The Determination of Annual Phosphorus Loading Limits for South African Dams

Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

Eutrophication threats to impoundments

Eutrophication (nutrient enrichment) of dams constitutes a major threat to the provision of raw potable and irrigation water within a country largely dependent on impounded water in order to ensure water supply. Such waters are typically associated with an increased incidence and frequency of algal development, often noxious, resulting in increased water treatment costs, loss of recreational use and property value and risks to human and animal health. The symptoms of eutrophication, most notably excessive aggregations of potentially-toxic cyanobacteria, are extremely difficult to manage and often pose long-term problems for affected waters and the provision of raw potable water therefrom.

Managing dams such that levels of eutrophication do not exceed thresholds above which problems are encountered, 'eutrophication capacity" should be a primary focus of South African water resource management. In cases where dams have become eutrophic, there is a need to attenuate the loading of nutrients in order to reverse the trend. In most cases the solution is complex, requiring not only nutrient reduction but also aspects such as sediment removal and restoration of components of the ecosystem lost to the ravages of eutrophication – for example dominance of the fish population by species which simply accelerate the eutrophication process.

The need for nutrient loading and assimilation assessments

The fundamental point of departure in any eutrophication assessment is to be able to determine the relationship between the level of nutrient loading, in particular phosphorus, and the in-lake condition. While this can be achieved at a high level of confidence and accuracy using sophisticated models with intensive data requirements, it is important to be able to undertake a screening level assessment, using simple model relationships, in order to identify management needs and opportunities. The time and costs associated with complex modelling are simply wasted if the ultimate result indicates that there is very little that can be done, or that the solution was almost obvious from the outset.

A number of simple relationships exist for predicting in-lake phosphorus conditions based on hydro-morphological data and catchment landuse. Such models, supporting screening-level assessments, have not been tested for their relevance in South Africa, i.e. across a wide range of impoundment types. Given the importance of having such workable models available it is therefore important that their local relevance be determined. This project has, for the first time, undertaken a preliminary testing of a suite of models across a set of 30 dams.

Aims of this project

This project comprised a pilot screening of models aiming to determine for each dam

(i) the current trophic status;
(ii) the current matrix of phosphorus sources contributing to the total annual phosphorus loads to each of these dams (based on landuse);
(iii) to set Total Median Annual Phosphorus Load (TMAPLs) for each, and
(iv) identify from the landuse-based loading profile where nutrient attenuation management practices should be focused.

The scope of this project entailed a screening-level approach to ascertain the workability of the approach and the associated limitations. The project did not encompass an exhaustive examination of peculiarities in the hydrology, limnology or nutrient loading characteristics of any of the impoundments examined. Several of the catchments are strongly dominated by point sources for which accurate data are not readily available. Some impoundments form part of cascading dam alignments, inter-basin transfers and/or augmentation schemes. Attention to these aspects would require many weeks to months per dam to identify and resolve. The findings of this project are simply intended to inform the basis of, and planning for, any future, more intensive, analysis.

Outcomes

Although unforeseen data limitations reduced the modelling set by 17, the aims were achieved for the remaining 13. The approach proved to be workable notwithstanding the identified need for a greater level of primary data sourcing and processing. As such the approach provides a means whereby impoundments and their catchments can be screened for their trophic status, sources of nutrient loading in relation to landuse, and Best Management Practices allocated accordingly.

Conclusions

The conclusions emanating from this study were the following:

- Determination of the restoration potential for any eutrophic impoundment requires that the aggregate nutrient loading be quantified and apportioned to the prevailing catchment landuse. Thereafter, and based on a Best Management Practice cost-benefit analysis, efforts can be directed at those sources of nutrient loading most likely to yield the desired reduction.
- South African impoundments have a threshold of nutrient availability, as total in-lake phosphorus concentration, above which an increased frequency and duration of potentially-problematical algal growth may be experienced. This level has been equated, in previous studies such as the Nutrient Enrichment Assessment Protocol (WRC, in preparation), as approximately 55 μg ℓ^{-1} TP. For the purposes of this project this phosphorus concentration, which

approximates the concentration below which a stable state of macrophyte-dominated, clear water conditions may be sustained, has been used as the guideline for setting the desired in-lake trophic state. The concentration approximates the boundary between meso- and eutrophic lake conditions as defined by contemporary guidelines.

- The use of simple modelling approaches, at screening level, have enormous value in focusing management needs and actions at a fundamental level – this as opposed to the extremely costly and time-consuming expedient of more sophisticated models having intensive data requirements. The approach described here allows for relatively rapid ranking and prioritization of needs and actions based on limited and generally-available data.
- This project has used the simple expedient of using flushing-corrected, annual time-step phosphorus models to analyze the conditions in a set of South African dams. Nutrient loadings to each dam were determined using a trial set of phosphorus export coefficients allocated to landuse practices. Model relevance (accuracy) was determined by comparison of predicted vs observed in-lake phosphorus concentrations.
- Models calibrated in this fashion allow for a desired total phosphorus load to be determined by reducing the loading to the point where the model output approximates the above-mentioned phosphorus boundary concentration.
- This approach has proved to be workable but remains subject to data constraints and verification of the relevance of the export coefficients used. Notwithstanding this, the approach was used to determine Target Median Annual Phosphorus Loads (TMAPLs) for 43% of the dams in the test set (13/30).
- Data constraints encompassed missing data, irreconcilable water balance data, wastewater treatment data on a works by works basis and an insufficient chronological matching of discharge and nutrient concentration for rivers influent to the dams. Although not within the scope of this pilot project, all of these limitations could be accommodated within a more comprehensive analysis.
- No one model was found to apply to all of the dams that could be modeled. However, the Walker Reservoir Model, previously used for the Nutrient Enrichment Assessment Protocol (NEAP), again appeared to have strong relevance for South African conditions, i.e. for impoundments with relatively short (< 2-3 years) water retention times. As with the findings of previous studies, the Combined OECD model was found to be generally applicable. The data constraints experience in this project preclude reaching a definitive conclusion on model relevance and the re-calibration of any particular relationship for South African use.
- All of the dams in the test set were in the eutrophic to hypertrophic range, with median annual in-lake phosphorus concentrations ranging from 31 to 626 µg TP ℓ^{-1}. For the dams that could ultimately be modeled, this range extended from 59 to 626 µg TP ℓ^{-1}. The test set included several dams on the

high priority management list determined by the DWAF Trophic State Assessment Program.

- Targeted load reductions were found to be high, ranging from 25 to 96% of current loadings. Eight of the thirteen dams evidenced load reduction requirements in excess of 50%, and five of these greater than 75%. These data indicate the severity of the eutrophication problems being experienced by these waters.
- The dams in the test set could be divided into three types, those dominated by urban sources of nutrient loading, those dominated by dryland and/or undeveloped landuse, and a mix of the two. In the cases of urban landuse dominance, the primary source of nutrient enrichment is assumed to be treated wastewater effluents high in phosphorus content. Such sources are further deemed to be more suited to rapid nutrient attenuation (process upgrades), although not without significant cost implications, than are the more diffuse sources associated with dryland and non-irrigated agricultural practices within the catchment.
- Certain impoundments dominated by dryland activities may have almost nil cost-effective options for the mitigation of eutrophication other than in-lake practices. The very nature (hydro-morphological) of these dams renders them prone to sustained eutrophication that is not manageable at the level of the catchment. Such dams are likely to be eutrophic in the absence of any development of any kind in their catchments (‘background’ or geochemical eutrophication).
- Based on the assumption that urban activities resulting in the pollution of impoundments are more readily managed, the modeled dams could be ranked based on landuse and target load (TMAPL) reductions.

Recommendations

Based on the foregoing, it is recommended that:

- The relevance of phosphorus export coefficients be verified for South African landuse types. This may be achieved using a pre-selected set of dams, landuse coverages and quantified nutrient loading data, as well as for selected river monitoring points monitored on an event-driven basis.
- Nutrient loading to an impoundment be quantified on the basis of flow-quality matching using software such as Flux. This is an essential component of the model verification process that has thus far only been completed for Hartbeespoort Dam.
- Nutrient loads from bulk point sources such as wastewater treatment works need to be quantified on a works by works basis. Data pertaining to such plants is currently not readily available but, in cases such as Hartbeespoort, Roodeplaat and Klipvoor Dams, constitutes a major component of the phosphorus nutrient loading profile.

- Water balances for complex hydrological environments such as the Vaal and Bloemhof Dams need to be accurately quantified prior to use in modelling as these can significantly confound any calculations based only on catchment landuse. Simple models such as those used in this project may have limited relevance for such dams.
- Given the value of this approach for management prioritization, it should be extended to a wider set of impoundments and impoundment-types (both hydro-morphological and provincial). Given the identified need for comprehensive data preparation, the activities could be divided within or between projects, i.e. a group screening and verifying the raw data, a group undertaking the flow-concentration modelling, and a third team using the output from the first two to test with the various models.

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"The Determination of Annual Phosphorus Loading Limits and Landuse-Based Phosphorus Loads for 30 Key South African Dams in Relation to Their Present and Likely Future Trophic Status".

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TABLE OF CONTENTS

EXECUTIVE SUMMARY i
ACKNOWLEDGEMENTS vi
1. INTRODUCTION AND BACKGROUND 1
  1.1 Aims 2
  1.2 Approach 3
2. METHODS 4
  2.1 Data sourcing and processing 4
  2.2 Phosphorus prediction models 8
  2.3 Modelling 10
  2.4 Landuse data 10
  2.5 Export coefficients 10
  2.6 TMAPL Allocations 11
3. RESULTS & DISCUSSION 12
  3.1 Water balances and hydromorphic data 12
  3.2 In-lake water quality 13
    3.2.1 In-lake phosphorus 13
    3.2.2 Chlorophyll-a 14
  3.3 Trophic state comparisons 16
  3.4 Catchment data 18
  3.5 Model fitting 19
  3.6 TMAPL allocations 21
  3.7 Implications for management 24
4. CONCLUSIONS 26
5. RECOMMENDATIONS 28
REFERENCES 29

APPENDIX A: Water Balances
APPENDIX B: In-lake phosphorus data
APPENDIX C: In-lake chlorophyll-a data
APPENDIX D: Landuse data.

The above appendices and a PDF copy of the report are available on the CD attached to this report

1. INTRODUCTION AND BACKGROUND

Eutrophication (nutrient enrichment of surface waters) constitutes the greatest single threat to the impoundment of raw potable and irrigation water. In countries such as South Africa, where treated effluents and other wastewaters comprise an often significant proportion of return flows to reservoirs (dams), the problems associated with eutrophication are exacerbated. This problem is especially apparent in the inland areas of South Africa, especially around major urban areas such as the Johannesburg-Pretoria complex.

> Worldwide, the greatest unresolved water quality concerns are in countries with the fewest resources, where demand for water is growing and research and restoration funding sources are scarce. The fate of aquatic resources in the world's poorest countries should be of concern to all countries. Because the toxicity of drinking water often increases with nutrient enrichment, excess nutrients should be treated as toxic substances and banned. There is an urgent need for the universal regulation of nutrients to protect drinking water supplies and aquatic biodiversity (Prepas and Charette, 2003)

If water storage reservoirs are to be effectively managed, in the face of burgeoning urban development and the associated increase in volumes of polluted runoff and effluent flows, then the 'eutrophication capacity' of each dam must be determined. In this regard eutrophication capacity refers to the capacity for a particular dam to assimilate phosphorus loads without 'trophic status thresholds' being exceeded. Trophic status thresholds pertain to the phosphorus loading levels, translated to concentrations of in-lake phosphorus, result in an observed increase in the frequency of problematical conditions such as blooms of cyanobacteria. Knowledge of the rate of phosphorus loading, in relation to the trophic status of a particular reservoir, will guide catchment managers in setting limits on nutrient discharges at the catchment level. In so doing the eutrophication-associated risks to ecosystem (the reservoir and its downstream environment) and human and animal health may be minimized. The approach is thus in accordance with the national Trophic Status, Eutrophication Monitoring and Catchment Best Management Practice initiatives.

> Purpose of this project: To evaluate a chemical-specific criterion (phosphorus) in order to establish allowable nutrient loads which, if exceeded, will result in impaired beneficial use(s) of the impoundment. Such impairments include adverse impacts on recreation and a change in fish population structure from desirable gamefish to rough (coarse) fish such as carp.

In the cases of dams where eutrophication thresholds are already exceeded, this approach will assist with the setting of target nutrient load levels corresponding to a desired in-lake condition. This does not presume to indicate that the reversal of eutrophication amounts to a simple reduction in loading. Sustained eutrophication embodies a build-up in resilience to measures designed to attenuate nutrient availability – these centered on a combination of internal loading and, importantly, degradation of foodweb structures resulting in diminished natural ability to offset the progressive change to an environment dominated by a few species of coarse and often noxious organisms – the so-called 'plagioclimactic' condition of hypertrophic waters.

The scope of this project entailed a screening-level approach to ascertain the workability of the approach and the associated limitations. The project does not encompass an exhaustive examination of peculiarities in the hydrology, limnology or nutrient loading characteristics of any of the impoundments examined. Several of the catchments are strongly dominated by point sources for which accurate data are not readily available. Some impoundments form part of cascading dam alignments, inter-basin transfers and/or augmentation schemes. Attention to these aspects would require many weeks to months per dam to identify and resolve. The findings of this project are simply intended to inform the basis of, and planning for, any future, more intensive, analysis.

Eutrophication impairment is (most) typically obvious as excessive algal development and, in some cases, macrophytes such as water hyacinth. However, it is important to note that this is simply the most obvious symptom. Directly-related and often severe ecosystem impacts are incurred through increased mineralization of nutrients, increased frequency of oxygen drawdowns and duration of such oxygen-depletion excursions below critical levels, with concomitant impacts on aquatic biota.

1.1 Aims

This project examined in-lake (dam) and catchment-exported phosphorus loadings for a set of 30 dams. The objective was to compare and contrast these dams in terms of:

- their current trophic status;
- the current matrix of phosphorus sources contributing to the total annual phosphorus loads for each (based on landuse);
- setting Total Median Annual Phosphorus Load (TMAPLs) for each, and
- identifying, from the landuse-based loading profiles, where nutrient attenuation management practices should be focused.

The project was based on a limited (time and cost) 'screening-level' approach, through which existing data for a set of dams is used to populate and test a series of annual time-step phosphorus loading models. The process was thus entirely dependent on the quality of the available data being suitable for the intended purpose. The data used for the project was not previously screened or evaluated.

This is the first (known) attempt at an interrogation of available SA reservoir data to characterize the phosphorus loading response and resultant in-lake condition. An earlier exercise, developing the Nutrient Enrichment Assessment Protocol (NEAP) undertook a provisional allocation of model applicability (Rossouw et al., in preparation).

1.2 Approach

This project extended work previously carried out for the development of the Nutrient Enrichment Assessment Protocol (WRC Report Details). This expanded the approach to a larger set of dams in order to seek similarities in model applicability. The selection of the test-set of dams was made, based on a worst- case prioritization analysis, by Mrs C van Ginkel of the Directorate of Resource Quality Services (RQS), Department of Water Affairs and Forestry (DWAF).

All of the data used in this project were obtained from DWAF, either from the Directorate: Hydrology (discharge data and impoundment water balances) or from RQS (landuse, in-lake and river water quality).

The approach entailed using generic phosphorus export coefficients to predict in-lake total phosphorus conditions based on catchment-exported loads. The results were then compared with observed in-lake values to identify those models with accuracies varying by no more than 30% of observed values.

> The approach adopted here does not intend to create algal growth-limiting conditions based on phosphorus. Rather, the intention has been to indicate the threshold below which a significant improvement in conditions may be expected. Additionally, a phased implementation of reducing loads towards the target, coupled with other rehabilitation (Best Management Practice) measures, will serve to further reduce eutrophication pressures.

The approach adopted for this project is akin to that utilized at a finer scale of interpretation to set Total Maximum Daily Loads (TMDLs) for nutrients (e.g. USEPA, 1999). These approaches follow the same generic pattern, namely:

- Identify the nature of a eutrophication problem for an impoundment;
- Identify the sources and loads of nutrients;
- Estimate the assimilable/desirable nutrient loading capacity;
- Set water quality targets for the desired trophic state of the impoundment;
- Set a total target load allocation that will not exceed the loading capacity;
- Apportion the load allocation (load reduction) amongst the identified sources;
- Implement load reduction strategies;
- Monitor and review.

This project examines this process at a relatively coarse level, based on identifying those loads which when exceeded are likely to result in an increased frequency of problematical algal blooms. The approach used has, however, been conducted on a site-specific basis but using a generic loading capacity target or tipping point threshold for all dams in test set. This threshold is based on an in-lake median concentration of total phosphorus of 55 µg ℓ^{-1}. At concentrations in excess of this value South African impoundments exhibit a marked increase in algal biomass development (Rossouw et al., in preparation).

2. METHODS

2.1 Data sourcing and processing

All data used in this project were sourced from DWAF. The dams utilized in this project are listed in **Table 1** and their locations shown in **Figure 1**. This table also summarizes the availability of hydromorphological and water quality data for each dam as determined by this project. Trophic status and Priority Status (those dams deemed by DWAF to have the highest management needs) were initially determined based on the findings of the DWAF Trophic Status Project (2001).

The minimum requirement for modelling is the availability of matched in-lake and water balance data for a particular dam, i.e. facilitating the population of a hydro-morphological relationship for the impoundment and the availability of in-lake Total Phosphorus data for the modelling period.

TABLE 1: DETAILS OF THE DAMS ASSESSED AND DATA AVAILABILITY Data for the period 1990-2005						
#	**Impoundment Name**	**Trophic State***	**Priority Status***	**Inflows: Discharge *vs* quality matched?**	**Availability of in-lake data?**	**Water balance data adequate?**
1	Allemanskraal	Hyper		No	No	Doubtful
2	Barrage			No	Yes	No
3	Bloemhof	Hyper	Yes	No	Yes	No
4	Blyderivierpoort			Yes	No	Doubtful
5	Bospoort			No	No	No
6	Bridledrift	Eutrophic		Yes	Yes	No
7	Bronkhorstspruit	Eutrophic		No	Yes	Yes
8	Bulshoek			Yes	No	No
9	Erfenis	Hyper	Yes	No	Yes	Doubtful
10	Grootdraai	Eutrophic		No	Yes	Yes
11	Hartbeespoort	Hyper	Yes	Yes	Yes	Yes
12	Kalkfontein			No	Yes	No
13	Klipfontein	Eutrophic		No	Yes	Yes
14	Klipvoor	Hyper	Yes	No	Yes	Yes
15	Koppies			No	Yes	Yes
16	Kosterrivier			No	Yes	No
17	Laing	Eutrophic		No	Yes	Yes
18	Lindleyspoort	Eutrophic		Yes	Yes	No
19	Misverstand	Eutrophic		Yes	Yes	Yes
20	Modimola			No	Yes	No
21	Nahoon			No	No	Yes
22	Rietvlei	Hyper	Yes	No	Yes	No
23	Roodekopjes	Meso		No	Yes	Yes
24	Roodeplaat	Hyper	Yes	Yes	Yes	Yes
25	Spitskop			No	Yes	No
26	Umtata			No	Yes	No
27	Vaal	Eutrophic		No	Yes	Yes
28	Voelvlei			Yes	Yes	No
29	Welbedacht			No	Yes	Yes
30	Witbank	Meso		Yes	Yes	No
* = details as per the Trophic Status Report (DWAF, 2001)						

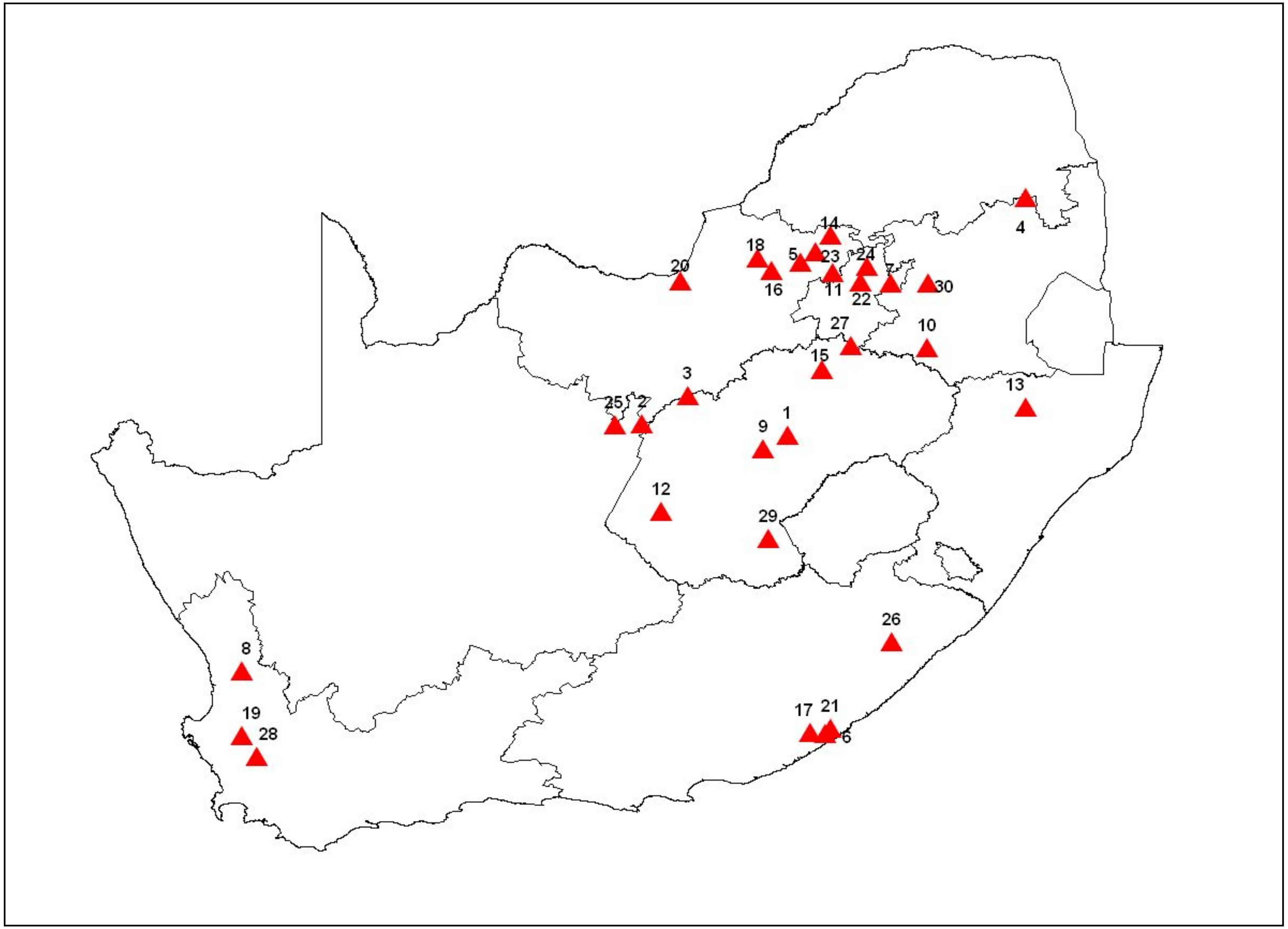

Figure 1: Map showing locations of the 30 dams used in this project
(Numbering as per Table 1)

Water balances (**Appendix A**) were received from DWAF, in the following general (example) format (**Table 2**), for each impoundment for which data were available (all values in millions of cubic meters):

TABLE 2: EXAMPLE OF PROCESSED WATER BALANCE DATA USED TO ESTABLISH THE HYDRO-MORPHOLOGICAL MODEL FOR EACH IMPOUNDMENT. All Units in MCM										
#	Hydro Year ending	Total River Discharge	Irrigation	Evaporation	Streamflow plus rain	Rain	Calculated streamflow	Total Discharge	Total Inflow	Nett inflow or -outflow
1	1986	37.344	85.638	16.914	132.090	4.960	127.130	139.896	132.090	-7.806
2	1987	54.131	87.573	21.297	251.177	9.732	241.445	163.001	251.177	88.176
3	1988	52.231	93.159	27.799	203.771	12.836	190.936	173.189	203.771	30.582
4	1989	68.432	102.288	29.575	202.592	10.745	191.847	200.295	202.592	2.297
5	1990	47.327	111.269	30.118	184.666	11.797	172.869	188.714	184.666	-4.048
6	1991	65.299	120.696	29.499	192.810	10.809	182.001	215.494	192.810	-22.684
7	1992	45.257	127.605	23.786	116.832	5.876	110.956	196.648	116.832	-79.816
8	1993	43.126	102.852	15.783	149.318	4.320	144.998	161.761	149.318	-12.443
9	1994	53.845	105.019	20.679	246.877	9.149	237.728	179.543	246.877	67.334
10	1995	50.334	127.899	23.887	215.525	8.523	207.003	202.120	215.525	13.405
11	1996	422.865	104.435	28.516	611.973	16.388	595.585	555.816	611.973	56.157
12	1997	483.760	116.300	29.302	641.501	21.818	619.245	629.362	641.501	12.139
13	1998	135.137	160.827	30.206	308.314	10.712	297.603	326.170	308.314	-17.856
14	1999	167.361	135.566	32.391	336.311	10.734	325.576	335.318	336.311	0.993
15	2000	512.944	139.469	33.575	702.438	16.637	685.801	685.988	702.438	16.450
16	2001	255.756	146.088	33.760	434.819	15.337	420.750	435.604	434.819	-0.785
17	2002	147.250	84.399	20.364	251.333	9.836	224.226	252.013	251.333	-0.680

The data, after correction for evaporation, were used to derive a median, phosphorus inflow-outflow relationship for each dam. This was undertaken for the period matched by the availability of in-lake Total Phosphorus data and generally spanned the years 1990-2005. Similarly, the water chemistry data were processed to derive a median in-lake Total Phosphorus concentration. The data were also examined to determine any inter- or intra-annual trending or seasonal cycles. Phosphorus and chlorophyll-a data are summarized graphically in **Appendices B** and **C**, respectively.

Voelvlei Dam was excluded on the basis of modelling complications caused by the complex nature of the dam's catchment (the dam has no natural catchment and water is drawn via canals from remote areas) and inadequate data pertaining to the augmentation scheme from the Berg River.

2.2 Phosphorus prediction models

The following set of phosphorus-loading lake/reservoir response models were used in a spreadsheet-based testbed.

1. Canfield-Bachman Artificial Lake Model (1981)
2. Canfield-Bachmann Natural Lake Model (1981)
3. Dillon-Kirchner-Rigler Lake Model (1975)
4. OECD Combined Lakes Model (1982)
5. Reckhow Anoxic Lake Model (1977)
6. Reckhow Natural Lake Model (1979)
7. Reckhow Oxic Lake Model 1 (1977)
8. Reckhow Oxic Lake Model 2 (1977)
9. Salas and Martino Lake Model 1 (1985)
10. Salas and Martino Lake Model 2 (1985)
11. Vollenweider Lake Model (1975)
12. Walker General Lake Model (1977)
13. Walker Reservoir Model (1987)

All of the models provide a simple, annual-timestep, flushing-corrected prediction of the in-lake phosphorus condition for a particular lake or reservoir. The output predicts the growing season mean phosphorus conditions. In terms of the screening-based approach of this project all of the models were examined irrespective of their original intention as predictors of phosphorus for, specifically, a lake or reservoir environment, or specific type thereof (e.g. shallow vs deep lakes).

The mathematical relationships for each model are provided in **Table 3**.

TABLE 3: DETAILS OF THE MODELS USED IN THIS PROJECT	
Canfield-Bachmann (1981) Artificial Lakes	$P = 0.8L / (z(0.0569(L/z)^{0.639}+R_w$
Canfield-Bachmann (1981) Natural Lakes	$P = 0.8L / (z(0.0942(L/z)^{0.422}+R_w$
Dillon-Rigler-Kirchner (1975)	$P = L (1-R) / zR_w$ where For $q_s < 10$ m y^{-1} $R=0.201exp(-0.0425q_s) + 0.574exp(-00949q_s)$ For $q_s > 10$ m y^{-1} $R=0.426exp(-0.271q_s) + 0.574exp(-00949q_s)$
OECD Combined Model (1982)	$P = 1.55(LT_w/z) / (1+ \sqrt{T_w}))^{0.82}$
Reckhow (1977) Anoxic Lakes	$P = L / 0.17z + 1.13 z/T_w$
Reckhow (1979) Natural Lakes	$P = L*1000 / (11.6 + 1.2q_s)$
Reckhow (1977) Oxic Lakes, $z/T_w < 50$ m y^{-1}	$P = L / (18z / 10 + z) +1.05 (z/T_w)e^{0.012z/Tw}$
Reckhow (1977) Oxic Lakes, $z/T_w > 50$ m y^{-1}	$P = L / 2.77z + 1.05 (z/T_w)e^{0.0011z/Tw}$
Salas & Martino Equation 1	$P = 0.290 L^{0.891} * T_w^{0.676} / z^{0.934}$
Salas & Martino Equation 2	$P = L/z * (T_w^{0.75} / 3)$
Vollenweider (1975) Lake Model	$P = L / 10 + zR_w$
Walker (1977) General Lake Model	$P = LT_w / z [0.824 T_w^{0.454})$
Walker (1987) Reservoir Model	$P = LT_w (1-R) / z$ where $R = 1+[1-(1+4Nr)^{0.5}] / (2Nr)$ $Nr = K_2 L Tw^2 / z$ $K_2 = 0.17 q_s / (q_s +13.3)$
<u>Symbols used</u> P = Predicted median annual in-lake total phosphorus (TP) concentration (µg ℓ^{-1}) L = Areal total phosphorus load (mg TP m^{-2} y^{-1}) z = Lake mean depth (m) T_w = Hydraulic retention time (years) R_w = Lake flushing (water exchange) rate (1/y) q_s = Areal water loading (m y^{-1}) R = fraction of P load retained in lake LT_w/z = Average concentration of total P in the inflow (mg ℓ^{-1}) K_2 = Second order decay rate	

None of the models are or were specifically developed for use in South African or southern hemisphere conditions. However, previous work has indicated that the Walker Reservoir Model, designed for highly-flushed impoundments, or the OECD Combined Model, is likely to be relevant for South African conditions (Harding, 2004; Thornton and Harding, 2005).

2.3 Modelling

Hydromorphological relationships were first established for each dam using the water balance data provided by DWAF. In-lake water quality conditions, as total phosphorus concentrations, were determined from the water quality data provided by RQS. In all cases median values were employed for each parameter.

When proposed this project intended to compare phosphorus loadings based on export coefficients with actual loads determined from a combination of discharge and concentration measured at the major inlet points to each of the dams. This approach, however, was abandoned as the available data (see Table 1, matching of discharge and quality at the point of inflow to each impoundment) did not support adequate matching of flows and concentrations for all inlets or provide enough representation of the hydrographic trends. No provision was made for the use of a data simulation model such as *Flux* (Walker, 1987). As a result this project relied on generic export coefficients for the screening process (see 2.5).

2.3.1 Trophic State boundaries

The Trophic State boundaries as used by the DWAF Trophic Status Assessment (Van Ginkel et al., 2001) are summarized in **Table 4**:

TABLE 4: TROPHIC STATE CLASSIFICATION BOUNDARIES Per DWAF Guidelines (Van Ginkel et al., 2001)				
Variable	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hypertrophic**
Total Phosphorus (mg ℓ^{-1})	< 0.015	0.015-0.047	0.048-0.130	>0.130
Median Chlorophyll-a (µg ℓ^{-1})	0-10	11-20	21-30	>30
% time chlorophyll-a >30 µg ℓ^{-1}	0	<8	8-50	>50
Values expressed as annual medians				

2.4 Landuse data

Landuse data from the National Landcover Project were kindly provided by DWAF(RQS) (**Appendix D**).

2.5 Export coefficients

There are currently no data on phosphorus export for South African landuse types. To compensate for this a set of generic export coefficients developed for the northern hemisphere (e.g. Reckhow and Simpson, 1980; Wilson, 2005) were modified (see explanation below table following) to reflect that deemed to be representative of a semi-arid environment (see **Table 5**). The modifications were tested using Hartbeespoort Dam as a test case. The breakdown (apportionment) of the influent loads to Hartbeespoort Dam is well known and verified by more than one method.

Accordingly the data for this dam could be used to 'calibrate' the set of export coefficients used in this project.

TABLE 5: PHOSPHORUS EXPORT COEFFICIENTS PER LANDUSE TYPE. Values indicate export of phosphorus in kg p ha^{-1} a^{-1}		
Landuse	**Export coefficient**	
	Original set	**Modified set**
Forests (all types)	0.1	0.1
Natural shrublands	0.02	0.02
Unimproved grasslands	0.3	0.1
Dryland agriculture	0.3	0.1
Irrigated agriculture	1.5	1.2
Urban residential	1.3	2.5
Urban rural	0.3	0.1
Commercial industrial	2.5	0.8

Coefficient modifications were based on:

(i) reducing the dryland exports by 60%;
(ii) a slight reduction for irrigated agriculture;
(iii) incorporation of wastewater effluent contributions into urban residential load origins;
(iv) reducing urban rural runoff to match dryland and
(v) reducing commercial-industrial to reflect the low spatial percentage contributions from this source.

In absence of individual wastewater treatment plant effluent data, the assumption was made that urban waste-streams will produce considerably higher loads of phosphorus containing runoff as compared with rural and commercial areas (which may be expected to generate relatively higher loads of suspended solids and nitrogen – e.g. McLeod et al., 2006). Accordingly, the loadings derived from urban residential areas were increased and those for commercial/industrial reduced.

2.6 TMAPL Allocations

The following method was used to determine guideline annual phosphorus loadings for each dam:

1. Identify model with closest predicted vs observed in-lake TP;
2. Allocate target trophic state class. For this screening trial the boundary condition (55 µg ℓ^{-1} median annual TP ; Rossouw et al., in preparation), approximating the mesotrophic:eutrophic boundary (see Table 3) was chosen;
3. Using the relevant model (1) determine the loading associated with the boundary condition for the impoundment in question;
4. Determine the total load reduction required per annum to achieve the target loading;
5. Qualify the required load reduction in terms of the dominant catchment landuse(s).

3. RESULTS & DISCUSSION

3.1 Water balances and hydromorphic data

The hydromorphological data used in this project are summarized in **Table 6**.

TABLE 6: HYDROMORPHOLOGICAL DATA FOR EACH IMPOUNDMENT					
DAM	**Surface Area**	**Volume**	**Mean Depth (z)**	**Hydraulic Loading***	**Hydraulic Retention Time (T_w)**
Units	**ha**	**MCM**	**m**	**MCM a^{-1}**	**yr**
Allemanskraal	2648	179	6.8	22	8.08
Barrage	2119	49	2.3	641	0.08
Bloemhof	23329	1240	5.3	635	1.95
Blyderivierpoort	249	55	22.1	263	0.21
Bospoort	373	16	4.2		
Bridledrift	746	101	13.6		
Bronkhorstspruit	861	58	6.7	12	4.69
Bulshoek					
Erfenis	3292	212	6.4	23	9.20
Grootdraai	3882	356	9.2	221	1.61
Hartbeespoort	2065	195	9.4	154	0.81
Kalkfontein	3770	258	6.9		
Klipfontein	296	18	6.1	19	0.93
Klipvoor	753	42	5.6	54	0.79
Koppies	1385	42	3.1	12	3.66
Kosterrivier	262	13	4.9		
Laing	204	20	9.7	42	0.47
Lindleyspoort	180	14	8.0	3	4.20
Misverstand	255	8	3.0	502	0.02
Modimola					
Nahoon	235	19	8.2	21	0.93
Rietvlei					
Roodekopjes	1559	102	6.6	60	1.71
Roodeplaat	395	43	11.0	34	1.28
Spitskop	2531	58	2.3	7	8.35
Umtata					
Vaal	32276	2610	8.1	1242	2.10
Voelvlei	1524	165	10.9	147	1.13
Welbedacht	1018	12	1.1	702	0.02
Witbank	1211	104	8.6	133	0.78
Units: ha = hectares; MCM = million cubic meters; shaded areas = No data available * Hydraulic loading calculated from water balances provided by DWAF (Appendix A)					

It is highly probable that the number of dams suitable for modelling, and the general accuracy of the dataset, could be increased following further data sourcing and interrogation. The time required for an intensive exercise of this nature was not available within the scope of this project.

3.2 In-lake water quality

Total phosphorus and chlorophyll-a data for each impoundment are summarized in percentile format in **Tables 7 and 8** and depicted graphically in **Figures 2 and 3**. The data have been ranked from lowest to highest and the incidence of trends, inter- or intra-annual, is indicated.

3.2.1 In-lake phosphorus

TABLE 7: PERCENTILE ANALYSIS OF TOTAL PHOSPHORUS CONCENTRATIONS PER IMPOUNDMENT

Impoundment	Total P percentile value (ppm)						n*	Trend*
	P25	P50	P75	P90	P95	P99		
Witbank	0.023	0.031	0.045	0.068	0.087	0.216	329	Stable
Roodekopjes	0.030	0.039	0.057	0.084	0.107	0.475	205	Stable
Lindleyspoort	0.029	0.040	0.048	0.059	0.066	0.184	237	Stable
Kalkfontein	0.036	0.045	0.076	0.116	0.155	0.464	97	(increasing)
Voelvlei	0.036	0.049	0.066	0.090	0.114	0.159	87	increasing
Grootdraai	0.047	0.059	0.074	0.096	0.120	0.182	664	Stable
Kosterrivier	0.044	0.066	0.096	0.136	0.166	0.422	437	[increasing]
Spitskop	0.054	0.067	0.086	0.123	0.184	0.279	86	ND
Umtata	0.070	0.076	0.083	0.091	0.093	0.367	30	Stable
Barrage	0.064	0.079	0.106	0.128	0.145	0.158	109	Stable
Vaal	0.056	0.083	0.128	0.195	0.245	0.479	624	increasing
Bronkhorstspruit	0.063	0.085	0.107	0.143	0.161	0.389	194	(increasing)
Bloemhof	0.060	0.086	0.118	0.163	0.201	0.377	396	Stable
Modimola	0.067	0.087	0.122	0.162	0.213	0.378	294	Stable
Klipfontein	0.064	0.095	0.134	0.184	0.229	0.464	336	Stable
Misverstand	0.074	0.097	0.136	0.205	0.270	0.580	555	Stable
Welbedacht	0.054	0.099	0.199	0.298	0.612	0.706	39	(increasing)
Koppies	0.070	0.102	0.157	0.216	0.320	0.498	175	(Stable)
Hartbeespoort	0.069	0.104	0.193	0.350	0.423	0.877	1992	Decreasing
Bridledrift	0.070	0.113	0.158	0.183	0.196	0.250	446	ND
Laing	0.084	0.126	0.167	0.193	0.257	0.426	332	Stable
Erfenis	0.125	0.166	0.246	0.288	0.302	0.348	342	ND
Roodeplaat	0.157	0.207	0.257	0.315	0.346	0.428	888	Stable
Rietvlei	0.190	0.250	0.393	0.602	1.064	1.820	216	(increasing)
Klipvoor	0.407	0.626	0.831	1.034	1.170	2.307	160	Stable
Allemanskraal	ND							
Blyedrivierpoort	ND							
Bospoort	ND							
Bulshoek	ND							
Nahoon	ND							

n = number of data values in set; ND = No data or insufficient data; trends qualified by () parentheses indicates very slight trend; trends qualified by [] parentheses indicates a recent change. Trends determined from visual examination of the long-term data.

Marked seasonal variation was quite rare and especially evident in dams such as Roodeplaat. Three out of thirteen dams showed increasing trends and only one, Hartbeespoort, was characterized by a long-term decline in in-lake phosphorus. Median concentrations approximated 100 µg ℓ^{-1} for eight out of thirteen dams. Grootdraai was the lowest (59 µg ℓ^{-1}) and Klipvoor the highest at 626 µg ℓ^{-1}, 3-fold higher than the next highest value, 207 µg ℓ^{-1} P, measured for Roodeplaat Dam. The concentrations of phosphorus in Klipvoor Dam considerably exceed the legendary highs associated with Hartbeespoort Dam.

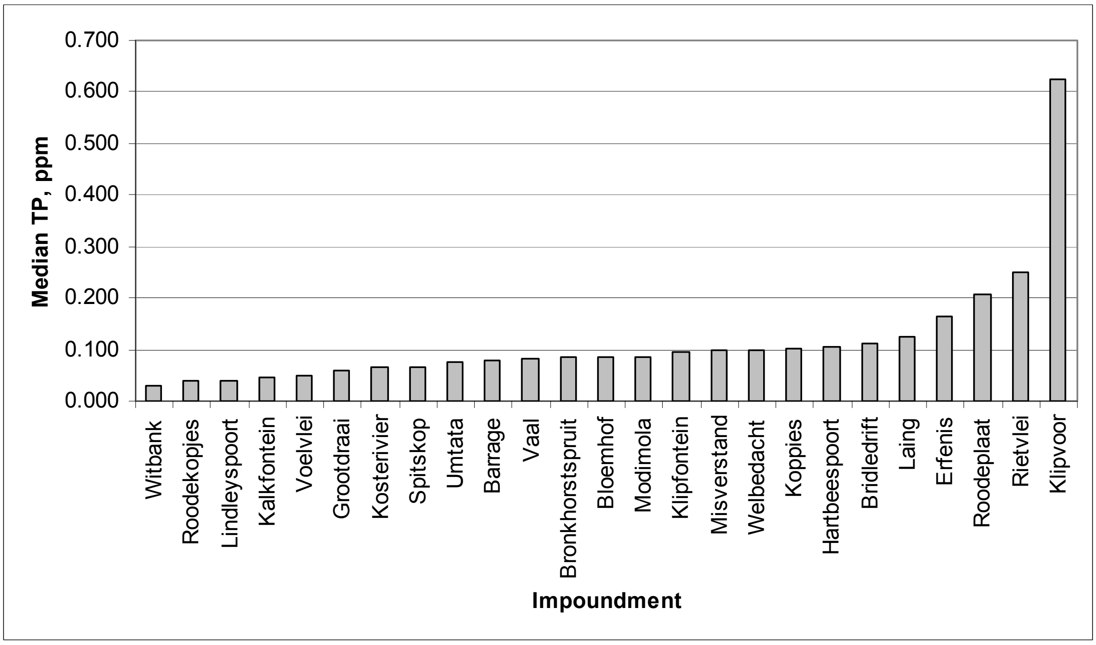

Figure 2: Ranking of impoundments (lowest to highest) in terms of median annual concentration of phosphorus (TP)

3.2.2 Chlorophyll-a

Data for chlorophyll-a are summarized as for phosphorus in **Table 8** and **Figure 3**.

Comparing Trophic State classifications determined from 50%ile values for TP and chlorophyll-a revealed a distinct lack of matching (see **Table 8**). However, if one more correctly considers seasonal high densities (peaks) of algal aggregations to be a problem, then a comparison of median phosphorus *vs* the 90th percentile value for chlorophyll-a makes more sense from a management perspective. Although discrepancies were still encountered for Laing and Erfenis Dams, comparison of the 50th percentile T values P vs the 90th percentile chlorophyll-a revealed a close match in terms of being able to gauge the Trophic State from either parameter (see **Table 10**).

TABLE 8: PERCENTILE ANALYSIS OF CHLOROPHYLL-a CONCENTRATIONS PER IMPOUNDMENT								
Impoundment	**Chlorophyll-a percentile value (ppb)**						**n***	**Trend***
	P25	**P50**	**P75**	**P90**	**P95**	**P99**		
Umtata	1.0	1.0	1.3	3.0	4.2	22.3	36	Stable
Erfenis	1.0	2.0	4.0	9.0	15.5	44.8	232	Stable
Voelvlei	1.0	2.2	7.0	16.1	38.7	92.8	71	Increasing
Laing	1.0	2.7	3.2	5.2	6.0	8.1	40	ND
Vaal	2.0	3.0	6.0	11.2	21.1	73.1	216	Stable
Lindleyspoort	1.3	3.2	5.3	9.9	12.0	28.8	161	Stable
Bridledrift	2.0	4.0	18.0	36.0	72.8	133.3	126	ND
Witbank	2.0	4.0	7.0	13.4	24.6	50.0	265	Stable
Grootdraai	3.0	5.0	9.9	22.2	40.2	92.4	275	Stable
Misverstand	2.0	5.0	9.9	22.4	35.1	93.2	157	Stable
Kosterrivier	3.0	5.5	10.0	19.0	31.1	58.1	279	Stable
Welbedacht	1.3	6.6	10.8	24.4	34.7	67.3	39	ND
Klipfontein	2.0	7.0	25.0	74.4	91.0	181.7	61	ND
Roodekopjes	2.3	7.0	13.1	20.0	35.7	49.9	111	(increasing)
Barrage	3.0	7.1	12.5	27.8	42.4	57.3	60	Increasing
Kalkfontein	5.0	7.3	8.2	10.9	12.3	13.3	6	ND
Koppies	5.1	9.0	17.0	36.0	50.0	170.9	111	Stable
Modimola	4.9	10.3	20.8	28.9	31.0	56.8	68	Stable
Hartbeespoort	5.0	12.0	38.0	91.0	153.0	361.0	2110	(decreasing)
Spitskop	4.0	15.9	49.0	88.9	110.3	261.0	25	ND
Bloemhof	5.0	16.3	33.0	64.4	121.3	322.5	246	Stable
Roodeplaat	5.1	17.4	48.1	86.4	115.9	305.6	920	Stable
Rietvlei	8.8	24.3	68.2	130.2	191.8	527.8	225	(increasing)
Bronkhorstspruit	20.6	40.3	65.0	106.0	174.2	523.0	118	(increasing)
Klipvoor	25.0	62.4	137.3	345.6	516.8	861.5	160	Stable
Allemanskraal	ND							
Blyedrivierpoort	ND							
Bospoort	ND							
Bulshoek	ND							
Nahoon	ND							
n = number of data values in set; ND = No data or insufficient data; trends qualified by ( ) parentheses indicates very slight trend.								

Based on the 50th:90th percentile TP:Chlorophyll-a comparison, chlorophyll-a levels were found to be correlated with phosphorus by the relationship

Chlorophyll-a $(\mu g\ \ell^{-1}) = 0.496\ TP\ (\mu g\ \ell^{-1})\ (r^2 = 0.793)$

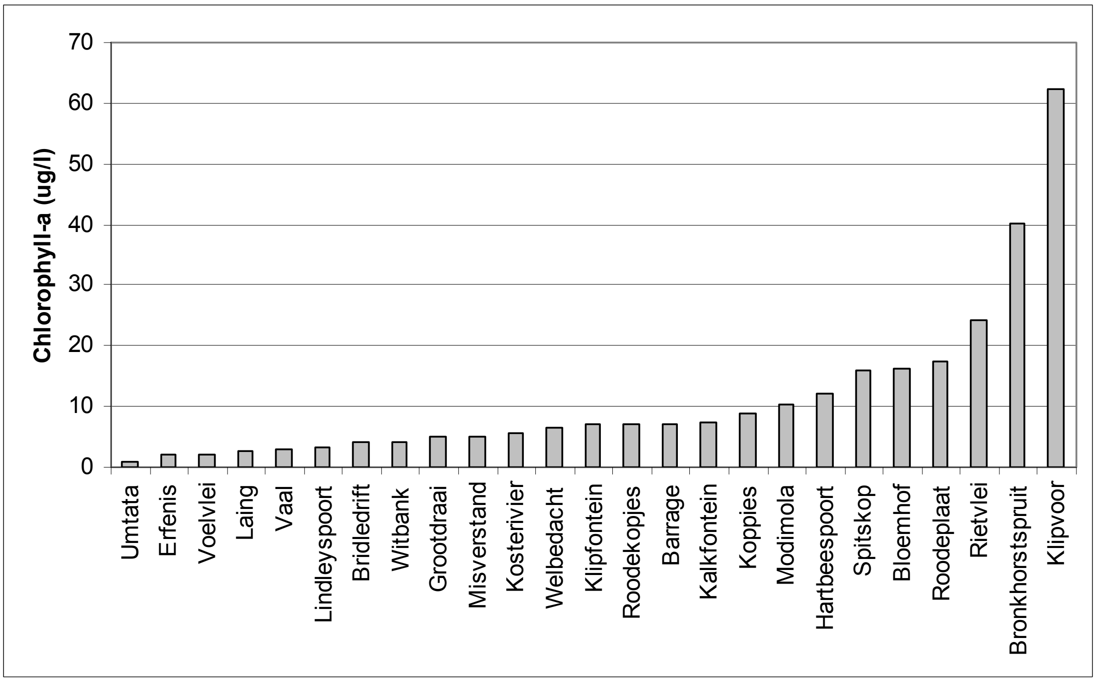

Figure 3: Ranking of impoundments based on median annual chlorophyll-a.

3.3 Trophic state comparisons

In the following table (**Table 9**), the Trophic State classifications are compared based on the 50%ile values for total phosphorus and chlorophyll-a. It is clear that the chlorophyll-a values result in a marked underestimation of the conditions.

TABLE 9: COMPARISON OF TROPHIC STATE CLASSIFICATIONS BASED ON 50th PERCENTILE VALUES FOR TOTAL PHOSPHORUS & CHLOROPHYLL-a
Bold text indicates matching Trophic State

Impoundment	50%ile TP (µg ℓ$^{-1}$)	50%ile Chlorophyll-a (µg ℓ$^{-1}$)	Total Phosphorus-based Trophic State	Chlorophyll-a – based Trophic State
Kalkfontein	0.045	7.3	Mesotrophic	Oligotrophic
Grootdraai	0.059	5.0	Eutrophic	Oligotrophic
Vaal	0.083	3.0	Eutrophic	Oligotrophic
Bronkhorstspruit	0.085	40.3	**Eutrophic**	**Hypertrophic**
Klipfontein	0.095	7.0	Eutrophic	Oligotrophic
Misverstand	0.097	5.0	Eutrophic	Oligotrophic
Welbedacht	0.099	6.6	Eutrophic	Oligotrophic
Koppies	0.102	9.0	Eutrophic	Oligotrophic
Hartbeespoort	0.104	12.0	Eutrophic	Mesotrophic
Laing	0.126	2.7	Eutrophic	Oligotrophic
Erfenis	0.166	2.0	Hypertrophic	Oligotrophic
Roodeplaat	0.207	17.4	Hypertrophic	Mesotrophic
Klipvoor	0.626	62.4	**Hypertrophic**	**Hypertrophic**

The values expressed in this Table should be read in conjunction with Table 4.

If the previous comparison is reworked based on the median TP value and the 90th percentile for chlorophyll-a then a close match in Trophic State classification is achieved (**Table 10**).

TABLE 10: COMPARISON OF TROPHIC STATE CLASSIFICATIONS BASED ON 50th PERCENTILE VALUES FOR TOTAL PHOSPHORUS & 90th PERCENTILE FOR CHLOROPHYLL-a **Bold text indicates matching Trophic State**				
Impoundment	**50%ile TP ($\mu g\ \ell^{-1}$)**	**90%ile Chlorophyll-a ($\mu g\ \ell^{-1}$)**	**Total Phosphorus-based Trophic State**	**Chlorophyll-a – based Trophic State**
Kalkfontein	0.045	11	**Mesotrophic**	**Mesotrophic**
Grootdraai	0.059	22	**Eutrophic**	**Eutrophic**
Vaal	0.083	11	**Eutrophic**	**Eutrophic**
Bronkhorstspruit	0.085	106	**Eutrophic**	**Hypertrophic**
Klipfontein	0.095	74	**Eutrophic**	**Hypertrophic**
Misverstand	0.097	22	**Eutrophic**	**Eutrophic**
Welbedacht	0.099	24	**Eutrophic**	**Eutrophic**
Koppies	0.102	36	**Eutrophic**	**Hypertrophic**
Hartbeespoort	0.104	91	**Eutrophic**	**Hypertrophic**
Laing	0.126	5	Eutrophic	Oligotrophic
Erfenis	0.166	9	Hypertrophic	Oligotrophic
Roodeplaat	0.207	86	**Hypertrophic**	**Hypertrophic**
Klipvoor	0.626	345	**Hypertrophic**	**Hypertrophic**
The values expressed in this Table should be read in conjunction with Table 4				

3.4 Catchment data

The landuse types were aggregated (see **Table 11**) to conform to the chosen set of export coefficients as described above (see 2.5 and **Table 5**).

TABLE 11: LANDUSE FOR ALL DAMS IN THE TEST SET, EXPRESSED IN NON-AGGREGATED AND COMBINED FORMATS		
NON-AGGREGATED LANDUSE TYPES	**Area (km^2)**	**%Total Area**
Forest and Woodland (Woodland & Wooded Grassland)	4343	2.1
Forest (indigenous)	164	0.1
Thicket; Bushland; Bush Clumps; High Fynbos	22194	10.7
Shrubland & Low Fynbos	3047	1.5
Unimproved Grassland	95134	45.8
Forest Plantations (exotic)	1411	0.7
Degraded Lands (Forest & Woodland)	899	0.4
Degraded Lands (Thicket; Bushland; Bush Clumps; High Fynbos)	1636	0.8
Degraded Lands (Unimproved Grassland)	1911	0.9
Cultivated Lands (permanent crops - commercial - irrigated)	523	0.3
Cultivated Lands (temporary crops - commercial - irrigated)	1924	0.9
Cultivated Lands (temporary crops - commercial - dryland)	59366	28.6
Urban / Built-up Land (residential)	3191	1.5
Urban / Built-up Land (residential - smallholdings - forest & woodland)	394	0.2
Urban / Built-up Land (residential - smallholdings - grassland)	1249	0.6
Urban / Built-up Land (commercial)	191	0.1
Urban / Built-up Land (industrial; transportation)	323	0.2
TOTAL CATCHMENT AREA (30 dams)	**197899**	
COMBINED LANDUSE TYPES	**Area (km^2)**	**%Total Area**
Forests (all)	6817	3.4
Natural shrublands	26877	13.6
Unimproved grasslands	97045	49.0
Agriculture dryland	59366	30.0
Agriculture irrigated	2447	1.2
Urban residential	3191	1.6
Urban rural	1643	0.8
Commercial and industrial	514	0.3
TOTAL CATCHMENT AREA (30 dams)	**197899**	

From **Table 11** it is apparent that 96% of the aggregate landcover for the 30 dams constituted dryland (non-irrigated) conditions. This substantiates the basis for reducing the natural and dryland-agriculture phosphorus export coefficients for lower rainfall conditions. Urban residential runoff was increased to reflect the high wastewater effluent content of South African rivers, and offset against the reduction in Commercial/industrial loads, i.e. the latter are included in the former.

3.5 Model fitting

All of the models were tested using a spreadsheet-based approach whereby each model relationship was used to predict the in-lake Total Phosphorus concentration using the hydro-morphological relationship constructed for each waterbody. The results were then compared with the observed in-lake values for each impoundment. Predicted values within 30% of the observed were accepted as being sufficiently accurate to indicate the applicability of a model.

Thirteen dams were excluded from the modelling analysis based on non-availability of water balance and/or in-lake water quality data:

- Barrage (Vaal)
- Blyderivierpoort
- Bospoort
- Bridledrift
- Bulshoek
- Kalkfontein
- Kosterrivier
- Modimola
- Nahoon
- Rietvlei
- Spitskop
- Umtata
- Voelvlei

Point source loads from wastewater treatment works were identified and included in the modelling for Hartbeespoort and Roodeplaat Dams. The loading for Roodeplaat was determined 12 years previously and may be an underestimate. The in-lake total P concentration for Allemanskraal was estimated based on data reported in the DWAF Trophic Status Assessment.

Use of the Reckhow oxic lakes model, for which a q_s >50 m y^{-1} is indicated, was excluded as no dams complied with this.

The modelling results for the remaining 18 dams are summarized in **Table 12**. All model outputs are reported irrespective of a complete hydro-morphological model fit having been obtained.

No model fits within the 30% variation limit were found for four dams, Bloemhof, Lindleyspoort, Roodekopjes and Witbank. The reasons for this were not immediately apparent from the available data. For the remaining 13 dams model fitting may be summarized as follows (**Table 13**):

TABLE 12: MODEL OUTPUT AND VARIATION BETWEEN PREDICTED vs OBSERVED MEDIAN ANNUAL IN-LAKE TOTAL PHOSPHORUS

Impoundment >>	Allemanskraal	Bloemhof	Bronkhorstspruit	Erfenis	Grootdraai	Hartbeespoort	Klipfontein	Klipvoor	Koppies	Laing	Lindleyspoort	Misverstand	Roodekopjes	Roodeplaat	Vaal	Welbedacht	Witbank
Observed In-Lake Total P (µg ℓ$^{-1}$) >>	**200**	**86**	**85**	**166**	**59**	**104**	**95**	**626**	**102**	**126**	**40**	**97**	**39**	**207**	**83**	**99**	**31**
Predicted in-lake Total Phosphorus (µg ℓ-1)																	
Walker Reservoir Model	136	185	114	156	65	109	66	246	64	101	130	77	82	175	61	139	65
Canfield-Bachmann Natural Lake Model	160	375	164	173	128	272	119	718	59	250	222	69	150	544	105	137	131
Canfield-Bachmann Artificial Lake Model	89	159	91	93	79	136	76	250	45	133	111	60	88	204	68	108	83
Reckhow Natural Lake Model	109	386	121	116	127	350	100	1092	14	338	223	73	124	1089	85	135	140
Reckhow Anoxic Lake Model	653	1443	581	762	293	647	230	2440	123	492	887	81	369	2059	241	163	250
Reckhow Oxic Lakes	168	624	183	184	156	413	136	1503	35	335	310	NV	177	1228	112	NV	162
Walker General Lake Model	523	997	421	630	203	469	165	1774	80	375	634	82	256	1445	166	163	182
Vollenweider Lake Model	126	451	140	134	149	413	118	1285	17	401	261	87	145	1284	100	161	166
Dillon-Rigler-Kirchner Lake Model	387	552	274	482	123	370	92	973	51	313	410	84	145	920	99	129	146
OECD Combined Model	222	401	190	255	110	224	94	668	49	190	267	57	132	555	94	101	101
Salas & Martino Equation 1	124	213	99	147	51	109	43	364	23	92	142	38	63	290	44	73	47
Salas & Martino Equation 2	323	593	252	389	121	287	100	1091	48	239	379	87	152	870	101	171	112
Percentage variation between predicted and observed in-lake Total Phosphorus value																	
Walker Reservoir Model	-32	115	34	-6	10	5	-30	-61	-37	-20	225	-20	111	-15	-27	40	109
Canfield-Bachmann Natural Lake Model	-20	336	93	4	117	161	25	15	-42	98	454	-28	283	163	27	38	324
Canfield-Bachmann Artificial Lake Model	-55	84	7	-44	34	30	-20	-60	-56	6	177	-38	125	-1	-18	9	167
Reckhow Natural Lake Model	-46	349	42	-30	115	237	5	74	-86	168	458	-25	218	426	2	36	352
Reckhow Anoxic Lake Model	226	1578	583	359	397	523	142	290	21	290	2117	-17	846	895	190	64	707
Reckhow Oxic Lakes	-16	626	115	11	165	297	44	140	-65	166	674		354	493	35		422
Walker General Lake Model	161	1060	395	280	245	351	74	183	-22	198	1485	-16	555	598	101	65	487
Vollenweider Lake Model	-37	425	65	-19	153	297	24	105	-84	218	551	-10	273	520	20	63	434
Dillon-Rigler-Kirchner Lake Model	93	542	222	190	108	256	-4	55	-50	149	926	-14	271	344	19	31	371
OECD Combined Model	11	366	124	54	86	115	-1	7	-52	51	568	-41	238	168	13	2	226
Salas & Martino Equation 1	-38	148	16	-11	-14	5	-55	-42	-77	-27	255	-61	62	40	-47	-26	52
Salas & Martino Equation 2	62	590	196	134	105	176	5	74	-53	90	848	-10	290	320	22	73	261

TABLE 13: NUMBER OF MODELS PER DAM WITH INDICATED ACCURACY OF PREDICTION			
Impoundment	Predicted vs Observed Variation, number of models		
	< 10%	11-20%	21-30%
Allemanskraal	0	2	1
Bronkhorstspruit	1	1	0
Erfenis	2	3	1
Grootdraai	0	2	0
Hartbeespoort	2	1	0
Klipfontein	4	1	3
Klipvoor	1	1	0
Koppies	0	0	2
Laing	1	1	1
Misverstand	0	6	2
Roodeplaat	1	1	0
Vaal	1	4	3
Welbedacht	2	0	1

Data for eighteen of the original thirty dams (60%) supported modelling. Of these results were obtained for thirteen (43%) (**Table 13**). Predicted *vs* observed matches at 10% or better were obtained for nine dams (30%); at 11-20% variation for eleven dams (37%) and for eight dams between 21 and 30% variation (27%).

Multiple model fits were found for several dams across all variation groupings (**Table 13**). No model proved to be consistently accurate at any level of predictive accuracy for all dams in the modelling set. However, the Walker Reservoir Model accurately described conditions for five out of the thirteen dams in the set and could be used as a substitute for the cumbersome Canfield-Bachmann relationship for a further two, raising the total to seven. Equally, no models were found to be associated with a particular range of volumes or water exchange rates. It is however deemed likely that, following an exhaustive process of data sourcing for point and diffuse sources, confirmation of the accuracy of the export coefficients and water balances, would identify a common relationship (see Conclusions). Conditions for nine of the thirteen dams were predicted at a variation of 10% or less compared with the observed.

3.6 TMAPL allocations

The central aim of this project was to allocate TMAPLs (Total, median annual phosphorus load limits) to each dam such that a desired Trophic State could be maintained or strived for. South African Dams have previously been shown to indicate a threshold level of 55 µg ℓ^{-1} TP, above which an increased incidence of problematical algal blooms may be experienced. In contemporary evaluations and especially for arid climate conditions, 55 µg ℓ^{-1} TP may be regarded as a very low level. However, it is an order of magnitude higher than levels used to set achievable TMDLs for some lakes in the USA (USEPA, 1999).

For the purposes of allocating TMAPLs to the dams in the modelling set, a comparison was made between the present in-lake TP and its associated P load per annum, and the desired values (**Table 14**).

TABLE 14: TMAPL ALLOCATIONS BASED ON COMPARISON OF PRESENT CONDITIONS VS DESIRED TROPHIC STATE

Impoundment >>	Allemanskraal	Bronkhorstspruit	Erfenis	Grootdraai	Hartbeespoort	Klipfontein	Klipvoor	Koppies	Laing	Misverstand	Roodeplaat	Vaal	Welbedacht
MODELLING OUTPUT													
Applicable model* (best fit)	OECD	CBALM	WRM	WRM	WRM	OECD	OECD	WGLM	CBALM	VLM	WRM	RNLM	OECD
Observed In-lake TP	200	85	166	59	109	95	626	102	126	97	207	83	99
Predicted In-lake TP	222	91	156	65	104	94	668	87	133	87	175	85	101
Accuracy of prediction (%)	20-30	< 10	< 10	10-20	10	< 10	< 10	20-30	< 10	10	10-20	< 10	< 10
Present Trophic State Class	HYP	EUTM	HYP	EUTL	EUTH	EUTM	HYP	EUTH	HYP	EUTM	HYP	EUTM	EUTH
Desired Target Trophic State Class	MESOTROPHIC												
TMAPL ALLOCATION													
Present External P loading, kgs P per annum	36200	13800	46800	90900	172000	5720	166000	2290	24900	46000	94200	445000	129000
% Reduction to Achieve Boundary Condition (55 ug/l P)	82	68	85	25	71	48	96	30	77	37	88	36	52
Target TMAPL, kg P per annum	6840	4490	7020	68300	49900	2980	6620	1600	5730	29000	11400	286000	62100
Boundary Condition Trophic State	EUTROPHIC (LOW)												
LANDUSE ANALYSIS													
Forests (all)	0.1	1.3	0.0	0.6	2.8	12.8	19.8	38.6	5.1	2.7	1.9	0.4	0.2
Natural shrublands	0.6	0.1	1.4	0.1	0.4	0.4	0.4	6.0	1.7	5.1	0.0	0.1	1.3
Unimproved grasslands	48.4	39.1	63.2	60.5	7.2	32.6	4.1	29.7	16.4	1.3	2.3	55.5	56.4
Agriculture dryland	40.2	46.2	28.3	24.3	3.7	8.3	3.1	25.2	0.1	43.1	0.5	27.9	20.7
Agriculture irrigated	0.1	0.5	0.1	0.1	0.6	0.0	1.1	0.0	0.2	22.1	0.2	0.1	0.2
Urban residential	4.9	8.6	7.0	12.8	78.6	39.1	67.3	0.5	75.3	25.3	91.6	14.1	20.6
Urban rural	0.0	1.8	0.0	0.0	3.6	0.0	1.9	0.0	0.0	0.0	0.9	0.0	0.0
Commercial and industrial	0.0	1.6	0.0	1.0	3.1	6.8	2.3	0.0	1.2	0.4	0.8	0.7	0.4

*** Model Codes**

CBALM Canfield-Bachman Artificial Lake Model
CBNLM Canfield-Bachmann Natural Lake Model
DKRLM Dillon-Kirchner-Rigler Lake Model
OECD OECD Combined Lakes Model
RALM Reckhow Anoxic Lake Model
RNLM Reckhow Natural Lake Model
ROLM Reckhow Oxic Lake Model
SMM1 Salas and Martino Lake Model 1
SMM2 Salas and Martino Lake Model 2
VLM Vollenweider Lake Model
WGLM Walker General Lake Model
WRM Walker Reservoir Model
HYP Hypertrophic
EUT Eutrophic (L,M,H = Low, Medium, High)
MESO Mesotrophic

All of the thirteen modelled dams were eutrophic to hypertrophic. For guideline purposes the target Trophic State was set to approximate the upper boundary of mesotrophic, i.e. the boundary condition of 55 µg ℓ^{-1} TP. Based on the analysis summarized in **Table 14** the following observations are made:

1. The load reductions required to achieve the target condition, i.e. the boundary between meso- and eutrophic, are substantial. These ranged from 25% to 96%, divided as follows (**Table 15**):

TABLE 15: GROUPING OF DAMS IN TERMS OF REQUIRED LOAD REDUCTION Reductions expressed as a percentage change from current loads.		
Required TP Load Reduction	**No of dams in group**	**Dams**
25-50%	5	Grootdraai, Klipfontein, Koppies, Misverstand, Vaal
51-75%	3	Bronkhorstspruit, Hartbeespoort, Welbedacht
> 75%	5	Allemanskraal, Erfenis, Klipvoor, Laing Roodeplaat

2. Based on landuse the dams can be grouped into two main categories (**Table 16**):

TABLE 16: GROUPING OF DAMS BY DOMINANT LANDUSE		
Dominant landuse	**No of dams in group**	**Dams**
> 60% urban/urban runoff	4	Hartbeespoort, Klipvoor, Laing, Roodeplaat
20-40% urban/urban runoff	2	Klipfontein, Misverstand
> 75% dryland activities	7	Allemanskraal, Bronkhorstspruit, Erfenis Grootdraai, Koppies, Vaal, Welbedacht

3.7 Implications for management

The allocation of a TMAPL has to be qualified in terms of the likelihood of being able to attain it in practice. This, in turn, is largely dependent on the origins of the nutrient enrichment and hence the landuses predominating in the catchment.

It was apparent from the phosphorus export coefficient analysis that the total landuse for all 30 dams used in this project was overwhelmingly dominated by dryland environments, either natural (undeveloped) or agricultural. Current understanding of nutrient attenuation Best Management Practices (BMPs) suggests that minimal reductions in loading are only achievable at high cost for dryland agriculture, if at all. The ability to make meaningful inroads into reducing nutrient loads is arguably easier with 'defined' sources or point sources – almost always related to the disposal of treated wastewater effluent into streams and rivers. The collection of such waste-streams forms a central part of water impoundment policies in South Africa (DWAF, 1991), notwithstanding the hugely detrimental impact these will have on the impoundment ecosystems and hence future re-use and recreational value of these waters. The fact that these sources are ‘defined’ renders them as primary foci of nutrient reduction programs.

Based on the foregoing argument, i.e. an assumption that, barring economic or other constraints, urban sources of nutrient enrichment lend themselves to options for rapid nutrient attenuation, the modeled dams in this project can be prioritized for management action as follows (**Table 17**):

TABLE 17: PRIORITIZATION OF MODELLED DAMS BASED ON DEEMED EASE (1 = easiest) OF IMPLEMENTING NUTRIENT ATTENUATION

Rank (1 = highest)	Dam	Required nutrient load reduction	Dominant landuse
1	Misverstand	Low	Medium urban
2	Klipfontein	Low	Medium urban
3	Hartbeespoort	Medium-high	High urban
4	Laing	High	High urban
5	Klipvoor*	High	High urban
6	Roodeplaat	High	High urban
7	Grootdraai	Low	High dryland
8	Koppies	Low	High dryland
9	Vaal	Low	High dryland
10	Welbedacht	Medium	High dryland
11	Bronkhorstspruit	Medium	High dryland
12	Erfenis	High	High dryland
13	Allemanskraal	High	High dryland

* water not used for domestic water supplies.

The analysis suggests that meaningful improvements in water quality, and/or offsetting of any further worsening in conditions, could be attained with relative ease at Misverstand and Klipfontein Dams. If one returns to the DWAF impoundment management priority list (Trophic Status Assessment) we find the following dams in the above modelling set listed: Klipvoor, Roodeplaat, Hartbeespoort and Erfenis. Following the above argument attention could be applied with meaningful gains at Hartbeespoort and Roodeplaat. With respect to Hartbeespoort this echoes and confirms the findings of the Hartbeespoort Dam Rehabilitation Study (DHEC, 2004). Success at Erfenis Dam is likely to be much more difficult to attain given that there is a large required load reduction and the catchment landuse is predominantly dryland.

Shallow dams, with large dryland catchment areas such as Erfenis and Allemanskraal, are likely to be especially prone to eutrophication. While ‘natural eutrophication’ is a rare phenomenon it is a factor to consider especially in cases where the geology of the drainage basin is sedimentary. Drainage basins that are flat, as well as those in low rainfall areas, exhibit low rates of leaching and are likely to export high relative concentrations of nutrients (e.g. D’Arcy and Carignan, 1997). In such cases, where the bulk of the nutrient load is derived from a catchment surface receiving only rainfall, there may be relatively little that can be achieved to improve (attenuate loading) conditions. Such dams are likely to remain in their present, stable eutrophic conditions unless actions are taken, where applicable, to maximize the benefits of in-lake Best Management Practices.

4. CONCLUSIONS

- Determination of the restoration potential for any eutrophic impoundment requires that the aggregate nutrient (as phosphorus) loading be quantified and apportioned to the prevailing catchment landuse. Thereafter, and based on a Best Management Practice cost-benefit analysis, efforts can be directed at those sources of nutrient loading most likely to yield the desired reduction.
- South African impoundments have a threshold of nutrient availability, as total in-lake phosphorus concentration, above which an increased frequency and duration of potentially-problematical algal growth may be experienced. This level has been equated, per the Nutrient Enrichment Assessment Protocol, as approximately 55 µg ℓ^{-1} P. For the purposes of this project this phosphorus concentration, which approximates the concentration below which a stable state of macrophyte-dominated, clear water conditions may be sustained, has been used as the guideline for setting the desired in-lake trophic state. The concentration approximates the boundary between meso- and eutrophic lake conditions as defined by contemporary guidelines.
- The use of simple modelling approaches, at screening level, have enormous value in focusing management needs and actions at a fundamental level – this as opposed to the extremely costly and time-consuming expedient of more sophisticated models having intensive data requirements. The approach described here allows for relatively rapid ranking and prioritization of needs and actions based on limited and generally-available data.
- This project has used the simple expedient of using flushing-corrected, annual time-step phosphorus models to analyze the conditions in a set of South African dams. Nutrient loadings to each dam were determined using a trial set of phosphorus export coefficients allocated to landuse practices. Model relevance (accuracy) was determined by comparison of predicted vs observed in-lake phosphorus concentrations.
- Models calibrated in this fashion allow for a desired total phosphorus load to be determined by reducing the loading to the point where the model output approximates the above-mentioned phosphorus boundary concentration.
- This approach has proved to be workable but remains subject to data constraints and verification of the relevance of the export coefficients used. Notwithstanding this, the approach was used to determine Target Median Annual Phosphorus Loads (TMAPLs) for 43% of the dams in the test set (13/30).
- Data constraints encompassed missing data, irreconcilable water balance data, wastewater treatment data on a works by works basis and an insufficient chronological matching of discharge and nutrient concentration for

rivers influent to the dams. Although not within the scope of this pilot project, all of these limitations could be accommodated within a more comprehensive analysis.

- No one model was found to apply to all of the dams that could be modeled. However, the Walker Reservoir Model, previously used for the Nutrient Enrichment Assessment Protocol (NEAP), again appeared to have strong relevance for South African conditions, i.e. for impoundments with relatively short (< 2-3 years) water retention times. As with the findings of previous studies the Combined OECD model was found to be generally applicable. The data constraints experience in this project preclude reaching a definitive conclusion on model relevance and the re-calibration of any particular relationship for South African use.
- All of the dams in the test set were in the eutrophic to hypertrophic range, with median annual in-lake phosphorus concentrations ranging from 31 to 626 µg TP ℓ^{-1}. For the dams that could ultimately be modeled this range extended from 59 to 626 µg TP ℓ^{-1}. The test set included several dams on the high priority management list determined by the DWAF Trophic State Assessment Program.
- Targeted (required) load reductions were found to be high, ranging from 25 to 96% of current loadings. Eight of the thirteen dams evidenced load reduction requirements in excess of 50%, and five of these greater than 75%. These data indicate the severity of the eutrophication problems being experienced by these waters.
- The dams in the test set could be divided into three types, those dominated by urban sources of nutrient loading, those dominated by dryland and/or undeveloped landuse, and a mix of the two. In the cases of urban landuse dominance the primary source of nutrient enrichment is assumed to be treated wastewater effluents high in phosphorus content. Such sources are further deemed to be more suited to rapid nutrient attenuation (process upgrades), although not without significant cost implications, than are the more diffuse sources associated with dryland and non-irrigated agricultural practices within the catchment.
- Certain impoundments, mainly those dominated by dryland activities, may have almost nil cost-effective options for the mitigation of eutrophication other than in-lake practices. The very nature (hydro-morphological) of these dams renders them prone to sustained eutrophication that is not manageable at the catchment level. Such dams are likely to be eutrophic in the absence of any development of any kind in their catchments (‘background’ or geochemical eutrophication).
- Based on the assumption that urban activities resulting in the pollution of impoundments are more readily managed, the modeled dams could be ranked based on landuse and target load (TMAPL) reductions.

5. RECOMMENDATIONS

Based on the foregoing it is recommended that:

- The relevance of phosphorus export coefficients be verified for South African landuse types. This may be achieved using a pre-selected set of dams, landuse coverages and quantified nutrient loading data, as well as for selected river monitoring points monitored on an event-driven basis.
- Nutrient loading to an impoundment be quantified on the basis of flow-quality matching using software such as Flux. This is an essential component of the model verification process that has thus far only been completed for Hartbeespoort Dam.
- Nutrient loads from bulk point sources such as wastewater treatment works need to be quantified on a works by works basis. Data pertaining to such plants is currently not readily available but, in cases such as Hartbeespoort, Roodeplaat and Klipvoor Dams, constitutes a major component of the phosphorus nutrient loading profile.
- Water balances for complex hydrological environments such as the Vaal and Bloemhof Dams, need to be accurately quantified prior to use in modelling as these can significantly confound any calculations based only on catchment landuse. Simple models such as those used in this project may have limited relevance for such dams.
- Given the value of this approach for management prioritization, it should be extended to a wider set of impoundments and impoundment-types (both hydro-morphological and provincial). Given the identified need for comprehensive data preparation the activities could be divided within or between projects, i.e. a group screening and verifying the raw data, a group undertaking the flow-concentration modelling, and a third team using the output from the first two to test with the various models.

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APPENDIX A

WATER BALANCE RAW DATA SETS

DAM 1: C4R001 Allemanskraal Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1959-01-31	1368.740/12.800	1355.940/ 0.000	1355.940/ 0.000	2673.80	189.19	219.57	Original
1976-10-01	1368.740/12.800	1355.940/ 0.000	1355.940/ 0.000	2741.00	178.66	186.45	Basin survey
1981-10-01	1368.740/12.800	1355.940/ 0.000	1355.940/ 0.000	2643.30	176.26	182.74	Basin survey
1988-04-01	1368.740/12.800	1355.940/ 0.000	1355.940/ 0.000	2648.10	174.20	179.31	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	11.539	142824	279	39526	36146 E	11518	28545 E
1991-01-01	9.869	106935	28131	30659	35104 E	15049 &	106776 E
1992-01-01	11.193	134866	313	52017	32728 E	6644 &	38342 E
1993-01-01	9.232	94795	677	48398	26176 E	11404 &	30896 E
1994-01-01	7.256	61844	690	55869	20443 E	6135 &	31565 E
1995-01-01	3.802	22542	387	15951	12189	4963 &	64449 &
1996-01-01	7.363	63427	971	27959	26317 E	14311 &	90528 E
1997-01-01	10.173	113020	0 M	39541	38493 E	18898	0 M
1998-01-01	11.723	147166	40428	45628	40455 E	19280 &	125180 E
1999-01-01	12.450	165115	0 M	57919	38009 E	13434 &	0 M
2000-01-01	10.467	119102	871	48091	35531 E	16104 &	72165 E
2001-01-01	10.646	122878	766	55500	30751 E	14881	104123 E
2002-01-01	12.043	154865	748	55639	34909 E	11500 &	17184 E
2003-01-01	9.094	92253	652	55935	24425 E	6658	13398 E
2004-01-01	4.753	31296	0 M	17013 Q	14838	3130	0 M
2005-01-01	3.096	16827	0 M	0 M	0 M	0 M	0 M
2006-01-01	0 M	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
E - Estimate
M - Data Missing, Data Missing
Q - Good edited unaudited

DAM 3: C9R002 Bloemhof Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1968-10-01	1228.496/17.986	1210.820/ 0.310	1210.510/ 0.000	23360.31	1284.57	1284.82	Original
1980-10-01	1228.496/17.986	1210.820/ 0.310	1210.510/ 0.000	23344.34	1263.26	1263.48	Basin survey
1997-10-01	1228.496/17.986	1210.820/ 0.310	1210.510/ 0.000	23328.94	1240.24	1240.24	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	16.333	912420	685671	319897 E	56394 &	506819 E
1991-01-01	13.534	470065	570963	287140 E	108330 &	982072 E
1992-01-01	15.148	702364	818922	217175 E	21003 &	665861 E
1993-01-01	12.506	353132	752579	129071 E	35813 &	655428 E
1994-01-01	10.226	162723	787996	153393 E	19609 &	859119 E
1995-01-01	9.058	100061	647246	94604 E	29363 &	1583324 E
1996-01-01	16.633	970899	8828661	354184 E	151835 &	9351668 E
1997-01-01	18.107	1291557	4876557	321787 E	133808	5018221 E
1998-01-01	18.007	1245243	0 M	330673 E	156252 &	0 M
1999-01-01	17.739	1183377	1103215	322622 *	63331 &	966551 *
2000-01-01	15.618	787421	6864786	339355 *	88170	7548009 *
2001-01-01	17.896	1219458	0 M	343829 *	110456	0 M
2002-01-01	18.294	1313258	1525171	346273 E	99478	1496853 E
2003-01-01	17.075	1038146	863885	256355 E	55925	342746 E
2004-01-01	12.342	316577	773560	138930 E	48699	714562 E
2005-01-01	10.576	167349	738837	122627 *	0 M	0 M
2006-01-01	9.696	112591	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Permanent Gap, Data Missing

DAM 4: B6R003 Blyderivierpoort Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1975-01-27	664.560/44.830	619.730/ 0.000	619.730/ 0.000	248.70	55.09	55.97	Basin survey
1979-10-01	664.560/44.830	619.730/ 0.000	619.730/ 0.000	247.41	55.17	56.06	Basin survey
1998-10-01	664.560/44.830	619.730/ 0.000	619.730/ 0.000	249.40	54.37	55.09	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	45.152	56371	216981	3302 E	1064 &	217566 E
1991-01-01	44.707	54717	266939	3453 E	986 &	269581 E
1992-01-01	44.755	54892	116157	3033 E	836 &	96753 E
1993-01-01	35.240	33290	223909	3475 E	1143 &	248965 E
1994-01-01	45.057	56015	146060	3416 E	817 &	131134 E
1995-01-01	37.827	38490	140713	3223 E	1311 &	159996 E
1996-01-01	45.016	55861	637224	3167 E	2634	637572 E
1997-01-01	44.966	55676	406712	3277 E	1297 &	408729 E
1998-01-01	44.976	55714	265702	3365 E	1306 &	267710 E
1999-01-01	45.329	55663	0 M	3243 E	1640 &	0 M
2000-01-01	45.010	54834	1177707	3035 *	2222 &	1178743 *
2001-01-01	45.095	55057	444010	3243 E	1820 &	445293 E
2002-01-01	45.041	54916	506259	3489 E	1059	505731 E
2003-01-01	43.860	51957	0 M	3324 E	742	0 M
2004-01-01	30.430	24654	0 M	3206 E	1563 Q	0 M
2005-01-01	43.770	51739	0 M	0 M	0 M	0 M
2006-01-01	37.059 Q	36866 Q	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 5: A2R006 Bospoort Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1936-10-01	1068.740/ 8.230	1060.510/ 0.000	1060.510/ 0.000	99.48	3.56	3.80	Original
1952-10-01	1068.740/ 8.230	1060.510/ 0.000	1060.510/ 0.000	96.45	2.58	2.58	Basin survey
1952-12-01	1068.740/ 6.710	1062.030/ 0.000	1062.030/ 0.000	96.45	2.58	2.58	Adjusted
1955-01-01	1073.310/11.280	1062.030/ 0.000	1062.030/ 0.000	234.17	9.91	9.91	Raised
1971-12-01	1076.380/14.350	1062.030/ 0.000	1062.030/ 0.000	378.90	19.16	19.16	Raised
1973-10-01	1076.380/14.350	1062.030/ 0.000	1062.030/ 0.000	374.80	18.91	18.91	Basin survey
1988-10-01	1076.380/14.350	1062.030/ 0.000	1062.030/ 0.000	378.80	18.21	18.21	Basin survey
2004-10-01	1076.380/14.350	1062.030/ 0.000	1062.030/ 0.000	373.40	15.80	15.80	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	9.223	4971	3221	143	3078	3027 *	1442 &	6834 *
1991-01-01	10.354	6999	3353	884	2469	3541 E	968 &	12961 E
1992-01-01	13.140	14035	3079	73	3006	2308 *	704 &	-905 *
1993-01-01	11.047	8446	0 M	0 M	2550	2921 E	1086 &	0 M
1994-01-01	10.710	7722	0 M	0 M	3377	3407 E	895 &	0 M
1995-01-01	10.574	7440	0 M	0 M	3059	3956 E	2586 &	0 M
1996-01-01	14.394	18383	0 M	0 M	0 M	4781 E	2527 &	0 M
1997-01-01	14.362	18259	0 M	0 M	3351	4854 E	3939 &	0 M
1998-01-01	14.498	18781	0 M	0 M	1727	4463 E	3406 &	0 M
1999-01-01	14.266	17900	0 M	0 M	0 M	4537	2004	0 M
2000-01-01	14.298	18018	0 M	0 M	0 M	4302 E	0 ?	0 M
2001-01-01	14.434	18534	0 M	0 M	529	4603	2222 &	0 M
2002-01-01	14.523	18876	10751	10751	0	5286	1637 &	12081 &
2003-01-01	13.897	16556	24766	24766	0	3952 *	1122	18757 *
2004-01-01	10.708	7717	20143 Q	20143 Q	0	4671 *	2430	30220 *
2005-01-01	14.285	15552	0 M	13819 Q	0 M	4913 E	1963 E	0 M
2006-01-01	14.147	15041	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:
& - Good monthly reading
* - Program Estimate
? - Data Unreliable
E - Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Good edited unaudited

DAM 6: R2R003 Bridle Drift Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1968-09-01	146.960/46.990	109.150/ 9.180	99.970/ 0.000	627.80	78.60	78.65	Original
1981-10-01	146.960/46.990	109.150/ 9.180	99.970/ 0.000	621.20	73.51	73.51	Basin survey
1984-10-01	151.050/51.080	109.150/ 9.180	99.970/ 0.000	746.22	101.49	101.49	Raised

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	51.330	103363	0 M	0	23146 Q	7445 E	4053 &	25789 E
1991-01-01	48.980	86478	0 M	5207	23227 Q	7023 E	3563	29743 E
1992-01-01	48.663	84327	0 M	15040	12910 Q	6651 E	3406 &	1223 E
1993-01-01	43.630	54355	0 M	24974	0 Q	5382 E	3681	53146 E
1994-01-01	48.136	80826	0 M	21580	2561 Q	7524 E	0 M	0 M
1995-01-01	50.415	96595	0 M	17909	5512 Q	8698 E	6897	60041 E
1996-01-01	51.530	104875	0 M	34825	0 Q	0 M	0 M	0 M
1997-01-01	51.230	102612	0 M	20356	0 Q	8405 E	6817	139273 E
1998-01-01	50.980	100749	0 M	23167	0 Q	8835 E	6594 &	95521 E
1999-01-01	51.568	105161	0 M	26292	0 Q	8690 E	5066	45147 E
2000-01-01	50.017	93734	0 M	19728	0 Q	7859 E	7140	167819 E
2001-01-01	50.991	100829	0 M	0 M	0 M	7989 E	7447	74336 E
2002-01-01	51.550	105028	0 M	0 M	0 M	8142 E	7265	0 M
2003-01-01	49.693	91426	58029 E	0 M	0 M	7517 E	3741 $	30460 E
2004-01-01	44.700 $	60081 $	46644	0 M	0 M	6501 E	4580 $	61661 E
2005-01-01	46.937 $	73176 $	59802 Q	0 M	0 M	8301 E	6412 $	89183 E
2006-01-01	50.969 Q	100668 Q	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

$ - Gauge Plate Readings
& - Good monthly reading
E - Used previous week's level as an estimate for this week, Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 7: B2R001 Bronkhorstspruit Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1949-11-26	1429.420/14.320	1415.100/ 0.000	1415.100/ 0.000	860.90	59.58	60.86	Basin survey
1976-10-01	1429.420/14.320	1415.100/ 0.000	1415.100/ 0.000	848.30	57.61	58.58	Basin survey
1983-10-01	1429.420/14.320	1415.100/ 0.000	1415.100/ 0.000	860.50	58.03	58.90	Basin survey
1996-10-01	1429.410/14.320	1415.090/ 0.000	1415.090/ 0.000	860.90	57.40	57.91	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Industry and Town (Ml)	River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	13.948	54888	34894	304	930	10609 E	5806 &	40271 E
1991-01-01	14.017	55462	29411	332	801	10133 E	6465 &	36187 E
1992-01-01	14.383	58571	14948	318	11337	10579 E	3567 &	2427 E
1993-01-01	11.842	39039	12067	313	10720	7996 E	4329 &	10720 E
1994-01-01	11.072	34024	10165	211	8788	8213 E	3642 &	8946 E
1995-01-01	10.099	28235	15073	175	8495	7043 E	4941 &	47849 E
1996-01-01	14.422	58910	246386	50	2276	10374 E	8574	246555 E
1997-01-01	14.306	57279	144487	45	2984	10354 E	7323 &	148221 E
1998-01-01	14.388	57982	0 M	66	12248	10719 E	5384 &	0 M
1999-01-01	14.387	57970	29136	91	19521	10375	5025 &	16204 &
2000-01-01	12.033	39687	223436	14	5507	9662 E	9813 &	241116 E
2001-01-01	14.334	57518	19864	13	19835	9582 E	4623 &	13516 E
2002-01-01	12.940	46211	20982	19	20963	8870 E	3255	4304 E
2003-01-01	9.419	23918	18555	29	18526	5961 E	2370	4081 E
2004-01-01	4.637	5853	9258 Q	247	9011	5668 Q	3242 Q	26314 Q
2005-01-01	8.735 Q	20482 Q	0 M	0 M	0 M	0 M	0 M	0 M
2006-01-01	0 M	0 M	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
E - Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Unaudited

DAM 8: E1R001 Bulshoek Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1921-01-01	64.060/ 5.510	58.410/-0.140	58.550/ 0.000	0.00	0.00	0.00	Original
1922-03-01	64.060/ 5.510	58.410/-0.140	58.550/ 0.000	177.44	6.55	6.55	Basin survey
1949-10-01	64.060/ 5.510	58.410/-0.140	58.550/ 0.000	180.20	6.06	6.78	Basin survey
1968-10-01	64.060/ 5.500	58.410/-0.150	58.560/ 0.000	180.20	6.06	6.78	A01 - Basin survey
1981-11-18	64.060/ 5.551	58.410/-0.099	58.509/ 0.000	180.20	6.06	6.78	A01 - Adjusted
1983-10-01	64.060/ 5.551	58.410/-0.099	58.509/ 0.000	180.20	5.66	6.30	Basin survey
1993-10-01	64.060/ 5.551	58.410/-0.099	58.509/ 0.000	177.30	4.97	5.58	Basin survey
2004-10-01	64.060/ 5.551	58.410/-0.099	58.509/ 0.000	176.42	4.81	5.39	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	4.633	4068	0 M	147651	0 M	0 M	0 M
1991-01-01	4.992	4653	406812	129065	2919 E	447	538119 E
1992-01-01	4.854	4423	184635	151152	2993 E	331	338982 E
1993-01-01	5.166	4956	379221	149143	3020 E	468	530453 E
1994-01-01	5.287	4494	0 M	0 M	0 M	0 M	0 M
1995-01-01	5.259	4443	0 M	0 M	0 M	0 M	0 M
1996-01-01	5.145	4246	0 M	0 M	0 M	0 M	0 M
1997-01-01	5.414	4722	0 M	0 M	0 M	0 M	0 M
1998-01-01	5.016	4030	0 M	0 M	0 M	0 M	0 M
1999-01-01	5.228	4389	0 M	0 M	0 M	0 M	0 M
2000-01-01	5.517	4908	0 M	0 M	0 M	0 M	0 M
2001-01-01	5.251	4429	0 M	0 M	0 M	0 M	0 M
2002-01-01	5.142	4241	0 M	0 M	0 M	0 M	0 M
2003-01-01	5.257	4440	0 M	0 M	0 M	0 M	0 M
2004-01-01	5.113	4192	0 M	0 M	0 M	0 M	0 M
2005-01-01	5.069	3980	0 M	0 M	0 M	0 M	0 M
2006-01-01	5.280	4332	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

E - Estimate
M - Data Missing, Temporary Gap, Data Missing

DAM 9: C4R002 Erfenis Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1959-04-01	1331.940/30.490	1318.220/16.770	1301.450/ 0.000	3304.50	222.20	235.20	Original
1986-10-01	1331.940/30.490	1318.220/16.770	1301.450/ 0.000	3298.00	210.20	215.13	Basin survey
1988-04-01	1331.940/30.490	1318.220/16.770	1301.450/ 0.000	3292.10	207.49	212.20	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	29.238	168402	0 M	48028	51871 E	13653	0 M
1991-01-01	28.720	153548	0 M	37536	48183 E	22328 &	0 M
1992-01-01	29.903	188600	521	59800	50963 E	10645 &	16348 E
1993-01-01	26.738	104310	380	52249	32755 E	11327 &	36148 E
1994-01-01	24.744	66401	375	52966	27150 E	5782 &	38190 E
1995-01-01	21.993	29883	234	19359	13473 E	4363 &	38244 E
1996-01-01	22.845	39424	8457	26055	41341 E	17652 &	224514 E
1997-01-01	30.437	205737	40082	43165	53546 E	21249	79566 E
1998-01-01	29.284	169757	73175	48236	52893 E	21788 &	147507 E
1999-01-01	29.114	164749	0 M	64782	44261 E	12090 &	0 M
2000-01-01	26.800	105663	78	53145	32525 E	13336 &	49233 E
2001-01-01	25.660	82484	70482	41670	29943 E	14789	254576 E
2002-01-01	30.559	209755	2561	51344	51077 E	13547	31371 E
2003-01-01	28.580	149690	362	68856	41341 E	7986 &	22257 E
2004-01-01	24.923	69373	220	50183	24953 E	6651	30038 E
2005-01-01	22.072	30706	212 Q	0 M	16513 *	0 M	0 M
2006-01-01	20.600	17252	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Temporary Gap, Data Missing
Q - Good edited unaudited

DAM 10: C1R002 Grootdraai Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1978-12-22	1540.950/19.000	1521.800/-0.150	1521.950/ 0.000	1892.49	137.53	139.25	Original
1980-10-01	1548.960/27.010	1521.800/-0.150	1521.950/ 0.000	3899.00	362.98	364.70	Gates installed
1991-10-01	1548.960/27.010	1521.800/-0.150	1521.950/ 0.000	3882.30	354.71	356.02	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	26.946	360495	69242	0 M	59049 *	24922 &	0 M
1991-01-01	24.665	279873	184117	0 M	54075 E	20232 &	0 M
1992-01-01	23.749	244042	16181	127691	45238 *	15910 &	138736 *
1993-01-01	21.202	177278	9980	133879	40778 E	20715 &	320693 E
1994-01-01	25.421	297070	85800	133985	58499 *	22531 &	340230 *
1995-01-01	26.782	345983	812221	152233	62934 *	40924 &	1032179 *
1996-01-01	27.050	357488	0 M	0 M	60028 *	0 ?	0 M
1997-01-01	27.254	365549	0 M	119006	56152 *	0 ?	0 M
1998-01-01	27.119	360204	299857	0 M	60675 *	30433 &	0 M
1999-01-01	27.372	370254	0 M	144452	61036 E	27933 &	0 M
2000-01-01	27.309	367733	1553280	121380	55511 *	35576 &	1701310 *
2001-01-01	27.019	355300	37411	140338	56521 *	26253 &	206340 *
2002-01-01	26.534	336647	46203	0 M	58574	21922 &	0 M
2003-01-01	24.742	274655	0 M	154293	61097 *	20167	0 M
2004-01-01	25.256	291500	149418	190223	58234 *	28245	436429 *
2005-01-01	26.240	325841	172055 Q	171996 Q	62695 *	29169 Q	392324 *
2006-01-01	25.752 Q	308445 Q	0	0	0	0	0

Explanation of codes:

& - Good monthly reading
* - Program Estimate
? - Data Unreliable
E - Estimate
M - Permanent Gap, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 11: A2R001 Hartbeespoort Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1922-10-01	1159.880/17.680	1142.200/ 0.000	1142.200/ 0.000	1743.87	165.85	184.99	Original
1960-10-01	1159.880/17.680	1142.200/ 0.000	1142.200/ 0.000	1681.18	143.33	153.49	Basin survey
1970-10-01	1162.340/20.120	1142.220/ 0.000	1142.220/ 0.000	2067.75	189.54	199.74	Gates installed
1979-10-01	1162.340/20.120	1142.220/ 0.000	1142.220/ 0.000	2065.60	189.46	198.67	Basin survey
1990-10-01	1162.340/20.120	1142.220/ 0.000	1142.220/ 0.000	2065.20	186.44	195.05	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	19.545	177840	166071	49820	116251	30866 E	10024 &	149182 E
1991-01-01	17.640	140109	188087	66725	121362	27512 E	10932 &	186530 E
1992-01-01	16.498	121972	160559	40989	119570	20625	4973 &	116237 &
1993-01-01	11.565	61998	148565	49413	99152	15348 E	4999 &	174176 E
1994-01-01	13.062	77260	182861	57566	125295	23581 E	9365 &	222770 E
1995-01-01	15.171	102953	172257	59810	112447	24697 E	11530 &	270056 E
1996-01-01	20.176	187587	539746	423915	115831	30172 E	14619 &	553921 E
1997-01-01	20.109	186209	620495	499619	120876	29180 *	23177 &	626543 *
1998-01-01	20.111	186254	320695	176308	144388	27664 *	10736 &	336002 *
1999-01-01	20.032	184633	261758	92136	169623	30903 E	7497 &	274510 E
2000-01-01	19.503	173979	743067	632481	110586	32741 *	22332 &	763788 *
2001-01-01	20.016	184291	374526	226634	147892	32860 *	14199 &	393103 *
2002-01-01	20.011	184206	274191	93907	180284	30086 *	6897 E	280797 *
2003-01-01	19.177	167624	213938	57532	156407	31097 *	3177	229053 *
2004-01-01	18.489	154820	292021	153849	138172	26340 E	15611	317999 E
2005-01-01	19.303	170069	0 M	132193	0 M	29657 *	11126 Q	0 M
2006-01-01	19.264	169303	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Data Missing
Q - Unaudited

DAM 12: C5R002 Kalkfontein Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1938-01-01	1229.020/18.960	1210.060/ 0.000	1210.060/ 0.000	4534.10	348.58	355.52	Original
1979-10-01	1229.020/18.960	1210.060/ 0.000	1210.060/ 0.000	4533.30	320.15	320.22	Basin survey
1988-10-01	1229.020/18.960	1210.060/ 0.000	1210.060/ 0.000	4532.30	318.91	318.94	Basin survey
2000-10-01	1229.020/18.960	1210.060/ 0.000	1210.060/ 0.000	4219.21	304.05	304.05	Basin survey
2000-11-01	1227.870/17.810	1210.060/ 0.000	1210.060/ 0.000	3769.68	258.27	258.27	New FSL 1227.87 from 1 Nov 2000

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	17.858	271823	134	51155	69687 E	13824 &	14706 E
1991-01-01	15.293	179378	136998	41211	70577	26852 &	345616 &
1992-01-01	18.601	303060	255	56741	79631 E	8954 &	7092 E
1993-01-01	15.392	182480	192	50329	48519	10104 &	7422 &
1994-01-01	12.072	100966	280	44196	66853 E	10634 &	189962 E
1995-01-01	15.635	190233	175	44218	52156 E	9986 &	9877 E
1996-01-01	12.688	113546	183	41814	31339 E	7422 &	4940 E
1997-01-01	9.130	52573	275	34496	22126 *	4097 &	24479 *
1998-01-01	6.603	24251	0 M	0 M	11074 E	2606 &	0 M
1999-01-01	3.610	5556	108	1647	4256 E	550 &	323 E
2000-01-01	1.045	418	372	12307	14006 E	4471 &	51831 E
2001-01-01	7.209	30378	508	21402	21619 E	11993 &	172515 E
2002-01-01	15.020	165606	0 M	36373	46640 E	13103 &	0 M
2003-01-01	14.002	139323	226	44623	40245 E	8646	25008 E
2004-01-01	11.615	90934	210	39522	29781	7553	23226
2005-01-01	9.192	53425	0 M	0 M	17210 *	0 M	0 M
2006-01-01	4.785 Q	11243 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Data Missing
Q - Good edited unaudited

DAM 13: W2R001 Klipfontein Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1983-02-16	1090.000/17.850	1072.150/ 0.000	1072.150/ 0.000	298.90	18.91	18.99	Basin survey
1984-02-01	1090.000/17.820	1072.150/-0.030	1072.180/ 0.000	298.80	18.91	18.97	Basin survey
1999-10-01	1090.000/17.820	1072.150/-0.030	1072.180/ 0.000	295.90	18.09	18.09	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	17.997	19439	0 M	0 M	3735 E	1929 &	0 M
1991-01-01	15.152	11981	0 M	0 M	0 M	0 M	0 M
1992-01-01	17.646	18390	21466	0 M	0 M	0 M	0 M
1993-01-01	13.368	8439	7437	0 M	2253 E	1197 &	11154 E
1994-01-01	14.745	11099	16115	0 M	3961 E	1758 &	20556 E
1995-01-01	15.722	13287	8808	0 M	2540 *	1228 &	0 M
1996-01-01	15.941	13814	75959 >	1862	4003 *	2982 &	83986 >
1997-01-01	17.838	18958	40714	931	3846 *	2885	42702 *
1998-01-01	17.870	19054	39014	1614	4336 *	2655 &	42327 *
1999-01-01	17.876	19073	0 M	1734	4050 E	1959	0 M
2000-01-01	17.530	17238	73170 >	1559	3255 *	2924 &	76064 >
2001-01-01	17.873	18243	43242	1752	3679 *	2449 &	46128 *
2002-01-01	17.840	18147	17091	1626	3765 E	1956	17114 E
2003-01-01	16.617	14735	11286	2843	3400 E	984	10005 E
2004-01-01	13.615	8194	6327	1545	3049 E	2090	15173 E
2005-01-01	16.541	14536	16825	6490 Q	3855 E	1938 Q	27074 E
2006-01-01	17.226 Q	16378 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
> - Minimum Value
E - Estimate
M - Data Missing, Permanent Gap, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 14: A2R012 Klipvoor Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1970-03-24	989.070/16.160	972.910/ 0.000	972.910/ 0.000	753.40	43.24	43.87	Original
1986-10-01	989.070/16.160	972.910/ 0.000	972.910/ 0.000	753.20	42.08	42.43	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	16.218	42521	63086	63086	13074 E	3017 &	53981 E
1991-01-01	13.086	23360	82788	82788	11783 E	3799 &	97158 E
1992-01-01	14.297	29746	31004	31004	7471 E	1442 &	22222 E
1993-01-01	10.991	14935	46553	46553	6103 E	1413 &	50489 E
1994-01-01	10.763	14181	55934	55934	9559 E	1679 &	62567 E
1995-01-01	10.365	12933	51561	51561	7108 E	1817 &	84113 E
1996-01-01	15.904	40194	364864 A	364864 A	12610 E	5306 &	374165 E
1997-01-01	16.174	42193	176687	176687	12661 E	5059 &	183241 E
1998-01-01	16.034	41145	86082	86082	12839 E	4437 &	96571 E
1999-01-01	16.311	43232	69513	69513	12898 E	3025 &	72483 E
2000-01-01	15.351	36329	0 M	0 M	12729 *	6190 &	0 M
2001-01-01	16.195	42349	0 M	0 M	12413 *	4749 &	0 M
2002-01-01	16.213	42486	0 M	0 M	13095 E	2504 &	0 M
2003-01-01	14.175	29046	63310	63310	9596 E	1179	52678 E
2004-01-01	9.309	9998	0 M	0 M	10172 E	3086 Q	0 M
2005-01-01	14.126	28768	0 M	0 M	10681 *	2186 Q	0 M
2006-01-01	10.757	14161	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
A - Above Rating
E - Estimate
M - Data Missing, Permanent Gap, Data Exists but Unreliable, Data Missing
Q - Unaudited

Dam 15: C7R001 Koppies Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1918-03-01	1406.860/ 4.880	1401.980/ 0.000	1401.980/ 0.000	480.80	8.23	8.91	Original
1926-01-01	1408.080/ 6.100	1401.980/ 0.000	1401.980/ 0.000	661.92	15.95	16.63	Raised
1932-10-01	1408.080/ 6.100	1401.980/ 0.000	1401.980/ 0.000	645.50	11.79	11.79	Basin survey
1948-01-01	1408.350/ 6.370	1401.980/ 0.000	1401.980/ 0.000	681.60	13.50	13.50	Raised
1955-10-01	1408.690/ 6.710	1401.980/ 0.000	1401.980/ 0.000	727.62	15.89	15.89	Raised
1965-10-01	1408.690/ 6.710	1401.980/ 0.000	1401.980/ 0.000	670.87	8.77	8.77	Basin survey
1966-12-01	1409.050/ 7.070	1401.980/ 0.000	1401.980/ 0.000	738.54	11.35	11.35	Raised
1969-10-01	1412.430/10.450	1401.980/ 0.000	1401.980/ 0.000	1349.74	46.58	46.58	Raised
1969-11-04	1412.430/ 5.940	1406.490/ 0.000	1406.490/ 0.000	1349.74	46.51	46.58	Adjusted
1976-10-01	1412.430/ 5.940	1406.490/ 0.000	1406.490/ 0.000	1364.45	40.59	40.59	Basin survey
1994-10-01	1412.430/ 5.940	1406.490/ 0.000	1406.490/ 0.000	1384.80	42.31	42.31	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	4.870	27427	1758	15451	21306 E	6183 &	25016 E
1991-01-01	4.170	20112	29678	12638	19313 E	6314 &	57109 E
1992-01-01	4.356	21906	0	14488	14344 E	3366 &	21114 E
1993-01-01	3.893	17554	0	8048	15546 E	6634 &	36588 E
1994-01-01	5.673	37181	50230	10328	21027	4985 &	60215 &
1995-01-01	4.149	20797	155790	0 M	15502 E	7757 &	0 M
1996-01-01	6.015	43362	175565	0 M	21242 *	11135 &	0 M
1997-01-01	5.510	36575	104271	0 M	20656 E	9490	0 M
1998-01-01	5.946	42390	0 M	0 M	22060 E	8863 &	0 M
1999-01-01	6.030	43571	2437	12217	21980 E	4975 &	17349 E
2000-01-01	4.922	29261	107852	4241	21835 E	8271 &	138750 E
2001-01-01	5.943	42353	130674	6809	22319 E	9415	151171 E
2002-01-01	5.999	43138	50258	6422	23715 E	7626 Q	61609 E
2003-01-01	5.147	31978	0 $	10929	19457 *	4476 $	4562 *
2004-01-01	3.016	10630	0	0 M	11050 E	3606	0 M
2005-01-01	1.686	2151	2588 Q	0 M	21545 Q	6394 Q	0 M
2006-01-01	4.816 Q	28026 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:
$ - Gauge Plate Readings & - Good monthly reading * - Program Estimate E – Estimate M - Data Missing, Permanent Gap, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 16: A2R011 Kosterrivier Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1964-12-25	1264.210/10.020	1254.190/ 0.000	1254.190/ 0.000	169.26	6.68	6.81	Original
1973-04-01	1267.200/13.010	1254.190/ 0.000	1254.190/ 0.000	262.20	13.03	13.16	Raised
1979-10-01	1267.200/13.010	1254.190/ 0.000	1254.190/ 0.000	262.20	12.90	12.99	Basin survey
1995-10-01	1267.200/13.010	1254.190/ 0.000	1254.190/ 0.000	261.90	12.78	12.80	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	10.489	7034	3031	2755	276	2840	1101 &	2562 &
1991-01-01	9.017	4826	2233	1971	262	2172 E	1061 &	2495 E
1992-01-01	8.472	3978	1850	1568	282	1492	433 &	1551 &
1993-01-01	7.285	2620	202	0	202	1323	454 &	203 &
1994-01-01	6.221	1752	268	2	266	1311	376 &	970 &
1995-01-01	5.980	1520	277	5	272	1083 E	605 &	2661 E
1996-01-01	7.903	3427	7560	7341	219	3536 E	1746 &	16953 E
1997-01-01	12.310	11030	24173	23769	404	3760 E	2700 &	26221 E
1998-01-01	12.714	12018	2527	2053	474	3975 E	1827 &	3313 E
1999-01-01	12.150	10656	3169	2597	572	3448 E	1232 &	1754 E
2000-01-01	10.366	7025	0 M	0 M	0 M	3600 E	2867	0 M
2001-01-01	13.068	12929	13489	13014	475	3636 E	2347 &	14715 E
2002-01-01	13.044	12865	5425	4900	526	3888 E	1481 &	5638 E
2003-01-01	12.157	10671	0 ?	0 ?	591	3086 E	1116	0 ?
2004-01-01	8.853	4631	0 M	0 M	828 E	1788	772	0 M
2005-01-01	7.246	2721	0 M	89	0 M	0 M	0 M	0 M
2006-01-01	5.557	1389	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
? - Data Unreliable
E - Estimate
M - Data Missing, Permanent Gap, Data Exists but Unreliable, Data Missing

DAM 17: R2R001 Laing Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1949-05-01	296.510/27.360	282.140/12.990	269.150/ 0.000	96.24	7.63	8.39	Temporary fsl
1949-11-25	295.850/26.700	282.140/12.990	269.150/ 0.000	92.93	7.01	7.76	Temporary fsl
1950-05-18	303.590/34.440	282.140/12.990	269.150/ 0.000	160.49	16.45	17.21	Temporary fsl
1950-10-01	306.640/37.490	282.140/12.990	269.150/ 0.000	204.20	21.99	22.74	Original
1976-02-09	304.966/35.816	282.140/12.990	269.150/ 0.000	179.80	18.78	19.54	Temporary fsl
1976-04-07	306.640/37.490	282.140/12.990	269.150/ 0.000	204.20	21.99	22.74	Adjusted
1979-04-23	306.640/25.100	282.140/ 0.600	281.540/ 0.000	204.20	21.99	22.74	A01 - Adjusted
1981-10-01	306.640/25.100	282.140/ 0.600	281.540/ 0.000	204.20	20.84	21.04	Basin survey
1993-10-01	306.640/25.100	282.140/ 0.600	281.540/ 0.000	203.80	19.83	19.86	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Industry and Town (Ml)	River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	25.128	20899	25507	4580	0 M	2431 E	922	26685 E
1991-01-01	24.965	20568	25889	5682	0 M	2427 *	1061	27485 *
1992-01-01	25.079	20798	6979	6979	0 M	2492 E	765	7157 E
1993-01-01	24.295	19249	36905 >	6955	0 M	2410 E	1214	39030 >
1994-01-01	25.271	20178	88700	5024	0	2358 E	1267	89684 E
1995-01-01	25.219	20070	118353	5292	22	2384 E	1478 &	119304 E
1996-01-01	25.240	20115	124100	5745	0	2312 E	1401	124904 E
1997-01-01	25.188	20008	174568 E	6874 E	0	2379 E	1503	175302 E
1998-01-01	25.119	19866	0 M	6790	0 M	2404 *	1525	0 M
1999-01-01	25.277	20190	44322	6945	187	2389 *	1350 &	45204 *
2000-01-01	25.200	20033	0 M	8069	0 M	2118 E	1710 &	0 M
2001-01-01	25.109	19847	0 M	7469	0 M	2164 E	1802	0 M
2002-01-01	25.153	19936	105579	7064	0	2341 E	1603	106270 E
2003-01-01	25.130	19889	18275	7755	0	2378 E	1050	18593 E
2004-01-01	24.626	18879	42464 E	6945 E	0	2234 E	1587 Q	44210 E
2005-01-01	25.174	19978	79247 Q	8087 Q	0	2275 E	1303 Q	79846 E
2006-01-01	24.990 Q	19605 Q	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:
& - Good monthly reading
* - Program Estimate
> - Minimum Value
E - Estimate M - Data Missing, Permanent Gap, Data Missing Q - Unaudited, Good edited unaudited

DAM 18: A2R007 Lindleyspoort Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1938-10-01	1174.960/19.810	1155.150/ 0.000	1155.150/ 0.000	144.84	12.02	12.33	Original
1967-10-01	1176.360/21.210	1155.150/ 0.000	1155.150/ 0.000	162.73	14.16	14.48	Raised
1970-02-01	1174.400/22.250	1155.150/ 3.000	1152.150/ 0.000	138.51	11.22	11.54	Raised
1976-10-01	1177.400/22.250	1155.150/ 0.000	1155.150/ 0.000	180.30	15.94	16.26	Basin survey
1979-10-01	1177.400/22.250	1155.150/ 0.000	1155.150/ 0.000	180.10	14.38	14.38	Basin survey
1995-10-01	1177.400/22.250	1155.150/ 0.000	1155.150/ 0.000	180.10	14.34	14.34	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	20.040	10858	5610	5610	2199 E	802 &	2109 E
1991-01-01	15.903	5959	5446	5446	1718 E	936 &	4914 E
1992-01-01	14.433	4645	4063 A	4063 A	777 E	217 &	3158 E
1993-01-01	12.417	3181	2236	2236	748 E	197 &	436 E
1994-01-01	7.230	830	636	636	678 E	102 &	1271 E
1995-01-01	7.440	889	316	316	857 E	353 &	5514 E
1996-01-01	15.540	5583	11974	2836	2567 E	0 M	0 M
1997-01-01	22.143	14146	0 M	0 M	2750 E	1428 &	0 M
1998-01-01	21.637	13274	5409	5049	2783 E	1162 &	6970 E
1999-01-01	21.600	13214	6418	6418	2393 E	747 &	2280 E
2000-01-01	17.370	7430	45476	3216	2448 E	0 M	0 M
2001-01-01	22.290	14408	32370	5291	2704 *	1263 &	33818 *
2002-01-01	22.293	14415	11615	6952	2871 *	844 &	10649 *
2003-01-01	20.460	11423	5694	5694	2266	685	2348
2004-01-01	16.484	6497	4123	4123	2117	851	8456
2005-01-01	19.130	9564	5794 Q	5794	2104 *	609 Q	3179 *
2006-01-01	15.400	5454	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
A - Above Rating
E - Estimate
M - Data Missing, Data Missing
Q - Unaudited

DAM 19: G1R003 Misverstand Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1977-07-12	26.130/ 3.640	22.490/ 0.000	22.490/ 0.000	260.30	6.52	7.89	Original
1988-10-01	26.130/ 3.640	22.490/ 0.000	22.490/ 0.000	255.20	6.44	7.74	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	3.622	6394	830860	5913	4546 *	1146 &	834345 *
1991-01-01	3.656	6479	836542	2689	4324 *	826 &	840017 *
1992-01-01	3.647	6456	744904	6524	4236 E	0 M	0 M
1993-01-01	3.731	6667	920882	12282	4487 *	1189	924115 *
1994-01-01	3.706	6603	509274	9538	5217 E	719	513733 E
1995-01-01	3.690	6563	396554	9715	4947 E	913 #	400989 #
1996-01-01	3.848	6964	965674	9578	4611 E	1289 #	969224 #
1997-01-01	3.936	7193	485350	10749	4623 E	857	488707 E
1998-01-01	3.777	6784	379353	11858	4805 E	1017 D	383078 E
1999-01-01	3.753	6722	507074	14586	4934 E	0 M	0 M
2000-01-01	3.770	6765	290939	15865	4931 E	379 &	295512 E
2001-01-01	3.778	6786	801593	12739	4568 E	1037	804738 E
2002-01-01	3.625	6400	506282 Q	26166 Q	4507 E	935	509845 E
2003-01-01	3.621	6390	170557 Q	13519 Q	4473 E	472	175036 E
2004-01-01	3.811	6869	186148 Q	14765 Q	4653 E	572	189477 E
2005-01-01	3.512	6117	0 M	0 M	4801 E	0 M	0 M
2006-01-01	3.736	6678	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

- Wet day within accumulated rainfall period
& - Good monthly reading
* - Program Estimate
D - Drops
E - Estimate
M - Data Missing, Data Missing
Q - Unaudited

DAM 21: R3R001 Nahoon Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1966-06-01	153.910/18.440	135.180/-0.290	135.470/ 0.000	81.52	5.70	5.72	Basin survey
1966-06-06	153.910/18.440	135.180/-0.290	135.470/ 0.000	81.52	5.70	5.72	Original
1980-05-01	164.590/29.120	135.180/-0.290	135.470/ 0.000	236.10	21.94	21.96	Raised
1981-01-25	164.590/29.410	135.180/ 0.000	135.180/ 0.000	236.10	21.94	21.96	A01 - Adjusted
1981-10-01	164.590/29.410	135.180/ 0.000	135.180/ 0.000	235.30	20.76	20.76	Basin survey
1992-10-01	164.590/29.410	135.180/ 0.000	135.180/ 0.000	237.70	19.93	19.93	Basin survey
2003-10-01	164.590/29.410	135.180/ 0.000	135.180/ 0.000	234.69	19.25	19.25	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	29.318	20540	1319	5683	2251 E	1220 &	3235 E
1991-01-01	27.093	15743	960	5854	1910 E	936	9191 E
1992-01-01	27.784	17146	1078	6876	1846 E	931 &	-345 E
1993-01-01	22.566	7932	7511	6601	1233 E	912	26598 E
1994-01-01	29.479	20097	29383	7769	2235 E	1556	37715 E
1995-01-01	29.430	19981	15516	8011	2144 E	2097 &	20891 E
1996-01-01	28.240	17300	15901	6479	2221 E	1589	25341 E
1997-01-01	29.280	19630	35850	8077	2185 E	1897	42026 E
1998-01-01	28.305	17441	31688	8248	2222 E	1942 &	42691 E
1999-01-01	29.403	19916	0 M	6459	2211 E	1719 &	0 M
2000-01-01	29.259	19579	45282	5941	2271 E	1784	51460 E
2001-01-01	29.151	19329	19782	6506	2275 E	2182	26979 E
2002-01-01	29.407	19928	52283	6892	2437 *	0 M	0 M
2003-01-01	28.768	18459	8985	6142	2357 E	1540	12012 E
2004-01-01	27.188	14527	11725	5893	2152 E	2179	22316 E
2005-01-01	29.412	19252	19688 Q	5985 Q	2240 E	1995 $	25197 E
2006-01-01	29.100 Q	18532 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:
$ - Gauge Plate Readings
& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 23: A2R015 Roodekopjes Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1984-06-01	1006.500/21.500	985.000/ 0.000	985.000/ 0.000	1559.23	102.33	102.46	Original

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	15.514	36511	71817	48630	23186	11940 E	4312 &	78613 E
1991-01-01	15.398	35679	67815	61632	6184	16354 E	5249 &	100356 E
1992-01-01	17.924	57115	70402	69397	1005	11817 E	2176 &	39292 E
1993-01-01	11.828	16364	45214	28902	16311	4886 E	1207 &	41679 E
1994-01-01	9.629	9150	59494	35693	23801	8046 E	1630 &	73362 E
1995-01-01	11.889	16603	49147	40279	8868	8459 E	3885 &	109823 E
1996-01-01	19.349	72704	523760 A	501830	21929 A	23118 *	9443 &	547667 *
1997-01-01	20.152	82937	674184 A	650912	23271 A	21841 E	0 M	0 M
1998-01-01	21.622	104228	223111 A	204823	18288 A	21671 *	8952 &	229180 *
1999-01-01	21.187	97578	139887 A	125134	14753 A	22904 E	6708 &	131797 E
2000-01-01	19.397	73292	0 M	0 M	0 M	20602 E	12184 &	0 M
2001-01-01	20.700	90477	252904 A	210736	42168 A	19180 E	8442 &	277553 E
2002-01-01	21.632	104389	137128	126978	10151	21444 *	0 M	0 M
2003-01-01	18.884	67253	117342 A	75616	41726 A	13205 *	0 M	0 M
2004-01-01	10.617	12072	141594 A	113368	28225 A	17904 E	5120	217841 E
2005-01-01	19.579	75535	0 M	0 M	0 M	0 M	0 M	0 M
2006-01-01	17.302 Q	51167 Q	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
A - Above Rating
E - Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Unaudited

DAM 24: A2R009 Roodeplaat Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1958-10-22	1214.020/28.290	1185.670/-0.060	1185.730/ 0.000	395.30	42.50	45.47	Original
1972-05-18	1214.020/28.320	1185.670/-0.030	1185.700/ 0.000	395.30	42.50	45.47	A01 - Adjusted
1980-10-01	1214.020/28.320	1185.670/-0.030	1185.700/ 0.000	395.20	41.66	44.17	Basin survey
1990-10-01	1214.020/28.320	1185.670/-0.030	1185.700/ 0.000	395.10	41.16	43.47	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Total Outflow (Ml)	Tot River Releases (Ml)	Irrigation (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	28.365	41835	24201	9780	14282	140	5718 E	2126 &	22636 E
1991-01-01	27.135	36677	50185	35030	14134	1022	5375 E	2990 &	57017 E
1992-01-01	28.311	41124	0 M	1771	18885	0 M	5656 E	1265 &	0 M
1993-01-01	26.685	35075	23631	5363	18117	151	5383 E	2706 &	32513 E
1994-01-01	28.351	41281	32874	14980	17874	21	5670 E	2182 &	36294 E
1995-01-01	28.334	41213	41109	22637	18458	14	5532 E	0 ?	0 ?
1996-01-01	28.363	41330	118047	100789	17243	15	5176 E	2953	120178 E
1997-01-01	28.340	41237	96976	78358	18603	16	5179 E	3421	98824 E
1998-01-01	28.363	41327	49848	28493	21337	18	5610 E	2413 &	53975 E
1999-01-01	28.595	42257	39761	18045	21697	18	5747 E	2560 &	42038 E
2000-01-01	28.368	41348	0 M	0 M	17031	18	5081 E	0 ?	0 ?
2001-01-01	28.344	41252	44628 $	27546 $	17067	15	4867 E	2362 &	47107 E
2002-01-01	28.337	41225	35209 $	17147 $	18044	18	5581 E	1818 &	37505 E
2003-01-01	27.960	39758	39650 $	20669 $	18962	18	5681 E	1899	40112 E
2004-01-01	27.068	36437	70000 $	52500 $	17454	46	5141 E	2498	77507 E
2005-01-01	28.356	41301	0 M	0 M	18007 Q	102 Q	5591 *	1937 Q	0 M
2006-01-01	26.934	35955	0 M	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

$ - Gauge Plate Readings
& - Good monthly reading
* - Program Estimate
? - Data Unreliable
E - Estimate
M - Data Missing, Data Missing
Q - Unaudited, Good edited unaudited

DAM 25: C3R002 Spitskop Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1975-06-25	1043.030/ 6.310	1036.720/ 0.000	1036.720/ 0.000	2495.40	61.75	63.43	Original
1988-10-27	1042.560/ 6.320	1036.720/ 0.480	1036.240/ 0.000	2508.60	56.65	56.66	Basin survey
1989-09-20	1042.560/ 6.320	1037.080/ 0.840	1036.240/ 0.000	2508.60	56.64	56.66	Lowest outlet changed to 1037.080
2003-10-01	1042.560/ 6.320	1037.080/ 0.840	1036.240/ 0.000	2531.21	57.83	57.89	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	River Releases (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	3.642	10299	0 M	0 M	0 M	0 M	0 M
1991-01-01	3.269	6941	73784	10907	39063 E	12171 &	144609 E
1992-01-01	6.087	50874	29419	29419	40717 E	3865 &	40895 E
1993-01-01	4.802	25499	26386	26386	33392	4869 &	58918 &
1994-01-01	5.048	29507	27684	27684	44761 E	5442 &	73709 E
1995-01-01	5.413	36212	36753	22232	44261 E	6464 &	87342 E
1996-01-01	6.008	49004	63568	25793	43859 E	12292 &	104548 E
1997-01-01	6.392	58417	104825	32307	44916 E	8509 &	137889 E
1998-01-01	6.258	55074	104837	43289	45068 *	8413 &	141197 *
1999-01-01	6.247	54778	51002	26602	44068 *	12909 &	88451 *
2000-01-01	6.496	61067	0 M	0 M	41647 E	11994 &	0 M
2001-01-01	6.383	58212	0 M	0 M	45634 *	15249	0 M
2002-01-01	6.431	59412	0 M	0 M	41779 E	11000 $	0 M
2003-01-01	6.356	57526	0 M	0 M	46850 E	7726	0 M
2004-01-01	6.257	56205	100774	39717	46261 *	12591	135384 *
2005-01-01	6.294	57145	33453	4677	45120 E	12787	45970 E
2006-01-01	5.435	37329	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

$ - Gauge Plate Readings
& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Permanent Gap, Data Missing

DAM 27: C1R001 Vaal Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1936-10-01	1477.342/15.240	1454.792/-7.310	1462.102/ 0.000	16303.03	1071.68	1086.82	Original
1945-10-01	1477.342/15.240	1454.792/-7.310	1462.102/ 0.000	15688.31	1006.81	1018.90	Basin survey
1954-10-01	1480.390/18.288	1454.792/-7.310	1462.102/ 0.000	22246.74	1581.23	1593.32	Raised
1956-02-01	1483.442/21.340	1454.792/-7.310	1462.102/ 0.000	29532.23	2372.57	2384.66	Gates installed
1977-10-01	1483.442/21.340	1454.792/-7.310	1462.102/ 0.000	29631.40	2309.27	2317.62	Basin survey
1982-10-01	1483.442/21.340	1454.792/-7.310	1462.102/ 0.000	29679.99	2256.27	2262.62	Basin survey
1986-12-01	1484.560/22.458	1454.792/-7.310	1462.102/ 0.000	32275.50	2603.45	2609.80	Gates installed
1992-06-29	1484.560/22.520	1454.792/-7.248	1462.040/ 0.000	32275.50	2603.45	2609.80	Adjusted

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	21.924	2434234	407651	565903	457819 E	157785 &	616506 E
1991-01-01	19.600	1777153	0 M	658311	381123	165476 &	0 M
1992-01-01	18.411	1493102	594090	780187	241807 *	53115 &	474349 *
1993-01-01	10.565	404482	588890	725084	128627	57115 &	1702402 &
1994-01-01	14.040	721399	474882	822404	225873 E	67639 &	1142538 E
1995-01-01	10.623	408418	912496	688742	115379 E	74804 &	3902687 E
1996-01-01	22.723	2669292	6037994	763359	438615 *	247029 &	6887965 *
1997-01-01	22.399	2564318	3000402	826890	451850 *	279342	4104088 *
1998-01-01	22.721	2668606	1386796	870983	441386 *	222598 &	2306984 *
1999-01-01	22.194	2499023	675317	896342	441308 *	116762 &	1458984 *
2000-01-01	20.727	2061801	4620270	861701	459353 *	282874 &	6194633 *
2001-01-01	22.503	2597985	740454	925931	424193 *	181568 &	1927314 *
2002-01-01	22.560	2616288	0 M	987030 Q	455370 *	187024 &	0 M
2003-01-01	20.586	2022232	382485	1013586 E	392400 *	0 M	0 M
2004-01-01	17.027	1193957	551376	906298 Q	253722 E	0 M	0 M
2005-01-01	14.385	766320	0 M	0 M	0 M	0 M	0 M
2006-01-01	15.305 Q	898035 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:
& - Good monthly reading
* - Program Estimate
E - Used previous week's level as an estimate for this week, Estimate
M - Data Missing, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 28: G1R001 Voelvlei Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1951-06-25	70.180/ 8.500	65.620/ 3.940	61.680/ 0.000	0.00	0.00	0.00	Original
1951-06-26	70.180/ 8.500	65.620/ 3.940	61.680/ 0.000	1099.49	45.46	56.22	Basin survey
1952-10-01	70.180/ 8.500	65.620/ 3.940	61.680/ 0.000	1099.49	45.46	56.22	Basin survey
1970-08-01	79.330/17.650	65.620/ 3.940	61.680/ 0.000	1580.70	168.02	178.78	Raised
1978-10-01	79.330/17.650	65.620/ 3.940	61.680/ 0.000	1573.00	164.31	172.82	Basin survey
1999-10-01	79.330/17.650	65.620/ 3.940	61.680/ 0.000	1524.20	158.58	165.49	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Measured Additions (Ml)	Total Outflow (Ml)	Irrigation (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	16.902	152724	71049	77791	30663	47128	26705 E	8370 &	4064 E
1991-01-01	15.502	131712	118875	99236	35494	63742	23658 E	7865 &	13012 E
1992-01-01	16.629	148570	85408	76405	19416	56989	23782 E	9680 &	6573 E
1993-01-01	16.726	150044	84597	107881	29190	78691	25000 *	5581 &	11681 *
1994-01-01	14.618	119022	99796	92536	19045	73491	27418 E	6634 &	9659 E
1995-01-01	14.343	115157	0 M	76732	18075	58657	25917 E	6542	0 M
1996-01-01	16.837	151729	109124	80509	20566	59943	25561 E	11287	-6348 E
1997-01-01	17.355	159722	0 M	0 M	0 M	60223	26251 E	6114 &	0 M
1998-01-01	15.429	130639	0 M	89372	30380	58993	25399 E	7759 &	0 M
1999-01-01	14.957	123830	0 M	96199	38271	57928	25568 E	6158 &	0 M
2000-01-01	15.129	121861	0 M	106603	52217	54386	23719 E	3929 &	0 M
2001-01-01	12.670	89595	0 M	92379	43228	49151	22302 E	9482 &	0 M
2002-01-01	16.318	138737	116432	99900 Q	48130	51770 Q	24687 E	8277	-3068 E
2003-01-01	16.114	135791	64344	75522 Q	25143	50379 Q	23356 E	5053	-5373 E
2004-01-01	13.568	100937	0 M	89112 Q	37829	51283 Q	21370 E	5306	0 M
2005-01-01	10.604	65259	116103	0 M	26157	0 M	22476 E	4636 Q	0 M
2006-01-01	14.061	107380	0 M	0 M	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

& - Good monthly reading
* - Program Estimate
E - Estimate
M - Data Missing, Permanent Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 29: D2R004 Welbedacht Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1988-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1370.10	30.51	30.52	Basin survey
1989-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1382.10	26.20	26.22	Basin survey
1990-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1255.10	17.05	17.06	Basin survey
1991-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1302.70	20.47	20.47	Basin survey
1994-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1175.30	15.14	15.14	Basin survey
1995-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1156.80	15.04	15.04	Basin survey
1996-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1100.60	15.84	15.84	Basin survey
1997-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1039.30	14.06	14.06	Basin survey
2000-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1012.20	9.71	9.71	Basin survey
2001-10-01	1402.900/17.680	1385.220/ 0.000	1385.220/ 0.000	1017.50	11.66	11.66	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	16.952	17276	844776	36411	12320 E	4592	877488 E
1991-01-01	16.489	5849	2002633	39592	16018 E	8546 &	2063234 E
1992-01-01	17.603	19386	0 M	41915	16609 E	2867 &	0 M
1993-01-01	17.426	17099	0 M	44501	18939 E	7804 &	0 M
1994-01-01	17.496	17974	668250	46854	13586 E	7108 &	708790 E
1995-01-01	16.190	5182	0 M	49564	13424 E	6209 &	0 M
1996-01-01	17.570	13808	0 M	40992	17166 E	10805 &	0 M
1997-01-01	17.460	13664	0 M	44081	0 M	0 M	0 M
1998-01-01	17.542 $	12846 $	0 M	47530	14778 E	5905 &	0 M
1999-01-01	17.275	10767	674463	40361	12515 E	4718 &	723366 E
2000-01-01	17.375	11512	0 M	38180	12666 E	6444	0 M
2001-01-01	17.450	7535	0 M	36690	0 M	0 M	0 M
2002-01-01	17.365	8965	0 M	34456	12582 E	4228 &	0 M
2003-01-01	17.317	8610	485842 E	39254	11770 E	3064	533696 E
2004-01-01	17.303	8504	0 M	39584 Q	10039 E	3062 $	0 M
2005-01-01	17.284	8368	0 M	0 M	0 M	0 M	0 M
2006-01-01	16.746 Q	5325 Q	0 M	0 M	0 M	0 M	0 M

Explanation of codes:

$ - Gauge Plate Readings & - Good monthly reading E – Estimate M - Data Missing, Permanent Gap, Temporary Gap, Data Missing
Q - Unaudited, Good edited unaudited

DAM 30: B1R001 Witbank Dam

Dam Parameters at Full Supply

Date	Full Supply RL/Gauge (m)	Lowest Outlet RL/Gauge (m)	Gauge Zero RL/Gauge (m)	Surface Area (ha)	Net Capacity (Mil m**3)	Gross Capacity (Mil m**3)	Reason
1953-11-04	1479.490/12.190	1465.000/-2.300	1467.300/ 0.000	113.80	5.72	5.73	Basin survey
1958-12-01	1485.130/17.830	1465.000/-2.300	1467.300/ 0.000	208.41	14.76	14.78	
1970-11-01	1502.690/35.390	1465.000/-2.300	1467.300/ 0.000	1210.83	105.54	105.56	
1983-10-01	1502.690/35.390	1465.000/-2.300	1467.300/ 0.000	1211.20	104.02	104.02	Basin survey

Date	Gauge Reading (m)	Contents (Ml)	Tot River Releases (Ml)	Industry and Town (Ml)	Gross Evap (Ml)	Rain (Ml)	Calculated Streamflow (Ml)
1990-01-01	35.348	103510	0 M	25193	11453 *	7640 &	0 M
1991-01-01	34.480	93596	0 M	0 M	12918 *	8224 &	0 M
1992-01-01	33.070	79550	0 M	24449	8279 *	3073 &	0 M
1993-01-01	29.230	52273	0 M	24789	6309 *	3553 &	0 M
1994-01-01	32.554	74987	16360	27286	12741 E	5540 &	50071 E
1995-01-01	32.192	72000	175155 A	26819	10147 E	6772 &	0 M
1996-01-01	34.718	96193	772995	0 M	13492 E	11809 &	0 M
1997-01-01	34.356	92271	416738	34163	13574 E	8783	463281 E
1998-01-01	35.038	99861	167919	36583	13333 E	7259 &	203892 E
1999-01-01	34.441	93178	53054	34006	11849 E	7089 &	83862 E
2000-01-01	33.673	85219	512741	0 M	13320 E	9927 &	0 M
2001-01-01	35.082	100378	822	0 M	11549 E	5234 &	0 M
2002-01-01	32.330	73125	0 M	0 M	8124 E	5347	0 M
2003-01-01	29.260	52432	631	0 M	6723 E	2795	0 M
2004-01-01	24.889	33095	0 M	0 M	6930 E	5280 Q	0 M
2005-01-01	30.179 Q	57733 Q	0 M	0 M	0 M	0 M	0 M
2006-01-01	0 M	0 M	0 M	0 M	0 M	0 M	0 M

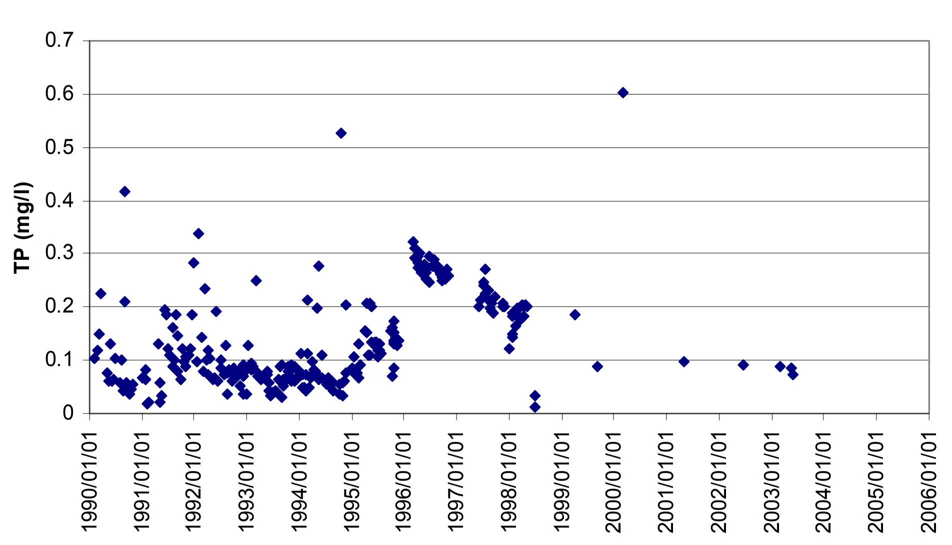
Explanation of codes:

& - Good monthly reading
* - Program Estimate
A - Above Rating
E - Estimate
M - Data Missing, Data Missing
Q - Unaudited

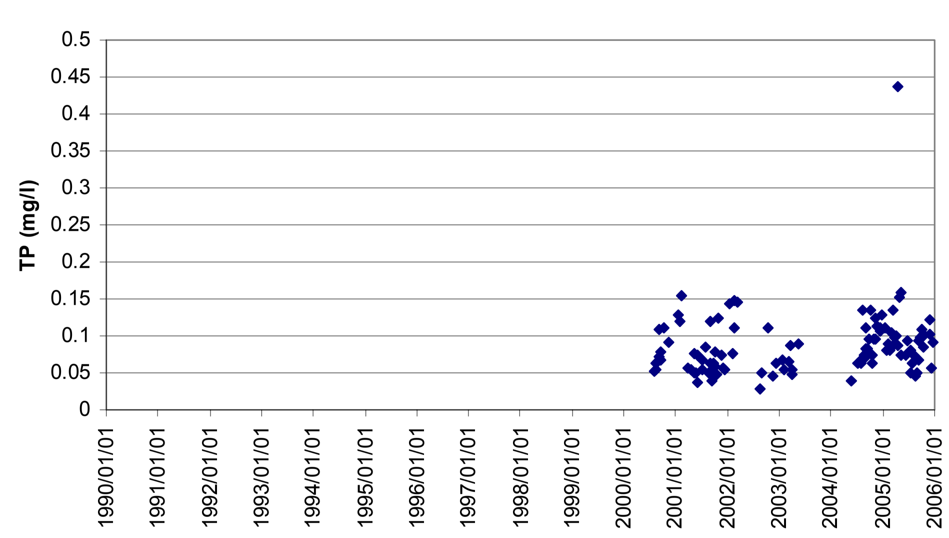
APPENDIX B

IN-LAKE TOTAL PHOSPHORUS DATA SUMMARIES

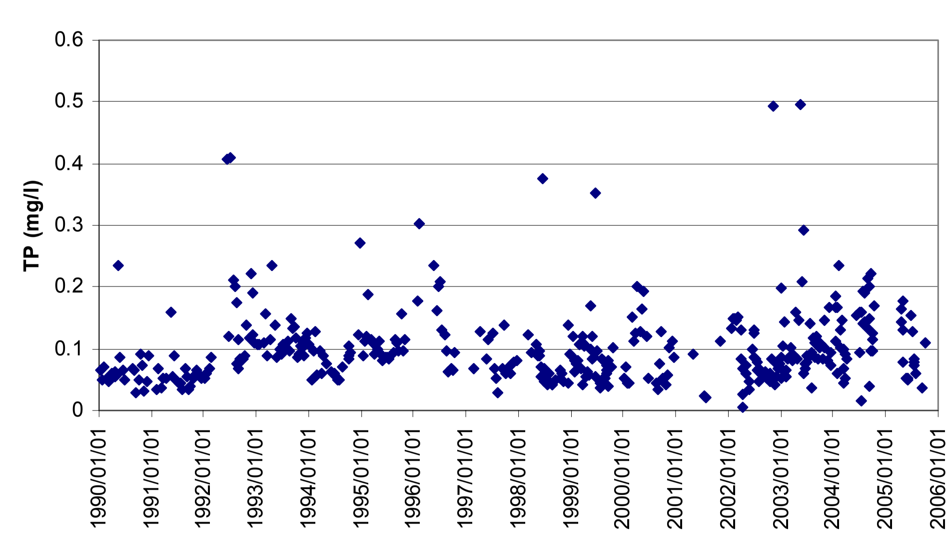
1: ALLEMANSKRAAL DAM IN-LAKE TOTAL P



2. BARRAGE IN-LAKE TOTAL P



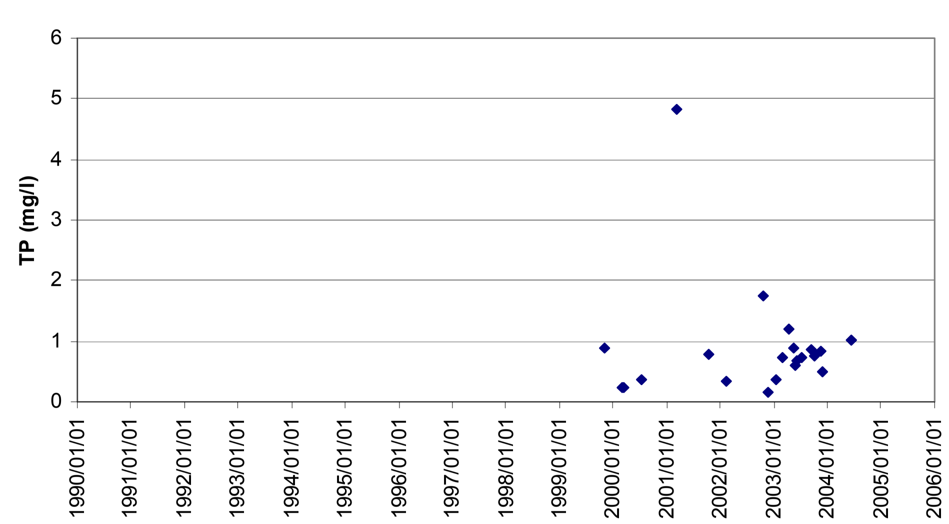
3. BLOEMHOF DAM IN-LAKE TOTAL P



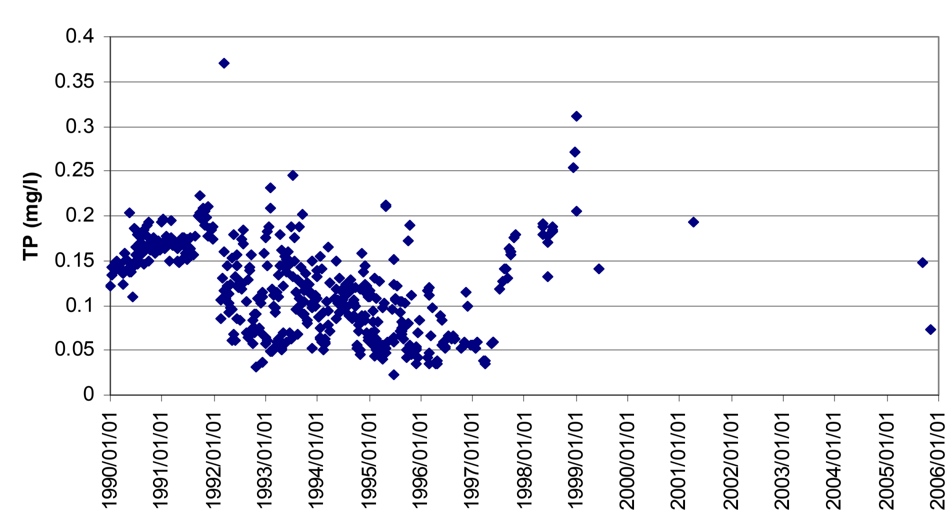
4. BLYDERIVIERPOORT

NO DATA

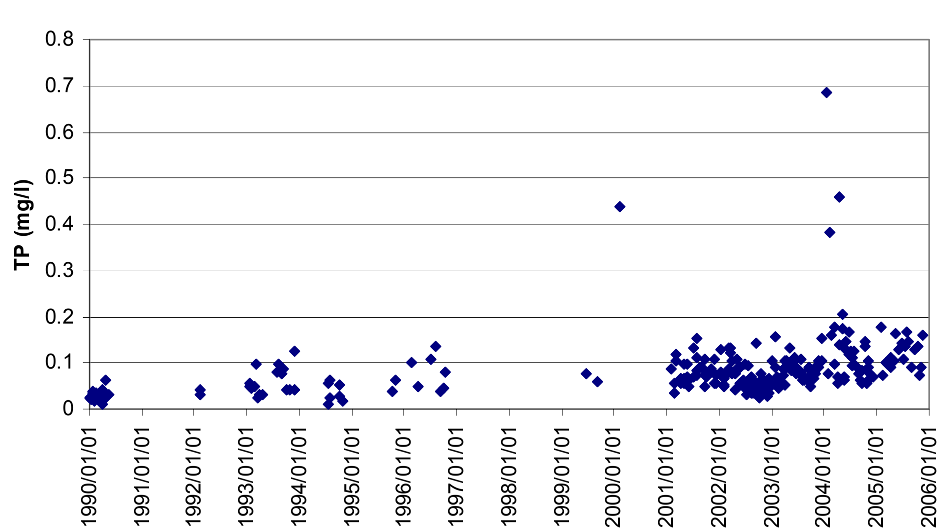
5: BOSPOORT DAM IN-LAKE TOTAL P



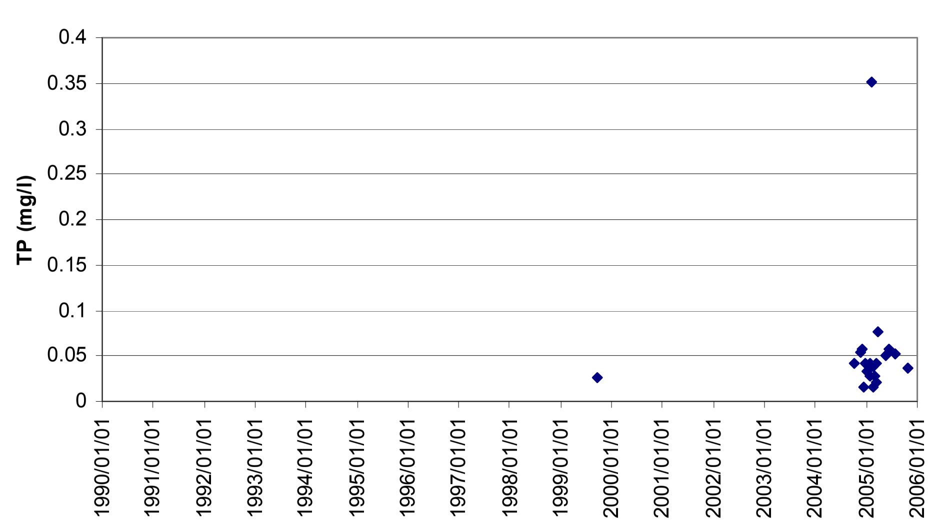
6: BRIDLEDRIFT DAM IN-LAKE TOTAL P



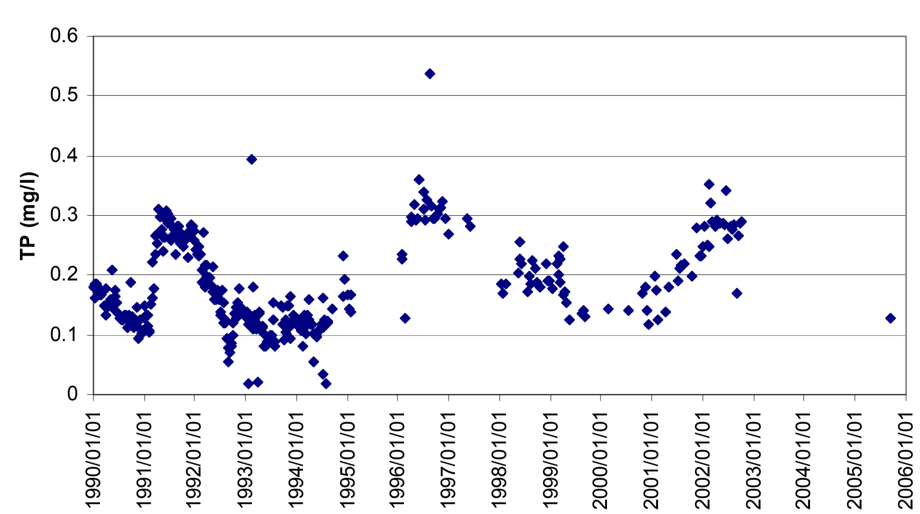
7: BRONKHORSTSPRUIT DAM IN-LAKE TOTAL P



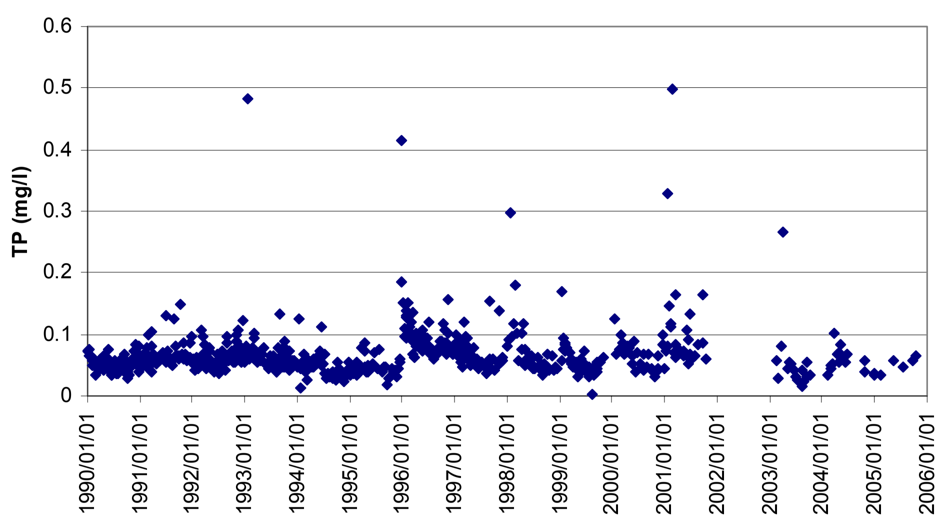
8: BULSHOEK DAM IN-LAKE TOTAL P



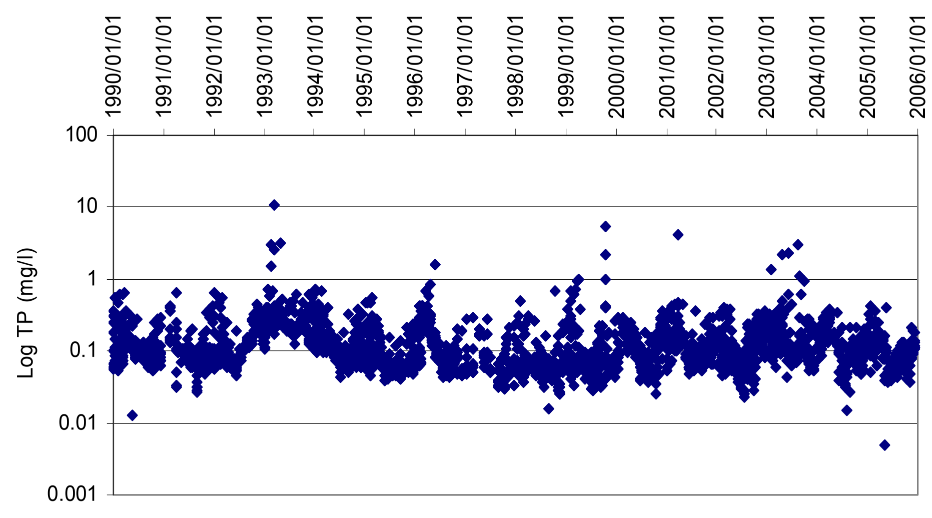
9: ERFENIS DAM IN-LAKE TOTAL P



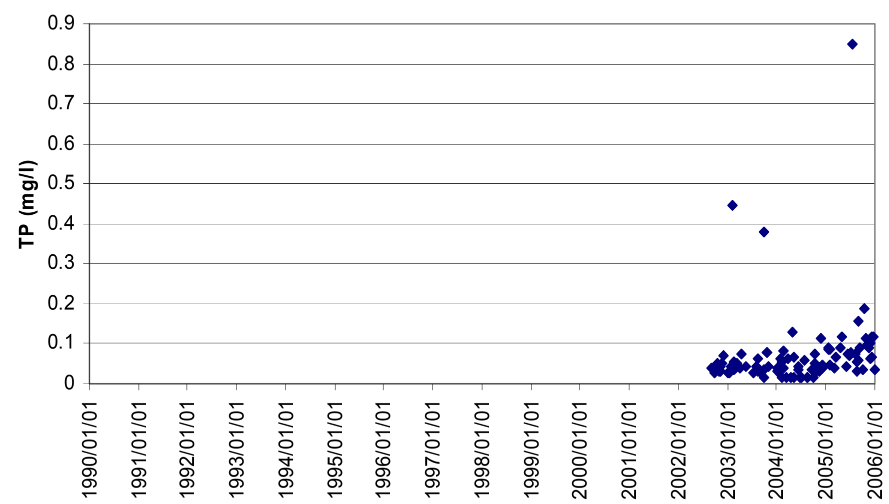
10: GROOTDRAAI DAM IN-LAKE TOTAL P



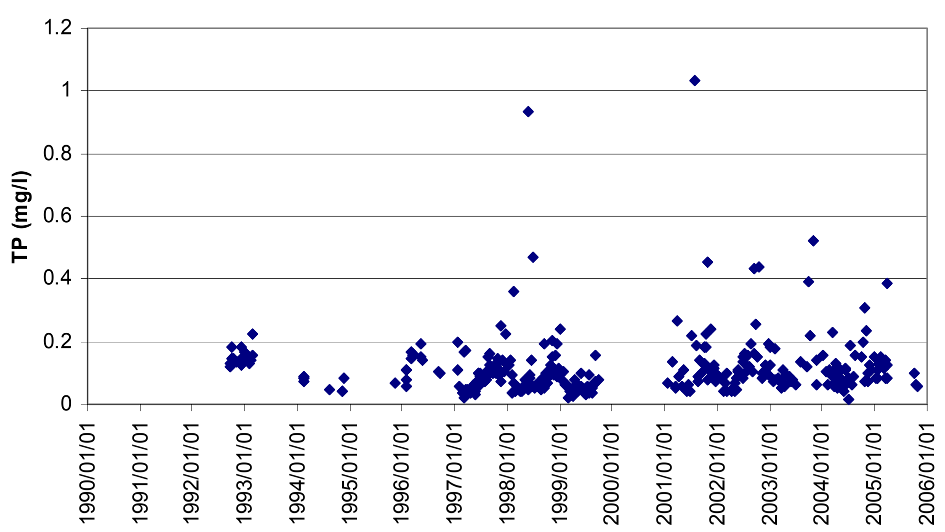
11. HARTBEESPOORT DAM IN-LAKE TOTAL P



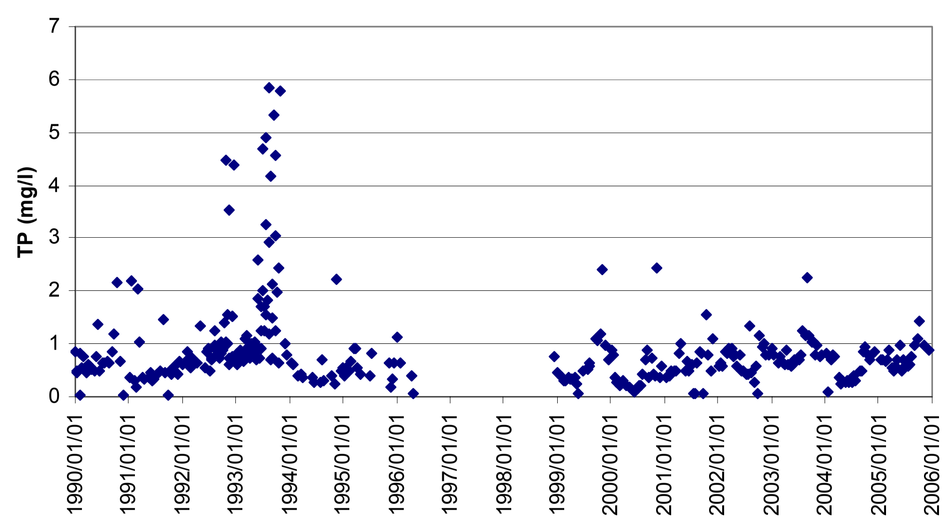
12. KALKFONTEIN IN-LAKE TOTAL P



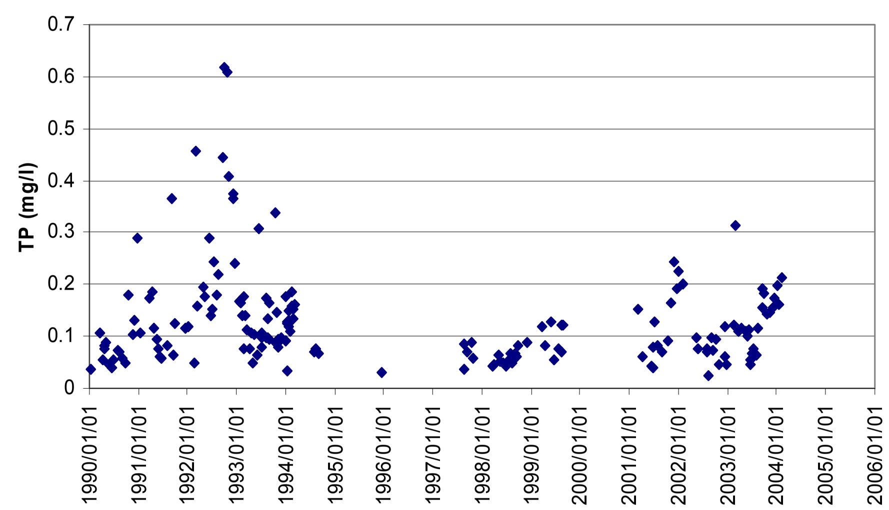
13: KLIPFONTEIN DAM IN-LAKE TOTAL P



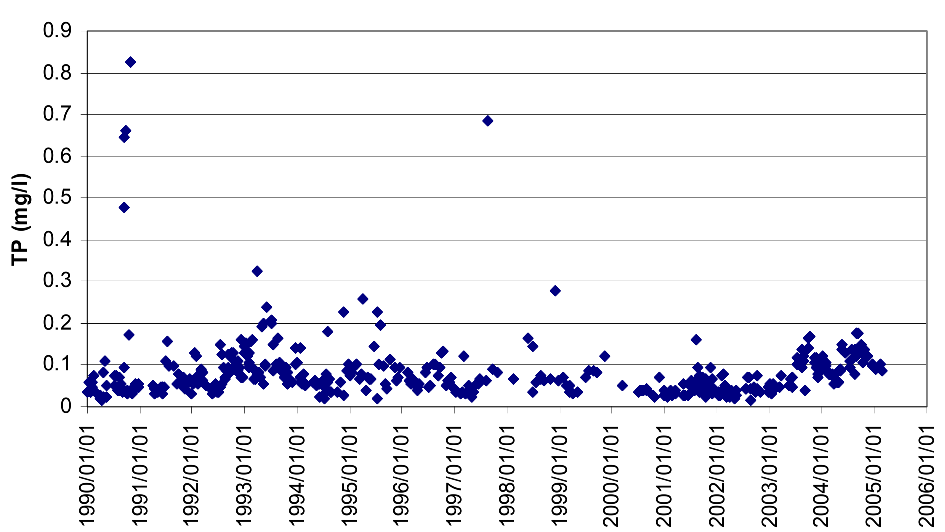
14: KLIPVOOR DAM IN-LAKE TOTAL P



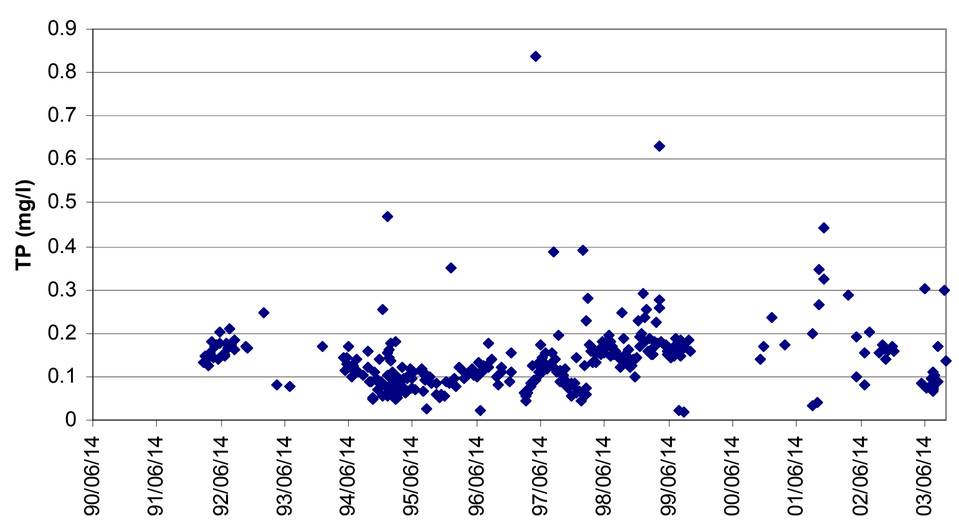
15: KOPPIES DAM IN-LAKE TOTAL P



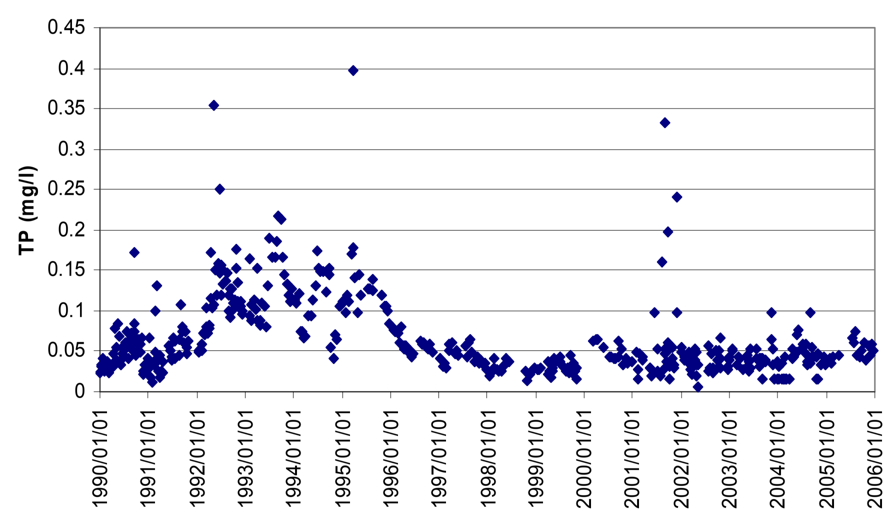
16. KOSTERRIVIER IN-LAKE TOTAL P



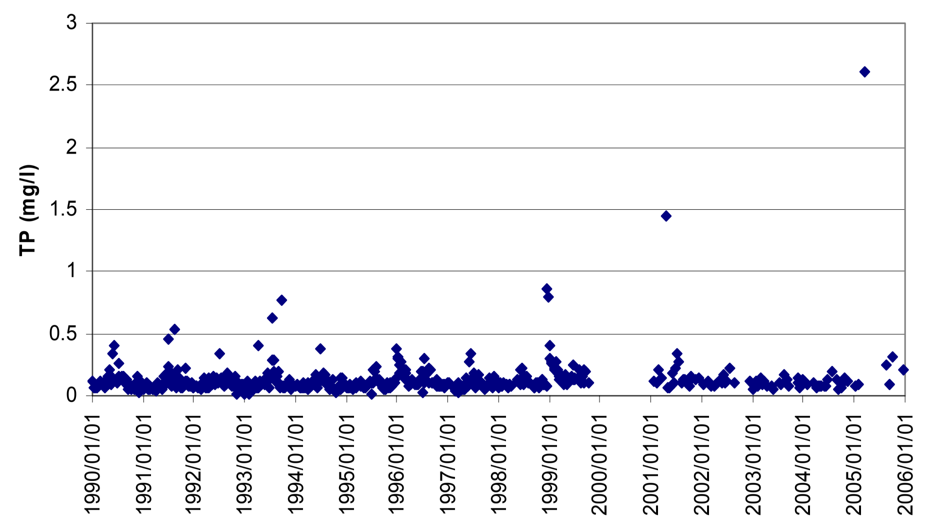
17: LAING DAM IN-LAKE TOTAL P



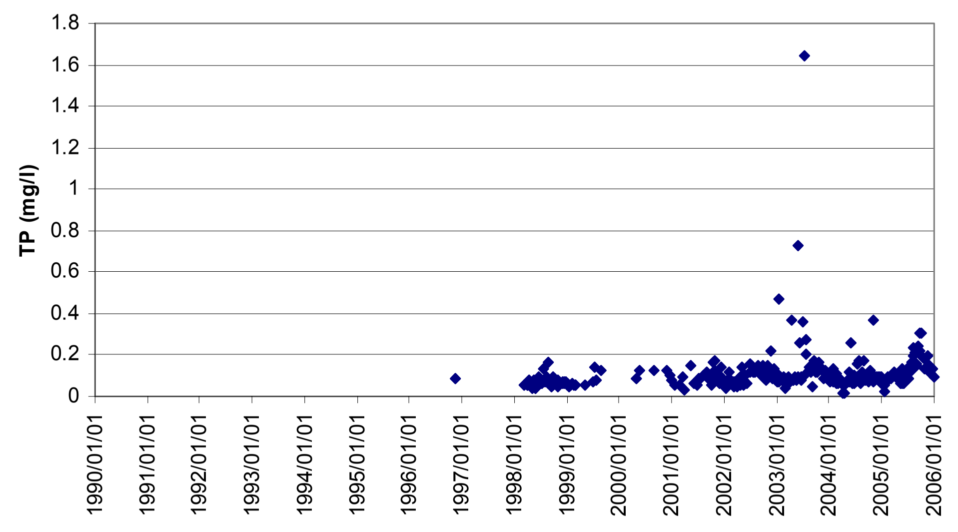
18: LINDLEYSPOORT DAM IN-LAKE TOTAL P



19: MISVERSTAND DAM IN-LAKE TOTAL P



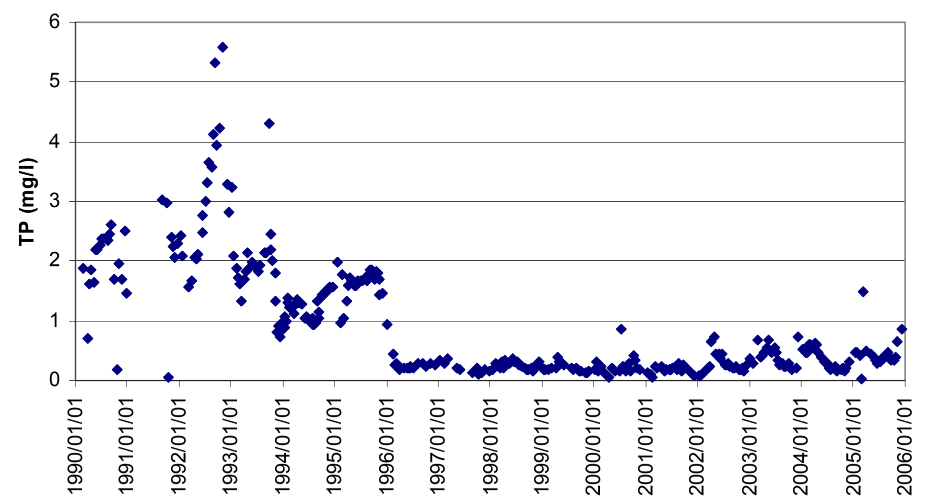
20: MODIMOLA DAM IN-LAKE TOTAL P



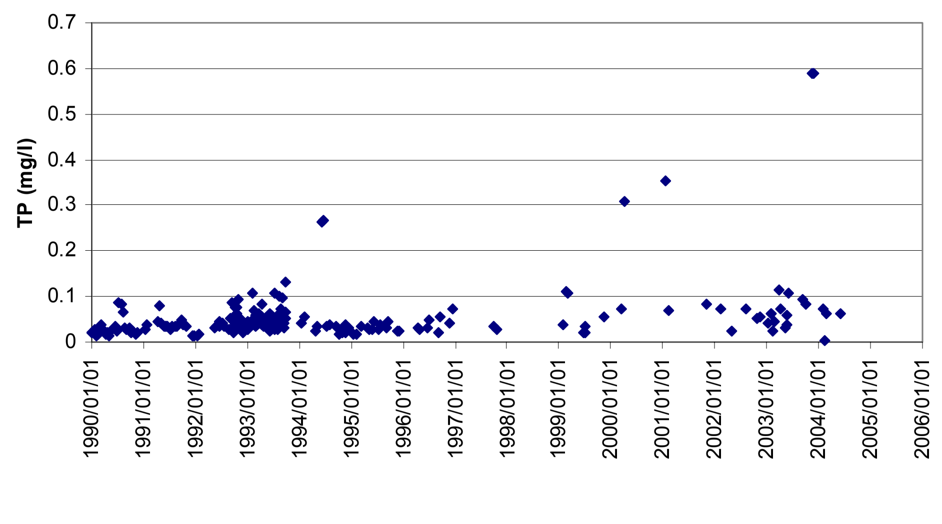
21. NAHOON

NO DATA

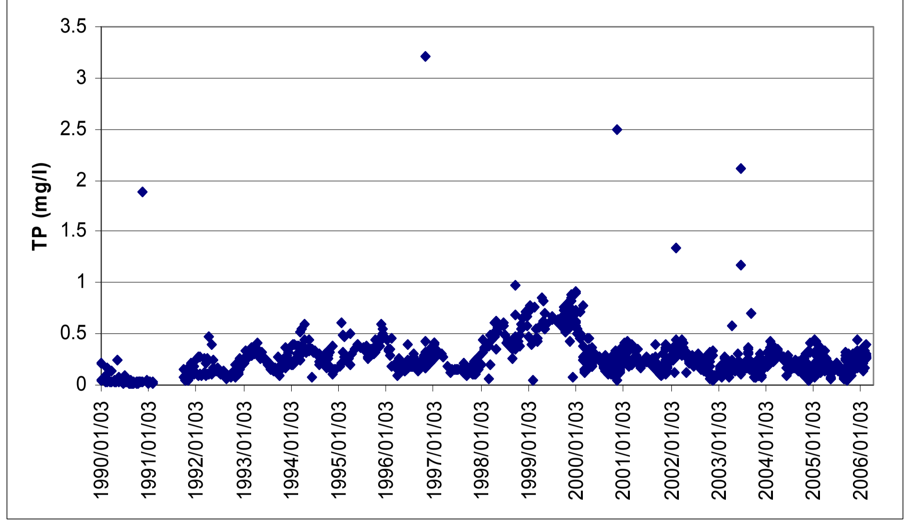
22: RIETVLEI DAM IN-LAKE TOTAL P



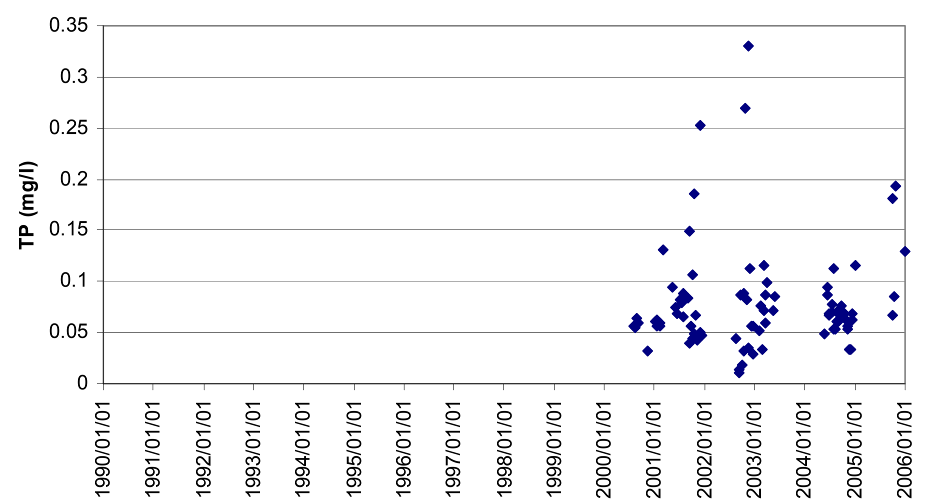
23: ROODEKOPJES DAM IN-LAKE TOTAL P



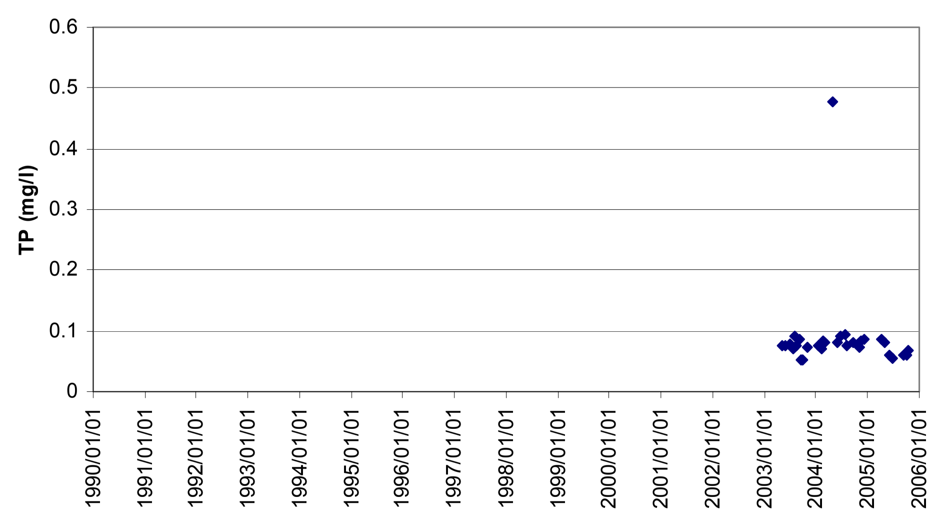
24: ROODEPLAAT DAM IN-LAKE TOTAL P



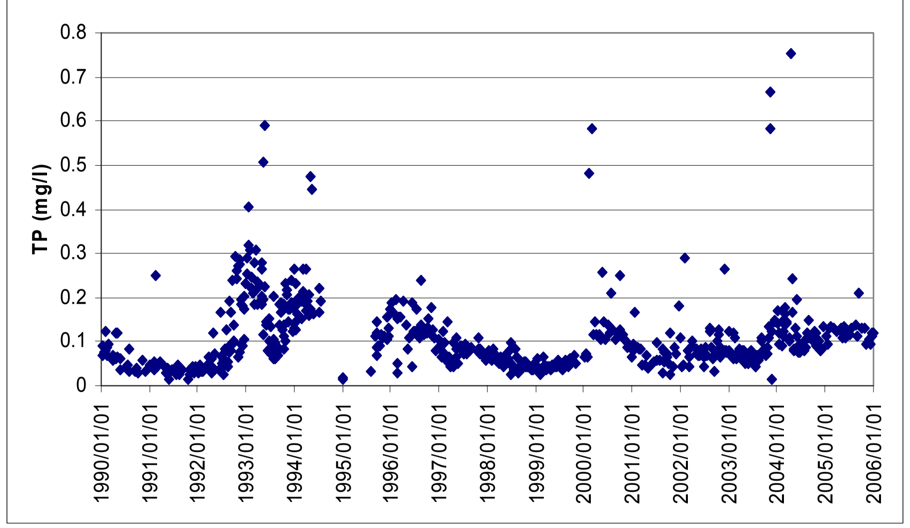
25: SPITSKOP DAM IN-LAKE TOTAL P

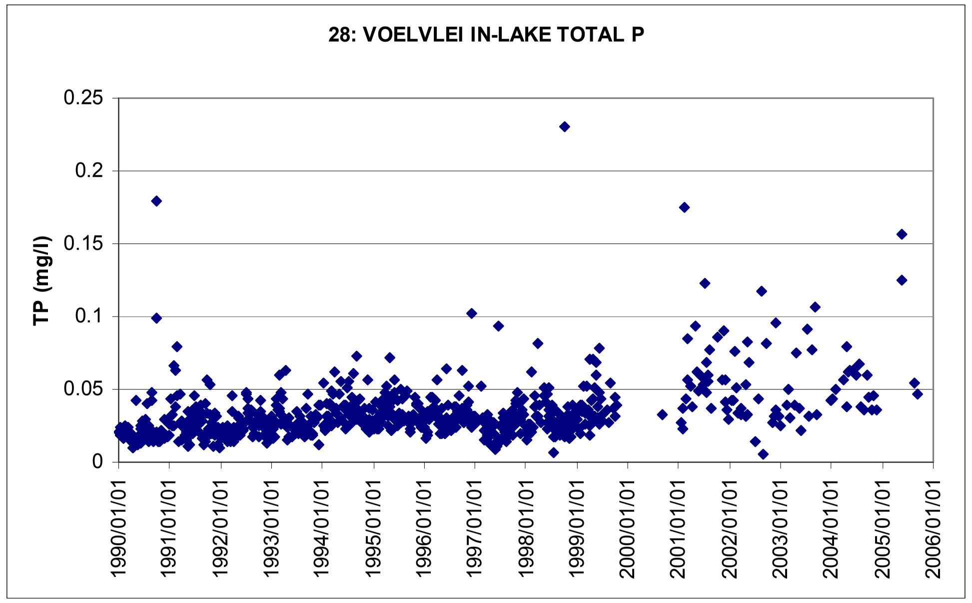


26: UMTATA DAM IN-LAKE TOTAL P



27: VAAL DAM IN-LAKE TOTAL P




28: VOELVLEI IN-LAKE TOTAL P
TP (mg/l)
0
0.05
0.1
0.15
0.2
0.25
1990/01/01
1991/01/01
1992/01/01
1993/01/01
1994/01/01
1995/01/01
1996/01/01
1997/01/01
1998/01/01
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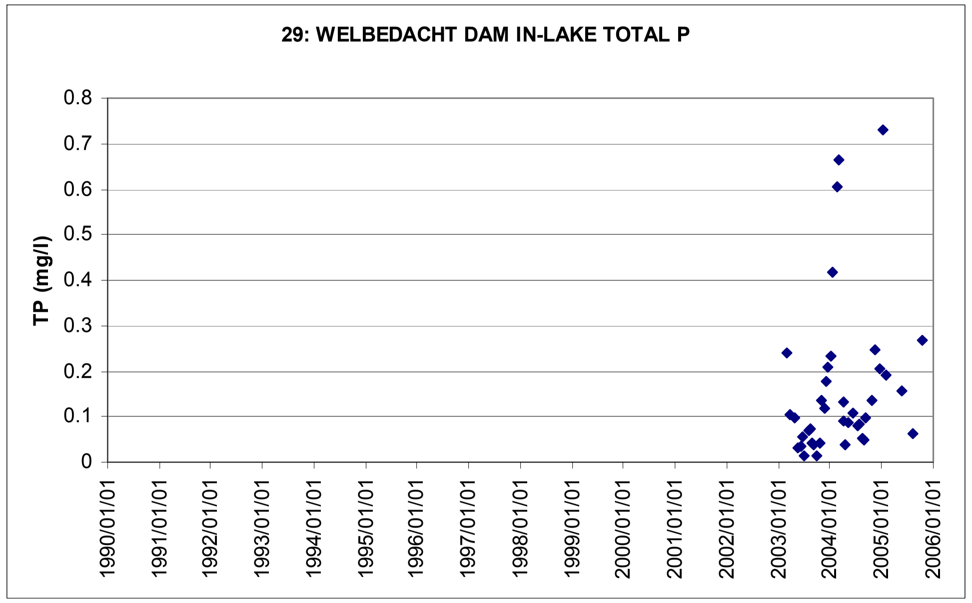
2005/01/01
2006/01/01


29: WELBEDACHT DAM IN-LAKE TOTAL P
TP (mg/l)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1990/01/01
1991/01/01
1992/01/01
1993/01/01
1994/01/01
1995/01/01
1996/01/01
1997/01/01
1998/01/01
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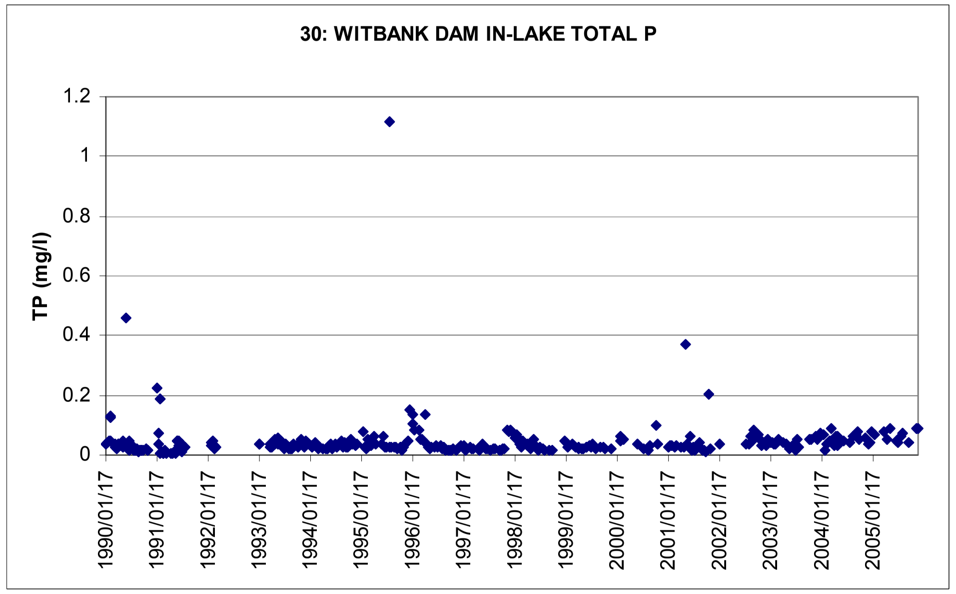
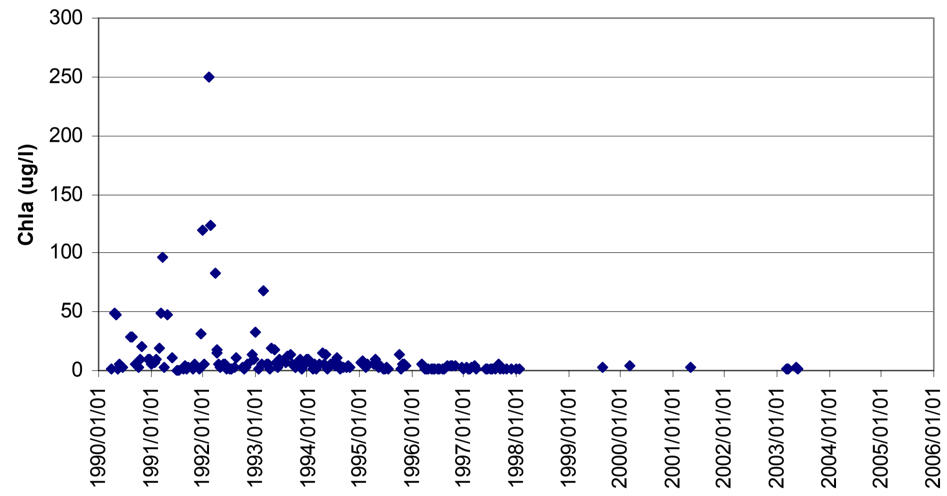
2005/01/01
2006/01/01


30: WITBANK DAM IN-LAKE TOTAL P
TP (mg/l)
0
0.2
0.4
0.6
0.8
1
1.2
1990/01/17
1991/01/17
1992/01/17
1993/01/17
1994/01/17
1995/01/17
1996/01/17
1997/01/17
1998/01/17
1999/01/17
2000/01/17
2001/01/17
2002/01/17
2003/01/17
2004/01/17
2005/01/17

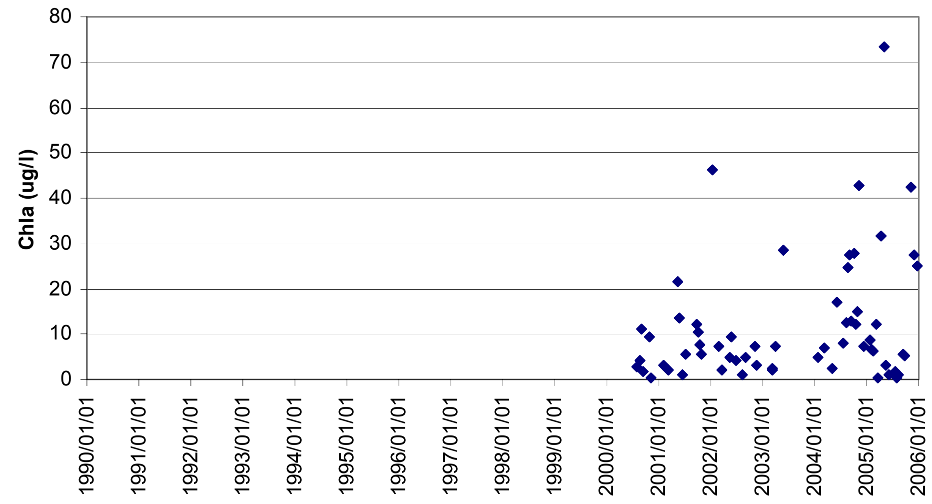
APPENDIX C

IN-LAKE CHLOROPHYLL-A DATA SUMMARIES

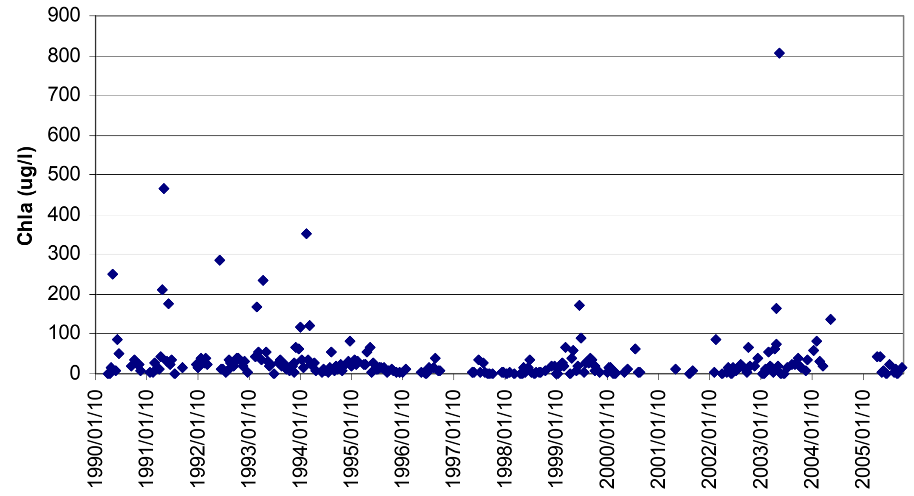
1: ALLEMANSKRAAL DAM IN-LAKE CHLOROPHYLL-A



2: BARRAGE IN_LAKE CHLOROPHYLL-A

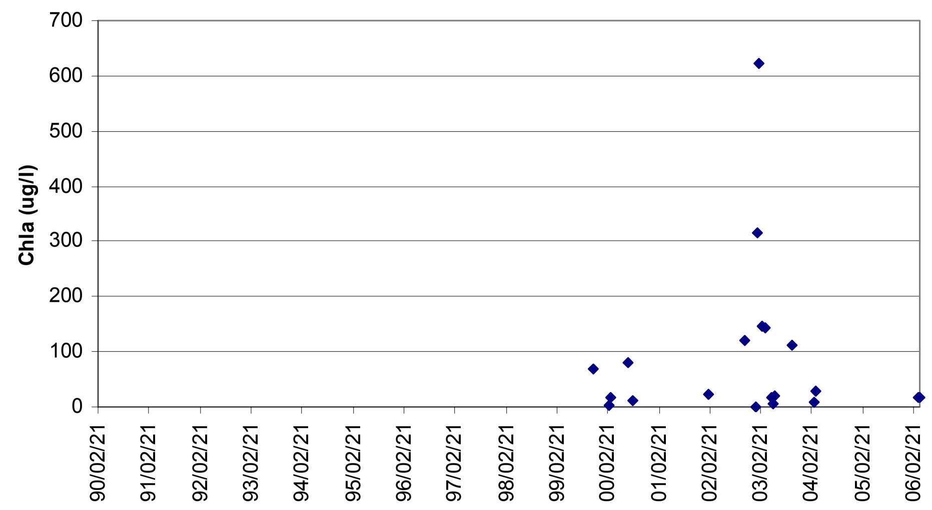


3. BLOEMHOF DAM IN-LAKE CHLOROPHYLL-A

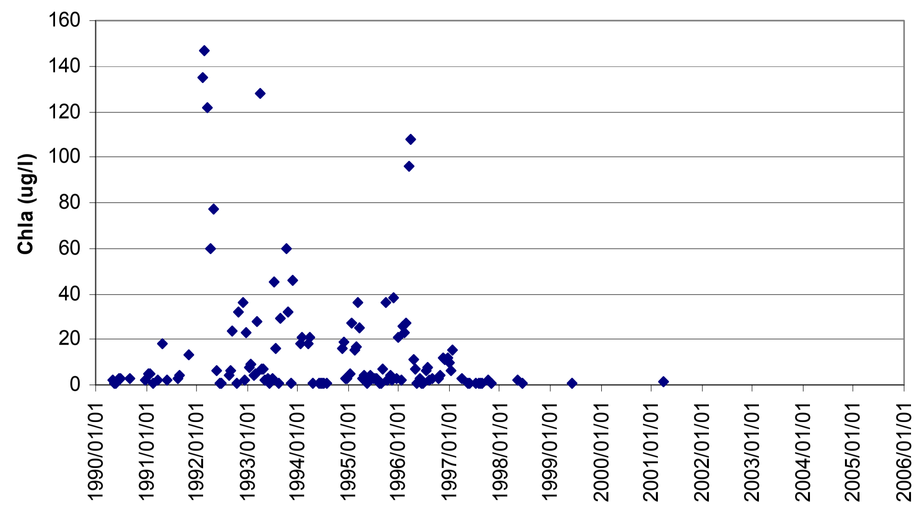


4: BLYDERIVIERPOORT
NO DATA

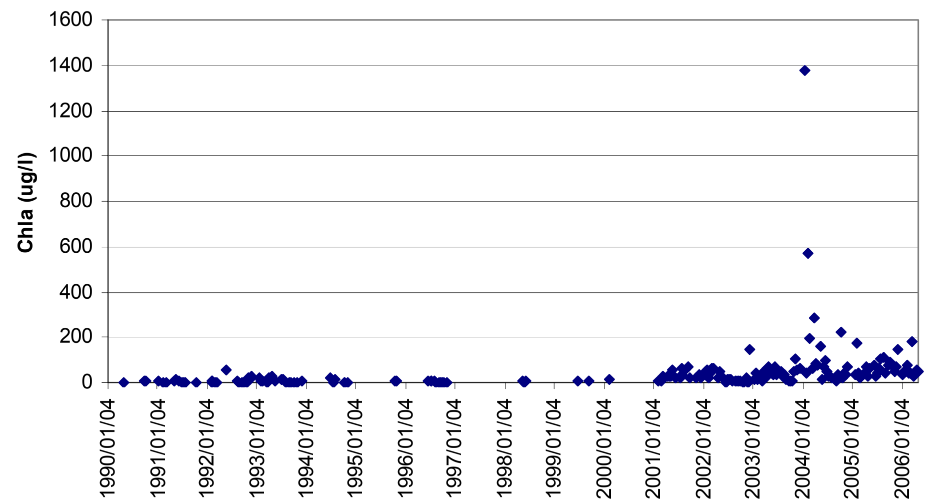
5: BOSPOORT DAM IN-LAKE CHLOROPHYLL-A



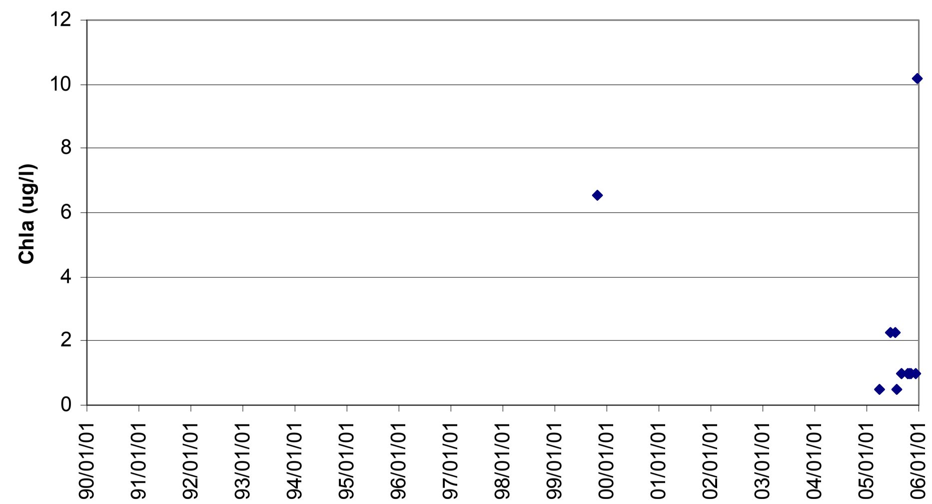
6: BRIDLEDRIFT DAM IN-LAKE CHLOROPHYLL-A



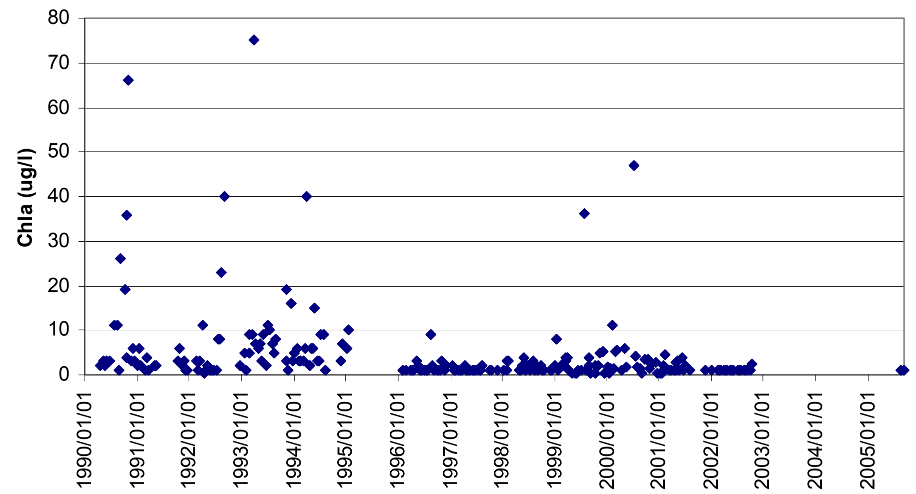
7: BRONKHORSTSPRUIT DAM IN-LAKE CHLOROPHYLL-A

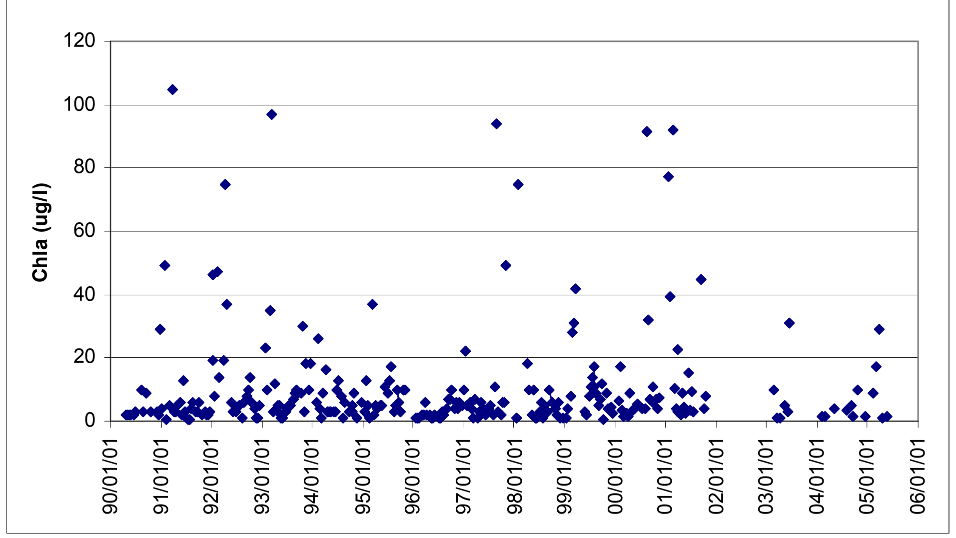


8: BULSHOEK DAM IN-LAKE CHLOROPHYLL-A

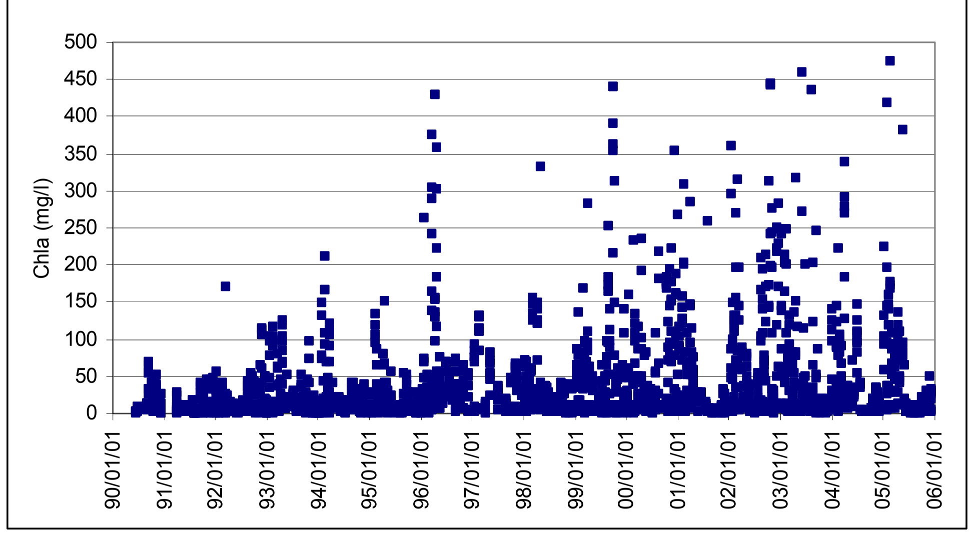


9: ERFENIS DAM IN-LAKE CHLOROPHYLL-A

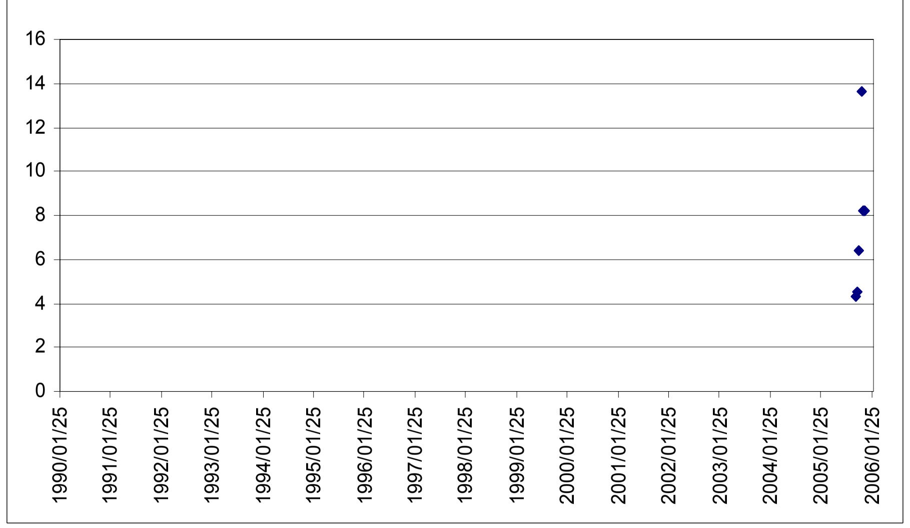


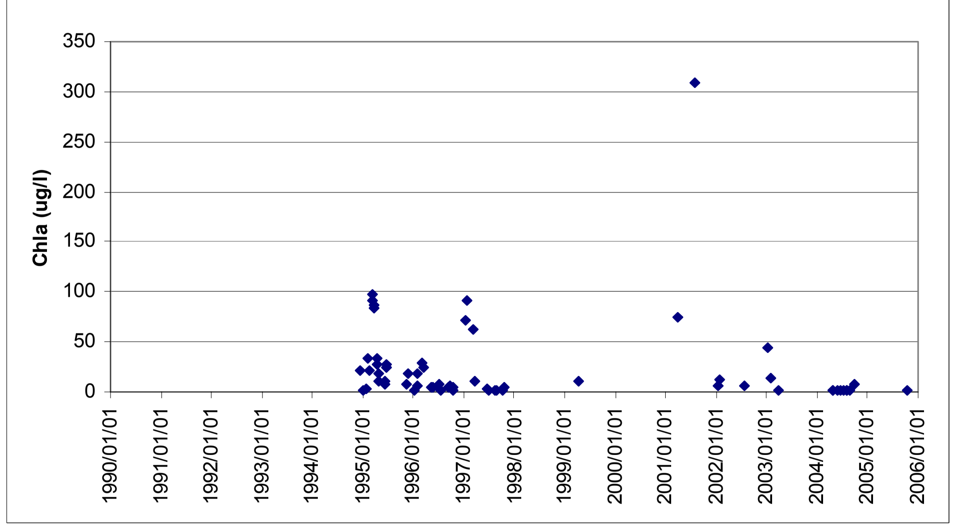


10: GROOTDRAAI DAM IN-LAKE TOTAL CHLOROPHYLL-A

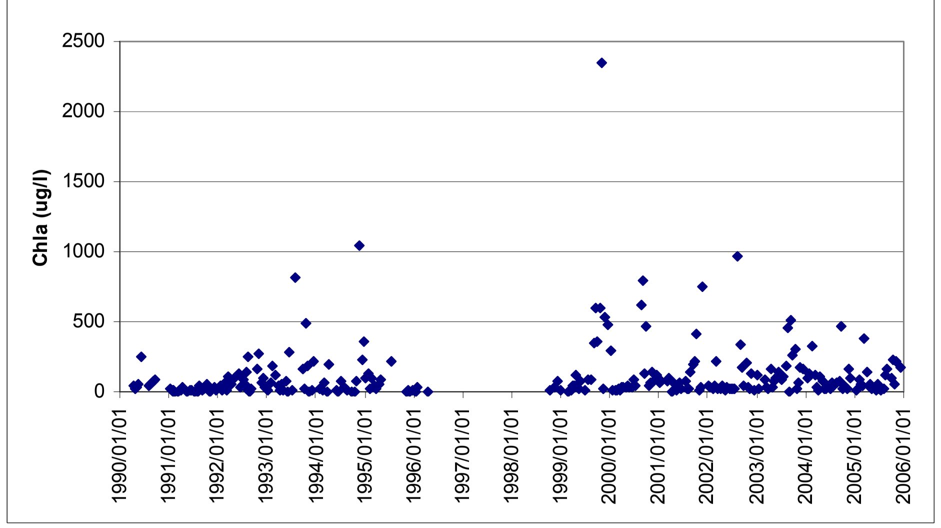


11. HARTBEESPOORT DAM IN-LAKE CHLOROPHYLL-A

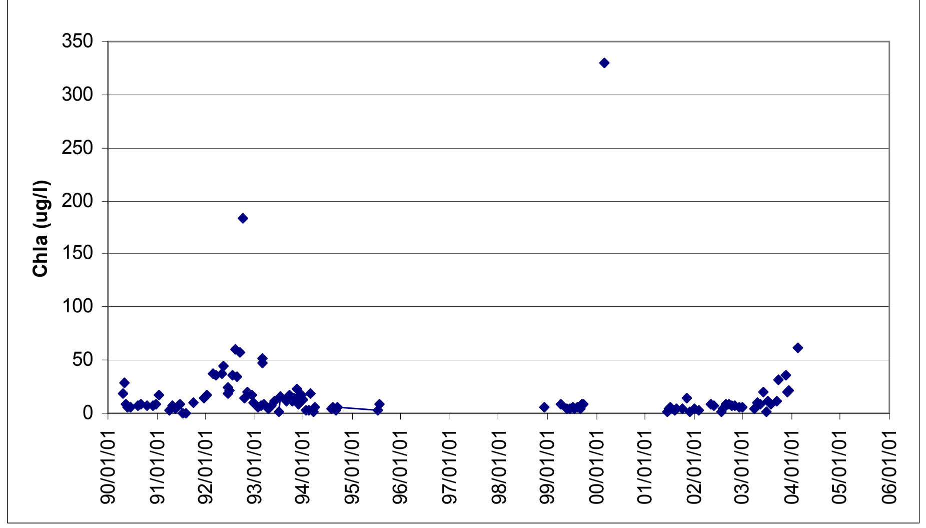

12. KALKFONTEIN IN-LAKE CHLOROPHYLL-A



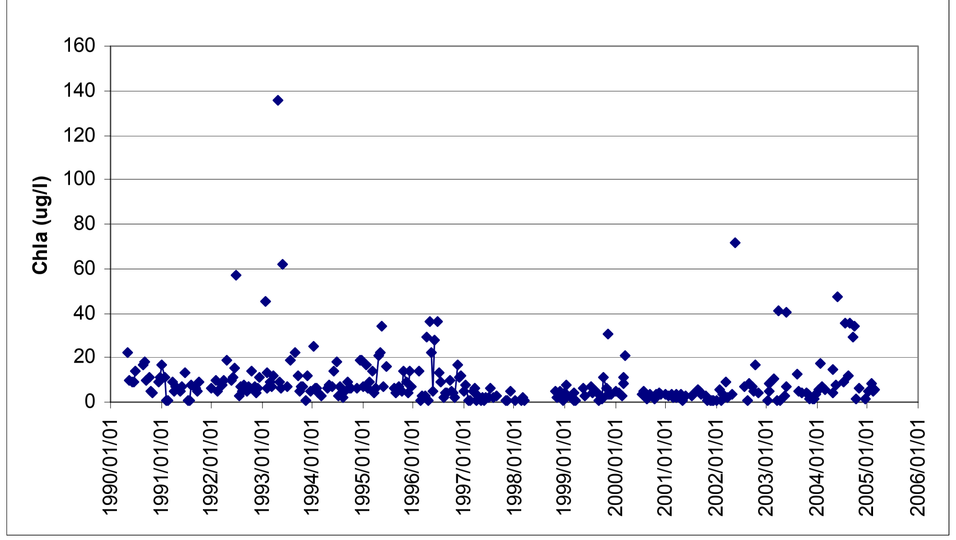
13: KLIPFONTEIN DAM IN-LAKE CHLOROPHYLL-A



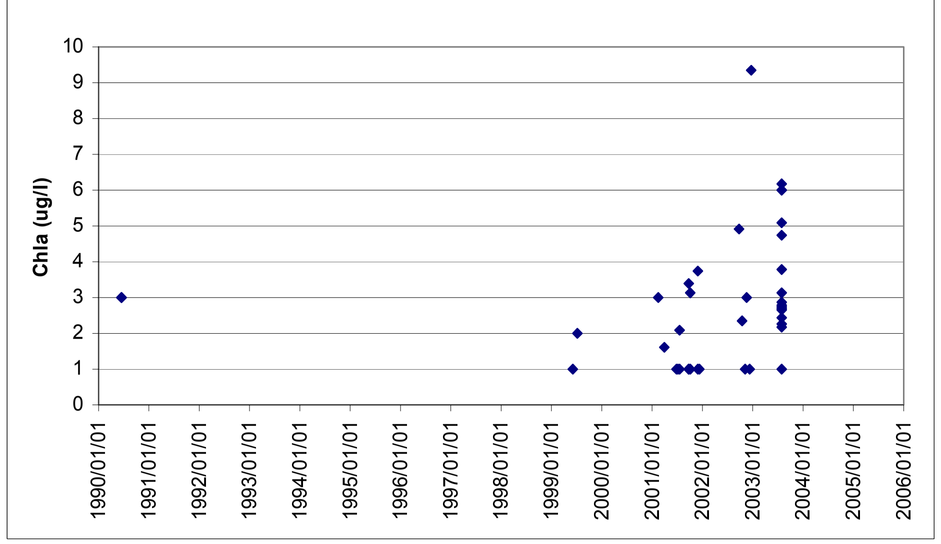
14: KLIPVOOR DAM IN-LAKE CHLOROPHYLL-A



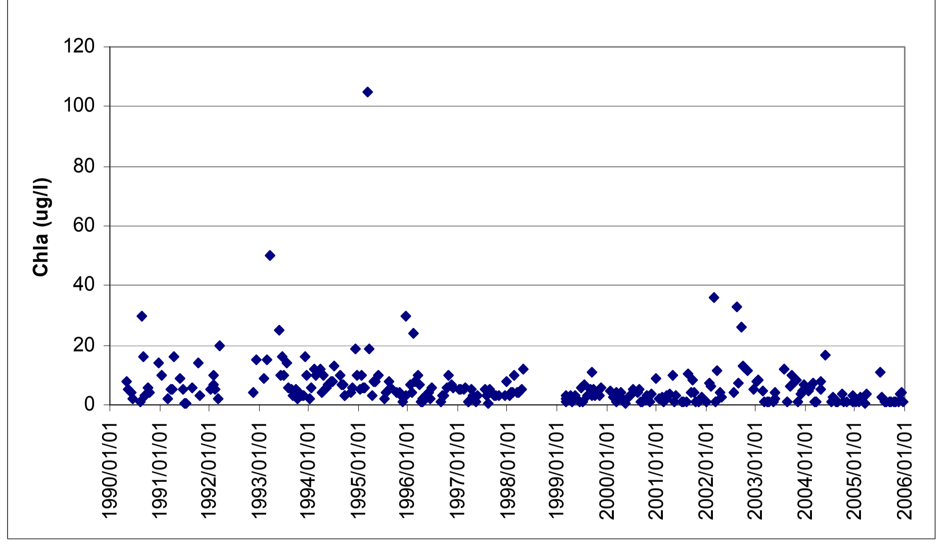
15: KOPPIES DAM IN-LAKE CHLOROPHYLL-A



16. KOSTERIVIER IN-LAKE CHLOROPHYLL-A

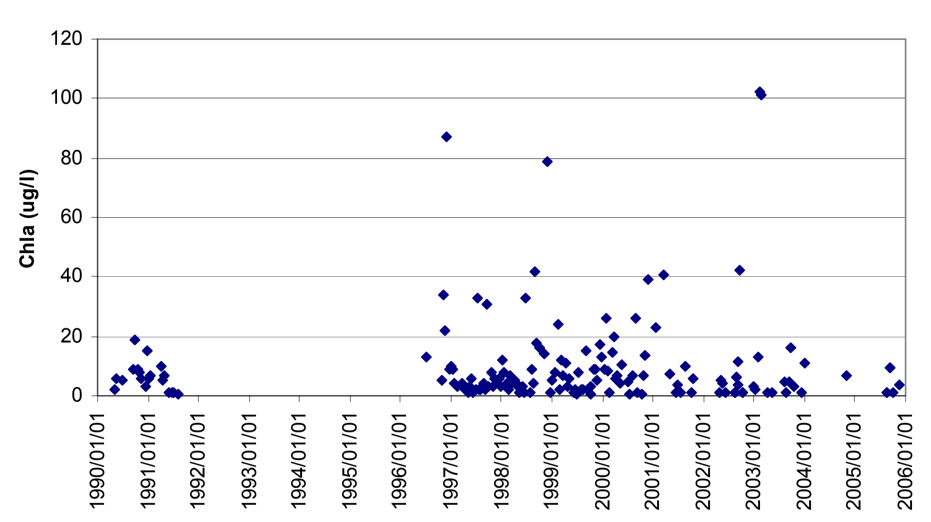


17: LAING DAM IN-LAKE CHLOROPHYLL-A

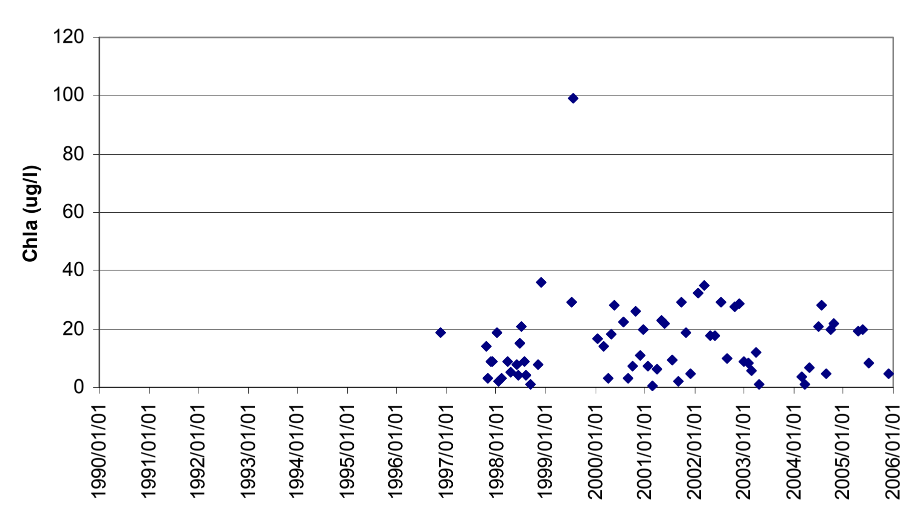


18: LINDLEYSPOORT DAM IN-LAKE CHLOROPHYLL-A

19: MISVERSTAND DAM IN-LAKE CHLOROPHYLL-A



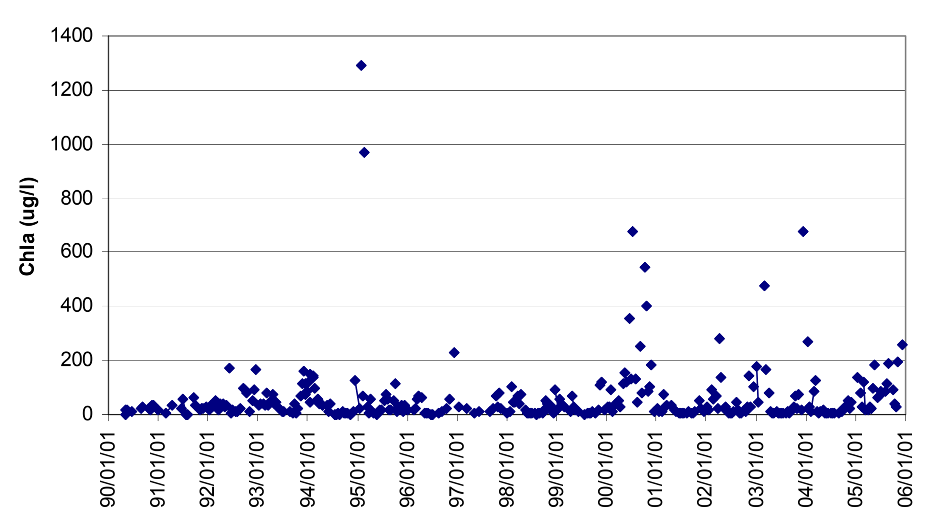
20: MODIMOLA DAM IN-LAKE CHLOROPHYLL-A



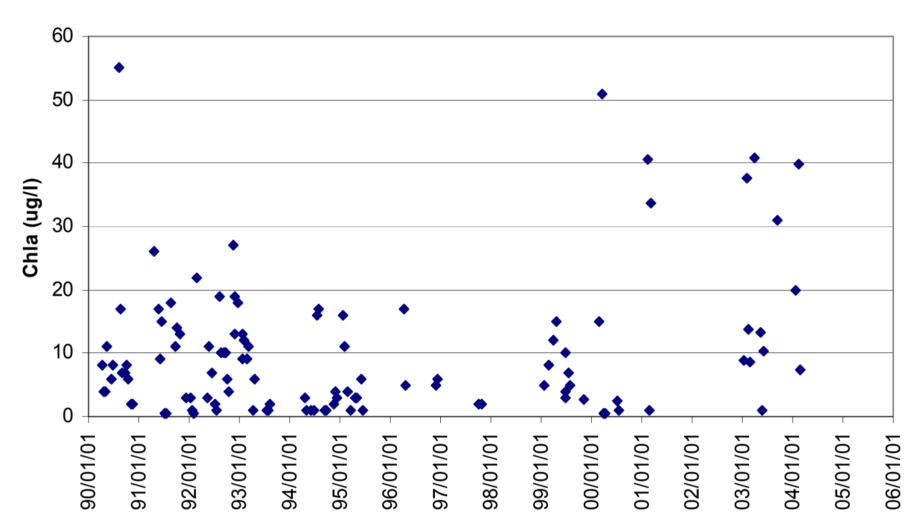
21: NAHOON DAM IN-LAKE CHLOROPHYLL-A

NO DATA

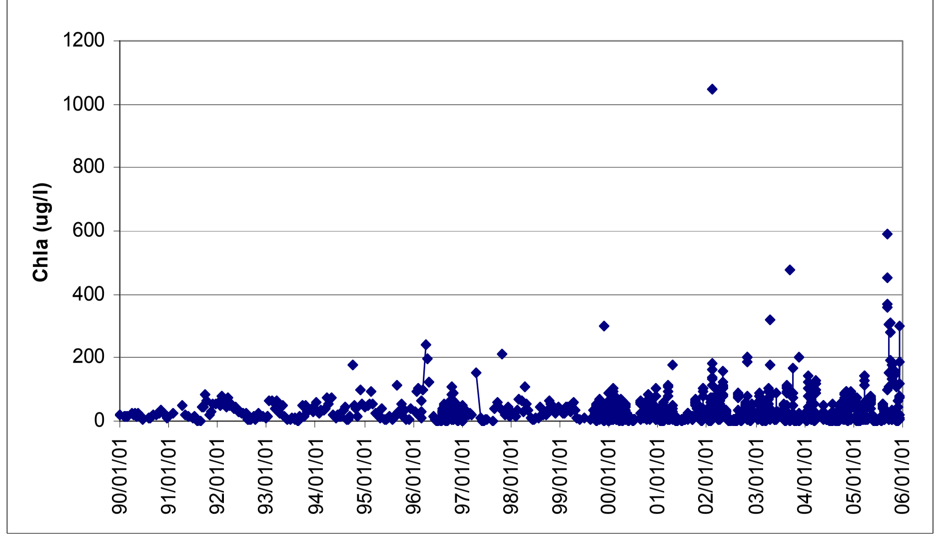
22: RIETVLEI DAM IN-LAKE CHLOROPHYLL-A



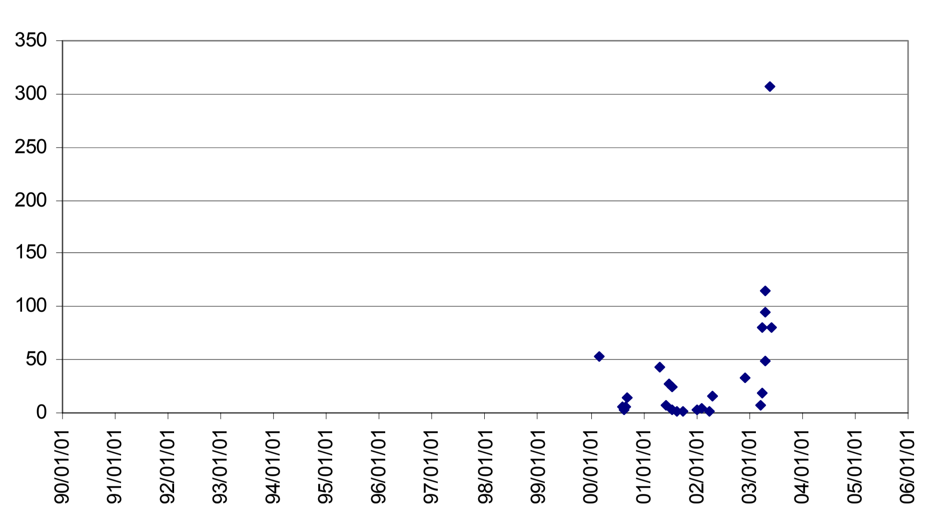
23: ROODEKOPJES DAM IN-LAKE CHLOROPHYLL-A



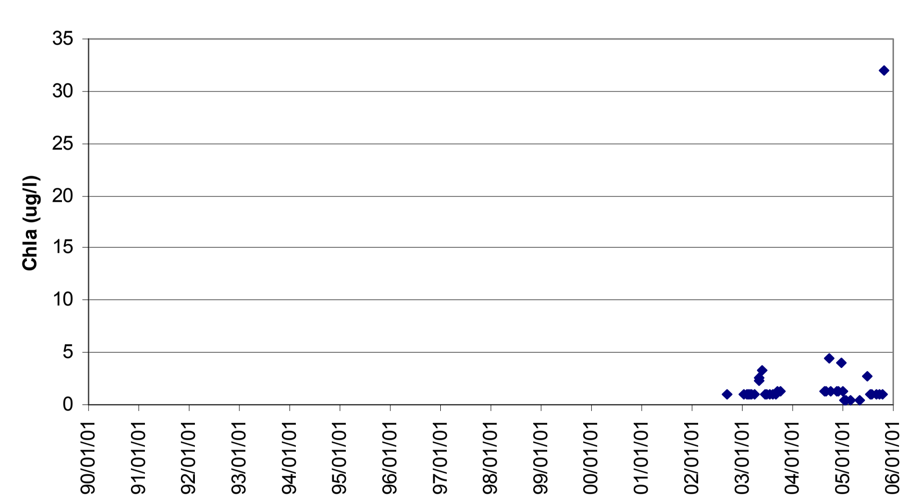
24: ROODEPLAAT DAM IN-LAKE CHLOROPHYLL-A



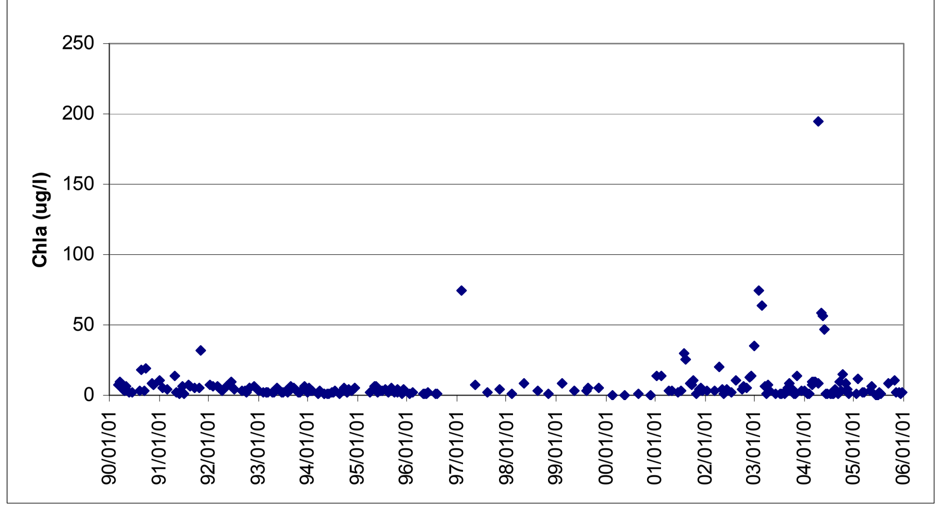
25: SPITSKOP DAM IN-LAKE CHLOROPHYLL-A

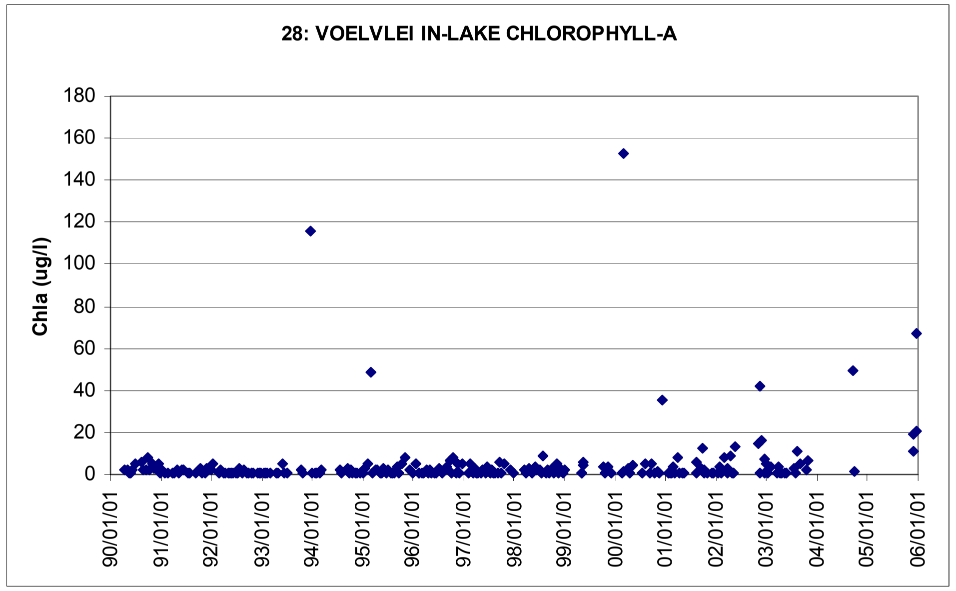


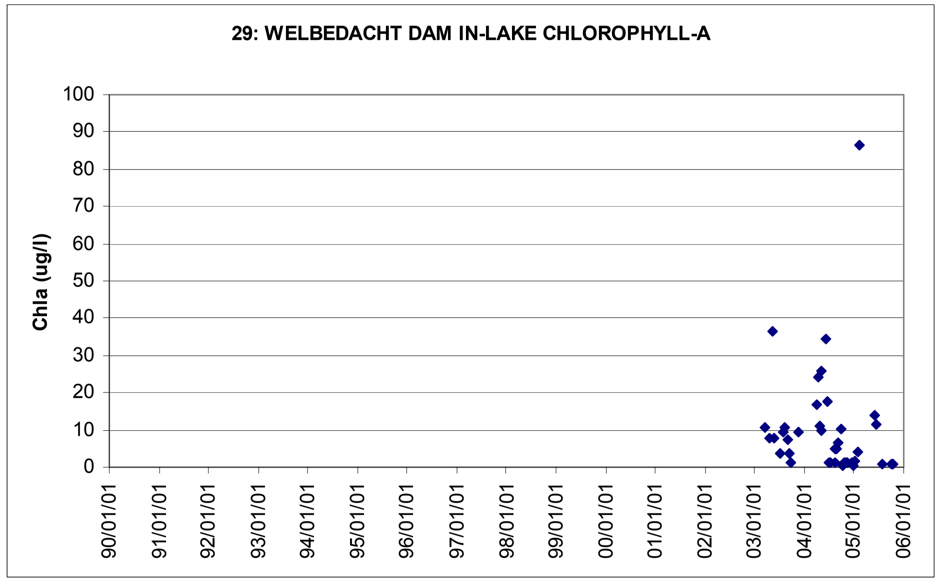
26: UMTATA DAM IN-LAKE CHLOROPHYLL-A

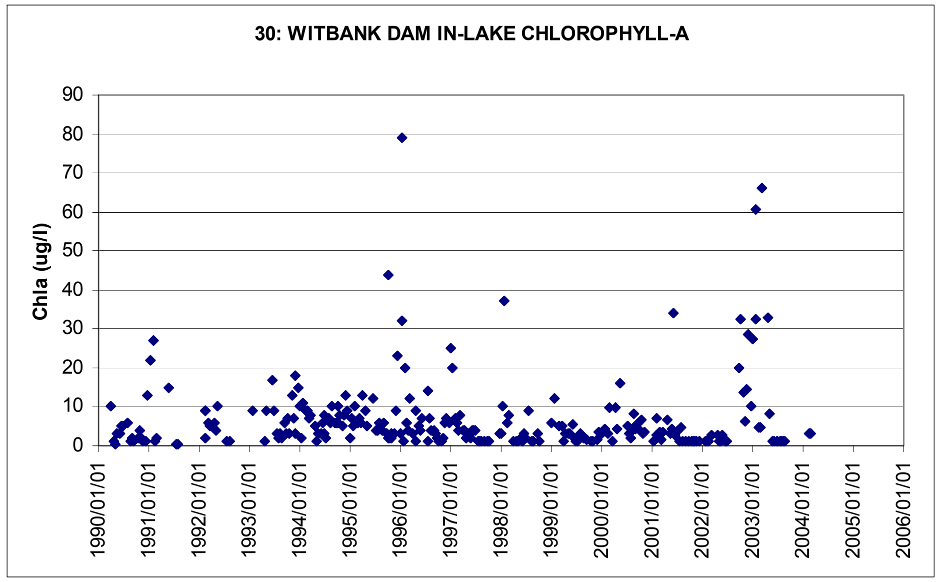


27: VAAL DAM IN-LAKE CHLOROPHYLL-A




28: VOELVLEI IN-LAKE CHLOROPHYLL-A
Chla (ug/l)

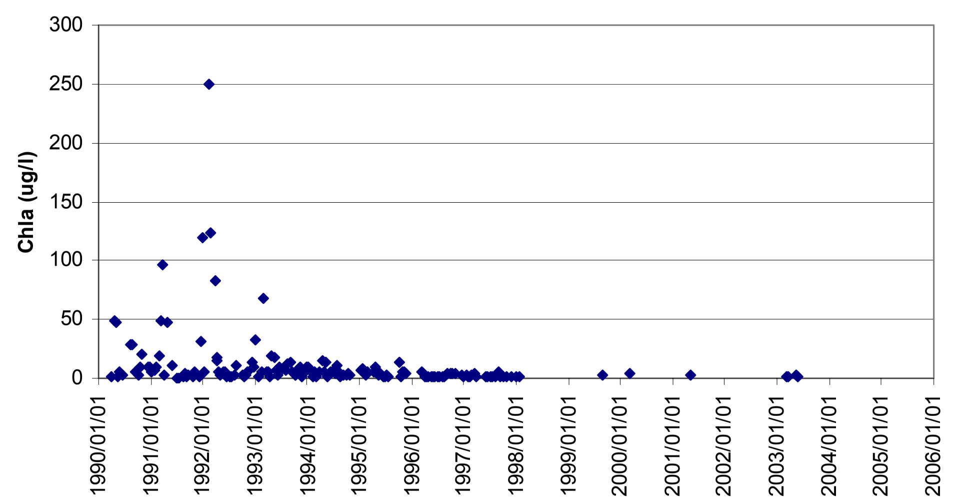

29: WELBEDACHT DAM IN-LAKE CHLOROPHYLL-A
Chla (ug/l)


30: WITBANK DAM IN-LAKE CHLOROPHYLL-A
Chla (ug/l)

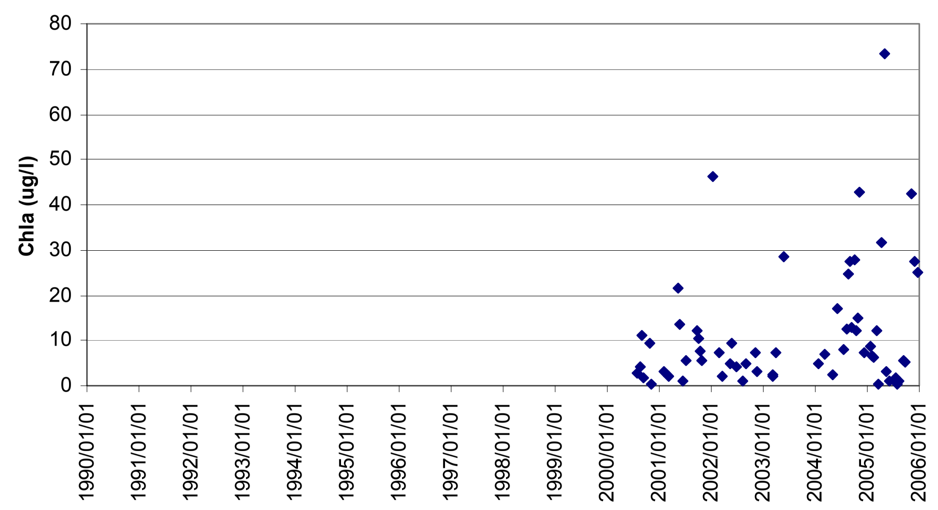
APPENDIX C

IN-LAKE CHLOROPHYLL-A DATA SUMMARIES

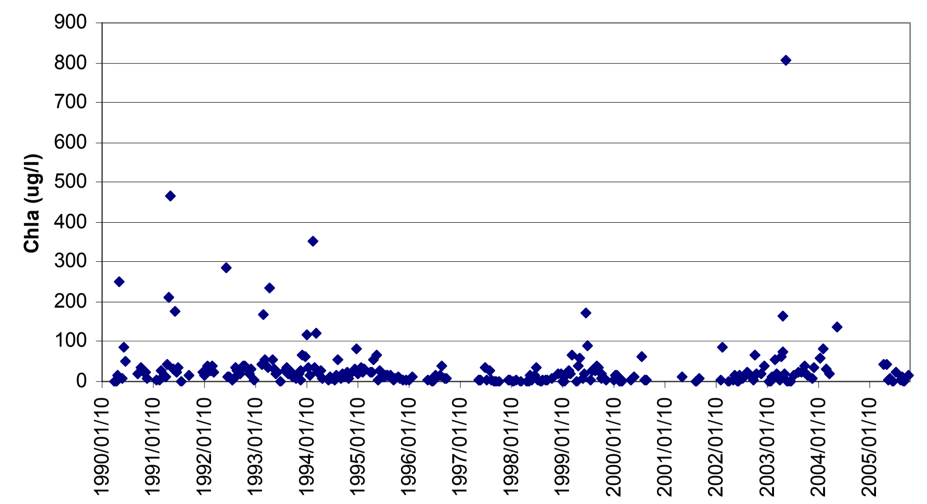
1: ALLEMANSKRAAL DAM IN-LAKE CHLOROPHYLL-A



2: BARRAGE IN_LAKE CHLOROPHYLL-A

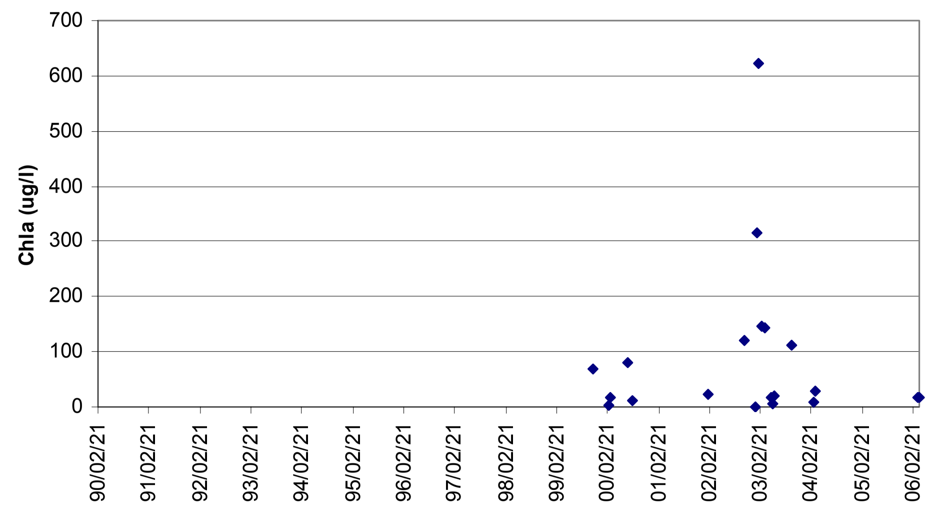


3. BLOEMHOF DAM IN-LAKE CHLOROPHYLL-A

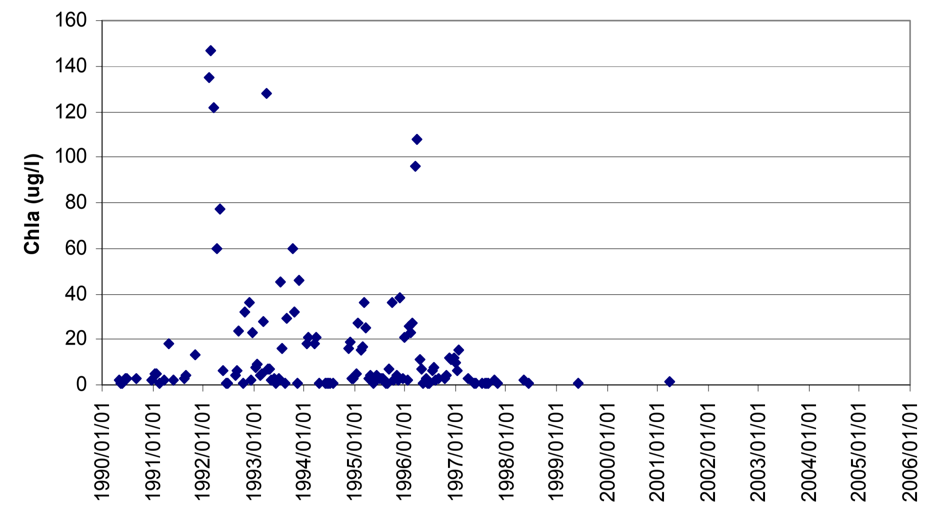


4: BLYDERIVIERPOORT
NO DATA

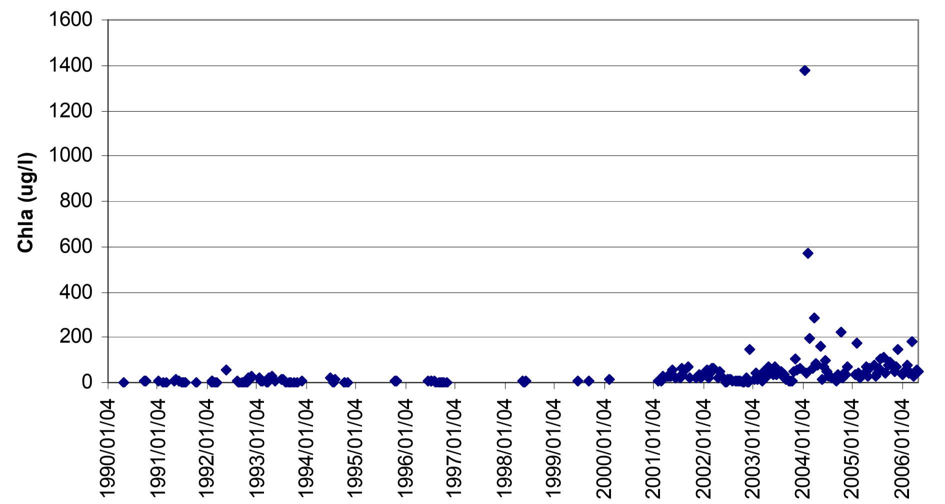
5: BOSPOORT DAM IN-LAKE CHLOROPHYLL-A



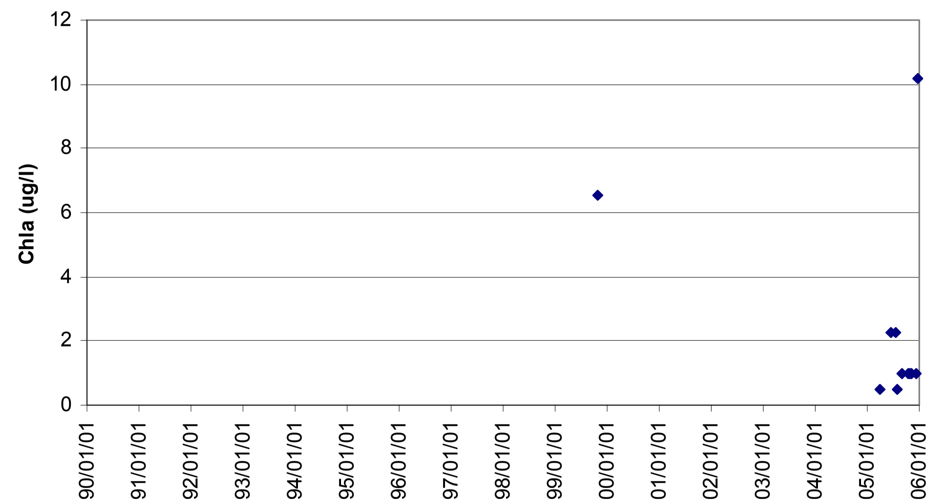
6: BRIDLEDRIFT DAM IN-LAKE CHLOROPHYLL-A



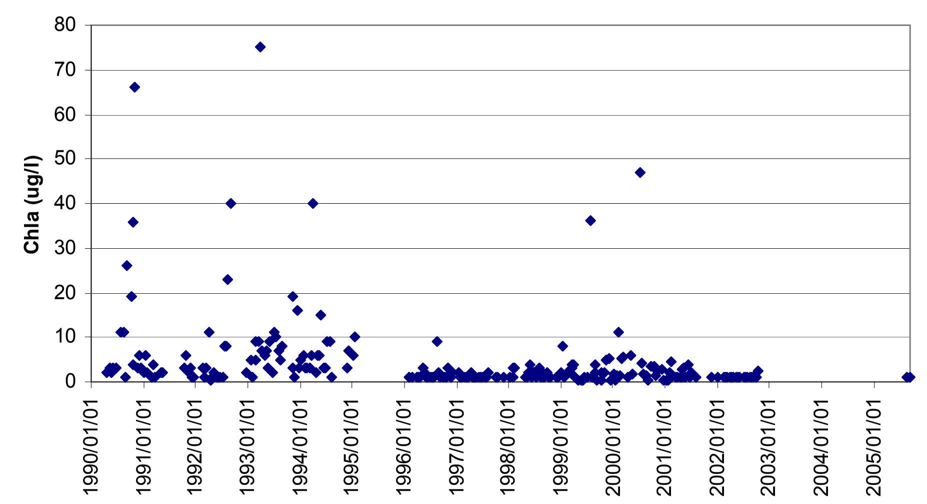
7: BRONKHORSTSPRUIT DAM IN-LAKE CHLOROPHYLL-A



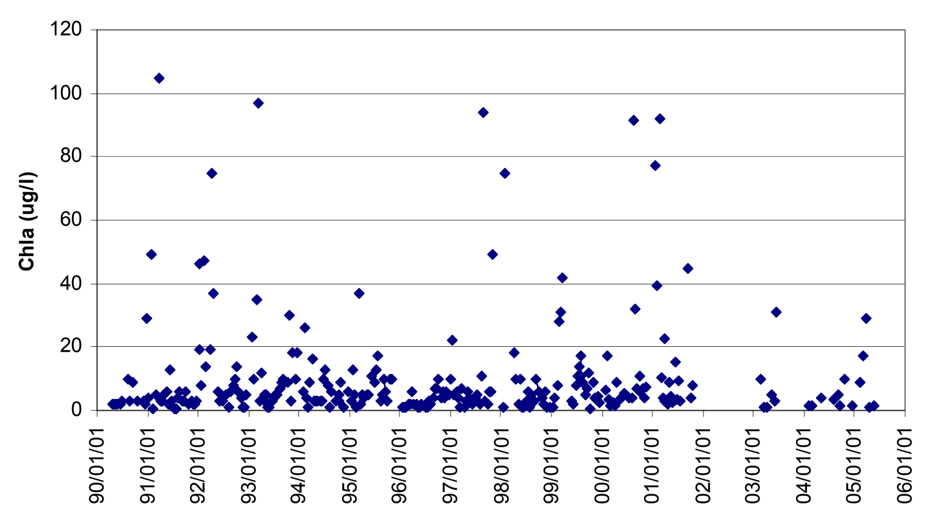
8: BULSHOEK DAM IN-LAKE CHLOROPHYLL-A



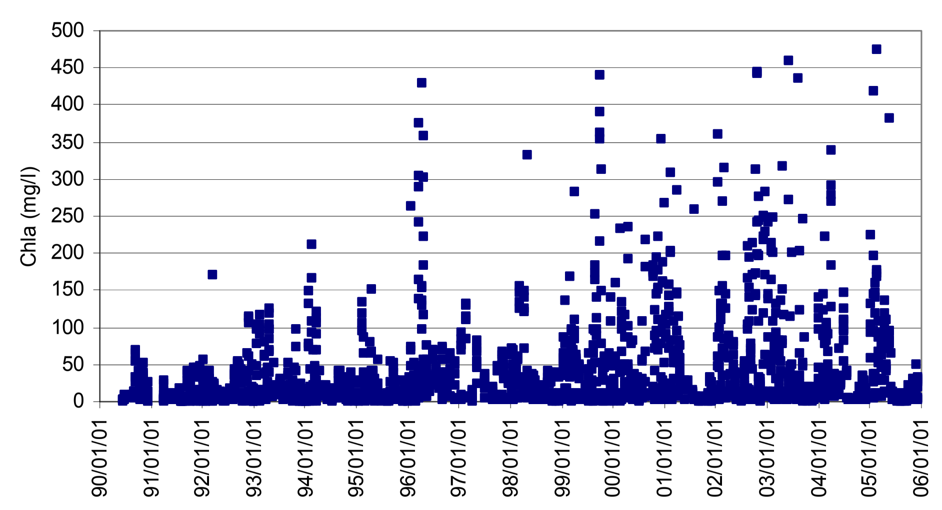
9: ERFENIS DAM IN-LAKE CHLOROPHYLL-A



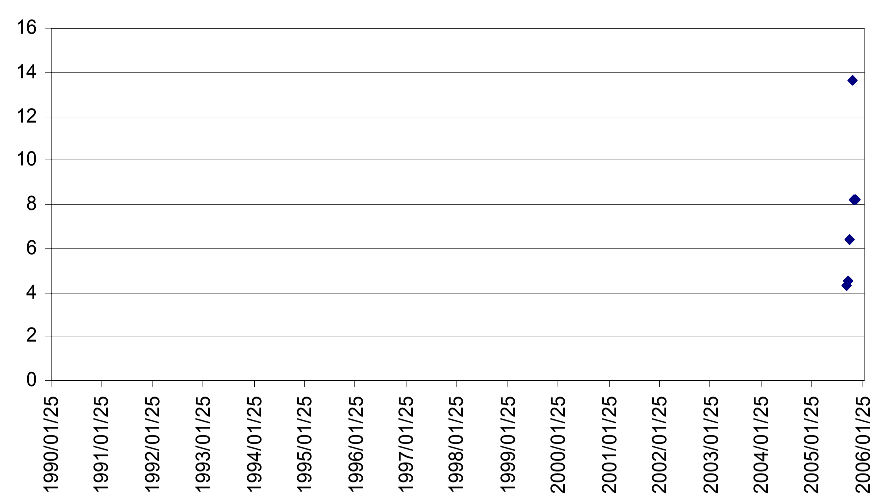
10: GROOTDRAAI DAM IN-LAKE TOTAL CHLOROPHYLL-A



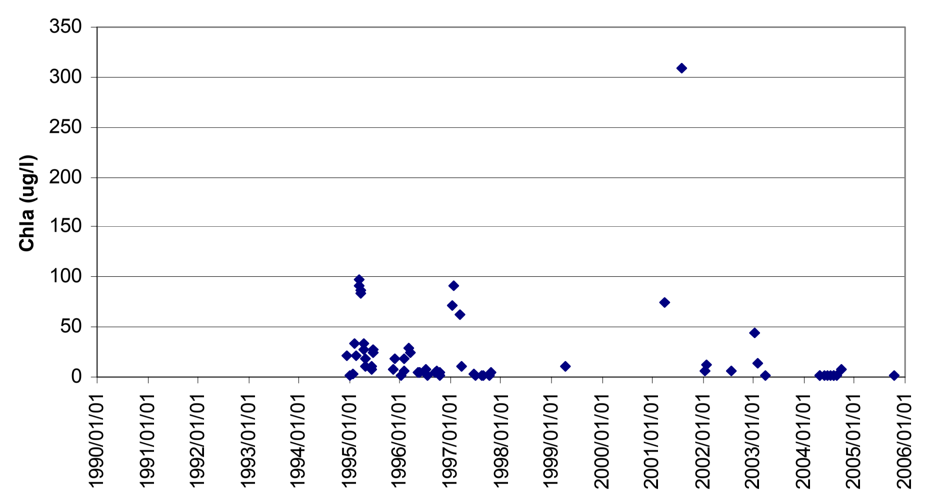
11. HARTBEESPOORT DAM IN-LAKE CHLOROPHYLL-A



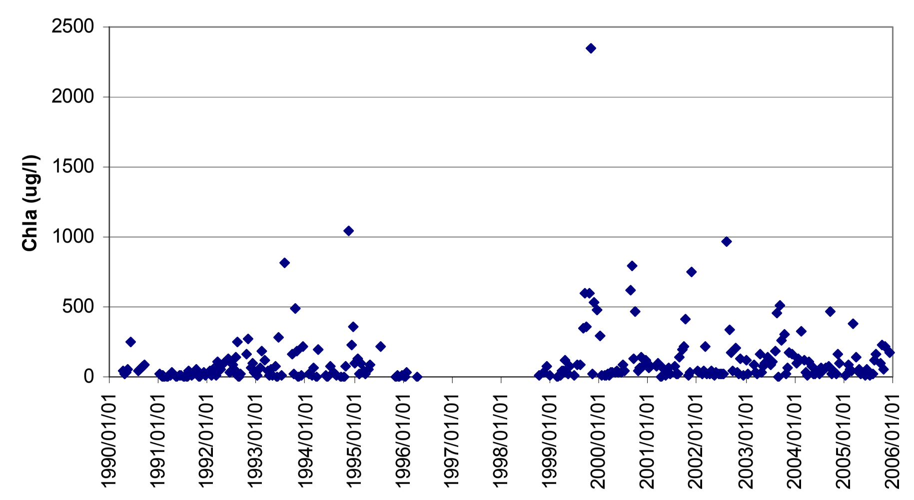
12. KALKFONTEIN IN-LAKE CHLOROPHYLL-A



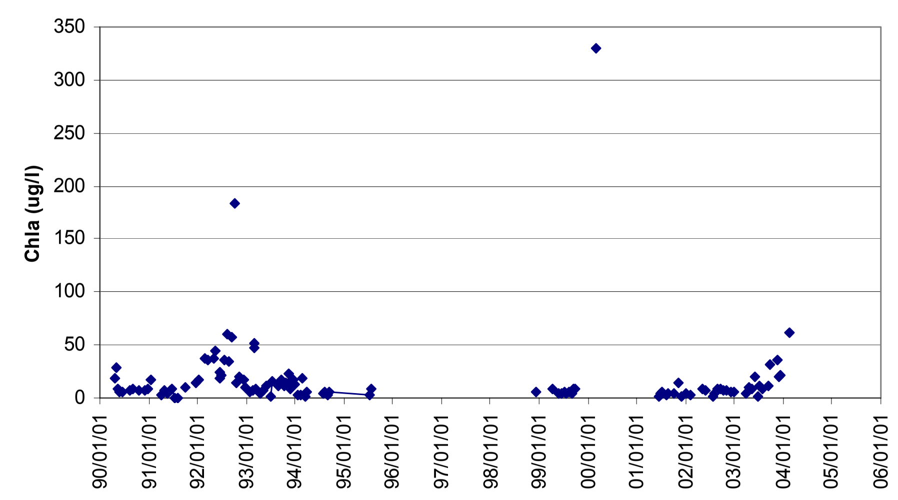
13: KLIPFONTEIN DAM IN-LAKE CHLOROPHYLL-A



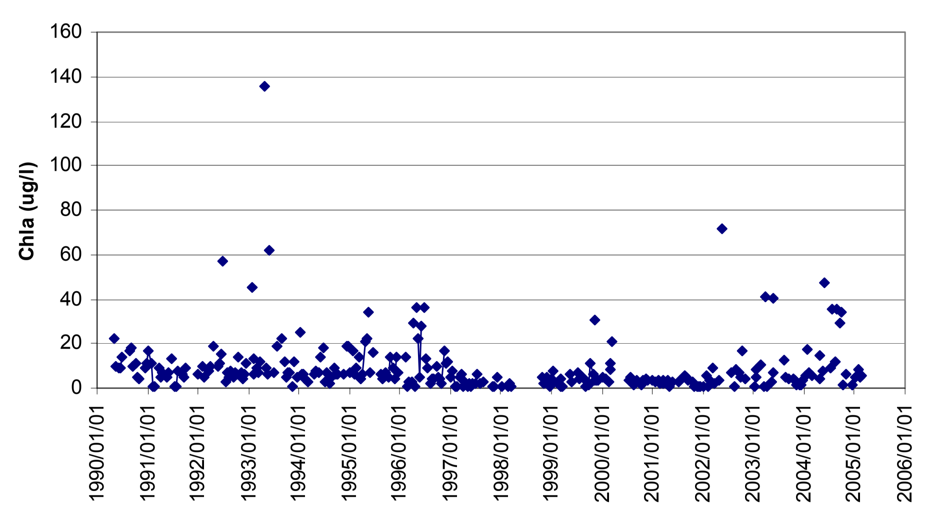
14: KLIPVOOR DAM IN-LAKE CHLOROPHYLL-A



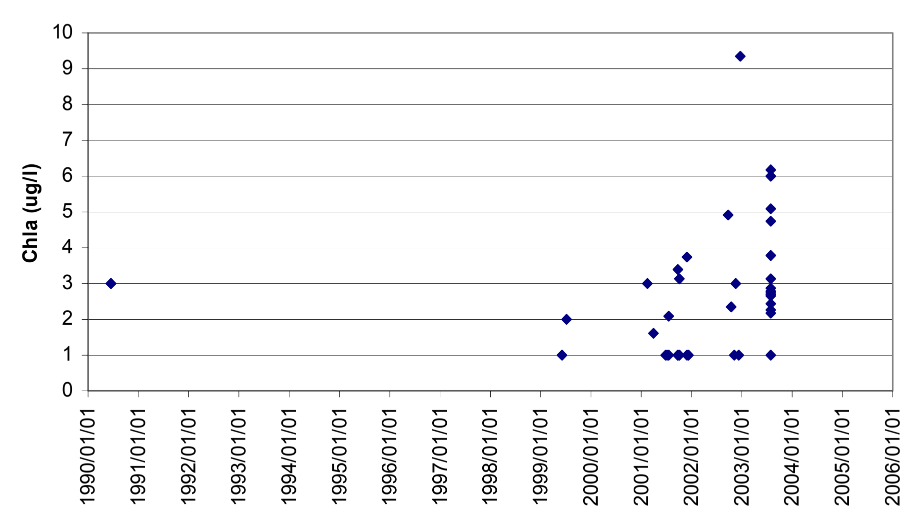
15: KOPPIES DAM IN-LAKE CHLOROPHYLL-A



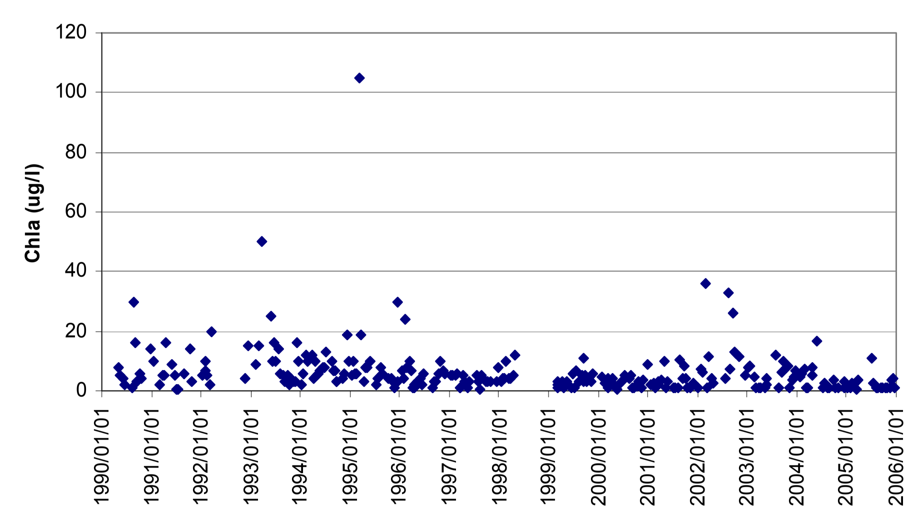
16. KOSTERIVIER IN-LAKE CHLOROPHYLL-A



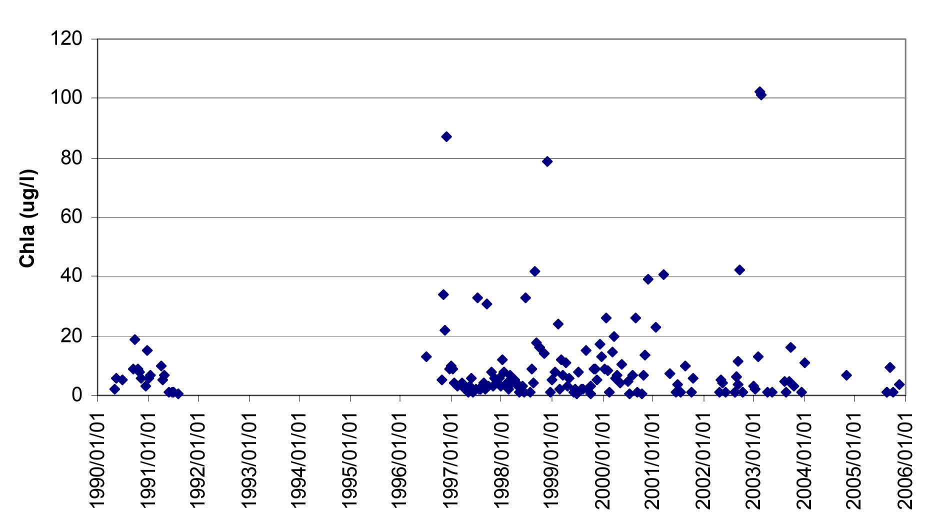
17: LAING DAM IN-LAKE CHLOROPHYLL-A



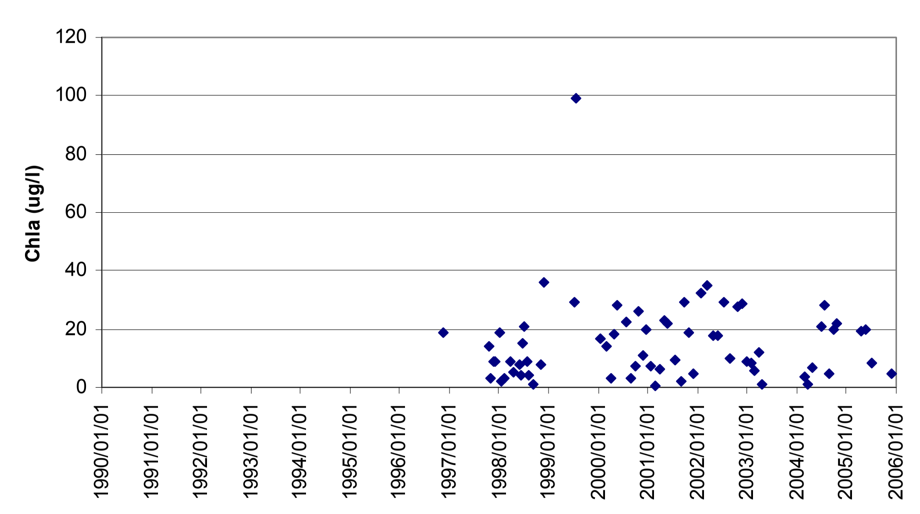
18: LINDLEYSPOORT DAM IN-LAKE CHLOROPHYLL-A



19: MISVERSTAND DAM IN-LAKE CHLOROPHYLL-A



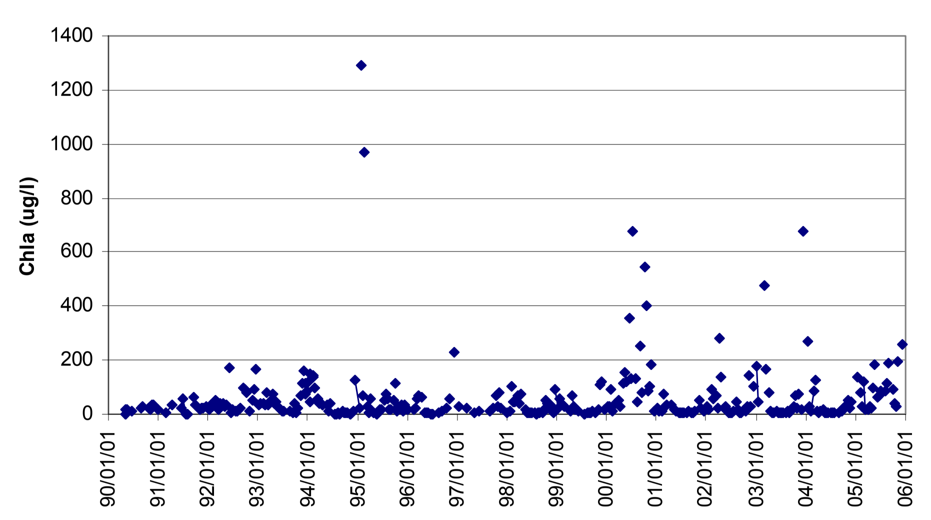
20: MODIMOLA DAM IN-LAKE CHLOROPHYLL-A



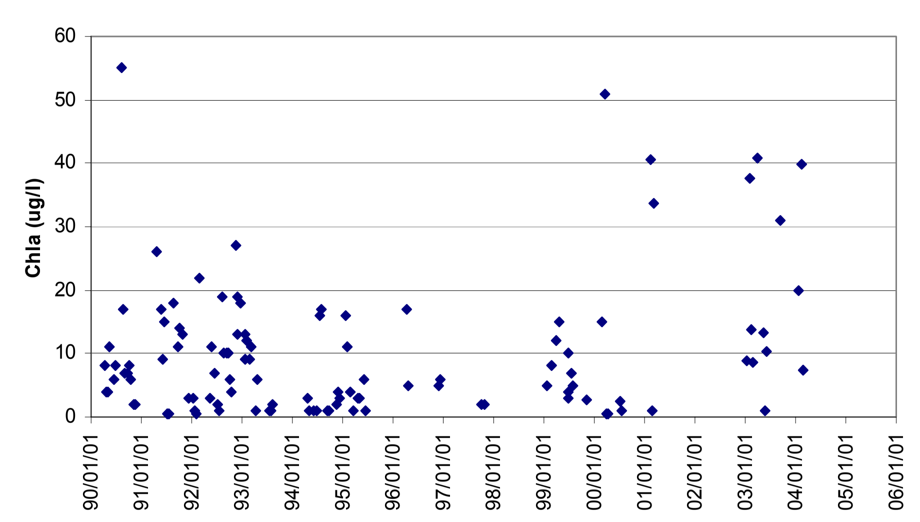
21: NAHOON DAM IN-LAKE CHLOROPHYLL-A

NO DATA

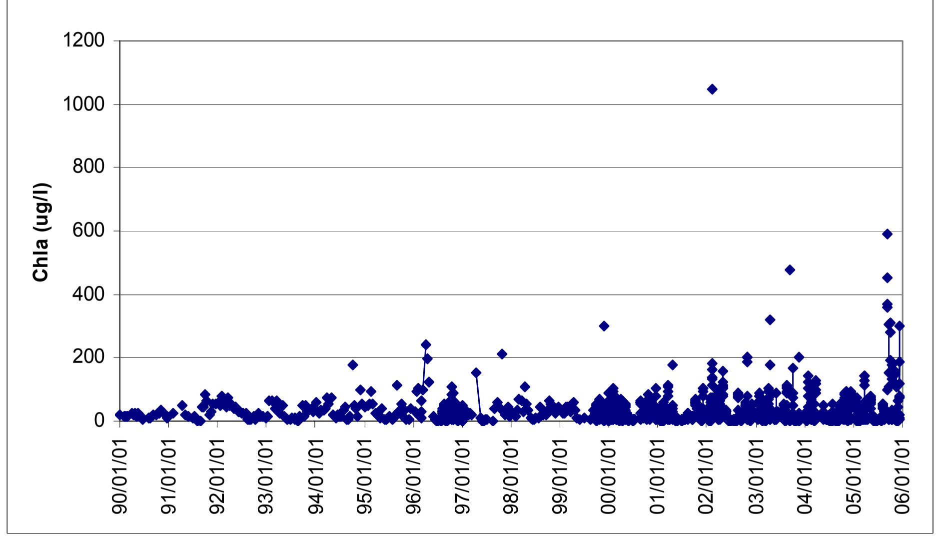
22: RIETVLEI DAM IN-LAKE CHLOROPHYLL-A



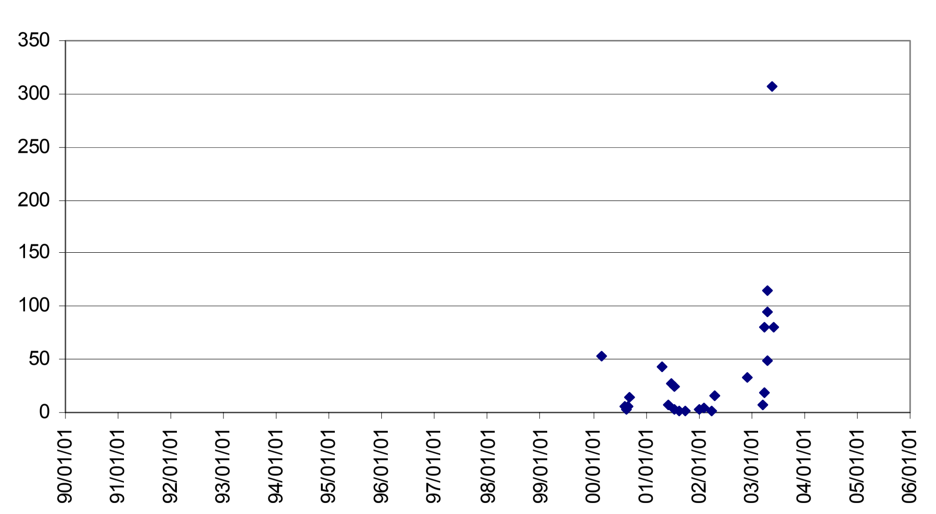
23: ROODEKOPJES DAM IN-LAKE CHLOROPHYLL-A



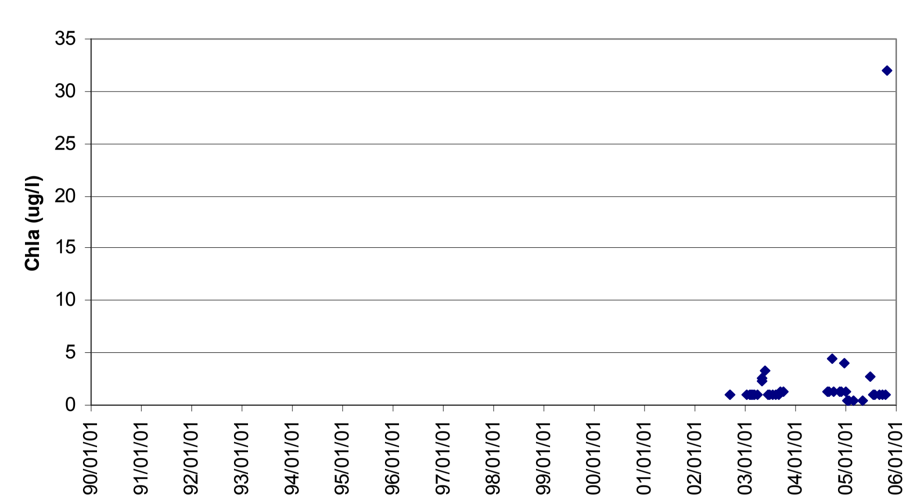
24: ROODEPLAAT DAM IN-LAKE CHLOROPHYLL-A



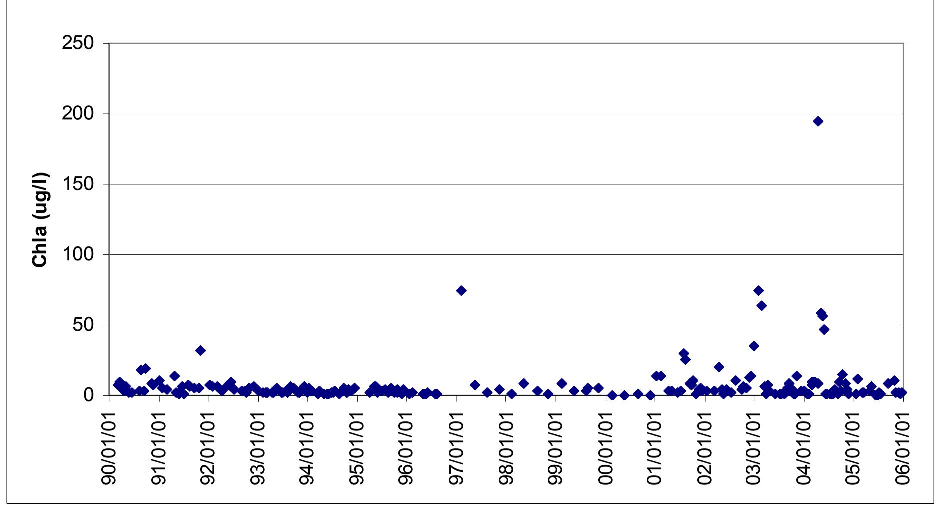
25: SPITSKOP DAM IN-LAKE CHLOROPHYLL-A

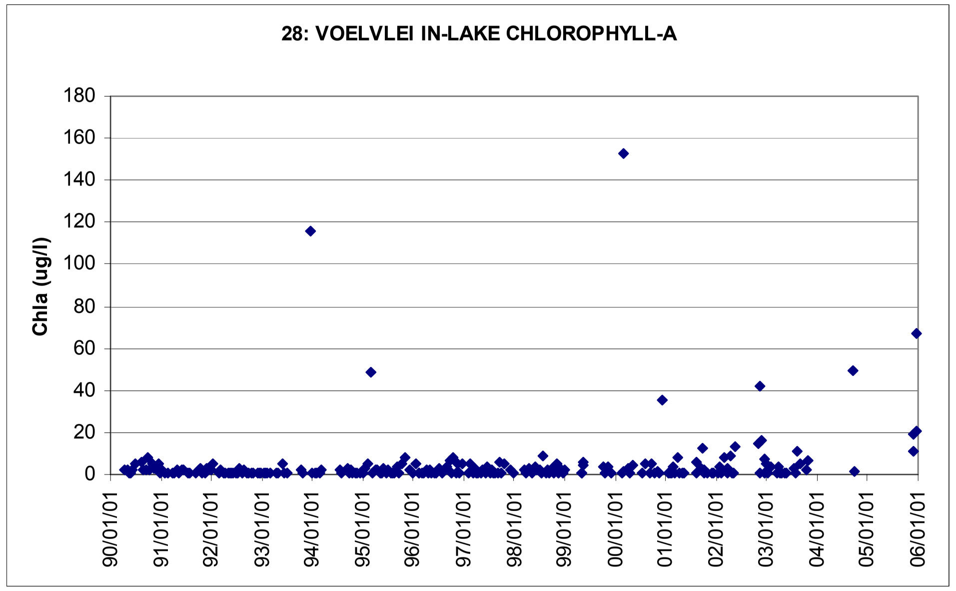


26: UMTATA DAM IN-LAKE CHLOROPHYLL-A



27: VAAL DAM IN-LAKE CHLOROPHYLL-A




28: VOELVLEI IN-LAKE CHLOROPHYLL-A
Chla (ug/l)
180
160
140
120
100
80
60
40
20
0
90/01/01
91/01/01
92/01/01
93/01/01
94/01/01
95/01/01
96/01/01
97/01/01
98/01/01
99/01/01
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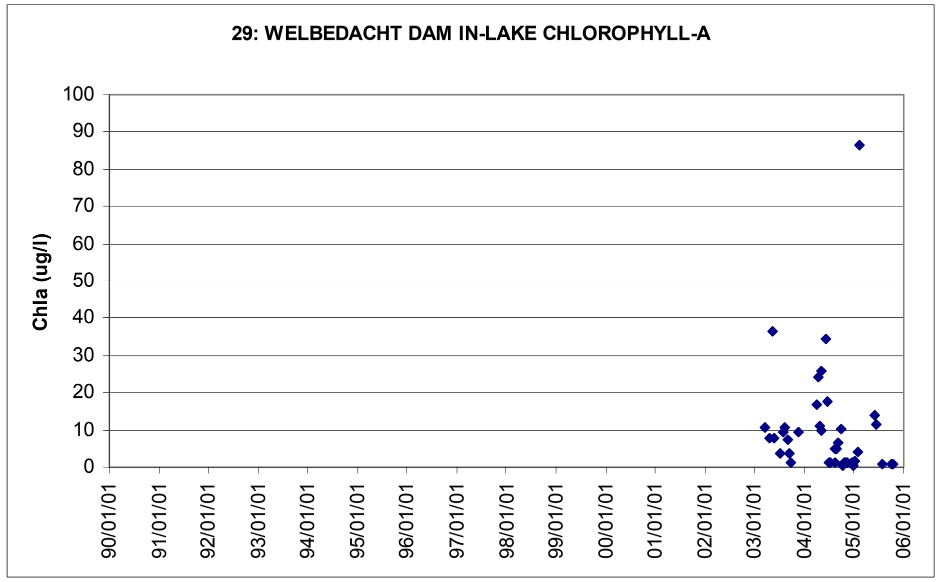
03/01/01
04/01/01
05/01/01
06/01/01


29: WELBEDACHT DAM IN-LAKE CHLOROPHYLL-A
Chla (ug/l)
100
90
80
70
60
50
40
30
20
10
0
90/01/01
91/01/01
92/01/01
93/01/01
94/01/01
95/01/01
96/01/01
97/01/01
98/01/01
99/01/01
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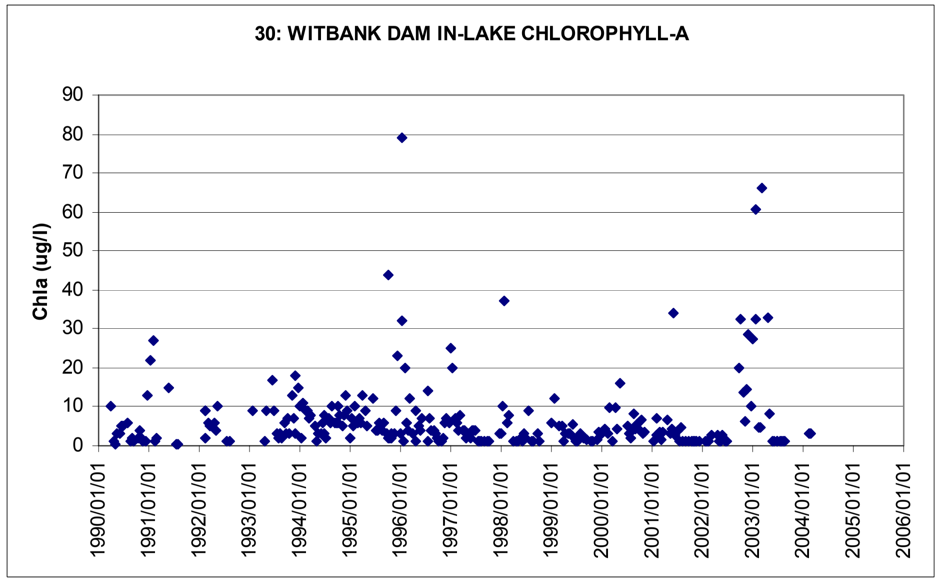
04/01/01
05/01/01
06/01/01


30: WITBANK DAM IN-LAKE CHLOROPHYLL-A
Chla (ug/l)
90
80
70
60
50
40
30
20
10
0
1990/01/01
1991/01/01
1992/01/01
1993/01/01
1994/01/01
1995/01/01
1996/01/01
1997/01/01
1998/01/01
1999/01/01
2000/01/01
2001/01/01
2002/01/01
2003/01/01
2004/01/01
2005/01/01
2006/01/01