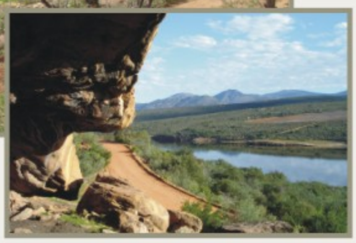
DWAF Report No. P WMA 17/E10/00/0509

DEPARTMENT OF
WATER AFFAIRS
AND FORESTRY

Feasibility Study for the Raising of Clanwilliam Dam

Water Quality



Final
February 2009

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DIRECTORATE OPTIONS ANALYSIS

FEASIBILITY STUDY FOR THE RAISING OF THE CLANWILLIAM DAM

WATER QUALITY

Final

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Department of Water Affairs and Forestry
Directorate Options Analysis

FEASIBILITY STUDY FOR THE RAISING OF THE CLANWILLIAM DAM

APPROVAL

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EXECUTIVE SUMMARY

Introduction

Clanwilliam Dam is situated adjacent to the town of Clanwilliam, on the Olifants River in the Western Cape Province. The Dam was completed in 1935 and has since been raised to its current full supply level of 105.25 metres above sea level (DWAF, 2005a). Stored water from the Dam is mainly used for irrigation with a small percentage being used for domestic purposes. It is estimated that an irrigated area of approximately 13 000 ha is currently being supplied by releases from the Dam.

The Olifants/Doring River Basin Study - Phase II – Possible Raising of Clanwilliam Dam (DWAF,2003), concluded that raising the Dam could cost-effectively result in the provision of increased yield and recommended that it be investigated further.

Two water quality related studies were identified for further investigation during the feasibility phase. These related to potential changes in the thermal structure of the dam and potential changes to the eutrophication status of the dam and the canals system of the Lower Olifants River Government Water Scheme:

- An increase in the height of the dam wall would affect the thermal structure and dynamics of Clanwilliam Dam. The potential impact of raising the dam wall on thermal stratification and release temperatures needed to be investigated as well as the mitigating effects of installing a multi-level outlet structure.
- Concerns about the potential impacts on eutrophication were raised by users. Raising the dam wall would affect the water residence time in Clanwilliam Dam which may in turn affect its trophic status. Concerns were also raised about the potential impacts on algal problems experienced in the canals of the Lower Olifants River Government Water Scheme.

This report was compiled in two parts. **Section 1** describes the application of the water quality model, CE-QUAL-W2, to investigate the possible water quality related effects of raising Clanwilliam Dam and presents various results, conclusions and recommendations. **Section 2** of the report describes the current eutrophication status of the dam and irrigation canals system and how this may change as a result of raising the dam wall. Measures are proposed to mitigate some of the potentially negative impacts.

Potential impacts on the thermal regime of Clanwilliam Dam

Dam raised to 110, 115 and 120 mamsl

It was proposed that a raising in the height of the Dam wall should be accompanied by a multi-level outlet structure which would release water from various levels thereby allowing water of different temperatures to mix in an attempt to meet the downstream temperature requirements. The proposed heights of these outlets are 81.12, 90.25, 95.25, 100.25, 105.25, 110.25 and 115.25 mamsl.

Based on the aforementioned release heights and the assumption that the Dam was full at the beginning of November and taking into account the specific release volumes from each height, it was found that the target temperature of 18 ºC downstream of the Dam could be met during the early parts of November, for all the scenarios.

Additionally, a case with multi-level outlets located at 115.25, 110.25, 105.25, 100.25, 83.56 and 81.12 mamsl was also modelled and showed that the desired target temperature of 18ºC could still be attained, provided that the dam level at the beginning of November was at 105 mamsl or higher.

Conclusions

Based on the results and the discussion in previous sections, the following can be concluded:

- More realistic outputs in terms of the temperature distribution in the Dam and temperature of releases can only be obtained if the input data to the model is more reliable. This is particularly relevant for inputs which drive the temperature profile within the Dam, *viz*. meteorological data, inflow temperature and volumes as well as release rates.

- Based on the available input data, the temperature requirement of 18º C for the releases would be achievable for the Dam raised to 110, 115 and 120 mamsl. This was, however, based on the assumption that the Dam was full on the first of November and that the highest available outlet could be used to make the releases during early November.

Reducing the number of offtakes below 110 mamsl could lead to the target temperature not being met at the beginning of November, especially if the Dam does not reach its full supply level (FSL) during the winter months.

Recommendations

Based on the results, discussions and conclusions, the following recommendations can be made:

- A monitoring programme for the systematic monitoring of the pertinent data for assessing or modelling water quality in the reservoir should be instituted. This programme should include:

  a. Hourly meteorological data (air temperature, dew point temperature, wind speed, wind direction, and percentage sunshine).
  b. Inflow rates.
  c. Inflow and in-lake water quality (see **Appendix A** for a complete list of water quality (WQ) variables).
  d. Release rates.

- Since the latest information on the ecological water requirements only became available after the modelling task was completed it is recommended that a more representative release pattern be created, based on the operating rules of the Dam as well as the ecological requirement and irrigation demands downstream of the Dam. This, in addition to more representative meteorological and inflow data will provide a more realistic representation of the temperature profile most likely to exist in the Dam and the ability to match the required temperature downstream of the Dam.

- For each of the proposed raised dam levels, the following approach should be adopted to determine the level of confidence that can be attached to the results presented in this report:

  e. Re-run the Dam trajectories with realistic ecological requirements imposed, to determine the most probable dam levels at the beginning of November for each proposed new dam height.
  f. Re-run the hydrodynamic and water quality model using the most probable starting level at the beginning of November to determine the probability of meeting the temperature requirement.
  g. Decide, in consultation with the ecological specialist whether the determined probability for meeting the downstream temperature requirement is acceptable.

- The most recent arrangement of the multi-level off-take structure should be investigated in more detail in terms of the approach outlined in the previous recommendation to determine whether an additional outlet is required between 100.25 mamsl and 83.56 mamsl.

Potential impacts on the eutrophication status of Clanwilliam Dam

A reconnaissance level assessment was undertaken of the present nutrient and eutrophication status of Clanwilliam Dam and Bulkshoek Weir, using available monitoring data and published or anecdotal information. The assessment included a synthesis of data and information that was available about the growth of filamentous algae in Bulkshoek Weir and specifically in the canal system of the Lower Olifants River Government Water Scheme. Assessment of the potential impacts of raising Clanwilliam Dam on the eutrophication status of the Dam was undertaken using simple, management oriented assessment tools.

Results

Algal growth potential in Clanwilliam Dam and Bulkshoek Weir - based on the water quality data records available at Clanwilliam Dam and at Bulkshoek Weir from 1998 to present, it was concluded that both dams could be classified as being oligo-mesotrophic. This means that in terms of nutrient enrichment, the dams are in an unenriched to moderately enriched state. The chlorophyll *a* concentrations that have been collected at the dams since 2005 as part of the National Eutrophication Monitoring Programme (NEMP) confirm these conclusions.

Filamentous algae in the irrigation canals - discussions with staff of the Lower Olifants River Water User Association (LORWUA) confirmed that problems with filamentous algae in the canals dated back to at least the early 1980s. The problem of nuisance algae used to occur in the lower reaches of the canal system in the Lutzville area. However, over time the problems have progressed in an upstream direction and these now occur from about the Vredendal area. The LORWUA has implemented an annual treatment programme to prevent the filamentous algae from reaching problematic proportions. The programme involves dosing the canals with a copper sulphate compound and the location, frequency and severity of treatments are guided by the algal biomass observed in the canal system during the high irrigation months (October to February). Research on filamentous algae in canals concluded that there was a weak link between nutrient availability and algal growth and that these algae could grow even under very low nutrient concentrations if other limiting factors such as suitable substratum, flow velocity and underwater light climate were favourable.

Conclusions

Algal growth potential in Clanwilliam Dam and Bulkshoek Weir - the potential impacts of raising Clanwilliam Dam on its trophic status were modelled using the simple web-based Nutrient Enrichment Assessment Protocol (NEAP) developed by Dr WR Harding for South African reservoirs. It was found that if the phosphorus loads into Clanwilliam Dam remain the same as present day loads but the water residence time increased from 0.34 to 1.04 years, then a slight increase in the chlorophyll a concentrations can be expected. It is estimated that with raising the dam wall by 10m, the dam may on average still be in an oligo-mesotrophic state with maximum chlorophyll *a* values bordering on eutrophic conditions. By raising the dam wall by 15 m, it is estimated that the dam may on average remain in an oligo-mesotrophic state although the maximum chlorophyll a concentrations could fall within eutrophic conditions.

Filamentous algae in the irrigation canals – it was concluded that the raising of Clanwilliam Dam would probably have little impact on the growth of filamentous algae in the lower reaches of the canal system. The current use of the canal system is very close to its design capacity and there appears to be little scope for transporting more water through the system without major modifications to the canal system. The implication in terms of filamentous algal growth is that there would probably be little change from the current situation and the current impacts would probably continue.

Recommendations

Algal growth potential in Clanwilliam Dam - Clanwilliam Dam is in a good trophic state and it was estimated that, provided the phosphorus loads remain unchanged, there would probably not be a major shift in trophic status if the dam wall is raised. No specific mitigation is therefore required other than a strategy for monitoring the situation closely, especially the inflowing nutrient loads. It is also recommended that monitoring of the inflow water chemistry be restored and that the inflowing nutrient loads be examined on an annual basis. If an increasing trend is detected in the inflowing nutrient loads, then the potential impacts on the trophic state of the Dam should be estimated and should it result in a major shift from an oligo-mesotrophic state to a meso-eutrophic state, a nutrient management plan should be developed and implemented for the catchment.

Filamentous algae in the irrigation canals – given that the raising of Clanwilliam Dam would probably not have a significant impact on the filamentous algal growth dynamics in the lower reaches of the canal system, no further mitigation measures are required. However, the LORWUA should continue to monitor and control the biomass of filamentous algae by chemical means. The Association could investigate alternative chemical control agents as a means of possibly reducing control costs.

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GLOSSARY AND ABBREVIATIONS

ARC	Agricultural Research Council
CEO	Chief Executive Officer
ºC	degrees Centigrade
DWAF	Department of Water Affairs and Forestry
EWR	Ecological water requirement
FSL	full supply level
ISCW	Institute for Soil, Climate and Water
LORWUA	Lower Orange River Water User Association
m	metre
mamsl	metres above mean sea level
mg/l	milligram per litre
MJ/m^2	megajoules per square metre
mm	millimetre
Mm^3	million cubic metres
m/s	metres per second
N	Nitrogen
NEAP	Nutrient Enrichment Assessment Protocol
NEMP	National Eutrophication Monitoring Programme
NH_3	ammonia
NTU	Nephelometric Turbidity Units
%	percentage
P	phosphorus
PES	Present Ecological State
ph	acidity/alkalinity
PO_4	phosphate
RL	reduced level
TDS	Total dissolved solids
2-D	two-dimensional
WQ	water quality

1. WATER QUALITY MODELLING

1.1 Introduction

Clanwilliam Dam is situated adjacent to the town of Clanwilliam, on the Olifants River in the Western Cape Province. The Dam was completed in 1935 and has since been raised to its current full supply level of 105.25 metres above mean sea level (DWAF, 2005a). Stored water from the Dam is mainly used for irrigation with a small percentage being used for domestic purposes. It is estimated that an irrigated area of approximately 13 000 ha is currently being supplied by releases from the Dam.

According to the Inception Report for this project (DWAF, 2004) as well as *The Third Dam Safety Inspection Report* (DWAF, 2005a), Clanwilliam Dam requires remedial work for dam safety reasons. Specific concerns are related to the pre-stressed cables having lost their shear resistance ability and there also being problems with the alkali-aggregate reaction. At present, the hazard and risk levels for the Dam fall within an unacceptable range according to current Department of Water Affairs and Forestry (the DWAF) standards.

The required remedial work presents an opportunity to raise the Dam by up to 15m. *The Olifants/Doring River Basin Study - Phase II – Possible Raising of Clanwilliam Dam* (DWAF, 2003), concluded that raising the Dam could cost-effectively result in the provision of increased yield and recommended that it be investigated further.

With an increase in the Dam height, water quality related concerns such as thermal stratification and unsuitable release temperatures could become a reality and would thus have to be quantified before the actual raising of the Dam.

The focus of this report was to investigate the temperature-related changes that could be expected from the raising of the Dam as well as the mitigating effects of installing a multi-level outlet structure.

The report will start with a description and background of the model used. It will then describe the application of this model to Clanwilliam Dam and various findings. Finally, some conclusions and recommendations will be made.

1.2 Background to CE-QUAL-W2 Model

CE-QUAL-W2 is a two-dimensional (2-D), laterally averaged, hydrodynamic and water quality simulation model (Cole and Wells, 2001). The model is based on the assumption that the water body shows maximum variation in water quality along its length and depth. Therefore, the model is suited to relatively long and narrow water bodies that show water quality gradients in the longitudinal and vertical directions. The two-dimensional model simulates the vertical and longitudinal distributions of thermal energy (water temperature) and selected biological and chemical constituents in a water body with time.

Inputs to the model include the following:

- *Bathymetric Data* - data representing the layout and volumetric dimensions of the water body.
- *Initial Conditions* - data representing the starting conditions within the reservoir in terms of temperature and reactant distribution.
- *Meteorological Data* - this data includes the site specific values for air temperature, wind speed, wind direction, dew point temperature and cloud cover.
- *Upstream Boundary Conditions* - this data includes the flow rates of the incoming streams as well as the time varying concentrations of the reactants being modelled.
- *Flow Rates of Releases* - this includes the data describing the predicted (or measured) release pattern from the reservoir and is essential for volume balance calculations.

In this study, version 3.11 of the CE-QUAL-W2 Model was used.

1.3 Application of the model to Clanwilliam Dam

To obtain a realistic prototype of the Dam it was necessary to represent the physical constraints as accurately as possible. As mentioned in **Section 1.2**, these include bathymetric data, initial conditions, meteorological data and upstream/downstream boundary conditions. These will be discussed in more detail in the ensuing sections.

1.3.1 Input data

Meteorological data
Meteorological data was obtained from the Agricultural Research Council (ARC), Institute for Soil Climate and Water (ISCW), in Stellenbosch. Hourly data available at the two meteorological stations in the Citrusdal area and the variables measured at each are listed below:

- Citrusdal Experimental farm (1995 – 2000)
  - Dry bulb temperature (°C)
  - Maximum daily temperature (°C)
  - Minimum daily temperature (°C)
  - Wet bulb temperature (°C)
  - Short wave solar radiation (MJ/m^2)
  - Wind speed (m/s)
  - Rainfall (mm)
  - Evaporation (mm)
  - Relative humidity (%)
  - Leaf wetness

- Citrusdal Noord (2001 – 2005)
  - This station, in addition to the parameters collected at the aforementioned station, also measured **wind direction** (degrees from north) but excluded **leaf wetness** data.

Bathymetric data
The bathymetric description of the Dam is probably the most fundamental data required to construct a numerical grid which is used in the model. The numerical grid is a simplified mathematical description of the volume and shape of the Dam. It is absolutely essential to construct an accurate description of the Dam, as this will determine how well the water level in the Dam is modelled. The water level in the Dam is closely linked to water quality modelling and if the initial hydraulic calibration is not achieved, then water quality calibration will be difficult, if not impossible.

Data for construction of the numerical grid was obtained from the DWAF and was available as cross-sections through the Dam basin. The original data was imported into the Civil Designer programme where break-lines (joining high and low points) were generated. This surface was used to calculate volume in the Dam at 1 m intervals. To expedite the process of constructing the bathymetry file, it was decided to allow the model segment boundaries to coincide with the cross-sections for determining sedimentation. The orientation of a segment was obtained by connecting the midpoint of the cross-section (between banks) to the midpoint of the following cross-section with the angle being measured relative to north, in a clockwise direction. The procedure used is outlined below:

1. Discretise the reservoir into segments.
2. Draw a line from the midpoint of the downstream segment boundary to the midpoint of the upstream segment boundary.
3. At the outlet of the segment draw in a North-South line.
4. The angle between the two lines (defined in **2** and **3** above) in a clockwise direction from north was then measured and taken to be the segment orientation.

In the *Olifants/Doring River Basin Study – Phase II* (DWAF, 2003), three possible new full supply levels (FSL) were reported and analysed in terms of the impact it would have on the reservoir yield. These levels and their associated capacities are reported in **Table 1.1**.

Table 1.1 Possible FSLs and Capacities for Clanwilliam Dam

Raising (m)	FSL (m RL)	Capacity (Mm^3)
0	104.41	122.26
5	109.41	185.56
10	114.41	264.77
15	119.41	361.82

To account for all the selected FSLs that the Dam could be raised to, it was necessary to build the bathymetry for the Dam to a reduced level (RL) of 125 m. At this level, the Dam will be inundating the lower portions of the Rondegat and Kransvlei tributaries. These portions of the Dam were subsequently modelled as additional branches to the main basin of the Dam. A plan view depicting the segment layout of the Dam is shown in **Figure 1.1**.

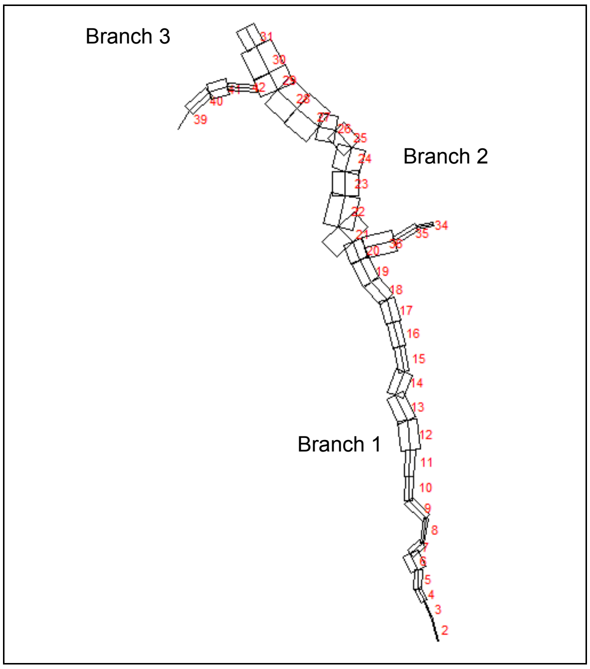

Figure 1.1 Layout of segments used for Clanwilliam Dam

Each segment was then divided into a number of layers, 1m in thickness, extending from the FSL to the bottom of the Dam. The width of each cell was then calculated by using the formula below:

$$\frac{\textit{Volume in cell}}{\textit{length of segment x height of segment}}$$

Using this method, the calculated volume of each cell in the grid was preserved. The entire grid for Clanwilliam Dam was made up of 43 segments and 49 layers with segments 1, 32, 33, 37, 38 and 43 representing boundary segments while layers 1 and 49 represented boundary layers that have zero width. These cells, however, need to be specified to enable the model to function. A visual representation of the grid is depicted in **Figure 1.2**. It should be noted that the main branch (Branch1) has 30 active segments while branches 2 and 3, have 3 and 4 active segments, respectively.

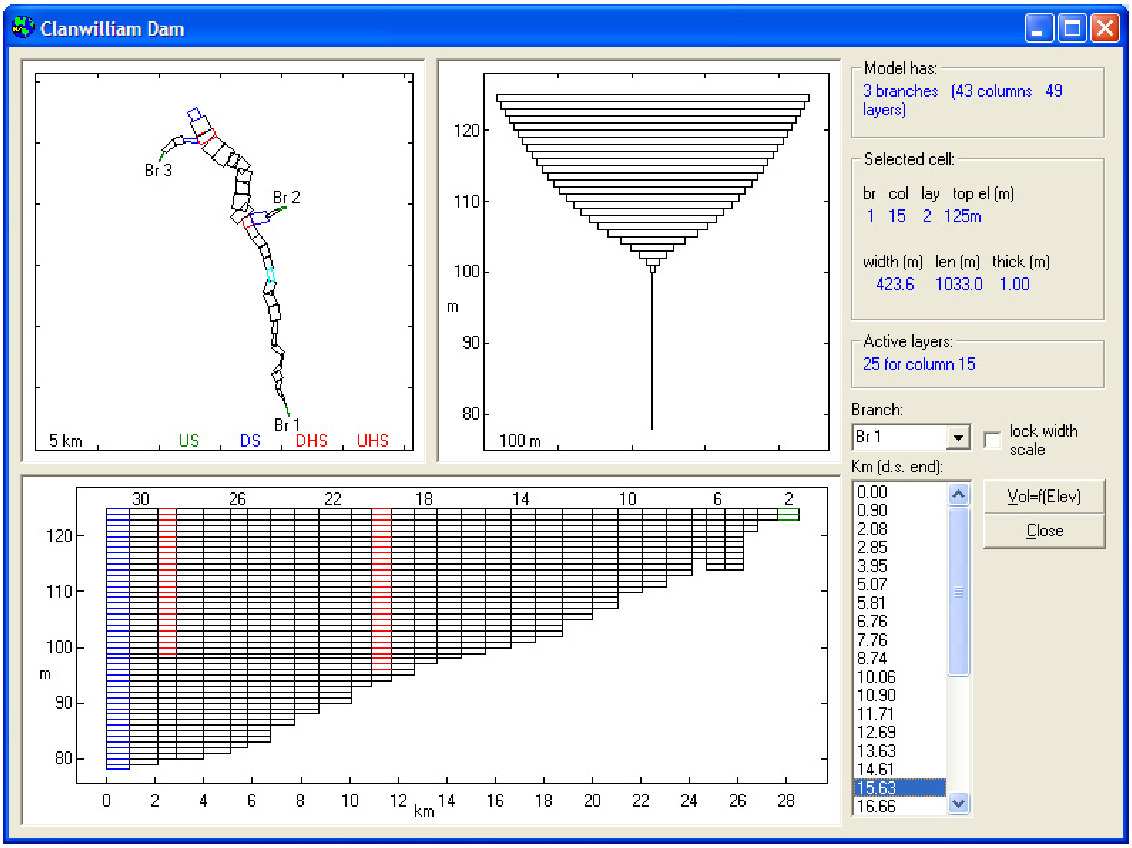

Figure 1.2 Clanwilliam Dam Bathymetry

The mathematical grid is only a representation of reality and should be compared with measured data to ensure that the grid is realistic. Since the calculated volume-height relationship was determined only from sediment surveys it was expected (based on previous experiences) to under-estimate the official volume-height relationship reported by the DWAF and that a scaling factor (1.24 in this case) would be required to match the official volume-height relationship.

The comparison of the calculated and official (obtained from the sediment survey) volume-height relationships is shown in **Figure 1.3** and it shows that the calculated volume-height relationship is representative of the official relationship.

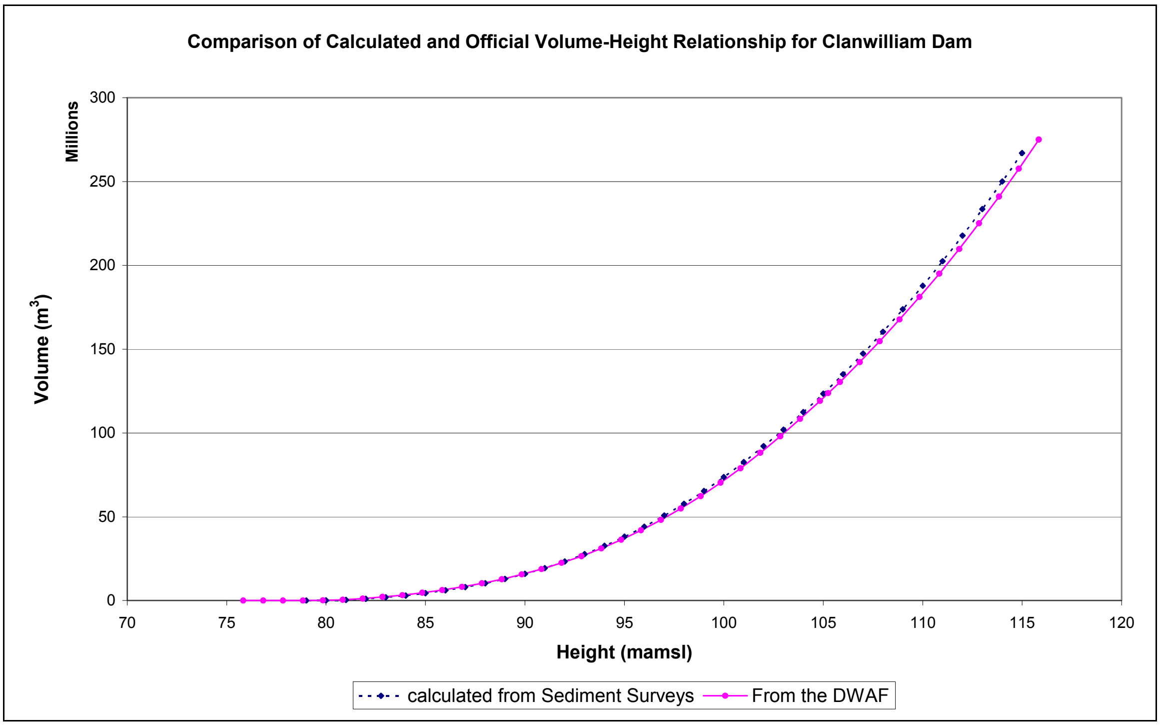

Figure 1.3 Comparison of volume-height relationships for Clanwilliam Dam

Upstream boundary conditions (inflows)

Inflows

As mentioned previously, Clanwilliam Dam is situated on the Olifants River and inflow from here was considered to be the major upstream boundary condition. Flow into Clanwilliam Dam is not gauged but is inferred from the Dam balance where inflow is calculated from the change in reservoir volume, evaporation, spills and other releases. The aim was thus to find a period where a minimum number of gaps existed in the calculated inflow record and which also overlapped with the meteorological data which was available. Examination of the calculated inflow record revealed that the period 1-11-1994 to 31-08-1995 was reasonably free of gaps and it was as a result selected as the calibration period.

Temperature

No inflow temperature data was collected for Clanwilliam Dam and it was necessary to estimate this information from the daily temperature measurements collected at the Citrusdal meteorological stations. The daily inflow temperature was estimated based on the method of Pilgrim M P, Fang X and Stefan H G (1998) who used the relationship:

$$T_w = 4.4 + 0.81T_a$$

Where

T_w = Average daily temperature in Celsius and
T_a = Average daily streamflow temperature in Celsius

Downstream boundary conditions (outflows)

Releases from the Dam are listed in **Table 1.2**, according to the *Third Dam Safety Inspection Report* (DWAF, 2005a):

Table 1.2 Releases from Clanwilliam Dam

Release Gauge no.	Release Description	RL of release (m)
E1H010	River releases	81.12
E1H009	Hydro-electric releases	83.56 (releases stopped in 1991)
E1H008	Agricultural releases	83.56
E1R002-A02	Spills	105.25

Daily flow rates for stations E1H010 and E1H008 were downloaded from the DWAF's website while daily spill rates were requested from the DWAF. This was then provided in the format of a daily volume balance for the Dam. The daily volume balance also contained information on releases made from the Dam which was useful for comparison with the release flow rates downloaded from the DWAF website. Upon comparison, it was found that irrigation releases (E1H008) downloaded from the DWAF website were representative of what was depicted in the daily dam balance file. The downloaded daily flows at gauging station E1H010, however, were substantially lower than the corresponding flows as represented in the daily dam balance file received from the DWAF. As a result, the accuracy of the release was a cause for concern.

1.3.2 Hydraulic verification

Measured dam levels for the calibration period (1-11-1994 to 31-08-1994) were obtained from the DWAF and were used for comparison with the simulated daily levels. A comparison of the initial simulated dam levels (using the daily river releases as downloaded from the DWAF's website at gauging station E1H010) from the model and the observed dam levels are depicted in **Figure 1.4**.

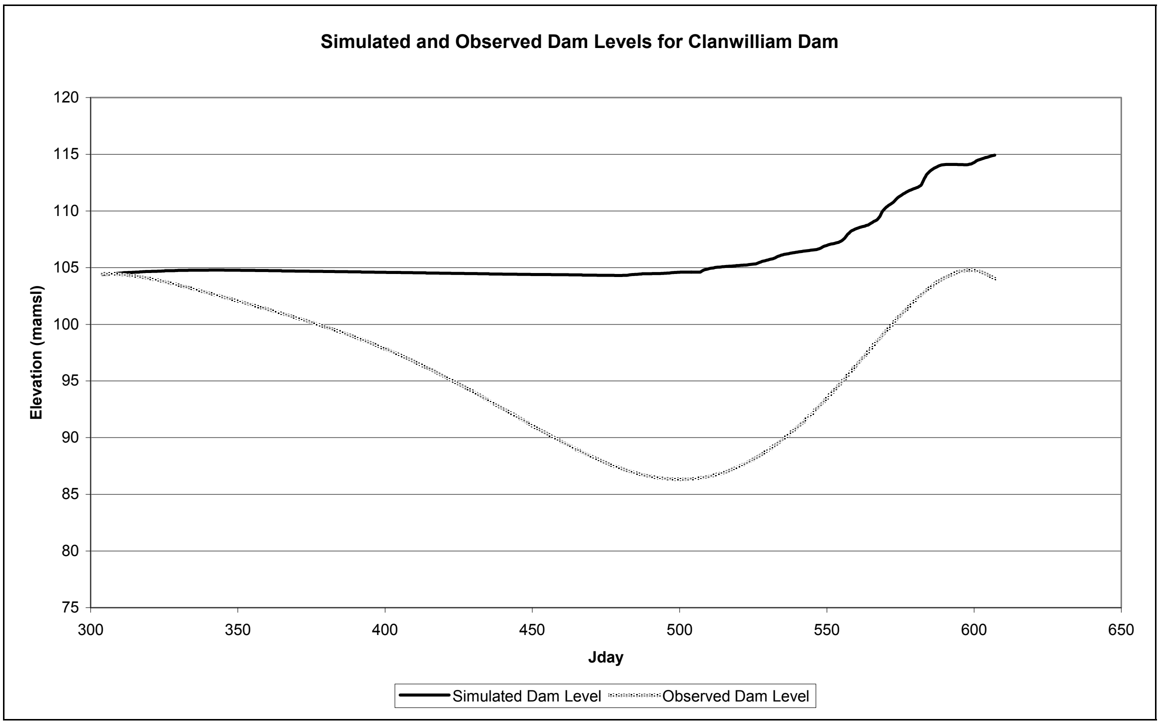

Figure 1.4 Simulated and observed dam levels for Clanwilliam Dam (based on river releases from gauge E1H010 downloaded from the DWAF website) (Julian day 300 = 27 October 1994)

As expected, the simulated flows were unrealistic and were subsequently replaced with the daily river releases as represented in the volume balance for the Dam. A comparison of the simulated and observed dam levels based on the updated river release values is depicted in **Figure 1.5.**

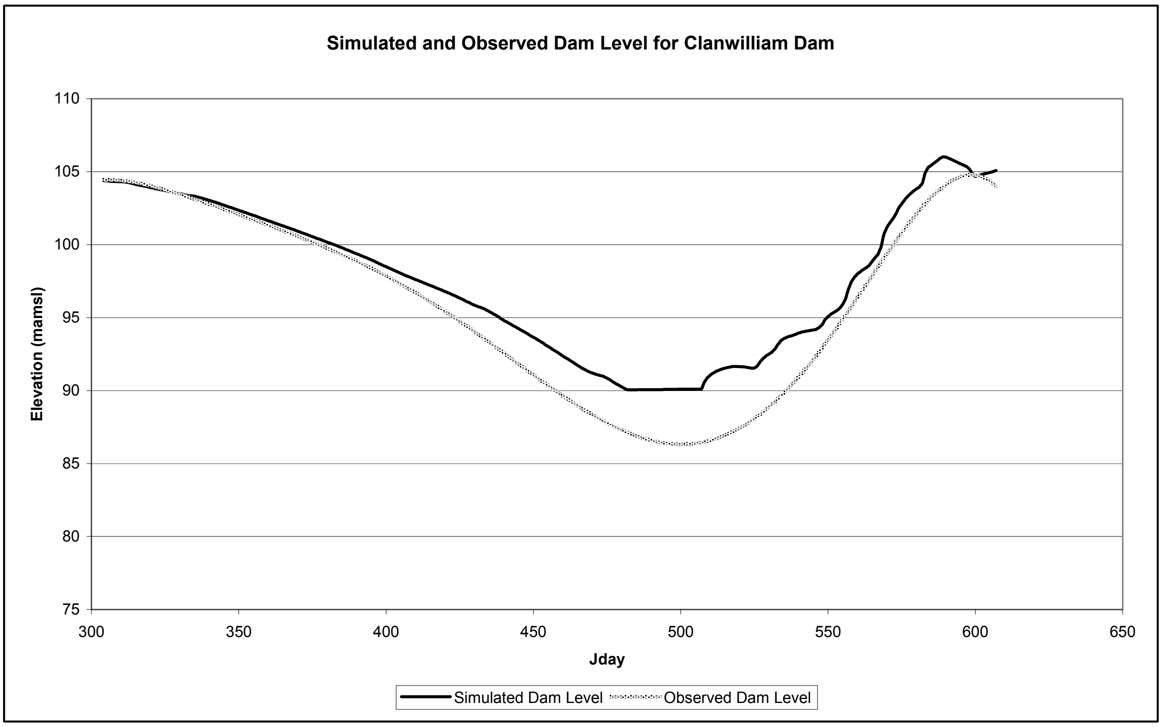

Figure 1.5 Simulated and observed dam levels for Clanwilliam Dam (based on river releases as represented in the daily dam balance from the DWAF) (Julian day 300 = 27 October 1994)

A marked improvement was seen in the comparison between the simulated and observed dam levels, but a discrepancy still existed. This discrepancy was eliminated using the "Mass Balance Utility" (Pers Comm, Annear, 2005) obtained from Portland State University. During the application of this utility the model inflows, outflows and simulated dam levels were compared with the observed dam levels (which were assumed to be the most accurate measured value) to calculate the "missing" flows in the system. Incorporation of these "missing" flows requires careful consideration, e.g. if flows are consistently negative it could indicate that inflows are consistently over-estimated or that the outflows are consistently under-estimated. Thus, subtracting these flows from the inflows as opposed to adding them to the outflows could have a significant effect on the simulation results. This type of consideration becomes critical for a calibrated installed model that is being used in an operational mode. In the study, all the "missing" flows with negative magnitude were added to the outflow while the missing flows with positive magnitude were added to the inflow to the Dam.

A comparison of the simulated and observed dam level, after adjustment for the missing flows, is depicted in **Figure 1.6**, from which it can be seen that simulated dam levels that are representative of reality were obtained.

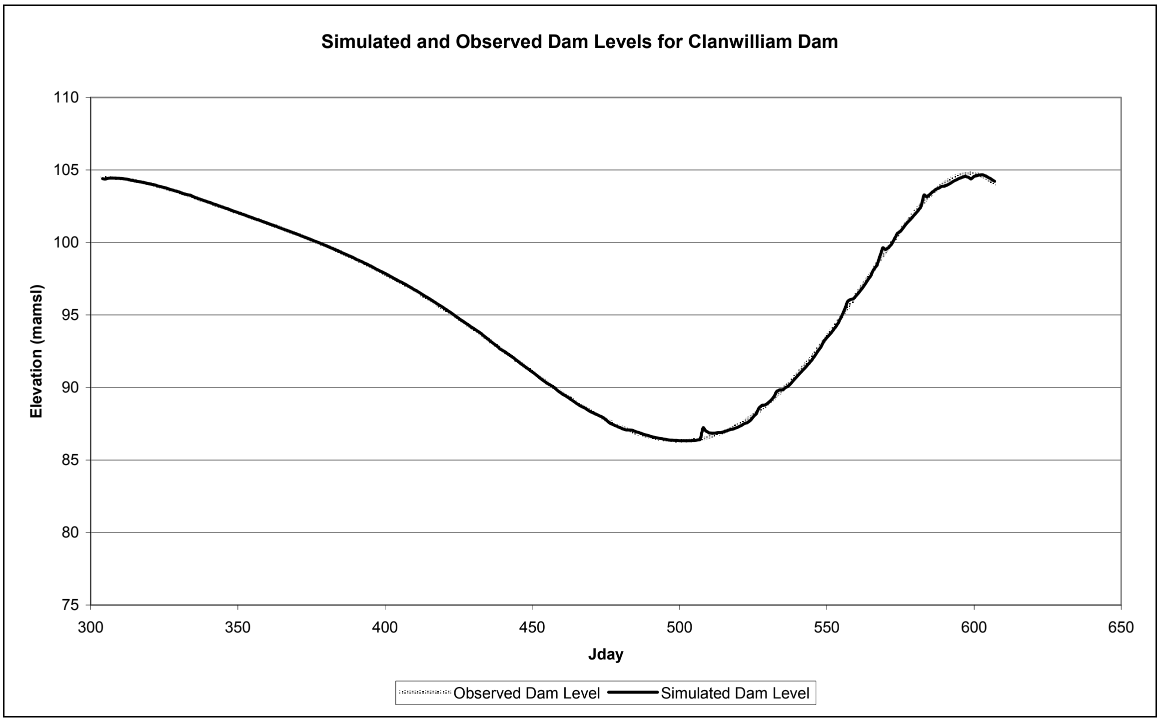

Figure 1.6 Simulated and observed dam levels after mass balance correction (Julian day 300 = 27 October 1994)

1.3.3 Simulation scenarios considered

As stated in Section 0, three possible new dam heights were considered. The simulation approach was to keep all variables constant across the three scenarios and to vary only dam FSL and the levels from which releases could be made.

It should be noted that a record of spills from Clanwilliam Dam was available for the calibration period and it was therefore used as a specified outflow. No information was, however, available on the hydraulic parameters for the raised dam walls and, in the absence of a spill record, it was assumed that spills could be calculated using the following relationship, as required by the CE-QUAL-W2 model.

$$Q = \alpha \times (\Delta h)^{\beta}$$

Where,

Q	= flow in m^3/s
α	= constant = 76.069
β	= constant = 1.626
Δh	= height above the spillway

In developing this equation it was assumed that the length of the spillway was 40m. Outlet arrangements for the Dam wall when raised to the various heights are discussed in the ensuing sections.

Current dam height

At present the FSL of the Dam is 105.25 mamsl (DWAF, 2005a) with a river outlet at a RL of 81.12 m which has a diameter of 1.219m. The maximum discharge capacity at FSL is $10m^3/s$.

Dam wall raised to 110, 115 and 120 mamsl

It was proposed that a raising in the height of the Dam wall should be accompanied by a multi-level outlet structure which can release water from various levels thereby allowing water of different temperatures to mix in an attempt to meet the downstream temperature requirements. The proposed heights of these outlets are 81.12, 90.25, 95.25, 100.25, 105.25, 110.25 and 115.25 mamsl.

The original daily volumes released from the bottom outlet structure were split amongst the various off-takes in the multi-level outlet structure to ensure that not only cold bottom waters were released and in an attempt to reduce the depth of stratification that may accompany the raising of the Dam.

1.4 Results

The results of the various modelling runs are presented in the ensuing sections.

1.4.1 Dam raised to 110 mamsl

The temperatures of the Dam releases, using the bottom and multi-level outlet structures respectively, are depicted in **Figure 1.7**.

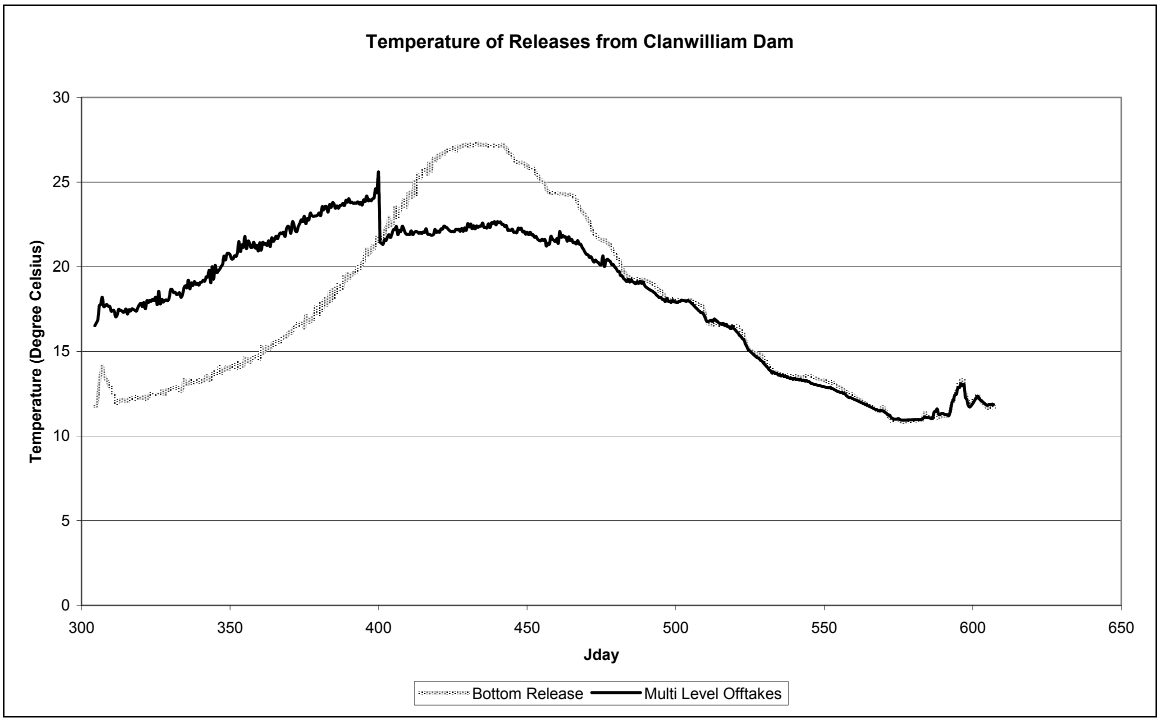

Figure 1.7 Temperature of dam releases made from the bottom outlet and from the multi-level outlet structure (FSL = 110 mamsl) (Julian day 300 = 27 October 1994)

It can be seen that the difference in temperature of releases from the Dam is significant, considering that the most sensitive time for the spawning of the Yellow Fish is in November (Julian day = 304 to 333). Although there is some uncertainty about the initial temperature profile in the Dam, it should be pointed out that both simulations had the same initial conditions and that the only difference was the multi-level offtake structure.

Time-depth plots showing the in-lake temperature for the bottom outlet and multi-level offtake scenario are shown in **Figure 1.8** and **Figure 1.9**, respectively. These figures suggest that the stratification that would occur, using a multi-level offtake structure, would be slightly stronger than using a bottom outlet structure. This can be seen more clearly in **Figure 1.10** which shows the comparison of the temperature profiles which would have existed when using only the bottom outlet structure compared to using the multi-level offtake, with hypolimnion temperatures of the latter scenario being approximately 5° Celsius colder than that for the scenario using only a bottom release. This observation is consistent with the findings of Hanna *et al.* (1999) who found a cumulative cooling effect of 5° Celsius in the hypolimnion in the late summer. The in-lake temperature conditions were a by-product of the simulation to determine the temperatures of releases made from the Dam. This should be analysed from an ecological perspective for acceptability. In this way, the model could (if other water quality variables are also modelled) provide early warning of unacceptable in-lake conditions that may exist as a result of the chosen release patterns to meet the downstream temperature requirements.

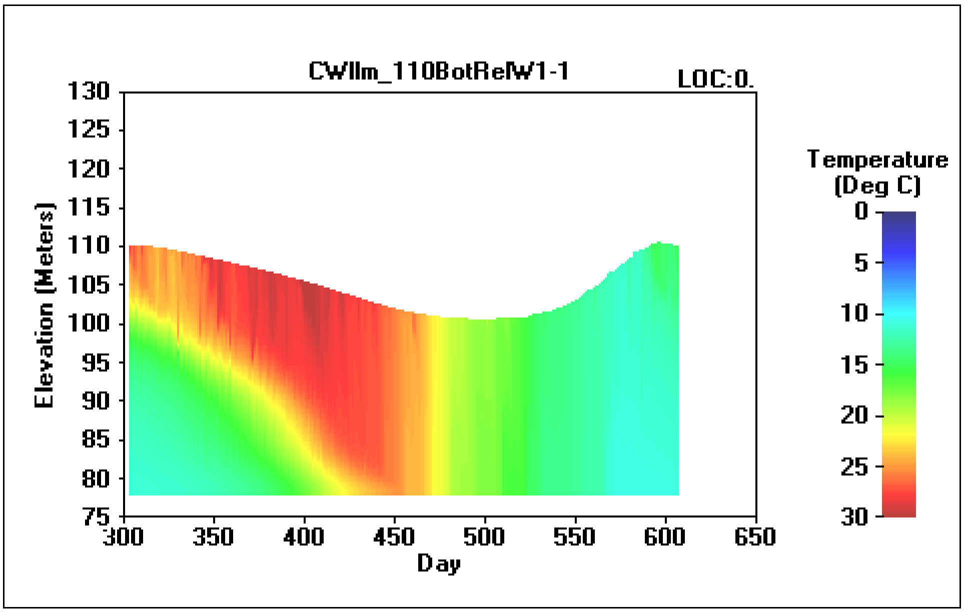

Figure 1.8 In-lake temperature conditions for the bottom-release scenario (FSL = 110 mamsl) (Julian day 300 = 27 October 1994)

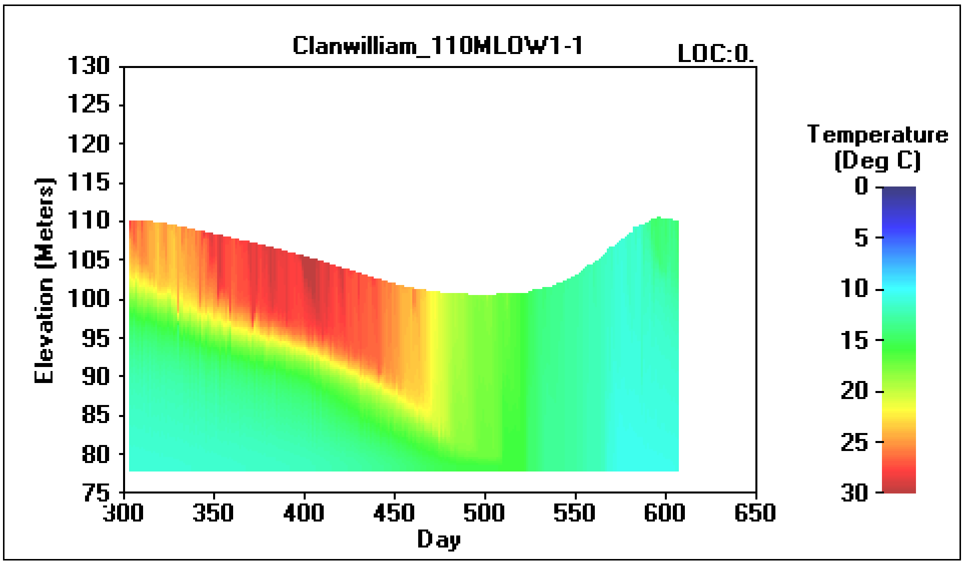

Figure 1.9 In-lake temperature conditions for multi-level offtake scenario (FSL = 110 mamsl) (Julian day 300 = 27 October 1994)

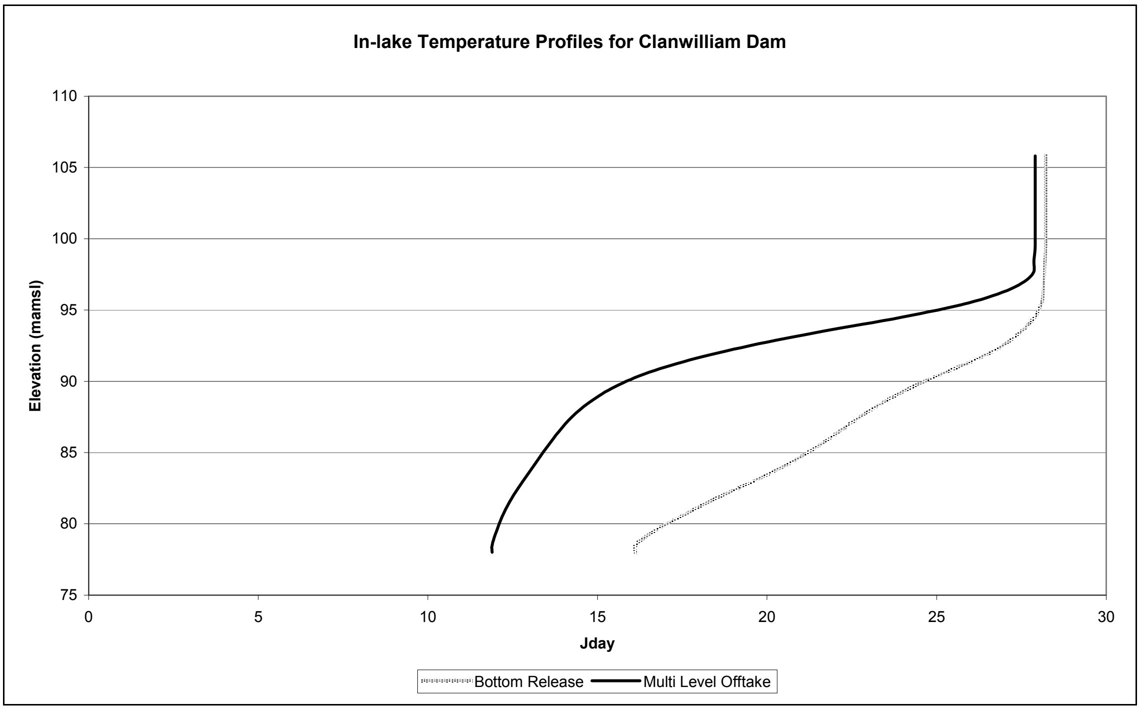

Figure 1.10 Inlake temperature profiles, (FSL = 110 mamsl) (Julian day 394 = 30 January 1995) (Julian day 300 = 27 October 1994)

1.4.2 Dam raised to 115 mamsl

The temperature of releases made from the Dam with and without the multi-level outlet structure is depicted in **Figure 1.11**.

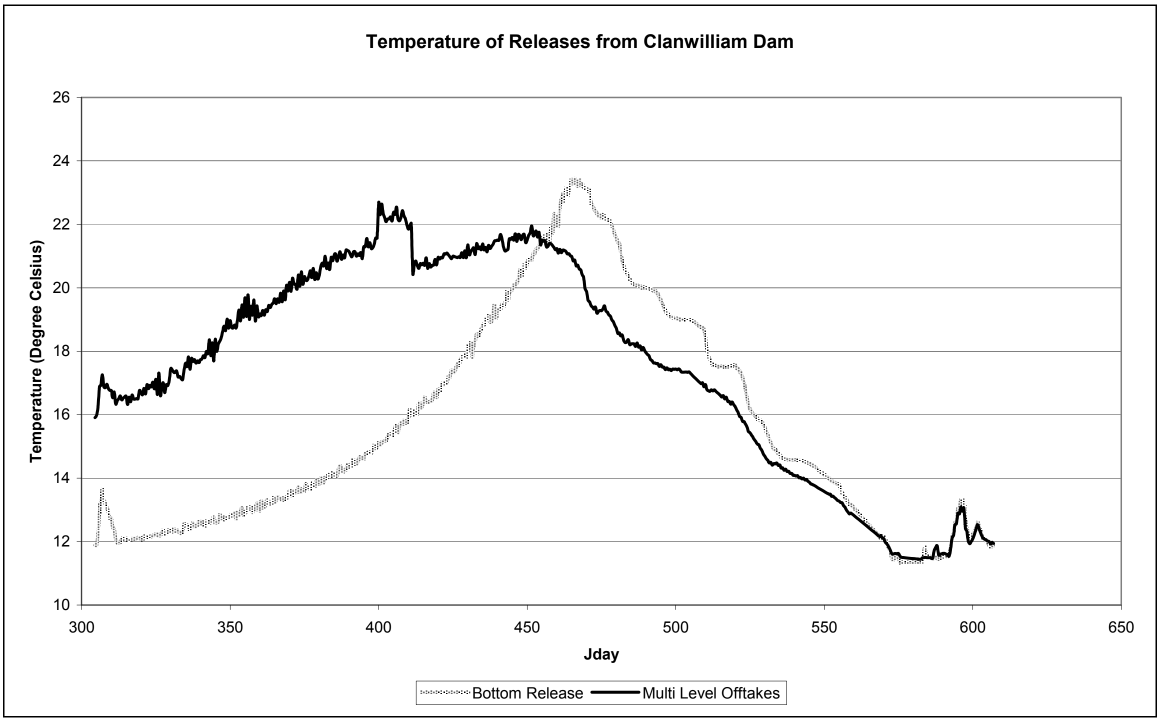

Figure 1.11 Temperature of dam releases made from the bottom releases and from the multi-level outlet structure (FSL = 115 mamsl) (Julian day 300 = 27 October 1994)

As before, **Figure 1.11** indicates that the multi-level outlet structure would allow for releases of a higher temperature, to be made from the Dam, which would be desirable from an ecological perspective. The temperature of releases made from the Dam could possibly be shifted closer to the 18° Celsius target if optimisation, with respect to the split in release volume amongst the various outlets in the multi-level offtake tower, were undertaken.

The in-lake temperature condition that could be associated with this release made only from the bottom outlet in the Dam, is depicted in **Figure 1.12** from which it can be seen that the warmer epilimnion water is incorporated into the hypolimnetic zone due to the flow patterns created by releasing water from higher levels in the Dam.

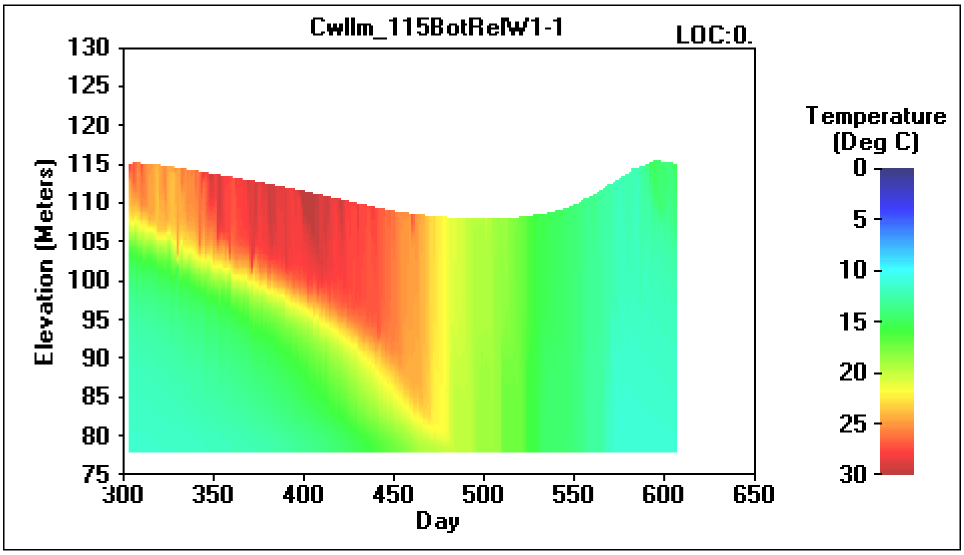

Figure 1.12 In-lake temperature conditions for bottom-release scenario (FSL = 115 mamsl) (Julian day 300 = 27 October 1994)

The in-lake temperature conditions using the multi-level offtake structure is depicted in **Figure 1.13**. As with the previous scenarios presented, a cooling effect is experienced in the hypolimnion towards the end of summer.

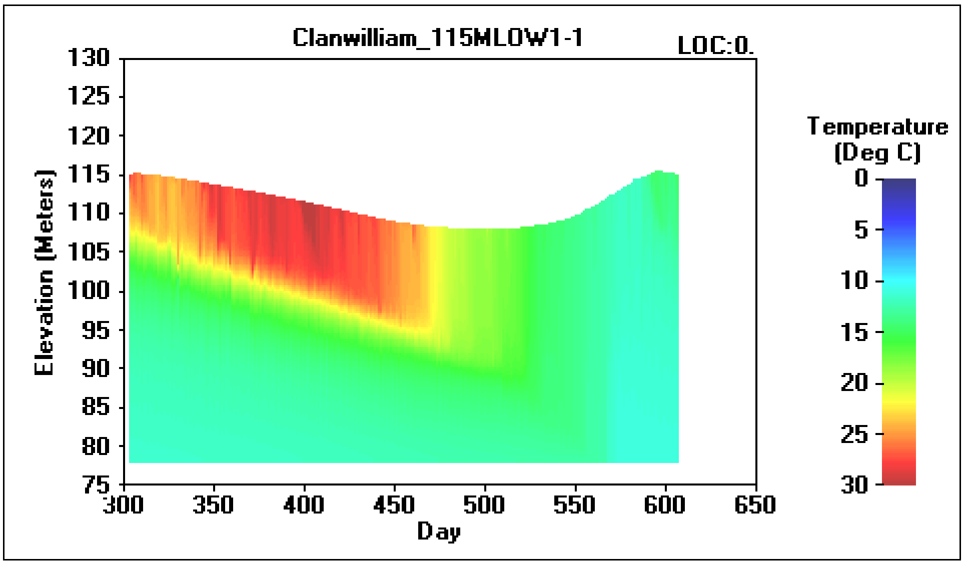

Figure 1.13 In-lake temperature conditions for multi-level offtake scenario (FSL = 115 mamsl) (Julian day 300 = 27 October 1994)

A comparison of the temperature profiles with and without the multi-level offtake structure is depicted in **Figure 1.14**.

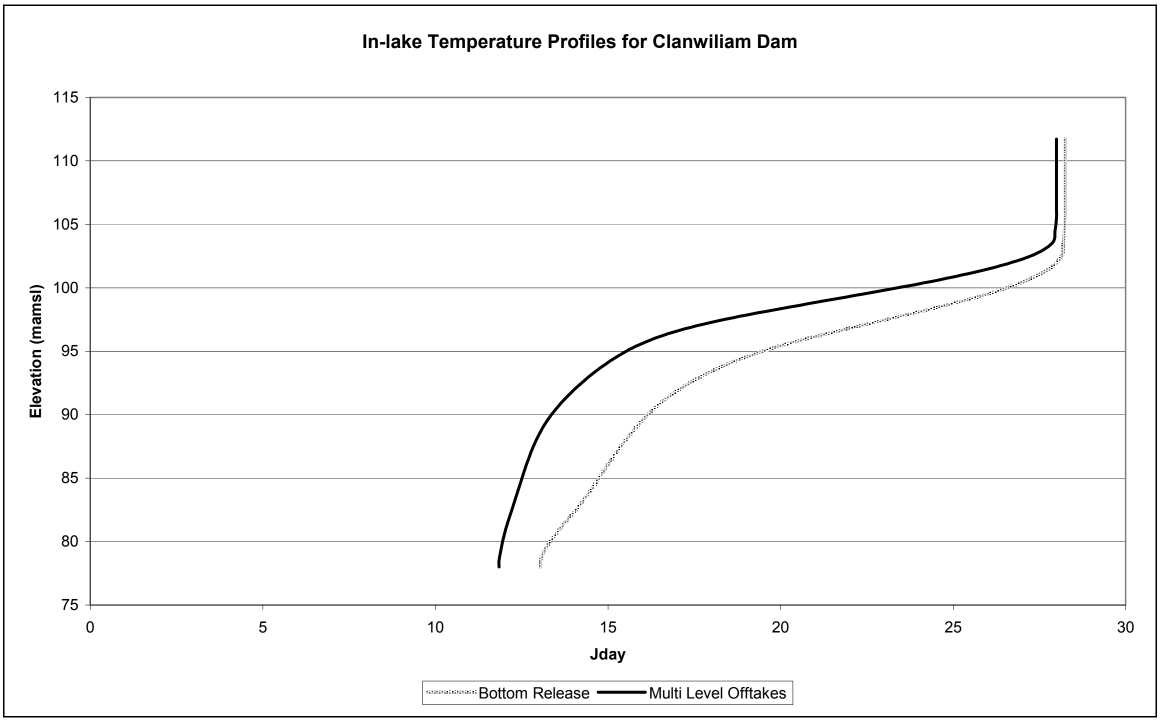

Figure 1.14 Inlake temperature profiles, (FSL = 115 mamsl, Julian day 394 = 30 January 1995) (Julian day 300 = 27 October 1994)

As seen before, the hypolimnetic temperatures at the end of summer are slightly cooler for the scenario with the multi-level offtake structure than the scenario without.

1.4.3 Dam raised to 120 mamsl

The temperature of the Dam releases with and without the multi-level outlet structure is depicted in **Figure 1.15** which once again shows that it would be possible to meet the downstream temperature requirements using a multi-level offtake structure.

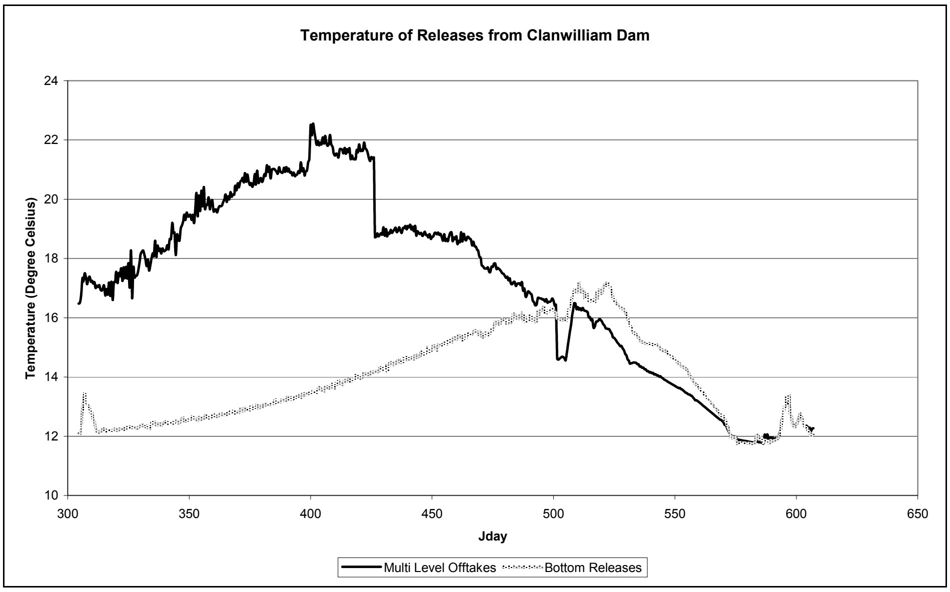

Figure 1.15 Temperature of dam releases made from the bottom releases and from the multi-level outlet structure (FSL = 120 mamsl) (Julian day 300 = 27 October 1994)

The in-lake temperature for the bottom outlet scenario is depicted in **Figure 1.16,** showing that hypolimnetic (bottom) releases would assist in destratifying the reservoir due to the release of colder water and subsequent intrusion of warmer water from the upper layers in the reservoir (Epilimnion).

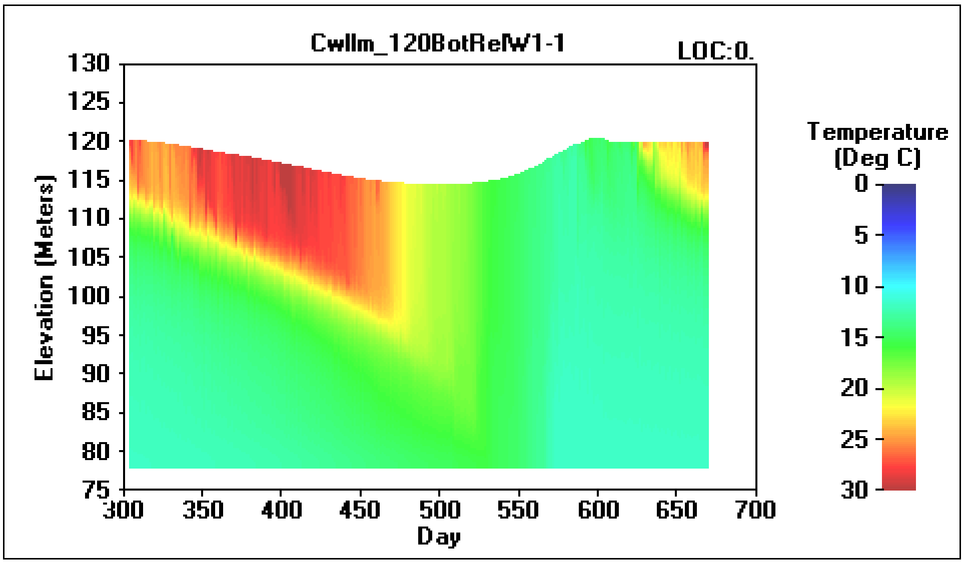

Figure 1.16 In-lake temperature conditions for bottom-release scenario (FSL = 120 mamsl) (Julian day 300 = 27 October 1994)

The in-lake temperature conditions for the multi-level offtake structure are shown in **Figure 1.17**. As before, a cooling of the hypolimnion is experienced towards the end of summer.

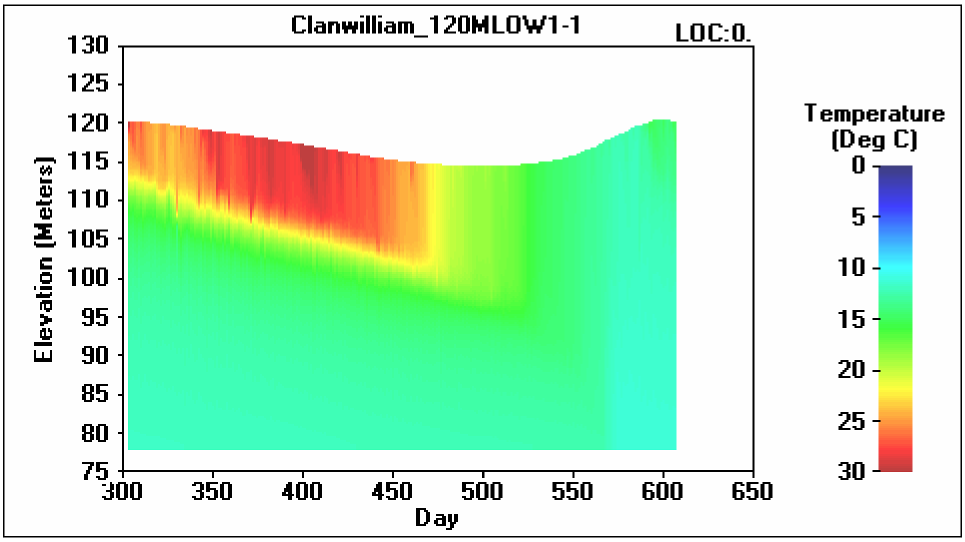

Figure 1.17 In-lake temperature conditions for multi-level offtake scenario (FSL = 120 mamsl) (Julian day 300 = 27 October 1994)

A comparison of the temperature profiles with and without the multi-level offtake structure is depicted in **Figure 1.18**.

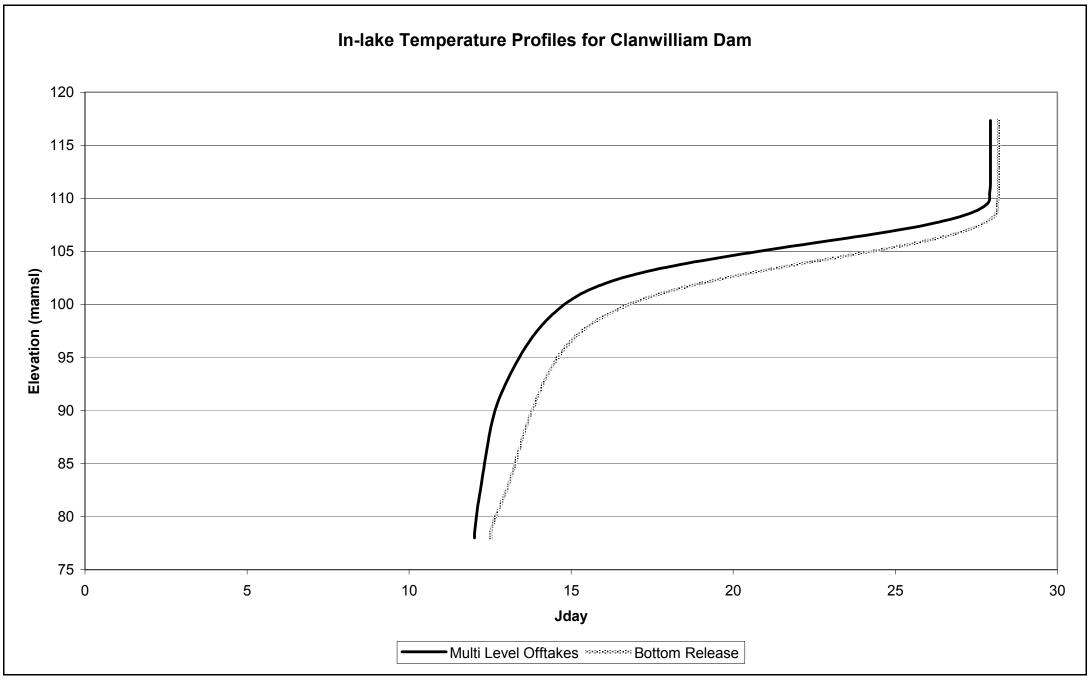

Figure 1.18 Inlake temperature profiles, (FSL = 120 mamsl, Julian day 394 = 30 January 1995)

1.4.4 Additional run – dam raised to 110 mamsl

An additional simulation run to assess whether fewer release heights (*viz*. at 115.25, 110.25, 105.25, 100.25, 83.56 and 81.12 mamsl only) could be used to meet the required downstream target temperatures was also performed for the Dam raised to 110 mamsl. In this simulation run it was found, based on the assumption that the Dam was full at the beginning of November and taking into account the specific release volumes from each height, that the target temperature could be met during the early parts of November. If the water level at the beginning of November was only at 100 mamsl, releases could only be made from the outlet at 83.56 mamsl. The required temperature would then probably be colder than the required target temperature. The time series of temperature for the releases made from the Dam is depicted in **Figure 1.19**.

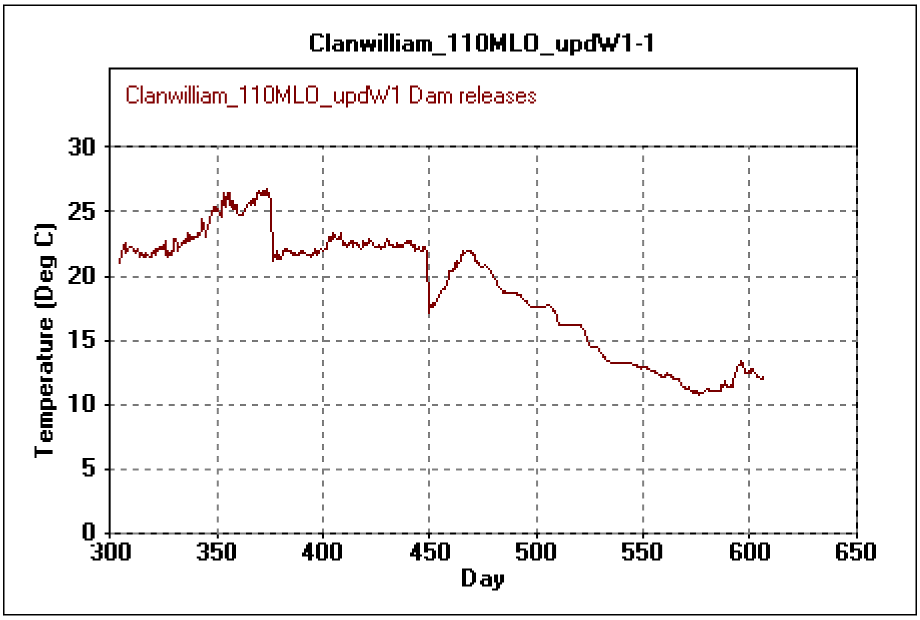

Figure 1.19 Temperature of dam releases made from the updated multi-level offtake structure (FSL = 110) (Julian day 300 = 27 October 1994)

1.5 Discussion

1.5.1 Data requirements for an installed model

During the modelling exercise it was recognised that the monitoring of inflow and outflow rates from the Dam would need to be improved substantially if it is intended to use mathematical models for informing the operating philosophy of the Dam. This is particularly crucial when a hydrodynamic and water quality model (such as CE-QUAL-W2) is to be employed, because the in-lake temperature regimes are largely determined by the hydraulics of the system, which in turn is influenced by the inflow and outflow patterns from the Dam. Similarly, it is important that temperature be measured at the inlet to the Dam. Although dissolved oxygen was not considered in this study it could possibly become important should the Dam be raised. Several additional water quality parameters would have to be measured at the inflow, should modelling of dissolved oxygen be required.

Meteorology is also an important driving force in the model and needs to be determined as accurately as possible. In this study, meteorological data was obtained from a weather station situated at Citrusdal which is approximately 45 km south of Clanwilliam Dam. Since the model is quite sensitive to the local weather data it would have been preferable to have a weather station at the Dam site.

1.5.2 Optimisation of releases

Hanna (1999) developed an optimisation programme that could be used with CE-QUAL-W2 to obtain the downstream temperature targets. With this programme it would be possible to determine what the required volume of flow through each level in the off-take structure should be, assuming that water from a maximum of two different levels could be mixed and that these outlets were not immediately above or below each other. This algorithm has recently been updated to be more rigorous in terms of the thermodynamic characteristics of the system. In the latter approach, the ***Target Temperature*** (or more correctly, the enthalpy) of the outflow stream, as determined by the ecologist, is used as the target with which the simulated temperatures are compared, thus providing a more direct approach for determining the relevant outlet structures required to meet the downstream target temperature.

1.5.3 Evaluation of updated release levels

Analyses of the Dam trajectory, obtained from a yield analysis of the Dam over the period 1920 to 1990 (DWAF, 2005) and without imposing the demands to meet the ecological flow requirements, showed that the Dam level reached 105 mamsl (FSL) for all but one year during the simulation period, suggesting that releases from 100.25 mamsl would probably be possible for most of the time. Temperature requirements would subsequently be met as well.

When conservative ecological requirements are imposed on the Dam, however, the same analyses shows that the water level may often not reach 105 mamsl, thus forcing the release of colder water from outlets located at 83.56 mamsl.

1.5.4 Evaluation of ecological requirements

Calculation of a realistic release pattern from Clanwilliam Dam is dependent on the knowledge of the ecological and irrigation demands downstream of the Dam. Information on the volume and timing of releases to satisfy the ecological water requirement, however, never became formally available to the modelling study and could therefore not be included. The most recent information on the ecological flow and water quality requirements, downstream of Clanwilliam Dam (EWR2) (DWAF, 2006), is shown in **Table 1.3** and **Table 1.4**, respectively.

Table 1.3 Water Quantities for maintaining the Present Ecological State (PES) at EWR 2 (Downstream of Clanwilliam Dam) (DWAF, 2006)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Volume (Mm³)
MAINTENANCE																
Low Flows (m³/s)	0.9	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	21.5
FLOOD Class1 - Daily Peak = 10.5 (m³/s)								1 no.		1 no.						6
FLOOD Class3 – Daily Peak = 42 (m³/s)									1 no.		1 no.					24
DROUGHT																
Low Flows (m³/s)	0.9	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	21.5

Table 1.4 Water Quality for EWR 2 (Downstream of Clanwilliam Dam) (DWAF, 2006)

EWR site	**2**
Water temperature	?
pH	6.5 – 9
EC	< 25
Dissolved Oxygen	> 6
Ammonia as NH_3 (mg/l)	< 0.007
Nitrates as N (mg/l)	< 0.100
Phosphorous as PO_4 – P (mg/l)	< 0.015

1.6 Conclusions

Based on the results and the discussion in previous sections, the following can be concluded:

- More realistic outputs in terms of the temperature distribution in the Dam and temperature of releases can only be obtained if the input data to the model is more reliable. This is particularly relevant for inputs which drive the temperature profile within the Dam, *viz.* meteorological data, inflow temperature and volumes as well as release rates.

- Based on the available input data, the temperature requirement of 18º C for the releases would be achievable for the Dam raised to 110, 115 and 120 mamsl. This was, however, based on the assumption that the Dam was full on the first of November and that the highest available outlet could be used to make the releases during early November.

- Reducing the number of offtakes below 110 mamsl could lead to the target temperature not being met at the beginning of November, especially if the Dam does not reach its FSL during the winter months.

1.7 Recommendations

Based on the results, discussions and conclusions, the following recommendations can be made:

- A monitoring programme for the systematic monitoring of the pertinent data for assessing or modelling water quality in the reservoir should be instituted as soon as possible. This programme should include:

  a. Hourly meteorological data (air temperature, dew point temperature, wind speed, wind direction, and percentage sunshine).
  b. Inflow rates.
  c. Inflow and in-lake water quality (WQ) (see **Appendix A** for a complete list of WQ variables).
  d. Release rates.

- Since the latest information on the ecological water requirements only became available after the modelling task was completed, it is recommended that a more representative release pattern be created, based on the operating rules of the Dam as well as on realistic ecological requirements and irrigation demands downstream of the Dam. This, in addition to more representative meteorological and inflow data, will provide a more realistic representation of the temperature profile most likely to exist in the Dam and the ability to match the required temperature downstream of the Dam.

- For each of the proposed raised dam levels, the following approach should be adopted to determine the level of confidence that can be attached to the results presented in this report:

  a. Re-run the Dam trajectories with realistic ecological requirements imposed, to determine the most probable dam levels at the beginning of November for each proposed new dam height.
  b. Re-run the hydrodynamic and water quality model, using the most probable starting level at the beginning of November, to determine the probability of meeting the temperature requirement.

c. Decide, in consultation with the ecologist whether the determined probability to meet the downstream temperature requirement is acceptable.

- The most recent potential arrangement of the multi-level off-take structure modelled should be investigated in more detail in terms of the approach outlined in the previous recommendation to determine whether an additional outlet is required between 100.25 mamsl and 83.56 mamsl.

2. EUTROPHICATION ASSESSMENT

2.1 Introduction

At the inaugural meeting for the Clanwilliam Dam Raising Study that was held on the 15th of March 2004, it was noted that in terms of eutrophication, only the temperature impact of the water released from Clanwilliam Dam was addressed in the study proposal. Concerns were further raised about eutrophication problems currently being experienced at Bulkshoek Weir (but not yet at Clanwilliam Dam). The Department therefore requested the team to undertake additional work on eutrophication.

From discussions with Mr. Matthee, CEO of the Lower Olifants River Water Users Association (LORWUA), it appeared that problems were experienced with filamentous algae and free-floating algae. The filamentous algae causes problems in the weir and in the canal system. The LORWUA spends about R 170 000 per year in an effort to control the algae in the canals. He noted that in 2003, taste and odour problems were encountered with water abstracted from Bulkshoek Weir. He ascribed these to phytoplankton, low water levels and the low flushing rate of water in the weir.

These symptoms appear to indicate that the eutrophication potential needed to be investigated as part of the feasibility study, even though it has not previously been identified as a concern. The raising of Clanwilliam Dam is expected to increase the retention time in the system, which can potentially increase eutrophication related water quality problems. In general, there is a direct relationship between the nutrient concentration in the water and amount of phytoplankton algae. However, with filamentous algae the relationship is more complex and these algae can occur even at low nutrient concentrations.

A reconnaissance level assessment was undertaken of the present nutrient and eutrophication status, using available monitoring data and published or anecdotal information. The assessment included a synthesis of data and information that was available about the growth of filamentous algae in the Bulkshoek Weir and in the canal system.

Assessment of the potential impacts of raising Clanwilliam Dam on the eutrophication status of Clanwilliam Dam and of Bulkshoek Weir was undertaken using simple, management oriented assessment tools.

2.2 Introduction to eutrophication

Eutrophication is the enrichment of waters with plant nutrients which results in an array of symptomatic changes. These include increased production of algae and aquatic macrophytes, deterioration of water quality and other undesirable changes that interfere with water uses. In South Africa, eutrophication has been recognised as a priority water quality problem for over 30 years. In a study on the eutrophication status of a number of South African reservoirs (Van Ginkel *et al*., 2000), it was found that the extent of eutrophication has increased since the problem was first identified in the 1970s.

The terms "eutrophic", "oligotrophic", "mesotrophic" and "hypertrophic" are generally used to describe the degrees of enrichment of aquatic ecosystems (**Table 2.1**).

- Oligotrophic refers to the presence of low levels of nutrients and no water quality problems;
- Mesotrophic refers to intermediate levels of nutrients, with emerging signs of water quality problems;
- Eutrophic refers to high levels of nutrients and an increased frequency of water quality problems; and
- Hypertrophic refers to excessive levels where plant production is governed by physical factors. Water quality problems are almost continuous.

Table 2.1 South African criteria for assessing the trophic status of water bodies (DWAF, 2002)

Variable	Trophic Status				
	Units	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Mean annual chlorophyll *a*	µg/l	0 < x ≤ 10	10 < x ≤ 20	20 < x ≤ 30	> 30
% of time chlorophyll *a* > 30 µg/l	%	0	0 < x ≤ 8	8 < x ≤ 50	> 50
Mean annual Total phosphorus	mg/l	x ≤ 0.015	0.015 < x ≤ 0.047	0.047 < x ≤ 0.130	> 0.130

The problems associated with excessive eutrophication are numerous and they may be both long- and short-term. These include, amongst others:

- Increased occurrence and intensity of nuisance algal blooms;
- An increasing dominance by blue-green algae;
- Increased occurrence of toxic algae;
- Clogging of irrigation canal systems by filamentous benthic algae;
- Increased occurrence of floating and rooted aquatic macrophytes;
- Increased occurrence of taste and odour problems in drinking water;
- Increased occurrence of deoxygenation in bottom waters with associated chemical effects (hydrogen sulphide and elevated levels of heavy metals);
- Increased fish and invertebrate mortality;
- Changes to ecological community structure and loss of biodiversity;
- Increased water treatment costs through filter clogging in water treatment works;
- Increased interference in recreational activities (boating, fishing, swimming);
- Increased occurrence of human health problems (gastroenteritis, skin complaints);
- Loss of property values;
- Interference with irrigation and livestock agriculture (e.g. mortality of stock);
- Undesirable aesthetic conditions (e.g. turbidity, foam, discolouration, odours.

Eutrophication in dams is generally characterised by a proliferation of free-floating algae (or phytoplankton) to such a level that it interferes with the normal use of the water and a general deterioration in water quality. In the shallow areas of the dam where light penetrates to the bottom, rooted or attached algae may also develop.

Generally, eutrophication in moderate to fast flowing rivers is characterised by a proliferation of rooted or attached aquatic plants or algae. Attached algae are generally referred to as periphyton. Periphyton can be mat forming algae that cover the cobbles in rivers or stringy filamentous algae that attach to stones and cobbles in the stream.

In slow moving rivers where large pools are present or in run-of-river dams such as those formed upstream of large weirs, free-floating algal blooms may also develop. However, these blooms are generally reduced when the algae are washed into faster flowing sections of the river and algal cells are physically damaged by the turbulence of the water.

Eutrophication symptoms in irrigation canals are similar to those observed in rivers with the exception that mat forming or filamentous algae generally tend to dominate especially in concrete lined canals (Joska and Bolton, 1994a, Joska *et al*., 2000).

2.2.1 Factors that control eutrophication in dams

Nutrient concentrations

A nutrient is a chemical compound or element that can be used directly by plant cells (algae and aquatic macrophytes) for growth. In terms of eutrophication, nutrients are mostly inorganic elements that are taken up by plants and, in conjunction with the process of photosynthesis, are utilized to produce and accumulate organic material in aquatic ecosystems. The rate and extent of aquatic plant growth is dependent on the concentration and relative ratios of nutrients present in the water. Plant growth is generally limited by the concentration of that nutrient that is present in the least quantities relative to the growth needs of the plant. It has been found that phosphorus (P) and nitrogen (N) are the most frequently limiting nutrients in freshwater systems. Increases in the levels of either of these two nutrients in a water body will increase the risk and frequency of eutrophication problems. Management of N and P inputs to the aquatic environment is, therefore, the key to management of the eutrophication problem. P is recognised as the fundamental cause of eutrophication because better empirical relationships have been observed between algal growth and P concentrations in reservoirs than with N, and P availability often determines the influence of the other nutrients. It is recognized that the systematic elimination of P in terms of its availability in surface waters is the only practical way to combat eutrophication.

Underwater light climate

Algae also need sunlight for photosynthesis and the better the underwater light climate and light penetration, the higher the algal growth rate. Inorganic turbidity influences algal growth because it reduces the amount of light available for aquatic plant growth. Turbid systems will tolerate higher levels of nutrients because the availability of light would limit the growth of algae.

Temperature

Seasonality and temperature regimes affect stratification and algal growth patterns. Temperature affects the rate of biochemical reactions and the higher the temperature, the higher the growth rate of algae, up to a maximum temperature beyond which the growth rate is slowed down.

Other factors

Other factors that affect the growth of algae, include the following:

- Hydrology has an impact through the flushing or non-flushing of materials through aquatic ecosystems. Well- flushed systems can tolerate higher inputs of nutrients.
- Timing in which nutrients are supplied to the aquatic system – the response of algae and aquatic macrophytes to increases in available nutrients is not always the same and can vary with the time of the year.
- Bottom sediments of rivers and reservoirs are well known for releasing nutrients into the water column hence exacerbating or prolonging the eutrophication problem. The rates of release for N and P from sediments differ.
- Reservoir morphology influences impacts through both depth and shape. Deep reservoirs can tolerate higher inputs of nutrients.

- General catchment characteristics (e.g. land-use, vegetation cover, presence of wetlands, reservoirs and other systems that retain or modify nutrient transport over the landscape) will modify the impacts of increased nutrient loading.

2.2.2 Factors that control eutrophication in irrigation canals

There are a number of factors that control the growth of nuisance algae in irrigation canals. These include the substratum to which the algae attach, the underwater light climate, water temperature, acidity of the water, salinity of the water, nutrient content, and the rate of flow in the canal.

Biggs (2000) summarised the counteracting processes of biomass accrual and biomass loss (**Figure 2.1**) in river systems. An increase in the nutrient content, underwater light climate and/or water temperature would lead to an increase in biomass. The processes that lead to a loss of biomass include a decrease in the stability of the substratum to which the algae are attached, or an increase in water velocity, or an increase in suspended sediment which in turn leads to a less favourable underwater light climate. Increased grazing by invertebrates and fish also leads to biomass loss.

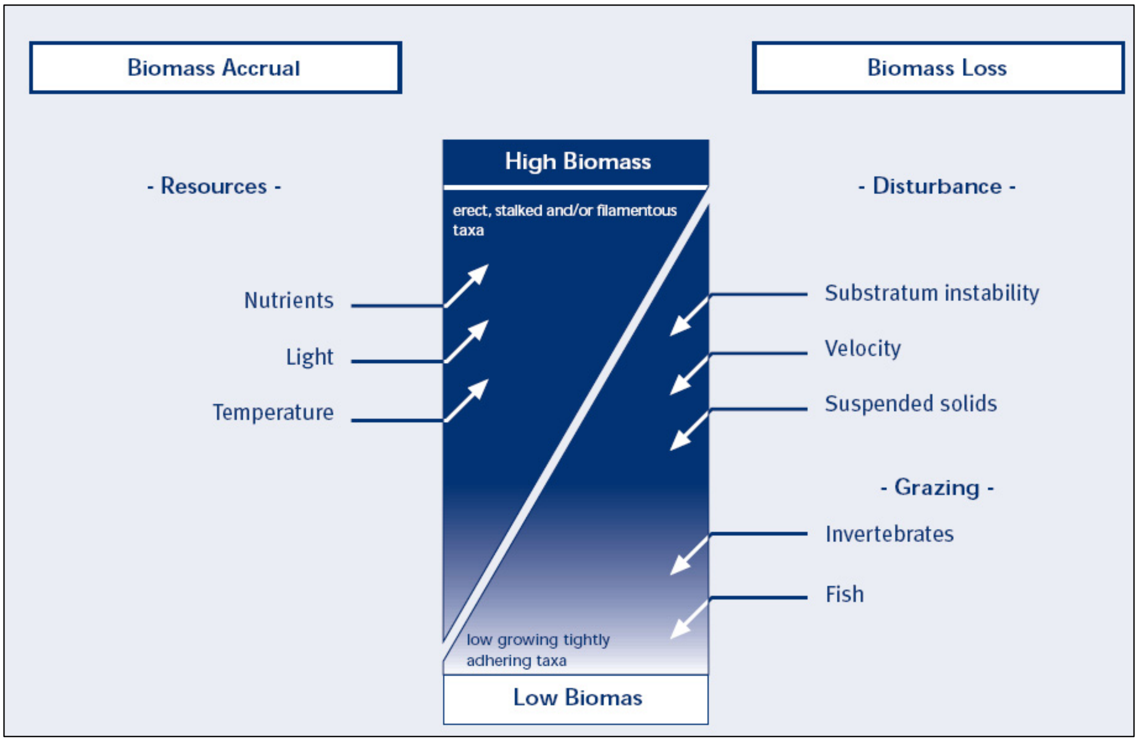

Figure 2.1 Diagram showing the counteracting processes that affect periphyton biomass accrual and loss and the principal factors contributing to these processes (from Biggs, 2000).

The growth cycle of periphyton in rivers was illustrated by Biggs (2000) and the cycle would be similar for periphyton growth in irrigation canals (**Figure 2.2**). After a natural event such as a flood (in a river) or draining and filling of an irrigation canal, pioneer or colonising taxa would start growing followed by a period of exponential growth and a succession to species that can compete better in the specific environment. At some stage loss processes such as auto-shading, death, spontaneous sloughing, and grazing become dominant processes, thus reducing the biomass. Some equilibrium state is then reached where accrual and loss processes are in balance.

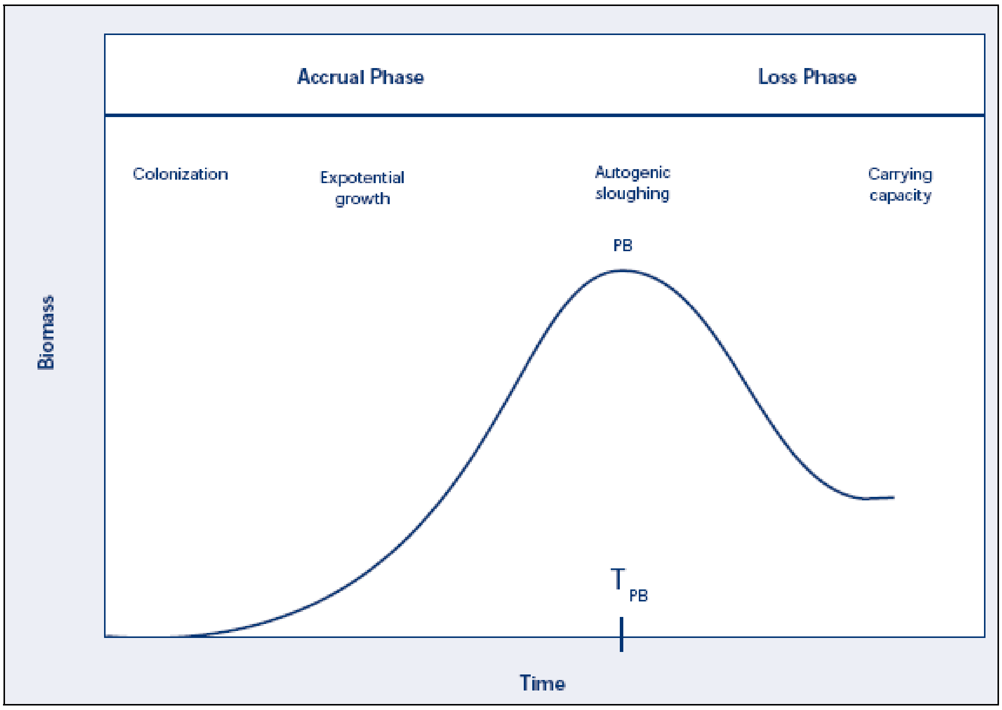

Figure 2.2 Diagram illustrating the short-term accrual of periphyton biomass following a flood or dry period (from Biggs, 2000).

The most common factors that affect algal growth in irrigation canals (Joska and Bolton, 1994) are:

Substratum – some groups of filamentous algae prefer solid substrata while others prefer soil or a sandy substrate. However, filaments can also break off and then become free-floating in waters with a low to moderate flow rate.

Flow rate and seasonal flushing – filamentous algae with strong attachment mechanisms can compete better in faster flowing rivers or canals. They are also adapted to reduce the effects of drag. In irrigation canals, the flow speed is generally fairly constant, creating favourable conditions for a specific algal species to dominate. In rivers, seasonal flooding is often the most important factor controlling algal biomass but seasonality has been reduced in impounded rivers.

Nutrients – in general, an increase in nutrients leads to an increase in algal biomass. However, Biggs (2000) and others (Dodds and Gudder, 1992) found that it was difficult to link the biomass to flowing water nutrient concentrations because of the dynamic nature of the biomass accrual and loss processes and flow replenishment. At moderate to high flows some species can thrive even under very low nutrient concentrations because the nutrients are continually replenished at the cell wall interface.

Water temperature – water temperature affects the rate of biochemical process and elevated water temperature leads to increased growth rates. Bosman (pers. comm., 2006) found that the optimum range for algal growth in South African canals was between 10°C and 25°C. Above 25°C, the photosynthetic rate decreases.

Underwater light climate – light is essential for plant growth. The underwater light climate is affected by the water clarity and the clearer the water, the more favourable conditions are for the growth of filamentous algae. Some species like *Cladophora* require quite high light intensities and Rand Water found that *Cladophora* growth increased markedly when turbidity levels dropped below 40 Nephelometric Turbidity Units (NTU) (Joska and Bolton, 1994a).

pH – pH is a measure of acidity or alkalinity and most aquatic plant species have a preference for a specific pH range. A sudden drop in pH can kill algae. Certain *Cladophora* species prefer more alkaline conditions.

2.3 Eutrophication situation in the Clanwilliam Dam study area

2.3.1 Algal growth potential in Clanwilliam Dam and Bulkshoek Weir

Assessment of the algal growth potential was based largely on the dissolved nutrient concentration data that was collected at Clanwilliam Dam and at Bulkshoek Weir for a number of years (**Table 2.2**). The two dams have also been part of the National Eutrophication Monitoring Programme since 2005 and some chlorophyll data were available to assess the present algal concentrations in the dams. Data for the four monitoring points at these two sites (in-dam and outflow monitoring points) were obtained from the Department of Water Affairs and Forestry's WMS database (**Table 2.2**). Data for the period 1998 - 2005 were used to assess the current trophic status.

Table 2.2 Monitoring points at Clanwilliam Dam and Bulkshoek Weir

Monitoring Point ID	Monitoring Point Name	Located on Feature Name	Number of Samples	First Sample Date	Last Sample Date
101896	E1H007Q01 Bulkshoek Weir On Olifants River: Left Canal	Left Canal From Bulkshoek Weir	118	10/03/1972	23/11/2005
101898	E1H011Q01 Clanwilliam Dam On Olifants River: Downstream Weir	Olifants - Drainage Region E	202	29/06/1972	23/12/2005
101900	E1R001Q01 Bulkshoek Weir On Olifants River: Near Dam Wall	Bulkshoek Weir	296	29/06/1972	05/01/2006
101901	E1R002Q01 Clanwilliam Dam On Olifants River: Near Dam Wall	Clanwilliam Dam	243	03/04/1968	05/01/2006

The water quality characteristics for selected variables (TDS, pH, PO_4-P and NO_3+NO_2-N) recorded at the four sampling points were compared using box-and-whisker plots (**Figure 2.3**). The in-lake and outflow concentrations at Clanwilliam Dam (E1H011 and E1R002) and at Bulkshoek Weir (E1H007 and E1R001) are quite similar for the four variables (**Figure 2.3**) which is to be expected. However, the inter-quartile ranges (represented by the upper and lower boundaries of the box) for TDS and NO_3+NO_2-N at Bulkshoek Weir were consistently elevated above those of Clanwilliam Dam. In contrast, the inter-quartile range for PO_4-P at Clanwilliam Dam was slightly higher than those measured at Bulkshoek Weir even though the median PO_4-P concentrations at all four sampling points are quite similar.

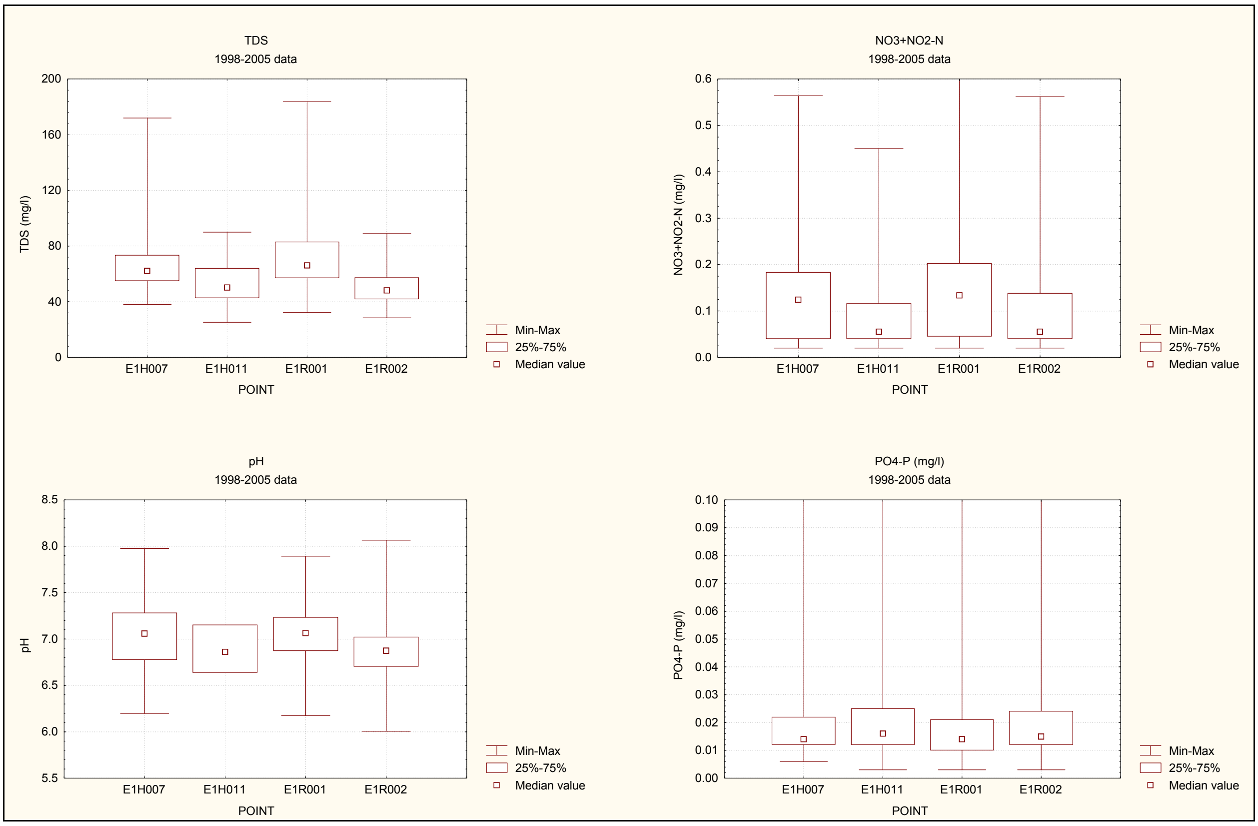

Figure 2.3 Box-and-whisker plots of TDS, NO3+NO2-N, pH and PO4-P concentrations recorded at Bulkshoek Weir (E1R001) and its outflow (E1H007) and Clanwilliam Dam (E1R002) and its outflow (E1H011).

The PO_4-P concentrations provide an indication of the algal growth potential. To estimate the number of samples that fell within a specific trophic class, exceedance diagrams with the trophic class boundaries drawn in were prepared (**Figure 2.4**). Exceedance diagrams also give some indication of the percentage of time certain trophic conditions were experienced in the Dam.

From the exceedance diagrams for Clanwilliam Dam (**Figure 2.4**) it can be seen that the Dam is mostly in an oligotrophic to mesotrophic state, that is, it is in an unenriched to moderately enriched state for 94% of the time. Only 6% of the samples fell within the eutrophic range. The algal growth potential for phytoplankton is therefore low to moderate in Clanwilliam Dam.

From the exceedance diagrams for Bulkshoek Weir and its outflow (**Figure 2.5**) it can be seen that the Dam is mostly in an oligotrophic to mesotrophic state, that is, it is in an unenriched to moderately enriched state for 97% of the time. Only 3% of the samples fell within the eutrophic nutrient concentration range. The algal growth potential for phytoplankton is therefore low in Bulkshoek Weir.

The nitrogen to phosphorus ratio (N:P ratio) is often used to assess which nutrients limit algal growth in a waterbody. A dissolved N:P ratio of less than 8 indicates that nitrogen would limit algal growth and a dissolved N:P ratio of greater than 12 would indicate that phosphorus would limit algal growth. A dissolved N:P ratio of between 8 -12 indicates optimum conditions for phytoplankton growth.

The N:P ratios in both dams varied between N-limited and P-limited. Clanwilliam Dam is in an N-limited state for about 60% of the time (**Figure 2.6**) while Bulkshoek Weir is in an N-limited state for about 40% of the time (**Figure 2.7**).

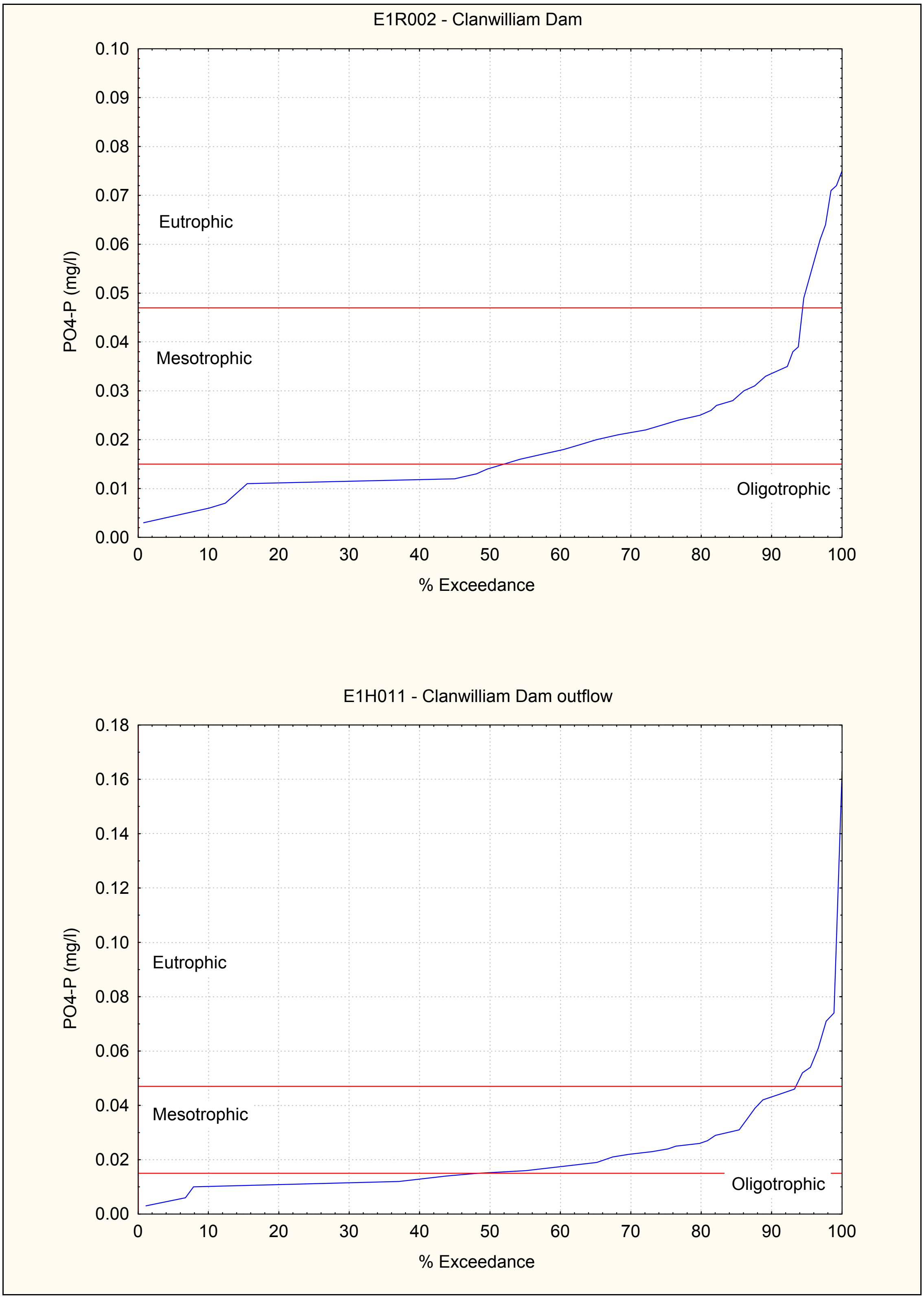

Figure 2.4 Exceedance diagram of PO_4-P concentrations recorded in Clanwilliam Dam and its outflow between 1998 and 2005

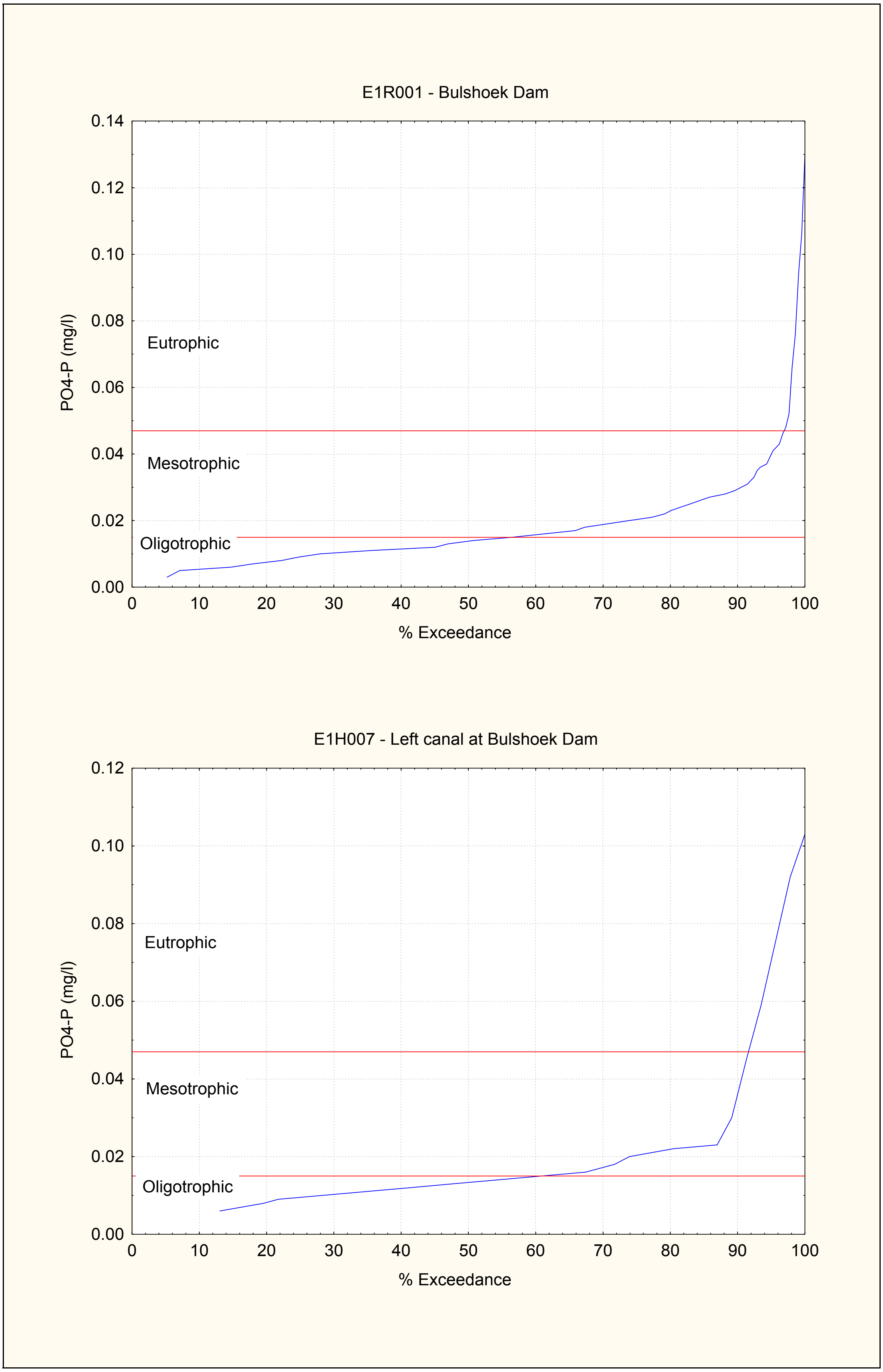

Figure 2.5 Exceedance diagram of PO_4-P concentrations recorded at Bulkshoek Weir (top graph) and its outflow to the canal (bottom graph) for the period 1998 - 2005

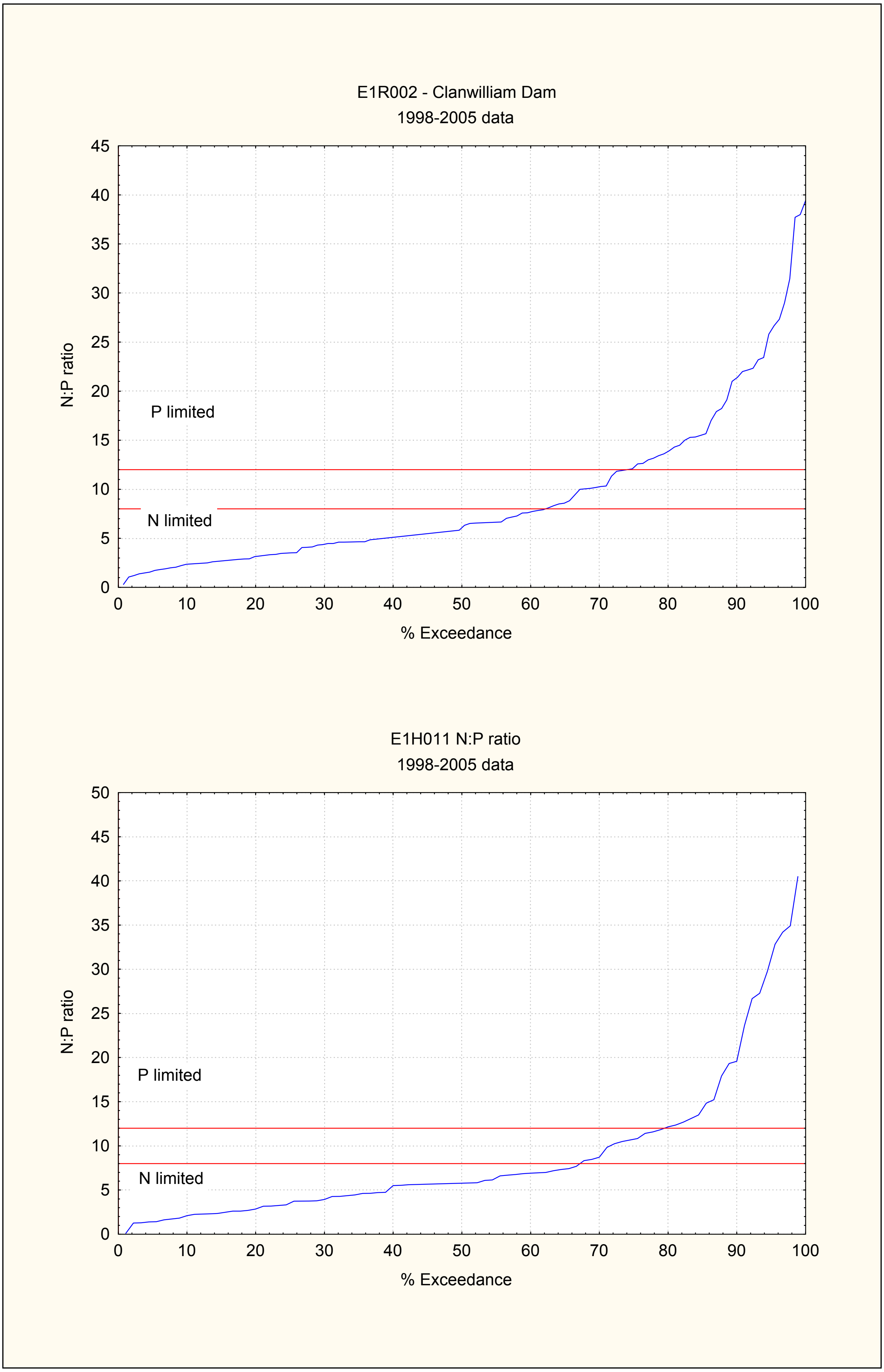

Figure 2.6 Exceedance diagram of N:P ratios measured at Clanwilliam Dam (top graph) and its outflow (bottom graph)

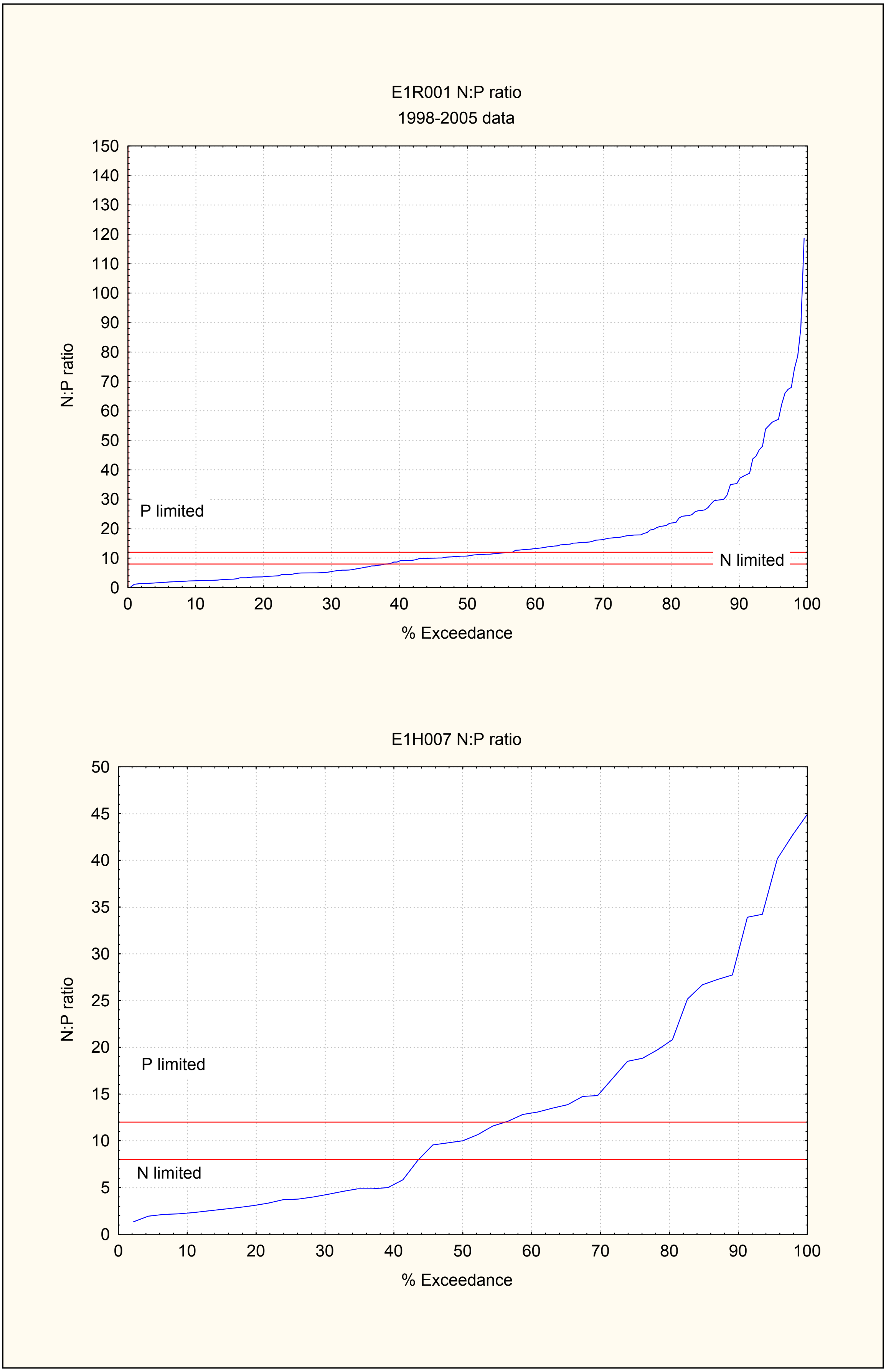

Figure 2.7 Exceedance diagram of N:P ratios measured at Bulkshoek Weir (top graph) and its outflow (bottom graph)

The National Eutrophication Monitoring Programme (NEMP) was implemented at Clanwilliam Dam and Bulkshoek Weir in 2005. The mean chlorophyll *a* concentrations measured in Bulkshoek Weir and in Clanwilliam Dam (**Table 2.3**) indicated that both dams could be classified as oligotrophic (unenriched), that is, the mean chlorophyll *a* concentrations fall between 0 – 10 µg/l (**Table 2.3**).

Table 2.3 Statistics of chlorophyll *a* concentrations (µg/l) recorded in Clanwilliam and Bulshoek dams from March 2005 to August 2006.

Statistics µg/l Chl *a*	Clanwilliam Dam (E1R002)	Bulkshoek Weir (E1R001)
Mean	1.45	2.30
Trophic state (mean)	Oligotrophic	Oligotrophic
Median	1	1
95%tile	3.2	9.5
Minimum	0.5	0.5
Maximum	3.4	16.26
Trophic state (max)	Oligotrophic	Mesotrophic
Number of observations	25	23

2.3.2 Nuisance Aquatic Algae in the LORWUA Irrigation Canals

Filamentous algae can, under optimal growth conditions, proliferate in a relatively short period of time to a dense biomass that results in large operational problems to managers of irrigation projects. These can in turn lead to crop losses with serious financial implication for irrigation farmers. Some of the typical problems associated with nuisance filamentous algae are (Du Plessis and Steyn, 2003):

- Reduction in the hydraulic capacity and flow speed in canals to such a degree that the supplied water cannot reach the terminal point of the canal. This decrease in canal capacity occurs particularly when the water demand is at its highest.
- Over-estimation of the amount of water supplied due to the artificially increased water levels that are measured at calibration weirs in the canal system.
- Water losses due to flooding of the canals.
- Impediment of floodgates (sluices) at dividing structures.
- Drowning or water logging of long-weirs.
- Structure (slab) failure of concrete-lined irrigation canals due to flooding.
- Aquatic weed fragments blocking irrigation systems and filters at water purification works.
- Aquatic weed fragments blocking cooling systems of transfer pumps.
- Mechanical removal of the biomass is extremely labour intensive, expensive and often ineffective.

The occurrence of nuisance filamentous algae in the canal system of the Lower Olifants River Government Water Scheme has occurred for a number of years, dating back to at least the early 1980s (Truter, pers. comm., 2006). Joska and Bolton (1994a) found that a number of species were observed in the canal system. These included *Spirogyra sp, Oedogonium sp., Zygnema spp., Nitela sp.,* and *Mougeotta sp*.

An interview was held on the 29th of September 2006 with officials of the LORWUA; Mr Jan Truter and Mr Leon van der Merwe. The purpose of the interview was to discuss the problem of nuisance filamentous algae in the LORWUA canal system and how it was managed by LORWUA. Initially, the problem was restricted to the lower reaches of the canal system, mainly in the Lutzville area and downstream of it. Over the years the occurrence of nuisance algae has slowly progressed in an upstream direction to the point where nuisance algae is now also observed in the canals from about the Vredendal area.

Typically, the canal system is drained during the winter months for maintenance. Early in September releases start from Bulkshoek Weir into the canal system. Small strands of filamentous algae are generally observed in the water released from Bulkshoek Weir. The officials are of the opinion that problems with filamentous algae in the lower reaches of the canal system generally start about a month after the canals are filled. The filamentous algae grow in the bottom sediments of the canals and during the summer months, the biomass can double every day until self-shading start limiting the growth of the algae. At high biomass, long strands of filamentous algae can be "peeled" off and washed downstream where it accumulates against structures causing the canal to overflow. In the past, the algae were controlled by mechanical means (raking to remove the filaments) but in recent times a chemical programme has been implemented to control algal biomass.

The LORWUA staff monitors the canals and start a chemical control programme when short strands of algae emerge from the bottom sediments. A product called Aquaplex, with Copper Sulphate Pentahydrate as active agent, is used to control the growth of algae. Aquaplex is administered by a pipeline close to the bottom of the canal, for a period of about three hours. The treatment is then repeated at about 7 km intervals. During this time damage to the algae is closely observed to ensure that the treatment is effective. The LORWUA follows a preventative treatment programme to keep the algal biomass in the canals under control. The preventative programme generally runs from October to February and the number and severity of treatments are guided by the amount of algal biomass observed in the canal system.

Based on their observations in the canal system, the officials felt that the growth of filamentous algae is controlled by water temperature, flow velocity and light penetration. In the lower reaches of the canal system, the canals are shallower, creating a more favourable underwater light climate at the bottom of the canal. The flow velocity is also slower, creating a more favourable flow climate for the algae, and the water is warmer, resulting in a higher algal growth rate.

During a site visit to the canal in September 2006, a fair amount of short algal strands were observed being transported in the canals. These short strands were observed throughout the length of the canal. These appeared to originate from Bulkshoek Weir as these strands were observed in the canal close to the dam. It was postulated that these strands may serve as important inoculums of algae to the lower reaches of the system. Kobus du Plessis of Envirokonsult, who is responsible for the control of filamentous algae in the Hartbeespoort Dam canal system, felt that these strands represented a very small source of algae that may eventually be established in the canal. The more significant source was the algal spores embedded on the sides of canal in the cement matrix or those embedded in the sediments on the bottom of the canal (Du Plessis, pers. comm., 2006).

Discussions with Mr H H Bosman confirmed the observations in the LORWUA canal system (Bosman, pers. comm., 2006). Mr Bosman was responsible for the eradication of aquatic weeds when he was still with the Department of Water Affairs and Forestry. He has for many years advised the LORWUA and its predecessor on the means to control the algae in the canals.

2.4 Assessment of the potential trophic state impacts of raising Clanwilliam Dam

2.4.1 Potential impacts on Clanwilliam Dam and Bulkshoek Weir

The potential impacts of raising Clanwilliam Dam on its trophic status were modelled using a simple web-based tool called the "Nutrient Enrichment Assessment Protocol" (NEAP) (Rossouw, Harding and Fatoki, 2005). NEAP is an internet-based phosphorus (P)-based nutrient loading tool for reservoirs which, depending on the level of information entered, allows the user to select one or more outputs that describe, for example, the P-loading generated by the catchment, the trophic condition of the lake, and the lake's likely response to a change (increase or reduction) in phosphorus (P) loading. NEAP has been purposefully designed as a simple, phosphorus-based, eutrophication screening tool. As such it provides a non-data intensive means of determining the trophic status (degree of nutrient enrichment) of open-water environments. It allows the user to determine the manner in which the annual mean concentration of phosphorus is likely to change in response to an increase or decrease in the loading of this element. Such determinations can be made with NEAP at a high (70%) level of confidence.

For the assessment it was assumed that inflow loads would remain unchanged from present day conditions and all that would change is the reservoir flushing rate (the rate at which water is replaced in the reservoir). The 10 m and 15 m raising options appeared to be the most favoured options. The hydrological values used in the yield analysis were used in the trophic state assessment.

Table 2.4 Estimated mean and maximum chlorophyll a concentrations using the NEAP system for Clanwilliam Dam under present day conditions and raising the dam wall by 10 m and 15 m

Parameter	Clanwilliam Dam		
	Present day	Dam wall raised 10m	Dam wall raised 15m
Volume (Mm^3)	122.26	264.77	361.82
Surface area (km^2)	11.30	17.00	20.40
Mean depth (m)	10.7	15.6	17.7
Inflow volume (Mm^3)	367.59	367.59	367.59
Surface rainfall (Mm^3)	4.286	6.183	7.615
Surface evaporation (Mm^3)	14.831	21.966	26.32
Hydraulic residence time (yr)	0.34	0.75	1.04
Estimated total P loading (Ton/yr)	30.056	30.141	30.192
Estimated mean Chlorophyll *a* (µg/l)	7	8	9
Estimated max Chlorophyll *a* (µg/l)	16	20	22
Trophic status (based on estimated mean and max Chl *a*)	Oligotrophic - Mesotrophic	Oligotrophic - Mesotrophic	Oligotrophic - Eutrophic

If the phosphorus loads into Clanwilliam Dam remain the same but the water residence time increases from 0.34 to 1.04 years, then a slight increase in the chlorophyll a concentrations can be expected. Based on observed chlorophyll and phosphorus concentrations, Clanwilliam Dam is classified to be in an oligo-mesotrophic state, that is, in an unenriched to moderately enriched state. The simulated present state also estimated the Dam to be in an oligo-mesotrophic state

(**Table 2.4**). It is estimated that, by raising the dam wall by 10 m, the dam may on average still be in an oligo-mesotrophic state, with maximum chlorophyll *a* values bordering on eutrophic conditions. By raising the Dam wall by 15 m, it is estimated that the Dam may on average remain in an oligo-mesotrophic state, although the maximum chlorophyll a concentrations would fall within eutrophic conditions.

These trophic state estimates are for the state of the Dam after it has filled to the new full supply level and it has reached a state of equilibrium. During the unsteady state, following filling to the new level, nutrient and chlorophyll concentrations would probably increase as nutrients are leached from the newly inundated soils and decomposing plant material.

Phytoplankton algal growth in Bulkshoek Weir is probably controlled by the water residence time due to its small volume. It is estimated that, under current conditions, the average residence time is about 5.3 days. Raising Clanwilliam Dam by 10 m or 15 m may result in increasing the water residence time to 5.7 and 5.8 days, respectively. In such a highly flushed system, phytoplankton growth should not be a problem provided the nutrient loads to the system do not change significantly as a result of other developments in the catchment.

2.4.2 Potential measures to mitigate eutrophication impacts on Clanwilliam Dam and Bulkshoek Weir

Clanwilliam Dam is in a good trophic state and it is estimated that, provided the phosphorus loads remain unchanged, there would probably not be a major shift in trophic status if the Dam wall is raised. No specific mitigation measures are therefore required other than a strategy for monitoring the situation closely, especially the inflowing nutrient loads. It is therefore recommended that the Department continue to monitor the in-reservoir nutrient and chlorophyll concentrations as part of the NEMP.

It is also recommended that monitoring of the inflow water chemistry be restored and that the inflowing nutrient loads be examined on an annual basis. If an increasing trend is detected in the inflowing nutrient loads, then the potential impacts on the trophic state of the Dam should be estimated and, should it result in a major shift from an oligo-mesotrophic state to a meso-eutrophic state, a nutrient management plan should be developed and implemented for the catchment.

2.4.3 Potential impacts on the LORWUA irrigation canals

The raising of Clanwilliam Dam would probably have little impact on the growth of filamentous algae in the lower reaches of the canal system. The current use of the canal system is very close to its design capacity and there appears to be little scope for transporting more water through the system without major modifications to the canal system. The implication in terms of filamentous algal growth is that there would probably be little change from the current situation and the current impacts would probably continue.

The physical factors that control algal growth in canals (**Figure 2.8**) are light intensity, temperature and flow velocity (Du Plessis and Steyn, 2003). The raising of Clanwilliam Dam would probably not change the turbidity of the water in Bulkshoek Weir and the underwater light climate in the canals would probably remain unchanged. The water temperature in the lower reaches of the canal system would probably not change because the flow in the canals would not change significantly. The flow velocity would probably not change significantly from the current situation. Water temperature is a function of sunlight radiation and light penetration. These factors are not expected to change with the raising of Clanwilliam Dam.

2.4.4 Potential measures to mitigate eutrophication impacts on the irrigation canals

There are a number of methods to control nuisance algae in canals (Du Plessis and Steyn, 2003, Sytsma and Parker, 1999). These have been grouped into chemical, physical/mechanical, and biological control measures (**Figure 2.8**).

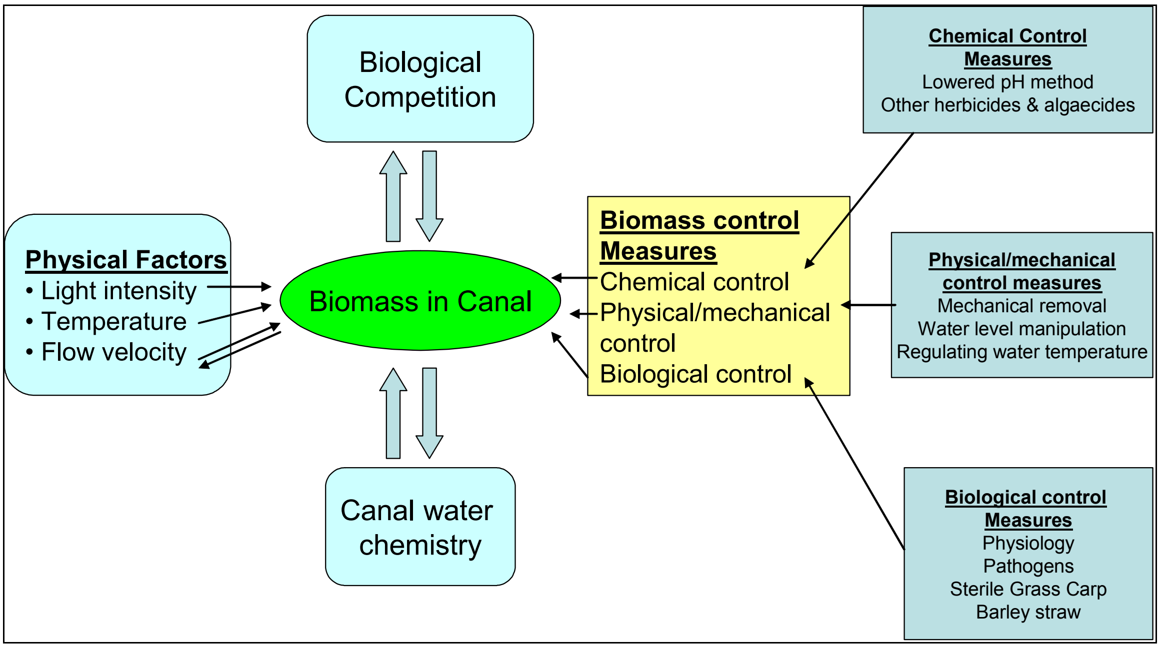

Figure 2.8 Diagram illustrating the key factors controlling algal biomass and possible measures to control excess biomass (redrawn from Du Plessis & Steyn, 2003)

The LURWUA currently uses chemical control measures in a programme to prevent the development of excessive biomass in the lower reaches of the canal. The nutrient concentrations in the canals and in Bulkshoek Weir is low and measures to further reduce nutrient concentrations are therefore not a cost-effective option at this stage. The relationship between nutrients and filamentous algae in flowing water is poor, making the manipulation of the nutrient environment a less viable control measure.

Further physical or mechanical measures are probably not feasible. The canal is emptied once a year during the winter for maintenance purposes. It is probably unfeasible to empty the canal and remove algal laden sediment during the summer irrigation months because the canal is used to its full capacity during those months. There is little scope for temperature manipulation in the lower reaches of the canals. Covering critical sections of the canal with 80% shade cloth to reduce light intensity has been used successfully elsewhere (Du Plessis, pers. comm.) but this method is often hampered by theft and vandalism.

Biological control measures include the use of grass carp (Du Plessis and Steyn, 2003), barley straw or the introduction of pathogens. Du Plessis and Steyn (2003) have used grass carp in the larger and deeper reaches of irrigation canals where the flow was between 5-10 m^3/s, and chemical control measures in the shallower, slower flowing reaches (<5 m^3/s) of the canal system.

It is the opinion of the author that, given that the raising of Clanwilliam Dam would probably not have a significant impact on the filamentous algal growth dynamics in the lower reaches of the canal system, no further mitigation measures are required. However, the LORWUA should continue to monitor and control the biomass of filamentous algae by chemical means. The

Association could investigate alternative chemical control agents as a means of possibly reducing control costs.

2.5 Discussion and conclusions of the eutrophication assessment

It is recommended that monitoring of the eutrophication status of Clanwilliam Dam and of Bulkshoek Weir continue via the National Eutrophication Monitoring Programme. Should the monitoring data indicate a trend that would change the trophic status from mesotrophic (moderately enriched) to eutrophic (enriched with nutrients) it is recommended that nutrient management plans be designed and implemented to protect the good quality water in the two affected dams.

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APPENDIX A

Data requirements for water quality modelling

APPENDIX A : DATA REQUIREMENTS FOR WATER QUALITY MODELLING

Water Quality Constituents to be Measured at the Inflow/Outflow Boundaries

Boundary Conditions		
Minimum Parameters	**Additional Parameters**	**Frequency**
Inflow temperature conductivity	Dissolved oxygen pH Total Dissolved Salts[1]	Daily or continuous
Total organic carbon	Dissolved Organic Carbon	Weekly grab sampling Storm sampling, if required
Soluble reactive phosphate Total phosphorous		Weekly grab sampling. Storm sampling, if required
Nitrate-nitrite nitrogen Ammonium nitrogen Total Kjeldahl nitrogen		Weekly grab sampling Storm sampling, if required
	Total suspended solids Inorganic suspended solids	Weekly grab sampling Storm sampling, if required
	Chlorophyll-*a* Dissolved silica Alkalinity	Weekly grab sampling Storm sampling, if required

[1] *Enough samples to allow for the determination of the relationship between EC and TDS*

In-Lake Water Quality Constituents To Be Measured

Minimum Parameters	Additional Parameters	Frequency
Temperature[2] Dissolved Oxygen[3] pH[3] TDS[3] or EC		Monthly grab sampling
Chlorophyll-*a*[4] Algal biomass and type		Monthly grab sampling
Total Organic Carbon[4]	Dissolved Organic Carbon	Monthly grab sampling
Soluble reactive phosphate[4] Total phosphorous[4]		Monthly grab sampling
Nitrate + nitrite nitrogen[4] Ammonia nitrogen[4] Total Kjeldahl nitrogen		Monthly grab sampling
Alkalinity		Monthly grab sampling
	Total suspended solids[4] Inorganic suspended solids[4]	Monthly grab sampling
Secchi depth		Monthly grab sampling
	Dissolved/total iron[5] Dissolved/total manganese[5] Dissolved/total silica[5] Total dissolved sulphide[5] Sulphate[5] Iron sulphide[5]	Monthly grab sampling

[2] *Initially, this could be done on a bi-weekly basis to supplement the automatic temperature vertical profiling at the Dam wall and to provide an alternative data set for calibration. Vertical profiling at 1m intervals using field instruments.*

[3] *Vertical profiling at 1m intervals, on a bi-weekly basis using field instruments.*

[4] *Vertical profiling at 3m intervals using field instruments.*

[5] *When concerned with the release from the sediment during anoxic conditions these parameters should be measured.*