	3.43	5.66	7.33	63.97
1965	6.79	3.97	5.71	6.88	2.14	7.47	3.26	3.67	3.14	2.19	4.84	4.47	54.53
1966	4.40	1.02	3.01	4.47	.76	3.33	1.00	3.56	.80	3.36	4.33	6.29	36.33
1967	7.06	3.22	5.39	7.85	8.19	3.70	1.83	2.81	3.25	2.81	4.73	7.26	58.10
1968	7.07	5.49	3.69	7.74	5.66	2.31	1.79	1.63	1.97	2.91	3.77	5.88	49.91
1969	4.52	4.36	7.05	8.47	6.62	5.82	3.26	1.97	4.16	1.47	5.24	7.05	59.99
1970	6.75	4.19	4.57	2.69	3.04	7.03	1.63	1.37	3.78	2.56	5.53	7.46	50.60
1971	6.05	4.30	5.26	3.88	7.15	2.94	1.14	1.41	4.06	3.57	5.08	6.60	51.44
1972	7.36	5.24	7.09	8.97	3.67	4.46	1.29	2.46	4.03	1.77	2.36	5.13	53.83
1973	6.34	4.50	3.31	3.26	.85	.37	.21	.23	2.04	3.27	2.09	4.69	31.16
1974	7.66	1.85	4.55	6.70	2.70	.50	1.61	.96	2.79	3.40	4.53	7.30	44.55
1975	8.73	3.39	1.81	.75	1.95	.69	.99	.88	2.47	2.97	4.34	6.41	35.38
1976	4.08	4.49	5.34	5.48	2.68	1.32	1.36	1.78	3.96	3.54	5.08	5.27	44.38
1977	7.14	5.42	3.79	5.52	3.84	2.71	.56	1.20	3.61	3.29	5.66	5.66	48.40
1978	7.73	4.81	5.40	5.80	4.26	5.42	2.04	1.46	3.57	3.41	3.58	5.96	53.44
1979	7.75	2.15	6.12	9.28	7.68	1.02	2.38	2.12	4.37	4.65	5.42	6.42	59.36
1980	7.70	3.41	4.51	6.05	1.81	2.44	2.39	1.36	4.10	4.24	3.91	6.43	48.35
1981	8.66	5.33	2.47	8.55	7.89	5.33	1.11	1.73	4.27	3.42	5.76	7.95	62.47
1982	7.24	4.45	3.90	7.97	7.27	5.80	1.32	1.04	1.61	1.38	2.27	3.62	47.87
1983	3.31	3.43	1.53	4.24	6.31	2.73	.43	.74	2.91	2.15	3.99	4.86	36.63
1984	4.79	3.57	2.15	5.09	2.00	1.20	.97	1.01	3.24	2.52	5.01	5.12	36.67
1985	6.48	1.85	1.51	3.52	1.91	2.07	1.70	1.88	2.65	2.46	4.16	4.25	34.44
1986	5.00	.90	3.22	3.27	2.85	3.44	1.70	1.80	3.51	3.33	4.01	4.50	37.53
1987	7.01	5.10	5.54	7.48	5.14	1.19	.36	.94	3.70	3.31	6.51	5.51	51.79
1988	4.98	3.70	2.70	1.86	4.27	4.66	1.62	.73	2.78	2.76	3.58	6.85	40.49
1989	6.39	5.24	3.31	4.23	3.57	3.83	.99	.89	3.36	2.66	5.11	5.17	44.75
1990	8.40	3.96	4.03	3.75	1.89	2.54	2.37	2.30	2.56	4.06	3.92	6.27	46.05
AVERAGE	4.63	2.72	2.82	3.84	2.94	2.48	1.28	1.51	2.22	2.02	3.25	4.17	43.47

H.9

File H9 : C3H007L3.RET - Return flow from the North Canal irrigation area

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.27	6.41	4.96	6.03	7.93	29.60
1953	6.86	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.34	5.54	4.15	4.42	4.50	29.81
1954	3.71	4.19	-1.00	-1.00	-1.00	-1.00	-1.00	6.09	4.99	3.05	5.21	5.01	32.25
1955	5.04	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	7.46	6.90	4.63	5.55	6.52	36.10
1956	3.40	-1.00	-1.00	-1.00	-1.00	-1.00	4.38	4.95	-1.00	3.77	4.84	-1.00	21.34
1957	5.58	-1.00	-1.00	-1.00	-1.00	5.67	-1.00	-1.00	-1.00	4.83	6.45	6.69	29.22
1958	4.52	-1.00	-1.00	-1.00	-1.00	4.26	4.48	4.32	4.89	4.52	5.43	5.29	37.71
1959	4.32	3.45	-1.00	-1.00	-1.00	-1.00	-1.00	4.36	6.19	4.30	-1.00	-1.00	22.62
1960	4.82	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.13	6.79	5.87	5.12	4.46	30.19
1961	4.18	-1.00	-1.00	2.61	-1.00	-1.00	-1.00	2.84	6.49	4.34	-1.00	-1.00	20.46
1962	3.21	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2.99	4.00	5.72	4.95	4.24	25.11
1963	-1.00	-1.00	-1.00	2.87	3.27	-1.00	1.68	2.34	2.95	2.38	2.94	2.83	21.26
1964	-1.00	1.96	-1.00	-1.00	-1.00	3.61	2.90	3.13	3.81	3.67	3.47	-1.00	22.55
1965	3.87	3.90	1.73	-1.00	-1.00	-1.00	2.49	1.83	2.11	1.30	1.64	1.63	20.50
1966	1.83	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.94	3.96	3.59	13.32
1967	2.96	3.75	1.38	-1.00	1.38	-1.00	-1.00	-1.00	3.24	2.01	2.11	1.56	18.39
1968	2.67	1.48	-1.00	1.06	-1.00	-1.00	1.74	-1.00	1.97	1.73	1.16	1.21	13.02
1969	-1.00	.85	1.80	.83	1.09	-1.00	.79	-1.00	1.89	1.87	1.45	1.39	11.96
1970	1.74	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.47	1.52	1.62	1.62	7.97
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2.35	2.47	2.27	1.91	9.00
1972	2.07	1.36	1.33	2.14	-1.00	-1.00	-1.00	1.24	2.29	2.54	2.19	-1.00	15.16
1973	2.96	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.49	4.91	3.98	3.51	19.85
1974	3.17	-1.00	2.84	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.05	4.19	14.25
1975	3.53	2.52	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.48	10.53
1976	-1.00	-1.00	2.60	-1.00	-1.00	-1.00	-1.00	-1.00	3.48	4.52	4.53	5.61	20.74
1977	4.67	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	4.37	-1.00	9.04
1978	4.31	2.97	3.62	.52	-1.00	3.27	2.87	2.47	3.23	3.57	3.08	3.29	33.20
1979	-1.00	-1.00	3.56	2.50	-1.00	-1.00	3.00	-1.00	3.26	4.67	4.59	4.93	26.51
1980	4.75	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.58	3.79	4.79	5.64	22.55
1981	-1.00	-1.00	-1.00	-1.00	3.74	-1.00	2.62	1.08	3.46	-1.00	3.66	3.57	18.13
1982	4.03	3.64	-1.00	2.90	2.36	3.18	1.03	.83	1.30	1.38	1.27	1.85	23.77
1983	3.92	-1.00	-1.00	-1.00	6.68	-1.00	-1.00	.82	1.17	.83	.95	1.13	15.50
1984	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	.62	1.11	1.01	.91	.97	1.08	5.70
1985	1.10	1.27	-1.00	-1.00	-1.00	1.57	.58	.45	.53	.67	.85	-1.00	7.02
1986	.95	-1.00	-1.00	.64	-1.00	-1.00	.63	.39	.50	.50	.59	1.12	5.32
1987	-1.00	1.52	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	5.58	4.59	4.92	5.55	22.16
1988	-1.00	2.75	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	3.36	3.51	3.93	3.62	17.17
1989	2.89	2.61	2.95	2.73	-1.00	1.92	-1.00	.71	2.73	4.60	5.31	3.42	29.87
1990	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2.19	3.95	-1.00	-1.00	4.46	10.60
AVERAGE	3.59	2.55	2.42	1.88	3.09	3.35	2.13	2.75	3.51	3.29	3.50	3.68	19.99

File H10 : UHRTQ9.ANS - Inflow from the UH sub-system

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	6.63	.26	.81	5.18	16.09	.74	.46	.00	.00	.00	1.32	31.49
1924	1.47	6.29	17.59	1.88	6.04	35.77	10.26	13.69	.98	.00	.00	.00	93.97
1925	.00	.00	.00	.00	.00	3.03	2.26	.00	.00	.00	.00	.00	5.29
1926	.45	1.75	4.56	4.86	3.69	3.30	.00	.00	.00	.00	.00	.00	18.61
1927	.32	.00	7.46	10.65	2.69	12.07	5.30	.00	.00	.00	.00	.00	38.49
1928	.00	2.55	1.36	3.58	.04	31.08	.99	.00	.02	.00	.00	8.83	48.45
1929	.06	.05	3.93	2.15	.34	.32	.14	.00	.00	.00	.00	.00	6.99
1930	.00	.87	2.40	4.42	6.33	19.21	13.58	.00	.00	.00	.00	.00	46.81
1931	6.98	15.35	.00	3.96	6.24	8.32	.00	.00	.00	.00	.00	.45	41.30
1932	.00	.66	2.72	.58	8.02	.70	2.64	.00	.00	.00	.00	.00	15.32
1933	.00	.98	12.95	58.86	33.32	2.03	8.02	.00	.00	.00	.00	.00	116.16
1934	.48	16.40	7.21	1.00	.00	2.87	4.16	.00	.00	.00	.00	.00	32.12
1935	.00	.69	3.46	6.72	2.64	15.38	6.29	1.77	.00	.00	.00	.03	36.98
1936	.00	63.87	.15	30.77	6.59	.24	.64	.00	.00	.00	.06	.00	102.32
1937	.01	.00	5.82	.51	.97	.26	.00	.00	.00	.04	.07	.05	7.73
1938	.12	.00	.25	1.61	9.74	5.57	.63	.00	.00	.15	.00	.08	18.15
1939	1.75	7.01	.44	.06	.05	2.87	.13	.00	.07	.13	.07	.06	12.64
1940	.12	.00	1.29	4.72	27.29	.35	.00	.00	.04	.14	.00	.05	34.00
1941	.08	.00	.22	.46	5.35	5.08	1.89	.00	.00	.00	.55	.01	13.64
1942	8.72	2.66	14.27	2.05	.73	1.91	12.86	15.24	.16	.01	2.13	14.41	75.15
1943	.13	3.20	19.28	5.64	131.06	3.58	.41	.00	1.57	.72	.04	.53	166.16
1944	1.36	.68	.00	.96	.44	10.30	.66	.64	.30	.02	.00	.00	15.36
1945	.00	.00	.00	9.38	2.98	12.66	.40	.03	.00	.00	.00	.00	25.45
1946	.10	10.17	.95	2.52	1.30	4.98	1.63	.46	.01	.05	.10	.00	22.27
1947	.13	2.37	7.72	5.31	7.35	20.55	1.17	.00	.00	.00	.00	.00	44.60
1948	.00	3.97	.05	.55	2.32	2.34	.00	.00	.00	.00	.00	.00	9.23
1949	.00	.00	3.95	2.09	3.30	9.61	4.12	20.29	.97	.24	.09	1.09	45.75
1950	.00	.00	8.77	4.37	.67	2.26	.55	.72	.09	.00	.01	.00	17.44
1951	.61	.31	.52	.01	4.60	.40	1.61	.00	.00	.03	.00	.00	8.09
1952	1.55	4.32	.87	1.48	11.93	.51	2.62	.01	.00	.00	.00	.00	23.29
1953	.09	.00	1.59	11.14	3.72	5.87	.37	.75	.00	.00	.00	.00	23.53
1954	.00	.00	2.80	21.91	63.38	.96	1.69	.00	.00	.00	.00	.00	90.74
1955	.00	.21	1.66	3.67	7.06	37.96	3.03	.03	.00	.01	.02	.03	53.68
1956	.05	4.14	1.38	.00	.45	.01	.02	.00	.11	.03	.00	2.86	9.05
1957	1.15	.00	.10	1.74	.00	.12	.02	.00	.00	.05	.00	.00	3.18
1958	.00	.30	3.60	.13	.40	.00	.00	.00	.00	.00	.00	.00	4.43
1959	.00	.00	4.36	.40	9.34	7.61	1.58	.00	.00	.00	.02	.00	23.31
1960	.00	1.61	3.25	2.90	.55	6.07	20.90	.04	.10	.03	.00	.00	35.45
1961	.00	5.51	2.01	.68	2.85	2.38	.64	.07	.00	.00	.00	.00	14.14
1962	.00	5.99	1.23	11.90	.17	.26	3.15	.50	.00	.05	.06	.11	23.42
1963	.13	4.29	.56	.00	.00	.61	.00	.00	.00	.00	.00	.00	5.59
1964	2.27	.49	3.19	22.28	1.39	.00	.00	.00	.00	.04	.02	.01	29.69
1965	.07	.13	.00	15.52	29.70	15.40	.01	.01	.00	.20	.18	.13	61.35
1966	.01	.28	2.28	27.70	52.20	22.50	13.70	6.33	2.18	.12	.02	.05	127.37
1967	.04	.36	.12	.24	.00	17.73	1.81	4.40	.36	.09	.01	.00	25.16
1968	.00	.00	4.27	.12	4.09	2.34	.64	2.77	.23	.03	.07	.10	14.66
1969	.33	.00	.00	.15	.31	.02	.00	8.04	.20	.14	.01	.00	9.20
1970	.00	.00	1.89	7.96	2.82	1.25	.69	1.33	.01	.04	.03	.00	16.02
1971	.61	2.23	4.28	23.00	6.03	24.20	3.17	.80	.49	.41	.03	.00	65.25
1972	.00	.00	.00	.00	3.45	.42	1.53	.08	.00	.31	.02	1.82	7.63
1973	.42	.16	1.05	12.40	27.00	32.00	78.20	18.10	1.28	.63	.60	.14	171.98
1974	.00	3.69	.55	14.20	35.60	51.80	51.70	26.30	4.99	2.89	1.20	.49	193.41
1975	.05	.50	7.04	237.00	90.40	126.00	29.90	34.50	6.09	3.50	2.01	1.16	538.15
1976	18.33	5.51	1.51	1.10	20.50	33.12	7.98	2.43	1.18	.88	.46	1.03	94.03
1977	1.20	1.82	3.05	4.73	23.50	15.10	46.90	7.56	2.81	2.09	1.14	1.35	111.25
1978	.88	.00	.02	1.91	1.18	.03	.09	.00	.02	.33	1.37	.38	6.21
1979	.78	1.39	.70	.24	2.48	2.46	.00	.01	.08	.32	.23	.19	8.88
1980	.11	6.04	9.82	6.48	52.67	12.70	8.25	1.71	.88	.57	.17	.00	99.40
1981	.94	1.05	1.85	.93	1.33	1.29	.01	.31	.25	.40	.21	.01	8.58
1982	.90	1.15	2.89	.82	.00	.00	.00	.00	.00	.01	.00	.00	5.77
1983	.03	.09	.42	.40	.51	4.13	.47	.00	.00	.00	.00	.00	6.05
1984	2.29	4.43	.00	.85	4.52	2.91	.05	.00	.00	.00	.00	.00	15.05
1985	.17	.08	.56	4.24	6.15	.19	.00	.00	.00	.00	.00	.00	11.39
1986	.22	15.69	.41	.01	1.27	.23	.00	.00	.00	.00	.00	.31	18.14
1987	.67	.00	2.32	.83	78.91	61.56	12.87	.56	.05	.52	.02	.09	158.40
1988	3.47	.54	.43	10.67	18.16	10.10	1.47	3.27	.54	.38	.01	.00	49.04
1989	.00	.68	.07	.37	1.31	.33	.17	.01	.00	.01	.00	.00	2.95
1990	.00	.00	.00	62.72	30.98	4.42	.30	.00	.02	.01	.00	.01	98.46
AVERAGE	.88	3.22	2.94	10.05	12.88	10.85	5.51	2.55	.38	.23	.16	.55	50.19

File H11 : NCLOSSES.FLW - Irrigation losses in the North Canal area determined from crop water balance

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1924	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1925	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1926	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1927	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1928	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1929	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1930	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1931	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1932	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1933	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1934	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1935	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1936	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1937	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1938	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1939	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1940	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1941	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1942	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1943	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1944	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1945	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1946	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1947	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1948	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1949	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1950	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1951	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
1952	6.93	2.36	2.96	3.84	3.27	4.54	10.67	16.31	13.24	2.38	5.00	5.08	76.58
1953	4.27	3.13	2.07	4.90	4.49	4.60	9.32	13.53	17.78	9.03	8.69	5.05	86.86
1954	5.12	4.28	4.29	16.46	5.79	1.68	3.68	15.31	14.51	1.54	5.42	4.91	82.99
1955	5.72	12.57	3.33	3.81	9.50	39.00	22.36	22.48	10.16	5.03	6.76	5.33	146.05
1956	10.51	2.93	2.73	5.21	4.22	3.92	3.53	20.20	37.87	.90	4.44	23.83	120.29
1957	4.15	7.38	6.09	2.17	4.31	5.57	2.35	20.98	14.90	5.11	7.44	5.72	86.17
1958	8.72	3.97	8.03	4.96	2.04	3.57	5.98	13.47	11.05	9.50	6.76	5.67	83.72
1959	5.55	3.28	4.62	5.14	7.64	5.84	29.45	6.91	14.46	7.45	10.11	4.89	105.34
1960	5.05	3.36	3.56	3.53	6.14	7.58	23.02	14.79	16.16	14.60	2.89	4.53	105.21
1961	6.12	2.68	3.19	5.73	2.39	7.17	6.74	13.54	12.31	7.96	6.78	6.16	80.77
1962	5.99	5.31	2.76	10.12	2.19	7.03	13.99	13.47	7.20	1.87	3.38	4.97	78.28
1963	7.69	5.54	2.84	8.58	4.83	9.12	3.19	12.90	15.16	1.64	3.37	4.45	79.31
1964	2.98	4.27	3.84	4.51	5.11	5.88	2.18	11.19	6.70	6.94	4.13	5.04	62.77
1965	4.65	2.66	3.88	4.71	1.37	5.13	2.16	10.09	6.30	1.41	3.28	3.01	48.65
1966	2.96	.57	1.97	5.35	3.39	2.21	7.17	32.22	.43	2.24	2.92	4.30	65.73
1967	4.84	2.13	3.66	5.39	5.64	5.57	8.75	26.93	7.71	2.04	3.20	4.98	80.84
1968	4.85	3.73	2.45	5.31	3.85	1.48	1.12	16.07	2.05	1.92	2.65	4.00	49.48
1969	3.04	2.93	4.83	5.82	4.53	5.37	4.55	14.92	20.33	.90	4.41	4.83	76.46
1970	4.62	2.80	3.08	1.74	2.00	4.82	1.01	11.27	8.80	1.67	4.73	5.18	51.72
1971	5.37	7.43	6.45	8.16	22.13	22.06	2.18	2.23	11.46	3.81	3.75	4.52	99.55
1972	5.05	3.55	4.85	6.18	8.41	9.35	10.62	6.43	7.97	1.11	1.52	5.68	70.72
1973	4.32	3.03	3.31	16.55	.48	20.80	13.32	5.29	1.81	2.20	1.47	3.16	75.74
1974	6.51	2.23	4.23	57.27	15.70	6.07	13.52	1.44	8.22	4.79	3.93	6.25	130.16
1975	12.05	3.91	13.58	11.43	22.97	12.90	4.87	3.82	2.19	1.97	3.27	7.13	100.09
1976	4.03	3.02	3.62	7.87	15.62	34.84	.81	3.19	10.59	5.11	4.24	8.07	101.01
1977	4.88	3.66	2.50	3.73	3.32	48.01	7.39	1.63	9.10	4.60	5.24	7.93	101.99
1978	6.28	3.25	3.66	6.18	2.84	4.11	10.24	4.12	9.94	9.74	8.43	4.30	73.09
1979	6.06	1.50	4.77	6.63	12.69	.65	1.58	4.74	11.12	10.34	10.57	10.15	80.80
1980	5.29	3.78	3.06	9.88	3.16	1.75	1.90	2.61	9.69	3.73	4.63	4.43	53.91
1981	9.26	16.61	3.08	7.27	8.39	6.14	14.93	3.43	13.25	7.17	7.65	6.90	104.08
1982	9.22	12.11	2.65	6.17	5.14	3.94	.89	.68	4.67	.98	1.64	2.53	50.62
1983	7.56	21.21	1.25	3.06	4.07	1.78	.26	.92	10.27	8.97	3.69	3.79	66.83
1984	30.03	13.19	3.02	5.83	7.71	3.67	1.09	2.84	9.51	6.50	3.26	3.96	90.61
1985	17.21	1.79	11.49	17.69	4.84	1.29	4.40	2.52	11.03	2.24	3.87	3.07	81.44
1986	3.07	.71	2.28	2.55	1.89	4.88	6.65	2.79	6.40	2.45	3.97	7.09	44.73
1987	4.95	7.78	3.58	5.46	118.06	26.81	30.75	2.16	10.77	4.86	5.58	17.23	237.99
1988	21.03	11.50	14.00	23.19	26.16	23.43	28.15	8.97	5.36	3.16	5.37	4.79	175.11
1989	6.15	3.90	3.11	4.27	18.09	14.95	23.55	2.85	12.42	4.37	6.52	5.64	105.82
1990	6.61	4.06	4.02	22.35	1.36	15.98	5.18	6.50	20.39	7.25	4.86	6.58	105.14
AVERAGE	7.15	5.23	4.33	8.69	9.89	10.09	8.81	9.63	10.85	4.60	4.83	6.03	90.17

APPENDIX I

TDS DATA FILES

File I1 : C9R01TDS.MOR - Patched TDS at Vaaharts weir (C9R001)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	332.29	290.38	271.50	149.28	137.38	162.54	219.28	222.35	243.04	249.41	262.13	283.87	2823.45
1924	148.31	122.69	155.18	146.00	143.42	126.67	178.00	129.09	197.16	218.84	241.61	200.29	2007.26
1925	139.06	121.07	160.70	176.26	128.97	171.15	244.51	235.86	238.73	253.83	272.92	217.09	2360.15
1926	252.35	199.10	140.59	145.50	122.37	126.58	165.45	183.86	220.02	244.29	240.75	323.10	2363.96
1927	173.37	145.21	140.16	159.42	227.27	167.14	197.24	228.24	251.46	285.27	330.74	248.71	2554.23
1928	191.28	179.18	185.86	143.74	160.71	122.55	214.02	240.70	217.55	241.87	260.58	133.67	2291.71
1929	109.23	135.22	113.87	136.34	191.24	176.15	179.52	249.55	250.70	261.24	270.63	316.39	2390.08
1930	299.61	281.02	295.87	159.73	145.24	184.01	148.77	203.16	325.66	274.03	295.08	575.55	3187.73
1931	290.49	179.23	273.92	214.87	148.33	177.91	211.62	215.39	236.20	266.67	374.62	737.74	3326.99
1932	266.02	241.77	205.75	233.06	156.00	137.02	173.23	290.40	344.97	348.40	415.35	651.70	3463.67
1933	835.87	177.26	170.06	154.08	194.87	181.62	196.23	186.20	231.00	216.54	131.84	172.91	2848.48
1934	211.38	142.40	124.68	195.97	182.83	166.52	224.86	196.55	225.63	244.85	275.98	402.33	2593.98
1935	618.50	199.19	249.63	134.12	192.70	217.72	173.53	130.83	182.06	238.93	283.13	827.71	3448.05
1936	632.77	144.86	178.07	134.43	120.19	162.88	188.77	226.57	237.11	245.72	258.08	290.55	2820.00
1937	245.98	210.14	229.06	225.50	210.17	274.73	202.04	266.81	219.33	195.46	174.76	199.89	2653.87
1938	178.34	239.16	242.93	173.73	132.12	166.60	203.19	186.83	199.14	218.39	236.13	174.66	2351.22
1939	160.43	196.70	164.89	164.80	158.05	182.49	181.01	192.78	208.80	197.47	172.82	181.68	2161.92
1940	180.97	196.82	188.38	158.68	156.13	201.81	158.98	184.72	185.35	178.94	165.12	140.47	2096.37
1941	140.47	150.12	179.05	218.16	239.38	200.99	268.06	201.72	179.12	173.11	188.01	177.08	2315.27
1942	227.86	226.60	223.63	223.76	189.70	196.39	217.86	155.42	184.48	139.43	157.64	141.36	2284.13
1943	152.28	128.22	153.13	146.20	144.82	235.10	192.58	213.40	243.43	242.29	217.32	195.64	2264.41
1944	192.14	208.44	226.05	146.33	239.46	194.05	303.79	223.82	231.09	237.21	179.87	137.52	2519.77
1945	133.43	141.71	165.72	216.13	343.53	220.92	244.09	185.36	213.37	186.84	151.84	140.24	2343.18
1946	148.25	261.96	311.49	289.11	175.03	236.20	219.74	213.37	200.72	200.20	180.02	157.51	2593.60
1947	151.16	193.41	226.31	337.61	318.31	169.62	231.08	230.98	221.88	198.20	173.77	157.55	2609.88
1948	155.47	240.48	225.62	218.95	235.25	293.06	263.49	223.99	235.55	247.12	214.67	181.95	2735.60
1949	169.16	311.97	251.58	215.62	205.18	175.42	183.38	219.06	306.90	237.98	205.58	174.33	2656.16
1950	154.30	175.66	265.49	292.51	330.93	246.05	266.12	332.35	342.64	285.50	245.55	195.66	3132.76
1951	260.96	321.14	249.98	220.20	217.07	199.78	209.89	209.22	216.11	285.30	263.72	182.35	2835.72
1952	169.48	175.27	198.48	395.14	204.77	162.64	160.46	201.48	190.93	183.77	156.51	139.60	2338.53
1953	148.48	208.22	280.94	320.42	227.54	245.73	331.93	261.67	233.62	218.94	172.13	155.87	2805.49
1954	160.89	255.56	237.55	317.06	176.41	152.65	230.79	259.23	291.59	258.13	194.76	148.03	2682.65
1955	152.35	268.90	312.63	343.19	242.81	289.91	194.58	255.45	273.08	265.72	211.20	175.03	2984.85
1956	192.75	246.17	156.19	145.75	201.29	215.99	251.08	216.21	227.93	280.12	275.03	127.62	2536.13
1957	113.71	141.67	156.35	169.98	257.48	217.97	223.83	175.42	210.13	229.92	189.15	217.47	2303.08
1958	163.15	212.69	244.97	262.46	279.76	228.42	203.12	187.26	234.20	234.69	196.57	161.34	2608.63
1959	181.74	269.33	298.16	245.08	279.99	233.49	269.35	259.55	239.51	240.18	214.30	175.24	2905.92
1960	159.24	234.43	245.36	292.20	261.05	253.68	251.86	300.08	277.89	278.42	228.13	160.53	2942.87
1961	141.47	211.69	282.43	229.55	273.63	295.69	207.21	303.02	266.83	252.42	209.39	174.47	2847.80
1962	161.68	255.88	344.20	291.12	402.78	314.52	227.69	328.71	371.58	398.65	302.44	185.34	3584.59
1963	161.60	262.35	420.89	323.02	327.69	254.48	237.40	280.49	253.52	266.08	243.51	208.56	3239.59
1964	175.35	214.80	164.72	195.94	207.28	171.40	249.05	257.32	253.96	267.19	239.52	167.00	2563.53
1965	145.90	213.62	237.52	238.02	274.26	316.01	230.72	261.88	339.96	319.44	275.00	217.72	3070.05
1966	241.07	343.73	282.92	335.00	186.67	262.15	234.42	340.16	224.81	297.23	272.17	239.67	3260.00
1967	201.25	338.13	430.58	304.29	200.75	433.27	553.80	476.27	540.05	414.30	299.21	209.88	4401.78
1968	172.63	328.45	360.73	339.57	271.61	453.04	557.60	422.98	495.34	642.55	503.27	310.77	4858.54
1969	319.16	471.28	526.76	446.69	392.80	326.20	308.78	388.66	429.17	458.00	368.26	248.19	4683.95
1970	237.53	403.68	341.77	334.00	345.15	353.50	365.51	375.41	389.58	403.56	419.15	439.23	4408.07
1971	462.89	487.96	508.33	454.98	417.42	372.00	344.65	350.99	359.03	367.56	377.39	389.65	4892.85
1972	404.03	421.48	445.39	469.62	481.50	489.14	497.42	507.19	522.20	536.86	552.54	568.35	5895.72
1973	580.77	582.20	580.17	437.53	318.67	287.01	294.92	304.20	312.75	320.60	329.10	339.21	4687.13
1974	351.40	356.00	311.40	247.50	176.20	136.50	146.90	157.40	167.80	178.20	178.20	184.80	2592.30
1975	121.60	180.50	231.50	231.40	176.70	176.90	174.80	164.90	199.50	210.30	221.10	221.40	2310.60
1976	221.00	233.20	276.20	312.30	259.40	227.40	241.30	257.10	266.60	260.60	267.00	261.90	3084.00
1977	261.80	274.00	279.70	348.30	263.10	222.20	245.30	249.00	257.20	251.50	262.40	259.70	3174.20
1978	262.40	264.10	271.90	280.10	288.40	296.60	297.40	300.40	324.00	342.20	353.20	364.10	3644.80
1979	383.00	394.70	434.00	519.80	520.60	448.20	453.80	467.50	480.60	493.90	535.50	525.30	5656.90
1980	548.90	543.60	213.10	465.10	438.30	419.20	402.50	403.90	389.10	402.80	417.10	422.80	5066.40
1981	414.80	407.10	399.30	424.10	407.30	414.90	450.10	431.20	421.60	436.70	440.80	459.20	5107.10
1982	482.20	480.20	486.90	510.40	564.60	618.80	654.50	695.80	737.00	709.40	769.00	828.60	7537.40
1983	719.30	614.20	494.00	404.70	398.20	391.60	435.50	562.00	688.40	572.90	543.70	514.50	6339.00
1984	485.30	389.30	355.80	412.90	396.40	379.90	396.00	439.60	390.30	448.30	452.10	455.90	5001.80
1985	410.20	286.10	371.50	302.10	255.70	424.00	557.60	566.20	321.70	618.40	407.30	550.10	5070.90
1986	487.10	370.90	335.20	322.80	371.40	395.90	474.40	483.10	508.40	517.70	798.80	719.10	5784.80
1987	449.80	385.30	362.80	364.70	388.40	250.70	215.60	154.10	218.90	224.40	216.60	221.80	3453.10
1988	227.70	228.40	264.60	290.00	279.10	209.60	222.70	243.30	258.50	256.10	253.00	250.00	2983.00
1989	248.50	254.90	269.70	270.20	270.00	280.90	298.40	311.80	342.90	385.50	391.60	399.20	3723.60
1990	433.30	444.30	462.40	450.60	440.30	448.20	345.80	385.70	416.90	411.40	412.90	414.70	5066.50
AVERAGE	272.16	270.81	277.15	273.20	259.88	258.00	272.05	281.84	295.83	303.94	293.96	296.05	3354.88

File I2 : C3M03TDS.MOR - Observed TDS at C3H003

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	595.00	779.60	-1.00
1972	-1.00	-1.00	306.20	525.20	325.20	-1.00	223.80	-1.00	-1.00	667.00	831.60	-1.00	-1.00
1973	-1.00	848.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1974	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1975	568.80	671.50	485.10	280.80	308.90	341.30	465.00	-1.00	566.60	613.80	681.10	662.70	-1.00
1976	495.30	492.80	630.20	609.80	395.10	306.70	424.70	522.90	596.20	660.80	700.30	619.00	6453.80
1977	548.80	711.70	431.50	412.20	346.30	354.00	-1.00	428.30	550.30	620.40	659.20	637.00	-1.00
1978	739.70	800.70	604.20	-1.00	-1.00	-1.00	-1.00	665.60	750.50	668.60	-1.00	818.20	-1.00
1979	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	757.10	-1.00
1980	779.00	-1.00	-1.00	300.20	197.60	254.70	308.50	494.40	589.60	644.10	515.30	788.40	-1.00
1981	690.20	328.40	518.90	480.40	335.20	567.00	-1.00	-1.00	913.30	884.80	926.30	642.80	-1.00
1982	-1.00	235.00	271.00	-1.00	-1.00	223.60	-1.00	-1.00	-1.00	309.10	703.50	-1.00	-1.00
1983	218.30	158.60	203.30	230.20	-1.00	72.20	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1984	-1.00	61.70	-1.00	-1.00	-1.00	63.00	339.60	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1985	-1.00	-1.00	-1.00	-1.00	88.90	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1986	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1987	-1.00	111.80	130.30	197.00	108.30	-1.00	-1.00	-1.00	698.20	703.40	820.60	737.40	-1.00
1988	357.50	598.70	348.20	197.80	182.10	222.30	291.30	288.70	504.80	632.40	679.70	914.60	5218.10
1989	764.00	585.40	-1.00	-1.00	259.90	-1.00	-1.00	-1.00	-1.00	888.60	919.50	-1.00	-1.00
1990	-1.00	-1.00	-1.00	304.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
AVERAGE	573.51	266.90	126.74	86.30	49.95	40.08	31.10	33.80	65.44	81.03	79.53	66.28	125.05

I.3

File I3 : C3M07TDS.MOR - Observed TDS at C3H007

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	766.70	-1.00
1972	-1.00	535.50	-1.00	491.70	508.50	-1.00	428.70	-1.00	-1.00	672.70	-1.00	-1.00	-1.00
1973	-1.00	700.60	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1974	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1975	708.00	-1.00	600.50	607.10	-1.00	-1.00	-1.00	613.20	698.70	836.70	926.40	922.50	-1.00
1976	746.80	824.40	953.50	887.50	510.30	466.30	604.60	859.20	917.60	976.20	990.60	828.80	9565.80
1977	833.30	878.80	781.70	609.80	351.70	422.50	538.50	603.80	777.90	882.40	883.00	875.30	8438.70
1978	880.70	917.60	769.60	-1.00	-1.00	-1.00	676.90	868.50	843.80	914.90	-1.00	934.40	-1.00
1979	782.60	770.40	805.00	964.50	-1.00	-1.00	-1.00	-1.00	979.40	946.30	984.20	-1.00	-1.00
1980	894.30	755.60	-1.00	608.70	360.70	410.00	444.10	652.10	873.70	935.40	898.80	897.20	-1.00
1981	941.70	760.70	830.10	835.60	808.60	779.30	894.80	-1.00	843.90	855.50	899.20	928.30	-1.00
1982	-1.00	827.10	-1.00	-1.00	904.30	-1.00	968.20	-1.00	925.60	-1.00	1017.80	867.50	-1.00
1983	-1.00	808.60	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1984	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	656.00	729.50	864.50	838.20	792.20	-1.00
1985	543.30	455.90	354.30	351.20	294.60	378.60	506.60	499.30	580.40	616.30	550.70	661.20	5792.40
1986	709.70	431.40	641.30	681.20	482.90	-1.00	492.90	599.60	-1.00	669.20	697.30	621.80	-1.00
1987	618.70	687.10	412.50	664.00	399.70	279.20	677.00	991.20	1321.30	1233.80	1354.80	1230.60	9869.90
1988	917.10	945.30	739.60	511.80	409.70	401.60	789.60	809.20	1088.80	1131.20	1186.80	1120.50	10051.20
1989	947.60	955.40	959.90	855.60	791.80	786.80	785.30	886.20	790.70	792.00	901.10	953.20	10405.60
1990	939.20	1011.00	948.20	685.40	-1.00	711.60	1073.20	1212.00	1112.60	1204.80	1138.50	1128.10	-1.00
AVERAGE	804.85	422.94	214.54	162.11	89.58	62.65	102.07	93.44	110.48	105.72	93.43	86.17	195.67

File I4 : C3R02TDS.MOR - Observed TDS at C3R002

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1972	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1973	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1974	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1975	585.60	661.50	687.50	390.00	-1.00	327.00	374.00	505.50	-1.00	557.10	-1.00	-1.00	4088.20
1976	-1.00	746.40	-1.00	-1.00	740.60	-1.00	-1.00	445.90	489.50	519.60	585.20	619.50	4146.70
1977	653.80	714.40	734.60	767.00	757.60	642.20	560.50	404.50	401.50	436.00	468.50	558.40	7099.00
1978	611.60	648.20	703.20	-1.00	-1.00	-1.00	791.90	794.80	830.40	857.70	866.20	-1.00	6104.00
1979	919.60	965.90	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1885.50
1980	-1.00	-1.00	-1.00	814.60	687.20	473.00	443.40	443.30	458.80	479.00	525.20	581.00	4905.50
1981	635.60	694.90	-1.00	757.30	801.30	822.30	837.90	796.30	681.00	-1.00	-1.00	-1.00	6026.60
1982	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	992.10	1096.30	-1.00	1088.20	1164.20	-1.00	4340.80
1983	-1.00	1134.60	913.00	689.60	-1.00	-1.00	350.50	-1.00	-1.00	-1.00	587.30	-1.00	3675.00
1984	-1.00	-1.00	-1.00	591.10	558.00	333.00	-1.00	-1.00	425.40	444.20	-1.00	-1.00	2351.70
1985	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1986	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1987	-1.00	626.60	529.90	406.80	551.90	283.20	532.90	1133.60	1206.80	1198.40	1226.10	1055.70	8751.90
1988	882.90	748.40	704.30	507.20	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2842.80
1989	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1088.90	-1.00	1088.90
1990	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	469.40	526.00	560.70	606.70	2162.80
1991	699.90	726.10	723.20	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	2149.20
AVERAGE	712.71	766.70	713.67	615.45	682.77	480.12	610.40	702.53	620.35	678.47	785.81	684.26	4107.91

File I5 : C3M13TDS.MOR - Observed TDS at C3H013

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1923	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1924	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1925	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1926	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1927	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1928	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1929	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1930	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1931	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1932	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1933	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1934	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1935	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1936	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1937	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1938	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1939	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1940	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1941	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1942	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1943	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1944	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1945	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1946	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1947	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1948	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1949	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1950	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1951	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1952	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1953	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1954	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1955	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1956	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1957	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1958	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1959	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1960	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1961	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1962	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1963	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1964	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1965	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1966	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1967	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1968	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1969	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1970	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1971	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	718.00	699.70	-1.00
1972	-1.00	607.40	623.70	549.30	418.60	481.50	498.50	670.00	783.80	661.30	738.70	738.40	-1.00
1973	618.50	588.80	686.30	494.20	291.40	-1.00	357.80	656.50	838.50	903.40	870.30	849.30	-1.00
1974	923.00	733.90	653.90	728.10	-1.00	382.90	555.60	467.40	552.00	-1.00	570.90	-1.00	-1.00
1975	772.50	779.30	712.50	613.50	-1.00	-1.00	420.30	456.60	514.90	542.80	611.10	683.00	-1.00
1976	680.80	718.30	796.60	855.30	729.40	587.90	446.60	481.00	538.40	573.50	599.80	658.60	7666.20
1977	694.50	743.50	788.00	788.10	741.70	631.20	506.00	410.10	-1.00	453.50	532.40	599.30	-1.00
1978	647.20	669.90	-1.00	-1.00	-1.00	-1.00	799.10	809.90	814.00	854.70	-1.00	-1.00	-1.00
1979	851.60	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1980	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1981	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1982	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1983	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1984	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1985	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1986	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	637.00	-1.00	-1.00	-1.00
1987	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
1988	866.90	722.90	-1.00	-1.00	-1.00	436.00	439.60	500.40	608.10	-1.00	835.30	850.10	-1.00
1989	956.70	1037.80	1104.40	1251.10	1171.00	1020.10	995.00	773.20	1017.10	-1.00	-1.00	1057.00	-1.00
1990	1123.90	1272.30	1061.90	1250.30	912.80	-1.00	853.40	564.40	573.60	606.20	587.10	652.20	-1.00
AVERAGE	813.56	393.70	229.55	181.39	101.55	73.74	101.24	85.14	81.04	61.56	64.51	65.90	187.74

APPENDIX J

SUB-MODEL PARAMETER DATA FILES

Page

Appendix J1 : Upper Harts sub-system (WRSM90 model)

Network file (WRSM90) for UH sub-system (naturalisation)

```
uh
c:\data\waterqua\vh\net
c:\data\waterqua\vh\net
N
Y
 3
1RUY
2CRY
3CRY
 1
  5
'MRC3M03.OBS'
1920 1990
 4
  1   1   2 0
  2   1   3 0
  4   2   3 0
  5   3   0 0
 4
'RT'  1 'Q'
'RT'  2 'Q'
'RT'  4 'Q'
'RT'  5 'Q'
```

Parameter file for runoff RU1 (UH)

```
  1 'Runoff 1'
10990.0  520 'C3M03.RAN'
3.0     0  170  0.1  0.1   45 1000  1.5 0.33  2.00 0.5
220  230  240  240  180  170  130   95   85   90  120  170
0.80 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.80 0.80 0.80
 0
 0
 2
  1  80.0
  2  20.0
```

Parameter file for channel reach CR2 (UH)

```
2 'Channel 2'
   0 'c3m03.ran'
 0.00 0.0 0.0
  0    0    0    0    0    0    0    0    0    0    0    0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  4
1
  1 ' '
1
  4 ' '
```

Parameter file for channel reach CR3 (UH)

```
3 'Channel 3'
 520 'c3m03.ran'
 0.00 0.0 0.0
  0    0    0    0    0    0    0    0    0    0    0    0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  5
2
  2 ' '
  4 ' '
1
  5 ' '
```

Appendix J2 : Middle Harts sub-system (WRSM90 model)

Network file (WRSM90) for MH sub-system (naturalisation)

```
MH
C:\DATA\WATERQUA\VH\NAT
C:\DATA\WATERQUA\VH\NAT
N
Y
 2
1RUY
2CRY
 0
1923 1990
 2
  1   1   2 0
  2   2   0 0
 2
'RT'  1 'Q'
'RT'  2 'Q'
```

Parameter file for runoff RU1 (MH)

```
  1 'Runoff 1'
15924.0  440 'C3R02.RAN'
3.0    0  200  0.0  0.0   45 1040  1.5 0.33  0.00 0.5
220  230  240  240  180  170  130   95   85   90  120  170
0.80 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.80 0.80 0.80
 0
 0
 1
  1 100.0
```

Parameter file for channel reach CR2 (MH)

```
2 'Channel 2'
   0 'C3R02.RAN'
 0.00 0.0 0.0
  0    0    0    0    0    0    0    0    0    0    0    0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  2
1
  1 ' '
1
  2 ' '
```

Parameter file for runoff RU2 (MH)

```
  2 'Runoff 2'
1231.0  440 'C3R02.RAN'
3.0    0  200  0.0  0.0   45 1040  1.5 0.33  0.00 0.5
220  230  240  240  180  170  130   95   85   90  120  170
0.80 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 0.80 0.80 0.80
 0
 0
 1
  1 100.0
```

Parameter file for channel reach CR3 (MH)

```
3 'Channel 3'
   0 'C3R02.RAN'
 0.00 0.0 0.0
  0    0    0    0    0    0    0    0    0    0    0    0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  2
1
  1 ' '
1
  2 ' '
```

Appendix J3 : Upper Harts sub-system (WQT model)

Command file for UH sub-system (WQT)

```
UH
C:\DATA\WATERQUA\VH
C:\DATA\WATERQUA\VH
N
Y
 6
1CRY
2RVY
4RRY
6RVY
5RRY
3CRY
 1
 9 'OBS POINT AT C3H003'
'C3H03Q.OBS' 'C3H03TDS.MOR'
C09
P01
G01
A05
T05
S05
H05
W01
C01
C02
C03
C05
C06
C07
C08
C04
```

Network file for UH sub-system

```
   1923   1990      2  0 0 0 ' '
31.00 30.00 31.00 31.00 28.25 31.00 30.00 31.00 30.00 31.00 31.00 30.00
   10
   1    1    2    0
   2    2    0    0
   3    6    0    0
   4    4    3    0
   5    2    3    0
   6    5    3    0
   7    6    5    0
   8    0    6    0
   9    3    0    0
  10    2    4    0
   10
   'SW'  01    'Q'
   'SW'  01    'C'
   'RT'  01    'Q'
   'RV'  02    'Q'
   'RV'  02    'C'
   'RT'  04    'C'
   'RT'  04    'Q'
   'RT'  05    'Q'
   'RT'  06    'Q'
   'RT'  06    'C'
   'RT'  09    'Q'
   'RT'  09    'C'
```

Parameter file for UH Salt wasoff sub-model SW1

```
    1  'UPPERHR-SW1'   0  7648.00        .00  'C3MO3AKB.NAT'  ' '
     .05       14.5        .0      577.0      .178      .0000
   .05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05 .05
     .5000      .30   .025000   .000000      .9000  400.0000
       2        1
    1923     1990
  1.0000  1.0000
       2        1
    1923     1990
  1.0000  1.0000
```

Parameter file for Channel Reach CR1 (UH)

```
  1   1   'UPPERHR-CR1'  01  .839 .839   00    ' '   ' '
  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
   0
  0.0  0.0   ' '
   0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  .00   .00   .00   .00   .00   .00   .00   .00   .00   .00   .00   .00
 520.    .0  .00
   2     1
1923  1990
1.00  1.00
```

Parameter file for Reservoir RV2 (UH)

```
  2    'SCHWEIZER RENEKE-RV'   1   5   0   5
 1935  5   7.69    .2
 1957  1   5.96    .001
 1976  1   6.19    .001
 1978  1   5.29    .001
 1984  1   6.20    .001
    .01   80. ' '
  1
  1  ' '  ' '
  3
  2  'C3R001.URB'  ' '
  5  ' ' ' '
 10  'C3R001.IRR'  ' '
   10 488.0     'MPSCHWI.RAN'
   0. 0.93    1.209  1.457  1.715  1.891  2.085  2.442  2.75  3.29
   0. 1.02    1.53   2.04   2.55   3.06   3.57   4.59   6.20  8.06
  178.  200.  199.  197.  119.  150. 112. 86.  80.   77.  104.  141.
```

Parameter file for Channel Reach CR3 (UH)

```
  3   9   'C3H003HR-CR3'  01  .161  .161   00    ' '   ' '
  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
   3
   4  ' '  ' '
   5  ' '  ' '
   6  ' '  ' '
  1000.0  1.5   'V-H.RAN'
  178.  200.  199.  197.  119.  150. 112. 86.  80.   77.  104.  141.
  .590  .786  .777  .780  .829  .858  .948  .865  .887  .634  .616  .590
 440.    1.0  .00
   2     1
1923  1990
1.00  1.00
```

Parameter file for Irrigation sub-model RR4 (UH)

```
  4  'SW-IRR4'  10  4   4    1    5.00     4    1  'C3R001.IRR' 1
 .00   .00   .650    .05   .00   0.95  3.00   .000  .00   .0000
 1400.00  4200.00    400.000  600.000    250.000     250.000
.600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600
257.  276.  294.  270.  216.  183.  135.  115.   93.  115.  155.  210.
.590  .786  .777  .780  .829  .858  .948  .865  .887  .634  .616  .590
 7
.70  .00  .00  .00  .00  .00  .00  .52  .30  .50  .09 1.00  24. WHEAT
.00  .28  .53  .84  .88  .47  .43  .00  .00  .00  .00  .00  46. COTTON
.00  .00  .30  .70  .60  .50  .50  .00  .00  .00  .00  .00   3. GROUNDNUT
.00  .22  .30  .65  .87 1.00  .67  .00  .00  .00  .00  .00  59. MAIZE
.70  .80  .80  .80  .80  .70  .50  .40  .30  .30  .40  .50   2. LUCERN
.00  .00  .00  .00  .00  .00  .00  .03  .34  .55  .64  .00   6. PEASEED
.70  .80  .80  .60  .40  .20  .20  .20  .20  .20  .20  .20  16. SUNFLOWER
'V-H.RAN'        440.00       100.00       .00
 1923  1934  1935  1990
 0.0  0.0  1.0  1.0
 1923  1934  1935  1990
 0.0  0.0  1.0  1.0
 4 1
 1923  1934  1935  1990
 0.0  0.0  1.0  1.0
 4 1
 1923  1934  1935  1990
 0.0  0.0  1.0  1.0
```

Parameter file for Irrigation sub-model RR5 (UH)

```
  5  'HARTS-IRR5'  7  6   6    1    11.31     6    1  ' ' 1
 .00   .00   .850    .010   .00   0.95  3.00   .005  .00   .0000
 1400.00  4200.00    400.000  600.000    250.000     250.000
.600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600
257.  276.  294.  270.  216.  183.  135.  115.   93.  115.  155.  210.
.590  .786  .777  .780  .829  .858  .948  .865  .887  .634  .616  .590
 7
.70  .00  .00  .00  .00  .00  .00  .52  .30  .50  .09 1.00  24. WHEAT
.00  .28  .53  .84  .88  .47  .43  .00  .00  .00  .00  .00  46. COTTON
.00  .00  .30  .70  .60  .50  .50  .00  .00  .00  .00  .00   3. GROUNDNUT
.00  .22  .30  .65  .87 1.00  .67  .00  .00  .00  .00  .00  59. MAIZE
.70  .80  .80  .80  .80  .70  .50  .40  .30  .30  .40  .50   2. LUCERN
.00  .00  .00  .00  .00  .00  .00  .03  .34  .55  .64  .00   6. PEASEED
.70  .80  .80  .60  .40  .20  .20  .20  .20  .20  .20  .20  16. SUNFLOWER
'V-H.RAN'        440.00       100.00       .00
 1923  1976  1977  1982  1985  1990
 0.0  0.0  8.01  8.01  9.96  11.00
 1923  1976  1977  1982  1985  1990
 0.0  0.0  0.73  0.73  0.91  1.00
 4 1
 1923  1976  1977  1990
 0.0  0.0  1.0  1.0
 4 1
 1923  1976  1977  1990
 0.0  0.0  1.0  1.0
```

Parameter file for Reservoir RV6 (UH)

```
 6    'DUMMY RES'   1   3   0   1
1935  5  1000.0     .1
   .01  200. ' '
 1
 8  'DUMMY.FLW'   'C9R001TDS.MOR'
 2
 3  ' '  ' '
 7  ' '  ' '
  10 0.0     'V-H.RAN'
  0. 5.00  10.00  15.00  20.00  25.00  30.00  35.00  40.00  45.00
  0. 100.00 200.00 300.00 400.00 500.00 600.00 700.00 800.00 1000.00
  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
```

Appendix J4 : Middle Harts between Spitskop Dam and C3H013 (WQT model)

Network file for sub-catchment between Spitskop Dam and C3H013

```
SP
a:
a:
N
Y
 2
2RRY
1CRY
 0
1974 1990
 3
  1   0   1 0
  2   1   2 0
  3   1   0 0
  3
'RT'  1 'Q'
'RT'  2 'Q'
'RT'  3 'Q'
```

Parameter file for channel reach sub-model CR1

```
1 'Channel 1'
   0 'MPSPITS.RAN'
 0.00 0.0 0.0
  0    0    0    0    0    0    0    0    0    0    0    0
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
  2
1
  1 'temp.sup'
2
  2 ' '
  3 ' '
```

Parameter file for irrigation sub-model RR2

```
2 'Irrigation 1'
 440 'MPSPITS.RAN'
 2
1974 1991
  1.00   1.00
0.70 0.70 0.70 0.70 0.50 0.50 0.50 0.50 0.50 0.50 0.70 0.70
257  276  294  270  216  183  135  115   93  115  155  210
0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60 0.60
9999 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00
  2
  0  0.0
```

Appendix J5 : Middle Harts sub-system (WQT model)

Command file for MH sub-system (WQT)

File mh.cmd

```
MH
C:\DATA\WATERQUA\VH
C:\DATA\WATERQUA\VH
N
Y
11
13RVY
11RRY
7CRY
16JNY
14RVY
12RRY
8CRY
15JNY
9RVY
17JNY
10CRY
 6
  13 'OBS POINT AT C3H007'
'C3H007.OBS' 'C3M07TDS.MOR'
  19 'OBS POINT AT C3H013'
'C3H013.OBS' 'C3M13TDS.MOR'
  11 'IRRIGATION ABS 11'
'NCANIRRM.SUP' 'C3M07TDS.MOR'
  15 'IRRIGATION ABS 12'
'WCANIRRM.SUP' 'C3R02TDS.MOR'
  10 'IRR RET FL'
'C3H007L3.RET'  'C3M07TDS.MOR'
  18 'OBS POINT AT C3R002'
'C3R002D1.OBS' 'C3R02TDS.MOR'
C18
C19
P02
G02
W02
C02
P03
C03
C10
C11
C13
C14
C15
C18
C17
```

Network file for MH sub-system

File mhnet.dat

```
   1923  1990    2  0 0 0 ' '
31.00 30.00 31.00 31.00 28.25 31.00 30.00 31.00 30.00 31.00 31.00 30.00
   19
   9     0   7    0
   10   11   7    0
   11   13  11    0
   12    0  13    0
   13   16   8    0
   14   12   8    0
   15   14  12    0
   16    0  14    0
   17   15   9    0
   18    9  17    0
   19   10   0    0
   20   14   0    0
```

```
21   13   0    0
22    8  15    0
23   15   0    0
24    7  16    0
25   16   0    0
26   17  10    0
27   17   0    0
19
'RT'  13    'Q'
'RT'  13    'C'
'SW'  02    'Q'
'SW'  02    'C'
'RT'  14    'Q'
'RT'  14    'C'
'RT'  17    'Q'
'RT'  17    'C'
'RV'  09    'Q'
'SW'  03    'Q'
'SW'  03    'C'
'RT'  19    'Q'
'RT'  19    'C'
'RT'  19    'S'
'RT'  18    'Q'
'RT'  18    'C'
'RT'  18    'S'
'RT'  22    'Q'
'RT'  22    'C'
```

Parameter file for Salt wasoff sub-model SW2

File mhsw2.dat

```
    2  'MIDDLEHR-SW2'   0  7891.00         .00  'C3R002AK.NAT'  ' '
    .0200       8.2        .0     370.0      .2000       .0000
 .02  .02  .02  .02  .02  .02  .02  .02  .02  .02  .02  .02
    .300      .5000  .025000   .000000      .8000  400.0000
     2         1
   1923      1990
 1.0000    1.0000
     2         1
   1923      1990
 1.0000    1.0000
```

Parameter file for Salt wasoff sub-model SW3

File mhsw3.dat

```
    3  'MIDDLEHR-SW3'   0  865.00         .00  'C3H013AK.NAT'  ' '
    .0200       7.40       .0     523.0      .1700       .0000
 .02  .02  .02  .02  .02  .02  .02  .02  .02  .02  .02  .02
    .3000     .5000   .025000   .000000      .8000  400.0000
     2         1
   1923      1990
 1.0000    1.0000
     2         1
   1923      1990
 1.0000    1.0000
```

Parameter file for Channel Reach CR7

File mhcr7.dat

```
 7  24   'C3M07-CR7'  02  .882  .882   00    ' '   ' '
 .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
  2
  9  'UHRTQ9.ANS'  'UHRTC9.ANS'
 10  ' '  ' '
 0.0  0.0   ' '
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
 .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
440.    0.  .00
  2     1
1923  1990
 1.00  1.00
```

Parameter file for Channel Reach CR8

File mhcr8.dat

```
 8  22   'DUMMY'  02  .118  .118   00    ' '   ' '
 .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
  2
 13  ' '  ' '
 14  ' '  ' '
 0.0  0.0   ' '
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.
 .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
440.    0.  .00
  2     1
1923  1990
 1.00  1.00
```

Parameter file for Channel Reach CR10

File mhcr10.dat

```
 10  19   'C3H013 -CR10'  03  1.0  1.0   00    ' '   ' '
 .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00  .00
  1
 26  ' '  ' '
 0.0  0.0   ' '
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.0
 0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.  0.0
440.    0.  .00
  2     1
1923  1990
 1.00  1.00
```

Parameter file for Reservoir RV9 (Spitskop Dam)

File mhrv9.dat

```
 9    'SPITSKOP-RV'   1   18   0   4
1974  1  82.4   2.1
1987  5   1.3   1.3
1988  1   1.3   1.3
1988  2  82.4   2.1
 0.1   635.  ' '
 1
17  ' '  ' '
 1
18  'c3r002.flw'  ' '
 10 446.0    'MPSPITS.RAN'
 0.  9.64   12.65  14.85  16.71  18.41  20.02  21.61  23.36  30.9
 0.  12.23  18.46  24.52  30.68  36.83  42.97  49.0   55.3   82.4
 162.  230.  249.  220. 199. 160.  144.  113.  99.   84.  104.  132.
```

Parameter file for Reservoir RV13 (Dummy reservoir)

File mhrv13.dat

```
 13    'DUMMY-RV13'   1  21   0   1
 1935  5   1000.      1.
    .01    200. ' '
  1
  12  'NCANIRRM.SUP'  'C9RO1TDS.MOR'
  2
  11  ' '  ' '
  21  ' '  ' '
  10 0.0  'V-H.RAN'
   0. 5.0   10.0  15.0  20.0  25.0  30.0  35.0  40.0  45.0
   0. 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 1000.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0   0.0   0.0   0.0  0.0  0.0
```

Parameter file for Reservoir RV14 (Dummy reservoir)

File mhrv14.dat

```
 14    'DUMMY-RV14'   1  20   0   1
 1935  5   1000.      1.
    .01    200. ' '
  1
  16  'NCANIRRM.SUP'  'C9RO1TDS.MOR'
  2
  20  ' ' ' '
  15  ' ' ' '
  10  0.0    'V-H.RAN'
   0. 5.0   10.0  15.0  20.0  25.0  30.0  35.0  40.0  45.0
   0. 100.0 200.0 300.0 400.0 500.0 600.0 700.0 800.0 1000.0
  0.0  0.0  0.0  0.0  0.0  0.0  0.0   0.0   0.0   0.0  0.0  0.0
```

Parameter file for Irrigation sub-model RR11

File mhrr11.dat

```
   11  'HARTS-IRR11' 11  10   6    1    729.4    4    1  ' ' 2
   .00   .00   .670   .065  .150   .50  6.00   .016  .04   .0400
   1400.00  4200.00   400.000  600.000   250.000   250.000
  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600
  257.  276.  294.  270.  216.  183.  135.  115.   93.  115.  155.  210.
  .590  .786  .777  .780  .829  .858  .948  .865  .887  .634  .616  .590
   8
  .70  .00  .00  .00  .00  .00  .00  .52  .30  .50  .09 1.00  38. WHEAT
  .00  .28  .53  .84  .88  .47  .43  .00  .00  .00  .00  .00   7. COTTON
  .00  .00  .30  .70  .60  .50  .50  .00  .00  .00  .00  .00  39. GROUNDNUT
  .00  .22  .30  .65  .87 1.00  .67  .00  .00  .00  .00  .00  22. MAIZE
  .70  .80  .80  .80  .80  .70  .50  .40  .30  .30  .40  .50  19. LUCERN
  .50  .72  .47  .40  .65  .90 1.00  .00  .00  .00  .00  .35   1. POTAT&CUCURB
  .00  .00  .00  .00  .00  .00  .00  .03  .34  .55  .64  .00   5. PEASEED
  .00  .00  .00  .00  .00  .45  .65  .70  .47  .00  .00  .00   1. BRASSIKA
  'V-H.RAN'       440.00     100.00      .00
   1923  1937  1938  1949  1955  1990
   0.0   0.0   13.2  222.1 268.7 268.7
   1923 1937 1938  1990
   0.0  0.0  1.00  1.00
   12 1
   1923 1937 1945 1962 1970 1973 1974 1981 1982 1987 1988 1990
   0.0  0.0  1.0  1.0  0.25  0.5 1.0  1.0  0.15 0.15  0.9  0.9
   4 1
   1923 1937 1938 1990
   0.0  0.0  1.0  1.0
```

Parameter file for Irrigation sub-model RR12

File mhrr12.dat

```
  12  'HARTS-IRR12'  15  14   5    1   141.0    4    1  ' ' 2
  .00   .00   .680   .00   .150   .50  5.00   .02  .04   .0400
  1400.00  4200.00   400.000  600.000   250.000   250.000
 .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600  .600
 257.  276.  294.  270.  216.  183.  135.  115.   93.  115.  155.  210.
 .590  .786  .777  .780  .829  .858  .948  .865  .887  .634  .616  .590
  8
 .70  .00  .00  .00  .00  .00  .00  .52  .30  .50  .09 1.00  38. WHEAT
 .00  .28  .53  .84  .88  .47  .43  .00  .00  .00  .00  .00   7. COTTON
 .00  .00  .30  .70  .60  .50  .50  .00  .00  .00  .00  .00  39. GROUNDNUT
 .00  .22  .30  .65  .87 1.00  .67  .00  .00  .00  .00  .00  22. MAIZE
 .70  .80  .80  .80  .80  .70  .50  .40  .30  .30  .40  .50  19. LUCERN
 .50  .72  .47  .40  .65  .90 1.00  .00  .00  .00  .00  .35   1. POTAT&CUCURB
 .00  .00  .00  .00  .00  .00  .00  .03  .34  .55  .64  .00   5. PEASEED
 .00  .00  .00  .00  .00  .45  .65  .70  .47  .00  .00  .00   1. BRASSIKA
 'V-H.RAN'      440.00     100.00      .00
  1923 1937 1938 1949 1990
  0.0  0.0  0.6  50.0 50.0
  1923 1937 1938 1990
  0.0  0.0  1.00 1.00
  8 1
  1923 1937 1938 1981 1982 1987 1988 1990
  0.0  0.0  1.0  1.0  0.0  0.0  1.0  1.0
  4 1
  1923 1937 1938 1990
  0.0  0.0  1.0  1.0
```

Parameter file for Junction sub-model JN16

File mhjn16.dat

```
 16   'JUNCTION 16'  0  0
  1
  24 ' '  ' ' 0
  2
  13 1 ' '  ' '  100
  25 1 'HARTU7.ABS' ' ' 10
```

Parameter file for Junction sub-model JN15

File mhjn15.dat

```
 15   'JUNCTION 15'  0  0
  1
  22 ' '  ' ' 0
  2
  17 1 ' '  ' '  100
  23 1 'HARTD7.ABS' ' ' 10
```

Parameter file for Junction sub-model JN17

File mhjn17.dat

```
 17   'JUNCTION 17'  0  0
  1
  18 ' '  ' ' 0
  2
  26 1 ' '  ' '  100
  27 1 'HARTDSP.ABS' ' ' 10
```

APPENDIX K

CALIBRATED SUB-MODEL PARAMETER DATA FILES

Table K1 : Upper Harts sub-system - Catchment salt washoff sub-model SW1

CODE	DESCRIPTION	PARAMETERS
SWSSP	Initial pervious zone salt storage (t/km^2)	14.50
SWSSU	Initial urban zone salt storage (t/km^2)	.00
SWSSG	Initial sub-surface zone salt storage (mg/l)	577.00
SWSSRP	Initial pervious zone salt recharge rate (t/km^2)	.1700
SWSSRU	Initial urban zone salt recharge rate (t/km^2)	.0000
SWEP	Salt washoff efficiency - pervious zone	.02500
SWEU	Salt washoff efficiency - urban zone	.000000
SWQG	Initial interflow/groundwater flow (mm)	.0200
SWGMB	Mean monthly groundwater flow limit (mm)	.0200
SWRDF	Antecedent runoff decay factor	.3000
SWPAF	Proportion of surface flow via interflow	.4000
SWPI	Proportion of salt washoff infiltration	.8000
SWHGW	Constant soil moisture storage depth (mm)	400.00

Table K2 : Upper Harts sub-system - Irrigatioin sub-model RR4

CODE	DESCRIPTION	PARAMETERS
RRERF	Mean annual effective rainfall factor	.6000
RRMA	Annual irrigation water allocation (10^{6}m^3)	5.00
RRTLPQ	Transfer Canal - flow loss factor	.0000
RRTLPS	Transfer Canal - salt loss factor	.0000
RRIE	Irrigation efficiency factor	.6500
RRLF	Return flow factor	.0500
RRPRFU	Proportion of return flow - upper zone	.0000
RRPRFL	Proportion of return flow - lower zone	.9500
RRSCF	Deep percolation salt concentration factor	3.0000
RRPSL	Proportion of salt loss to deep storage	.0000
RRSLDI	Initial salt load applied to irrigated land - (t/ha)	.00
RRSLD2	Subsequent salt load applied to irrigated land - (t/ha)	.00
RRHSU	Soil moisture storage capacity - upper zone (mm)	400.00
RRHSL	Soil moisture storage capacity - lower zone (mm)	600.00
RRHT	Soil moisture storage capacity - target (mm)	250.00
RRHI	Soil moisture storage capacity - initial (mm)	250.00
RRSSUI	Initial salt storage - upper zone (mg/l)	1400.00
RRSSLI	Initial salt storage - lower zone (mg/l)	4200.00

Table K3 : Upper Harts sub-system - Irrigation sub-model RR5

CODE	DESCRIPTION	PARAMETERS
RRERF	Mean annual effective rainfall factor	.6000
RRMA	Annual irrigation water allocation (10^6m^3)	11.31
RRTLPQ	Transfer Canal - flow loss factor	.0000
RRTLPS	Transfer Canal - salt loss factor	.0000
RRIE	Irrigation efficiency factor	.8500
RRLF	Return flow factor	.0100
RRPRFU	Proportion of return flow - upper zone	.0000
RRPRFL	Proportion of return flow - lower zone	.9500
RRSCF	Deep percolation salt concentration factor	3.0000
RRPSL	Proportion of salt loss to deep storage	.0050
RRSLDI	Initial salt load applied to irrigated land - (t/ha)	.00
RRSLD2	Subsequent salt load applied to irrigated land - (t/ha)	.00
RRHSU	Soil moisture storage capacity - upper zone (mm)	400.00
RRHSL	Soil moisture storage capacity - lower zone (mm)	600.00
RRHT	Soil moisture storage capacity - target (mm)	250.00
RRHI	Soil moisture storage capacity - initial (mm)	250.00
RRSSUI	Initial salt storage - upper zone (mg/l)	1400.00
RRSSLI	Initial salt storage - lower zone (mg/l)	4200.00

Table K4 : Upper Harts sub-system - Irrigation sub-model RR11

CODE	DESCRIPTION	PARAMETERS
SWSSP	Initial pervious zone salt storage (t/km^2)	8.20
SWSSU	Initial urban zone salt storage (t/km^2)	.00
SWSSG	Initial sub-surface zone salt storage (mg/l)	370.00
SWSSRP	Initial pervious zone salt recharge rate (t/km^2)	.2000
SWSSRU	Initial urban zone salt recharge rate (t/km^2)	.0000
SWEP	Salt washoff efficiency - pervious zone	.02500
SWEU	Salt washoff efficiency - urban zone	.000000
SWQG	Initial interflow/groundwater flow (mm)	.0200
SWGMB	Mean monthly groundwater flow limit (mm)	.0200
SWRDF	Antecedent runoff decay factor	.3000
SWPAF	Proportion of surface flow via interflow	.5000
SWPI	Proportion of salt washoff infiltration	.8000
SWHGW	Constant soil moisture storage depth (mm)	400.00

Table K5 : Middle Harts sub-system - Catchment salt washoff sub-model SW2

CODE	DESCRIPTION	PARAMETERS
RRERF	Mean annual effective rainfall factor	.6000
RRMA	Annual irrigation water allocation ($10^6 m^3$)	729.40
RRTLPQ	Transfer Canal - flow loss factor	.0000
RRTLPS	Transfer Canal - salt loss factor	.0000
RRIE	Irrigation efficiency factor	.6700
RRLF	Return flow factor	.0650
RRPRFU	Proportion of return flow - upper zone	.1500
RRPRFL	Proportion of return flow - lower zone	.5000
RRSCF	Deep percolation salt concentration factor	6.0000
RRPSL	Proportion of salt loss to deep storage	.0160
RRSLD1	Initial salt load applied to irrigated land - (t/ha)	.04
RRSLD2	Subsequent salt load applied to irrigated land - (t/ha)	.04
RRHSU	Soil moisture storage capacity - upper zone (mm)	400.00
RRHSL	Soil moisture storage capacity - lower zone (mm)	600.00
RRHT	Soil moisture storage capacity - target (mm)	250.00
RRHI	Soil moisture storage capacity - initial (mm)	250.00
RRSSUI	Initial salt storage - upper zone (mg/l)	1400.00
RRSSLI	Initial salt storage - lower zone (mg/l)	4200.00

Table K6 : Middle Harts sub-system - Irrigation sub-model RR12

CODE	DESCRIPTION	PARAMETERS
RRERF	Mean annual effective rainfall factor	.6000
RRMA	Annual irrigation water allocation (10^6m^3)	141.00
RRTLPQ	Transfer Canal - flow loss factor	.0000
RRTLPS	Transfer Canal - salt loss factor	.0000
RRIE	Irrigation efficiency factor	.6800
RRLF	Return flow factor	.0000
RRPRFU	Proportion of return flow - upper zone	.1500
RRPRFL	Proportion of return flow - lower zone	.5000
RRSCF	Deep percolation salt concentration factor	5.0000
RRPSL	Proportion of salt loss to deep storage	.0200
RRSLDI	Initial salt load applied to irrigated land - (t/ha)	.04
RRSLD2	Subsequent salt load applied to irrigated land - (t/ha)	.04
RRHSU	Soil moisture storage capacity - upper zone (mm)	400.00
RRHSL	Soil moisture storage capacity - lower zone (mm)	600.00
RRHT	Soil moisture storage capacity - target (mm)	250.00
RRHI	Soil moisture storage capacity - initial (mm)	250.00
RRSSUI	Initial salt storage - upper zone (mg/l)	1400.00
RRSSLI	Initial salt storage - lower zone (mg/l)	4200.00

Table K7 : Middle Harts sub-system - Catchment salt washoff sub-model SW3

CODE	DESCRIPTION	PARAMETERS
SWSSP	Initial pervious zone salt storage (t/km²)	7.40
SWSSU	Initial urban zone salt storage (t/km²)	.00
SWSSG	Initial sub-surface zone salt storage (mg/l)	523.00
SWSSRP	Initial pervious zone salt recharge rate (t/km²)	.1700
SWSSRU	Initial urban zone salt recharge rate (t/km²)	.0000
SWEP	Salt washoff efficiency - pervious zone	.02500
SWEU	Salt washoff efficiency - urban zone	.000000
SWQG	Initial interflow/groundwater flow (mm)	.0200
SWGMB	Mean monthly groundwater flow limit (mm)	.0200
SWRDF	Antecedent runoff decay factor	.3000
SWPAF	Proportion of surface flow via interflow	.5000
SWPI	Proportion of salt washoff infiltration	.8000
SWHGW	Constant soil moisture storage depth (mm)	400.00

APPENDIX L

MODEL CALIBRATION STATISTICS

Table L1 : Upper Harts at route 9 - Harts River at C3H003 (1972-1990)

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	7.05	7.04	483.59	547.10	2225.08	2225.45
Std. dev.	22.14	22.15	222.45	190.06	7498.93	6659.74
N	228	228	98	98	136	136
r		.999903		.491776		.973740
E1		-.17		13.13		.02
E2		.06		-14.56		-11.19
SF		1.00		.95		.93
Mean		7.04		549.59		2242.22
Std. dev.		22.15		173.44		5833.71
N		228		179		228

Table L2 : Middle Harts at route 10 - return flow from irrigation sub-model RR11 (1952-1990)

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	3.18	2.71		1134.59		2463.46
Std. dev.	1.67	1.35		240.59		1460.44
N	245	245		157		85
r		.626573		.034964		.506235
E1		-14.83		46.39		-4.53
E2		-19.44		8.71		-14.17
SF		.72		.79		.72
Mean		3.20		929.20		2767.80
Std. dev.		1.99		299.18		2291.87
N		468		468		468

Table L3 : Middle Harts at route 13 - Harts River at C3H007 (1972-1990)

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	3.71	3.59	775.03	817.04	3185.27	3109.04
Std. dev.	1.84	1.88	221.31	302.37	1913.64	1643.53
N	289	289	157	157	112	112
r		.782108		.271073		.695940
E1		-3.39		5.42		-2.39
E2		2.14		36.63		-14.12
SF		-.51		.85		-.13
Mean		13.83		789.20		6123.28
Std. dev.		48.46		258.84		14866.72
N		468		468		468

Table L4 : Middle Harts at route 18 - outflow from Spitskop Dam (1974-1990)

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	11.43	11.60	675.79	778.13	8385.03	8367.94
Std. dev.	44.71	45.49	229.17	317.00	22882.28	21420.51
N	189	189	88	88	83	83
r		.999642		.488509		.998222
E1		1.50		15.14		-.20
E2		1.74		38.33		-6.39
SF		.51		.81		.90
Mean		18.34		924.08		8404.53
Std. dev.		77.88		388.34		26106.46
N		204		200		204

Table L5 : Middle Harts at route 19 - Harts River at C3H013 (1967-1990)

Parameter	Discharge (M cub.m)		Concentration(mg/l)		Load (t)	
	Observed	Modelled	Observed	Modelled	Observed	Modelled
Mean	2.59	2.63	704.25	844.82	2248.89	2538.62
Std. dev.	1.52	1.88	205.84	424.36	1067.31	1511.15
N	207	207	102	102	63	63
r		.770463		.703338		.442008
E1		1.83		19.96		12.88
E2		23.51		106.16		41.59
SF		-.67		.88		-.38
Mean		16.57		879.31		7678.76
Std. dev.		70.07		344.65		23755.99
N		288		287		288

APPENDIX M

PLOTS OF MODELLED AND OBSERVED MONTHLY VALUES

Figure **Page**

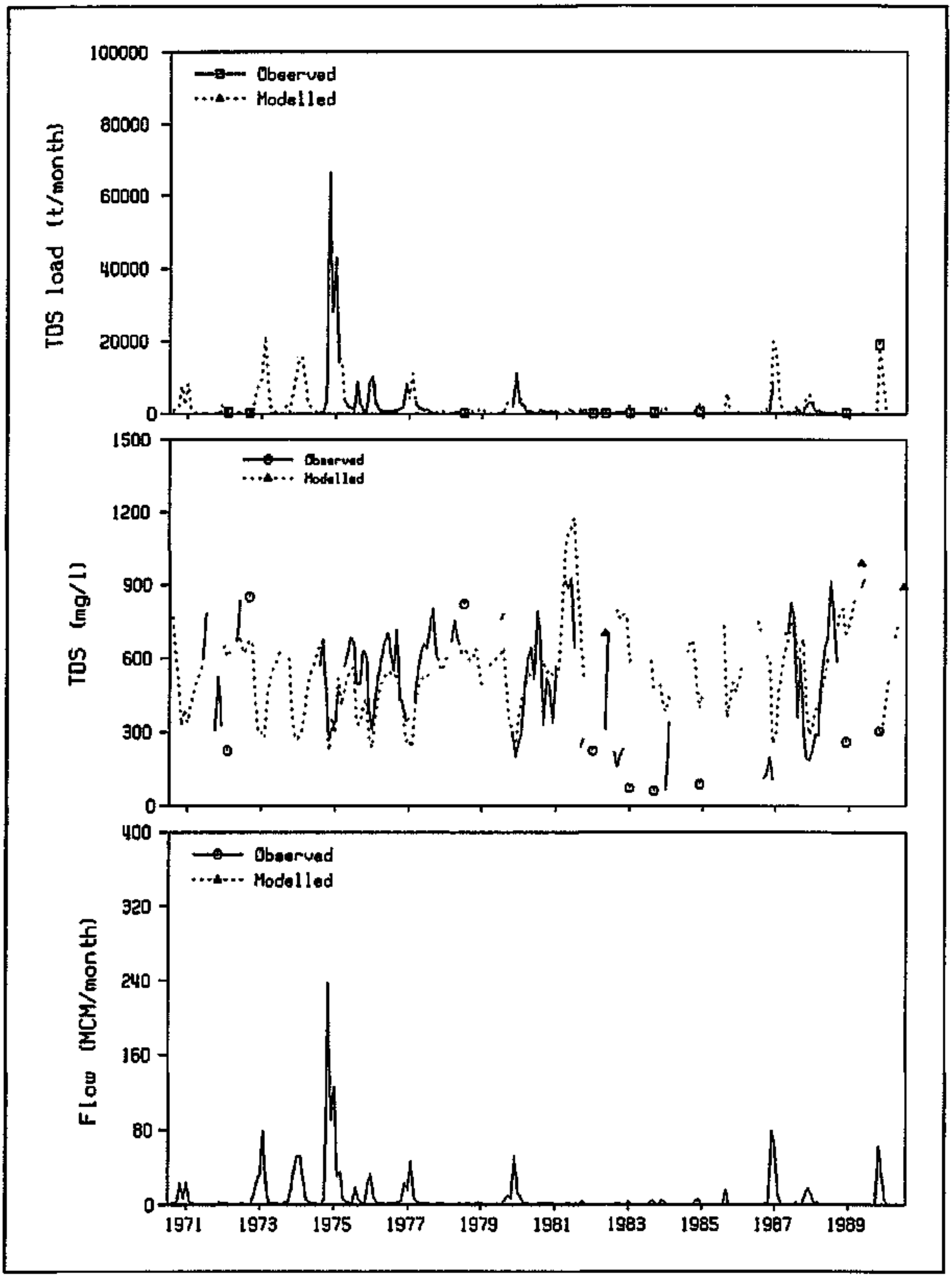

Figure M1 : Upper Harts at route 9 - Harts River at C3H003

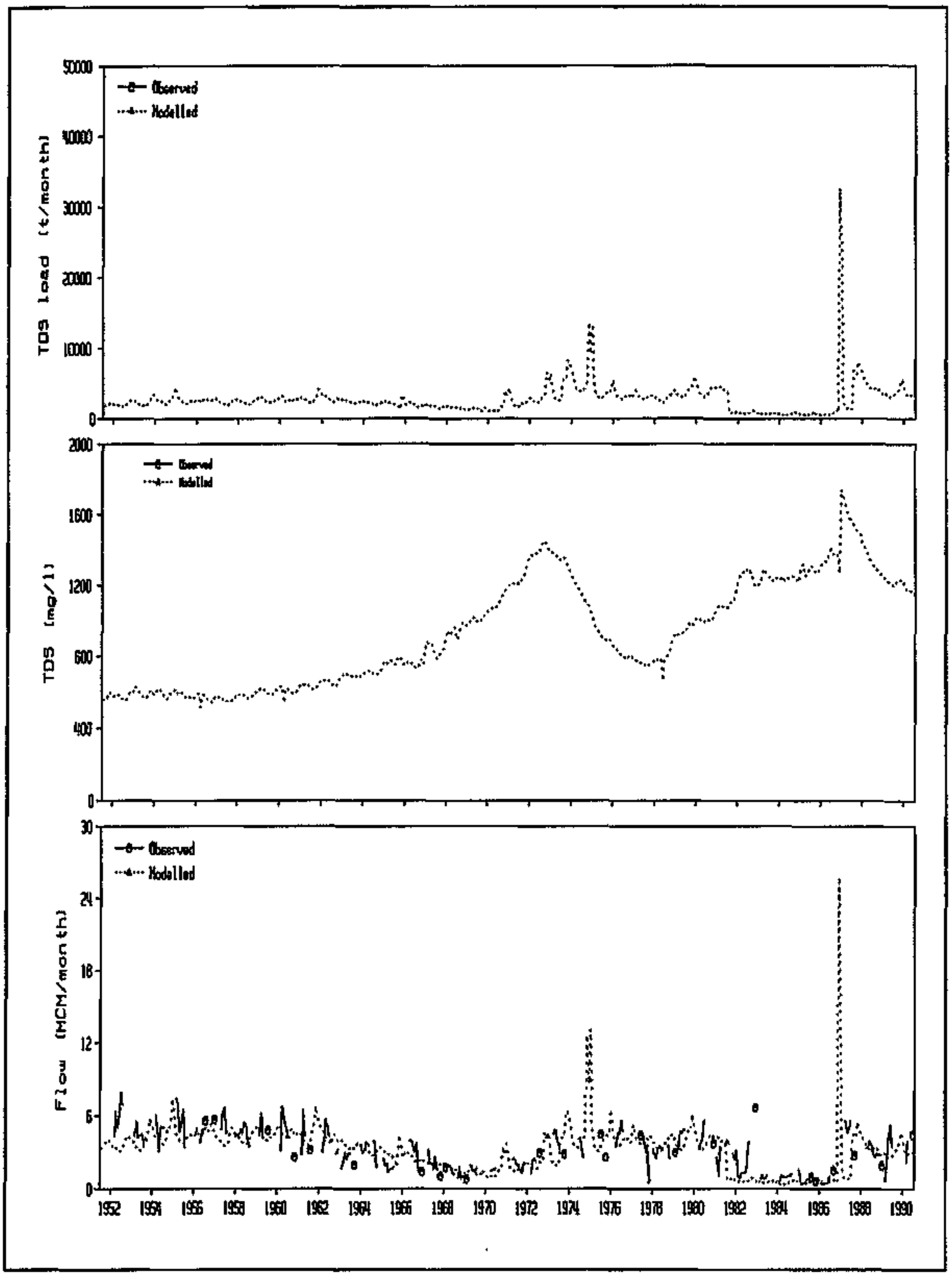

Figure M2 : Middle Harts at route 10 - return flow from irrigation sub-model RR11

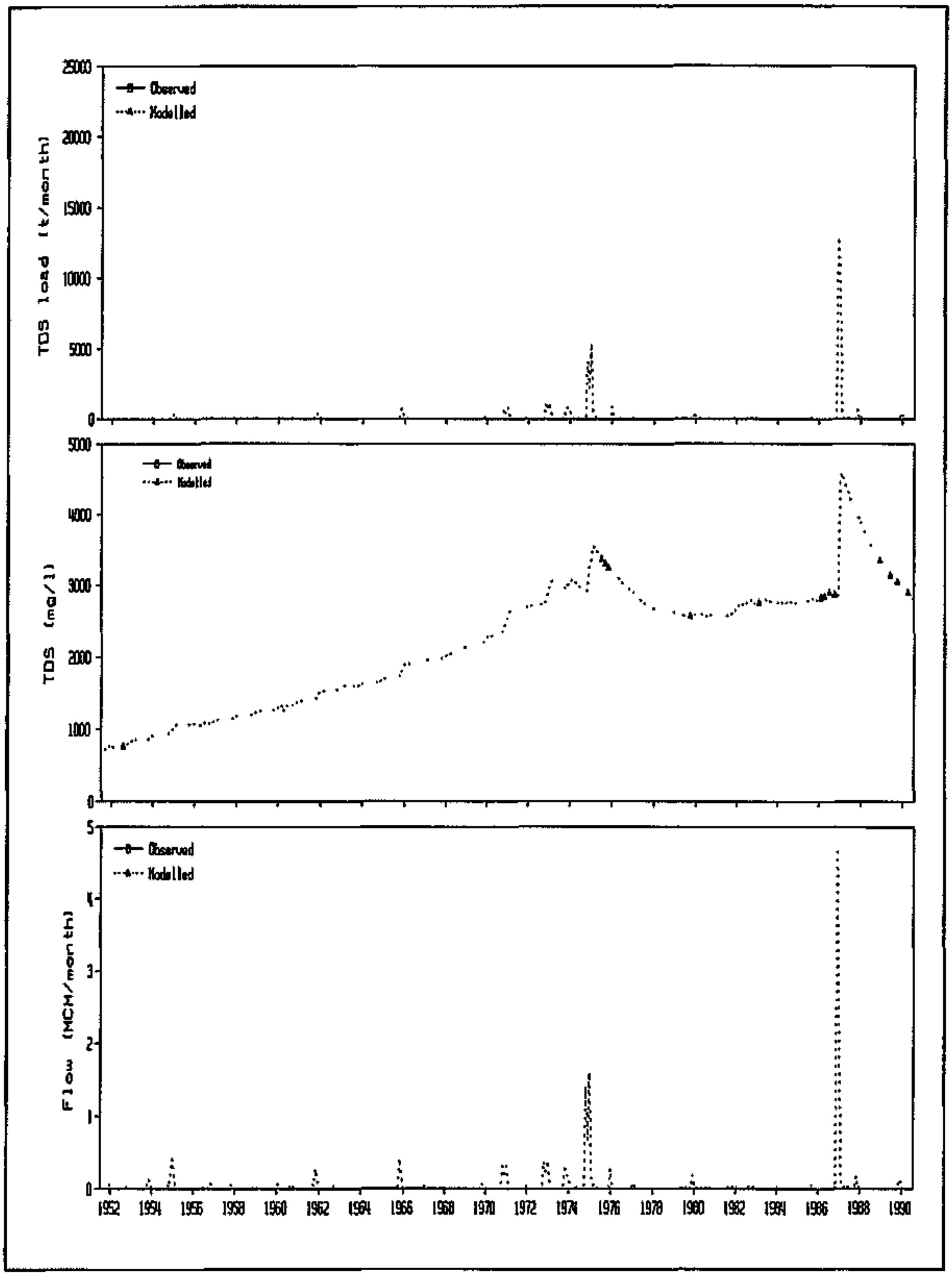

Figure M3 : Middle Harts at route 14 - return flow from irrigation sub-model RR12

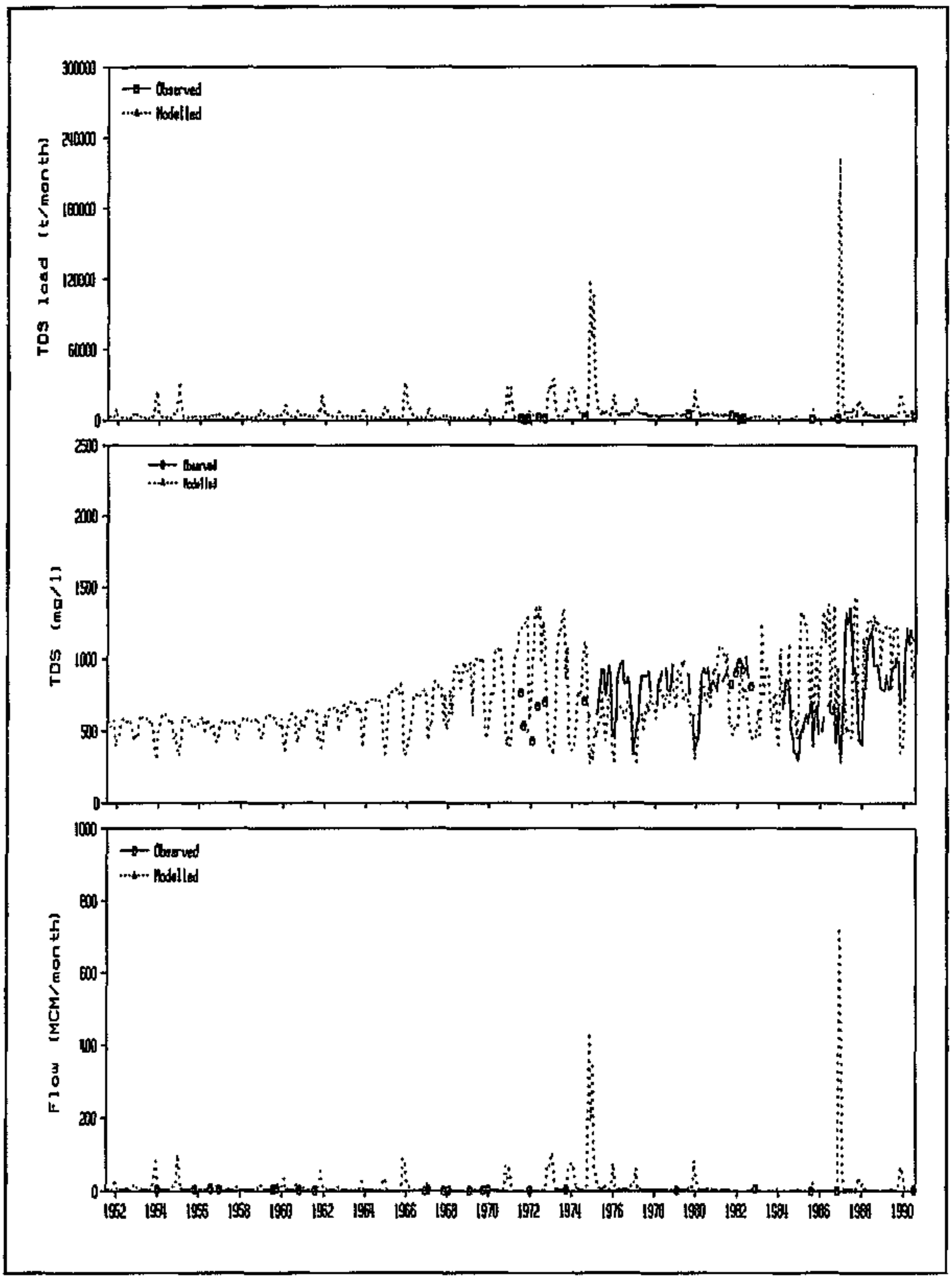

Figure M4 : Middle Harts at route 13 - Harts River at C3H007

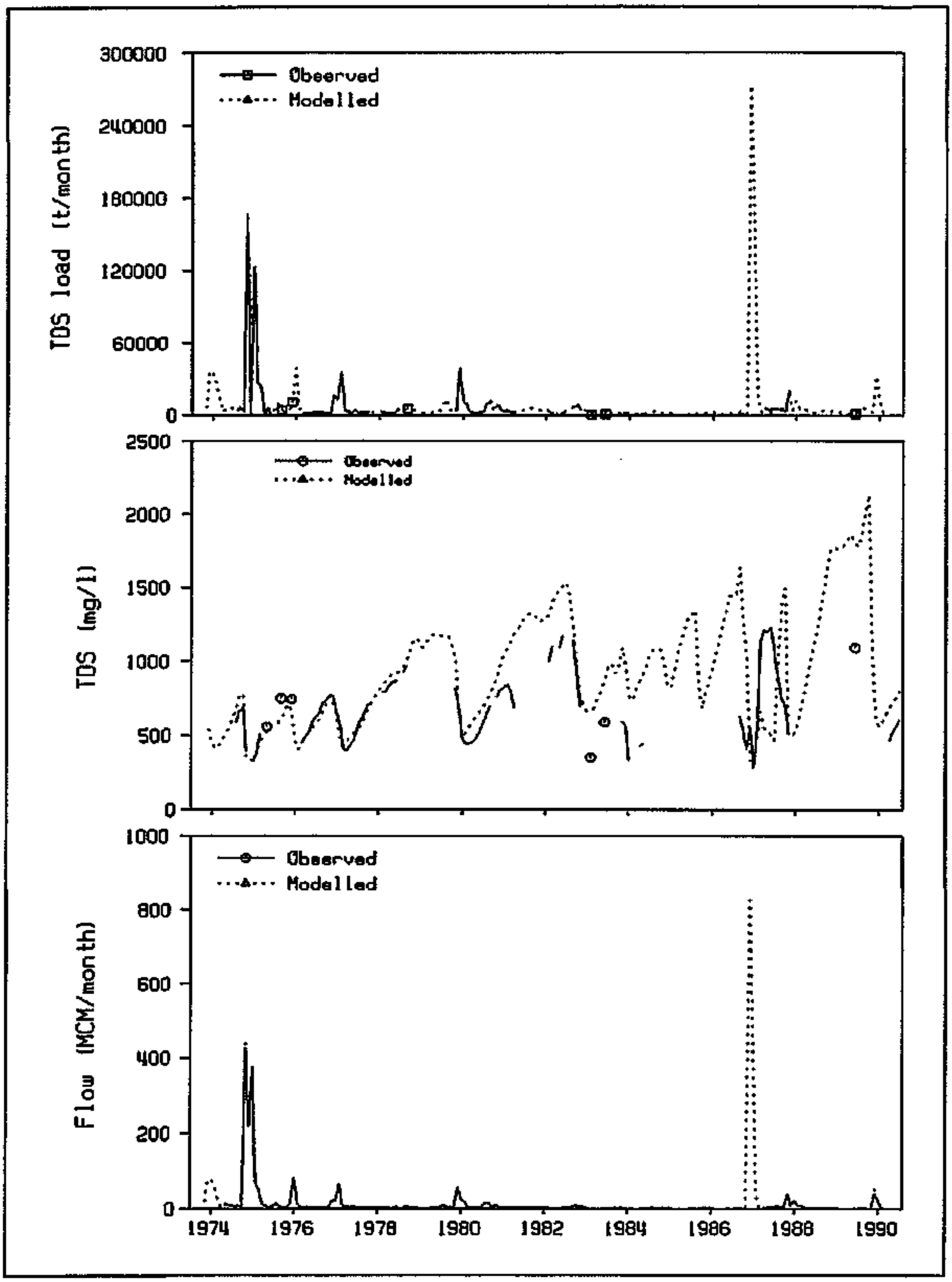

Figure M5 : Middle Harts at route 18 - Outflow from Spitskop Dam (C3R002)

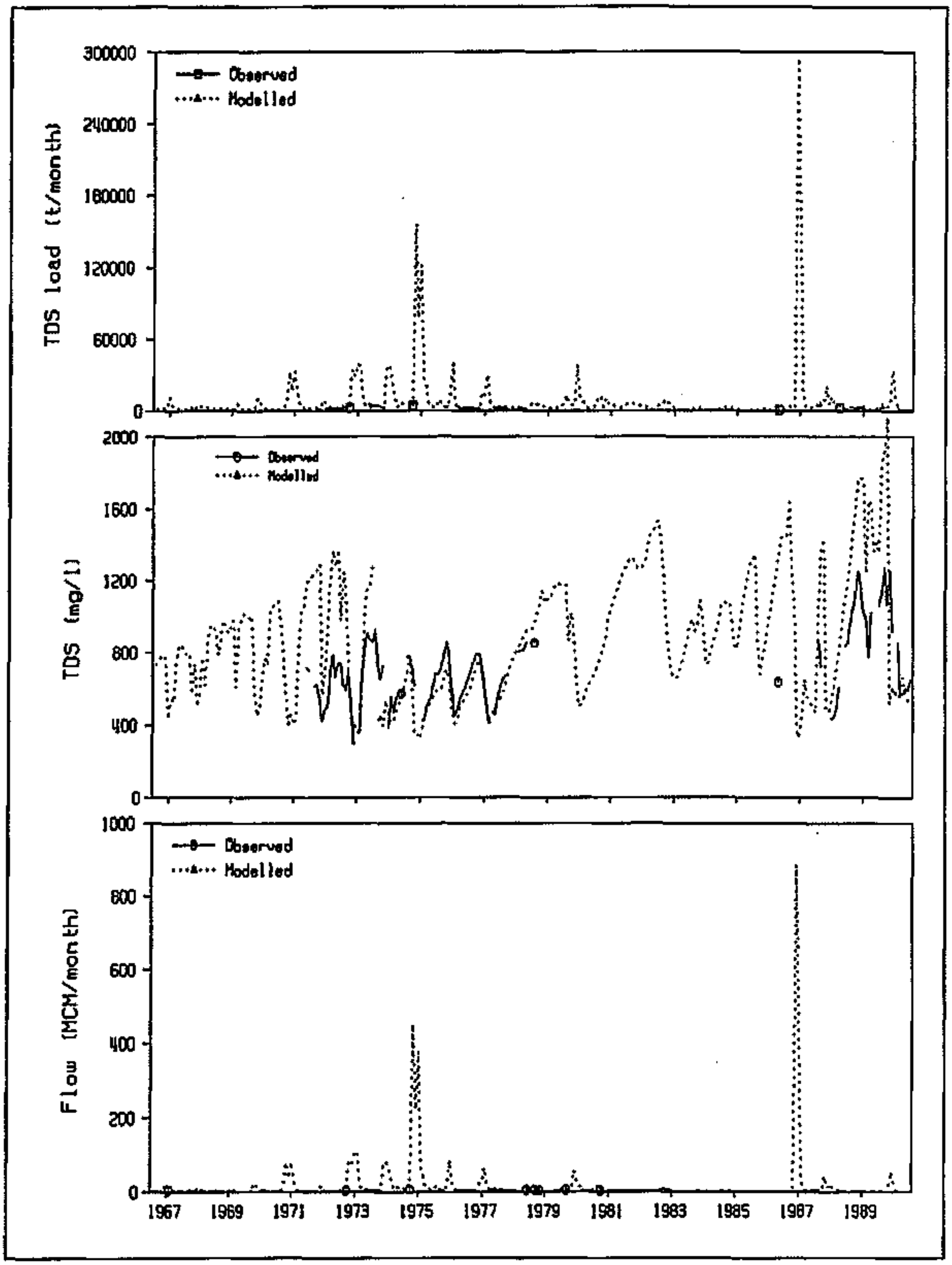

Figure M6 : Middle Harts at route 19 - Harts River at C3H013