# THE IMPACTS OF HIGH WINTER FLOW RELEASES FROM AN IMPOUNDMENT ON IN-STREAM ECOLOGICAL PROCESSES

Report to the Water Research Commission

by

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# Executive Summary

## Abstract

The Albert Falls Dam on the uMngeni River in KwaZulu-Natal, South Africa, provides an ideal system in which to test the impacts of downstream water releases on the river ecosystem. The particular system releases high flow volumes during the winter dry season and lower volumes during the summer wet season, thus exhibiting a reversed hydrograph situation. Considerable data on the hydrology, water quality and biological composition existed from previous monitoring programmes, which were supplemented by additional surveys during this project.

This project firstly set out to document the potential causes of downstream ecological stress, in particular the flow volumes and the quality of the water released from the dam. It was speculated that while the seasonal release of flow volumes was significantly altered, it was probably the loss of variability, both in the short and long term, that created the greatest stress. With regard to the quality of the water released, it was found that the quality of the scour water during summer was not as different to a natural reference site as had been anticipated. Mean temperatures of the scour water were close to the natural situation but the diurnal range was substantially curtailed. This latter was a possible but untested source of stress on the downstream system. The chemical content of the water indicated two main potential sources of stress, i.e. excessive concentrations of ammonia and manganese. The former, in particular, was rapidly removed from the system by natural chemical processes while the latter persisted at a reducing concentration for the entire 54 km of the downstream river that was monitored.

Following on from this was an investigation into the signs of stress that were being exhibited by the ecosystem. Investigation of the riparian vegetation, the fish and the invertebrates all revealed that while there were significant changes induced by the dam, these were rapidly ameliorated with distance downstream, probably due to the ingress of tributary water and the processes of purification that remove toxic substances from the water. The greatest changes were to fish and macroinvertebrate population structures and dominance by species, but the implications of these could only be proposed. Attempts to prove the causal relationship between physical and chemical variables and the resulting biotic changes were not successful, but speculations have been made. From these, a guideline for the management of water releases from dams in summer rainfall areas is presented.

The central conclusion of this project is that, while the quality and quantity of water released from the dam does not pose an obvious threat to the downstream river environment at a distance beyond a few kilometres, there are without doubt significant changes to the ecosystem including its biodiversity. Whether these changes are unacceptable is difficult to

evaluate in terms of the Water Act (1998) but in terms of the National Environmental Management Act (1998), these changes may be unacceptable.

## Introduction

Water Boards and all other similar authorities (e.g. Department of Water Affairs and Forestry, Irrigation Boards etc.) charged with managing and manipulating large dams for whatever reason, have a legal responsibility under the National Environmental Management Act (NEMA, 1998) to minimise environmental damage caused by their operations. One of the largest impacts caused by such organisations is those associated with the damming of the rivers and the release of water to the downstream river. The in-stream ecological impacts of this have not been adequately addressed by these organisations. This includes the situation where the water releases from a dam are out of synchronisation with the "natural" (or un-dammed) flow of water. A typical situation is the water releases between Albert Falls Dam and Nagle Dam, where flow volumes are significantly higher during the dry winter months than during the wet summer. This effectively results in a "reverse hydrograph" and a situation where the fluctuations in river level, normally essential components of river ecology, are almost totally out-of-phase with the natural situation. As a result of this "reverse hydrograph" and the unnatural water flows, there is a potential for ecological damage to the downstream river. In the Southern African context there is a need to better understand this situation as decisions made on inadequate understanding have a material impact on the management of water resources.

The routine monitoring of macroinvertebrates in this Albert Falls Dam to Nagle Dam reach (using SASS) over more than a decade had, from a cursory examination, revealed that the river was in better condition than expected. This rather tenuous conclusion (based on superficial data) has been used as a case study reference for several other investigations in the country, including the Bivane Dam on the Bivane/Phongolo River where it was planned that high winter flow releases would be necessary. As the Albert Falls-Nagle system had been in operation for many years, this provided an ideal system in which to determine the severity of impact on the aquatic environment. Besides complying with the National Environmental Management Act and the National Water Act, a better understanding of this would provide valuable information to environmental flow assessment and Reserve studies around the country, where this type of information is distinctly lacking. It was envisaged that the information provided by this project would allow relevant water authorities to alter the management of water releases to the downstream river in a way that would benefit the environmental. There are also potential health related issues attached to this reverse hydrograph problem as certain pest organisms are advantaged by the "non-natural" flow regime and become pest organisms (e.g. the black fly). This project set out to consider these issues.

### The “reverse hydrograph” phenomenon

An issue that is pertinent to this project has here been labeled the “reverse hydrograph” phenomenon i.e. flow volumes in a river which are the opposite of the natural situation. In the case of the Albert Falls Dam example (in a summer rainfall area) in summer, lower amounts of water are released from the dam because there is sufficient flow generated in the downstream catchment by the high seasonal runoff to supply the downstream demands. However, in winter when the river flows are naturally low and sporadic, operators release larger quantities of water from the dam to supply to the downstream users via Nagle Dam. Such operations may completely reverse the flow hydrograph compared to that of the natural condition (Figure 1). The opposite would be the situation in a winter rainfall area. It has been suggested that both of these scenarios are likely to have a severe influence on the downstream river ecology.

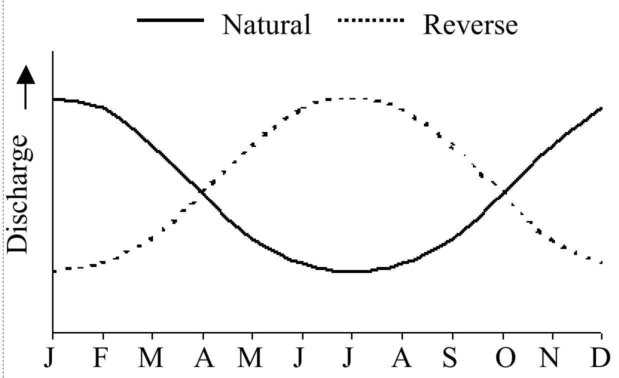


Figure 1: Typical example of hydrographs showing the discharge throughout a year for a “Natural” system and a “Reverse” hydrograph caused by management operations (for impoundments in summer rainfall areas).

### Objectives of this project:

- Determine the ecological impacts of high winter flow volumes (in a summer rainfall area) on the longitudinal profile of the river downstream of an impoundment.
- Determine if bottom (scour) releases are negatively impacting on the downstream aquatic ecosystem.
- Develop management guidelines for environmentally optimal releases of water from dams where these are unnaturally high in winter.
- Provide information to the water community for use in Reserve and EFA determinations as well as provide the means to satisfy the legal requirements of the dam operators.

## Choice of site

The site used for this investigation is well suited to the testing of the assumption that ecological damage will result from high and sustained un-seasonal winter flow releases from a dam in the following way:

- Water is stored in Albert Falls Dam and released into the uMngeni River to supplement the water in Nagle Dam, some 53 km downstream. Water from Nagle Dam is the primary source of water for the city of Durban.
- Albert Falls Dam has been in existence and has operated in this way since its construction in 1976. This means that the downstream river has in all likelihood, been substantially changed to accommodate the artificial flow regime it is subjected to.
- The water released from Albert Falls is regulated for downstream user purposes. Flows are comparatively constant but with higher dry season (winter) and lower wet season flow.
- A tolerably good reference site exists on the Karkloof River only a few km distant from the Albert Falls Dam wall. The river is somewhat smaller than the uMngeni would naturally be but because it is an unregulated river; it provides a suitable control or reference site for comparison. It also has a gauging weir albeit some kilometres upstream of the confluence between the two rivers.
- Gauging weirs exist at the upper and lower extremes of the river between the two dams thus providing good hydrological data for the entire regulated river reach.
- Many years of water quality monitoring have taken place along this stretch of river covering all of the various flow scenarios.
- Over a decade of biological surveys (of invertebrates using the SASS method) have likewise taken place.

## Flow regime below Albert Falls Dam

The typical flow situation in the uMngeni River downstream of Albert Falls Dam is characterized by four scenarios:

- **High volume water releases in winter (~6-8 $m^3$/s).** This is done to supplement supply to Nagle Dam as the supply from the downstream catchment and tributaries diminishes in the dry season.
- **Low volume water releases in summer (~2-3 $m^3$/s).** Supply to Nagle Dam is supplemented by downstream inputs from tributaries during the wet season.
- **Sporadic high flow volumes in summer during wet seasons when the dam overflows.** The dam spills infrequently and may go several years before this situation recurs.
- **Highly variable spring flows**, where flow volumes may drop when rainfall increases. The cause of this is that tributary flow downstream takes over the provision of water to Nagle Dam.

The location of the control site on the Karkloof River and the four sites on the downstream uMngeni River are illustrated in the figure below.

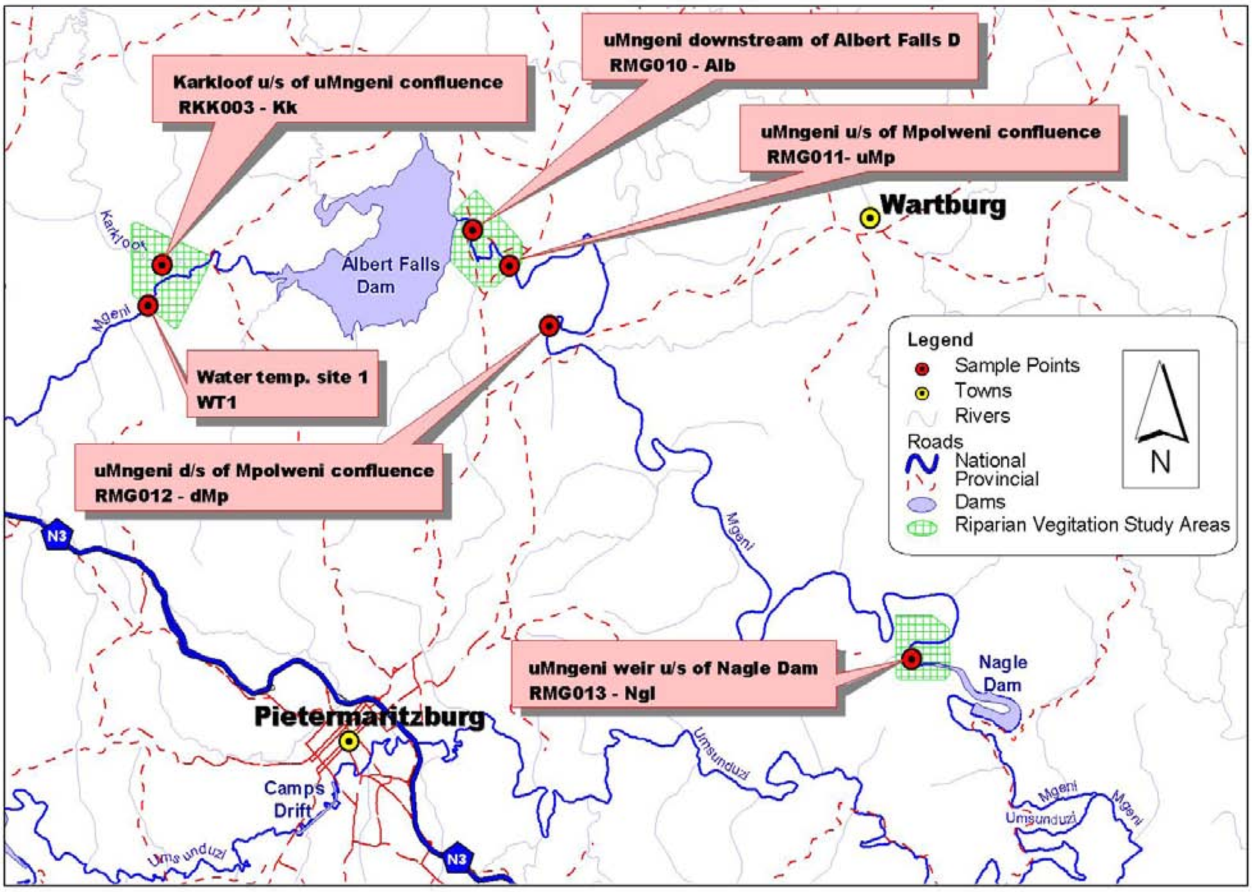
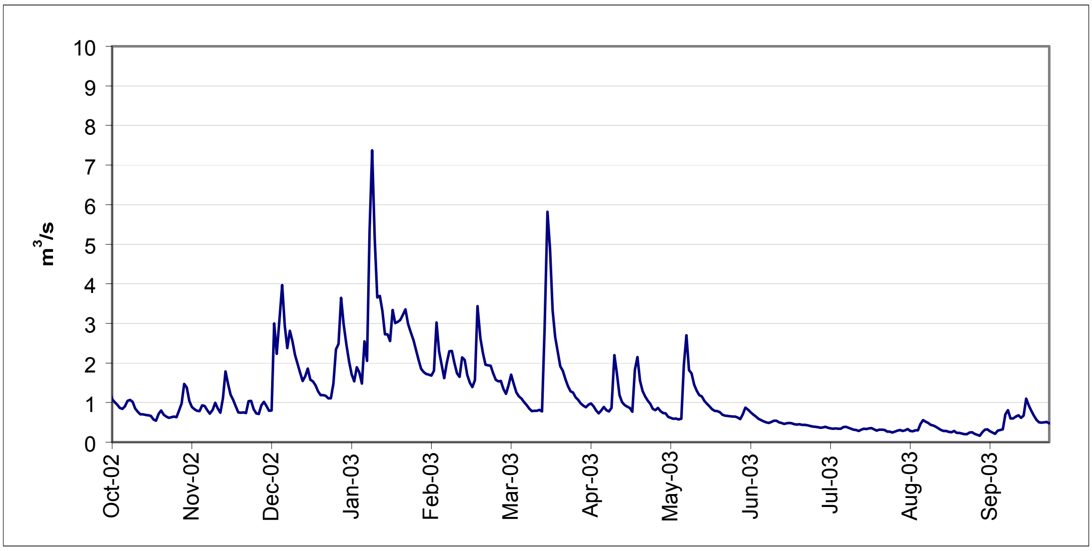


Figure 2: Map of the study area in KwaZulu-Natal, South Africa.

The above-mentioned flow regime means that the flows in the downstream uMngeni River are substantially different to the natural regime which would be high summer and low winter flows. Not only this, but the existing flows are relatively constant while the natural flow regime would be more variable, as is the situation in the Karkloof River control. This loss of variability could be the source of the most significant downstream stress on the system. To illustrate this difference, the hydrographs from the unregulated Karfloof River and the regulated uMngeni River are shown below, at the time that the survey for this project was carried out.



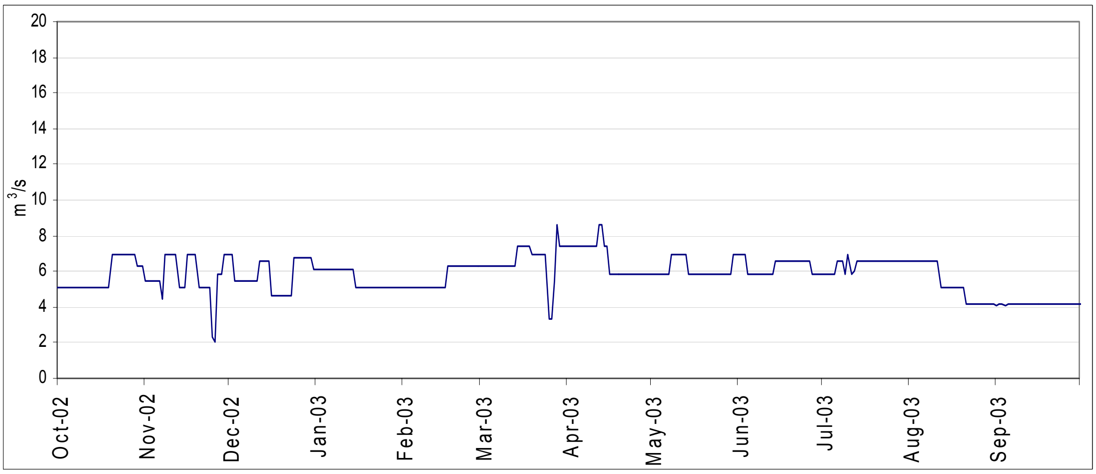


Figure 3: Hydrographs from the natural Karkloof River (top) and regulated uMngeni River (bottom) during 2002/3.

### Water quality of the downstream nMngeni River

It is commonly speculated that the water released from dams, particularly when this is dominated by scour (hypolimnion) water, is damaging to the downstream ecology, and that much of this impact is due to the altered water quality. The nature of the water quality in the downstream river changes depending on whether the impoundment is stratified or not, and whether it is spilling or not. The actual quality of the river water is summarized below. Note that in the text below the water at site Alb, immediately below Albert Falls, is termed “release water”. This is done deliberately to emphasise that this describes the water quality released from the dam with minimal moderation from the downstream environment, with the exception of the oxygen levels which are often replenished during the “spray” of water released from a dam.

Table 1: Water quality variables in the upstream Karkloof River control and in the uMngeni River downstream of Albert Falls Dam summarized from four years of data from 2000 onwards into the four "seasons". This information is provided in detail in Annexure A (at the end of this chapter).

| **Variable** | **Stratified and spilling (summer months)** | **Stratified and not spilling (summer months)** | **Isothermal and spilling (winter months)** | **Isothermal and not spilling (winter months)** |
|---|---|---|---|---|
| **Temperature** | Release water slightly warmer than the Karkloof River, made up of spill and scour water. Rising downstream to Nagle due to lower altitude. | Release water temperature the same as the control at the Karkloof River. Rising downstream to Nagle due to lower altitude. | Release water warmer than Karkloof River, dropping further downstream due to low ambient and incremental water temperatures. | Warmer release, cooling below the dam and then increasing again at low altitude. |
| **Conductivity** | Karkloof River water lower conductivity. Rest of uMngeni higher with peak below Mpolweni. | Peak below Mpolweni confluence. | Conductivity lower throughout but a peak below dMp possibly due to run-off from land | During this dry period, conductivity low throughout. |
| **Suspended Solids** | Release SS lower than Karkloof River. High in dam hypolimnion Increase downstream. | Release lower than Karkloof River. High in dam hypolimnion. Increase downstream. | Despite mixing, higher in hypolimnion, low in release. | Low throughout during dry season. |

| **Variable** | **Stratified and spilling (summer months)** | **Stratified and not spilling (summer months)** | **Isothermal and spilling (winter months)** | **Isothermal and not spilling (winter months)** |
|---|---|---|---|---|
| **$NH_3$** | High in hypolimnion with some recovery by Ngl but not complete. | High in release and downstream with some recovery by Ngl but not complete. | Lower concentrations than in summer with high input at Mpolweni. | Lower concentrations than in summer. |
| **Nitrate** | Karkloof River higher than all sites on uMngeni. Slight increase to Ngl. | Karkloof River higher than all sites on uMngeni. Slight increase to Ngl. | Karkloof River higher than all sites on uMngeni. High input from Mpolweni. Slight increase to Ngl. | Karkloof River higher than all sites on uMngeni. Slight increase to Ngl. |
| **SR Phosphorus** | Higher in Karkloof River with peak at Mpolweni. | Higher in Karkloof River with peak at Mpolweni. | Highest in Karkloof River, low downstream. | Highest in Karkloof River, low downstream with some input from Mpolweni. |
| **Total Org Carbon** | Lowest in Karkloof River, elevated by dam, continuing through downstream. Slight increase by Ngl. | Lowest in Karkloof River, elevated by dam, continuing through downstream. Slight increase by Ngl. | Marginal changes. | Lowest in Karkloof River. Marginal changes downstream. |
| **Algal count** | Highest in epilimnion. Elevated downstream. | Highest in epilimnion. Elevated downstream but at lower levels due to non-spillage. | High numbers in epilimnion carrying through to release at Alb. Decreasing to Ngl. | Highest numbers in downstream river maybe due to *in situ* growth. |

| **Variable** | **Stratified and spilling (summer months)** | **Stratified and not spilling (summer months)** | **Isothermal and spilling (winter months)** | **Isothermal and not spilling (winter months)** |
|---|---|---|---|---|
| ***E.coli*** | Highest in Karkloof River, removed by dam. Increasing to Ngl. Overall low concentrations. | High in Karkloof River, removed by dam. Increasing to Ngl. Overall low concentrations. | High in Karkloof River, removed by dam. Increasing to Ngl. Overall low concentrations. | High in Karkloof River, removed by dam. Increasing to Ngl. Overall low concentrations. |

**Noteworthy points from the above information.**

**Temperature** – the release water temperature was warmer than the control at the Karkloof River during winter, and similar during summer. This conclusion is supported by the detailed study of temperatures reported on in Chapter 5 (summarized below). It had been anticipated that the temperatures would be considerably colder, but this was found not to be the case.

**Detailed Temperature Analysis**

The main objective of this part of the project was to investigate in more detail the fluctuations of the thermal regime of the uMngeni River as affected by water releases from Albert Falls Dam. It was hypothesised that the temperature of the water released from Albert Falls Dam would have a decreased diurnal and seasonal variability with above normal water temperatures in winter and below normal water temperatures in summer. *Note that during the time of the investigation Albert Falls Dam was in a non-spilling state and therefore because of the release design of the dam, all water that was released was scour water.*

Diurnal and seasonal fluctuations in hourly water temperature were greater in the Karkloof River control than below the dam. The mean daily temperatures in the upstream control site were found to follow a similar trend to those below Albert Falls, although the range in the daily fluctuation was far greater in the control. Winter temperatures were also higher below Albert Falls than the control.

During summer, with distance downstream the mean daily water temperatures increased during the time that Albert Falls Dam was stratified revealing no obvious impact of the dam on downstream mean water temperatures.

During winter, when Albert Falls Dam was isothermal the mean daily water temperature of the release water at Alb was significantly higher than the control upstream and instead of increasing the temperatures decreased with downstream distance to Nagle Dam.

Irrespective of Albert Falls Dam being in a stratified or isothermal state, the mean water temperature range (minimum to maximum) was significantly reduced by Albert Falls Dam and increased when moving further downstream to Nagle Dam.

Changes in water temperature result in adverse impacts to the existing aquatic populations and may result in changes to the species composition. Variability of temperature provides much of the habitat to which species are adapted, serving to support those species that have evolved for the particular river. This variability may occur along the length of the river, as well as over a 24 hour day or over the seasons. This variability of temperature and thus habitat has been significantly altered by the presence of the dam upstream and the controlled releases of water from that dam. The implication of having a smaller variation of water temperature below Albert Falls Dam is that a much smaller thermal niche is made available for aquatic organisms to exist. Certain invertebrate and fish species may however be more suited to conditions below the dam. These are mostly likely to include stenothermal species i.e. species occupying a narrow thermal range (Allan, 1995). These specific organisms are able to colonise and dominate the river reaches below impoundments and it can be expected that a low diversity of organisms would occur below Albert Falls Dam as a result. The reduced inter-specific competition for the remaining species would result in their relative abundances being potentially higher.

The displayed thermal variation and standard deviation between the monitoring sites provides some indication of a “reset distance”, this being the distance downstream of the Albert Falls Dam where the thermal regime approaches a more natural state. Based on the data available, it seems that the “reset distance”, within which natural conditions should develop, does not occur within the distance between Albert Falls Dam and Nagle Dam. Unfortunately the absence of a downstream river reference site prevented this from being confirmed.

Since river temperature is a measure of the amount of heat energy per unit volume of water, changing either the amount of heat energy entering the river or the amount of water flowing in the channel has the potential to alter river temperature (Poole and Berman, 2000). It is important to note that impoundments can be operated to provide “desirable” stream temperature regimes directly downstream e.g. through selective withdrawal of water from different depths (and hence different temperatures) (Poole and Berman, 2000; Vinson, 2001) as well as through the modification of releases (Carron and Rajaram, 2001). This would require the introduction of variable abstraction structures to dams. Retrofitting would be expensive although this has become the norm for new dam designs in South Africa, which makes this a possibility for the future.

**Conductivity** – conductivity would not be expected to change due to the presence of the dam. An increase due to the Mpolweni would be due to catchment conditions in that tributary.

**Suspended Solids** – the dam removes SS from the river under most circumstances. Even though the concentrations are high in the hypolimnion the downstream concentrations are lower. There is a slight increase as the river makes its way to Nagle Dam which is to be expected as the river picks up sediment etc.

**Turbidity** – the only time that the release water was more turbid than the Karkloof River was when the dam was fully isothermal and not-spilling i.e. during the height of late winter.

**Oxygen** – concentrations and saturation were high throughout with the exception of the hypolimnion. There was a slight depression downstream when the dam was isothermal and spilling.

**pH** – the water in the dam was more acid than the rivers especially during winter, but marginally so.

**Iron** – surprisingly the downstream concentrations were lower than the Karkloof River control, even when the dam was stratified with high concentrations in the hypolimnion. It is possible that oxidation was complete by the time the release water passed over the Albert Falls waterfall, and thus was precipitated out of the samples collected at the site below Albert Falls.

**Manganese** – concentrations were greatly elevated by the dam, and these high concentrations persisted to Nagle Dam with only slight recovery. Concentration levels were only problematic (failing DWAF Target Water Quality Range) under stratified (winter) conditions at the two sites below the dam. These concentrations were thus a potential source of stress for the downstream aquatic system.

**Ammonia** – concentrations were elevated by the dam during summer but not during winter when the dam was isothermal. This applied also to the toxic form of unionized-ammonia, the concentrations of which fell within the Target Water Quality Range with the exception of during isothermal spilling conditions when it was slightly over the acceptable level. There was thus a slight chance of ammonia being a source of problems in the river.

**Nitrate** – was lower in the downstream river than the Karkloof River control.

**Soluble Phosphate** – this was highest in the Karkloof River, mostly being removed by in-dam processes and thus lower downstream. Heavy pollution inputs were recorded below the Mpolweni confluence. This pollutant is not toxic but may have an adverse effect by adding excessive nutrient to the system and altering the balance of organisms that inhabit the river.

**Total Organic Carbon** – this was elevated by the presence of the dam, but only marginally.

**Algae** – numbers were elevated by the presence of the dam as the releases contain algae having grown there, even when water is released from the scour. In the middle of winter there is a possibility that elevated numbers in the downstream river were due to *in situ* growth in the slow-flowing parts of the river.

***E. coli*** – as to be expected, the dam removed most from the system although there were increases downstream to Nagle Dam. Surprisingly there was no sign of a large increase from the Mpolweni or from the feedlots in the area above the Mpolweni.

**Biotic responses to the above physical and chemical conditions**

**Riparian vegetation changes**

The change in riparian cover below the Albert Falls water-fall was clearly illustrated in a sequence of clear photographs from 1912 to the present. This was again supported by aerial photographs from 1937 and 2003. These photographs indicate that there has been a significant change in the structure of the riparian vegetation community below the Albert Falls Dam which may be due to the impoundment of the river but also due to land management practices, as the thickening of the vegetation precedes the construction of any dams upstream.

To determine the impact of the largely artificial flow regime created by the Albert Falls Dam on the riparian community, this study sought to determine if the riparian community had in fact changed in response to the altered flow. To do this the percentage areas of different vegetation classes from the various eras, were determined.

For the Karkloof River control/reference study site there has clearly been very little change in cover class of the riparian community over time (1937-2003). All changes are less than 10% over the study period. The open water component increased very slightly by around 8%, with a small decline in the shrub/tree cover class. The grass/reed cover class was virtually unchanged. This was the situation even though the surrounding landscape showed significantly thickening of the terrestrial vegetation, as was the situation at all the sites investigated. There was unfortunately no data to link or de-link the thickening of the terrestrial vegetation from what was happening in the riparian vegetation.

The site below Albert Falls Dam demonstrated the most dramatic change in riparian cover classes for the study period (1937-2003). The grass/reed cover class decreased on average by over 20%, whilst the shrub/tree class increased by around 30%. Open water and riffle/rapids cover classes were virtually unchanged.

The changes at the Nagle study site were similar but less pronounced, with grass/reeds declining and shrub/trees increasing over time (1937-2001). As with the upper sites, the terrestrial vegetation also showed significant thickening but the association between this and the thickening of the riparian vegetation was not clear.

The results show that the Karkloof River control/reference study site illustrates no consistent or systematic change in either the grass/reed or shrub/tree riparian vegetation cover classes over time, despite an apparent increase in shrub/tree vegetation in the surrounding landscape, which was probably the result of changed grazing and fire regimes.

Given that this site is within the same ecoregion as the other study sites, it was postulated that without the presence of the dam similar results would be obtained from the other two study sites. However this analysis illustrates that for both sites downstream of the Albert Falls impoundment there are consistent and statistically significant changes in both the riparian grass/reed and shrub/tree cover classes with a shift occurring towards the latter i.e. thickening of the riparian community. The open water habitat in each of the impacted sites showed no statistically significant change over time, suggesting that the active channel of the river had remained essentially the same.

It is well known that riparian vegetation growth is hampered by periodic flooding which tends to remove large species. This is particularly so where the river current carries considerable power as it would at these sites. The buffering effect of the upstream dam tends to flatten out the flood peaks, resulting in less scouring of the riparian zone. Only the largest of floods, such as that in September 1987, would travel unaffected by the dam into the downstream river where they cause considerable damage as they remove trees that have grown during the intervening period.

### Changes in fish community structure

The dominant fish species collected at the control site on the Karkloof River was the Natal Mountain Catfish which is intolerant of aberrations in water flow and quality. The habitat in this river (cold clear water, rapid flow over cobbles) is clearly ideal for this species but it is possible that the location is approaching its lower boundary as they are not often found in rivers at a lower altitude. Accordingly, it would be difficult to conclude that this species should be found in abundance at Albert Falls even though this is only a few kilometers away although they were found a few km downstream but only isolated individuals.

Immediately below Albert Falls Dam, there were large numbers of the endemic KwaZulu-Natal Yellowfish at all times of the year. They were reported to spawn prolifically at this site during early summer (November) where they spawn over shallow fast-flowing gravel beds, apparently unaffected by aberrations in water quality and temperature, in particular those of ammonia and manganese which do occur at toxic concentrations particularly when the dam is stratified. Few other species, other than Yellowfish, were found at this site below Albert Falls although they were reported to be abundant in past years (even post dam construction). A possible cause of their demise could be the extreme drought that occurred during the 1990s' which may have eliminated these species from the area. This may have been due to the rich scour water which could have been released at the time.

A general conclusion for this site is that the river-reach supports the presence of large numbers of *Labeobarbus natalensis* (Yellowfish) but there is a general absence of *Amphillius natalensis* and other species such as *Tilapia sp.* which would be expected. It is possible that the continuous high flow favours Yellowfish, supporting greater numbers than would be the case if the river were to be stressed during winter.

Further down the river, at the site above the Mpolweni River confluence, there remained a low diversity of fish, with good numbers of Yellowfish but low numbers of the other species found (Smallmouth Bass and juvenile Tilapia). The presence of favourable habitat devoid of fish strongly suggests periodic adverse water quality conditions.

Further downstream at the site below the Mpolweni confluence, there was a much greater diversity. Large Yellowfish were collected year round at this site although they were most abundant in March.

Above Nagle Dam the species of fish found were diverse although the local conditions for catching them were poor. Unfortunately this site was a poor choice as it was bound between the upstream weir and the downstream Nagle Dam with its recent construction activities.

The overall conclusion for the fish survey, whilst somewhat inconclusive, suggests that while there is suppression of diversity and possibly of abundance in the river downstream of Albert Falls Dam, the one fish that capatalises on the situation is the endemic KZN Yellowfish. This fish appears to breed successfully despite the perturbations in the quantity and quality of the water released from the dam, which it manages to avoid due to its strong swimming and migration abilities. The conditions that would be required to allow for a return of the other species can only be speculated, but would probably include a cessation of zero flow conditions and maximizing the spilling of the dam as opposed to the release of scour water.

### Changes in aquatic macroinvertebrate community structure

#### Analysis of SASS Index historical data

The first part of the investigation of invertebrate changes made use of over a decade of regular SASS data collected by Umgeni Water. What this data lacked in precision and detail, it made up for with the long time span and numerous samples.

Historical data (1993 to 2006) existed for three sites only, namely the site on the Karkloof River (Kk), that on the uMngeni River downstream of the confluence with the Mpolweni River (dMp) and that upstream of Nagle Dam (Ngl).

Results of the analysis on the historical data indicate that it is only on the basis of comparisons between the SASS ASPT index, that there is a statistically significant difference between sites. In all cases the control site on the Karkloof River is found to be statistically significantly higher than both the uMngeni downstream of the Mpolweni confluence and the uMngeni upstream of Nagle Dam. Interesting too is that of the two uMngeni River sites the lowermost site (with the greatest chance of recovery from the impacts of the dam regulated flows) has the higher ASPT index suggesting a better aquatic macro-invertebrate health.

Although not statistically different, this pattern also appears to be consistent for the other SASS indices, particularly the SASS scores. In all cases the SASS scores are lower for all sites on the uMngeni River below the impoundment with the site closest to the impoundment apparently most impacted. Although there are statistically significant differences between the control and the "impacted" sites (as measured by the ASPT) the differences are relatively small when related to river health class boundaries – changing from a "natural" on the Karkloof River to "good" on the two sites on the uMngeni.

To determine if there was a greater seasonal impact (due to the unseasonal high winter flows), paired seasonal data were considered. From these results it was speculated that:

- The high and un-seasonal winter base flows below Albert Falls Dam are having an impact on the SASS scores during the winter months but the incremental summer flows from the Mpolweni are ameliorating this impact.
- Once the river has reached Nagle Dam during winter the impact of the high winter base flows have been moderated by processes in the river and are hence not showing up as significant, whilst on the other hand summer flushing from polluted side tributaries (Mpolweni and feedlots around the upper/middle reaches of the river) could be influencing water quality at the lowermost site on the uMngeni.

Hence on the basis of the historical data alone there appeared to be *prima facie* evidence for an apparent, but minor, impact of the Albert Falls impoundment on the macroinvertebrates in the uMngeni River. This initiated a more comprehensive placement of monitoring and survey sites and study to determine the nature of this impact, the result of which is this report.

A more detailed, although shorter in duration, investigation into SASS indices below Albert Falls compared to the Karkloof River control site showed a significant drop in the respective SASS indices below the Albert Falls Dam (the new sites were closer to the dam wall). However with increasing distance from the Albert Falls impoundment, down the uMngeni River towards the last site monitored at the weir above Nagle Dam, there were clear signs of recovery in the respective indices. To test if these differences were statistically significant appropriate statistical tests were applied and only the SASS score and number of taxa were shown to be statistically significantly different between the Karkloof River control site and the first site below the Albert Falls impoundment, with the ASPT comparison almost statistically significant.

In other words, by the time the river has traveled some 4 km downstream of the Albert Falls Dam (reaching site uMp upstream of the Mpolweni), based on the SASS indices there appears to be no statistically significant difference between the results obtained on the

Karkloof River control site, the uMngeni upstream of the Mpolweni (uMp) site and this site at Nagle Dam.

A criticism of the SASS method is that, as an index, it hides much of the component taxonomic data and in this way may lead to misleading information. In order to "unpack" the index, the underlying taxa collected in the SASS analyses were investigated using multivariate statistical tools. Key results from those analyses are summarised as follows:

**Analyses of SASS taxon (family) data**

The most obvious feature of the analysis is, when compared to the Karkloof River control, how different the Albert Falls site (immediately below the dam) is from the Nagle site (furthest from the Albert Falls Dam). The site below Albert Falls was consistently different from the Karkloof River control while at times the Nagle site had almost the same composition as the Karkloof River control (during the summer when incremental flows "reset" the biological condition of the uMngeni) whilst at others it was distinctly different. Of interest was that during March 2001, when the Albert Falls Dam was spilling strongly, the biota were most like the Karkloof River control. Winter appears to be the season displaying the greatest taxonomic difference between the Karkloof River control site and all other sites sampled, suggesting the greatest impact possibly resulting from the high winter flows.

In terms of the taxonomic responses to differences between the control site and study sites, it appears that the Simuliidae (blackflies) are important in differentiating the Albert Falls site from the others, while Coenagrionidae (as well as others) appear to distinguish the Nagle sites from the Karkloof River in the Vegetation biotope.

It can therefore be proposed that the conditions at the Albert Falls site might be different in some way that causes the pattern of community change there to differ consistently from that of the reference Karkloof River site (in a way that none of the other sites appear to do). In this, the site at Nagle dam was notably different.

**Water quality impacting on the macroinvertebrates**

In order to determine how the physico-chemical characteristics of Albert Falls release water at site Alb differed from the Karkloof River control (Kk), and the other sites, a similar multivariate analysis was applied to the environmental data set.

The key question was to determine if there were patterns or variations in the physico-chemical data set which:

- differentiated the surveyed sites from the Karkloof River control site; and
- mirrored that observed in the biological data.

The results of this analysis suggest that the pattern of change in the water quality below Albert Falls Dam (Alb) and all other sites downstream of the dam differed from the Karkloof River during the summer period but were similar to the Karkloof River at other times. This was in contrast to the biological picture described above which suggested that the invertebrates were "reset" in summer.

The site on the uMngeni downstream of the confluence with the Mpolweni (dMp) showed the same general trend as the others, but at times (August & October 2003) high levels of pollutants made this site considerably different. Higher saturated dissolved oxygen, conductivity and free (un-ionised) ammonia also appear to differentiate the surveyed sites on the uMngeni from the Karkloof River control especially during summer.

A correlation analysis between the biological family level data and measured environmental determinants showed none of the determinants were statistically significantly correlated with the biological data. Hence it appears that there is some as yet unmeasured environmental parameter(s) which occurs during the high unseasonal winter flow season which is impacting upon and accounting for the biological picture displayed by the macroinvertebrates.

To better understand which invertebrate species were responding to this regime, multivariate analyses were repeated for respective biotopes but in this instance using the macroinvertebrate data identified down to the highest possible taxonomic resolution (in most cases species level data). It was anticipated that species information would reveal more changes than was revealed by the gross SASS scores or even by the SASS family level data.

**Analyses of aquatic macroinvertebrate species data**

Analysis of the species level data followed the same process as that applied to the family level data. Again a number of interesting features emerge from these analyses.

Firstly the Albert Falls site (Alb) consistently (i.e. over all biotopes) showed the largest compositional differences compared to the control, while all other sites are very similar in their species composition both amongst themselves and with the Karkloof River control site.

For the Vegetation biotope there appeared to be no strong seasonal pattern in the response of aquatic communities, other than perhaps the Nagle site which was most different from the Karkloof River control during winter (August 2003). At all other sampling occasions during the study, the Nagle composition is virtually identical to the Karkloof River control. This appears to imply that the unseasonal "high" winter flows (at least during August 2003) may still be having some effect on the aquatic macroinvertebrates downstream of Albert Falls as far as Nagle Dam. This is in contrast to the results obtained using the simple SASS indices. Within the Vegetation biotope the Albert Falls site is again consistently the most different from the reference site, and this generally most strongly during the winter periods (August 2003 & June 2004). Unseasonal flow changes due to flow regulation below the Albert Falls impoundment may well be responsible for this effect having the greatest impact on the marginal vegetation inhabitants and least impact on the in-stream Stones and GSM inhabitants. The probable mechanism for this impact is by either leaving the marginal vegetation “high and dry” during the summer when flows are reduced or inundating it out-of-season with un-seasonal high winter flow releases. This probably makes for a harsh and unpredictable habitat for marginal vegetation dependent macroinvertebrate species. On the other hand during flow regulation the available habitat for the Stones and GSM biotopes is probably least affected, as are species dependant on those biotopes.

For the Stones biotope the greatest compositional variance with the Karkloof River control site was displayed by the Albert Falls site (Alb) especially during the winter. Within this biotope, most of the other sites studied downstream of Albert Falls Dam on the uMngeni appeared to have a very similar composition to the Karkloof River, but with some exceptions.

An examination of the species counts (richness) of each of the biotopes further illustrates some of the differences between sites and between seasons. Overall the Albert Falls sites (Alb) generally show the lowest diversity of all sites monitored. On the other hand the Karkloof River control site tended to have the highest overall species counts, particularly in the Stones and Vegetation biotopes. Winter appears to be the most species rich time of the year for all sites, with early summer showing the lowest diversity. The higher species diversity in winter probably contributes to the sensitivity of these systems to flow modification in the winter months.

It was significant that most of the species that characterized the site below Albert Falls Dam were filter feeders, i.e. they obtain suspended food particles from the water column.. The regular and consistent winter flow releases from Albert Falls Dam undoubtedly contributes a regular and consistent food source for these organisms.

Many authors have highlighted the importance that fluctuations of physical phenomena have on biological systems. As a measure of this fluctuation the coefficient of variation (CV%) of the flow for each survey period was examined. A number of observations could be made about this flow variability:

- In the natural system, March appears to have the highest flow variability, to be expected during summer flows in response to natural rainfall events
- Winter appears to have the lowest flow variability, probably in response to low rainfall and sustained/regular base flows.

- The Karkloof River control site consistently has the highest and most natural flow variability. This was to be expected in response to an unregulated catchment where river flows respond to episodic rainfall events.
- Besides the 2001 survey when the dam was spilling, the sites below the dam had relatively low flow variability in response to regulated and consistent flows from the dam.

Coetzee (1982) noted that the increase in black fly populations succeeding the completion of the inter-basin transfer (IBT) on the Great Fish River were likely to be due to the combined effects of permanent flows, faster current speeds and increased food supply, all factors likely to have "improved" the success of the black fly below Albert Falls Dam.

In a study of streams downstream of hydroelectric schemes in Sweden, Zhang et al. (1998) found that regulated sites showed an increase in simulid (blackfly) numbers, and an associated decrease in predators and competitors. They further propose that under conditions of flow disturbance (un-natural flow regime) black fly larvae are better able to cope than their predators and competitors (Zhang et al., 1998). The results from this study on the Albert Falls Dam in many ways corroborate those findings, with black fly (and other filter feeders) the dominant taxa accounting for differences between the unregulated Karkloof River control site and the Albert Falls site.

However within a relatively short distance downstream of the dam the "natural" composition of the aquatic macroinvertebrate fauna is largely restored, compared to that exhibited by the unregulated Karkloof River rive. The Vegetation biotope appears to be most variable and takes longer (distance downstream) to return to the "natural" community.

**Conclusion from the aquatic macroinvertebrate assessment**

The dam undoubtedly has an impact on the invertebrate populations immediately downstream (approximately 500 m). There is rapid recovery even 4 km below the dam, where there are differences but many of these could not be substantiated statistically. To a large extent there had been resetting of the populations by the time the river had reached Nagle Dam some 54 km downstream although some residual effects were detectable.

An investigation of the environmental factors that could be causing the changes in invertebrate families suggested that some as yet unmeasured variable/s were accounting for this impact, and that the anticipated impacts of ammonia, manganese, temperature and others were not clearly manifesting.

Examination of the species that were found in the river did not add substantially to the investigation other than to confirm the degradation at the site below Albert Falls (Alb) where difference were most pronounced in winter when the flows were high. The data did reveal that those invertebrates living in the marginal vegetation were most impacted by the dam water releases, while those on the river bottom were less so. These populations also took the greatest distance to "reset". The investigation also revealed that the species found in the downstream river were dominated by filter feeing organisms, which were thriving by capitalising on the planktonic algae emanating from the dam.

**Overall conclusions**

Monitoring of the macroinvertebrate populations over more than a decade by Umgeni Water had superficially suggested that the impacts of Albert Falls Dam on the downstream river were not as severe as was originally expected. This study set out to uncover the stresses that are put onto the downstream system by the dam and to determine with greater accuracy the extent of the impacts on the ecosystem.

The physical and chemical condition of the water released from the dam was surprisingly good, although differing substantially from what could be considered a normal condition in the following respects:

- The range of daily and seasonal temperature variation was substantially curtailed. Mean temperatures below the dam were higher than natural during winter.
- The variability of water flow (quantity), both in the short term and over the seasons was substantially curtailed.
- The quality of the water, in particular the concentrations of manganese and ammonia, was a potential source of stress for instream biota.

The above perturbations were greatest at the site immediately below the Albert Falls Dam and were ameliorated with distance downstream so that there was either partial or total reset by the time the river reached Nagle Dam.

The Albert Falls Dam was found to be a sink for nutrients under higher flow conditions, with both SRP and TP accumulating in the dam, probably within the sediments. During extreme drought periods when the water levels in the dam were very low, the dam became a net exporter of these nutrients, discharging more into the downstream river than was flowing in. The dam also accumulates suspended solids, but is a net generator of ammonia and manganese, both of which are elevated by the presence of the dam and released to the downstream river. Both of these chemicals are toxic to biota.

The biological condition of the river was anticipated to reflect the above physical and chemical drivers. This it did to some extent as follows:

- The riparian vegetation was substantially thicker than it should be, probably due to the elimination of floods and the imposition of regular flows.
- The fish diversity was substantially altered, with many species inexplicably missing from below the dam, while the endemic KZN Yellowfish was able to adapt and thrive under the altered conditions.

- The use of SASS Index data, SASS family data and detailed species data to represent the invertebrate populations, indicated significant stress at the site immediately below the dam but a substantial recovery 4 km downstream. The more detailed analyses did reveal more information about the changes that were taking place but not in a way that added significant interpretation that would enable better management.
- While there were changes in the dominance and overall structure of the invertebrate populations, which reflect the changes in habitat below the dam, it was not possible with certainty to know what the causes of these changes were.
- The implications of altered species composition were not considered in detail but should be held up against the intention of the UN Convention on Biological Diversity, which is ratified by the National Environmental Management Act (1999), that there should be no net loss of biodiversity. Changes in population structure as exhibited in this system can only be managed as part of a comprehensive conservation management plan.
- Because of this lack of certainty, it is thus not possible to give clear guidelines for the operation of the dam in order to prevent negative impacts on the ecosystem. Nevertheless, speculative guidelines are provided below.

# Guideline for the operation of dams in summer rainfall areas.

These guidelines are speculative as no clear causal relationships between the anticipated causes of impacts on the river biota and the downstream ecosystem have been determined. The guidelines are made combining what has been shown in this project together with information from the literature.

**Flow release variability** – it is anticipated that the lack of variability in flow, both in the short term (over days and weeks) and in the long-term (seasons) is a major source of stress in the downstream system. Accordingly, the release of water should be varied in a way that mimics, to the best degree possible, the natural flow of the river, i.e. more variable in summer than winter, higher base flows in summery than winter. Every attempt should be made to have a mix of drought conditions as well as periodic flooding. The principles of this have been well developed in the design of Environmental Flow Requirements (or IFRs) as part of the Ecological Reserve implemented by DWAF, which are well documented in King et al. (2000).

**Short-term variability** – the almost natural variability of the Karkloof River reference site can be seen in Figure 3 above. It should be possible to model the release of the water from Albert Falls Dam to accommodate this type of variability for the sake of the river ecosystem, reconciled with the needs of the downstream users, plus the needs of the impoundment above the dam.

**Long-term variability** – depending on the downstream needs for water, it may or may not be possible to mimic the natural flow regime, in this case high summer and low winter flows, with the operation of the dam (in the case of Albert Falls, the opposite to natural). Nevertheless attempts should be made to reconcile the needs of downstream users, together with the needs of the impoundments itself, plus the needs of the river ecosystem. This would mean making every attempt to have higher flow releases during the wet season and lower during the dry season.

**Release patterns** – water should be released from the dam in a way that is sympathetic to the natural flow of the river. Accordingly, if the flow to the downstream is to be reduced, this should be done gradually over several days, as would be the case in a natural river. Where variable aperture valves are used, this can be done incrementally over these days, while in the case of valves where there is either an open or closed position, the options are less. The duration of the decrease or increase in flow should ideally mimic the natural situation and can be determined by close observation of the natural hydrograph. Commonly, increasing flows occur rapidly (within a few hours) as would happen after a storm event. Decreases in flow occur fairly rapidly (several hours) soon after the peak, but then the rate of decrease generally slows over days, weeks or months. As part of dam management, there is generally the need to store maximum water in the impoundment, in which case releases can be designed to hold back "excess" water but nevertheless to mimic the natural patterns of flow.

**Quality of release water during summer** – it has been demonstrated that while there is some merit in releasing water via scouring the dam, in order to remove nutrients (phosphorus) and suspended solids, the quantities of toxic ammonia and manganese are elevated by this practice which will have a negative impact on the downstream ecosystem. While surface water also causes stress to the downstream river (too transparent, high temperature, presence of algae, nutrient poor, sediment poor), it is likely that this water is less stressful to the river than scour water. Accordingly, wherever possible water should be released from the epilimnion or surface. This may be through over-topping or spilling of the dam, or in dams with the relevant design, through a variable abstraction structure.

**Quality of release water during winter** – when the dam is isothermal (mixed), the differences between releasing top or bottom water are slight although there may be slightly higher turbidity and iron with slightly reduced oxygen in the scour water. Thus, during winter, while surface water releases would still be desirable, the advantages are less. There is also less opportunity of doing this in dams without a variable abstraction structure as the surface level during winter is likely to be low.

**Mixed water quality releases** – in those dams with a variable abstraction structure, as well as when a dam is spilling, it is possible to mix surface and bottom water releases to obtain the greatest advantage. The addition of a portion of bottom water would contribute a raised turbidity/suspended solids and more natural nutrient levels, which would make the downstream water more natural (in many areas of the country). Caution should be exercised to ensure that concentrations of toxins do not become excessive in the process. It would be possible to model the optimal mixtures of surface and bottom water to be released.

**Monitoring** – as with any management regime, there should be a deliberate process to monitor, review and adapt the practices that are implemented during dam management. As has become central to the philosophy of the National Water Act (DWAF, 1998), the emphasis should be placed on monitoring the response of the environment in order to gauge the success or shortcomings of dam management. This means monitoring the downstream ecosystem. Recent developments by DWAF to develop a suite of methods to do this, called the Ecostatus methods (DWAF – under development), are ideally suited to do this. These methods convert ecological data into numerical indices that can be interpreted for better management.

## References

DWAF (1998) National Water Act, Department of Water Affairs and Forestry, South African Government, Pretoria

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# Table of Contents

## Acknowledgements

This project has extended over a long period, initially due to circumstances beyond the control of any of its participants i.e. construction activities that took place at Nagle Dam, but later by the change in employment of some of the team, in particular the project leader. The project team has changed slightly over this time, with a few people leaving and being replaced by others. The ongoing support by Umgeni Water, who led the project, and the Water Research Commission, who funded and managed it, allowed the project to survive under these somewhat trying circumstances. Both organizations are thanked for their steadfastness.

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Special thanks are due to Clive Harries, a resident below Albert Falls, who makes it his business to keep an eye on the river. He provided us with valuable insights into the fish populations including the finesse of fishing for Yellowfish!

# Glossary

| | |
|---|---|
| Aquatic macroinvertebrates | Those invertebrates which live in water and are collected (in this project) by a net with a 1mm mesh size. They are thus visible to the naked eye. |
| ASPT | Average Score Per Taxon, a derivation of the SASS Score that is calculated from the range of aquatic macroinvertebrates collected from a river. ASPT provides an average of the tolerance values of all the taxa found at a site. |
| Dam | In South Africa, Dam is often used interchangeably with Reservoir or Impoundment. Internationally dam refers only to the concrete structure. |
| De-stratification | The breakdown of the stratification of an impoundment that normally takes place at the onset of winter when air temperatures drop cf. stratification. |
| DWAF | Department of Water Affairs and Forestry (South Africa). |
| Ecological Reserve | A term used in the National Water Act (1998) to describe the amount and quality of water that is required to maintain the ecosystem. By law this water requirement has to be met before any water is allocated for other purposes. |
| Environmental flows | The quantity and timing of water required to maintain a river ecosystem cf. IFR. |
| Epilimnion | The surface, warmer and oxygenated layer of an impoundment, floating on top of the deeper hypolimnion. Normally occurring in summer months. |
| Flow | Referring to the quantity ($m^3/s$) and velocity of water in a river. |
| GSM | Gravel/Sand/Mud. A group of substrates surveyed together as part of the SASS method. |
| Hypolimnion | The deeper layers of an impoundment that are deprived of oxygen and are generally colder than the surface layer or epilimnion. |
| IFR | Instream Flow Requirements. The quantity and timing of water required to sustain a river ecosystem cf. Environmental Flows. |
| Isothermal | An impoundment where the temperature is the same from top to bottom. In South Africa this usually refers to a winter condition. |
| Load | The quantity (mass) of a substance that enters into an impoundment during the space of a year. |
| Macroinvertebrates | See Aquatic macroinvertebrates above. |
| Natural | Used to refer to the original, pristine condition. This term often generates heated discussion as many feel that there is no natural environment remaining. Nevertheless, in this project the term refers to the best available, and in some instances to a construction of what the original situation would have been like. |
| Regulated flow | Water quantities and velocities in a river where the water is released from an upstream dam under controlled conditions. |
| Reverse hydrograph | Flow volumes in a river which are the opposite of the natural situation. In this situation, this means high winter flows and lower summer flows. |

| | |
|---|---|
| Riparian vegetation | Vegetation growing at the edge of a river, directly affected by the presence of the water. This may extend several meters away from the river bank. |
| SASS5 | Version 5 of a method used for monitoring the health of rivers using aquatic macroinvertebrates, published by Dickens and Graham in 2002. |
| SASS Score | Output of the SASS method. The summed total score of all of the tolerance values of aquatic macroinvertebrates collected from a site. |
| Scour | A term used by dam operators to refer to water released from the lower-most valve in a dam wall, intending to scour sediments from the bottom of the reservoir. |
| Spilling | Water spilling from the surface, over the crest of the dam wall. This water is normally warm and clear. |
| SRP | Soluble Reactive Phosphorus – the generally more biologically available form of this nutrient. |
| Stratification | Warming of the surface of an impoundment during summer causes a separation between the surface water and colder bottom waters. This leads to different chemical conditions in the two layers cf. De-stratification. |
| Taxon/taxa | A grouping of organisms at any level on the hierarchy used to classify biota. |
| TP | Total phosphorus – much of this is not biologically available but may become so under certain condition. |
| TWQR | Target Water Quality Range – contained in Guidelines produced by DWAF (1996) to describe water used for different purposes. In this report this refers to water quality required to protect the aquatic ecosystem. |

# Chapter 1. Introduction

River systems are primarily defined by the quantity and quality of their water, and how they change along their longitudinal axes (Rivers-Moore, 2003). Historically, their exploitation has been for both consumptive (urban water supply, irrigation) and non-consumptive (hydro-electric power generation, flood control) water use, both of which have resulted in them being dammed or impounded (Ward et al., 1984; Ferrar et al., 1988; Carron and Rajaram, 2001). In South Africa a rapidly growing population and a relatively well-developed economy has placed demands on the water supplies to the extent that few of any large or medium sized rivers remain undisrupted by impoundments (Ferrar et al., 1988; Allanson et al., 1990). Worldwide this trend is exacerbated by the low proportion of rivers that carry useable quantities of water, yet many of these systems have become intensively developed (Ferrar et al., 1988). Such development projects have however been implemented with only cursory attention to the function and values of the aquatic ecosystem that they alter and in many cases severely damage (Ferrar et al., 1988).

A situation that frequently arises in a dam development is where a storage dam is required to release water into the downstream river from where it can be abstracted for a number of purposes. Usually these releases increase when the downstream demand for water is greatest

## 1.1 The influence of impoundments on river ecosystems

Rivers are dynamic systems that are difficult to measure and predict and yet they have strong tendencies of stability and resilience reflecting very precisely the climate and other physical characteristics of their catchment (Ferrar et al., 1988). However, significant anthropogenic influences have altered river systems, which has largely been attributed to impoundments and the changes that they have inflicted on downstream river ecosystems. Such impacts include both quantitative (reduced river flow and flood peaks) and qualitative (altered seasonality of flows and sediment loads) (Macdonald, 1989). This has led to a range of impacts in the downstream river, including increased production of plankton; decreased sediment with resulting downstream erosion; alteration of natural flow regimes; interference with fish migrations; reduced temperature fluctuations and alteration of water chemistry, particularly associated with hypolimnetic water releases (Allanson et al., 1990). Additionally and otherwise neglected are the consequences that take place upstream of a dam. Here a flowing-water (lotic) ecosystem is converted to a standing-water (lentic) ecosystem, where wetland as well as dry land ecosystems are flooded and become part of a reservoir (Hunter, 1996). Ultimately, the river continuum is offset due to the changes in physical, chemical and biological features along its longitudinal course (Ward et al., 1984; Chapman, 1992).

Observed decreases of river flow in South Africa are mainly thought to have arisen from the increasing impoundment of rivers in the country (Macdonald, 1989) and that the number of reservoirs has become a significant influence on the river systems as they capture a large proportion of the mean annual runoff. Reductions in the flow of rivers have compounded the effects of catchment degradation, and have converted a number of South Africa's perennial rivers to a seasonal flow (Allanson et al., 1990).

## 1.2 Dynamic processes within impoundments

In order to understand the quality of the water released to the downstream river, the processes within the impoundment need to be understood. Changes in the impoundment will naturally have large impacts on the quality and quantity of water released. Impoundments may be characterized by the nature of their stratification which takes place due to the physical separation of water masses of different densities, usually determined by temperature differentials (Chapman, 1992), and exacerbated by the fact that the residence times of the water in the impoundment are long (Tchobanoglous and Schroeder, 1985). Energy is lost or gained through the surface of the lake because of forces of wind, solar heating, and radiant cooling (Tchobanoglous and Schroeder, 1985). Figure 1 illustrates the extremes of stratification in lake systems. In warm climates thermal strata are most evident in summer when the effects of vertical convectional currents develop from differential cooling and heating (Tchobanoglous and Schroeder, 1985). The top layer, termed the epilimnion, has a constant temperature due to mechanical mixing and circulation and is usually warm (Allanson et al., 1990; Chapman, 1992; Cooke et al., 1993). Below this is a zone of rapidly decreasing temperature, the metalimnion or thermocline (Cooke et al., 1993). The lowest layer consists of cold, high-density water, termed the hypolimnion (Allanson et al., 1990; Chapman, 1992). This pattern of stratification is often mirrored by a stratification of oxygen concentrations, where the intermediate layer may be termed the oxycline. The water in the lower layer is usually anoxic as it contains little or no dissolved oxygen.

This situation of thermal stratification becomes unstable as the air temperature declines in winter and the surface waters cool down. At the point where the temperature of the epilimnion equals that of the hypolimnion, then the densities of the two layers are the same and there is now nothing stopping the water from mixing. It is said that the impoundment then "turns over". With this comes a mixing of the water quality with oxygen reaching the bottom, and dissolved metals normally associated with the hypolimnion, briefly reaching the surface. This situation is then reversed when the air temperature rises again in summer, heating the surface and re-creating the epilimnion.

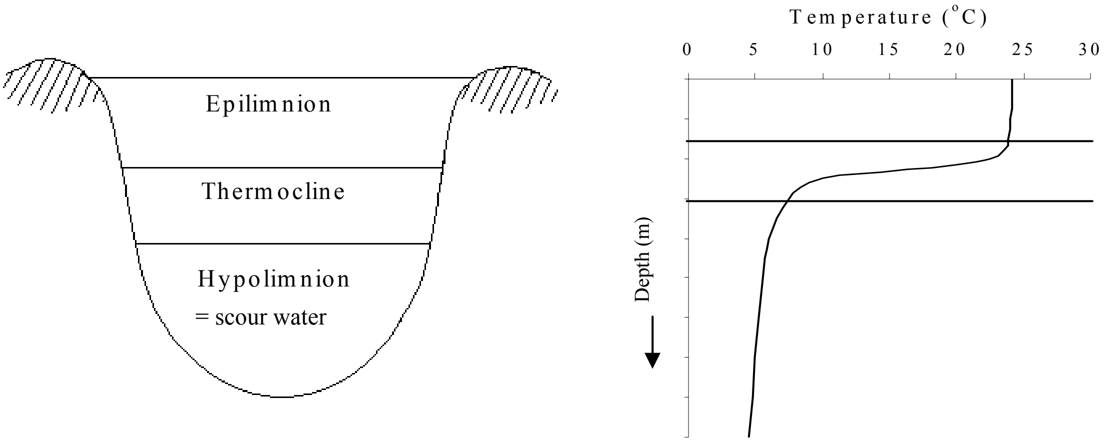

Figure 1.1 Temperature profile of a thermally stratified lake (Tchnobanoglous and Schroeder, 1985).

### 1.3 Water releases from impoundments

While natural lake outflows are from the surface, or occasionally through the ground, man-made systems usually have constructed outlets that release water either from the surface of the lake, or from the bottom hypolimnion (scour water). Recent moves in South Africa and elsewhere have been to ensure that both types of releases are possible so that some control on the quality of water released can be exercised. Regulation of the amount and abstracted depth of water released from an impoundment can affect the river downstream (Ward et al., 1984). The nature of the released water can be vastly different from natural river water, being generally colder and having a water quality strongly influenced by the impoundment. Reductions in water temperature, the result of water stored in reservoirs being cooler than streams due to the attenuation of solar heating with depth (Carron and Rajaram, 2001) is most common. Thus the greater the depth at which water is released from an impoundment the colder and more oxygen deficient it is. Impoundments also trap suspended material and significantly alter the quality of the water. Chemical and biological processes within the lake change the quality of the water in many ways, some of which will have an impact on the downstream ecosystem.

Once a river becomes regulated by the operations of an impoundment, the quantity of water released downstream is usually at a minimum, sufficient to meet the demands of downstream users (Ward et al., 1984). River regulation has been a management practice that has generally neglected the importance of water requirements for the downstream ecology although the South African Water Act (1998) introduced innovative legislation to take care of this. This legislation also seeks to ensure that the quality of the downstream river water is sufficient to sustain the ecosystem so that it can continue to provide the benefits to society that it does. Unfortunately, many impoundments release water only from the hypolimnion which makes the meeting of downstream requirements difficult. This is particularly so during dry periods when the impoundment is not full.

Multiple impoundment or cascading river systems provide an opportunity for the regulation of discharges within the constraints of other legitimate uses of the water (Ward et al., 1984). Thus quantities of water may be balanced and released from each impoundment to sustain the functioning of the system downstream. The dams on the uMngeni River are typical of this possibility, with four major dams occurring down the length of the river.

## 1.4 River responses to regulation

Rivers are connecting systems and are highly dynamic both in space and time (Ferrar et al., 1988) yet they may be irreparably damaged by inappropriate changes. The regulation of flow in rivers by impoundments is recognised as the major perturbation to river systems in South Africa (Allanson et al., 1990) as it gives rise to dramatic changes in the characteristics of a river (Petts, 1984). Some of the changes are more obvious than others, for example downstream flows and flow patterns are easily noticed as a modification by the impoundments. However, less obvious is the change of physico-chemical variables and biological properties of the controlled rivers (Ward et al., 1984). It is also well known that a river recovers given sufficient time and distance from the dam as the water flows and quality are ameliorated. The concept of a “reset distance” as developed by Ward et al. (1984) is defined as the length of stream required for a parameter (physical or biological) to recover to its pre-impoundment characteristics. Ferrar et al. (1988) noted that the concept of “reset distance” is an important one for ecological research. This is a major thrust of this report.

Many investigations have been conducted to establish the impacts that water releases, both surface and scour, have on the downstream aquatic ecosystems (Ward, 1976; Ward & Stanford 1979, 1982; Lillehammer & Saltveit, 1984; Craig & Kemper, 1987, cited in Gore, 1994; Lloyd et al., 2002). The effects of cold yet thermally stable, nutrient rich but sediment hungry waters include the adverse effect on the life cycle of macroinvertebrates, proliferation of periphyton mats and reduced food availability due to the altered thermal regime. Indeed, according to Lowe (1979), regulated streams are characterized by modified chemical and physical parameters, which in turn influence phytobenthic communities and macroinvertebrate communities. Physical controlling factors include temperature, substrate, flow and turbidity, whereas chemical factors can be categorized into nutrients and toxins.

The responses of a river to regulation may be either physical and chemical or biological. These are described below.

## 1.5 Physical and chemical consequences of regulation

The section below outlines the physical and chemical changes that may take place in a river downstream of an impoundment, which in turn may have consequences for the ecosystem. These physical and chemical changes thus become drivers of ecological change.

Flow volume is an important hydrological factor influencing the aquatic ecosystem in rivers (Petts, 1996; Poole and Berman, 2000). The flow rate has direct effects on the aquatic life in rivers as it alters the streambed conditions, which directly determines which biota will inhabit the river. Many biota have requirements for particular flow depths and velocities, which may form micro-habitats which would be destroyed by alterations in flow. In most rivers, discharges vary seasonally, imposing seasonal changes in biological communities (Chapman, 1992). Further complicating this is the influence of flow changes caused from impoundments. A long-term study of invertebrate assemblages downstream from a large dam revealed a decline in macroinvertebrate genera following the construction of the dam (Vinson, 2001). Additionally, the effects of eutrophication (nutrient enrichment), a situation most likely to occur in slow flowing or impounded rivers, can lead to deoxygenation, which results in a rapid decrease in aquatic life particularly fish (Chapman, 1992). Eutrophication causes an explosive response of zooplankton populations actively feeding on the readily available nutrients and the reductions in oxygen concentration is attributed to their metabolic processes.

## 1.6 The "reverse hydrograph" phenomenon

An issue that is particularly pertinent to this project has been labeled here the "reverse hydrograph" phenomenon i.e. flow volumes in a river which are the opposite of the natural situation. For example, in summer rainfall areas, in summer, lower amounts of water may be released from impoundments because there is sufficient flow generated in the downstream catchment by the high seasonal runoff, together with the contributing tributaries, to supply the downstream demands. However, in winter when the river flows are low and sporadic, operators release larger quantities of water from impoundments to supply to the downstream users. Such operations may completely reverse the flow hydrograph compared to that of the natural condition (Figure 2). The opposite would be the situation in a winter rainfall area. It has been suggested that both of these scenarios are likely to have a severe influence on the downstream river ecology.

Besides the effects that dams have on the bulk quantity of water that is discharged downstream, the periodicity of that discharge is likely to be substantially different to the natural situation. The ecosystems of many rivers, and in particular rivers in regions that are essentially dry, like South Africa, are reliant on variability of flow

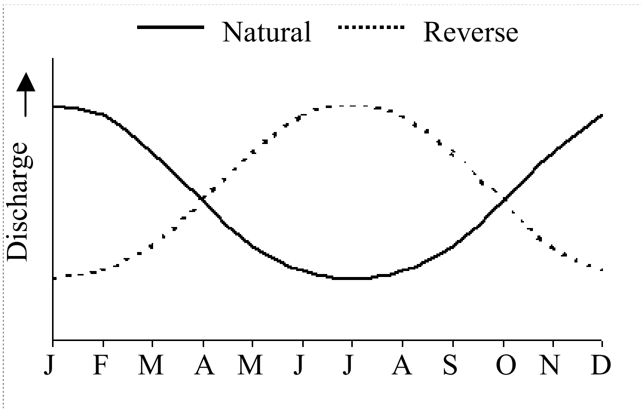

Figure 1.2 Typical example of hydrographs showing the discharge throughout a year for a "Natural" system and a "Reverse" hydrograph caused by management operations (for impoundments in summer rainfall areas in the southern hemisphere).

The inhabitants of rivers like these have evolved in response to a natural variability in flow, where low drought flows are as important as high flood flows to maintain species diversity. Reducing this variability to a stable flow can have dire consequences as species that thrive under this new situation tend to assume dominance at the expense of the original inhabitants.

## 1.7 Water temperature

Water temperature is an important and widely measured physical property of streams and rivers (Webb, 1996; Gu et al., 1998) and the thermal condition of a river is considered as one of the most important single criteria influencing aquatic ecosystems (Smith, 1972). Rivers-Moore (2003) stated that a rivers thermal regime is the product of a multitude of thermal drivers and buffers interacting at different temporal and spatial scales; including air temperature, flow volume, channel geomorphology and riparian vegetation. Additionally, temperature influences most of the physical, chemical and biological properties of water (Smith, 1972; Petts, 1984; Chapman, 1992). Thus the importance of water temperature has become recognised and significant research has been devoted to the thermobiology of freshwater organisms which has demonstrated that water temperature can moderate many different aspects of stream and river biota (Webb, 1996).

At a worldwide scale the influence of impoundments on the downstream river water temperatures has been well studied e.g. Webb and Walling (1985), Boon and Shires (1976), Gu et al. (1998), and Carron and Rajaram (2001). However, these have mostly been northern hemisphere studies and local studies are few e.g. Davies et al. (1989). South African rivers have several marked differences from the temperate rivers in the north on which most regulated river research has been carried out (Davies et al., 1989). This has necessitated the need for increased recognition to the importance of similar studies in the context of South African rivers.

Pitchford and Visser (1975) compared water temperature downstream of the H F Verwoerd Dam (now Vanderkloof Dam) on the Orange River before and after the dam was constructed, and found that the temperature range was reduced from 19.6$^{o}$C (pre-impoundment) to 12.8$^{o}$C (post-impoundment). They also found that winter water temperatures increased downstream after the completion of the impoundment whilst the summer water temperatures subsequently decreased (Pitchford and Visser, 1975). They concluded that seasonal effects were delayed by the thermal inertia of the reservoir water mass. Seasonal variation of water temperature downstream from an impoundment should have some correlation with the seasonal mixing occurring within the impoundment. In summer when the epilimnion is warmer, due to higher solar radiation, the difference between the epilimnion and hypolimnion is significantly greater. As a result the water released from the bottom of the impoundment consists of the much colder, hypolimnetic water. The temperature difference between the two layers is much less during winter when the effect of stratification is less pronounced.

River water temperature is regarded as a major controller of aquatic life (Smith, 1972) mostly due to its influences on physiological processes (Chapman, 1992), the distribution patterns (Weeks et al., 1996) as well as the survival and fecundity rates of organisms (Allan, 1995). The temperature of the environment has long been considered to play an important role in the reproductive cycles of freshwater fish (Cornish and Smit, 1995) as well as being important for fish growth and behaviour (Rivers-Moore, 2003). Higher water temperatures are often necessary to produce the high growth rates necessary for fish and other aquatic biota to attain significant populations, especially in flowing water (Chapman, 1992). More specifically, an increase in water temperature is an important cue (stimulus) for endocrine control of reproduction e.g. for gonadal maturity to occur (Cornish and Smit, 1995). Changes in the thermal regime can even result in the survival or otherwise of organisms in a river (Pitchford and Visser, 1975). In a natural river system, aquatic animals are adapted to cope with or avoid specific conditions such as low water temperatures in winter (Stuckenberg, 1969). Fish species have a tendency to escape changes in thermal conditions because of their ability to migrate to more favourable regions. However, once the river becomes impounded the system becomes fragmented, limiting or preventing the movement of fish species attempting to escape unfavourable conditions.

The chemical changes that take place within the upstream impoundment, with the consequent changes to the water released to the downstream river, may have severe impacts on river ecosystems.

Besides the temperature changes discussed above, the quality of the downstream water may vary as follows:

- Stratified dam with scour water releases – these waters are usually anoxic, containing dissolved metals and nutrients (iron, manganese, sulphur, ammonia and phosphorous) many of which are toxic to organisms. The dissolved solids increase the turbidity of the water although the water is devoid of larger particles that would provide sediment to the downstream river.
- Stratified dam with surface spillage – these waters are generally clearer than lowland rivers in many parts of South Africa, with the exception of mountain streams, thus creating an unnatural situation in the downstream river. With less turbidity, predation amongst biota changes to be more visual thus disadvantaging those organisms that thrive by feeling or smelling for food. Benthic algae flourish as more light is available, creating a new food source and altering the surface characteristics of the substrate, which is exacerbated by the lack of sediment deposition which is needed by some organisms. The water coming from the dam also contains free-floating phytoplankton in numbers greater than usually found in flowing rivers. Again, this provides a new food source that favours organisms that filter food from the water, advantaging them over those normally found in turbid South African rivers.

## 1.8 Biological consequences of regulation

Riverine communities include the truly aquatic plants, animals and micro-organisms as well as the terrestrial riparian vegetation and its associated biota (Ferrar et al., 1988). Recently concerns have been expressed about the negative impacts of impoundments on the downstream ecology of South African river systems e.g. Cornish and Smit (1995), Palmer (1995), Weeks et al. (1996), Vinson (2001). Focus on the protection of rivers has shifted from mainly physical and chemical measures, to include biological measures (Norris and Thoms, 1999). This is mostly because the link between abiotic processes and biotic patterns is an important consideration in order to maintain biodiversity. Thus, in studying the impacts of impoundments on downstream river ecosystems, the importance of linking abiotic parameters such as flow and water chemistry with the diversity of aquatic life that resides in the river system is necessary. Each one of these factors may act as a limiting factor, either alone or by interacting with other components (Stuckenberg, 1972).

Unfortunately there is a paucity of data and information regarding the links between physico-chemical parameters and biota. There is growing concern regarding the extent that the data that has been recorded in the past is mostly of short duration and/or unreliable. Furthermore, there has been little detailed examination of the relationships between ecosystem degradation and biological response (Norris and Thoms, 1999). This is particularly important in aquatic systems, which further necessitates the requirement of extended years of record. In order to predict and mitigate the effects of dams throughout their long life span, data on how ecological communities respond over longer time periods is needed (Vinson, 2001).

Richter et al., 2003 suggests that the species richness and productivity characteristic of freshwater ecosystems is attributable to the natural variability of their hydrological conditions. Bunn and Arthington (2002) reviewed the consequences of altered flow regimes on aquatic biodiversity and suggested that four principles link hydrology and aquatic biodiversity and that these can be used to illustrate the impacts of altered flow regimes. The four principles are:

- Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition;
- Aquatic species have evolved life history strategies primarily in direct response to the natural flow regime;
- Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species; and
- The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

According to Lloyd et al. (2004) small flow modifications do not result in small ecological changes, and contrary to expectations, severe ecological changes can occur in response to even the smallest alteration to the flow regime. Furthermore, rivers respond to three scales of hydrological behavior, which are the change in flow regime, change in flow history as well as flow pulses.

A lag time is reported to exist for any hydrological change before an ecological response can be expected. For large organisms, such as large fish and riparian trees, this lag time is longer and can take decades before an ecological change is effected. However, for small organism, such as in-channel fauna and flora, the ecological response can be immediate, such that even small hydrological changes result in significant loss of several taxa (Sheldon et al., 2000, cited in Lloyd et al., 2004).

## 1.9 Influence of regulated flow on aquatic plants

Most impoundments alter the flow regime of the stream downstream of the dam by making the flow constant thus eliminating large spates or severe droughts. This steady flow has been shown to contribute to increased densities of phytobenthos and periphytic algae. Part of the effect of steady flow to increased phytobenthos and periphytic algae is attributed to bed stability which is an advantage to aquatic vascular plants. In regulated streams the effects of scour on root systems are reduced, furthermore the shoreline and bank become more stable (Richter et al., 2003). Changes in water flow regime can have a profound effect on the establishment and survival of many aquatic plant species due largely to their narrow range of tolerances and inability to regenerate under modified conditions. Reduced summer floods and higher winter flows have been found to cause excessive growths of submerged aquatic macrophytes (Bunn & Arthington, 2002).

### 1.10 Influence of regulated flow on macroinvertebrates

According to Munn and Brusven (1991), macroinvertebrates are vulnerable to rapid changes in flow regimes and sudden increases in flows can cause as much as 14% of the standing crop to be eliminated. However, the impact of high flows downstream of dams can be selective with growth of some species e.g. orthoclad chironomids encouraged by the high flows. Regulation of a sporadic winter flow regime can have an adverse impact of allowing large populations of blackfly larvae to survive winter and proliferate in summer, thus posing a health risk. In South Africa, an example of the consequences of this type of flow regulation is that of the blackfly populations (*Simulium chutteri*) have become a serious problem along the Orange River since the river flows have become altered due to impoundments (Palmer, 1995). Palmer stated that the significantly lower summer flows and higher winter flows caused by the dams favoured the breeding and therefore success of blackfly populations. An effective way to reduce larval numbers of blackflies was found by using management operations to control the flows in the river at various times of the year.

A study conducted by Petts and Greenwood in 1985 found that alteration of communities' composition was the most common response to flow modification for both macro and micro invertebrates. Timms (1992) reported that the richness of invertebrate taxa decreased as a result of flow modification.

### 1.11 Influence of regulated flow on fish

The effect of impoundments on riverine fishes is generally negative. Impacts by dams on riverine fishes can be divided into immediate and delayed impacts. Immediate impacts are those that become apparent as soon as the dam becomes operational and include blocking of upstream and downstream migration of fish, habitat alteration, change in temperature downstream of the impoundment (Ward & Stanford, 1979).

Fish assemblage structure is associated with habitat structure and this correlation is influenced to a large extent by flow variability at a range of spatial scales. This relationship is widely researched and findings also indicate that altering the flow regime also affect the diversity of fish in regulated streams. Flow is said to play a significant role in the lives of fish since some critical life events are linked to flow regime. These life events include phenology of reproduction, spawning behavior, larval survival growth patterns and recruitment. Most of these life events are harmoniously linked to temperature and day length and such changes in flow regime that are not in natural harmony with these seasonal cycles may have a negative impact on aquatic biota (Bunn & Arthington, 2002). However, over time many species in regulated streams evolve life history strategies that enable strong recruitment despite the altered flow regime and associated disturbances. Humphries and Lake, cited in Bunn & Arthington (2002), proposed a low flow recruitment hypothesis to explain the patterns of spawning in southeastern Australian fishes in response to seasonal pattern of river flow. Milton and Arthington, cited in Bunn & Arthington, (2002) however, suggested that small subtropical stream fishes recruit successfully by spawning in the months of low and relatively stable stream flows when their spawning habitats are less likely to be scoured out or stranded.

A study conducted by Osmundson et al. (2002), investigated the effect that modifications of the natural flow regime by river regulation have on fish distribution and assemblage structure. The study area of concern, which is the Colorado River, is one of the most regulated rivers in North America with three mainstem, low-head, diversion dams collectively diverting water during the irrigation season. Furthermore other reservoirs store runoff in the spring and release it slowly over the rest of the year for power generation and to meet irrigation demands. This results in higher summer and winter base flows. The findings of the study indicated that the abundance of main-channel native fish declined in a downstream direction. Benthic biomass was also observed to be reduced downstream in both the riffles and runs. Measurements of turbidity also suggested a decrease in light penetration downstream of impoundments, whereas concentrations of nitrates and phosphorous tended to increase.

### 1.12 Implications for Instream Flow Requirements (IFR)

An Instream Flow Requirement (IFR), or environmental flow, is the amount and timing of flow that is needed in order for riverine ecosystems to maintain ecological functioning (Malan and Day, 2002). In recent years the necessity to maintain such flows has been recognised globally (Allanson et al., 1990) and the processes for doing so are being formalized in order to allow for proper management.

From a list of priorities for ecological research, Ferrar et al. (1988) suggested that the IFR should be determined for regulated rivers, a suggestion to which the scientific and legal fraternity in South Africa has responded with enthusiasm. The South African National Water Act (1998) is a prime example of a legislative response to this need. Within South Africa various methods have been developed to calculate the discharge required to maintain a given level of ecological functioning in river ecosystems, which has become referred to in South Africa as the IFR (Hughes, 2001) and in more recent years as the water quantity component for the Ecological Reserve. Most of these methods have been based on the assumption of a reduction of available habitat with successive decreases in flow (Allanson et al., 1990).

### 1.13 The Water Act and the Ecological Reserve

The South African National Water Act of 1998 has introduced the concept of Resource Protection through the derivation and implementation of an Ecological Reserve. The Ecological Reserve sets out to ensure that water of sufficient quantity and quality is always available in a river at the correct time, to sustain the ecological processes on which the river depends. The implementation of this policy has led to the development of various methods designed to determine in detail the quantity of water required by the ecosystems in a river. These methods attempt to produce an artificial flow regime, including the fluctuations that are so important in the natural river, which provides the minimum flow required to sustain the ecosystem thus allowing any "excess" water to be abstracted for consumption by various users. Methods for undertaking the same investigation but to ensure that the quality of the water is acceptable are also relevant here, where the capacity of the river water to assimilate additional chemical substances is assessed. The methods for doing this are not as well developed but their need has become increasingly obvious. Malan et al. (2003) developed a simple method which inter-relates water quality and quantity. In order for this to be achieved, quantitative predictions of the concentrations of chemical constituents and values of physical variables that can be expected for a given flow need to be made (Malan and Day, 2002).

The most recent suite of assessment methods are the Ecostatus methods (DWAF, 2005). These methods are designed to assess the responses of various response variables i.e. invertebrates, fish, riparian vegetation and geomorphology to various flows and in this way to allow for proper management.

The most common type of assessment done over the past several years in South Africa deals with establishing the minimum quantity of water acceptable to a river, thus anticipating a situation where there is a planned removal of water from the river. There are nevertheless situations where the opposite occurs i.e. where a river receives more water than it would naturally have. This is a situation which occurs, for example, where water is released from a dam and into a river for the sake of transportation, to be picked up downstream by users. This occurs in several situations in South Africa and has been the subject of extensive debate and controversy during some Reserve determinations. The concern that has been debated is based on the thesis that most South African rivers thrive on fairly high levels of stress (King et al. 2000), where it is necessary periodically for flows to drop to a point where organisms in the river retreat into survival mode. It is assumed that this should take place in symphony with the natural stress on a river that takes place during the low flow season. This natural and regular stressing of the river is thought to significantly alter the population dynamics of the river as the less tolerant organisms are curtailed and a succession of pioneering species develops once higher flows are restored. Under a regulated flow situation, when the stress is reduced by the addition of unnaturally large volumes of water, particularly if out of season, it is assumed that inappropriate species would flourish to the overall detriment of the ecosystem, This project has set out to test that assumption in the case of a dam operated by Umgeni Water. Water releases result in the so-called "reverse hydrograph" situation, where water released into the uMngeni River between Albert Falls Dam and Nagle Dam is higher in winter (dry season) than in summer (wet season). Thus the control of flow by Albert Falls Dam has completely altered the natural seasonal fluctuations and variability in the river flow as well as several aspects of the water quality.

## 1.14 Objectives of this project

1. Determine the ecological impacts of high winter flow volumes (in a summer rainfall area) on the longitudinal profile of the river downstream of an impoundment.
2. Determine if bottom (scour) releases are negatively impacting on the downstream aquatic ecosystem.
3. Develop management guidelines for environmentally optimal releases of water from dams where these are unnaturally high in winter.
4. Provide information to the water community for use in Reserve and EFA determinations as well as provide the means to satisfy the legal requirements of the dam operators.

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# Chapter 2. Legal review

The NWA (National Water Act No. 36 of 1998) is the principal legal instrument relating to water resources management in South Africa and contains comprehensive provisions for the protection, use, development, conservation, management and control of South Africa's water resources.

The Act restructured the previous administrative system by decentralising the responsibility and authority for water resources management to appropriate regional and local institutions. The Minister of Water Affairs and Forestry is appointed as the public trustee of water resources on behalf of the national government and has overall responsibility for all aspects of water resources management in South Africa.

In terms of Section 1(1)(xxvi) of the Act, Umgeni Water is classified broadly as a Water Management Institution and consequently, the organisation is assigned powers and duties relating to the management of water resources in general which include watercourses, surface water, estuaries and aquifers within KwaZulu-Natal. The organisation manages and operates 12 storage dams (including Albert Falls), 13 waterworks, a number of wastewater works and an extensive network of pipelines, an inter-basin transfer system, major pump stations and reservoirs. Umgeni Water operates within the framework of the Water Services Act, Public Finance Management Act and the Public Audit Act and is accountable directly to the Minister of Water Affairs and Forestry.

The National Water Act requires that the nation’s water resources are protected, managed and controlled and takes the following factors into account:

- Meeting the human needs of present and future generations
- Promoting equitable access to water
- Redressing the results of past racial and gender discrimination
- Promoting the efficient, sustainable and beneficial use of water in the public interest
- Facilitating social and economic development
- Protecting aquatic and associated ecosystems and their biological diversity

Various instruments, such as licensing and regulations, are available under the NWA which could be used to achieve these purposes. Under the National Water Act, any “water use” requires a licence. The definition of “water use” in the Act includes “storing water”[1] and “altering the bed, banks, course or characteristics of a watercourse”.[2] Consequently, Umgeni Water requires a licence to construct and operate a dam. Prior to issuing a licence, the responsible authority (minister or delegate that may be a Catchment Management Agency) is obliged to consider various factors including “efficient and beneficial use of water in the public interest” and the “socio-economic impact”. Little or no consideration is given to environmental concerns. DWAF has however, issued a document which describes the water use authorisation process and seeks to harmonise this with the National Environmental Management Act (NEMA, 1998) processes.

The National Environmental Management Act gives effect to the rights contained under section 24 of the constitution which states that “everyone has the right to an environment that is not harmful to their health or well-being; and to have the environment protected, for

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[1] Section 21(b)
[2] Section 21(i)

the benefit of present and future generations". The NEMA provides for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment. These principles include that development must be socially, environmentally and economically sustainable.[3] NEMA sets the requirements for dam practice from an environmental perspective and provides checks to the NWA. The Environment Conservation Act (No. 73 of 1989), the precursor to NEMA, is the legislation that requires that an environmental impact assessment be undertaken for all dam projects.

Although an EIA is required for the construction of new dams, many dams were constructed prior to the enactment of the EIA regulations and as a result the impacts of construction and operation on the environment have been given little or no consideration. South Africa is in the early phases of developing a policy and comprehensive systems for monitoring and evaluating performance, benefits and impacts for existing large dams, improving benefits and mitigating environmental impacts.[4]

The NWA takes operational environmental impacts into consideration within the reserve determination. The Act requires that a "reserve" be identified before any authorisation for water use is granted. The basic reserve contains the minimum quality and quantity of water required to satisfy basic human needs, and protect aquatic ecosystems.

Although the reserve determination seeks to address environmental impacts associated with the minimum amount of water required to protect aquatic ecosystems, large discharges of water from dams also have associated environmental impacts. Under the Water Services Act, Umgeni Water in performing its activities is obliged to comply with environmental policies[5] and consequently is required to uphold the principles set out in NEMA. In fact, all organs of state are required to consider the NEMA principles for actions that may significantly affect the environment and consequently discharges from dams need to be assessed in this light. The danger now lies in the consideration of environmental concerns falling between stakeholders with no-one taking responsibility for the implementation of plans to address these problems. This is the case with Albert Falls Dam.

The Department of Water Affairs and Forestry planned, designed, constructed and operated the dam until 31 March 1993. Operation was then delegated to Umgeni Water who bears the responsibility for the operation and maintenance of the dam structure on an agency basis for the Department. Inspection, maintenance and operational procedures are set out in the Operation and Maintenance Manual, a policy document drafted by DWAF. Umgeni Water is responsible for implementing this policy. The manual requires that the officer-in-charge undertake various inspections of the dam on a monthly basis or after the conclusion of an event such as a flood. No environmental elements are monitored for the express purpose of maintaining ecosystem integrity and the manual makes no reference to discharges from the dam which may impact on the downstream environment. A letter from DWAF to Umgeni Water, however, does identify that sudden increases in discharges from dams may cause severe, if not disastrous repercussions downstream and stipulates that future releases be made at an incremental rate not in excess of $2m^3/s$ per hour. This condition relates specifically to public safety rather than the environment.

Although DWAF is ultimately responsible for drafting operational guidelines and policy around dams, such as Albert falls, other organs of State including Umgeni Water must

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[3] Chapter 1 Section 2(3)

[4] The World Commission on Dams and South Africa

[5] WSA Section 34(1)(h)

ensure that the issues around dams and the impact of their discharges on the environment are included in such policy. This is a legal obligation imposed by both the National Water Act and the NEMA through the inclusion of the precautionary principle, and the environmental duty of care placed on all organs of state and individuals.

**Protection of Biodiversity**

The National Water Act (No. 36 of 1998), the National Environmental Management Act (No. 107 of 1998) and the Biodiversity Act (No. 10 of 2004) do not themselves address the issue of an acceptable change in biodiversity but create an enabling framework for integrated management of water resources, environmental management and biodiversity conservation respectively.

The National Water Act sets out to ensure that the nations' water resources are protected, used and managed[6] and in so doing that aquatic and associated ecosystems and their biological diversity are protected.[7] The Act itself does not provide guidance on how this may be achieved but enables the formulation of a National Water Resource Strategy (NWRS).[8] The NWRS indicates that a systematic and strategic approach is being developed to ensure that biodiversity conservation - required to conserve representative diversity and ecological functioning of South Africa's water resources - is achieved.[9] The issue of changes in biodiversity is not addressed.

The National Environmental Management Act (NEMA) is underpinned by a set of environmental principles[10] which further concretise the environmental right contained in the Constitution. Although some of these principles have relevance to biodiversity conservation, the Act does not specifically address the issue of changes in biological diversity. The NEMA provides the overarching framework within which the Biodiversity Act may function.

The Biodiversity Act focuses much attention on the protection of threatened or protected ecosystems or species[11] but does make provision for the protection of species and ecosystems not listed in Section 52 through the use of biodiversity management plans.[12] The Act does not designate responsibility to any person or organ of state to draft such a plan but instead places the onus on any person wishing to contribute to biodiversity management.[13] Furthermore, the Act simply requires that such plans ensure the long-term survival in nature of the species or ecosystems to which the plan relates, provides for monitoring of the plan and alignment of the plan with other relevant legislation. It does not go so far as to stipulate the inclusion of specific norms and standards or any changes in the associated biodiversity.

In an effort to provide for monitoring and conservation status of various components of South Africa's biodiversity, the Act requires that the Minister prepare and adopt a National Biodiversity Framework.[14] Consequently, South Africa has drafted a National Biodiversity

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[6] Section 2
[7] Section 2(g)
[8] Chapter 2
[9] NWRS Chapter 3.
[10] Chapter 1
[11] Chapter 4
[12] Section 43
[13] Section 43(1)
[14] Section 38

Resource Strategy and Action Plan which sets out a framework and a plan of action for the conservation and sustainable use of the country's biological diversity.[15] One of the outcomes of this strategy is to ensure that national initiatives to manage terrestrial and aquatic ecosystems are co-ordinated, developed and implemented with full stakeholder participation to contribute to sustainable socio-economic development.[16] This will entail, in part, integrating biodiversity objectives into the national river classification system by linking the biodiversity status of rivers to guidelines for water management and to land practices and environmental management in the quaternary catchment.[17] The strategy also aims to establish a monitoring and evaluation framework (including indicators and thresholds) for ecosystems and species.[18] It is hoped that these activities will address what constitutes an acceptable change in biodiversity for various ecosystems.

The above discussion on protection of biodiversity is particularly pertinent to this project, and is fully described at the end of Chapter 7 on macroinvertebrates. It has been highlighted in this section, that while there appears to be some success in the protection of biodiversity and River Health when measured using coarse techniques such as the SASS 5 method of macroinvertebrate assessment, when the population structure is examined by using species level identification, the picture changes dramatically. This situation is being addressed, but only partly, by the implementation of the Ecostatus approach (Kleynhans, *pers com*) to measuring river health and will in future be partially addressed by the River Classification as is required by the Water Act. There is nevertheless potential in-congruence between the requirements of the Water and Environmental/ Biodiversity Acts. This is an issue that needs urgent attention.

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[15] Department of Environmental Affairs and Tourism (2005) South Africa's National Biodiversity Strategy and Action Plan.
[16] Outcome 3.1
[17] Activity 3.1.3
[18] Outcome 2.5. Activity 2.5.4 and 2.5.5.

# Chapter 3. Site and project details

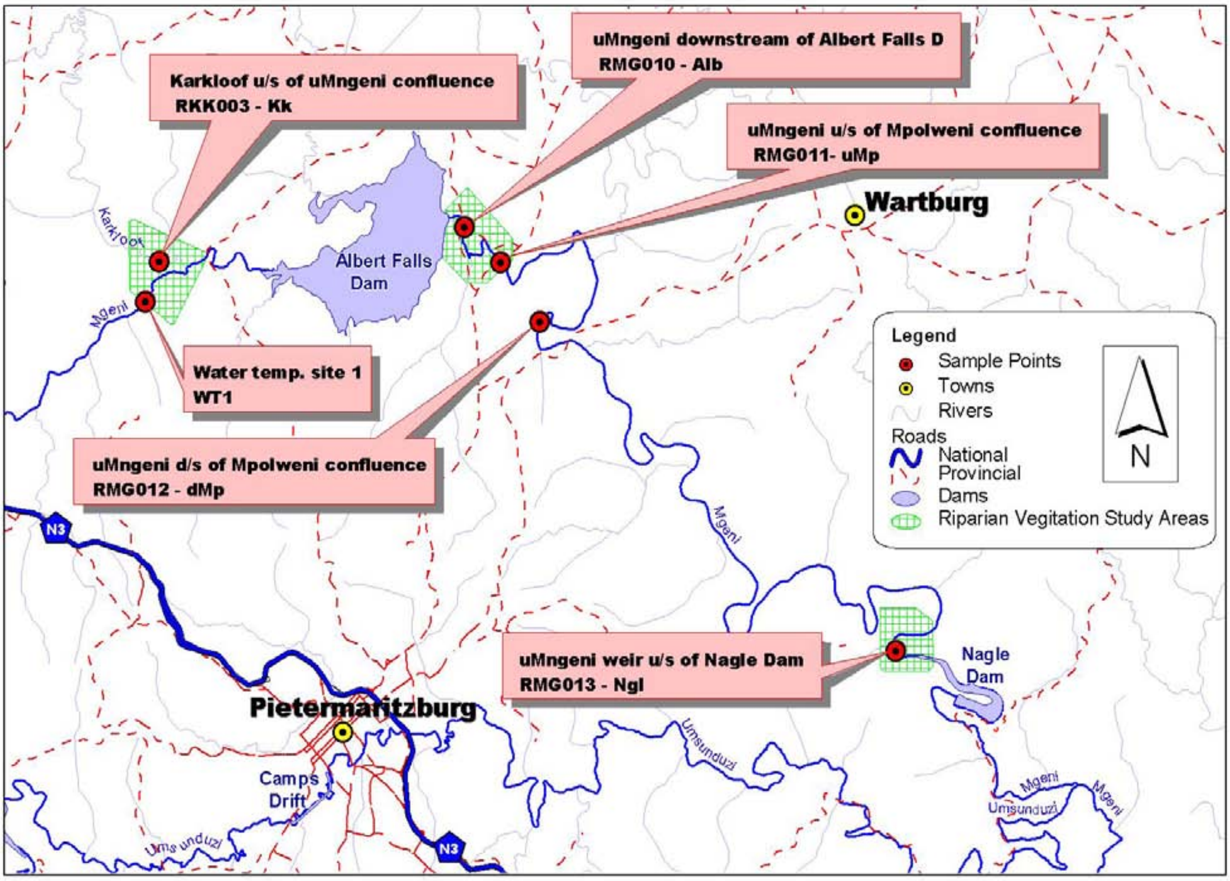


Figure 3.1: Site localities in KwaZulu-Natal, South Africa.

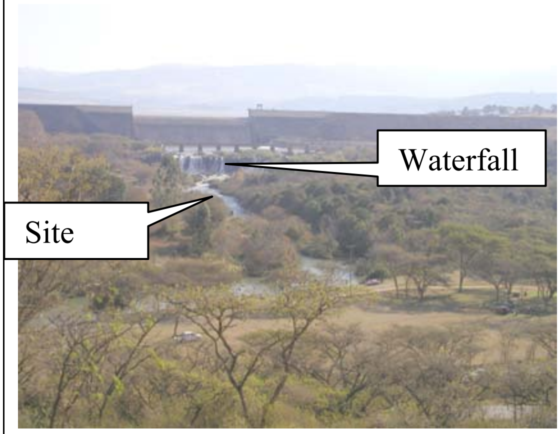
Table 3.1: Site names used during this study

| Site name | Umgeni Water code | Project code |
|---|---|---|
| Karkloof River upstream of uMngeni confluence | RKK003 | Kk |
| uMngeni downstream of Albert Falls Dam | RMG010 | Alb |
| uMngeni upstream of Mpolweni confluence | RMG011 | uMp |
| uMngeni downstream of Mpolweni confluence | RMG012 | dMp |
| uMngeni weir upstream of Nagle Dam | RMG013 | Ngl |

### 3.1: Illustrations

**Site Kk (RKK003) Karkloof River upstream of confluence** - upstream of road drift (19th August 2003)

**Albert Falls Dam** (12th July 2002)



**Site Alb (RMG010) uMngeni River downstream of Albert Falls Dam** (12th August 2003)

**Site uMp (RMG011) uMngeni River upstream of Mpolweni confluence** (12th August 2003)

**Site dMp (RMG012) uMngeni River downstream of Mpolweni confluence** (12th August 2003)

**Site Ngl (RMG013) uMngeni River above Nagle Dam** (3rd September 2003)

## 3.2 Site selection and survey

Sites for detailed monitoring were chosen as follows:

Table 3.2: Sites used to investigate high winter flow volumes below Albert Falls Dam.

| Acronym | UW site no. and co-ords. | Location | Rationale | Data availability |
|---|---|---|---|---|
| **Kk** | RKK003<br>Lat-29.443833<br>Lon30.310833<br>Dec degrees | **Karkloof River** 1,5 km upstream of its confluence with the uMngeni River. The site was up and downstream of the low-level bridge servicing Game Valley Estates. | This site was the control for the study.<br>The Karkloof River is unregulated, rising in the Karkloof hills. Although not pristine, the river at this site is in very good condition as substantiated by years of bio- and chemical monitoring by Umgeni Water. Although smaller than the uMngeni River study sites, it was considered large enough to be a reference site, particularly for those uMngeni sites just below Albert Falls Dam which are only ~10 km away.<br>Unfortunately the site falls in a different ecoregion (see State of the uMngeni River Report) but is close to the boundary. | Flow data only available from a site at Shafton, some distance upstream.<br>Good water quality records since 1987 at Umgeni Water.<br>Good SASS data since 1993 at Umgeni Water. |
| **Alb** | RMG010<br>Lat-29.432889<br>Lon30.432167<br>Dec degrees | **uMngeni River downstream of Albert Falls Dam** and the waterfall, in the vicinity of the old hydro power station. | This site most strongly reflects the regulated flows from the dam as the entire flow volume emanates from the dam. It is also under the direct influence of bottom water released from the dam, with all the quality problems associated with that, although aeration is not a problem as the water tumbles over the waterfall immediately upstream. | Flow records from U2H014 0,5 km downstream.<br>No long term water quality and biological data which was only collected for the duration of the project. |

| Acronym | UW site no. and co-ords. | Location | Rationale | Data availability |
|---|---|---|---|---|
| **uMp** | RMG011<br>Lat-29.444667<br>Lon30.446667<br>Dec degrees | **uMngeni River upstream of the Mpolweni confluence** and just above the Greytown road bridge. | This site is sufficiently far from the dam (~4 km) so that some of the immediate problems associated with scour water would be ameliorated. The river is nevertheless almost entirely regulated by the dam. | Flow records – will be essentially the same as site Alb.<br>Long-term water quality data exists for this site. |
| **dMp** | RMG012<br>Lat-29.464583<br>Lon30. 461972<br>Dec degrees | **uMngeni River downstream of Mpolweni confluence** and just above the Wartburg road bridge. | This site is ~16 km from the dam. A major tributary, the Mpolweni River, joins the river approximately 6 km upstream of the site. The Mpolweni provides a major portion of the flow at site 12 during the summer months when releases from the dam are curtailed. | Flow records – there are no records directly for this site although the sum of the weirs on the uMngeni and Mpolweni rivers upstream will approximate.<br>Long-term water quality data exists for this site.<br>Long-term SASS data also exists although from a site a short distance away. |
| **Ngl** | RMG013<br>Lat-29. 575000<br>Lon30. 603333<br>Dec degrees | **uMngeni River weir upstream of Nagle Dam**, the site immediately below the gauging weir. | This site represents the maximum recovery of the river and lies some 54 km below the dam. Regulated flows are substantially mitigated by catchment inputs although during the dry season high flow | Flow data is good from the weir at the inflow to the dam.<br>Long-term water quality and SASS data |

| Acronym | UW site no. and co-ords. | Location | Rationale | Data availability |
|---|---|---|---|---|
| | | | releases from the dam will make up a large portion of the flow. The quality of the site was somewhat compromised by the presence of the gauging weir immediately upstream. | exists at Umgeni Water. |

### 3.3 Date of surveys

Flow, water and biological monitoring data for most of the sites was collected for several years prior to the commencement of the project, as part of Umgeni Water's routine monitoring programme. For the intensive survey that was part of this project, a single survey of invertebrates was conducted in March 2001. The project was then delayed due to construction activities that took place at Nagle Dam, which necessitated making alterations to the flow releases from Albert Falls Dam in a way driven totally by the needs of the construction teams. This rendered the downstream flows unsuitable for this investigation. The project was accordingly put on hold until the construction activities were completed, and then several months allowed for the river to "normalise" before the survey recommenced. The assumption was made that there were no substantial long-term effects. The main ecological surveys that yielded the information for this project took place in August and October 2003, and March and June 2004.

A chronology of events over the past years, that may have some bearing on the results of this project, are listed below.

Table 3.3: Chronology of relevant events prior to and during the survey.

| Date | Event | Consequences for project |
|---|---|---|
| 1976 | Completion of construction of Albert Falls Dam | Flow regulation begins. Note that the Midmar Dam was completed in 1963 and lies several km upstream of Albert Falls, so regulation by that dam had been taking place for a decade longer. |
| 1987 | Water quality sampling of the downstream river by Umgeni Water commences. | Providing good foundation for later interpretation. |
| March 2001 | Initiated survey for this project initially as an internal Umgeni Water project. Sites were | Good biological data at a time when the river was full and the dam spilling strongly. It could be said that the |

| Date | Event | Consequences for project |
|---|---|---|
| | selected and preliminary data collected. | river came as close to its natural condition as is possible below the dam. |
| August 2001 | Flow releases from Albert Falls Dam reduced to begin rehabilitation of a weir at Nagle Dam. | The flows were lower than usual during winter months. This alteration of the managed flow may have had some short and possibly medium term consequences. |
| October 2001 | Project approved by WRC | Greater funding allows for more intensive survey. |
| Jan 2002 | Project officially delayed due to construction of fuze-plug and renovation of gates at Nagle Dam. | Necessary so as to gain data not affected by the construction activity. |
| August 2001 – April 2002 | Flow volumes kept to a minimum with pulses of high flow to top up Nagle Dam as needed. Dam spilled periodically. | This would have been almost typical of the summer management regime over past years although the high flows releases would have been unusual. |
| May 2002 | For 10 days flows increased to 30 m$^3$/s in order to fill Nagle Dam. Dam spilled periodically. | Although not uncommon to have floods during May, this was atypical for the managed flow. |
| June 2002 | High flows to fill Nagle Dam. | High winter flows of this magnitude were abnormal. |
| July 2002 | Weir construction completed and normal operation of river regulation resumed but at slightly reduced flows. Repairs to gates continue. Periodic high releases to fill Nagle Dam. | |
| 23 April 2003 | Guidelines drafted by project team for the regulation of flow releases from Albert Falls in accordance with this project accepted by Umgeni Water operations staff. These included:<br>1. No releases from the dam were to exceed 9 m$^3$/s measured at the Nagle Dam weir. This did not apply in the event of overtopping of the dam.<br>2. Between 1 May and the 15th August, release from the dam should not be less than 4 m$^3$/s at any time, even for short periods. As a principle, any reduction in release should take place gradually (over 48 hours) and in step-wise fashion. | |

| Date | Event | Consequences for project |
|---|---|---|
| | The operators were exceedingly cooperative and all of these rules were met. | |
| May 2003 | Work on diversion gates completed. River operation returns to normal. | |
| July 2003 | **Project recommences.** Contract with WRC signed. Detailed ecological surveys begin. | The low volumes of water in Albert Falls Dam, due to poor rainfall, were advantageous to the project as they made possible the manipulation of downstream flow volumes without the confounding influence of water spilling over the crest of the dam in an uncontrolled manner. |
| August and October 2003 | Survey of all sites. | |
| 18th January 2004 | Extensive fish kill below the Wartburg Road bridge and just below Site dMp. | Unknown cause of the fish kill, thus with unknown effects on the project. It is possible that the killing of fish would have affected subsequent fish surveys which were next conducted in early March. Dead fish were not found at the survey site dMp above the Wartburg Road bridge so only migratory fish would have been affected. It is possible that there was an effect at site Ngl above Nagle Dam. |
| March and June 2004 | Survey of all sites. | |
| 3rd June 2004 | Report by local farmer Rob Parker, of suspected pollution in the Yarrow River, a tributary of the Karkloof River. DWAF investigated. | As this was upstream of the Reference site, this could have consequences for the quality of the Karkloof River data. |

### 3.4 Albert Falls Dam and water releases.

This dam acts to store water for downstream release to Nagle Dam where abstraction for Durban is based. The dam does not have a variable height release structure, which means that controlled releases can only take place through the scour mechanism (i.e. containing hypolimnion, bottom water). At those times when the dam is spilling, when the volume exceeds 100%, then there is minimal control on flow volumes in the downstream river. At these times the river gets closer to its normal unregulated flow regime, but cannot ever be completely natural, for the following reasons:

1. the volume of the impoundment buffers the flow variability occurring in the inflowing rivers. Flood peaks are thus dispersed over a longer time and do not reach the same maxima.
2. the quality of the spilling water does not reflect that of a natural river in this ecoregion, bring excessively clear, with low nutrients and abundant algae of types not normally found in this type of river.
3. even during spilling, it is common practice to release scour water at the same time, on the assumption that excessive nutrients and sediments are scoured from the bottom of the dam, thus providing for dam maintenance.

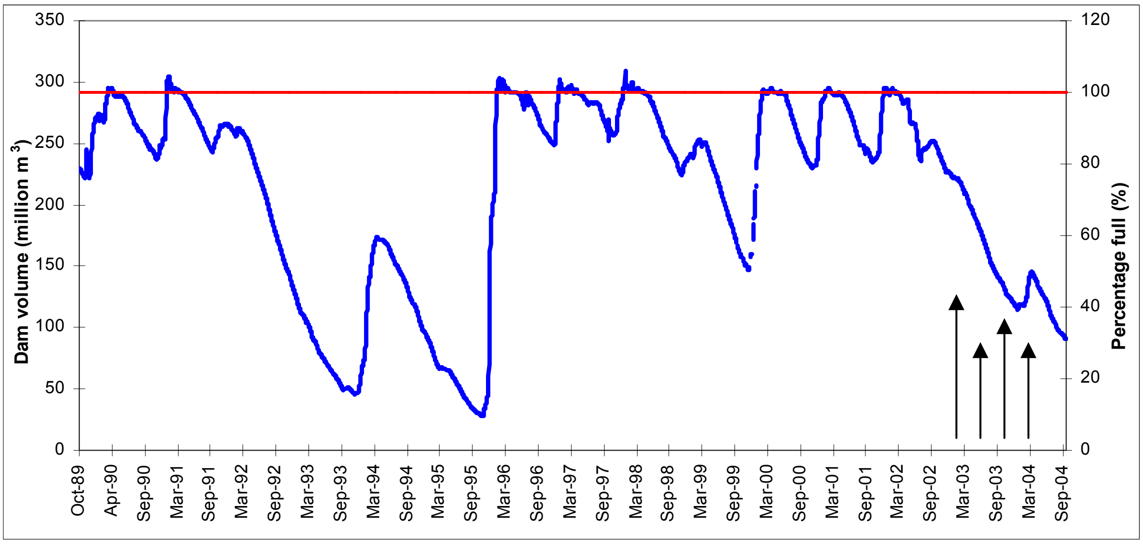


Figure 3.2: Volume of water in Albert Falls dam illustrating when spilling took place (>100%). The vertical arrows indicate the survey times for this project.

The site used for this investigation is well suited to the testing of the assumption that ecological damage will result from high and sustained winter flow releases from a dam in the following way:

- Water is stored in Albert Falls Dam and released into the uMngeni River to supplement the water in Nagle Dam, some 53 km downstream. Water from Nagle Dam is the primary source of water for the city of Durban.
- Albert Falls dam has been in existence and has operated in this way since its construction in 1976. This means that the downstream river has in all likelihood, been substantially changed to accommodate the artificial flow regime it is subjected to.

- The water released from Albert Falls is regulated for downstream user purposes. Flows are comparatively constant but with higher dry season (winter) and lower wet season flow.
- A tolerably good reference site exists on the Karkloof River only a few km distant from the Albert Falls Dam wall. The river is somewhat smaller than the uMngeni would naturally be but because it is an unregulated river, it provides a suitable control for comparison. It also has a gauging weir albeit some kilometers upstream of the confluence between the two rivers.
- Gauging weirs exist at the upper and lower extremes of the river between the two dams thus providing good hydrological data for the entire regulated river reach.
- Many years of water quality monitoring have taken place along this stretch of river covering all of the various flow scenarios.
- Many years of biological surveys (of invertebrates using the SASS method) have likewise taken place.

### 3.5 Flow regime below Albert Falls Dam

The common flow situation in the uMngeni River downstream of Albert Falls Dam is as follows:

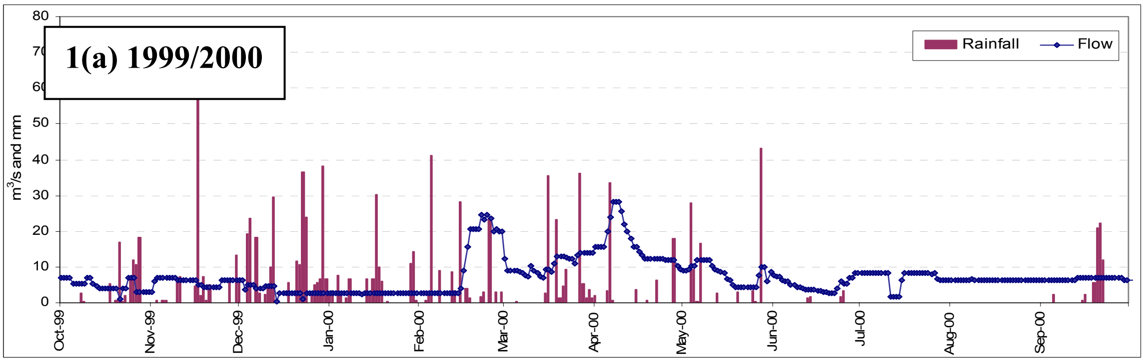
- **High volume water releases in winter (~6-8 $m^3$/s).** This is done to increase supply to Nagle Dam as the supply from the downstream catchment and tributaries diminishes in the dry season.
- **Low volume water releases in summer (~2-3 $m^3$/s).** Supply to Nagle Dam is supplemented by downstream inputs from tributaries during the wet season.
- **Sporadic high flow volumes in summer during wet seasons when the dam overflows.** The dam does not spill frequently and may go several years between this situation.
- **Highly variable spring flows**, where flow volumes may drop when rainfall increases. The cause of this is that tributary flow downstream takes over the provision of water to Nagle Dam.

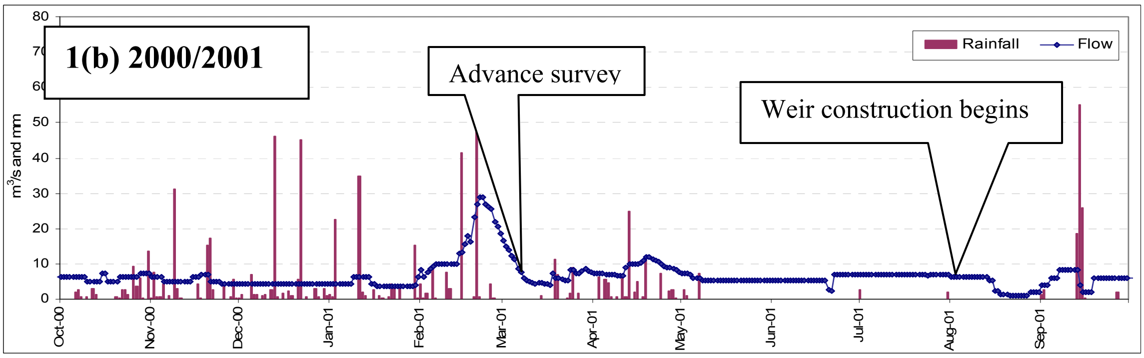
The above flow regime means that the flows in the downstream uMngeni River are substantially different to the natural regime which would be high summer and low winter flows. Not only this, but the existing flows are relatively constant while the natural flow regime would be more variable, as can is the situation in the Karkloof River control. This loss of variability could be the source of the most significant downstream stress on the system.

# Chapter 4. Flows in the uMngeni River

For nearly thirty years the flows below Albert Falls Dam have been regulated in order to provide water to the downstream Nagle Dam. Prior to this, there was a further fifteen years of regulation by Midmar Dam which sits further upstream on the uMngeni River. The common situation below Albert Falls Dam has been that the release of water is at its greatest during the dry winter months, when the downstream incremental flows are insufficient to provide Nagle Dam with the water that it needs. During the summer months, incremental flows are much greater, with the result that the flows from Albert Falls can be reduced. During times of high rainfall, when the dam volume exceeds 100% capacity, then the spillage of water overrides any form of regulation, and the flows in the river return to a something a bit closer to natural although this cannot ever be achieved (as was described above).

The figure below (Figure 1) illustrates the rainfall and flow volumes recorded at the weir immediately below Albert Falls Dam over a period of five years prior and concurrent with this project. The trend of low summer, high winter flows and periods of spillage are clearly illustrated. Also indicated are significant events including the dates when the ecological surveys were conducted. This makes it possible to observe the flow situation that gave rise to the particular ecological response that was recorded during this investigation.





Advance survey

Weir construction begins

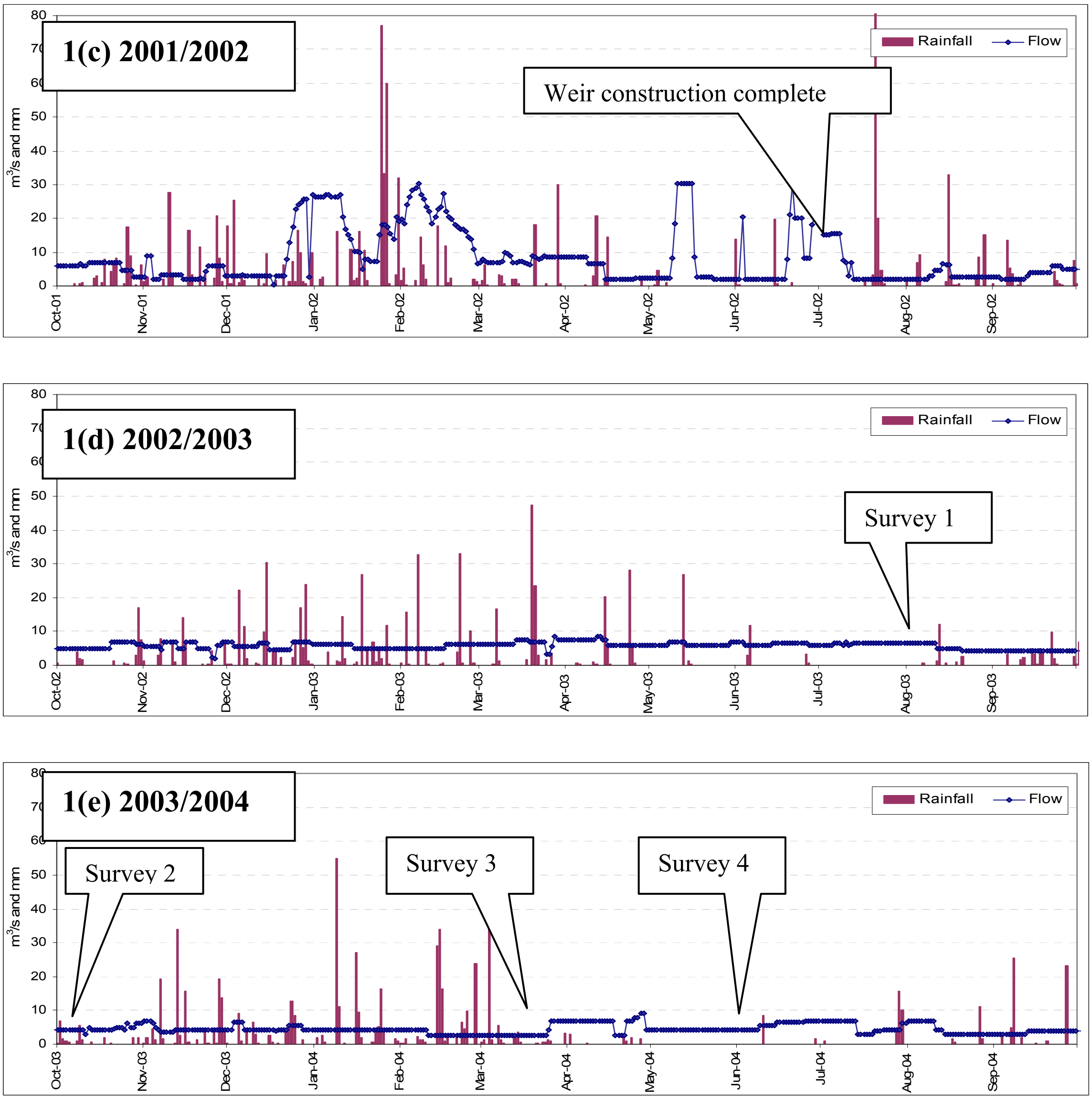


Figure 4.1: Five years of rainfall and flow volumes from the weir immediately below Albert Falls Dam.

## 4.1 The natural hydrograph of the region

Figure 4.2 below illustrates the shape of the hydrograph from the Karkloof River, illustrating the variability and seasonal change that is natural for the area i.e. high flows during summer, with maximum variability introduced by periodic flooding, with diminishing flows in autumn and the lowest, and most constant flows during winter.

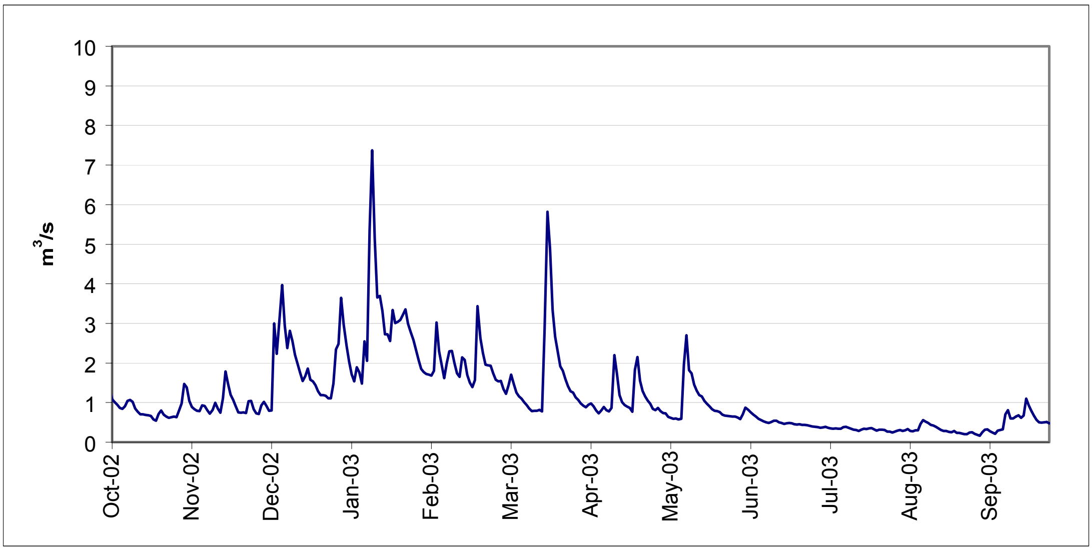


Figure 4.2: Flow record ($m^3/s$) from the Karkloof River at Shafton

The hydrographs below show the flow situation by the time the river reaches Nagle Dam, with the flow variations somewhat ameliorated by tributary and incident flows. Nevertheless, it can be seen that the high winter flow releases from Albert Falls Dam continued to dominate the river even at this distance from the dam as the shape of the hydrograph does not resemble that of the control Karkloof River (Figure 4,2). During wetter seasons this may not be the case.

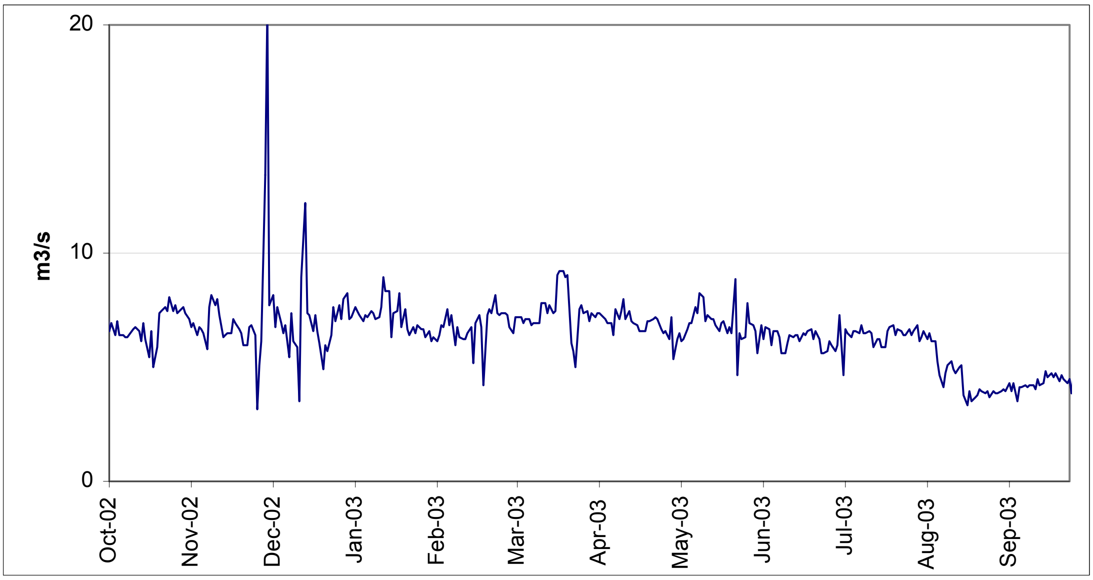


Figure 4.3: Nagle inflow rates ($m^3/s$) illustrating the pattern of flows arriving at that dam

# Chapter 5. Water Quality

The quality of the water in any river produces a wide range of possibilities for the habitation of different organisms, as it is well known that both plants and animals enjoy and/or tolerate water of different natures. So, while the water quality to be found in the river downstream of the dam is partially the result of the presence of the dam, this water quality acts as a driver of the condition of the ecosystem downstream. While a later chapter of this report attempts to reveal the correlations between water quality and the resulting biota, this chapter merely sets out to describe in detail the quality of the water in the uMngeni River downstream of Albert Falls Dam, as compared with that found in the unregulated Karkloof River upstream.

NOTE that the water quality discussion below documents the trends that are illustrated in box and whisker plots shown in graphs in Annexure A. The outer limits of the boxes indicate the 25th and 75th percentile, with the line across the box as the median. The outer edges of the whiskers on the box indicate the minima and maxima. The average is shown as an x.

## 5.1 Temperature

Temperature was anticipated to be one of the most important aspects of water quality that affects the downstream ecosystem. A comprehensive review of this issue is presented in the next chapter while the points below summarise the issue in the same way as the other water quality variables.

- Under all dam operating scenarios, the temperature of the Karkloof reference site was colder than the temperature of all the other sites.
- Under isothermal conditions, similar temperatures were recorded for all impoundment and downstream sites.
- Under stratified and spilling conditions, the colder water released from the Albert Falls dam bottom via scouring was mitigated by the warmer water recorded at the Albert Falls dam surface, as indicated by the warmer temperatures recorded downstream of the Albert Falls dam.

## 5.2 Conductivity

- Under all dam operating scenarios, similar conductivity values were recorded, ranging from 5.9 to 9.6 mS/m, indicating soft waters. Conductivity is a “conservative” variable, unlikely to be improved by normal environmental processes.
- The elevated conductivity at the site dMp could be the result of the Mpolweni confluence and is likely to be due to episodic pollution from the extensive feedlot activity in the area upstream.

## 5.3 Suspended Solids

- At the Karkloof reference site, suspended solids concentrations recorded under the summer stratified conditions were higher (median 15 – 17 mg/l) compared with those recorded during the winter (6 – 7 mg/l). This is due to higher rainfall during the summer period.
- Under the stratified conditions, the suspended solid concentrations downstream of the dam were generally lower than the upstream Karkloof reference site due to the dam acting as a sink for suspended materials. The trend downstream was generally upwards downstream of the dam.

- Under isothermal conditions, the suspended solids concentrations in the downstream of uMngeni river were generally higher than the Karkloof reference site, particularly downstream of the Mpolweni confluence. The Mpolweni catchment is generally degraded, with steep slopes and overgrazing leading to erosion. The significant forested areas in the Mpolweni catchment (with poorly maintained road networks) also contribute to the suspended solids load.
- Of note is that the high suspended solids in the dam bottom water did not carry through to the uppermost site in the river. A possible explanation is that the large pool immediately below the dam wall acted to settle the sediment, or a less satisfactory explanation is that the bottom water samples from dam were contaminated with sediments, which is a persistent problem.

## 5.4 Turbidity

- Under stratified conditions, the water in the Karkloof reference site was noticeably more turbid (median 17-18 NTU), than the downstream sites. This is likely to be due to afforestation practices in this catchment.
- Under isothermal conditions (winter, low rainfall-runoff conditions), all sites generally recorded low turbidity values (median below 10 NTU), with the exception of the dam bottom and the uMngeni river downstream of the Mpolweni confluence. The intensive agricultural practices (informal and formal) as well as the relatively high density peri-urban settlements contribute to the increased turbidity noted.
- Under all dam operating scenarios, turbidity was noted to increase downstream of the Albert Falls dam as the water accumulated sediments from the river and run-off from the banks.
- Of note is that the high turbidity in the dam bottom water did not carry through to the uppermost site in the river. A possible explanation is that the large pool immediately below the dam wall acted to settle the sediment but a less satisfactory explanation is that bottom samples are notoriously unreliable as the bottom sediments are easily incorporated into the water sample.

## 5.5 Dissolved Oxygen and Saturated Dissolved Oxygen

- All the sites under all dam operating scenarios were well oxygenated, with the exception of the Albert Falls main basin bottom, under the stratified conditions. The median dissolved oxygen concentration recorded at all sites was above 5 mg/l.
- The high percentage saturated dissolved oxygen (median values ranging from 78.9 to 100.6%) recorded further confirms that all downstream sites contained adequate oxygen to sustain the aquatic environment.

## 5.6 pH

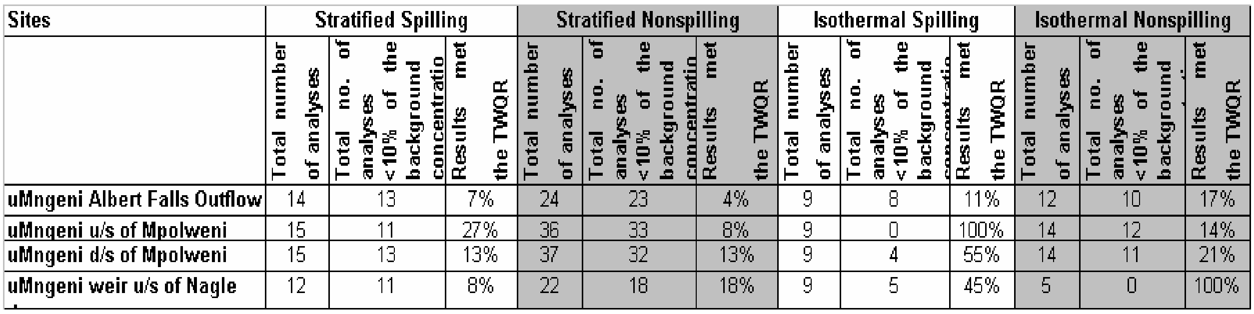
- The pH results recorded for all the sites were between 7.0 and 8.5, which fall within the pH range of most natural waters. There was no noticeable impact of dam operating scenarios on pH values recorded in the downstream river.

## 5.7 Iron

- Iron concentrations were generally higher during the summer stratified period (particularly when the dam is spilling, possibly as the inflowing water including that from the Karkloof River is rich in iron sediments resulting from storm erosion of soils, than the winter isothermal period. The non–spilling period, usually occurs during autumn when conditions are mildest, explaining the lower iron concentrations.

- Concentrations in the bottom of the stratified lake were particularly high but this may be an artifact of the sample collection as it is a common problem that incorporation of sediments into the water sample takes place during bottom sampling. This would explain why the release waters at site Alb were generally much lower in iron than the hypolimnion although the stilling pond and distance from the dam, with excellent aeration, would serve to lower these levels.
- The DWAF Water Quality Guidelines for Aquatic Ecosystems (1996) set a Target Water Quality Range which specifies that the iron concentration should not be allowed to vary by more than 10% relative to the background or reference condition (in this case the Karkloof reference site) at a specific time. These guidelines recommend that a site should meet the Target Water Quality Range for iron for 90% of the time. No iron related problems are anticipated in the downstream river.
- Under the stratified dam operating scenarios (spilling and non-spilling), none of the sites downstream of the Albert Falls dam met Target Water Quality Range for iron for more than 30% of the time (see Table 5.1 below). This suggests that the downstream organisms were subjected to condition that might cause toxic effects but it is important to note that the reference site concentrations in the Karkloof were higher! As there is no known reason fro the Karkloof concentrations to be elevated (due to pollution etc) is could be concluded that these concentrations are natural for the area. However, it should be noted that only total iron and not the dissolved species were analysed.
- Under the isothermal dam operating scenario, only two sites, i.e. uMngeni upstream of the Mpolweni confluence and uMngeni weir upstream of the Nagle dam met the Target Water Quality Range for 100% of the time, with iron concentrations similar to those recorded at the Karkloof reference site.

Table 5.1: Statistical analyses for the total iron concentrations under the dam operating scenarios



| Sites | Stratified Spilling | | | Stratified Nonspilling | | | Isothermal Spilling | | | Isothermal Nonspilling | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total number of analyses | Total no. of analyses <10% of the background concentratio | Results met the TWQR | Total number of analyses | Total no. of analyses <10% of the background concentratio | Results met the TWQR | Total number of analyses | Total no. of analyses <10% of the background | Results met the TWQR | Total number of analyses | Total no. of analyses <10% of the background | Results met the TWQR |
| **uMngeni Albert Falls Outflow** | 14 | 13 | 7% | 24 | 23 | 4% | 9 | 8 | 11% | 12 | 10 | 17% |
| **uMngeni u/s of Mpolweni** | 15 | 11 | 27% | 36 | 33 | 8% | 9 | 0 | 100% | 14 | 12 | 14% |
| **uMngeni d/s of Mpolweni** | 15 | 13 | 13% | 37 | 32 | 13% | 9 | 4 | 55% | 14 | 11 | 21% |
| **uMngeni weir u/s of Nagle** | 12 | 11 | 8% | 22 | 18 | 18% | 9 | 5 | 45% | 5 | 0 | 100% |

## 5.8 Manganese

- Concentrations are high in the hypolimnion, which concentrations persist in the release water and down to Nagle Dam. Concentrations downstream were higher than those in the Karkloof.
- The median manganese concentrations recorded in all sites under all the operating dam scenarios, ranges between 0.01 to 0.15 mg/l. The calculated 90th percentile values ranges between 0.02 to 0.57 mg/l. The DWAF Water Quality Guidelines for the Aquatic Ecosystem require the concentration of manganese to be within the Target Water Quality Range (TWQR) of 0.18 mg/l for 90% of the time, for the protection of the aquatic ecosystem.

- The Karkloof reference condition complied with the Target Water Quality Range (TWQR) of 0.18 mg/l for 90% of the time under all dam operating scenarios.
- Under stratified conditions (both spilling and non-spilling), the two sites immediately downstream of the dam (uMngeni downstream of Albert Falls Dam and uMngeni upstream of the Mpolweni confluence) do not comply with the Target Water Quality Range (TWQR) of 0.18 mg/l for 90% of the time. However, these high manganese concentrations are mitigated further downstream by the Mpolweni tributary.
- Under isothermal conditions, all sites complied with the Target Water Quality Range (TWQR) of 0.18 mg/l for 90% of the time.
- Figure 5.1 below illustrates that there is a net manganese loading by the dam, which adds manganese to the system downstream.

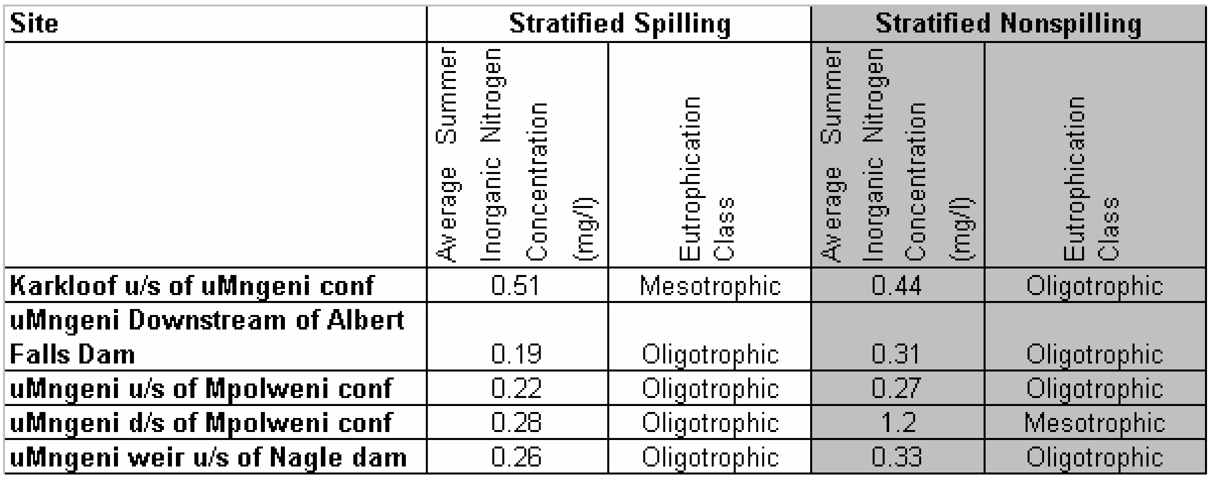
### 5.9 Nutrients: Nitrogen

Using the measured ammonia and nitrate concentrations, under the stratified spilling conditions, the average summer nitrogen concentrations reflected that the sites downstream of the Albert Falls dam fall within the oligotrophic condition while the Karkloof reference sites falls within the mesotrophic condition. The high concentration of nitrogen in the Karkloof is as a result of high nitrate concentrations, possibly emanating from upstream agriculture.

Under the stratified non-spilling condition, the sites downstream of the Albert Falls dam as well as the Karkloof reference site reflected the oligotrophic condition (their average summer nitrogen concentrations are less than 0.5 mg/l) with the exception of uMngeni downstream of Mpolweni confluence site which reflected the mesotrophic condition.

The determined eutrophication class based on nitrogen does not match the class based on soluble reactive phosphate (discussed below). However, as phosphorus is likely to be the limiting nutrient in the uMngeni catchment, the classification based on phosphorus should take preference.

Table 5.2: Eutrophication classification of the Karkloof reference site and sites downstream of Albert Falls Dam under the stratified conditions.



| **Site** | **Stratified Spilling** | | **Stratified Nonspilling** | |
|---|---|---|---|---|
| | Average Summer Inorganic Nitrogen Concentration (mg/l) | Eutrophication Class | Average Summer Inorganic Nitrogen Concentration (mg/l) | Eutrophication Class |
| **Karkloof u/s of uMngeni conf** | 0.51 | Mesotrophic | 0.44 | Oligotrophic |
| **uMngeni Downstream of Albert Falls Dam** | 0.19 | Oligotrophic | 0.31 | Oligotrophic |
| **uMngeni u/s of Mpolweni conf** | 0.22 | Oligotrophic | 0.27 | Oligotrophic |
| **uMngeni d/s of Mpolweni conf** | 0.28 | Oligotrophic | 1.2 | Mesotrophic |
| **uMngeni weir u/s of Nagle dam** | 0.26 | Oligotrophic | 0.33 | Oligotrophic |

### 5.10 Toxics: Unionized ammonia

Unionised ammonia is of particular importance here, as it is this form of ammonia that is most toxic to fish (see DWAF WQ Guidelines).

- Using the ammonia data with the corresponding pH and temperature data, the total un-ionised ammonia concentrations were determined. The DWAF Water Quality Guidelines for the Aquatic Ecosystem require the concentration of unionized ammonia to be within the Target Water Quality Range (TWQR) of 0.007 mg/l for 90% of the time, for the protection of the aquatic ecosystem.
- The concentrations of unionized ammonia for all sites, under all dam operating scenarios, were below the TWQR of 0.007 mg/l provided in the Aquatic Ecosystem, for 90% of the time, with the exception of the uMngeni downstream of the Mpolweni confluence under the isothermal spilling condition.
- Unionized ammonia concentrations in the uMngeni downstream of the Mpolweni confluence under the isothermal spilling condition falls within the acute effect range (> 0.015 mg/l).

### 5.11 Nutrients: Phosphorus

- The Soluble Reactive Phosphorus (SRP) concentrations downstream of the dam were generally lower than upstream reference site, confirming that the dam acts as a sink for nutrients.

The calculated average summer SRP concentrations (determined by using the stratified conditions) for the Karkloof reference site, the impoundment sites and uMngeni downstream of the Albert Falls site reflect the mesotrophic conditions. However, evidence of nutrient pollution downstream of the uMngeni Mpolweni confluence was noted and the water in this area falls within the hypertrophic conditions.
The South African Water Quality Guidelines for Aquatic Life (DWAF, 1996) were used to assess trophic status (Average Summer: Oligotrophic <5 ug/l, Mesotrophic 5 – 25 ug/l, Eutrophic 25 – 250 ug/l, Hypertrophic >250 ug/l) .

### 5.12 Total Organic Carbon

- Marginally lower total organic carbon concentrations were recorded for the Karkloof reference site compared to those recorded downstream of the dam. This is attributed to the organic input along the main uMngeni river up to the Nagle dam. The median total organic carbon concentrations recorded under all dam operating scenarios varied between 1.95 and 3.74 mg/l.

### 5.13 Algal counts

- The algal counts recorded throughout the sites were low, indicated by the low median counts ranging between 376 and 2 824 counts/ml.
- Under the all operating dam scenarios, the algal counts recorded for the Karkloof reference site were lower than those recorded for the uMngeni river sites downstream of the Albert Falls dam, reflecting the presence in the downstream river of free floating phytoplankton typical of lake water.
- Algae counts in the river downstream of the dam were particularly elevated when the dam was spilling.

### 5.14 Bacteriological

Under all dam operating scenarios, impoundment of the water in Albert Falls dam resulted in low bacteriological counts in the dam, and in the uMngeni river immediately downstream of the dam relative to the Karkloof reference site. This decrease is due in-dam processes such as ultra-violet disinfection, predation and sedimentation.

Evidence of modest bacteriological pollution was noted downstream of the impoundment from uMngeni upstream of Mpolweni confluence to upstream of the Nagle dam due to faecal contamination from intensive agricultural activities and to inadequate sanitation in the Mpolweni settlement area.

## 5.15 Nutrients and suspended solids in the scour water

Operators of dams generally anticipate that the scouring of hypolimnetic water helps to eliminate undesirable components from the impoundment. Most commonly, the expectation is that by scouring, quantities of sediment and nutrients (especially dissolved phosphorus) are eliminated.

The information below (Figures 5.1-5.5) illustrates the extent to which nutrients and suspended matter are held within the impoundment, in which case it is said that it acts as a sink for this matter.

The graphs below indicate the loading (in kgs) of nutrients and suspended matter into the dam, and that discharged from the dam. From these it can be seen that:

- The dam balance indicates that under normal and wet hydrological years, the dam acts as a sink for suspended materials including nutrients, despite almost all the water being released from the scour.
- Under drought conditions (1992 - 1993), because of the reduced inflow volumes, the dam acts as a source of nutrients and suspended matter. This can have severe consequences for the downstream river as releases will be highly contaminated with nutrients at a time when there is minimal water in the river and where there are few refuges for biota.

The conclusion of this is that scouring the dam (i.e. releasing water from the bottom of the dam to the downstream river) is marginally effective in removing sediment and nutrients from the dam with a large portion of it remaining behind. Only 1-2 tons of SRP, 7-17 tons of TP and 3-5000 tons of Suspended solids are removed from the dam per annum.

From this information it can be deduced that the dam is acting as a sink for nutrients, accumulating these at a substantial rate. Much of this nutrient will become submerged below sediments on the lake floor, effectively taking them out of circulation with in the ecosystem. Yet there is potential for re-suspension during anoxic periods to levels that can cause major outbreaks of algae and thus severe nuisance problems.

### 5.15.1 SRP Load

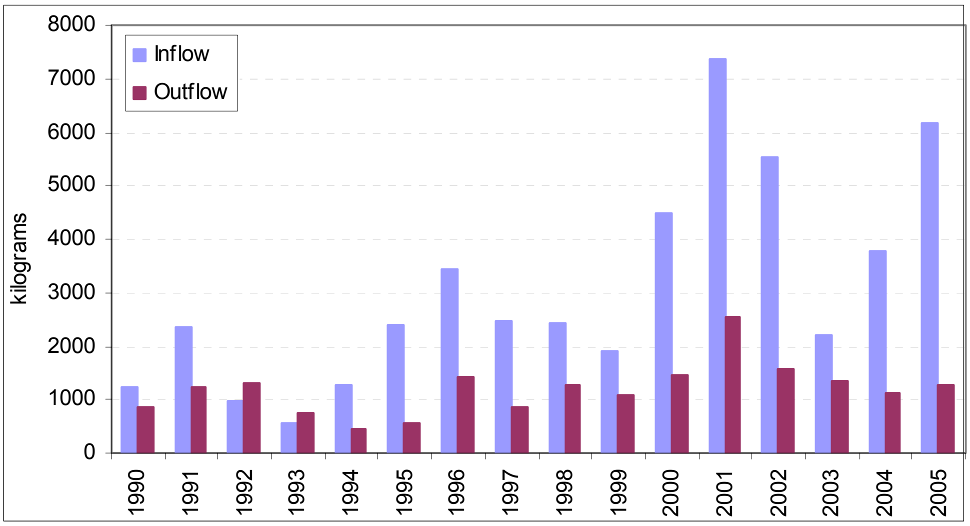


Figure 5.1: Soluble phosphate loads to Albert Falls Dam (Inflow) and in the release water (Outflow) from the Dam.

### 5.15.2 TP Load

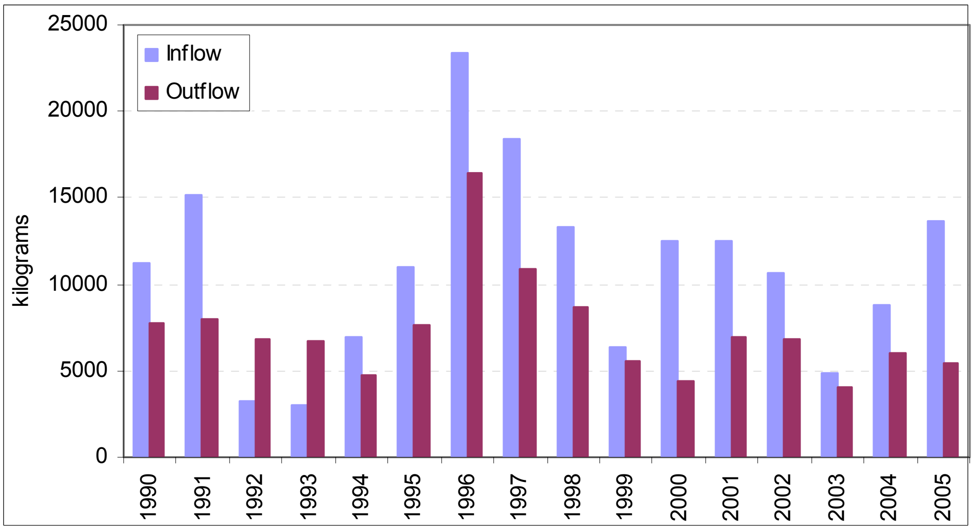


Figure 5.2: Total phosphate loads to Albert Falls Dam (Inflow) and in the scour release water (Outflow) from the Dam.

### 5.15.3 Suspended Solids Load

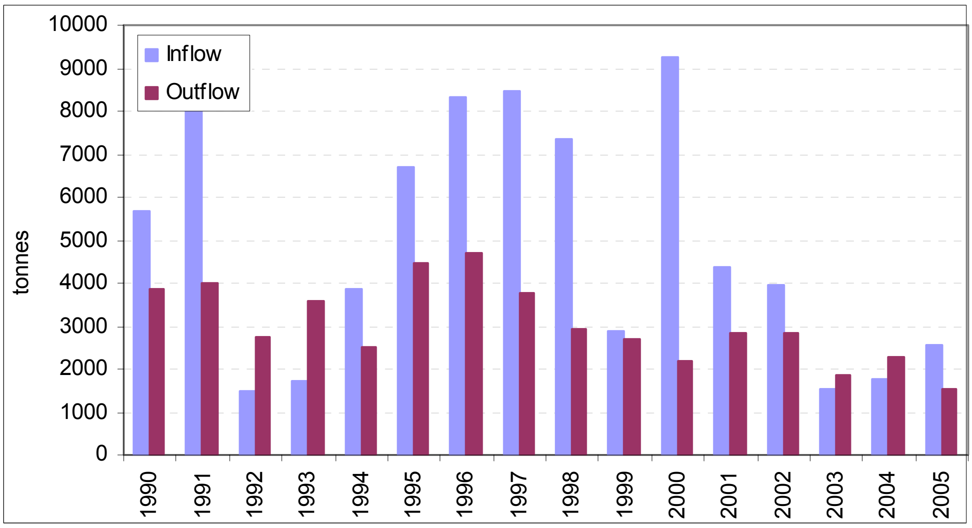


Figure 5.3: Suspended Solids load to Albert Falls Dam (Inflow) and in the scour release water (Outflow) from the Dam.

### 5.15.4 Ammonia Load

The situation for ammonia is somewhat different. Derived largely from nitrates and organics entering the dam, the discharge quantities of ammonia are higher than those entering the dam (Figure 5.4). Thus the dam is acting as a generator of ammonia, a substance that is toxic to fish in particular. It can be seen that this is the case under all flow scenarios.

### 5.15.5 Manganese Load

Dam water releases are also well known to be rich in manganese which is released from the sediments under anoxic conditions. Figure 5.5 illustrates that the amount of manganese released to the downstream river is substantially higher than that entering the dam. Manganese is also toxic to animal life, so this demonstrates another of the negative practices of scour releases from dams. Again it can be seen that this is the case under all flow scenarios.

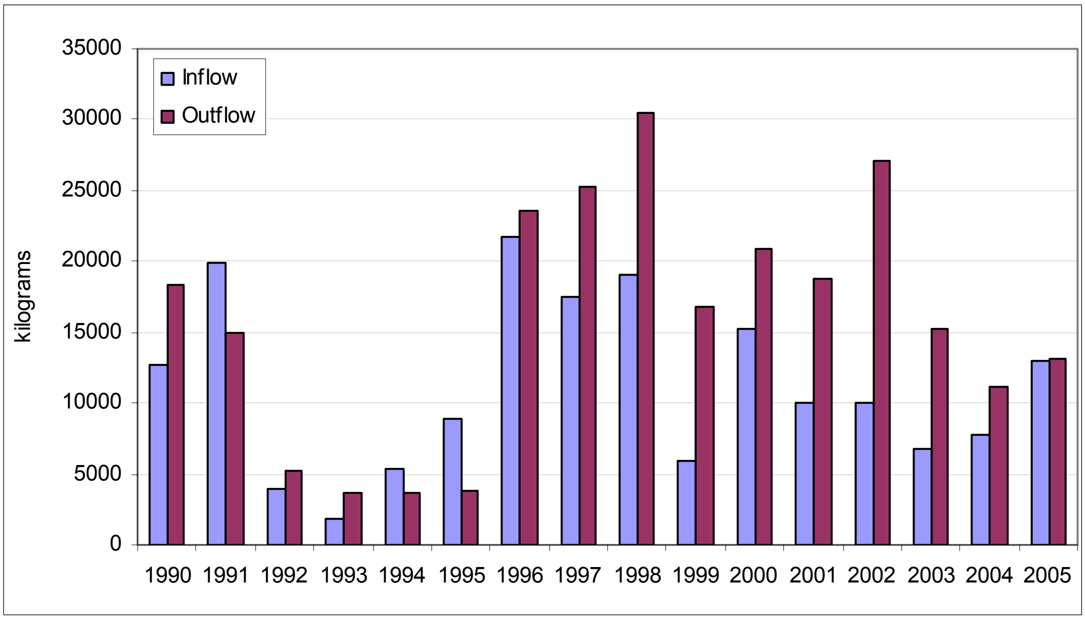


Figure 5.4: Ammonia loads to Albert Falls Dam (Inflow) and in the scour release water (Outflow) from the Dam.

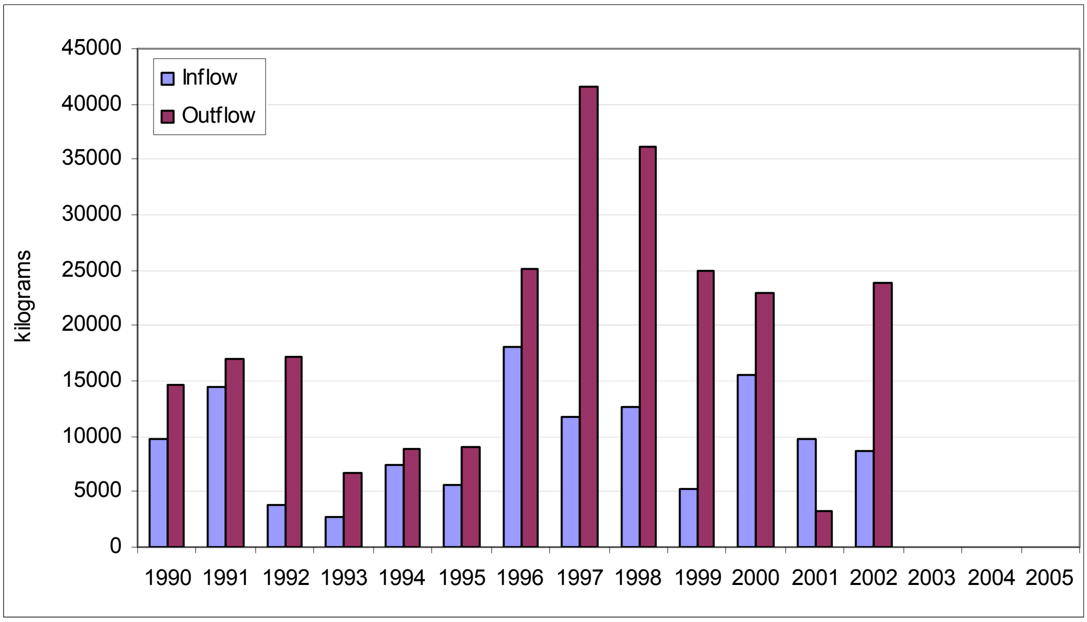


Figure 5.5: Manganese loads to Albert Falls Dam (Inflow) and in the scour release water (Outflow) from the Dam.

## 5.16 The influence of Albert Falls Dam on water temperatures

Research is a crucial step to improving understanding and the advice to resources managers and related organisations (Malan and Day, 2002). The research undertaken in this study was to quantify the significance of altered water quality, and in this case, temperature variation, brought about by the regulation of the uMngeni River by the Albert Falls Dam. The following questions were posed:

- To what extent do the water temperatures in the uMngeni River vary in space and time?
- How evident is the "reverse hydrograph" downstream of Albert Falls Dam?

The longitudinal section of the Dungeni River was used for the purpose of this study to investigate the impacts of water releases from Albert Falls Dam on the in-stream thermal regime of the Dungeni River. The study profile stretches from a point upstream of Albert Falls Dam to a point just upstream of Nagle Dam (Figure 3.1). This section of the Dungeni River has a moderate gradient with a relatively wide channel and is therefore classified as a mid-order stream. Poole and Berman (2000) define mid-order streams as channels that carry more water than low-order steams due to the decreases in gradient and the increases in channel size. Such differences in flow volumes between headwaters and lower reaches result in the thermal lag (i.e. the time differences between water temperature responses to air temperature) becoming more pronounced with downstream distance (Smith, 1972). As a consequence water temperatures vary along the longitudinal axis of a river, on a seasonal and daily temporal scale (Allan, 1995).

The main objective of the thermal component of the project was to investigate the fluctuations of the thermal regime for the study profile of the uMngeni River based on the water that is released from Albert Falls Dam. Thus it was hypothesised that the water released from Albert Falls Dam decreases the diurnal and seasonal variability in water temperature, although the increased flows in winter, which exceed the summer flows, are likely to result in above normal water temperatures in winter and below normal water temperatures in summer.

### 5.16.1 Methods of water temperature measurement

Hourly water temperatures were recorded using water temperature sensors installed at several monitoring sites along the longitudinal section of the Dungeni River for the period 23 December 2003 to 7 July 2004. One site (i.e. WT1) was located upstream of Albert Falls Dam and three sites downstream (i.e. RMG010 (Alb), RMG012 (dMp), RMG013 (Ngl)) (Figure 3.1). Initially, as was the case with the rest of this investigation, it was intended for water temperatures to be recorded from the RKK003 (Kk) site on the Karkloof River serving as an upstream control that represents a natural catchment system uninfluenced by regulations from dams in a near pristine condition. Unfortunately the temperature sensors were placed at an incorrect site (i.e. WT1) on the Dungeni River nearby. This site was thought to be unsuitable for the purpose of the project being deemed unnatural because of its position downstream of Midmar Dam, where it is consequently subject to the regulation activities of the releases. However after some speculation this site (i.e. WT1) was considered to have some value in terms of a control as the downstream distance is far enough for the water temperatures to approach the natural situation (a previous study below Midmar Dam had found that temperatures recovered within the first few km below the dam – Hodgson *pers com*). Hence the information obtained from the WT1 site was used to give some indication of what the thermal condition of the Dungeni River should look like under natural conditions along the section between Albert Falls Dam and Nagle Dam.

Hobo single-channel data loggers were used to record water temperatures (Onset, 1999). They have been used successfully to record water temperatures within the Sabie Catchment (Rivers-Moore, 2003; Rivers-Moore and Jewitt, 2004). The Hobo loggers, containing internal temperature sensors (thermisters), were sealed within water waterproof polycarbon cylinders. These were then mounted inside steel cases which enabled the loggers to be secured to anchor points (e.g. rocks or trees) using a steel cable. The loggers were submersed at each monitoring site, at a depth ranging between 0.3 – 1.0 metres and these depths varied in terms of the differences in flow and channel characteristics at each of the monitoring sites. Rivers-Moore (2003) found through laboratory studies that a time lag of 10-15 minutes existed between actual temperature change and the logger recording, due to the Hobo loggers being placed inside the cases and therefore a logging interval of 60 minutes compensated for the lag.

### 5.16.2 Variations of water temperature in the uMngeni River

The water temperatures of the uMngeni River were shown to have different temporal (at each sites) and spatial scales (between sites). Concurrent recordings at the monitoring sites allowed for suitable comparisons to be made between sites, as well as to show temporal thermal dynamics over the seven month study period. During this time Albert Falls Dam was in a non-spilling state and therefore because of the release design of the dam, all water that was released was from the bottom, termed scour water.

Diurnal and seasonal fluctuations of water temperature at the site above (i.e. WT1) and below (i.e. RMG010 (Alb)) Albert Falls Dam are shown by the thermographs in Figure 5.6. The changes in hourly water temperature on a daily basis are far greater in the control above Albert Falls Dam compared to below the dam. A strong correlation ($r^2$=0.88), calculated from daily mean water temperatures, existed between WT1 and RMG010 (Alb) based on the change in water temperature for the entire study period (Figure 4). RMG010 (Alb) displayed a lower amplitude for the seasonal change water temperature compared to site WT1 (Figure 5.6). Consequently the water releases from Albert Falls Dam produced below normal water temperatures in summer and above normal water temperatures in winter thus decreasing the daily as well as the seasonal variation in water temperature.

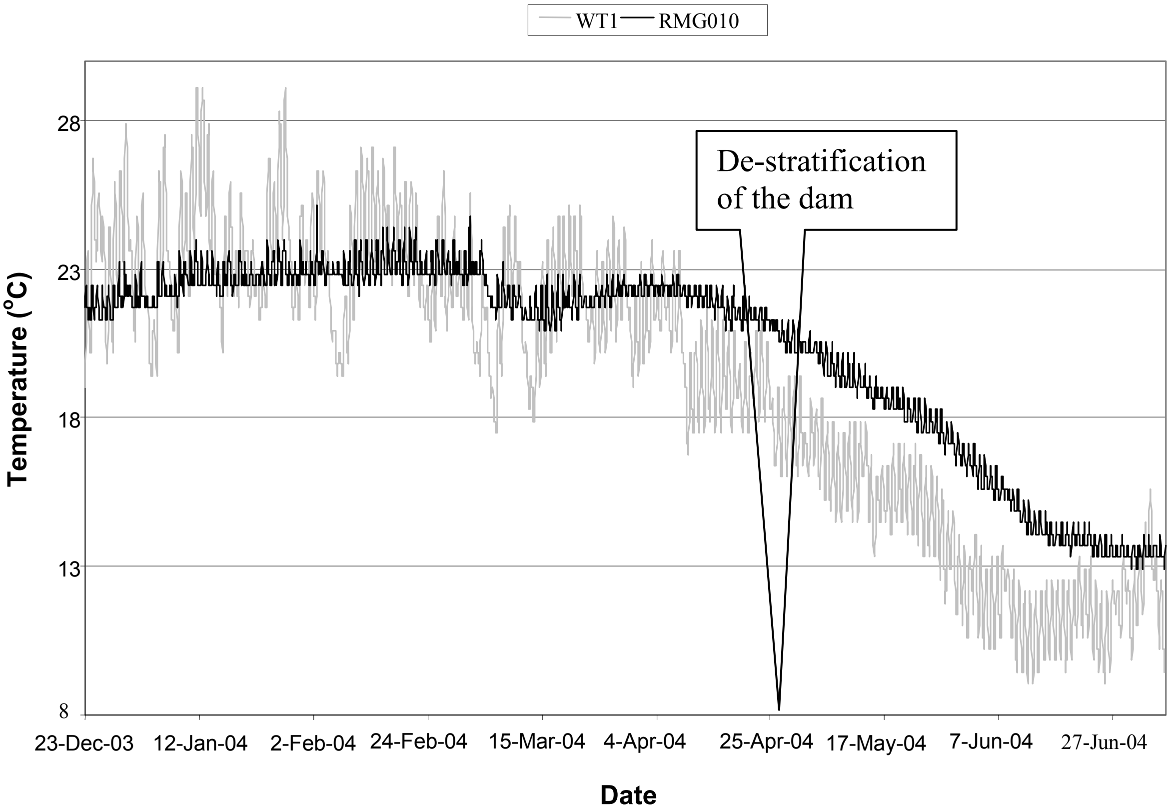


Figure 5.6: Hourly time series of the water temperatures measured at site WT1 and RMG010 (Alb). Albert Falls Dam was thermally stratified (23 December 2003 to 29 April 2004) and isothermal (30 April to 7 July 2004).

Hourly water temperatures were summarized into mean daily water temperature statistics. The daily temperature data was analysed separately for the two time periods when Albert Falls Dam was either thermally stratified (23 December 2003 to 29 April 2004) or isothermal (30 April to 7 July 2004). The mean daily water temperatures increased gradually with downstream distance during the time that Albert Falls Dam was stratified revealing no obvious impact of the dam on downstream water temperatures (Figure 5.7). However, when Albert Falls Dam was isothermal the mean daily water temperature increased significantly at RMG010 (Alb) and instead of increasing the temperatures decreased with downstream distance to Nagle Dam (i.e. RMG013 (Ngl)) (Figure 5.8).

Irrespective of Albert Falls Dam being in a stratified (Figure 5.7) or isothermal state (Figure 5.8), the mean water temperature range (minimum to maximum) was significantly reduced by Albert Falls Dam and increased when moving further downstream to RMG013 (Ngl). During the time that the dam was thermally stratified, the mean daily temperatures at RMG010 (Alb), immediately below the dam, fluctuated within a range of 1.5°C and the variability increased to 4°C at RMG013 (Ngl) before the uMngeni flowed into Nagle Dam (Figure 5.7). When Albert Falls Dam was isothermal the range was further decreased with water temperatures fluctuating between 1°C at RMG010 (Alb) and 3°C at RMG013 (Ngl) (Figure 5.8). In a system not influenced by dams, Rivers-Moore (2003) found that the mean and range of water temperatures on the Sabie River increased with downstream distance from the source.

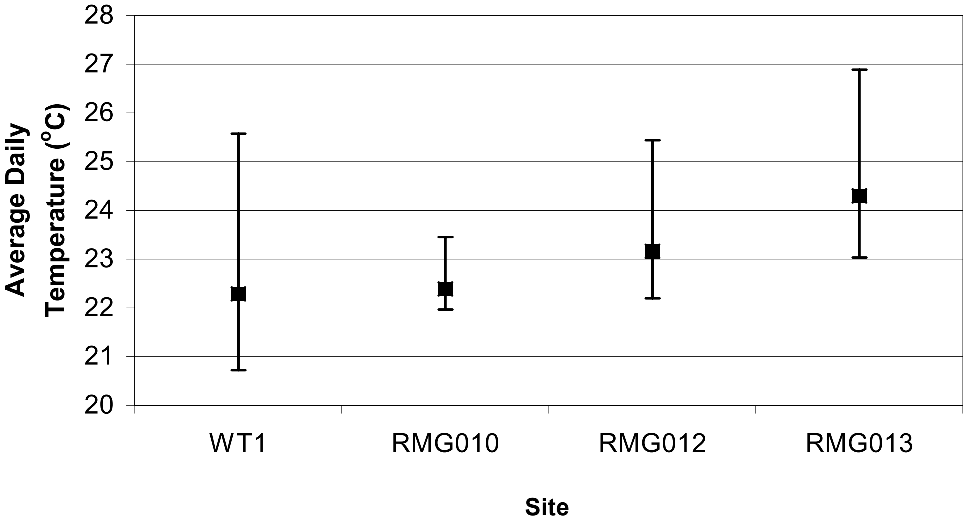


Figure 5.7: Variation in the daily water temperature range (mean, minimum and maximum) during the time that Albert Falls Dam was thermally stratified (23 December 2003 to 29 April 2004).

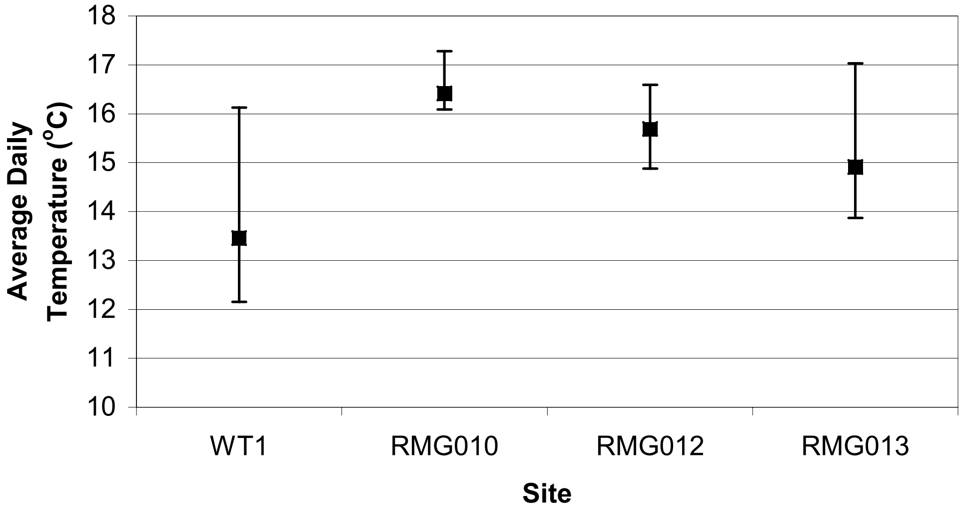


Figure 5.8: Variation in the daily water temperature range (mean, minimum and maximum) during the time that Albert Falls Dam was isothermal (30 April to 7 July 2004).

During the warmer period of the study, when Albert Falls Dam was stratified, the absolute maximum and minimum daily water temperatures each respectively showed a considerable decrease and increase respectively as a result of the water releases from the dam (Figure 5.9). Moving downstream towards Nagle Dam from RMG010 (Alb) to RMG013 (Ngl) the observed water temperatures displayed increasing maxima and decreasing minima. When Albert Falls Dam changed over to an isothermal state the observed maximum temperatures remained fairly stable downstream of the dam whilst the trends of minimum temperatures remained unchanged but displayed a more rapid decrease in temperature (Figure 5.10).

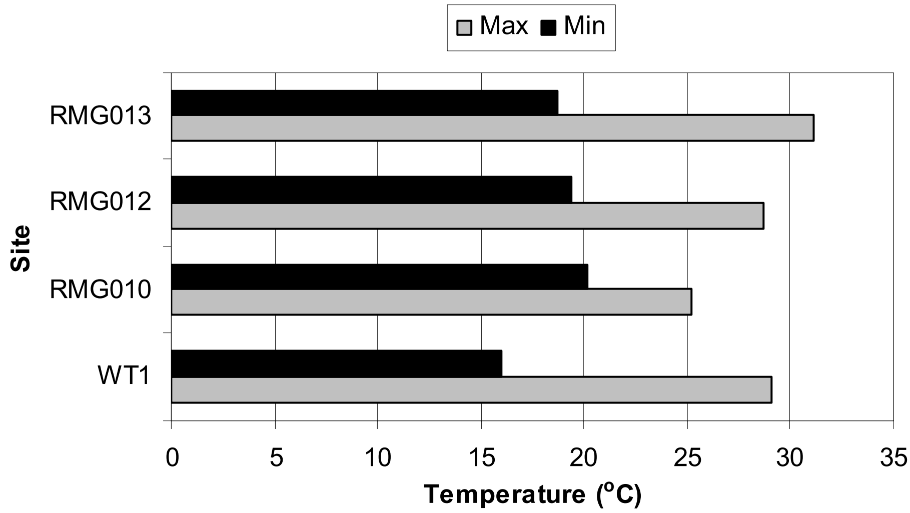


Figure 5.9: Absolute daily minima and maxima of water temperatures during the time that Albert Falls Dam was thermally stratified (23 December 2003 to 29 April 2004).

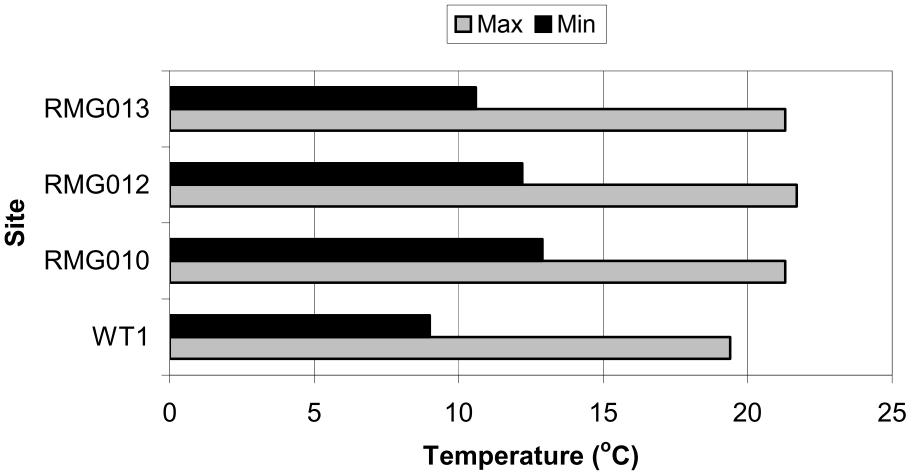


Figure 5.10: Absolute daily minima and maxima of water temperatures during the time that Albert Falls Dam was isothermal (30 April to 7 July 2004).

The average range (maximum – minimum) in daily water temperature (Figure 5.11) was observed to be greatest above Albert Falls Dam (i.e. WT1) irrespective of the thermal condition of the dam whereas directly below the dam at RMG010 (Alb) the displayed thermal range was the smallest. The temperature ranges were consistently lower during the isothermal period than during the period when Albert Falls Dam was thermally stratified. For the entire study period the temperature range increased with downstream distance from RMG010(Alb) to RMG013 (Ngl).

Significant differences ($p<0.01$) in daily temperature range between the monitoring sites were calculated through an analysis of variance (ANOVA) done separately for both periods when Albert Falls Dam was either stratified or isothermal. A test of least significant differences (LSD) revealed that for the period of stratification the difference in range of water temperature was most significant between WT1 and RMG010 (Alb) with the level of significance decreasing downstream to RMG013 (Ngl) whilst still remaining within the limits of significant differences (Table 5.3). The differences between RMG010 (Alb) and the two sites further downstream (i.e. RMG012 (dMp) and RMG013 (Ngl)) were significant becoming more significant with downstream distance. Statistical findings during the isothermal period were the same except for the non-significant differences between WT1, above Albert Falls Dam, and RMG013 (Ngl) the most distant downstream site from the dam (Table 5.3).

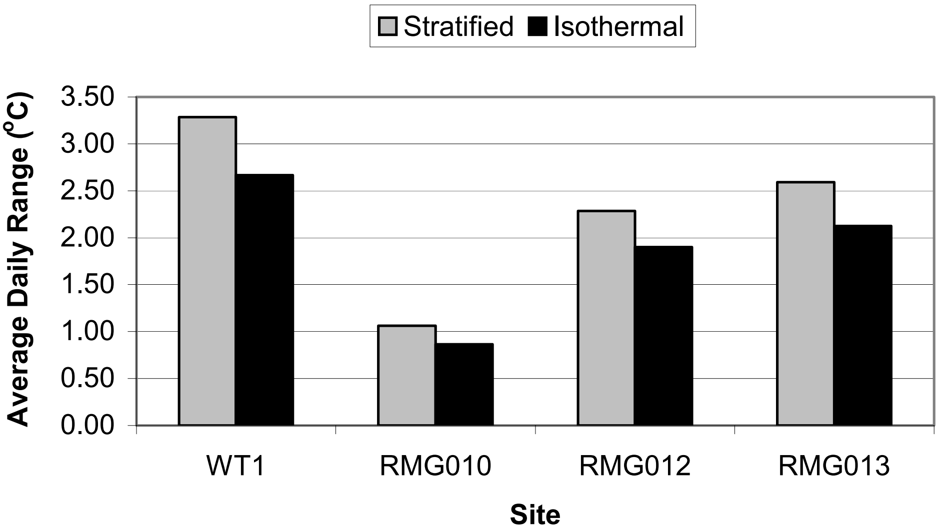


Figure 5.11: Average daily range in water temperature measured at the site WT1 and downstream for when Albert Falls Dam was thermally stratified (23 December 2003 to 29 April 2004) and isothermal (30 April to 7 July 2004).

Table 5.3: Least significant differences of mean daily water temperature range (maximum – minimum) during the time that Albert Falls Dam was thermally stratified (23 December 2003 to 29 April 2004).

|  | WT1 | RMG013 (Ngl) | RMG012 (dMp) | RMG010 (Alb) |
|---|---|---|---|---|
| WT1 | - |  |  |  |
| RMG013 (Ngl) | 0.74 | - |  |  |
| RMG012 (dMp) | 1.04** | 0.30 | - |  |
| RMG010 (Alb) | 2.40** | 1.66** | 1.36** | - |

* Significant difference ($p<0.05$)

** Significant difference ($p<0.01$)

Table 5.4: Least significant differences of mean water temperature range (maximum - minimum) during the time that Albert Falls Dam was isothermal (30 April to 7 July 2004).

|  | WT1 | RMG013 (Ngl) | RMG012 (dMp) | RMG010 (Alb) |
|---|---|---|---|---|
| WT1 | - |  |  |  |
| RMG013 (Ngl) | 0.77* | - |  |  |
| RMG012 (dMp) | 1.06** | 0.30 | - |  |
| RMG010 (Alb) | 1.89** | 1.13** | 0.83* | - |

* Significant difference ($p<0.05$)

** Significant difference ($p<0.01$)

Changes in the standard deviation of water temperature throughout the study period reflect that WT1 upstream of Albert Falls Dam has higher variations of water temperature than the other sites below the dam (Figure 5.12). Directly below Albert Falls Dam at RMG010(Alb) the standard deviation drops and remains fairly constant irrespective to the changing seasons. Further downstream the other sites reveal standard deviations that become more similar to WT1 with the increasing distance downstream but do not quite reach the same degree of deviation.

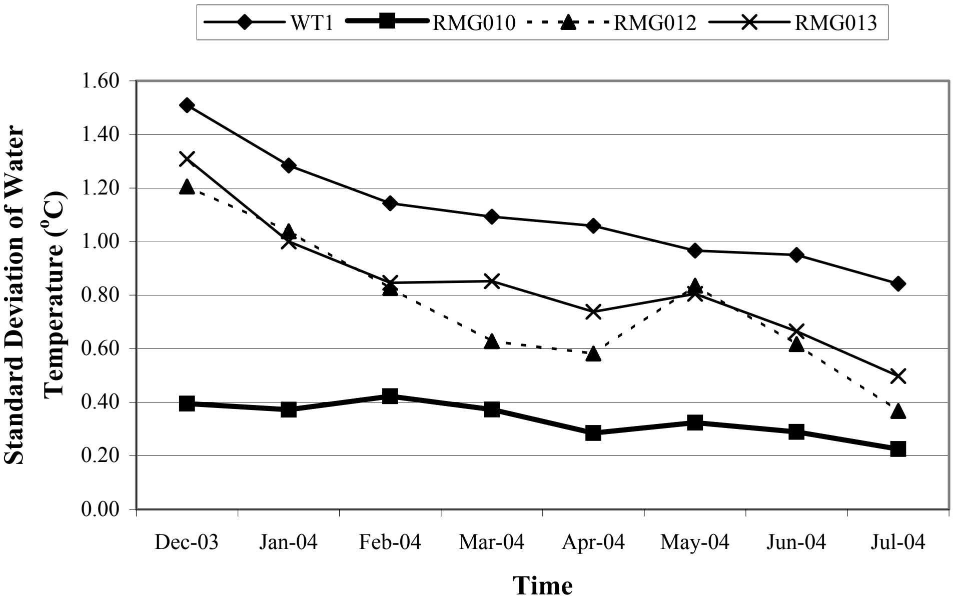


Figure 5.12: Average monthly standard deviation of water temperatures at all the water temperature sites.

### 5.16.3 Discussion of impacts of temperature on the river

The accelerating growth of thermal pollution (such as that below Albert Falls Dam) has resulted in concern for ecosystems as water temperature is an important abiotic factor controlling aquatic life (Smith, 1972). Changes in water temperature result in habitat impacts adverse to the existing aquatic populations and may result in changes to the species composition (Carron and Rajaram, 2001). Because of this, concern based on the adverse impacts of impoundments on the aquatic ecosystems downstream has led to the need for reconsidering the objectives for the management of reservoir releases.

Spatial variability in river water temperature, which is enhanced by habitat heterogeneity, provides “refugia” for aquatic organisms to escape temperature extremes. Thus the species composition and abundances change downstream as each species exhibits their specific response to the changing environmental gradients, according to their physiological adaptations and life history traits (Rivers-Moore, 2003). However the function of heterogeneous habitats in providing a variation in temperature is cancelled out by the controlling effects of dam regulations (Petts, 1984). The implication of having a smaller variation of water temperature below Albert Falls Dam is that a much smaller thermal niche is made available for aquatic organisms to exist and therefore optimal foraging and successful reproduction decreases. Certain invertebrate species may however be more suited to conditions below the dam. These are mostly likely to include poikilothermic organisms that are stenothermal i.e. species occupying a narrow thermal range (Allan, 1995). These specific organisms are able to colonise and dominate the river reaches below impoundments and it can be expected that a low diversity of organisms would occur below Albert Falls Dam as a result. The reduced inter-specific competition for the remaining species will result in their relative abundances being potentially higher. Water temperatures outside of the optimal range of certain species will lead to thermal stress and these biota will attempt to move to more favourable “refugia”, this being downstream in the case of Albert Falls Dam. This movement being only possible if other abiotic factors are favourable.

Studying the thermal regime of the uMngeni River in relation to Albert Falls Dam highlights that low thermal variation directly below the dam is a result of continuous releases of water from Albert Falls Dam particularly when there is no spillage of surface water from the reservoir. The increasing mean and maximum water temperatures evident during the stratified period as well as the increasing thermal variations for the entire study period are likely to be a result of complex interactions between, *inter alia*, river geomorphology, flow volume, lateral inputs from tributaries, altitude and solar radiation (Rivers-Moore and Jewitt, 2004) as well as a progressive addition of thermal energy (Rivers-Moore, 2003). However a decrease in water temperatures with the downstream distance, particularly evident in the isothermal period, indicates that the water released from the dam is warmer on average than from the shallow rivers in this system. This is likely because thermal inertia allows for the dam to store energy; where as the shallow water in the rivers is subjected to radiant cooling from low air temperatures. Isothermal mixing in Albert Falls Dam results in warmer water being released downstream into the uMngeni River. Additionally, tributaries to the uMngeni River contribute a cold supply of water to the system, especially rivers such as the southerly flowing Mpolweni River.

The displayed thermal variation and standard deviation between the monitoring sites provides some indication of a “reset distance”, this being the distance downstream of the Albert Falls Dam where-by the thermal regime approaches a more natural state. Based on the data available, intuitively, it seems that the “reset distance”, within which natural conditions should develop, does not occur within the longitudinal distance between Albert Falls Dam and Nagle Dam. This may be attributed to longer residence times and larger surface areas exposed to the atmosphere resulting in a higher exchange rate of heat energy with distance downstream. Furthermore the regulatory processes and impacts caused by Albert Falls Dam is likely to be replicated downstream of Nagle Dam.

Since river temperature is a measure of the amount of heat energy per unit volume of water, changing either the amount of heat energy entering the river or the amount of water flowing in the channel has the potential to alter river temperature (Poole and Berman, 2000). It is important to note that impoundments can be operated to provide “desirable” stream temperature regimes directly downstream e.g. through selective withdrawal of water from different depths (and hence different temperatures) (Poole and Berman, 2000; Vinson, 2001) as well as through the modification of releases (Carron and Rajaram, 2001). This may require extensive research to implement and the cost to introduce variable abstraction structures will be very expensive.

## References

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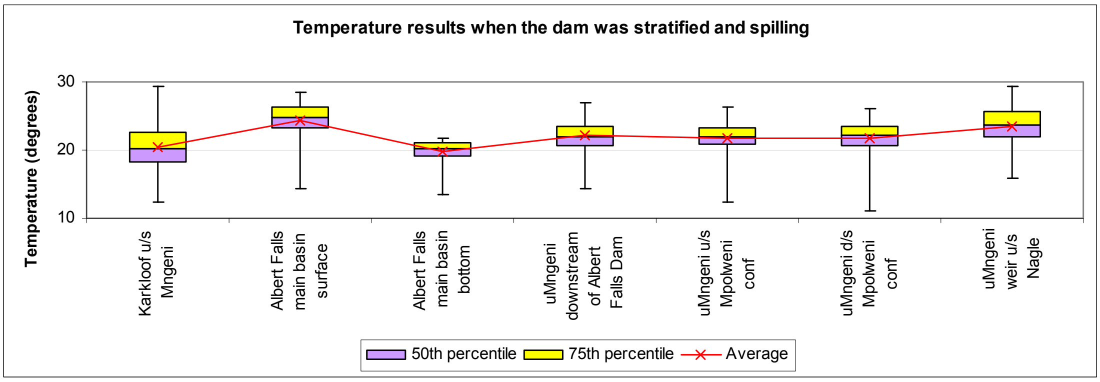
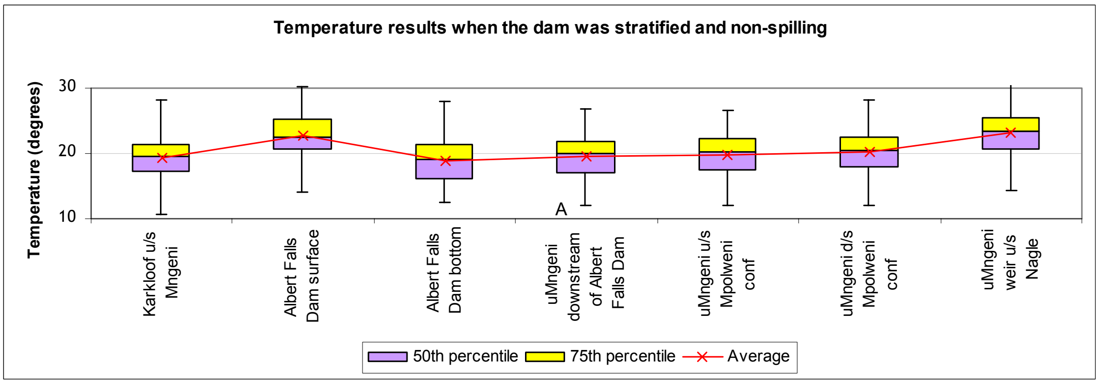
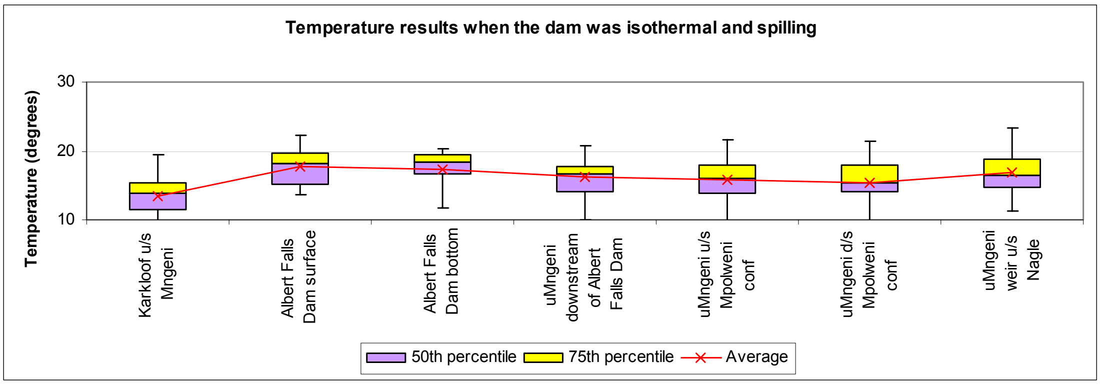
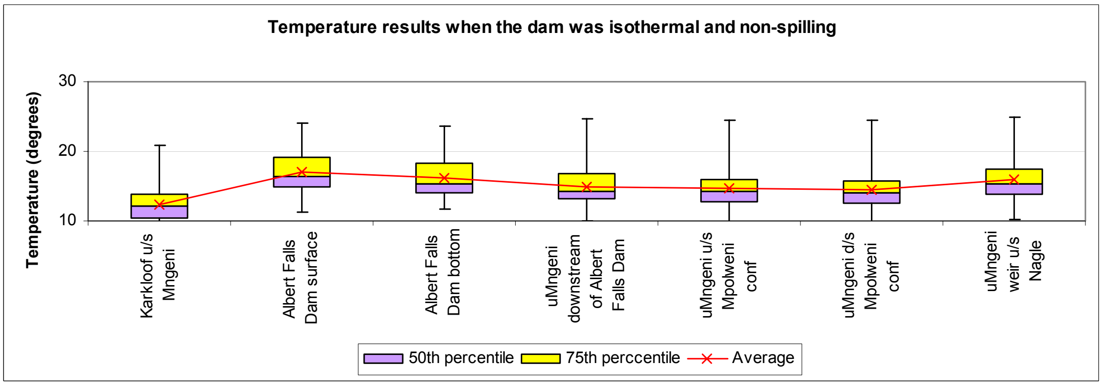
# Annexure A Water quality trends

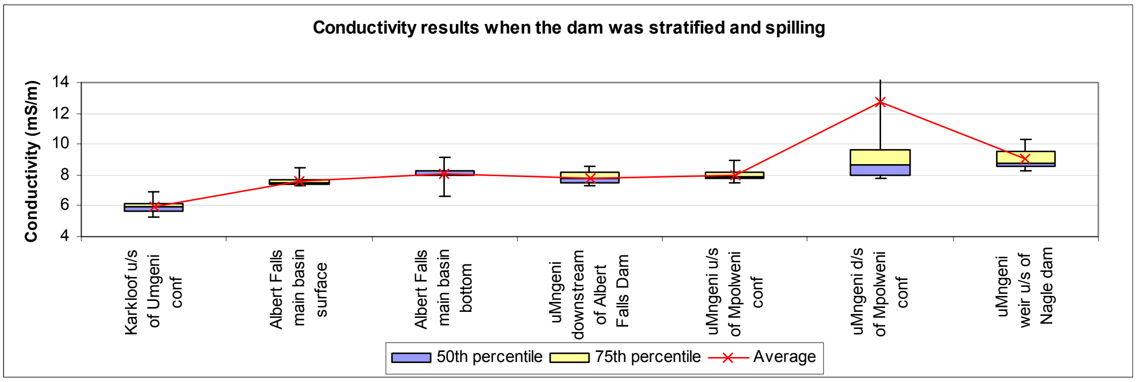
The graphs starting on the next page represent a summary of data collected by Umgeni Water over the duration of the project (four years). Each variable has been examined using samples collected from the Karkloof River control, the surface and bottom of the impoundment itself (as this illustrates the in-dam processes that are contributing to the downstream releases), then in the four uMngeni River downstream sites to Nagle Dam. Summary statistics have been illustrated with box and whisker plots.

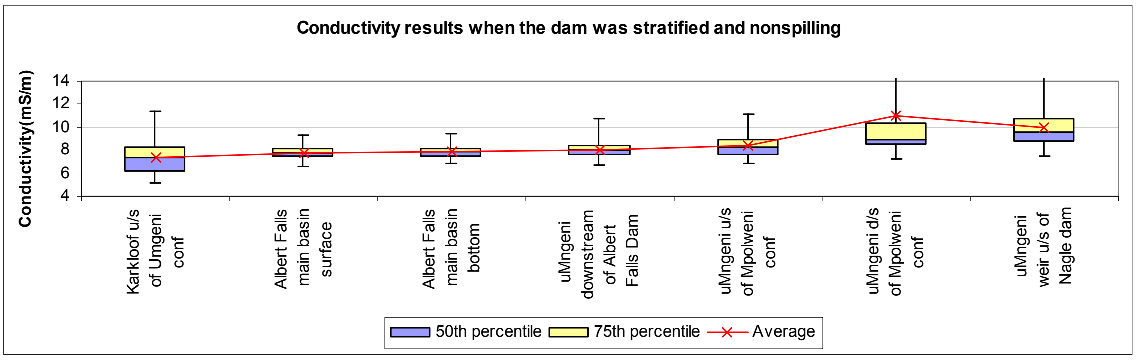

Temperature results when the dam was stratified and spilling
Temperature (degrees)
30
20
10
Karkloof u/s Mngeni
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni conf
uMngeni d/s Mpolweni conf
uMngeni weir u/s Nagle
50th percentile
75th percentile
Average

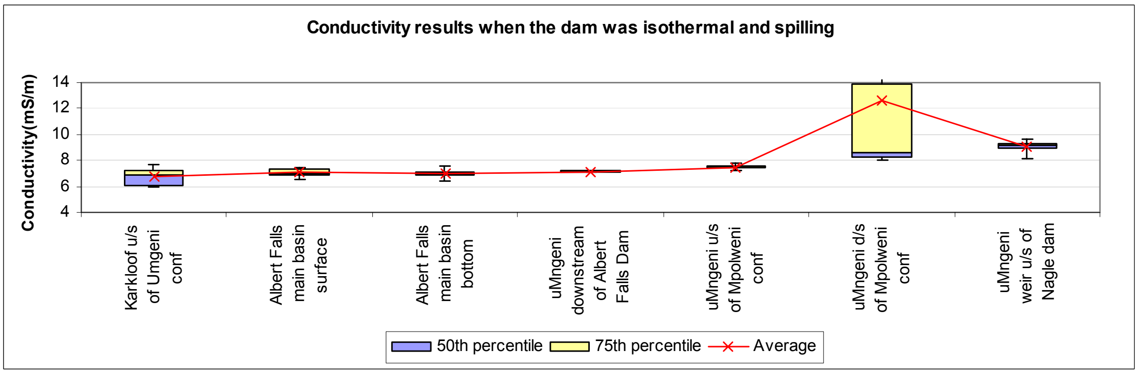

Temperature results when the dam was stratified and non-spilling
Temperature (degrees)
30
20
10
A
Karkloof u/s Mngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni conf
uMngeni d/s Mpolweni conf
uMngeni weir u/s Nagle
50th percentile
75th percentile
Average

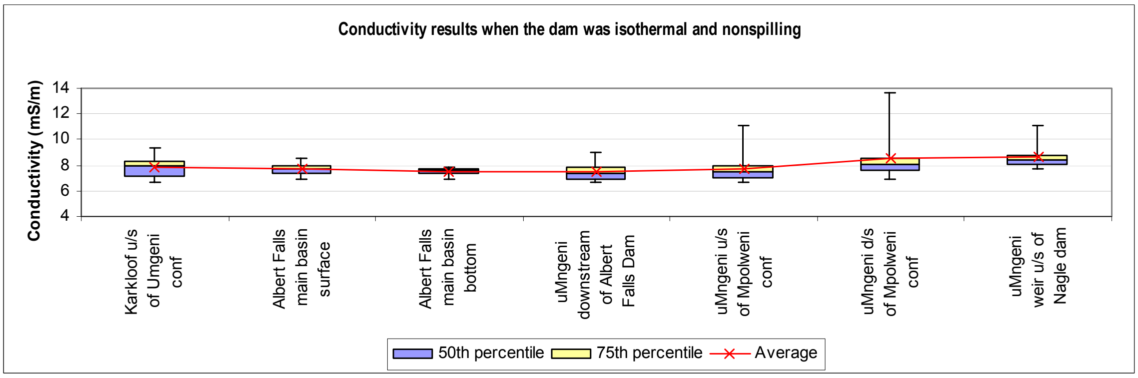

Temperature results when the dam was isothermal and spilling
Temperature (degrees)
30
20
10
Karkloof u/s Mngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni conf
uMngeni d/s Mpolweni conf
uMngeni weir u/s Nagle
50th percentile
75th percentile
Average

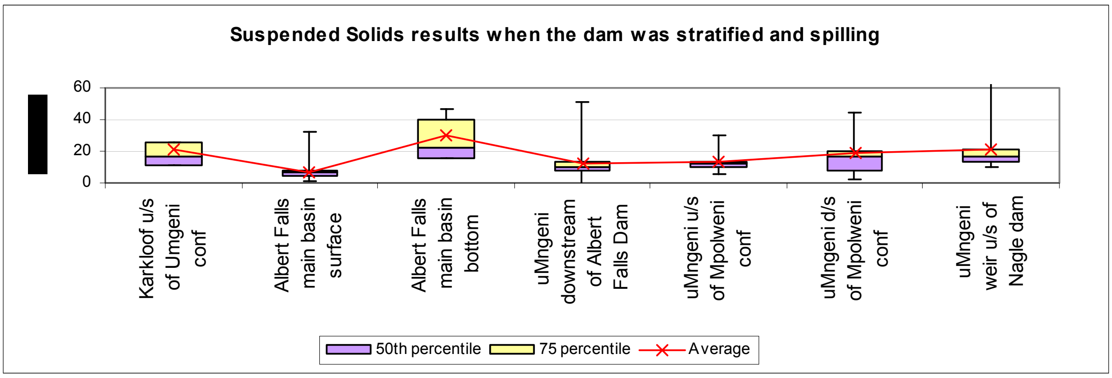

Temperature results when the dam was isothermal and non-spilling
Temperature (degrees)
30
20
10
Karkloof u/s Mngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni conf
uMngeni d/s Mpolweni conf
uMngeni weir u/s Nagle
50th percentile
75th perccentile
Average

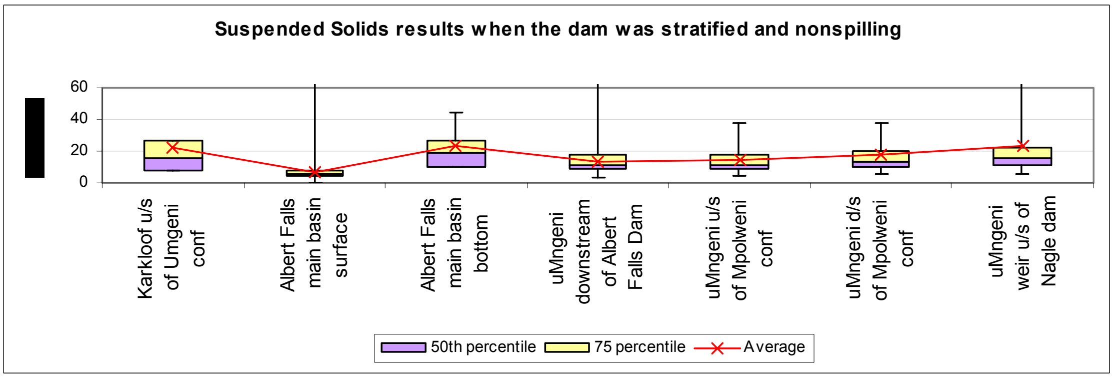

Conductivity results when the dam was stratified and spilling

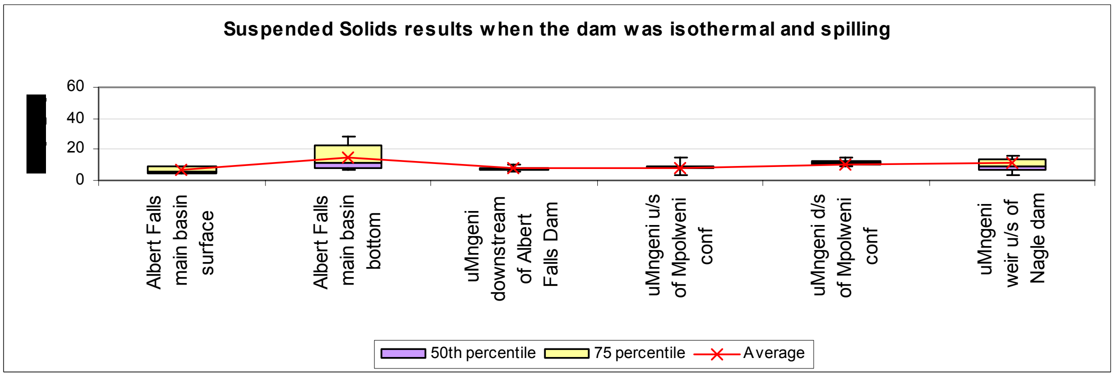

Conductivity results when the dam was stratified and nonspilling

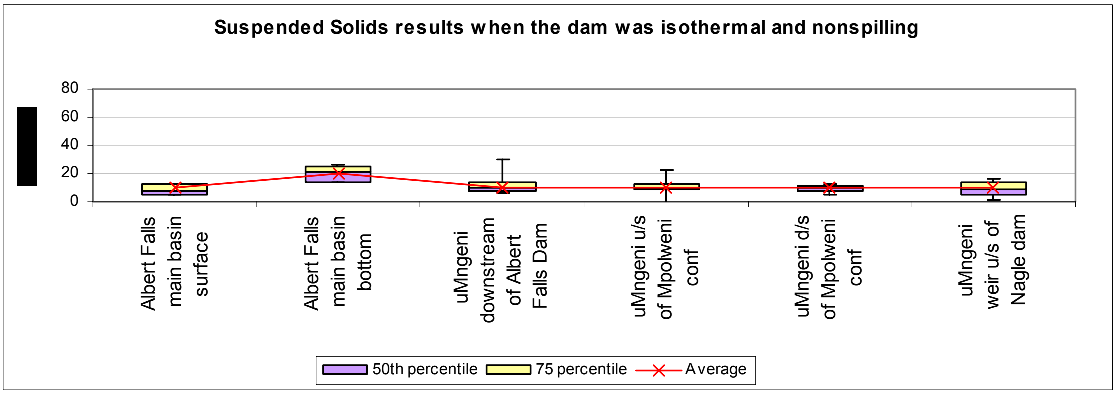

Conductivity results when the dam was isothermal and spilling

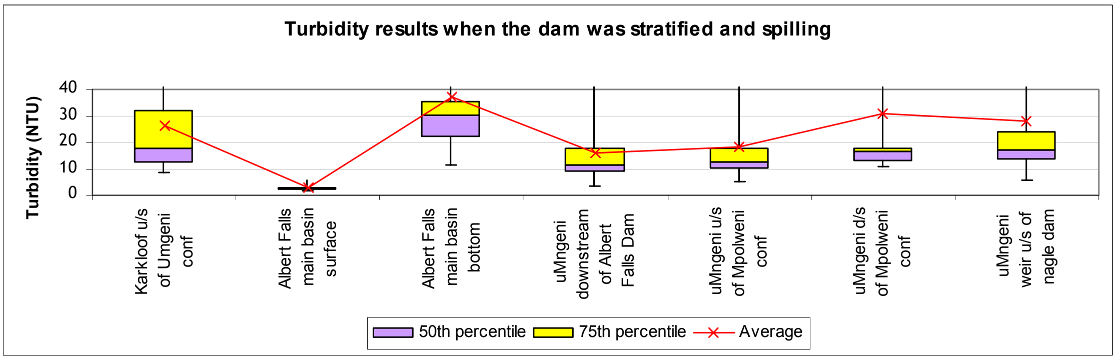

Conductivity results when the dam was isothermal and nonspilling

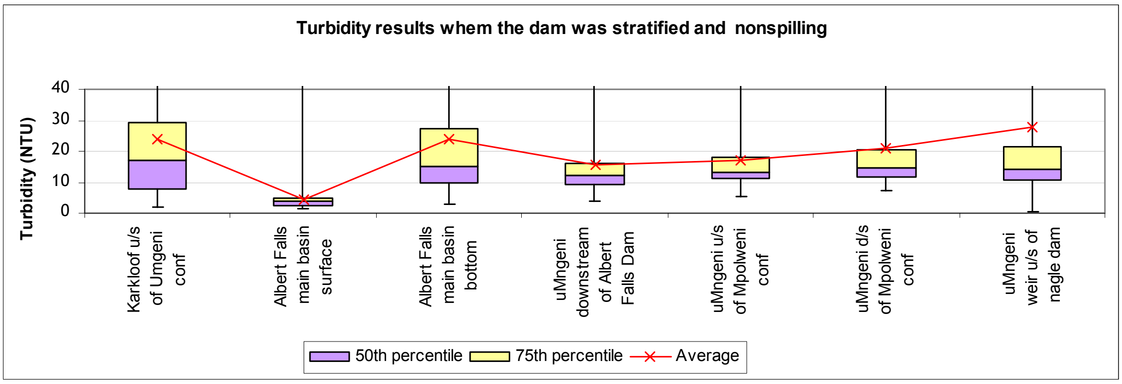

Suspended Solids results when the dam was stratified and spilling

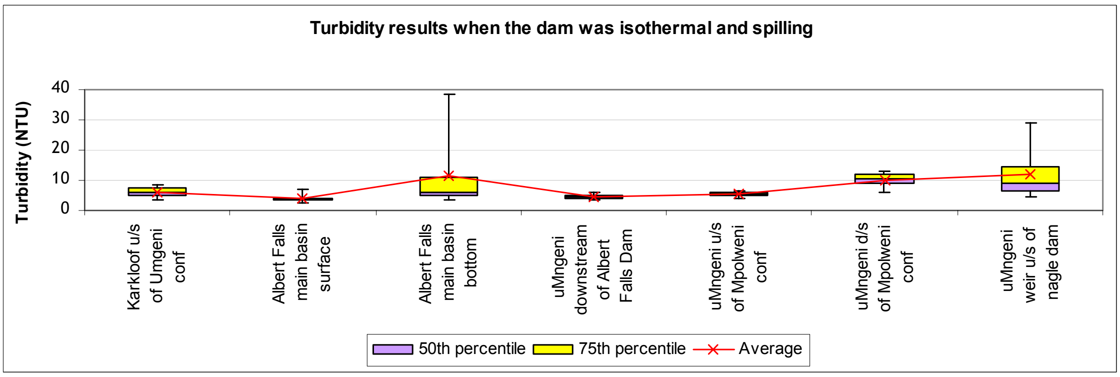

Suspended Solids results when the dam was stratified and nonspilling

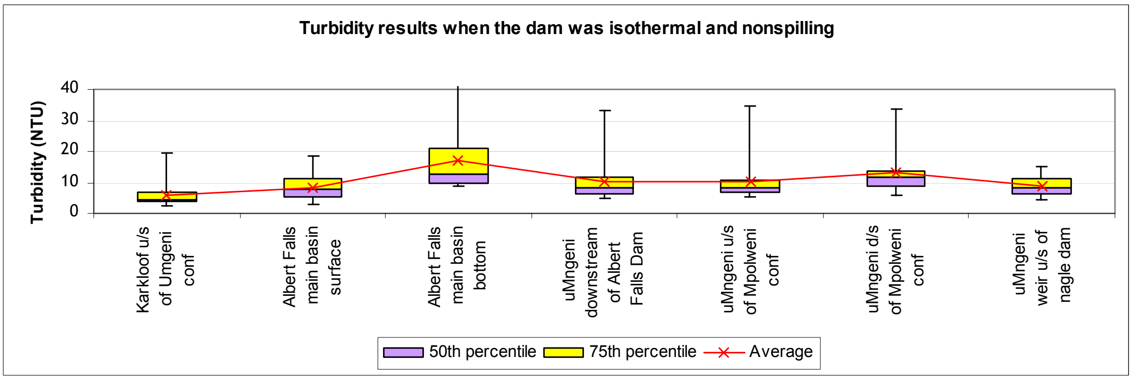

Suspended Solids results when the dam was isothermal and spilling

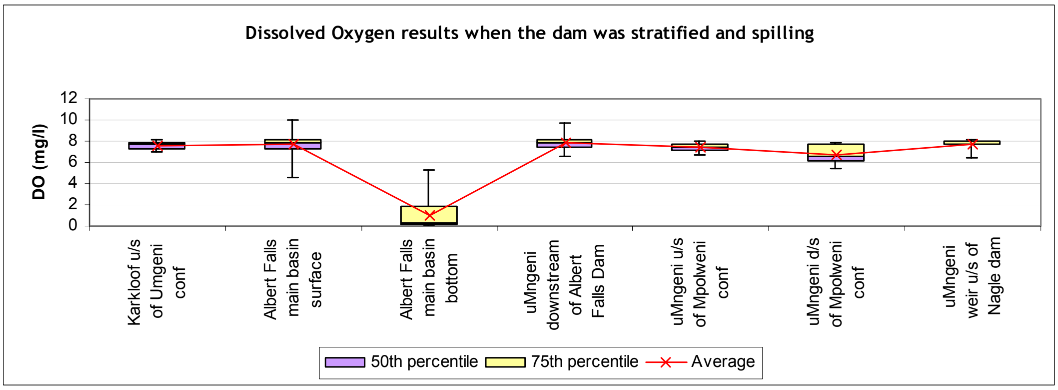

Suspended Solids results when the dam was isothermal and nonspilling

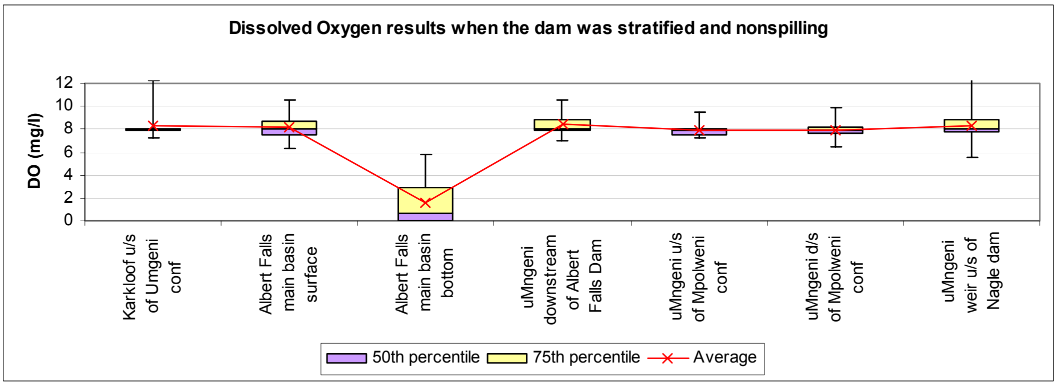

Turbidity results when the dam was stratified and spilling
Turbidity (NTU)
40
30
20
10
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of nagle dam
50th percentile
75th percentile
Average

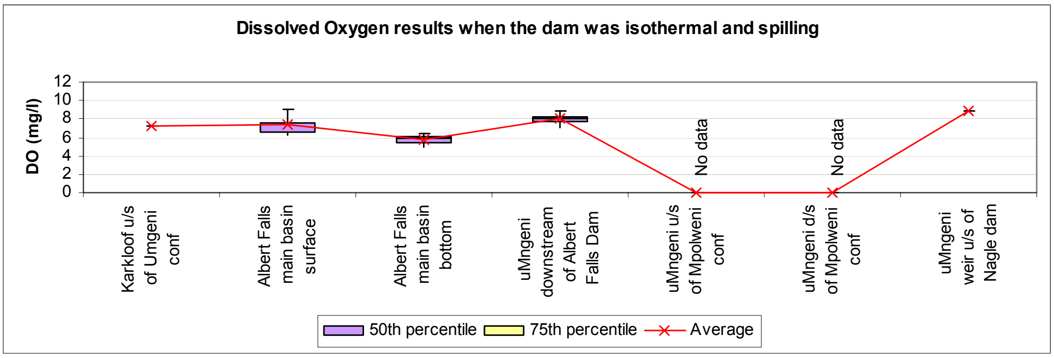

Turbidity results whem the dam was stratified and nonspilling
Turbidity (NTU)
40
30
20
10
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of nagle dam
50th percentile
75th percentile
Average

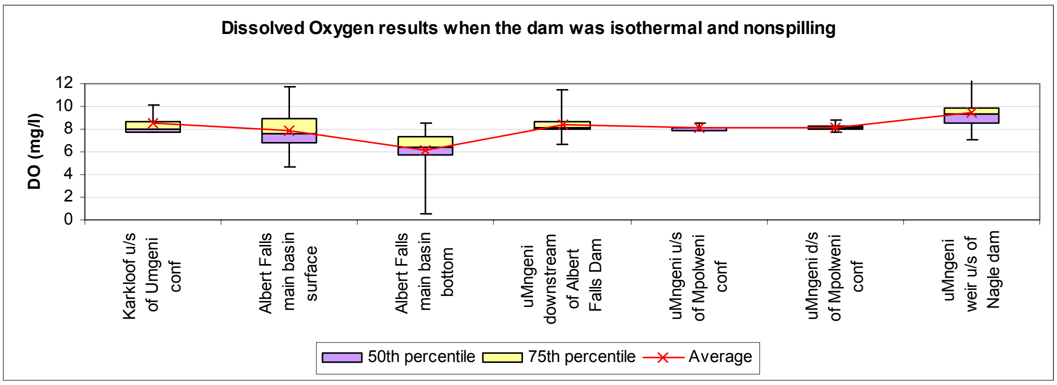

Turbidity results when the dam was isothermal and spilling
Turbidity (NTU)
40
30
20
10
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of nagle dam
50th percentile
75th percentile
Average

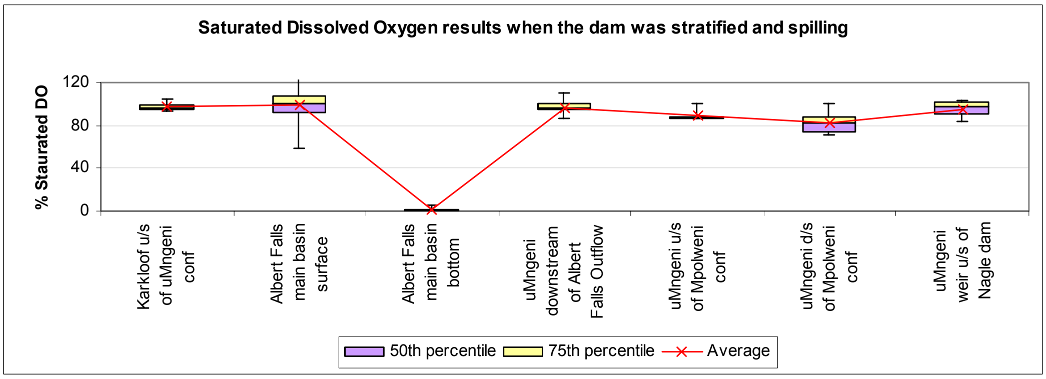

Turbidity results when the dam was isothermal and nonspilling
Turbidity (NTU)
40
30
20
10
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of nagle dam
50th percentile
75th percentile
Average

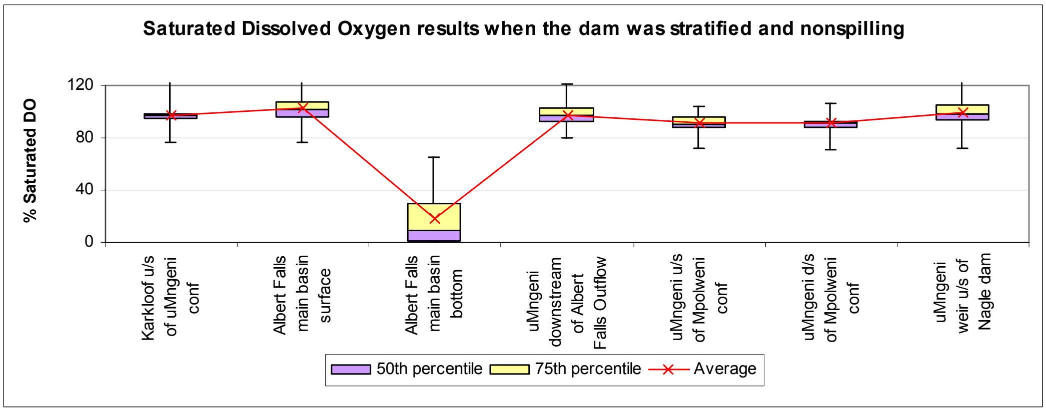

Dissolved Oxygen results when the dam was stratified and spilling


Dissolved Oxygen results when the dam was stratified and nonspilling


Dissolved Oxygen results when the dam was isothermal and spilling


Dissolved Oxygen results when the dam was isothermal and nonspilling


Saturated Dissolved Oxygen results when the dam was stratified and spilling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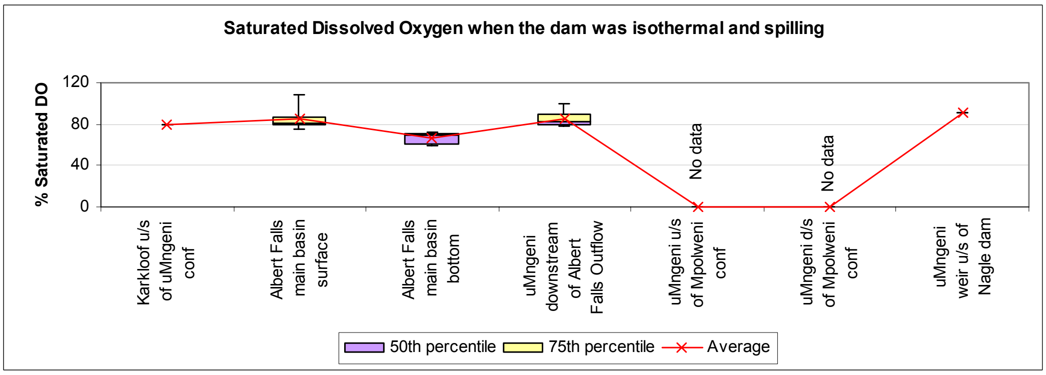
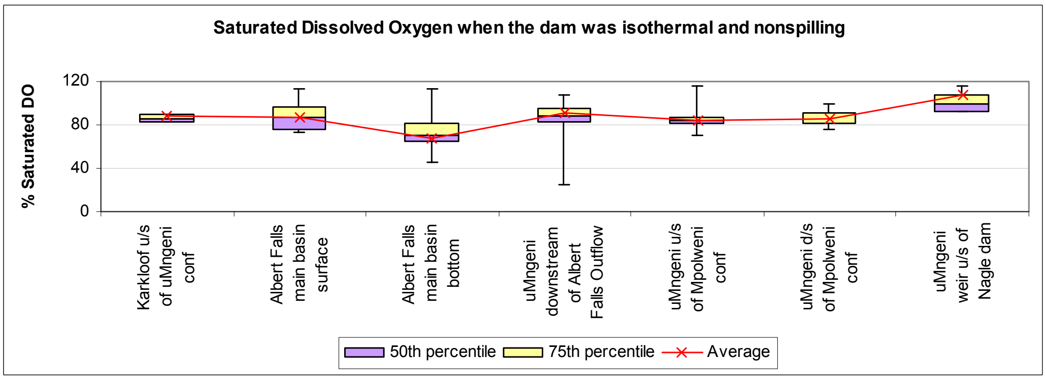
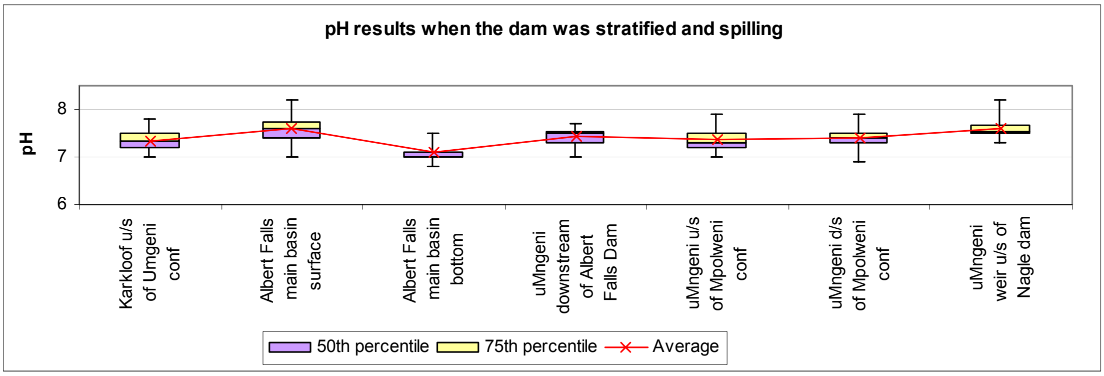
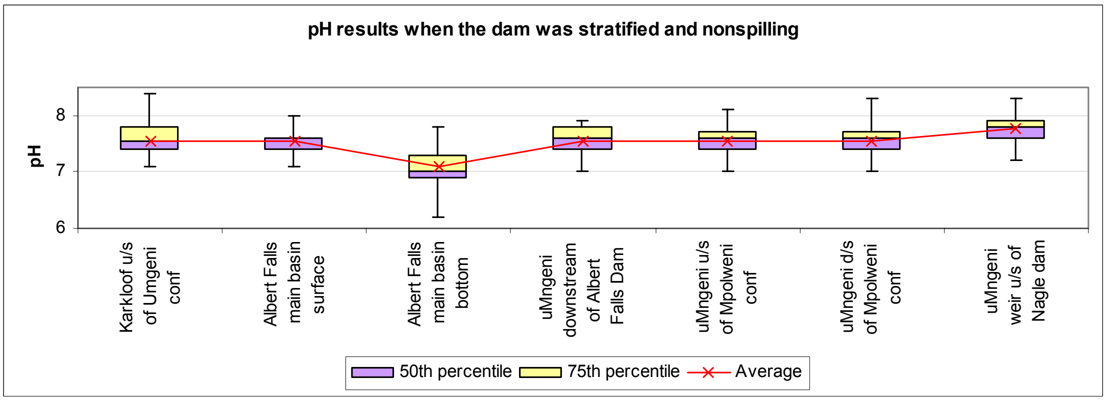
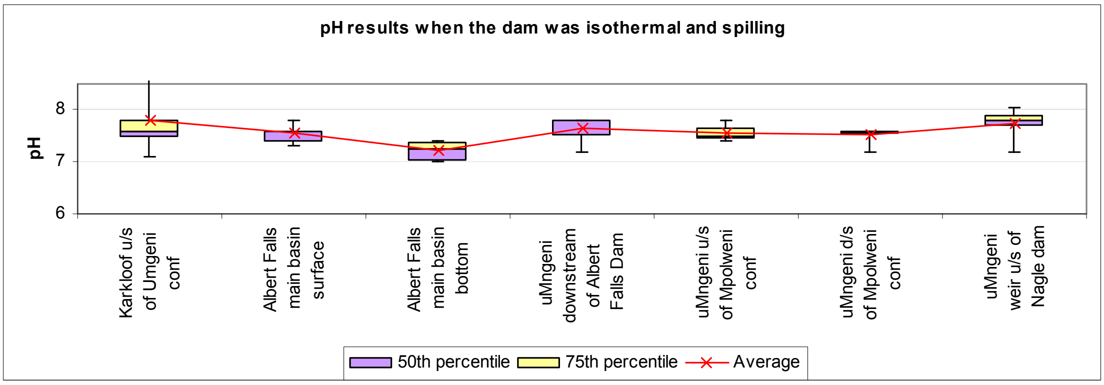
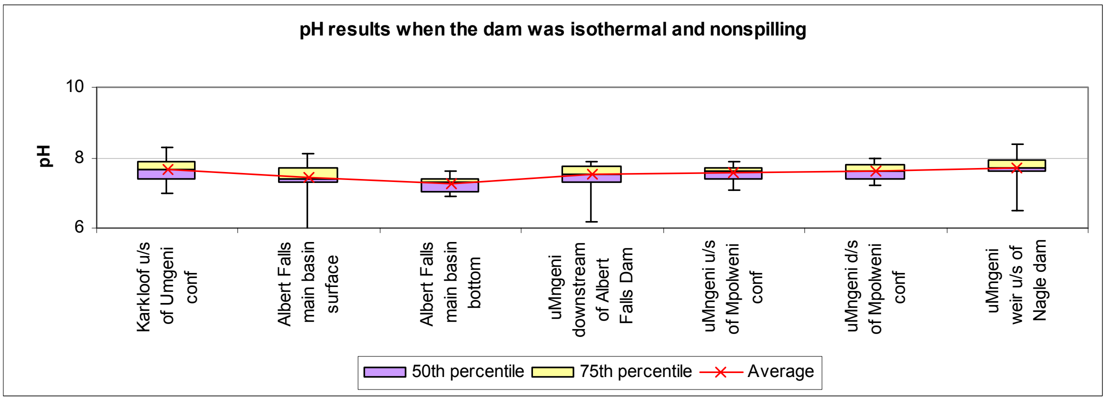

Saturated Dissolved Oxygen when the dam was isothermal and spilling

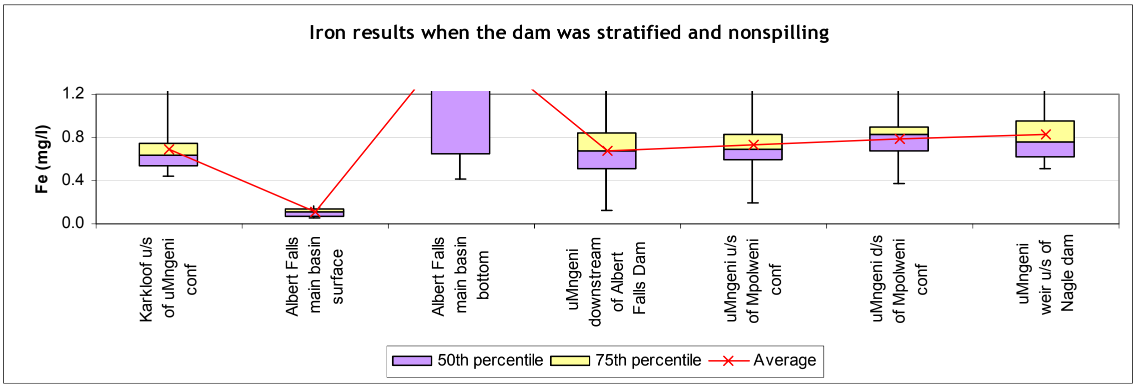

Saturated Dissolved Oxygen when the dam was isothermal and nonspilling

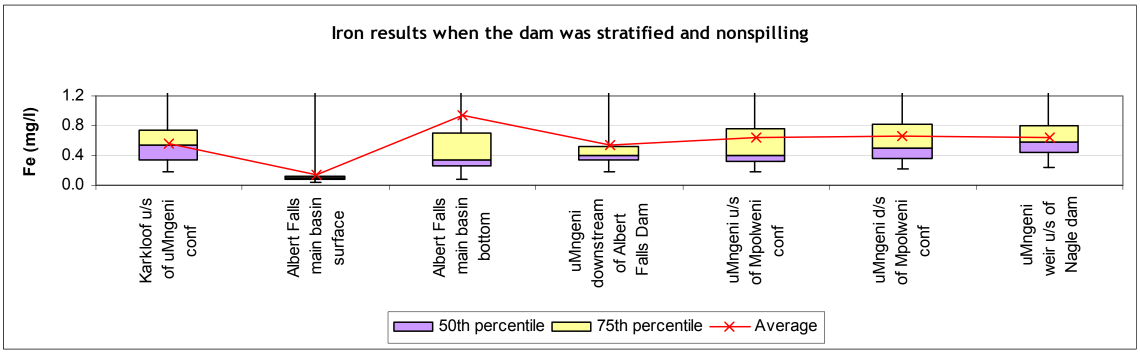

pH results when the dam was stratified and spilling

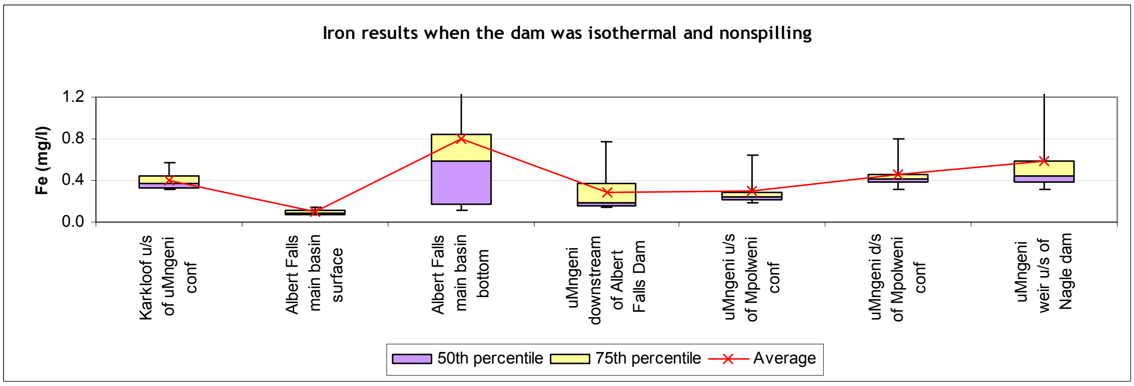

pH results when the dam was stratified and nonspilling

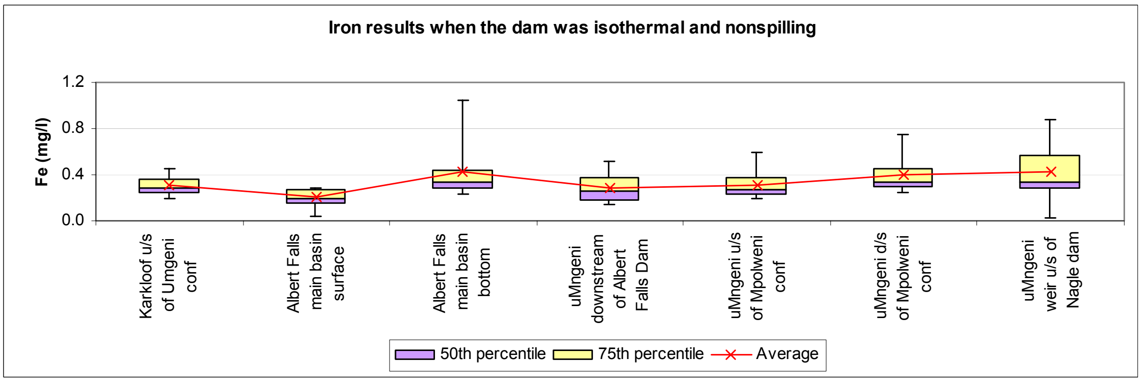

pH results when the dam was isothermal and spilling

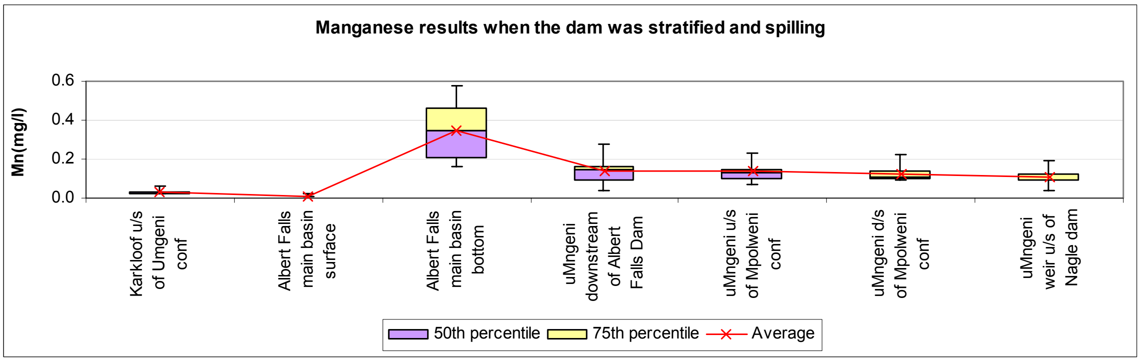

pH results when the dam was isothermal and nonspilling

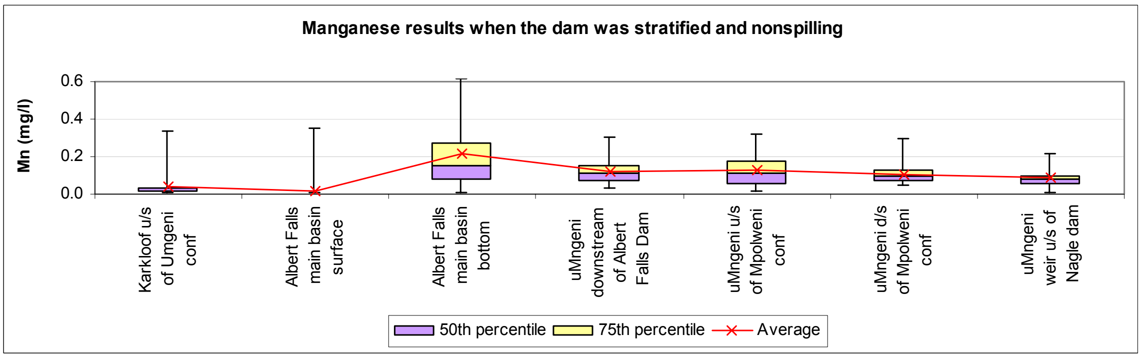

Iron results when the dam was stratified and nonspilling


Iron results when the dam was stratified and nonspilling


Iron results when the dam was isothermal and nonspilling


Iron results when the dam was isothermal and nonspilling


Manganese results when the dam was stratified and spilling
Mn(mg/l)
0.6
0.4
0.2
0.0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


Manganese results when the dam was stratified and nonspilling
Mn (mg/l)
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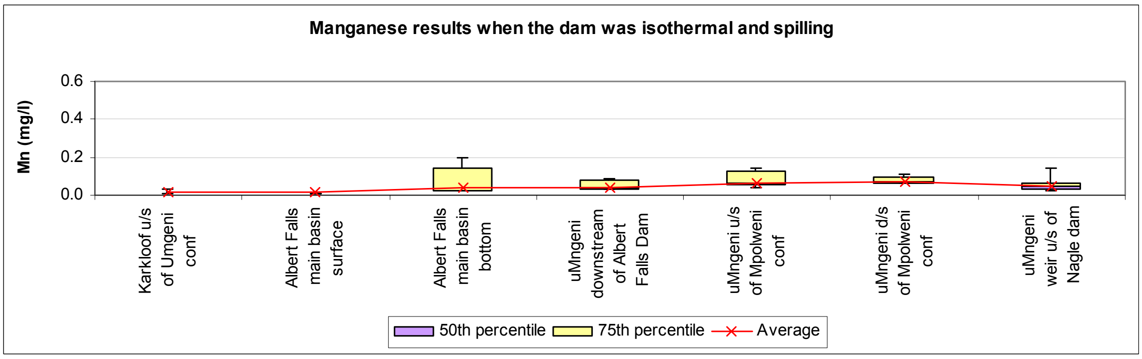
0.4
0.2
0.0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


Manganese results when the dam was isothermal and spilling
Mn (mg/l)
0.6
0.4
0.2
0.0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
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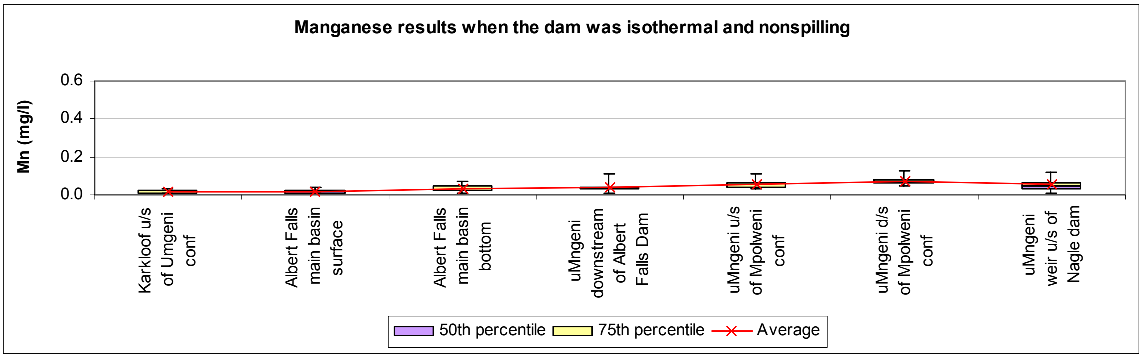
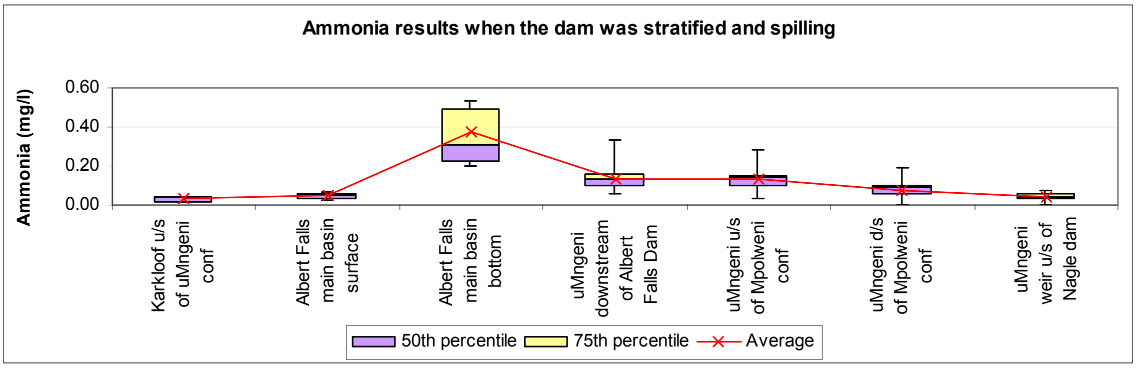
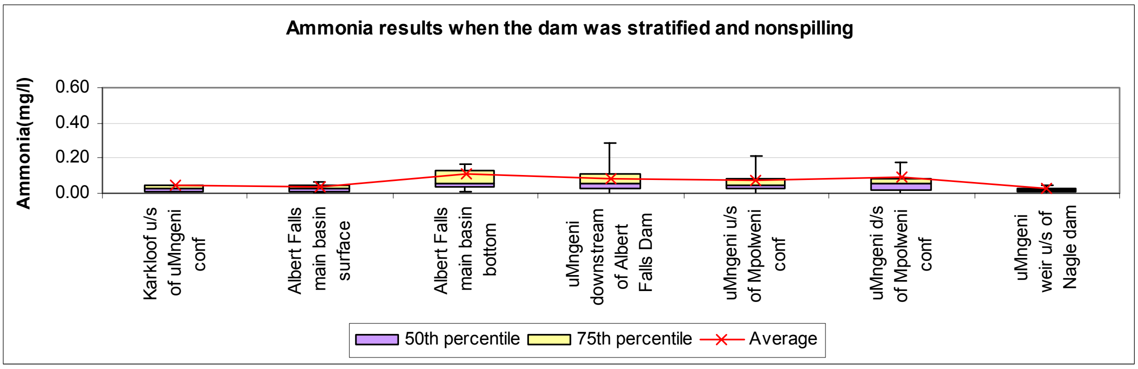
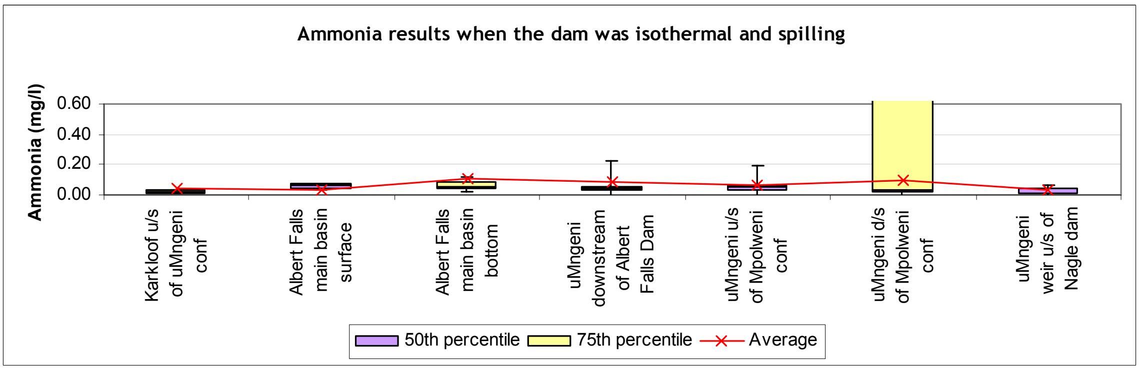
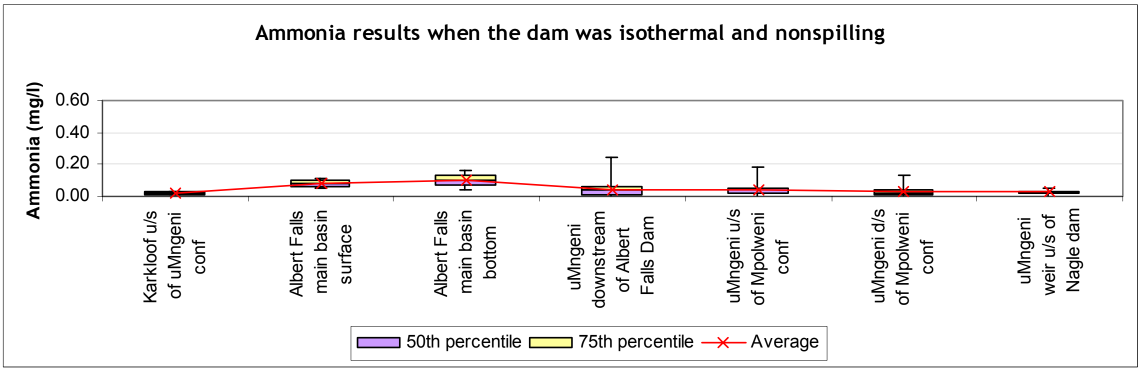
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

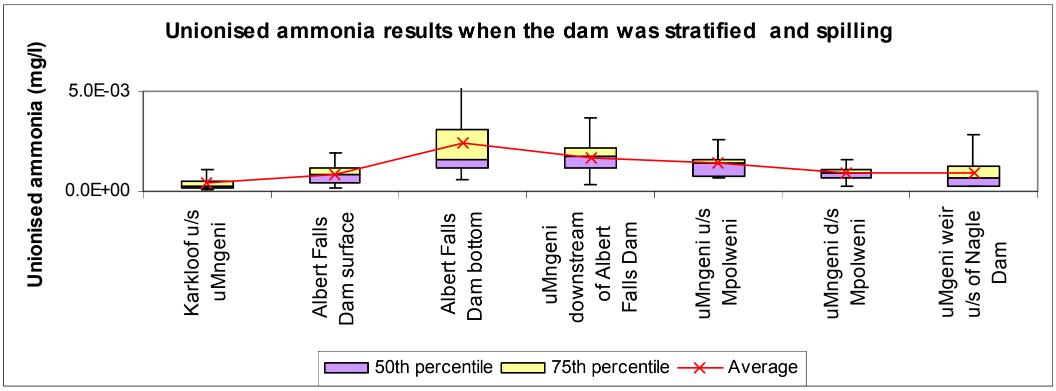

Manganese results when the dam was isothermal and nonspilling
Mn (mg/l)
0.6
0.4
0.2
0.0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

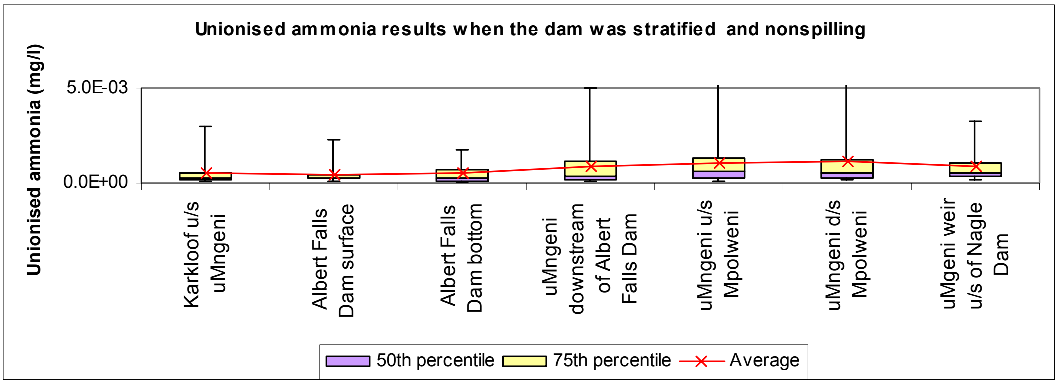

Ammonia results when the dam was stratified and spilling
Ammonia (mg/l)
0.60
0.40
0.20
0.00
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

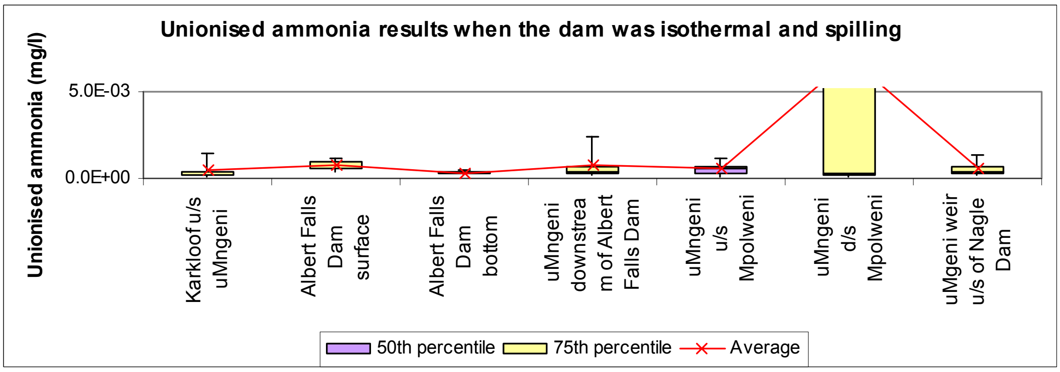

Ammonia results when the dam was stratified and nonspilling
Ammonia(mg/l)
0.60
0.40
0.20
0.00
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

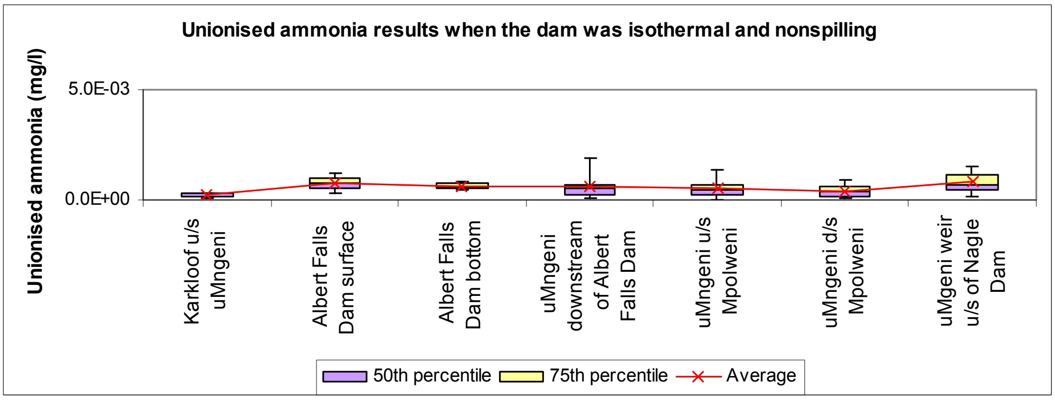

Ammonia results when the dam was isothermal and spilling
Ammonia (mg/l)
0.60
0.40
0.20
0.00
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

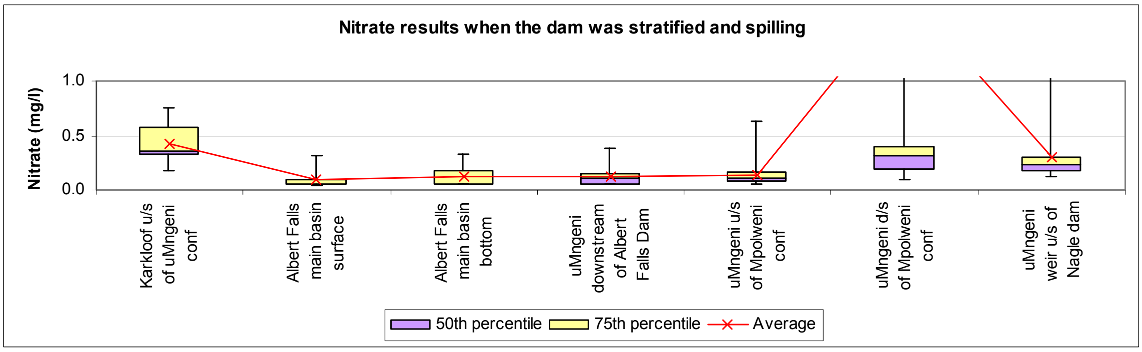

Ammonia results when the dam was isothermal and nonspilling
Ammonia (mg/l)
0.60
0.40
0.20
0.00
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

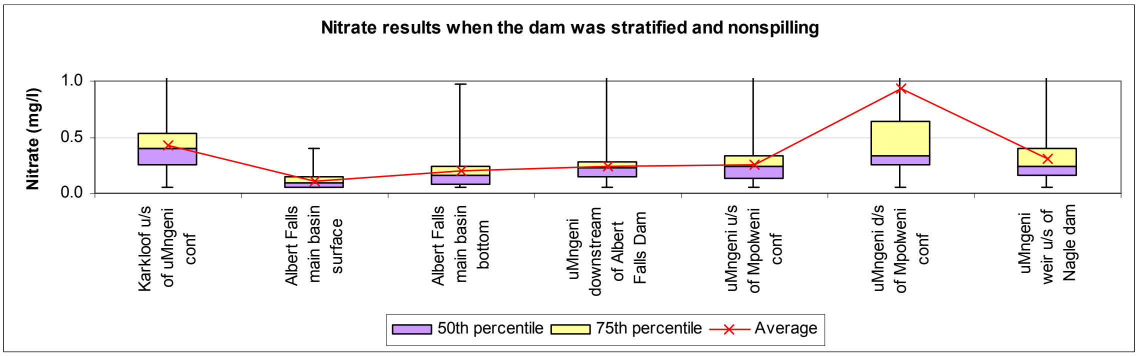

Unionised ammonia results when the dam was stratified and spilling
Unionised ammonia (mg/l)
5.0E-03
0.0E+00
Karkloof u/s uMngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni
uMngeni d/s Mpolweni
uMgeni weir u/s of Nagle Dam
50th percentile
75th percentile
Average

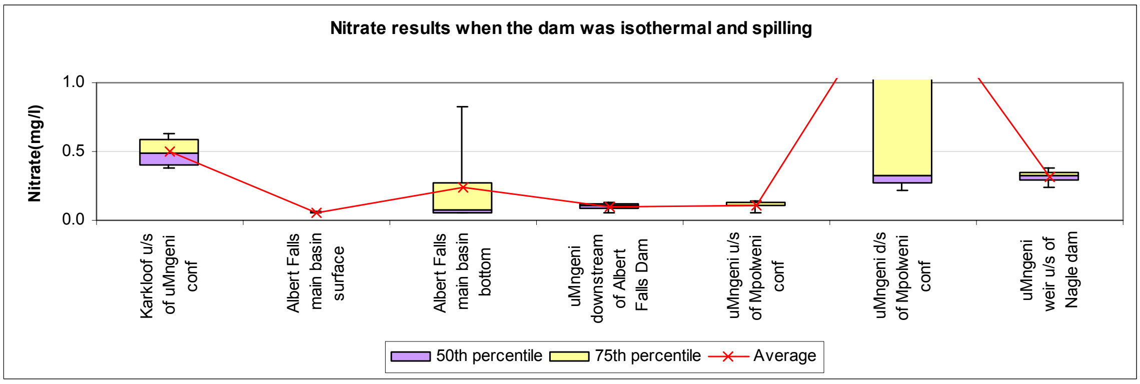

Unionised ammonia results when the dam was stratified and nonspilling
Unionised ammonia (mg/l)
5.0E-03
0.0E+00
Karkloof u/s uMngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni
uMngeni d/s Mpolweni
uMgeni weir u/s of Nagle Dam
50th percentile
75th percentile
Average

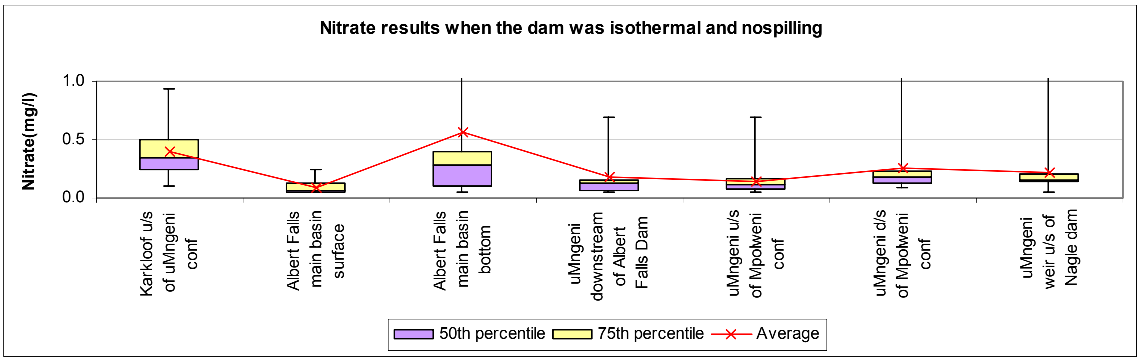

Unionised ammonia results when the dam was isothermal and spilling
Unionised ammonia (mg/l)
5.0E-03
0.0E+00
Karkloof u/s uMngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni
uMngeni d/s Mpolweni
uMgeni weir u/s of Nagle Dam
50th percentile
75th percentile
Average

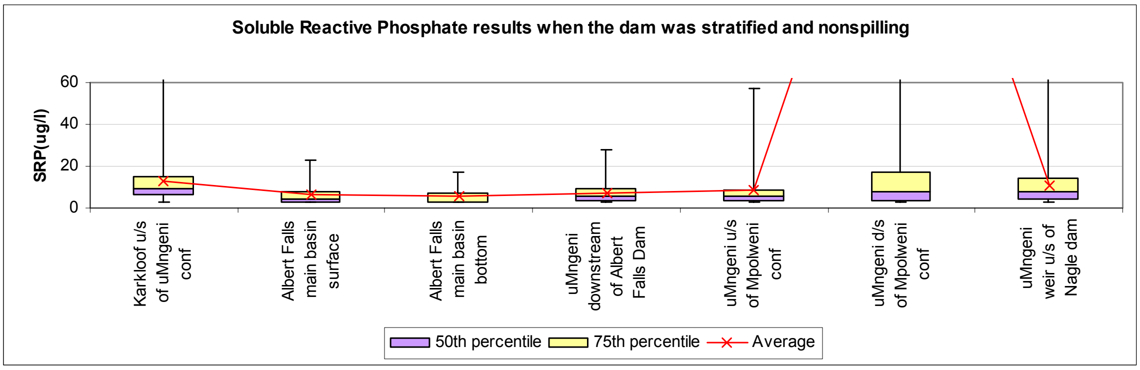

Unionised ammonia results when the dam was isothermal and nonspilling
Unionised ammonia (mg/l)
5.0E-03
0.0E+00
Karkloof u/s uMngeni
Albert Falls Dam surface
Albert Falls Dam bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s Mpolweni
uMngeni d/s Mpolweni
uMgeni weir u/s of Nagle Dam
50th percentile
75th percentile
Average

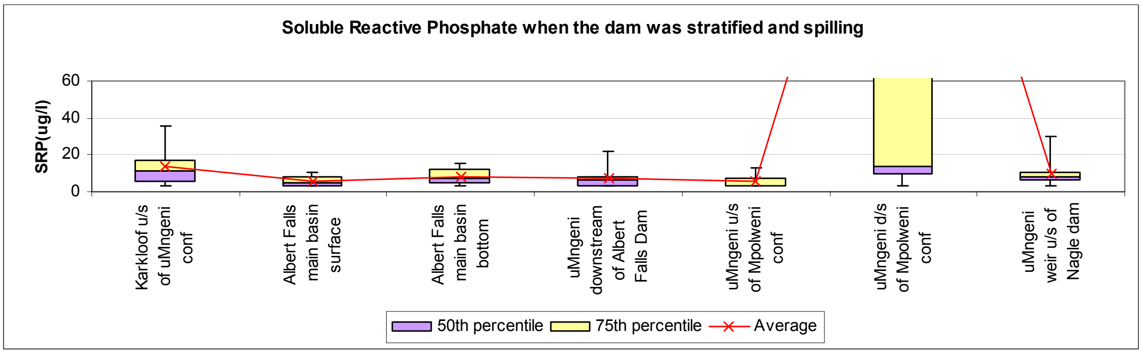

Nitrate results when the dam was stratified and spilling
Nitrate (mg/l)
1.0
0.5
0.0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

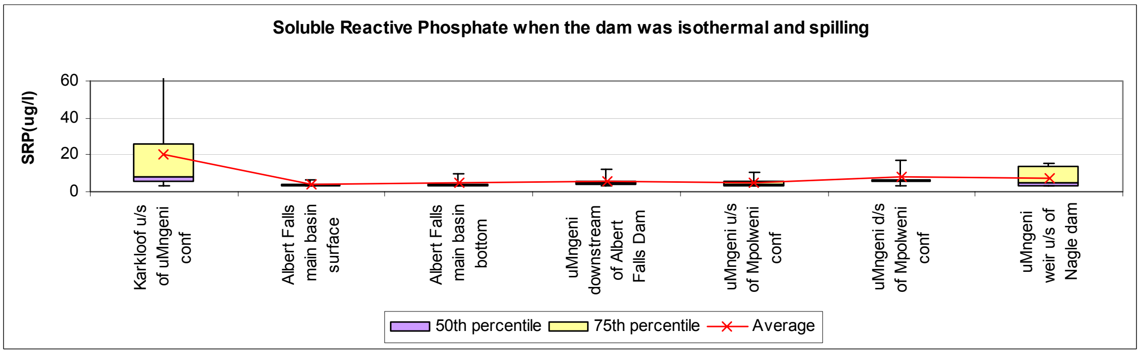

Nitrate results when the dam was stratified and nonspilling
Nitrate (mg/l)
1.0
0.5
0.0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

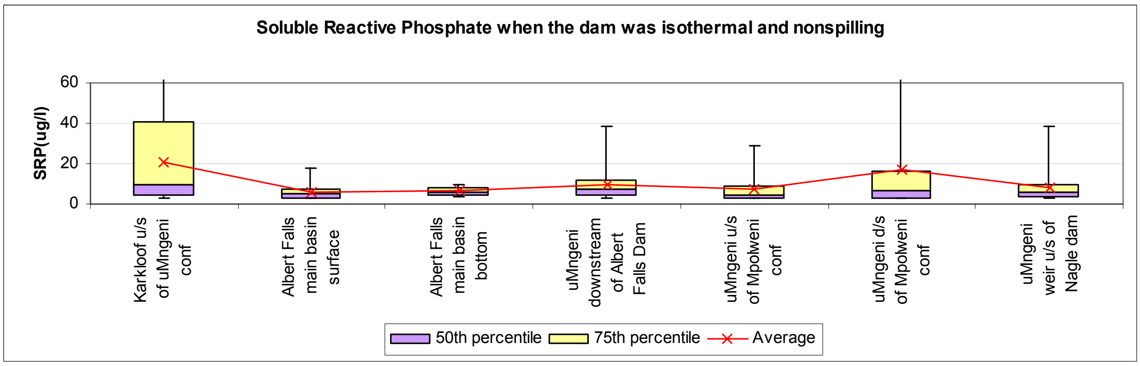

Nitrate results when the dam was isothermal and spilling
Nitrate(mg/l)
1.0
0.5
0.0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

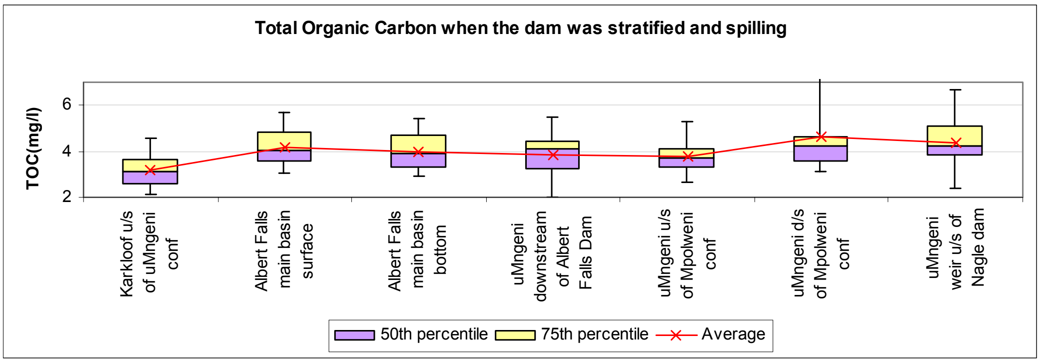

Nitrate results when the dam was isothermal and nospilling
Nitrate(mg/l)
1.0
0.5
0.0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

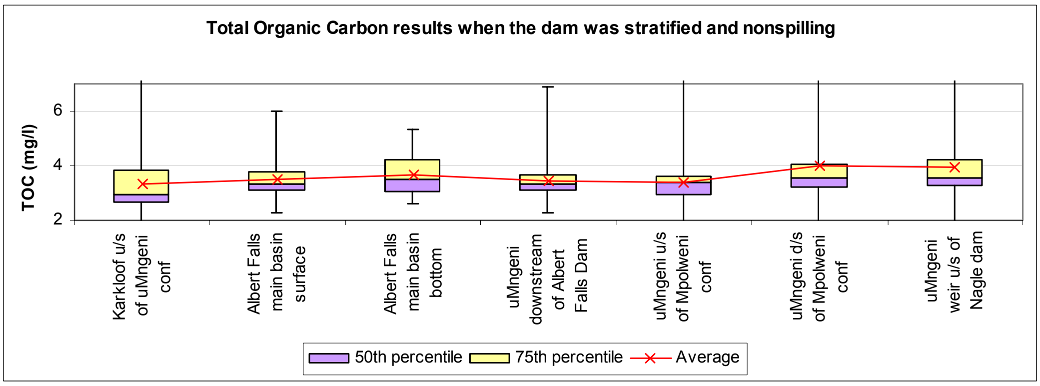

Soluble Reactive Phosphate results when the dam was stratified and nonspilling
SRP(ug/l)
60
40
20
0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

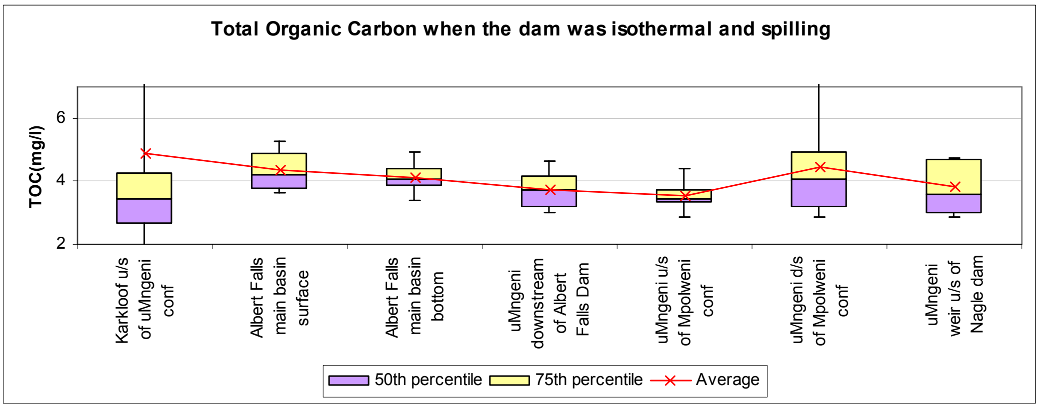

Soluble Reactive Phosphate when the dam was stratified and spilling
SRP(ug/l)
60
40
20
0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

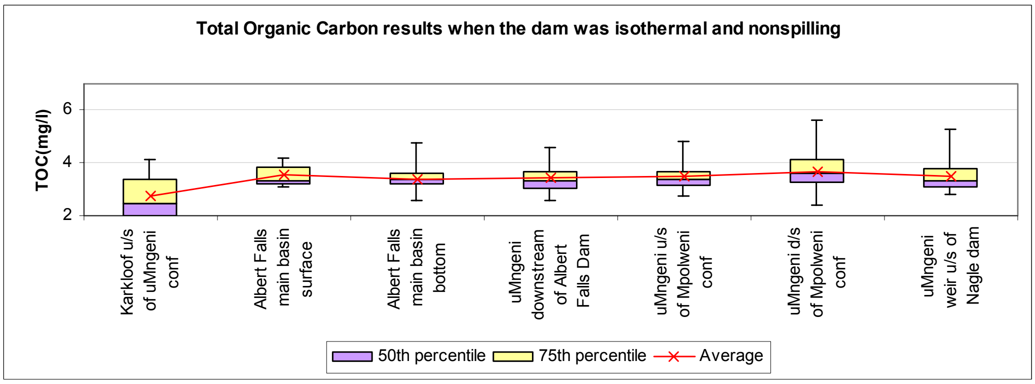

Soluble Reactive Phosphate when the dam was isothermal and spilling
SRP(ug/l)
60
40
20
0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

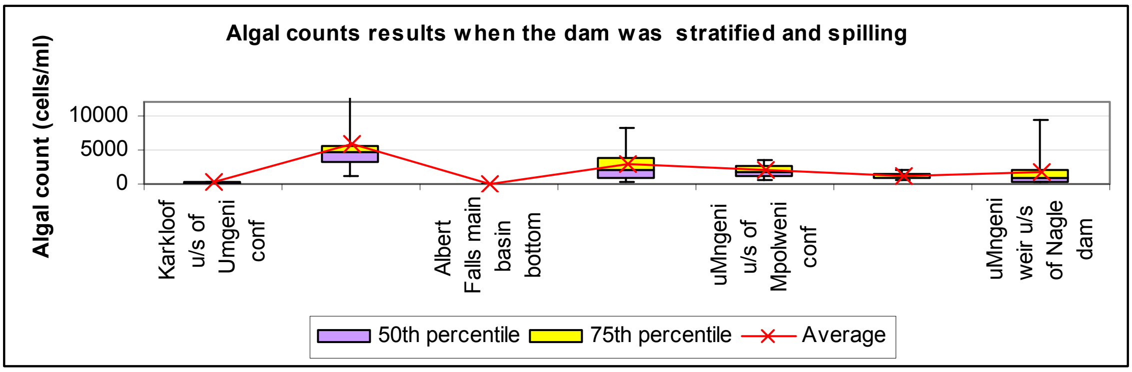

Soluble Reactive Phosphate when the dam was isothermal and nonspilling
SRP(ug/l)
60
40
20
0
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

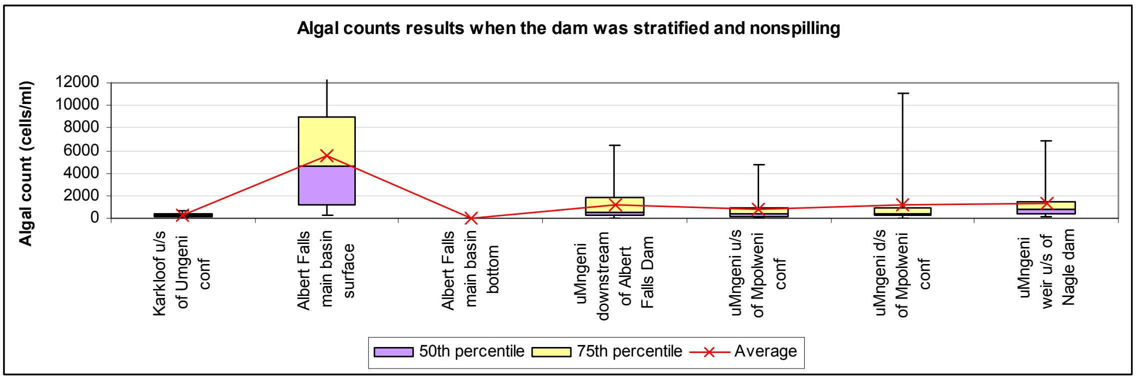

Total Organic Carbon when the dam was stratified and spilling
TOC(mg/l)
6
4
2
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

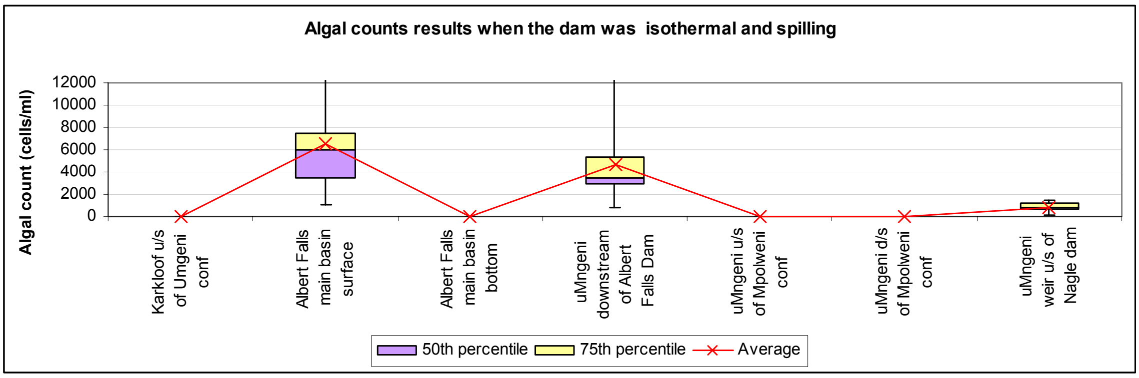

Total Organic Carbon results when the dam was stratified and nonspilling
TOC (mg/l)
6
4
2
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

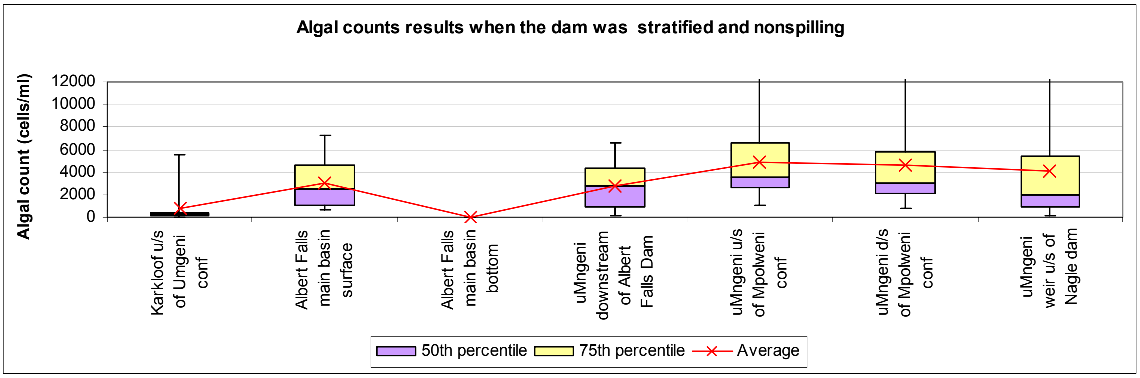

Total Organic Carbon when the dam was isothermal and spilling
TOC(mg/l)
6
4
2
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

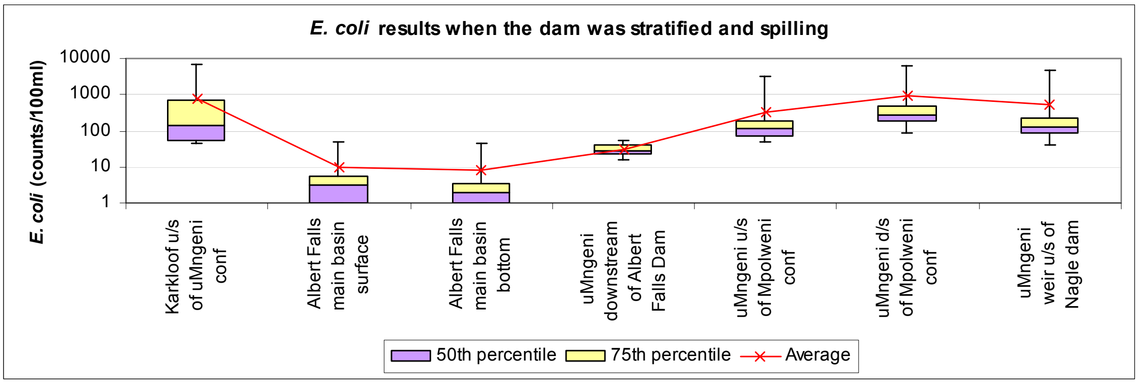

Total Organic Carbon results when the dam was isothermal and nonspilling
TOC(mg/l)
6
4
2
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

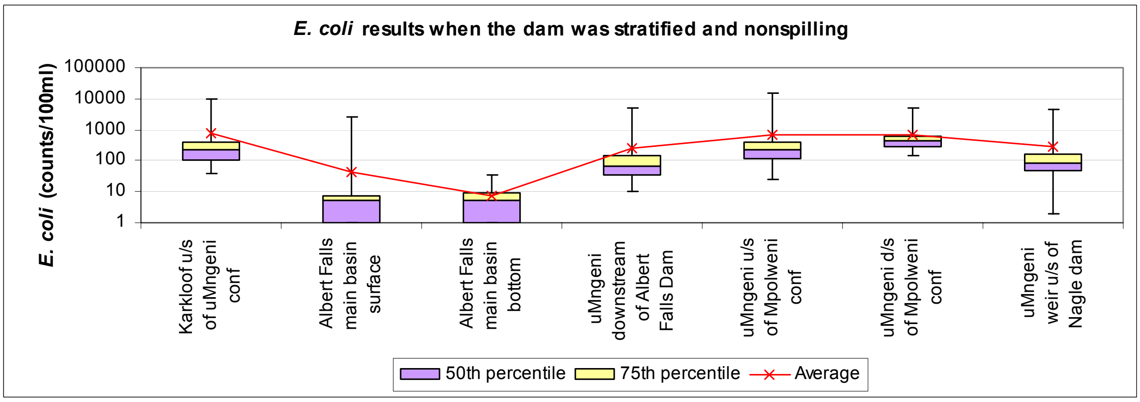

Algal counts results when the dam was stratified and spilling
Algal count (cells/ml)
10000
5000
0
Karkloof u/s of Umgeni conf
Albert Falls main basin bottom
uMngeni u/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

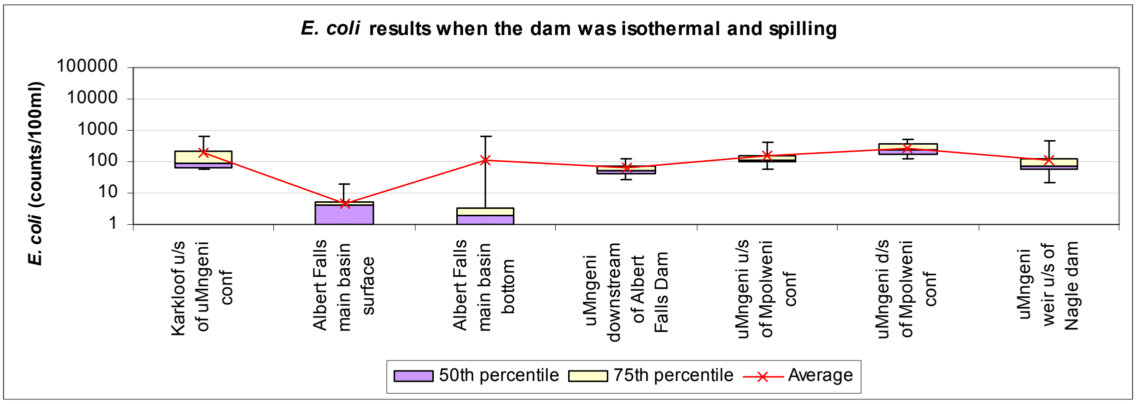

Algal counts results when the dam was stratified and nonspilling
Algal count (cells/ml)
12000
10000
8000
6000
4000
2000
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

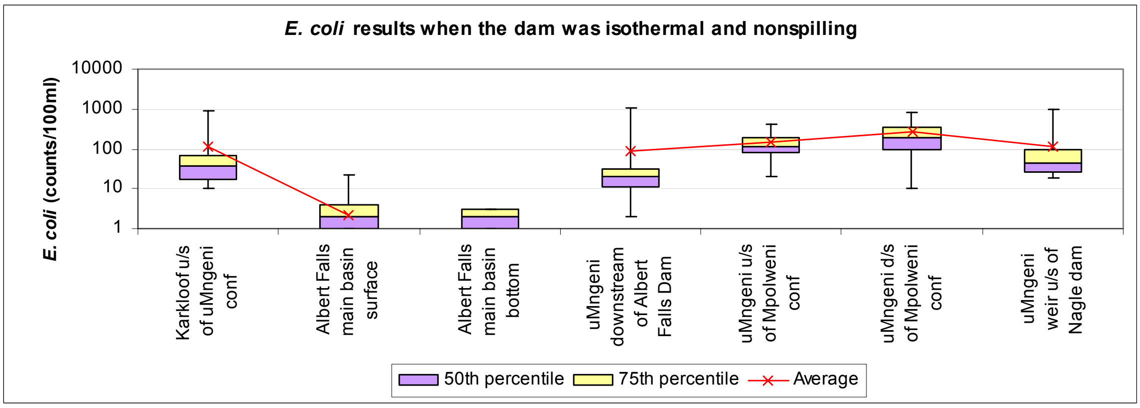

Algal counts results when the dam was isothermal and spilling
Algal count (cells/ml)
12000
10000
8000
6000
4000
2000
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


Algal counts results when the dam was stratified and nonspilling
Algal count (cells/ml)
12000
10000
8000
6000
4000
2000
0
Karkloof u/s of Umgeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


*E. coli* results when the dam was stratified and spilling
*E. coli* (counts/100ml)
10000
1000
100
10
1
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


*E. coli* results when the dam was stratified and nonspilling
*E. coli* (counts/100ml)
100000
10000
1000
100
10
1
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


*E. coli* results when the dam was isothermal and spilling
*E. coli* (counts/100ml)
100000
10000
1000
100
10
1
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average


*E. coli* results when the dam was isothermal and nonspilling
*E. coli* (counts/100ml)
10000
1000
100
10
1
Karkloof u/s of uMngeni conf
Albert Falls main basin surface
Albert Falls main basin bottom
uMngeni downstream of Albert Falls Dam
uMngeni u/s of Mpolweni conf
uMngeni d/s of Mpolweni conf
uMngeni weir u/s of Nagle dam
50th percentile
75th percentile
Average

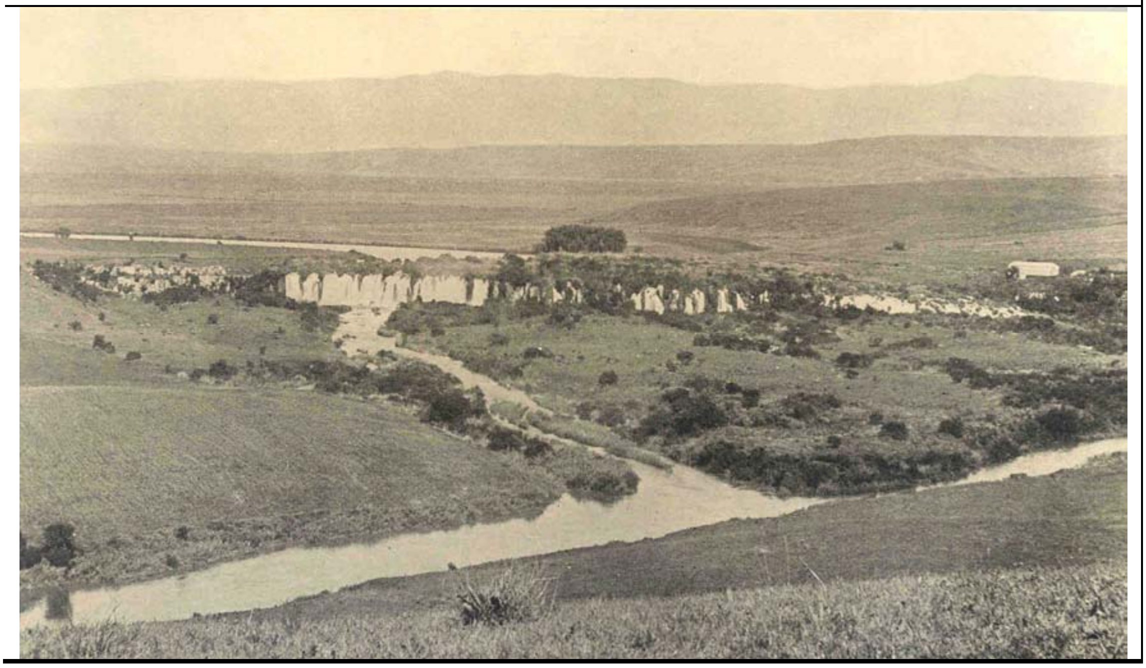
# Chapter 6. Riparian Vegetation

## Introduction

The “high” winter flows experienced by the uMngeni River below Albert Falls dam have already been discussed in greater detail in Chapter 4. However, the cascade of impoundments along the uMngeni River upstream, most notably Midmar and Albert Falls dams, capture most of the flood peaks that would normally maintain a riparian community in some state of dynamic equilibrium. Only very large floods overtop these impoundments in sufficient quantities to perform the range of functions that floods naturally have in riparian communities. The 1987 (and possibly 1984) floods were possibly the only two events, since the construction of these two dams, which were able to perform this role (with Midmar Dam constructed in ~1963 and Albert Falls Dam in ~1975).

The change in riparian cover below the Albert Falls waterfall is illustrated in the following oblique photography (Figure 6.1), a rare 1912 oblique photograph of the Albert Falls waterfall and then a sequence from 1952 to the present of the same site. These photographs indicate that there has indeed been a significant change in the riparian vegetation community below the Albert Falls Dam which may be due to the impoundment of the river but also due to land management practices as the thickening of the vegetation precedes the construction of any dams upstream.

*1912*



(contd. below)

*1952*

*July 2002*

Figure 6.1: A sequence from 1912 to 2002 of oblique photographs of Albert Falls

To determine the impact of the largely artificial flow regime created by the Albert Falls Dam on the riparian community, this study sought to determine if the riparian community had in fact changed in extent in response to this situation.

The specific questions posed were:

- Has the impoundment at Albert Falls had an impact on the riparian community below the dam?
- If the answer to the above question was "yes", what is the local spatial and geographic extent of this impact?

**Methods and data sources**

Three study sites were identified to examine the response of riparian vegetation to altered flow regimes associated with the Albert Falls impoundment. Figure 3.1 illustrates the locality and extent of these study sites. These were:

1. On the Karkloof River, upstream of its confluence with the uMngeni River and Albert Falls Dam.
2. Immediately downstream of the impoundment of the Albert Falls Dam and down to the Greytown Road
3. Immediately above the gauging station and weir at the inflow to Nagle Dam

The first site constituted a control or reference site, as it was largely unregulated and with no significant impoundments along its length. The second site was immediately below the Albert Falls Dam impoundment, and hence likely to be most impacted by the effects of regulated flows, whilst the last study site was just above the Nagle Dam impoundment and furthest away from the Albert Falls impoundment. Other than the control site on the Karkloof River, the last site was also potentially least impacted by the flow regulation as tributaries between Albert Falls and Nagle (most notably the Mpolweni River) would have had a chance to restore something of the natural flow regime (and natural flooding) to the lower uMngeni River, before it enters Nagle Dam.

This investigation was undertaken by examining historical aerial photography from each of the study sites, and quantifying changes in broad riparian community structure over time.

Some of the earliest available aerial photography for the province was that flown in August 1937. Contact prints of the study areas were obtained from the Surveyor Generals Offices. The most recent accessible aerial photography was available digitally and was from 2003 for the Karkloof and Albert Falls sites, and 2001 for the Nagle Dam site. Because the 1937 photography was only available as hard copy prints, these had to be scanned and geo-referenced by a process of "warping" or "rubber sheeting" to bring them into the same geographical space as the most recent digital aerial photography. Once the two data sets (1937 and 2000 vintage) were aligned, within each study site 10 to 12 transparent transects were placed at random at right angles across the length of uMngeni and Karkloof Rivers (see Figures 6.2 to 6.4) which were visible on the underlying base aerial imagery. The process of siting of these transects was as follows:

- The mid lines of the river within the study areas were digitised and then buffered by 100 m on either side of the mid line to create a 200 m wide “river strip” which would encompass the main river channel and riparian community.
- Points for the placement of these transects were initially randomly placed down the length of the river in the study sites and at each transect point a 20 wide transect was placed at right angles to the “river strip” to create a transect of dimension 20X200 m.
- These transects were then digitally clipped out and used to create GIS polygon shape files which were close in extent and position for each study site and for each study period.
- This ensured that within the boundaries and accuracy obtainable with the alignment of the old (1937) and modern (2001/3) aerial photography, equivalent areas could be assessed (Figures 6.2 to 6.4).

Figure 6.2: Illustration of the position of riparian vegetation transects along the Karkloof River upstream of Albert Falls Dam (1937 (top) and 2003 (bottom) base imagery)

Figure 6.3: Illustration of the position of riparian vegetation transects along the uMngeni River downstream of Albert Falls Dam (1937 (top) and 2003 (bottom) base imagery).

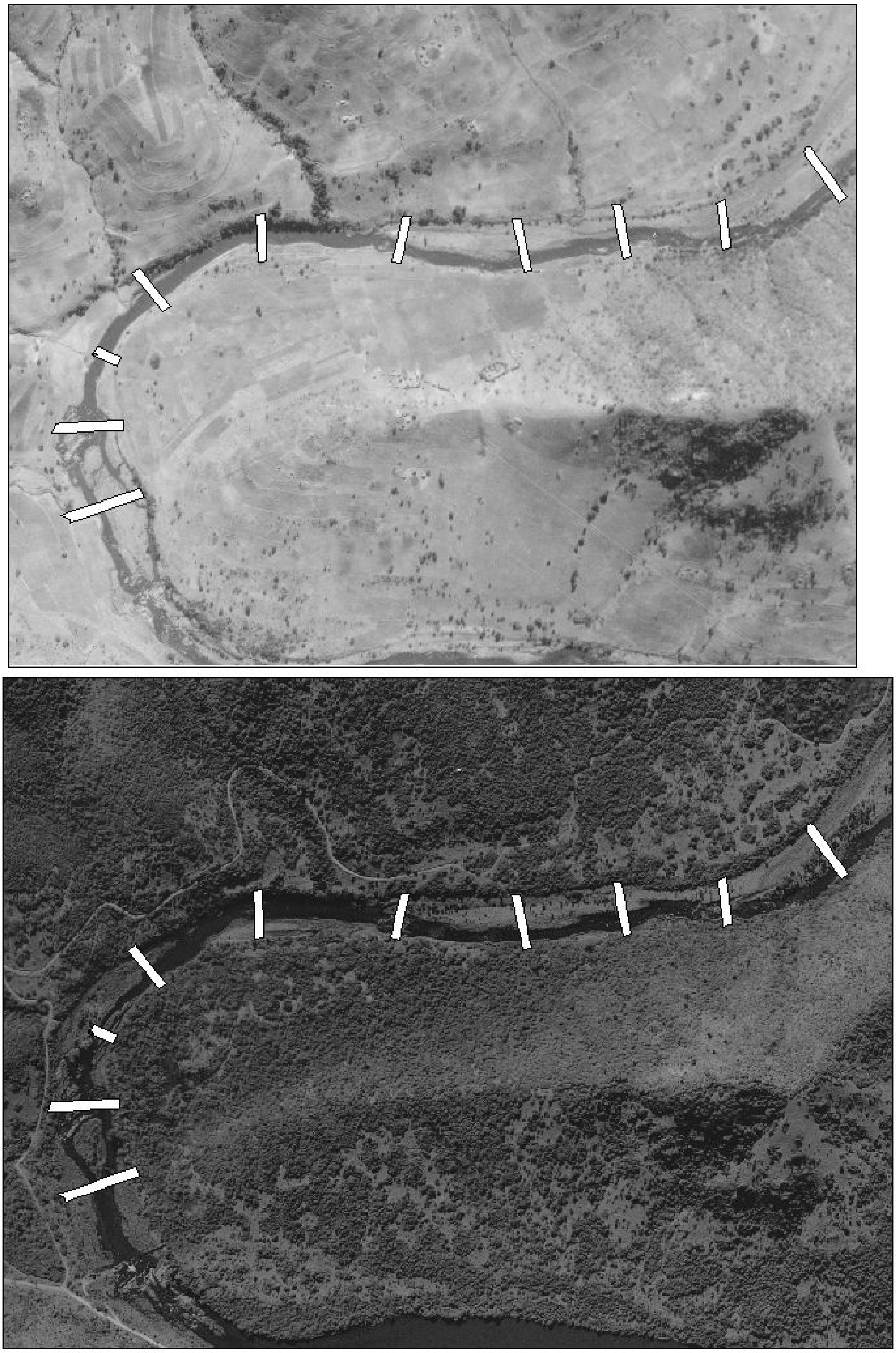


Figure 6.4: Illustration of the position of riparian vegetation transects along the uMngeni River upstream of Nagle Dam (1937 (top) and 2001 (bottom) base imagery)

Due to the limitations of the aerial imagery, and available historical records for early riparian communities within the study sites, the most practical resolution possible for identifying riparian community changes along the rivers was based on a classification according to the following functional cover classes:

- Open Water
- Grass/Reeds
- Shrubs/Trees
- Riffles/Rapids
- Anything else outside or beyond the stream macro channel

For each of the 1937 transects, the macro channel was defined and this boundary was used to trim the respective 2001/3 transects so that equivalent areas were assessed for each transect, i.e. each study period considered the same transect length. In some instances the macro channel had shifted slightly over time and new endpoints for the transects had to be defined.

In summary, the aerial imagery formed the base map over which transparent transects were overlaid and then visible riparian community features identified within the respective transects to further digitally subdivide the riparian zone according to the functional cover classes (as defined above). The areas for each cover class within the riparian zone for each transect was then calculated and this provided a summary of the state of the riparian community classification for each of the study periods. Because transects were not all of the same size (due to macro-channel differences between sites, and over time) riparian cover classes (e.g. water, grass/reeds, shrubs/trees) had their areas normalised to a percentage contribution of the total transect. In other words, determining the percentage of the total area (100%) of each transect which comprised the above cover classes. This allowed the change in cover classes, with time and position downstream from Albert Falls Dam and within the control site, to be estimated.

### Data analysis

The experimental design for the sampling within each study area (and subsequent data), was an example of “Student’s” method of paired differences. In this instance the one member of the pair was the transect placed over the 1937 imagery, whilst the second member of the pair was the transect placed over exactly the same area for the 2001/3 imagery. This has statistically useful advantages over unpaired data in that there is greater homogeneity within pairs than between pairs, and as such the standard errors of the difference of the means (or of the mean difference) would be reduced as compared to a design without pairing (Rayner, 1967). Generally a statistical design with pairing is therefore the more efficient. Appropriate statistical analyses were therefore conducted and reported accordingly.

## Results

As previously indicated, for each transect in each study area, the percentage contribution of respective cover classes to the total transect area were used to reflect the change in time and distance downstream from Albert Falls Dam. This summarised data is presented in Annexure B (at the end of this chapter). At some sites (and particularly for the analysis undertaken for the site immediately below Albert Falls), there were dramatic changes in cover classes noted. To illustrate this, the percentage contribution of each cover class to the total transect area for a single transect from the Albert Falls study site (Transect 1, immediately below the Albert Falls waterfall) is displayed in Figure 6.5.

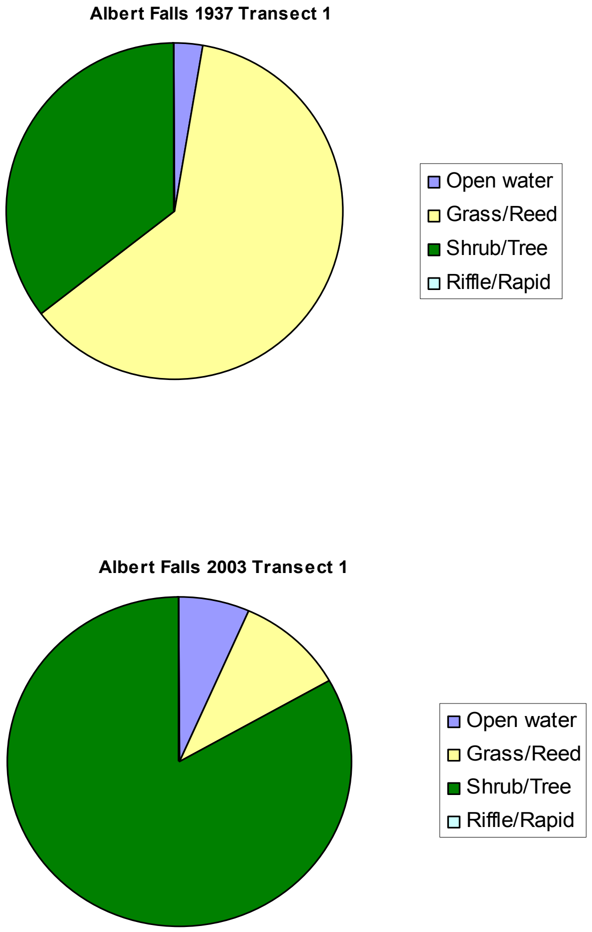
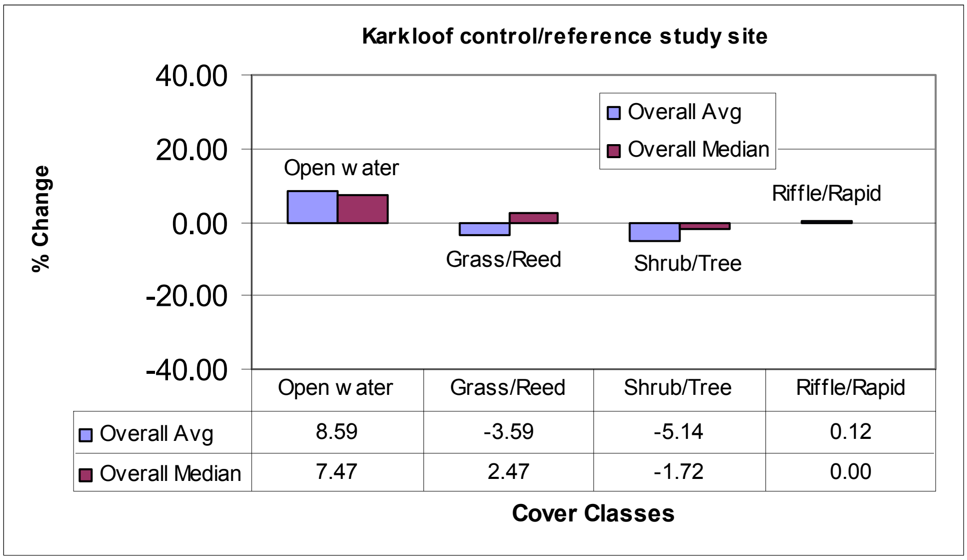


Figure 6.5: Proportional (percentage) contribution of each cover class to the total transect area for a single transect from the Albert Falls study site (Transect 1, immediately below the Albert Falls – see Figure 6.3 for locality) for 1937 and 2003 imagery.

Figure 6.6: Plan view of proportional contribution of each cover class to the total transect area for a single transect from the Albert Falls study site (Transect 1, immediately below the Albert Falls – see Figure 6.3 for locality) for 1937 (top image) and 2003 (bottom image) aerial photography.

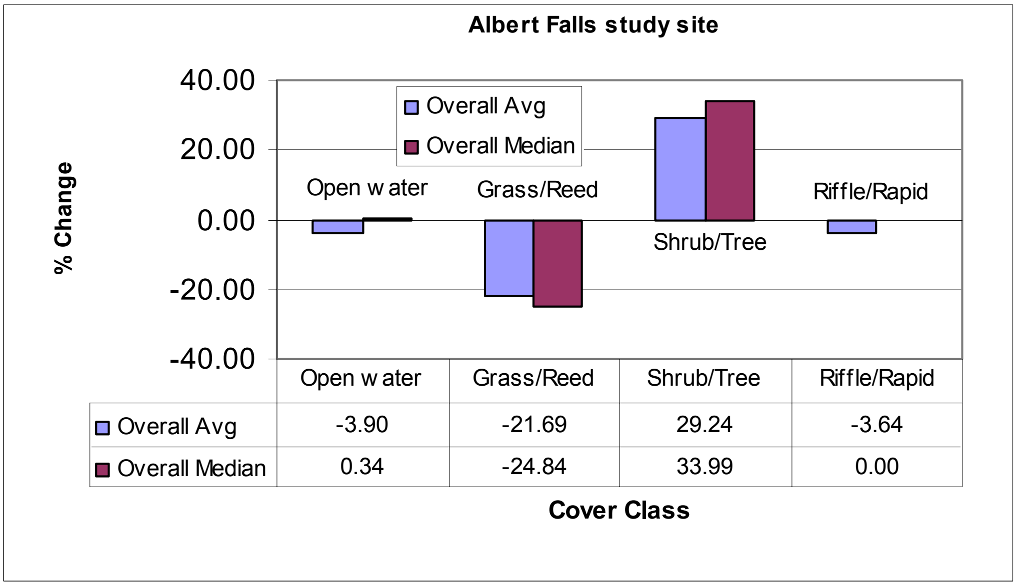
To gain an overall picture for each study area, the percentage change in cover class over the two sets of imagery was summarised in the following figures (with attached tables). For comparative purposes the % Change (Y axis) scales have been kept the same for each study site.



| | Open w ater | Grass/Reed | Shrub/Tree | Riffle/Rapid |
|---|---|---|---|---|
| ▢ Overall Avg | 8.59 | -3.59 | -5.14 | 0.12 |
| ■ Overall Median | 7.47 | 2.47 | -1.72 | 0.00 |

Figure 6.7: Summary of cover class changes over time (1937-2003) in the Karkloof control/reference study site.

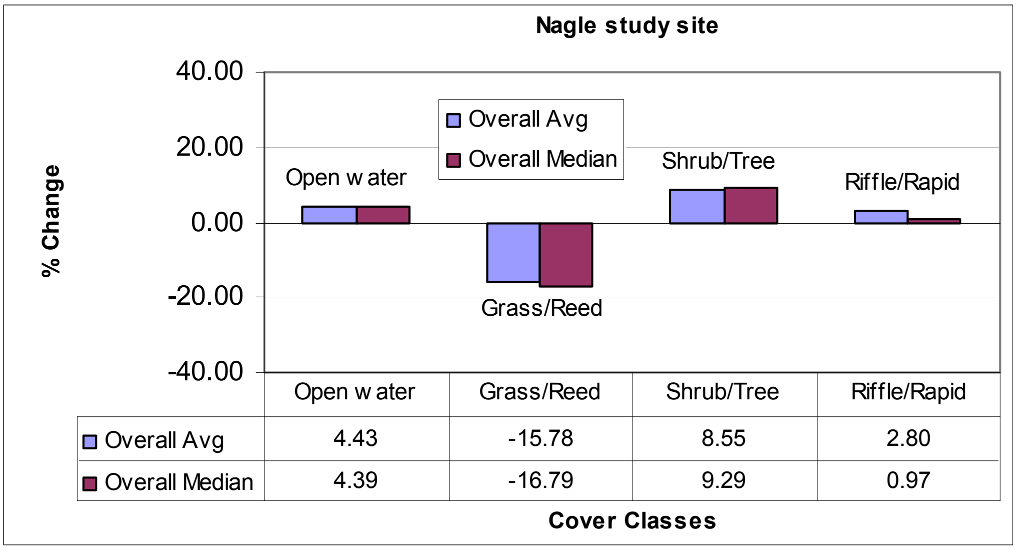
For the Karkloof control/reference study site there has clearly been very little change in cover class of the riparian community over time (1937-2003). All changes are less than 10% over the study period. The open water component increased very slightly by around 8%, with a small decline in the shrub/tree cover class. The grass/reed cover class was virtually unchanged.



| | Open w ater | Grass/Reed | Shrub/Tree | Riffle/Rapid |
|---|---|---|---|---|
| ▢ Overall Avg | -3.90 | -21.69 | 29.24 | -3.64 |
| ■ Overall Median | 0.34 | -24.84 | 33.99 | 0.00 |

Figure 6.8: Summary of cover class changes over time (1937-2003) in the Albert Falls study site (immediately downstream of the current Albert Falls Dam impoundment).

As the pie diagrams in Figure 6.5 showed, this study site demonstrated the most dramatic change in riparian cover classes for the study period (1937-2003). The grass/reed cover class decreased on average by over 20%, whilst the shrub/tree class increased by around 30%. Open water and riffle/rapids cover classes were virtually unchanged.



|  | Open w ater | Grass/Reed | Shrub/Tree | Riffle/Rapid |
|---|---|---|---|---|
| Overall Avg | 4.43 | -15.78 | 8.55 | 2.80 |
| Overall Median | 4.39 | -16.79 | 9.29 | 0.97 |

Figure 6.9: Summary of cover class changes over time (1937-2001) in the Nagle Dam study site (immediately upstream of the current Nagle Dam impoundment).

The relative changes for the Nagle study site was very similar to that observed at the Albert Falls site, only less pronounced, with grass/reeds declining and shrub/trees increasing over time (1937-2001). By contrast with the Albert Falls site, the grass/reed cover class declined most by comparison with the shrub/tree class at this Nagle site. This situation was reversed at the Albert Falls site with the greatest change taking place within the shrub/tree class (increasing relative to the grass/reeds).

## Discussion

A summary of the key statistics, and Student’s paired *t* test for the comparisons of respective riparian cover classes between the sets of imagery is presented in the Annexure B Table B1 (at the end of this chapter). The table may either be read horizontally, for cover class comparisons or vertically for study site comparisons.

The results highlighted in Table B1 show that besides the marginally significant change in the open water cover class, the Karkloof River control/reference study site illustrates no consistent or systematic change in either the grass/reed or shrub/tree riparian vegetation cover classes over time. Note that it is important to appreciate that this was the situation despite the apparent (from the oblique and aerial photographs) increase in shrub/tree vegetation in the surrounding landscape, which was probably the result of changed grazing and fire regimes. Given that this site is within the same ecoregion as the other study sites, it is postulated that in the absence of regulated flows from Albert Falls dam, similar results would be obtained from the other two study sites. However this analysis illustrates a different picture. For both sites downstream of the Albert Falls impoundment there are consistent and statistically significant changes in both the riparian grass/reed and shrub/tree cover classes. The open water habitat in each of the impacted sites showed no statistically significant change over time.

## Annexure B Vegetation statistics

Table B1 Summary of the key statistics, Student's paired *t* test, and statistical significance of these results for the comparisons of respective riparian cover classes between the sets of imagery at study sites (NS = non significant, * = P<0.05, ** = P<0.01).

| Open water comparisons per study site | | | | | | |
|---|---|---|---|---|---|---|
| Site/Year | Karkloof 1937 | Karkloof 2003 | Alb Falls 1937 | Alb Falls 2003 | Nagle 1937 | Nagle 2001 |
| *Cover Classes* | *Open water* | *Open water* | *Open water* | *Open water* | *Open water* | *Open water* |
| Mean | 19.62 | 28.21 | 25.50 | 21.60 | 27.37 | 31.80 |
| Variance | 48.27 | 83.20 | 513.97 | 145.75 | 188.80 | 118.65 |
| Observations | 10 | 10 | 12 | 12 | 10 | 10 |
| Pearson Correlation | 0.28 | | 0.65 | | 0.79 | |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | |
| Df | 9 | | 11 | | 9 | |
| t Stat | -2.77 | | 0.77 | | -1.65 | |
| P(T<=t) two-tail | 0.02 | * | 0.46 | (NS) | 0.13 | (NS) |
| t Critical two-tail | 2.26 | | 2.20 | | 2.26 | |
| Grass/Reed comparisons per study site | | | | | | |
| Site/Year | Karkloof 1937 | Karkloof 2003 | Alb Falls 1937 | Alb Falls 2003 | Nagle 1937 | Nagle 2001 |
| *Cover Classes* | *Grass/Reed* | *Grass/Reed* | *Grass/Reed* | *Grass/Reed* | *Grass/Reed* | *Grass/Reed* |
| Mean | 63.93 | 60.34 | 42.74 | 21.05 | 63.12 | 47.35 |
| Variance | 200.96 | 166.44 | 504.18 | 522.41 | 276.85 | 109.41 |
| Observations | 10 | 10 | 12 | 12 | 10 | 10 |
| Pearson Correlation | -0.12 | | -0.16 | | 0.48 | |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | |
| Df | 9 | | 11 | | 9 | |
| t Stat | 0.56 | | 2.18 | | 3.37 | |
| P(T<=t) two-tail | 0.59 | (NS) | 0.05 | * | 0.01 | ** |
| t Critical two-tail | 2.26 | | 2.20 | | 2.26 | |
| Shrub/Tree comparisons per study site | | | | | | |
| Site/Year | Karkloof 1937 | Karkloof 2003 | Alb Falls 1937 | Alb Falls 2003 | Nagle 1937 | Nagle 2001 |
| *Cover Classes* | *Shrub/Tree* | *Shrub/Tree* | *Shrub/Tree* | *Shrub/Tree* | *Shrub/Tree* | *Shrub/Tree* |
| Mean | 16.45 | 11.31 | 28.11 | 57.35 | 7.38 | 15.93 |
| Variance | 288.73 | 62.90 | 222.39 | 859.95 | 30.17 | 88.28 |
| Observations | 10 | 10 | 12 | 12 | 10 | 10 |
| Pearson Correlation | 0.39 | | 0.24 | | 0.29 | |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | |
| Df | 9 | | 11 | | 9 | |
| t Stat | 1.03 | | -3.44 | | -2.87 | |
| P(T<=t) two-tail | 0.33 | (NS) | 0.01 | ** | 0.02 | * |
| t Critical two-tail | 2.26 | | 2.20 | | 2.26 | |

From the data presented in Table B1, a selection of the key, statistically significant results are presented in Figures B1 to B3.

Figure B1: Comparison of the change over time (1937-2003) of the overall contribution of the grass/reed cover class at the Albert Falls study site.

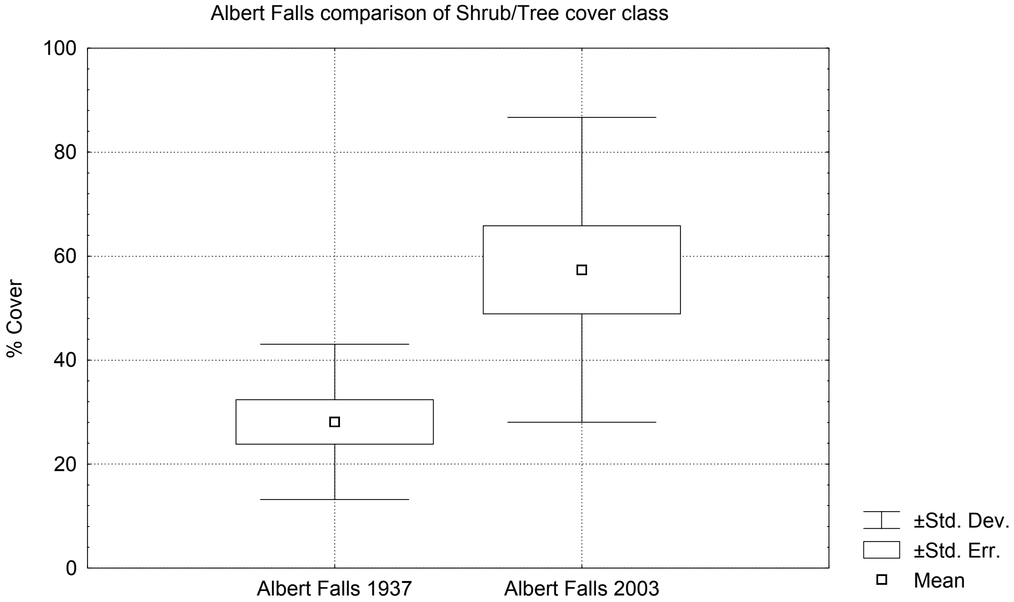


Figure B2: Comparison of the change over time (1937-2003) of the overall contribution of the shrub/tree cover class at the Albert Falls study site.

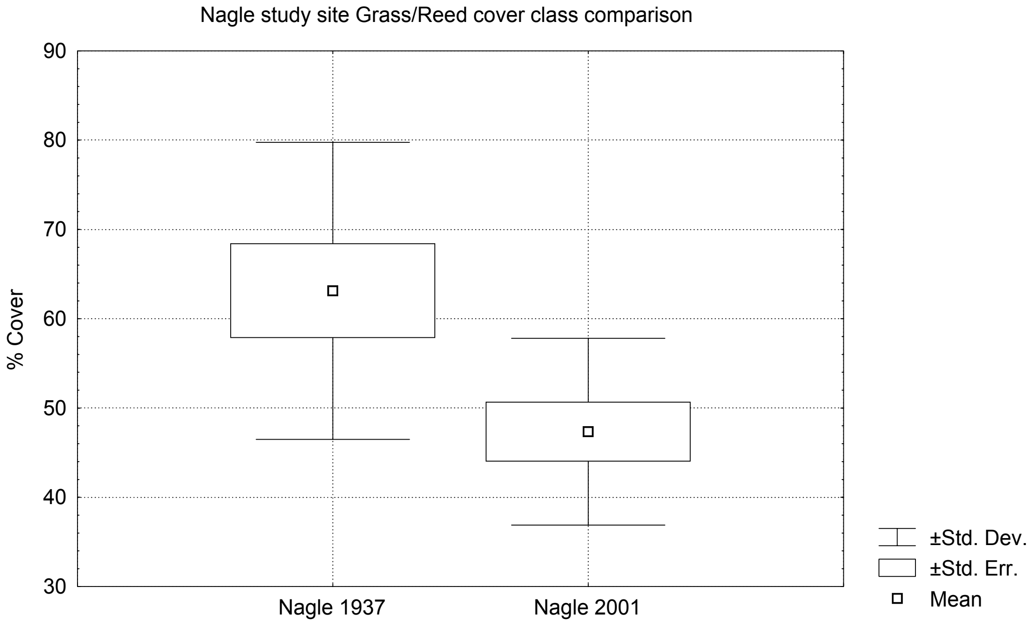


Figure B3: Comparison of the change over time (1937-2003) of the overall contribution of the grass/reed cover class at the Nagle study site.

# Chapter 7. Aquatic Macroinvertebrates in the uMngeni River

## Introduction

The “high” winter flows experienced by the uMngeni River below Albert Falls dam have already been discussed in greater detail earlier in this report. The impact of this flow regulation on the aquatic macroinvertebrates in the river was initially examined by investigating their response as measured by SASS indices, collected from a number of key sites on the Karkloof and uMngeni River systems[19].

The specific questions posed were:

- Has the impoundment at Albert Falls had an impact on the aquatic macro-invertebrate community as measured using the SASS index
- Have the generally “high” winter base flows had a significant impact on the aquatic macroinvertebrate community as measured using the SASS index?
- If the answers to the above questions were “yes”, what was the nature of the impact on the aquatic macro-invertebrate community?

## Methods and data sources

The SASS5 (and earlier versions) method of monitoring the aquatic macroinvertebrates in rivers (Dickens and Graham, 2002) has been used to monitor this river over an extended period. The invertebrates that are investigated are only those collected by the SASS method, which uses a 1mm mesh size net and concentrates on collecting benthic invertebrates off solid substrates. It also includes visible surface-dwelling invertebrates.

Three routine and long-term SASS monitoring sites were used to examine the response of macroinvertebrates to altered flow regimes associated with the Albert Falls impoundment. Figure 3.1 illustrates the locality of these study sites with Table 7.1 describing the site locality of these and further sites studied. The sites specifically examined at this stage of the study were:

1. On the Karkloof River, upstream (u/s) of its confluence with the uMngeni River and Albert Falls Dam (the routine Umgeni Water sample site RKK003 = Kk).
2. On the uMngeni River downstream (d/s) of Albert Falls Dam and immediately downstream of the confluence with the Mpolweni River (above the Wartburg road) (the routine Umgeni Water sample site RMG012 = dMp)
3. Immediately downstream of the gauging station and weir at the inflow to Nagle Dam (the Umgeni Water sample site RMG013 = Ngl)

The first site constituted a control or reference site, as it was largely unregulated and with no significant impoundments along its length. The second site was below the Albert Falls Dam impoundment, and hence likely to be impacted by the effects of regulated flows, but with the ameliorating flows of the unregulated Mpolweni River influencing the site, whilst the last study site was just above the Nagle Dam impoundment and furthest away from the Albert Falls impoundment. This site was potentially least impacted by the flow regulation as tributaries and the incremental flows between Albert Falls and Nagle (most notably the

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[19] This WRC study initiated and collected further aquatic macro-invertebrate data from a number of other sample sites for the duration of the study and which were reported on in subsequent sections of this report.

Mpolweni River) would have had a chance to restore something of the natural flow regime to the lower uMngeni River, before it enters Nagle Dam.

This investigation was undertaken by examining long-term SASS records available from the Umgeni Water database for each of the study sites. The database consisted of a combination of monthly and quarterly data records covering the period February 1993 to March 2006 (summarised data available in Annexure C (at the end of this chapter))

Table 7.1: Summary of names and localities of aquatic macroinvertebrate monitoring sites (site codes in brackets used in subsequent Figures) – see Figure 3.1

| New (routine) Umgeni Water sample point code | Site Description (and site codes used in subsequent Figures) | Distance downstream of Albert Falls Dam (km) | Latitude (decimal degrees) | Longitude (decimal degrees) |
|---|---|---|---|---|
| RKK003 | Karkloof u/s of uMngeni confluence (Kk) | N/A | -29.443833 | 30.310833 |
| RMG010 | uMngeni downstream of Albert Falls Dam (Alb) | 0.3 | -29.432889 | 30.432167 |
| RMG011 | uMngeni u/s of Mpolweni confluence (uMp) | 4.0 | -29.444667 | 30.446667 |
| RMG012 | uMngeni d/s of Mpolweni confluence (dMp) | 14.8 | -29.464583 | 30.461972 |
| RMG013 | uMngeni weir u/s of Nagle Dam (Ngl) | 52.5 | -29.575000 | 30.603333 |

**Data analysis**

Initial investigations simply looked to see if there were statistical differences between the key SASS indices that make up the SASS method i.e. Number of Taxa, Average Score per Taxon (ASPT) and SASS Score (Dickens & Graham, 2002) between monitored sites. Simple univariate statistical tests (*t* Tests) were undertaken to test these differences.

Closer examination of the data indicated that a reduced data set of paired samplings represented an example of "Student's" method of paired differences. In this instance the one member of the pair occurred when a SASS sample was collected and analysed at the control/reference site on the Karkloof at virtually the same time as either of the two sites below Albert Falls Dam (the corresponding pair). This has statistically useful advantages over unpaired data in that there is greater homogeneity within pairs than between pairs, and as such the standard errors of the difference of the means (or of the mean difference) will be reduced as compared to a design without pairing (Rayner, 1967). Generally a statistical design with pairing is therefore the more efficient. Appropriate statistical analyses were therefore conducted and reported accordingly.

**Results**

Results of the analyses, initially on the unpaired (Table 7.2) and then paired (Tables 7.3 & 7.4) data, are presented in the following tables and figures. The data was also aggregated into winter and summer seasonal data to further refine the investigation.

Table 7.2: Summary of the key statistics, Student's paired *t* test, and statistical significance of the results for the comparisons of historical SASS indices at the Karkloof control (site RKK003 = Kk), uMngeni d/s Mpolweni confluence (site RMG012 = dMp) and uMngeni u/s Nagle Dam (site RMG013 = Ngl) study sites (<u>unpaired data</u>) (NS = non significant, * = P<0.05, ** = P<0.01).

| *SASS index* | *Number of Taxa* | | | | *ASPT* | | | | *SASS Score* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Site Kk* | *Site dMp* | *Site Kk* | *Site Ngl* | *Site Kk* | *Site dMp* | *Site Kk* | *Site Ngl* | *Site Kk* | *Site dMp* | *Site Kk* | *Site Ngl* |
| Mean | 19.32 | 18.95 | 19.32 | 19.42 | 7.36 | 6.53 | 7.36 | 6.81 | 142.22 | 124.35 | 142.22 | 131.85 |
| Variance | 18.45 | 32.40 | 18.45 | 26.92 | 0.54 | 1.22 | 0.54 | 0.60 | 1118.45 | 1904.72 | 1118.45 | 1390.75 |
| Observations (n) | 37 | 34 | 37 | 40 | 37 | 34 | 37 | 40 | 37 | 34 | 37 | 40 |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| df | 61 | | 74 | | 57 | | 75 | | 62 | | 75 | |
| t Stat | 0.3086 | | -0.0869 | | 3.6831 | | 3.1770 | | 1.9235 | | 1.2858 | |
| P(T<=t) two-tail | 0.7587 | (NS) | 0.9310 | (NS) | 0.0005 | ** | 0.0022 | ** | 0.0590 | (NS) | 0.2025 | (NS) |
| t Critical two-tail | 1.9996 | | 1.9925 | | 2.0025 | | 1.9921 | | 1.9990 | | 1.9921 | |

Table 7.3: Summary of the key statistics, Student's paired *t* test, and statistical significance of the results for the comparisons of historical SASS indices at the Karkloof River control (site RKK003 = Kk) and uMngeni d/s Mpolweni confluence (site RMG012 = dMp) study sites (paired data) (NS = non significant, * = P<0.05, ** = P<0.01).

| | *Kk No Taxa* | *dMp No Taxa* | *Kk ASPT* | *dMp ASPT* | *Kk SASS* | *dMp SASS* |
|---|---|---|---|---|---|---|
| Mean | 19.38 | 19.18 | 7.36 | 6.60 | 142.59 | 126.28 |
| Variance | 22.32 | 35.05 | 0.50 | 0.89 | 1269.04 | 1705.99 |
| Observations (n) | 29 | 29 | 29 | 29 | 29 | 29 |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | |
| df | 28 | | 28 | | 28 | |
| t Stat | 0.1562 | | 3.4231 | | 1.7329 | |
| P(T<=t) two-tail | 0.8769 | (NS) | 0.0019 | ** | 0.0941 | (NS) |
| t Critical two-tail | 2.0484 | | 2.0484 | | 2.0484 | |

Table 7.4: Summary of the key statistics, Student's paired *t* test, and statistical significance of the results for the comparisons of historical SASS indices at the Karkloof River control (site RKK003 = Kk) and uMngeni u/s Nagle Dam (site RMG013 = Ngl) study sites (paired data) (NS = non significant, * = P<0.05, ** = P<0.01).

| | *Kk No Taxa* | *Ngl No Taxa* | *Kk ASPT* | *Ngl ASPT* | *Kk SASS* | *Ngl SASS* |
|---|---|---|---|---|---|---|
| Mean | 19.41 | 19.54 | 7.39 | 6.86 | 143.63 | 133.06 |
| Variance | 19.73 | 31.41 | 0.44 | 0.50 | 1177.15 | 1496.77 |
| Observations (n) | 32 | 32 | 32 | 32 | 32 | 32 |
| Hypothesized Mean Difference | 0 | | 0 | | 0 | |
| df | 31 | | 31 | | 31 | |
| t Stat | -0.1361 | | 3.6052 | | 1.8212 | |
| P(T<=t) two-tail | 0.8927 | (NS) | 0.0011 | ** | 0.0782 | (NS) |
| t Critical two-tail | 2.0395 | | 2.0395 | | 2.0395 | |

From the data presented in Table 7.2, a graphical representation of some of the results are presented in Figures 7.1 to 7.3.

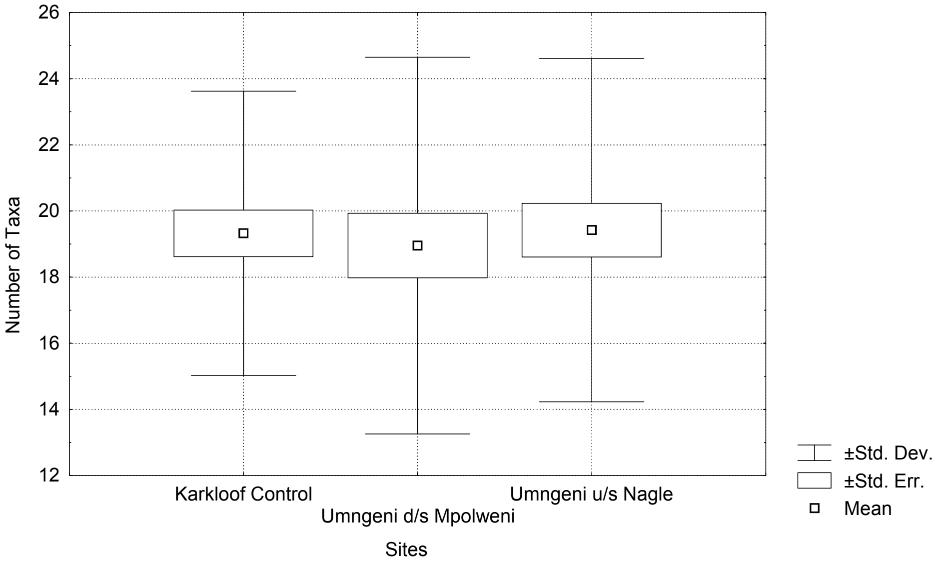

Figure 7.1; Comparison of the number of taxa (1993-2006) for historical unpaired data examined.

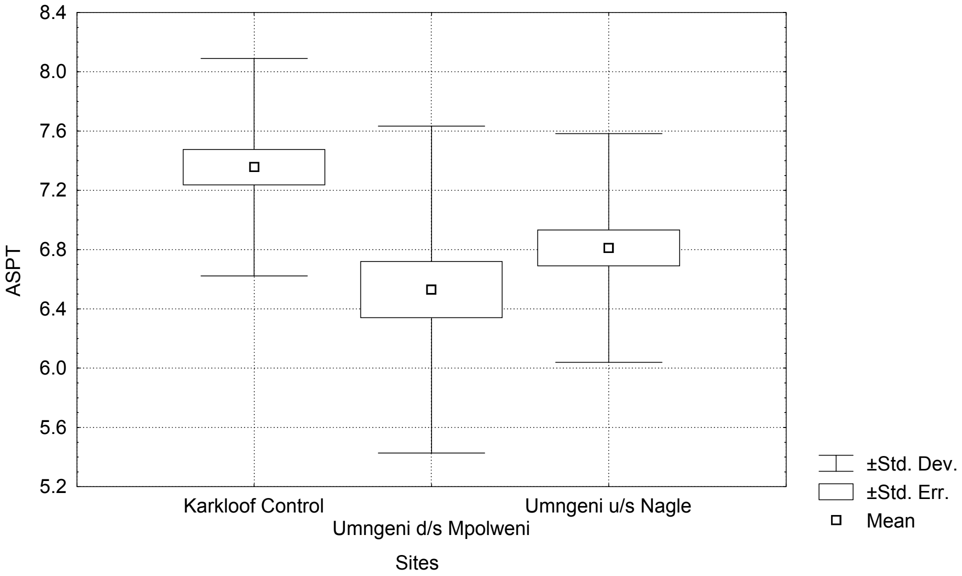

Figure 7.2: Comparison of the ASPT (1993-2006) for historical unpaired data examined.

As previously discussed, the traditional operating rule for Albert Falls Dam has been one of high "un-seasonal" winter flow releases to the uMngeni River below the dam. This therefore formed a central question for this study, viz:

- Have these generally "high" winter base flows had a significant impact on the macroinvertebrate community as measured by historical SASS indices?

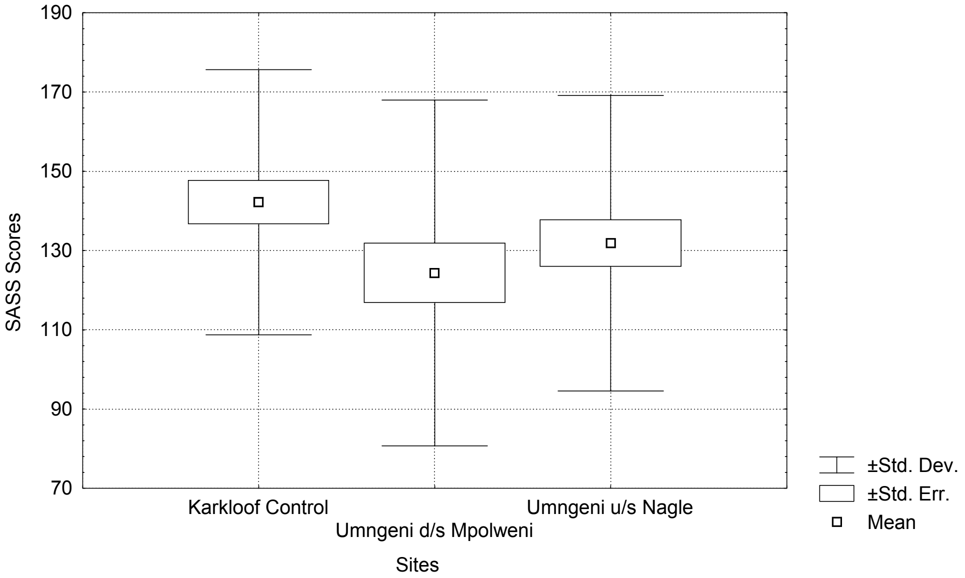

Figure 7.3: Comparison of the SASS scores (1993-2006) for historical unpaired data examined.

To examine this further the historical SASS data was aggregated into those measurements made during the summer, and those made during the un-seasonal "high" winter flows. A visual inspection of the data (Figures 7.4 to 7.6) appears to indicate some seasonal response with the changes in indices during winter, between the control site on the Karkloof River and the downstream sites below Albert Falls Dam, apparently more pronounced than the corresponding summer data. This was particularly pronounced for the comparison of the winter data between the Karkloof River (Kk) and the uMngeni River site downstream of the confluence with the Mpolweni River (dMp) (Figures 7.4 & 7.5).

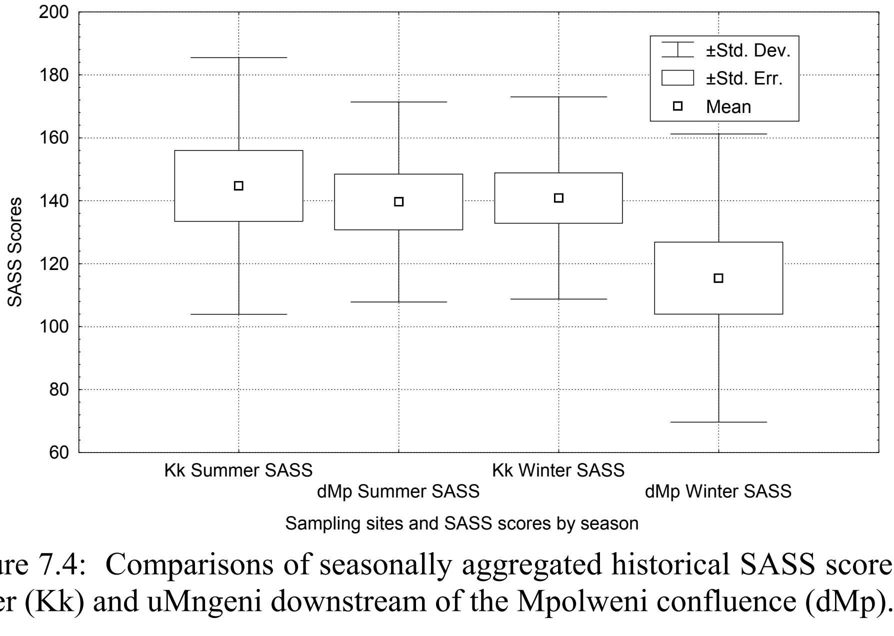

Figure 7.4: Comparisons of seasonally aggregated historical SASS scores for the Karkloof River (Kk) and uMngeni downstream of the Mpolweni confluence (dMp).

Although the contrast was not as pronounced within the ASPT index for these same site comparisons, it was still evident as shown in Figure 7.5.

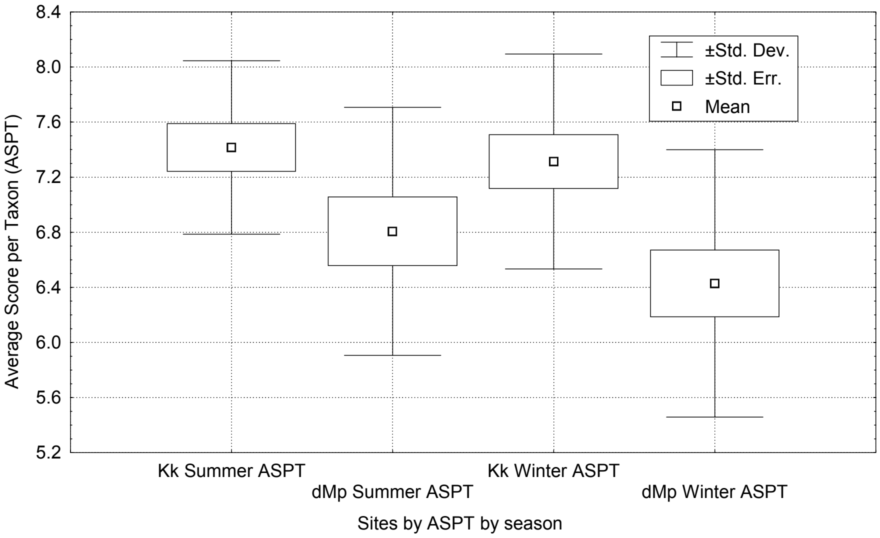

Figure 7.5; Comparisons of seasonally aggregated historical SASS ASPT scores for the Karkloof River (Kk) and uMngeni downstream of the Mpolweni confluence (dMp).

However by the time the river has reached Nagle Dam the seasonal contrasts within the historical data appear to be less obvious (see Figure 7.6).

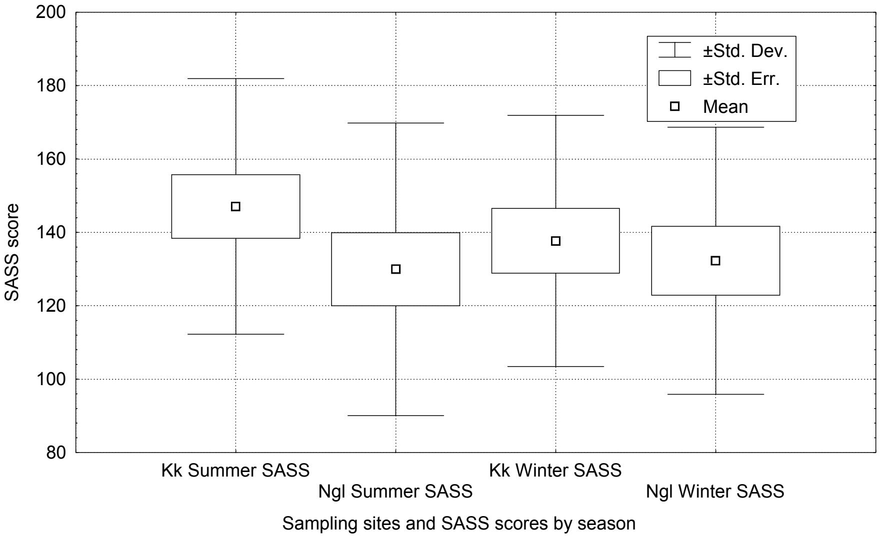

Figure 7.6: Comparisons of seasonally aggregated historical SASS scores for the Karkloof River (Kk) and uMngeni upstream of Nagle Dam (Ngl).

Interestingly, for most sites monitored, the summer results (SASS indices) were higher (suggesting the river to be in better condition) than the corresponding winter results.

To clarify the significance of these seasonally aggregated observations the historical data was reanalysed using the Wilcoxon Matched Pairs Test. This test is the non-parametric equivalent of the Student's Paired *t* Test and was employed because of the lower sample sizes subsequent to the historical data being divided on a seasonal basis. This test was used to avoid violation of some of the assumptions of the statistically more powerful parametric equivalent. As previously mentioned, the statistical design with pairing (as conducted here) is more efficient than without pairing.

The results (summarised in Table 7.5 below) show that in both site comparisons made (Karkloof River vs uMngeni downstream of Mploweni, and Karkloof River vs uMngeni upstream of Nagle Dam) there were statistically significant differences ($p<0.05$) between the SASS ASPT indices in both summer and winter. Furthermore for the Karkloof River vs uMngeni downstream of Mpolweni confluence site (closest to Albert Falls Dam) comparison, there was a non-significant difference between the paired SASS score data during summer, but in winter this difference was only marginally statistically significant ($p<0.1$). However, by time the river has travelled down to Nagle Dam this difference has swung the other way around, i.e. the summer SASS score differences are marginally significant ($p<0.06$) with the winter differences clearly not significantly different. The reasons for this could be speculated as follows:

The high and un-seasonal winter base flows below Albert Falls Dam are having an impact on the SASS scores during the winter months but the incremental summer flows from the Mpolweni (and other rivers between Albert Falls and Nagle Dams) are ameliorating this impact during the summer months. Once the river has reached Nagle Dam during winter the impact of the high winter base flows have been moderated by biophysical processes in the river and are hence not showing up as significant, whilst on the other hand summer flushing from polluted side tributaries (Mpolweni and feedlots around the upper/middle reaches of the river) could be influencing water quality at the lowermost site on the uMngeni.

Table 7.5: Summary of Wilcoxon Matched Pairs Tests for historical SASS indices partitioned into seasonal data sets with respective site comparisons

| **Site comparisons** | **Season** | **Index** | **Valid N** | **T** | **Z** | **p-level** | **Significance** |
|---|---|---|---|---|---|---|---|
| Karkloof River vs uMngeni downstream of Mpolweni confluence | Summer | SASS Score | 13 | 38.5 | 0.4892 | 0.62 | NS |
| | Winter | SASS Score | 16 | 36.0 | 1.6547 | 0.10 | NS |
| | Summer | ASPT | 13 | 14.0 | 2.2014 | 0.03 | * ($p<0.05$) |
| | Winter | ASPT | 16 | 28.0 | 2.0684 | 0.04 | * ($p<0.05$) |
| | Summer | No Taxa | 13 | 28.5 | 0.8237 | 0.41 | NS |
| | Winter | No Taxa | 16 | 55.5 | 0.6464 | 0.52 | NS |
| Karkloof River vs uMngeni upstream of Nagle Dam | Summer | SASS Score | 16 | 32.0 | 1.8615 | 0.06 | NS |
| | Winter | SASS Score | 15 | 39.0 | 0.8475 | 0.40 | NS |
| | Summer | ASPT | 16 | 22.0 | 2.3786 | 0.02 | * ($p<0.05$) |
| | Winter | ASPT | 15 | 21.0 | 2.2151 | 0.03 | * ($p<0.05$) |
| | Summer | No Taxa | 16 | 51.0 | 0.5112 | 0.61 | NS |
| | Winter | No Taxa | 15 | 48.5 | 0.6532 | 0.51 | NS |

**Discussion**

Results of the analysis on the historical unpaired data (Table 7.2) indicates that it is only on the basis of comparisons between the SASS ASPT index, that there is a statistically significant difference between sites. In all cases the control site on the Karkloof River (RKK003) is found to be statistically significantly different ($p<0.01$) from both the uMngeni downstream of the Mpolweni confluence (RMG012) and the uMngeni upstream of Nagle Dam (RMG013). This is illustrated in Figure 7.2. The same picture emerges with the analysis of the paired data (Table 7.5 and Figure 7.5). In all of these instances the mean of the SASS ASPT index for the control site on the Karkloof River is always higher than that measured on the uMngeni River sites. Interestingly too is the fact that of the two uMngeni River sites, the lowermost site (with the greatest chance of recovery from the impacts of the dam regulated flows) has the higher ASPT index (most similar to the control site on the Karkloof River).

Although not strictly statistically different, this pattern also appears to be consistent for the other SASS indices, particularly the SASS scores. In all cases the SASS scores are lower for all sites on the uMngeni River below the impoundment with the site closest to the impoundment (RMG012) apparently more impacted than that furthest from the impoundment (RMG013), where incremental flows from tributaries downstream of Albert Falls dam would have had a chance to restore something of the natural flow regime and water quality in the river.

Previous work, determining the main areas of variability associated with the SASS5 method (Dickens & Graham, 2002), had shown that the ASPT index was the most consistent and repeatable measure of the three available indices (SASS score, ASPT and Number of Taxa). This consistency gave greater confidence that the differences between sites noted in this study were therefore reflecting some "real" differences between the historically monitored sites.

Examining some of the more subtle differences emerging in response to seasonal variations between historically monitored sites showed:

- That in most instances the summer "condition" of the river at all sites monitored was better compared to the winter "condition".
- The site closest to the Albert Falls Dam was most impacted during winter flows. This could be attributable to poor water quality due to a concentration effect (lower dilution of pollutants from the Mpolweni River and feedlots in the upper to middle reaches of the uMngeni River). Alternatively it could be due to the impact of the unseasonal "high" winter base flows from Albert Falls to Nagle Dams experienced by this river – the original thesis for this study.

These results may also be considered in terms of their relation to the KZN ecoregions level II benchmarks using SASS 5 ASPT scores. The benchmark scores (see Table 7.6) indicate the class boundaries and hence the class of the river as defined by the SASS ASPT score. In all instances the Karkloof River sites were in a Natural class (ASPT >7) whilst the other sites were in a Good class (ASPT 6-7) (Tables 7.3 & 7.4 vs Table 7.6). This suggests that even though there were some apparent impacts measured downstream of Albert Falls, these impacts were "not that bad".

Table 7.6: KZN Ecoregion level II benchmark SASS5 ASPT scores used to define class boundaries

| **Class** | | **Ecoregion falling within the study site** |
|---|---|---|
| | | **Savannah Streams** |
| Natural | > | 7.0 |
| Good | > | 6.0 |
| Fair | > | 5.0 |
| Poor | < | 5.0 |

Hence on the basis of the historical data alone there appeared to be *prima facie* evidence for an apparent impact of the Albert Falls impoundment on the macroinvertebrates in the uMngeni River. This initiated a more comprehensive placement of monitoring sites and study to determine the nature of this impact.

## Analysis of SASS indices and macroinvertebrate taxonomic data

### Introduction

In the previous section, the analysis of the long-term SASS monitoring data for a number of sites below the Albert Falls impoundment, compared to the un-impounded Karkloof River control site, appeared to indicate that there were significant changes, albeit small, associated with the impoundment. To examine this in more detail this project investigated SASS indices and the accompanying family level data on aquatic macroinvertebrate taxa. Furthermore, and where possible, the aquatic macroinvertebrates collected as part of this investigation were identified to the highest practicable level of taxonomic resolution to further investigate the impact of the flows on the invertebrates.

The specific questions investigated remained similar to those posed in the previous section, viz.:

- Has the impoundment at Albert Falls had an impact on the macroinvertebrate community as measured by SASS indices?
- If the answer to the above question was "yes", what was the nature of this impact on the macroinvertebrate community?
- Does analysis of SASS index data reveal as much information as analysis of the component taxonomic data?

### Methods and data sources

In addition to the three routinely and historically monitored SASS study sites already mentioned, two additional sites were monitored. Figure 3.1 illustrates the locality of all study sites with Table 7.1 summarising the locality, names and distance downstream of Albert Falls Dam of all of the study sites. The additional sites examined at this level of the study were:

- On the uMngeni River immediately downstream of the waterfall below Albert Falls Dam and above the routine DWAF gauging weir (the Umgeni Water sample site RMG010 = Alb)
- On the uMngeni River below Albert Falls dam and immediately upstream of the Greytown Road bridge (the Umgeni Water sample site RMG011 = uMp) and upstream of the uMngeni/Mpolweni confluence.

As previously indicated the Karkloof River site constituted a control or reference site, as it was within a nature reserve, unregulated and with no significant impoundments along its length. Site RMG010 was immediately below the Albert Falls Dam impoundment, and hence likely to be most impacted by the effects of regulated flows, whilst site RMG011 was above the Mpolweni/uMngeni confluence. Other than the control site on the Karkloof River, the most downstream site (site RMG013) was also potentially least impacted by the flow regulation as tributaries and their incremental flows between Albert Falls and Nagle (most notably the Mpolweni River) would have had a chance to restore something of the natural flow regime to the lower uMngeni River, before it enters Nagle Dam. However confounding this picture of flow regulation and its potential impacts on the aquatic biota was the relatively intense feedlot and chicken farming in the vicinity of the Greytown Road, downstream of Albert Falls Dam. Runoff and nutrient rich pollutants emerging from these farms were noted as contributing significantly to the nutrients in the uMngeni River below this site (see Chapter 5).

The initial sampling was conducted in March 2001, with a delay during 2002 and some of 2003 due to uncharacteristic flow patterns to accommodate repair work on Nagle Dam (see Table 3.3 and Figure 7.7 of the project sequence). The field work for this project was completed in the winter of 2004. All sampling dates per sample site are as indicated in Table 7.7.

Table 7.7: Sample dates for SASS5 sampling and macroinvertebrate collections

| **Karkloof u/s of uMngeni confluence (RKK003)** | | **uMngeni downstream of Albert Falls Dam (RMG010)** | | **uMngeni u/s of Mpolweni confluence (RMG011)** | | **uMngeni d/s of Mpolweni confluence (RMG012)** | | **uMngeni weir u/s of Nagle Dam (RMG013)** | |
|---|---|---|---|---|---|---|---|---|---|
| | 19/03/2001 | | 08/03/2001 | | 09/03/2001 | | 09/03/2001 | | 13/03/2001 |
| | 13/08/2003 | | 11/08/2003 | | 12/08/2003 | | 12/08/2003 | | 19/08/2003 |
| | 10/10/2003 | | 13/10/2003 | | 13/10/2003 | | 15/10/2003 | | 14/10/2003 |
| | 30/03/2004 | | 02/03/2004 | | 01/03/2004 | | 01/03/2004 | | 01/03/2004 |
| | 21/06/2004 | | 17/06/2004 | | 18/06/2004 | | 17/06/2004 | | 21/06/2004 |

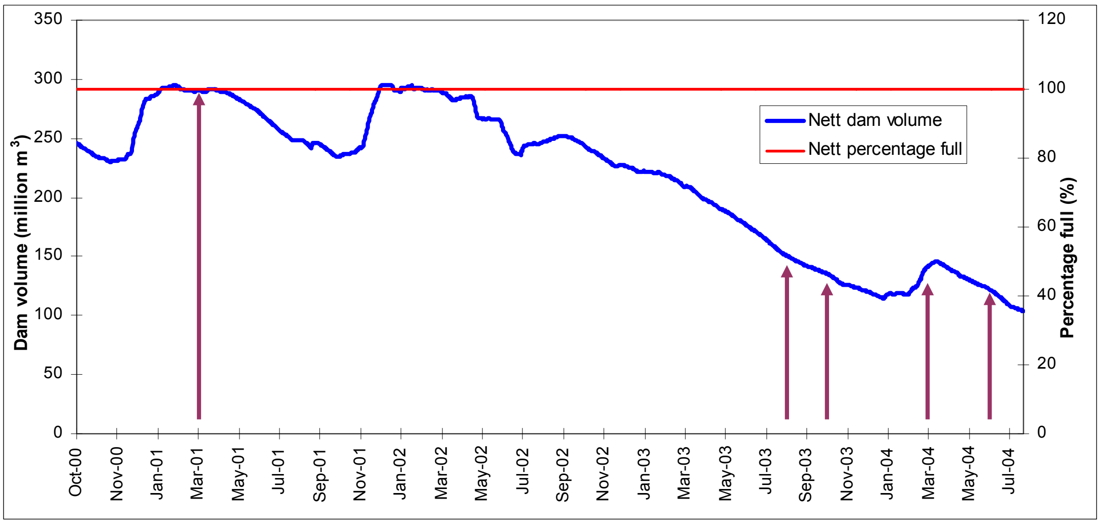

Figure 7.7: Illustration of the spilling status of Albert Falls Dam for the duration of sampling (vertical arrows) for this project.

At each site sampled a rapid bioassessment was conducted using the form of a full SASS5 analysis (Dickens & Graham, 2002) but with all aquatic macroinvertebrates collected, preserved and further analysed to the highest level of taxonomic resolution practically possible by the macroinvertebrate specialists at the Albany Museum, Grahamstown. In most instances this resulted in a species level of identification but for some taxa this was not possible. The full list of taxa identified at respective sites is summarised in Annexure C (at the end of this chapter). Supplementary collections of Simuliids and other chance organisms were made in the field by hand picking from appropriate instream substrates. This was to ensure that the Simuliids were adequately represented in the invertebrate material as the SASS collection protocol does not do so effectively. It also presented a chance to more carefully collect some of the more delicate invertebrates (e.g. mayflies) which are subject to damage when collected in the bulk SASS sample.

As part of this project a suite of water quality determinants were also collected in order to characterise the changes to the river water in response to the high winter flow releases. The results of that analysis are presented in Chapter 5. Of direct significance though to the analysis of the aquatic macroinvertebrates was the physico-chemistry and flow conditions at sites sampled. The full suite of available water quality determinants and supplementary physical measures of the environment were summarised to reflect the dominant physico-chemical conditions in the river in the month prior to the biological (SASS) sampling (Tables 7.8 & 7.9). In most instances this involved calculating the maximum "concentration" of the respective determinants, but in others cases the minimum "concentration" was potentially biologically more meaningful, e.g. minimum dissolved oxygen concentration. The unionised (free) ammonia concentration was also calculated from the corresponding water temperature, pH and total ammonia concentration for each site. It is generally accepted that in aquatic ecosystems it is the unionised ammonia concentration that is the most toxic to aquatic life.

Table 7.8: Water quality and flow determinants measured at sites sampled

| **Determinant name** | **Short name** | **Units** |
|---|---|---|
| Dam spilling status | Spilling | 1=Y, 0=N |
| Dam stratification status | Stratified | 1=Y, 0=N |
| River flow/discharge | River Flow | $m^3/s$ |
| Flow variability (Standard Deviation) | FlowSD | |
| Flow variability (Coefficient of Variation) | FlowCV | |
| Algal Counts | Algae | counts/mL |
| Ammonia | NH3 | mg/L |
| Ammonia Free (unionised) | NH3_Fr | mg/L |
| Conductivity | Cond | mS/m |
| Dissolved Oxygen | DO | mg/L |
| *E. coli* | *E.coli* | counts/100 mL |
| Iron | Fe | mg/L |
| Manganese | Mn | mg/L |
| Maximum pH | Mx pH | |
| Minimum pH | Mn pH | |
| Nitrate | NO3 | mg/L |
| Saturated Dissolved Oxygen | %SatDO | % |
| Soluble Reactive Phosphate | SRP | ug/L |
| Suspended Solids | SS | mg/L |
| Temperature | Temp | degrees |
| Total Organic Carbon | TOC | mg/L |
| Total Phosphate | TP | ug/L |
| Turbidity | Turbid | NTU |

Table 7.9  Summarised water quality and flow data measured in the month prior to biological sampling

| UW Smpl Pt | Sample Nm | Sample Date | Season | Spill. | Strat. | Flow | Flow SD | Flow CV | Mn | NH3 | NH3 _Fr | NO3 | SRP | SS | TOC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | 1=Y, 0=N | 1=Y, 0=N | $m^3/s$ |  |  | mg/ L | mg/ L | mg/L | mg/ L | ug/L | mg/ L | mg/ L |
| RKK003 | Kk | 19/03/01 | Summer | 1 | 0 | 3.46 | 2.08 | 59.94 | 0.11 | 0.07 | 0.0008 | 0.6 | 12.0 | 47.1 | 2.7 |
| RKK003 | Kk | 13/08/03 | Winter | 1 | 0 | 0.33 | 0.07 | 21.10 | 0.01 | 0.09 | 0.0008 | 0.4 | 7.0 | 0.0 | 1.3 |
| RKK003 | Kk | 10/10/03 | Summer | 1 | 0 | 0.57 | 0.17 | 29.86 | 0.02 | 0.03 | 0.0007 | 0.3 | 20.7 | 5.6 | 2.5 |
| RKK003 | Kk | 30/03/04 | Summer | 1 | 0 | 5.14 | 4.53 | 88.13 | 0.11 | 0.12 | 0.0014 | 0.3 | 13.8 | 15.4 | 2.3 |
| RKK003 | Kk | 21/06/04 | Winter | 1 | 0 | 0.48 | 0.06 | 12.68 | 0.02 | 0.09 | 0.0004 | 0.4 | 54.3 | 0.0 | 2.9 |
| RMG010 | Alb | 08/03/01 | Summer | 1 | 1 | 16.12 | 7.01 | 43.49 | 0.04 | 0.14 | 0.0020 | 0.1 | 7.8 | 15.9 | 3.9 |
| RMG010 | Alb | 11/08/03 | Winter | 0 | 0 | 6.13 | 0.39 | 6.40 | 0.04 | 0.08 | 0.0013 | 0.1 | 9.4 | 9.6 | 2.7 |
| RMG010 | Alb | 13/10/03 | Summer | 0 | 1 | 3.83 | 0.26 | 6.70 | 0.07 | 0.12 | 0.0006 | 0.1 | 9.9 | 15.6 | 3.1 |
| RMG010 | Alb | 02/03/04 | Summer | 0 | 1 | 3.02 | 0.54 | 18.00 | 0.16 | 0.09 | 0.0035 | 0.4 | 7.6 | 25.6 | 3.4 |
| RMG010 | Alb | 17/06/04 | Winter | 0 | 0 | 4.35 | 0.93 | 21.55 | 0.11 | 0.06 | 0.0005 | 0.2 | 14.3 | 14.8 | 3.4 |
| RMG011 | uMp | 09/03/01 | Summer | 1 | 1 | 16.12 | 7.01 | 43.49 | 0.24 | 0.15 | 0.0024 | 0.2 | 13.2 | 21.7 | 3.1 |
| RMG011 | uMp | 12/08/03 | Winter | 0 | 0 | 6.13 | 0.39 | 6.40 | 0.05 | 0.12 | 0.0013 | 0.1 | 4.8 | 10.0 | 2.4 |
| RMG011 | uMp | 13/10/03 | Summer | 0 | 1 | 3.83 | 0.26 | 6.70 | 0.06 | 0.06 | 0.0013 | 0.1 | 4.0 | 13.2 | 3.0 |
| RMG011 | uMp | 01/03/04 | Summer | 0 | 1 | 3.02 | 0.54 | 18.00 | 0.24 | 0.19 | 0.0019 | 0.2 | 14.7 | 16.3 | 2.9 |
| RMG011 | uMp | 18/06/04 | Winter | 0 | 0 | 4.35 | 0.93 | 21.55 | 0.08 | 0.07 | 0.0006 | 0.2 | 28.6 | 0.0 | 3.1 |
| RMG012 | dMp | 09/03/01 | Summer | 1 | 1 | 19.02 | 8.54 | 44.90 | 0.06 | 0.10 | 0.0010 | 0.4 | 14.1 | 21.5 | 3.9 |
| RMG012 | dMp | 12/08/03 | Winter | 0 | 0 | 6.25 | 0.47 | 7.58 | 0.06 | 0.02 | 0.0002 | 0.8 | 20.0 | 16.1 | 3.8 |
| RMG012 | dMp | 15/10/03 | Summer | 0 | 1 | 3.99 | 0.30 | 7.42 | 0.09 | 0.06 | 0.0004 | 0.2 | 5.1 | 11.6 | 3.1 |
| RMG012 | dMp | 01/03/04 | Summer | 0 | 1 | 7.35 | 3.82 | 52.01 | 0.12 | 0.25 | 0.0029 | 4.1 | 549. 0 | 14.4 | 3.9 |
| RMG012 | dMp | 17/06/04 | Winter | 0 | 0 | 4.51 | 0.95 | 21.06 | 0.08 | 0.07 | 0.0005 | 0.2 | 18.4 | 11.5 | 2.9 |
| RMG013 | Ngl | 13/03/01 | Summer | 1 | 1 | 16.47 | 7.57 | 45.97 | 0.09 | 0.08 | 0.0012 | 0.2 | 10.9 | 21.1 | 4.6 |
| RMG013 | Ngl | 19/08/03 | Winter | 0 | 0 | 6.07 | 0.61 | 10.10 | 0.07 | 0.05 | 0.0022 | 0.1 | 16.3 | 13.6 | 3.3 |
| RMG013 | Ngl | 14/10/03 | Summer | 0 | 1 | 4.21 | 0.23 | 5.60 | 0.10 | 0.06 | 0.0008 | 0.1 | 10.0 | 18.0 | 2.8 |
| RMG013 | Ngl | 01/03/04 | Summer | 0 | 1 | 7.69 | 3.93 | 51.17 | 0.16 | 0.11 | 0.0028 | 0.6 | 30.1 | 32.0 | 4.1 |
| RMG013 | Ngl | 21/06/04 | Winter | 0 | 0 | 4.70 | 1.15 | 24.41 | 0.05 | 0.11 | 0.0015 | 0.2 | 10.1 | 12.4 | 2.8 |

Table 7.9 Summarised water quality and flow data measured in the month prior to biological sampling (continued)

| UW Smpl Pt | Sampl Nm | Sample Date | TP | Temp | Turbid | Mx pH | Mn pH | %Sat DO | Algae | Cond | DO | E.coli | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ug/L | degrees | NTU | | | % | Counts | mS/m | mg/L | counts/100mL | mg/L |
| RKK003 | Kk | 19/03/01 | 67.0 | 23.0 | 66.0 | 7.5 | 7.2 | 1.29 | 279 | 6.9 | 7.5 | 590 | 0.95 |
| RKK003 | Kk | 13/08/03 | 15.3 | 12.0 | 2.7 | 8.3 | 8.3 | 3.69 | 250 | 9.4 | 7.8 | 62 | 0.21 |
| RKK003 | Kk | 10/10/03 | 21.9 | 19.9 | 3.4 | 7.9 | 7.2 | 2.31 | 274 | 9.2 | 7.9 | 140 | 0.23 |
| RKK003 | Kk | 30/03/04 | 28.7 | 21.9 | 18.0 | 7.9 | 7.2 | 1.19 | 279 | 6.6 | 8.9 | 284 | 0.94 |
| RKK003 | Kk | 21/06/04 | 55.2 | 17.1 | 5.2 | 7.7 | 7.2 | 0.53 | 251 | 9.3 | 7.8 | 870 | 0.45 |
| RMG010 | Alb | 08/03/01 | 43.9 | 24.5 | 15.3 | 7.6 | 7.1 | 1.78 | 8298 | 7.6 | 7.1 | 82 | 0.31 |
| RMG010 | Alb | 11/08/03 | 30.3 | 15.6 | 8.5 | 7.8 | 7.4 | 1.65 | 968 | 7.8 | 7.9 | 90 | 0.24 |
| RMG010 | Alb | 13/10/03 | 20.0 | 18.2 | 17.3 | 7.8 | 6.2 | 2.12 | 2915 | 8.1 | 7.8 | 240 | 0.50 |
| RMG010 | Alb | 02/03/04 | 23.6 | 24.0 | 36.0 | 7.9 | 7.3 | 3.93 | 480 | 8.7 | 7.6 | 158 | 0.75 |
| RMG010 | Alb | 17/06/04 | 29.8 | 17.1 | 15.3 | 7.5 | 7.2 | 0.78 | 6470 | 8.6 | 8.3 | 30 | 0.45 |
| RMG011 | uMp | 09/03/01 | 25.0 | 23.6 | 25.7 | 7.6 | 7 | 1.57 | 928 | 8.2 | 7.4 | 330 | 1.47 |
| RMG011 | uMp | 12/08/03 | 17.7 | 13.0 | 7.2 | 7.7 | 7.3 | 1.06 | 5761 | 7.9 | 7.2 | 400 | 0.27 |
| RMG011 | uMp | 13/10/03 | 24.6 | 18.2 | 12.2 | 7.9 | 7.2 | 2.14 | 2255 | 7.9 | 8.0 | 450 | 0.37 |
| RMG011 | uMp | 01/03/04 | 34.0 | 23.9 | 20.3 | 7.8 | 7.6 | 1.02 | 928 | 8.4 | 7.6 | 257 | 1.47 |
| RMG011 | uMp | 18/06/04 | 204.0 | 18.5 | 15.8 | 7.6 | 7.5 | 0.92 | 7356 | 8.6 | 7.9 | 310 | 0.46 |
| RMG012 | dMp | 09/03/01 | 54.1 | 23.1 | 17.0 | 7.5 | 6.9 | 1.39 | 677 | 8.9 | 7.3 | 480 | 1.12 |
| RMG012 | dMp | 12/08/03 | 44.5 | 13.1 | 13.1 | 7.7 | 7.2 | 1.11 | 2209 | 8.7 | 8.7 | 560 | 0.46 |
| RMG012 | dMp | 15/10/03 | 23.1 | 18.7 | 9.0 | 7.4 | 6.5 | 0.64 | 2507 | 8.2 | 8.2 | 1290 | 0.37 |
| RMG012 | dMp | 01/03/04 | 771.6 | 24.9 | 19.0 | 7.8 | 7.6 | 0.93 | 677 | 16.2 | 7.1 | 1492 | 1.12 |
| RMG012 | dMp | 17/06/04 | 37.7 | 17.6 | 15.7 | 7.6 | 7.4 | 0.77 | 5419 | 8.8 | 7.8 | 500 | 0.44 |
| RMG013 | Ngl | 13/03/01 | 27.8 | 25.9 | 29.5 | 7.6 | 7.5 | 1.86 | 1822 | 9.5 | 7.6 | 230 | 0.62 |
| RMG013 | Ngl | 19/08/03 | 35.0 | 21.9 | 9.9 | 8.1 | 7.3 | 4.30 | 9473 | 8.9 | 8.6 | 350 | 0.40 |
| RMG013 | Ngl | 14/10/03 | 19.2 | 22.6 | 10.2 | 7.6 | 7.1 | 1.31 | 2938 | 9.3 | 8.8 | 100 | 0.59 |
| RMG013 | Ngl | 01/03/04 | 59.7 | 27.3 | 36.6 | 7.8 | 7.6 | 3.99 | 594 | 11.3 | 6.6 | 110 | 1.54 |
| RMG013 | Ngl | 21/06/04 | 26.9 | 18.0 | 10.3 | 8 | 7.5 | 2.35 | 1094 | 11.0 | 7.1 | 244 | 0.41 |

The estimated average flow rate in the month prior to sampling was also calculated for each sampling point. Daily flow records were available for the Karkloof River at Shafton (upstream of the sample site), the uMngeni at sites RMG010 and RMG013, and the Mpolweni at Groothoek (again upstream of the sample site). From these records it was possible to extrapolate and based on mass balance type calculations, generate flow records for each site sampled. A potentially important environmental parameter of flow was its variability (reflecting "natural" or "regulated" conditions). To gain some measure of the "naturalness" of flow variability the coefficient of variation (CV%) in the month prior to sampling was also calculated (see Table 7.9).

Furthermore, records to indicate if the Albert Falls impoundment was stratified or isothermal, and spilling or not spilling at the time of invertebrate sampling were also added to the environmental data set. This ultimately provided a relatively comprehensive picture of physico-chemical and flow conditions at each sampling site to be used in analyses to determine what aspects of the environment may be responsible or linked to possible biological patterns observed.

**Data analysis**

Initial investigations simply looked to see if there were differences between the key SASS indices i.e. SASS Score, Average Score per Taxon (ASPT) and Number of Taxa (Dickens & Graham 2002) between monitored sites over the duration of the project. A summary of these indices is presented in the following figures.

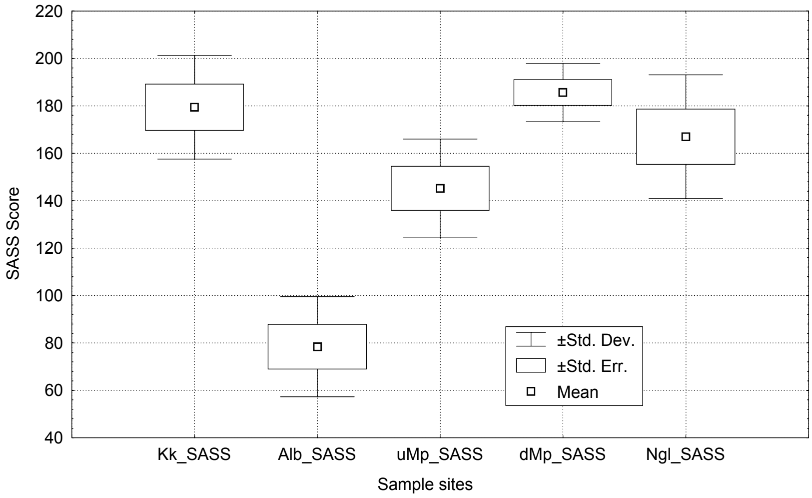

Figure 7.9: Summary of the SASS scores at respective sites monitored over the study period, 2001 to 2004.

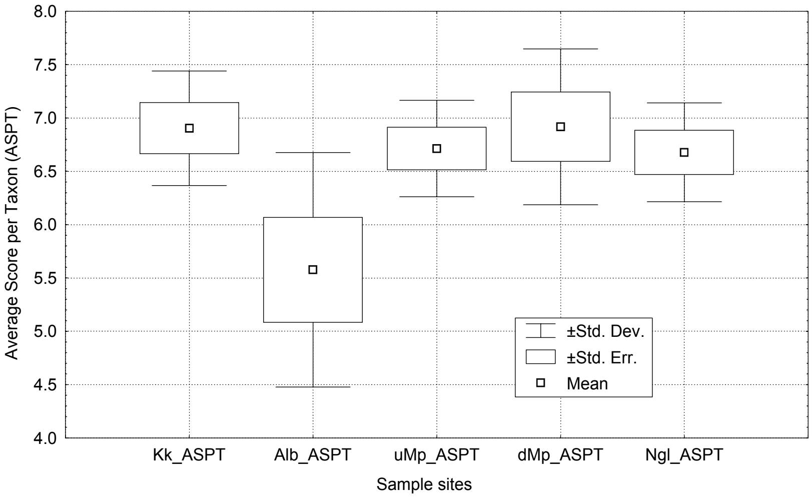

Figure 7.10: Summary of the Average Score per Taxon (ASPT) at respective sites monitored over the study period, 2001 to 2004.

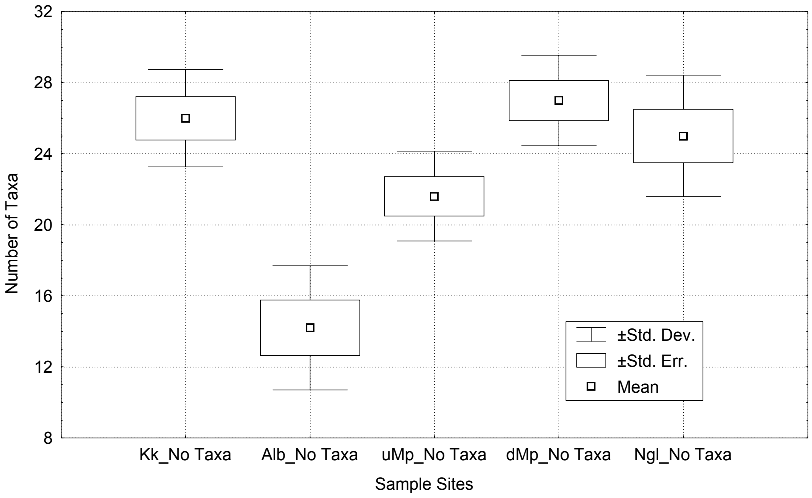

Figure 7.11: Summary of the Number of Taxa at respective sites monitored over the study period, 2001 to 2004.

These results showed that for all SASS indices measured there appeared to be a significant drop in the respective index immediately below the Albert Falls Dam. With increasing distance from the Albert Falls impoundment, down the uMngeni River towards the last site monitored at the weir above Nagle Dam, there were clear signs of recovery in the respective indices. To test if these differences were statistically significant the Wilcoxon Matched Pairs Test was applied to examine the differences between the Karkloof River control site and all other sampled sites down the uMngeni River. This test is the non-parametric equivalent of the Student's Paired *t* Test and was employed because of the low sample size (in this case only 5 cases).

Interestingly a comparison of the difference in long term results and these just presented for the Karkloof River site (Kk), and the uMngeni site downstream of the Mploweni confluence (dMp), showed somewhat different results. In the analysis of the long term data set the ASPT of the Karkloof River site was generally relatively higher (7.4) than in more recent times (this study ~6.9). Hence in the analysis of the long term SASS record, the relative condition of the uMngeni downstream of the confluence with the Mpolweni (dMp) site was lower than the Karkloof River (Kk) site, whilst in this analysis they were virtually the same. Checking the data provided no clear explanation as to why this should be so and appeared to be simply an artefact of the data.

**Results**

Results of the analyses to investigate if there were statistically significant differences between SASS indices at respective sites down the uMngeni River, compared to the control site on the Karkloof River, are presented in the following tables and figures. All the paired comparisons start with the uppermost uMngeni River site (Albert Falls) and work their way sequentially down the river to the Nagle site (furthest from Albert Falls Dam).

Table 7.10: Summary of Wilcoxon Matched Pairs Tests for respective SASS indices with various site comparisons

| SASS indices | Site comparisons | Valid N | T | Z | p-level | Significance |
|---|---|---|---|---|---|---|
| SASS Scores | Karkloof vs Albert Falls | 5 | 0 | 2.02260 | 0.04 | * (p<0.05) |
| | Karkloof vs u/s Mpolweni | 5 | 1 | 1.75292 | 0.08 | NS |
| | Karkloof vs d/s Mpolweni | 5 | 5 | 0.67420 | 0.50 | NS |
| | Karkloof vs Nagle | 5 | 6 | 0.40452 | 0.69 | NS |
| ASPT | Karkloof vs Albert Falls | 5 | 1 | 1.75292 | 0.08 | NS |
| | Karkloof vs u/s Mpolweni | 5 | 7 | 0.13484 | 0.89 | NS |
| | Karkloof vs d/s Mpolweni | 5 | 7 | 0.13484 | 0.89 | NS |
| | Karkloof vs Nagle | 5 | 4 | 0.94388 | 0.35 | NS |
| No Taxa | Karkloof vs Albert Falls | 5 | 0 | 2.02260 | 0.04 | * (p<0.05) |
| | Karkloof vs u/s Mpolweni | 5 | 0 | 1.82574 | 0.07 | NS |
| | Karkloof vs d/s Mpolweni | 5 | 3 | 0.73030 | 0.47 | NS |
| | Karkloof vs Nagle | 5 | 5.5 | 0.53936 | 0.59 | NS |

Only the SASS score and number of taxa were shown to be statistically significantly different between the Karkloof River control site and the first site below the Albert Falls impoundment (RMG010 = Alb), with the ASPT comparison almost statistically significant (p<0.08). The SASS score (p<0.08) and Number of Taxa (p<0.07) were also almost statistically significantly different between the Karkloof River and the uMngeni site upstream of the confluence with the Mpolweni River (RMG011 = uMp). Table 7.10 also illustrates that with increasing distance down the river from Albert Falls dam there was a decreasing probability of significant differences between the Karkloof River control site and the respective comparative (paired) site.

In other words, by the time the river has travelled some 4 km downstream of the Albert Falls Dam, based on the SASS indices there appears to be no statistically significant difference between the results obtained on the Karkloof River control site and the paired monitoring sites on the uMngeni River (uMngeni u/s Mpolweni, uMngeni d/s Mpolweni & uMngeni u/s Nagle Dam).

To examine this picture further, the underlying SASS taxa data was investigated using multivariate statistical tools.

## Analysis of detailed aquatic macroinvertebrate data

### Introduction

The analysis of the historical and more recent (this study) SASS monitoring data for a number of sites below the Albert Falls impoundment, compared to the un-impounded/un-regulated Karkloof River control site, appeared to indicate that there were significant changes associated with the impoundment, particularly at those sites immediately downstream of the dam. However only the SASS indices were used in that investigation and as such significant information about invertebrate taxa responses to the impoundment may have been lost in the collapsing of information into the indices. Hence to examine this in more detail the aquatic macroinvertebrate taxa collected as part of this investigation were examined in an attempt to better understand the impact of the flows at a finer level of taxonomic resolution. This essentially became a multivariate response study, as the entire aquatic macroinvertebrate community was being considered, as opposed to a single index measure of response to the regulated and unseasonal flows below the dam.

The specific questions remained similar to those posed in the previous section, viz.:

- Has the impoundment at Albert Falls had an impact on the macroinvertebrate community as measured by SASS taxa? (largely family level taxonomic resolution)
- Has the impoundment at Albert Falls had an impact on the macroinvertebrate community as measured by macroinvetebrate taxa identified to a higher taxonomic resolution?
- If the answers to the above question were “yes”, what was the nature of this impact on the macroinvertebrate community?

### Methods and data sources

Data from the five SASS study sites (Table 7.7) already mentioned were used. Table 7.1 summarised the locality, names and distance downstream of Albert Falls Dam of all of the sampling sites Taxa identified in the field to family level as part of the SASS analysis were initially examined and then those same samples, subsequently identified at a higher order of taxonomic resolution (species and higher) were considered. Unfortunately the first set of Karkloof River samples collected in March 2001, were not analysed to species level. Hence valid analyses of the species level data only covered the last four sampling occasions (viz. August 2003, October 2003, March 2004 and June 2004).

As previously mentioned the Karkloof River site (site RKK003 = Kk) constituted a control or reference site, as it was within a nature reserve, unregulated and with no significant impoundments along its length. Site RMG010 was immediately below the Albert Falls Dam impoundment, and hence likely to be most impacted by the effects of regulated flows, whilst the third site (site RMG011) was above the Mpolweni confluence. Other than the control site on the Karkloof River, the most downstream site (site RMG012) was also potentially least impacted by the flow regulation as tributaries and their incremental flows between Albert Falls and Nagle (most notably the Mpolweni River) would have had a chance to restore something of the natural flow regime to the lower uMngeni River, before it enters Nagle Dam. However confounding this picture of flow regulation and potential impacts on the aquatic biota was the relatively intensive feedlot and chicken farming in the uMngeni valley in the vicinity of the Greytown Road. Runoff and nutrient rich pollutants emerging from these farms were noted as contributing significantly to the nutrients in the uMngeni River below this site (Chapter 5). The names etc. of environmental determinants used are summarised in Table 7.8.

All sampling dates per sample site are as indicated in Table 7.9.

### Data analysis

Due to the multivariate nature of this study, i.e. numerous environmental parameters, over various sites with the potential to simultaneously influence the aquatic macroinvertebrates in the river, appropriate multivariate analytical techniques were required (e.g. Manly, 1991). The techniques used to illuminate different aspects of these relationships were largely based on Principal Components Analysis (PCA), Redundancy Analysis (RDA) (Ter Braak, 1987) and Principal Response Curves (PCR) (Van den Brink & Ter Braak, 1999). All of these could be classified as ordination methods.

Ordination is the collective term used to describe multivariate techniques that arrange sites along axes on the basis of the species composition at respective sites. The general result is an ordination diagram in which sites are represented by points. Sites, which are closer together will have a greater biological similarity compared to sites further apart on the diagram. The ordination diagram represents a graphical summary of the biological data. However with time-dependent multivariate responses (as was the case in this study – same sites sampled at different times and with differing physico-chemical water conditions) ordination diagrams may become too cluttered to allow easy interpretation of the changes over time (for example Figure 7.14). Additionally the measured community response in a control site may also vary with time, further confounding the picture or relative changes of "impacted/treated" sites compared to that control site. A relatively new and novel multivariate method, based on RDA and called the principal response curve (PRC) method (Van den Brink & Ter Braak, 1999) overcomes these problems and was used extensively in these analyses.

The PRC technique allows differences between treatments (in this instance sites/distance downstream from Albert Falls Dam) and the control site (on the Karkloof River) to stand out by focussing on the differences between the species composition of the treatments and that of the control at the corresponding time (see for example Figure 7.14). Curves are obtained for each treatment that can be interpreted as the principal response curve of the community, with accompanying species weights allowing an interpretation at the species level – essentially the higher the weight the more the actual response pattern of the species is likely to follow the pattern in the PRC (Van den Brink & Ter Braak, 1999). The time trajectory for the Karkloof River control sites in this study is represented by a horizontal line running through the origin of the PRC diagrams. This is achieved by taking the control treatment as the reference to which the other treatments are compared and by defining "time" as the horizontal axis of the diagram (Van den Brink & Ter Braak, 1999). In a sense then the PRC method accounts *a priori* for the development and changes in the control communities over time, allowing for *other treatment* type effects (in this case impacts from the impoundment) to be measured as variations from the control.

**Results**

The entire family level data set was initially analysed using non-metric multidimensional scaling (NWMS) to establish if there were distinctly different community responses related to biotopes. See Figure 7.12 for the results of this analysis. The three biotopes (Stones (S), Vegetation (V) and Gravel/Sand/Mud (GSM)) were clearly separated and hence subsequent analyses were performed on respective biotope data. The GSM and Vegetation biotopes are most dissimilar to each other, whilst families collected from the Stones have overlap with both of these previous biotopes.

Initial analyses focussed on the family taxonomic level data, summarised in Table 7.11 with subsequent analyses considering the species taxonomic level data, summarised in Annexure C (at the end of this chapter).

Table 7.11: Summary of all family level taxa used in analyses, their taxonomic associations and shortened names used in analyses and figures

| Order | SASS Family | Taxa Name for Analyses | Order | SASS Family | Taxa Name for Analyses |
|---|---|---|---|---|---|
| PORIFERA | PORIFERA | PORIFERA | TRICHOPTERA | ECNOMIDAE | ECNOMIDA |
| TURBELLARIA | TURBELLARIA | TURBELLA | TRICHOPTERA | HYDROPSYCHIDAE 1sp | HYDROP_1 |
| ANNELIDA | OLIGOCHAETA | OLIGOCHA | TRICHOPTERA | HYDROPSYCHIDAE 2sp | HYDROP_2 |
| ANNELIDA | LEECH | LEECH | TRICHOPTERA | HYDROPSYCHIDAE >2sp | HYDROP>2 |
| CRUSTACEA | AMPHIPODA | AMPHIPOD | TRICHOPTERA | PHILOPOTAMIDAE | PHILOPOT |
| CRUSTACEA | POTAMONAUTIDAE | POTAMONA | TRICHOPTERACased caddis: | LEPTOCERIDAE | LEPTOCER |
| CRUSTACEA | ATYIDAE | ATYIDAE | TRICHOPTERACased caddis: | HYDROPTILIDAE | HYDROPTI |
| CRUSTACEA | HYRACARINA | HYRACARI | TRICHOPTERACased caddis: | PISULIIDAE | PISULIID |
| PLECOPTERA | PERLIDAE | PERLIDAE | COLEOPTERA | DYTISCIDAE | DYTISCID |
| EPHEMEROPTERA | BAETIDAE 1sp | BAETID_1 | COLEOPTERA | ELMIDAE/DRYOPIDAE | ELMIDAE |
| EPHEMEROPTERA | BAETIDAE 2sp | BAETID_2 | COLEOPTERA | GYRINIDAE | GYRINIDA |
| EPHEMEROPTERA | BAETIDAE >2sp | BAETID>2 | COLEOPTERA | HELODIDAE | HELODIDA |
| EPHEMEROPTERA | CAENIDAE | CAENIDAE | COLEOPTERA | PSEPHENIDAE | PSEPHENI |
| EPHEMEROPTERA | HEPTAGENIIDAE | HEPTAGEN | DIPTERA | ATHERICIDAE | ATHERICI |
| EPHEMEROPTERA | LEPTOPHLEBIIDAE | LEPTOPHL | DIPTERA | CERATOPOGONIDAE | CERATOPO |
| EPHEMEROPTERA | OLIGONEURIDAE | OLIGONEU | DIPTERA | CHIRONOMIDAE | CHIRONOM |
| EPHEMEROPTERA | POLYMITARCYIDAE | POLYMITA | DIPTERA | CULICIDAE | CULICIDA |
| EPHEMEROPTERA | PROSOPISTOMATIDAE | PROSOPIS | DIPTERA | EPHYDRIDAE | EPHYDRID |
| EPHEMEROPTERA | TRICORYTHIDAE | TRICORYT | DIPTERA | MUSCIDAE | MUSCIDAE |
| ODONATA | CALOPTERYGIDAE | CALOPTER | DIPTERA | PSYCHODIDAE | PSYCHODI |
| ODONATA | CHLOROCYPHIDAE | CHLOROCY | DIPTERA | SIMULIIDAE | SIMULIID |
| ODONATA | COENAGRIONIDAE | COENAGRI | DIPTERA | TABANIDAE | TABANIDA |
| ODONATA | PROTONEURIDAE | PROTONEU | DIPTERA | TIPULIDAE | TIPULIDA |
| ODONATA | AESHNIDAE | AESHNIDA | GASTROPODA | ANCYLIDAE | ANCYLIDA |
| ODONATA | GOMPHIDAE | GOMPHIDA | GASTROPODA | BULININAE | BULININA |
| ODONATA | LIBELLULIDAE | LIBELLUL | GASTROPODA | HYDROBIIDAE | HYDROBII |
| LEPIDOPTERA | PYRALIDAE | PYRALIDA | GASTROPODA | LYMNAEIDAE | LYMNAEID |
| HEMIPTERA | BELOSTOMATIDAE | BELOSTOM | GASTROPODA | PHYSIDAE | PHYSIDAE |
| HEMIPTERA | CORIXIDAE | CORIXIDA | GASTROPODA | PLANORBINAE | PLANORBI |
| HEMIPTERA | GERRIDAE | GERRIDAE | PELECYPODA | CORBICULIDAE | CORBICUL |
| HEMIPTERA | HYDROMETRIDAE | HYDROMET | PELECYPODA | SPHAERIIDAE | SPHAERII |
| HEMIPTERA | NAUCORIDAE | NAUCORID | | | |
| HEMIPTERA | NEPIDAE | NEPIDAE | | | |
| HEMIPTERA | NOTONECTIDAE | NOTONECT | | | |
| HEMIPTERA | PLEIDAE | PLEIDAE | | | |
| HEMIPTERA | VELIIDAE/MESOVELIIDAE | VELIIDAE | | | |

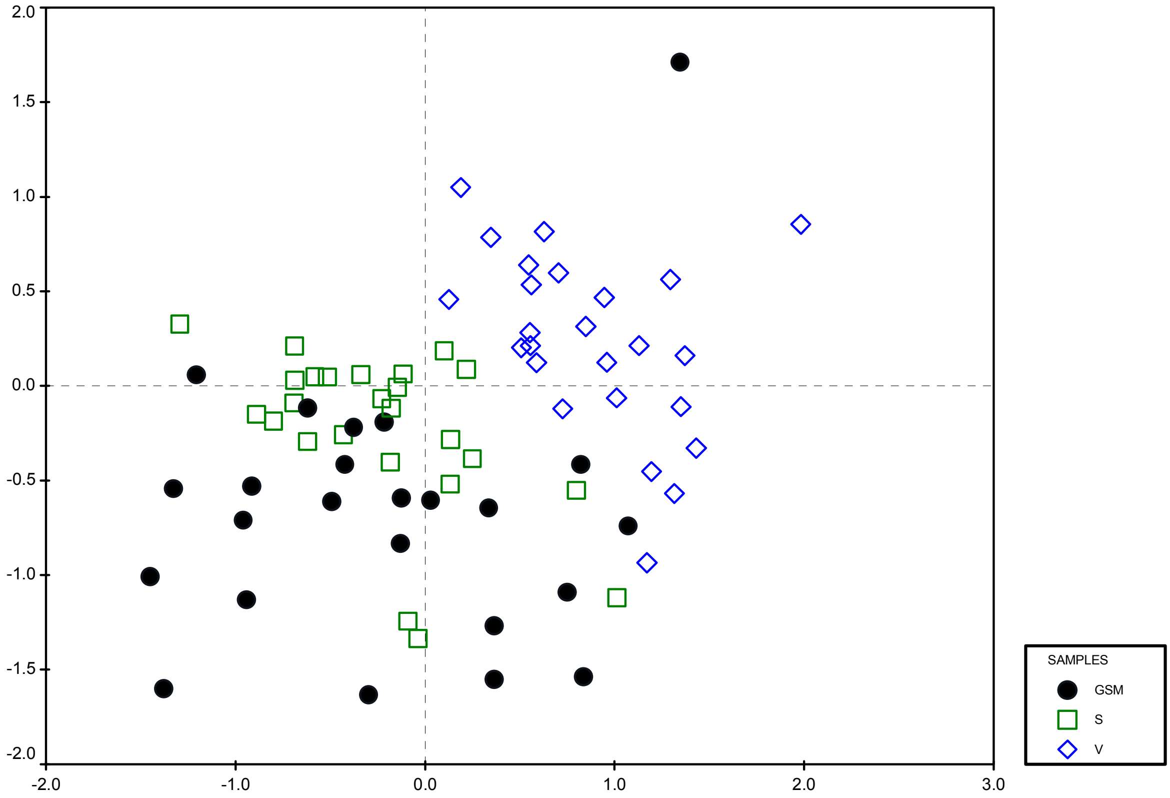

Figure 7.12: A plot of samples in three biotopes in non-metric multi-dimensional scaling (NMS) space (rotated by principal component analysis) based on the Soerensen distance measure for presence/absence invertebrate data classified to family level. The stress value for the 2-dimensional NMS was 0.229. GSM = gravel, stones and mud; S = stones; V = vegetation. [Outlier site for GSM on top-right of the ordination is the GSM biotope from Nagle sampled in March 2004].

As predicted in the introduction to the data analysis, PCA analysis and ordination of the family level taxa within the various biotopes (e.g. Stones (St), Figure 7.13) shows a rather chaotic picture of how sites and their composition change over time. Only the Stones biotope ordination diagram was illustrated to demonstrate this picture. An examination of the same data but analysed using PRC is much more informative – see Figures 7.13 to 7.15.

The PRC figures represented the principal pattern in community response over time with respect to the Karkloof River reference or control site, i.e. how did the temporal changes in family level composition at each site differ from that at Karkloof River. Noteworthy in interpreting the following figures are the taxa on the extreme right-hand-axis (species scores) as these most closely follow the trend of sites most distant (above or below) the reference horizontal line (representing the Karkloof River control). So for example, in the case of the Stones biotope (Figure 7.13) the black fly (Simuliidae) are important in separating the Albert Falls site from all other sites and most particularly from the Karkloof River control site.

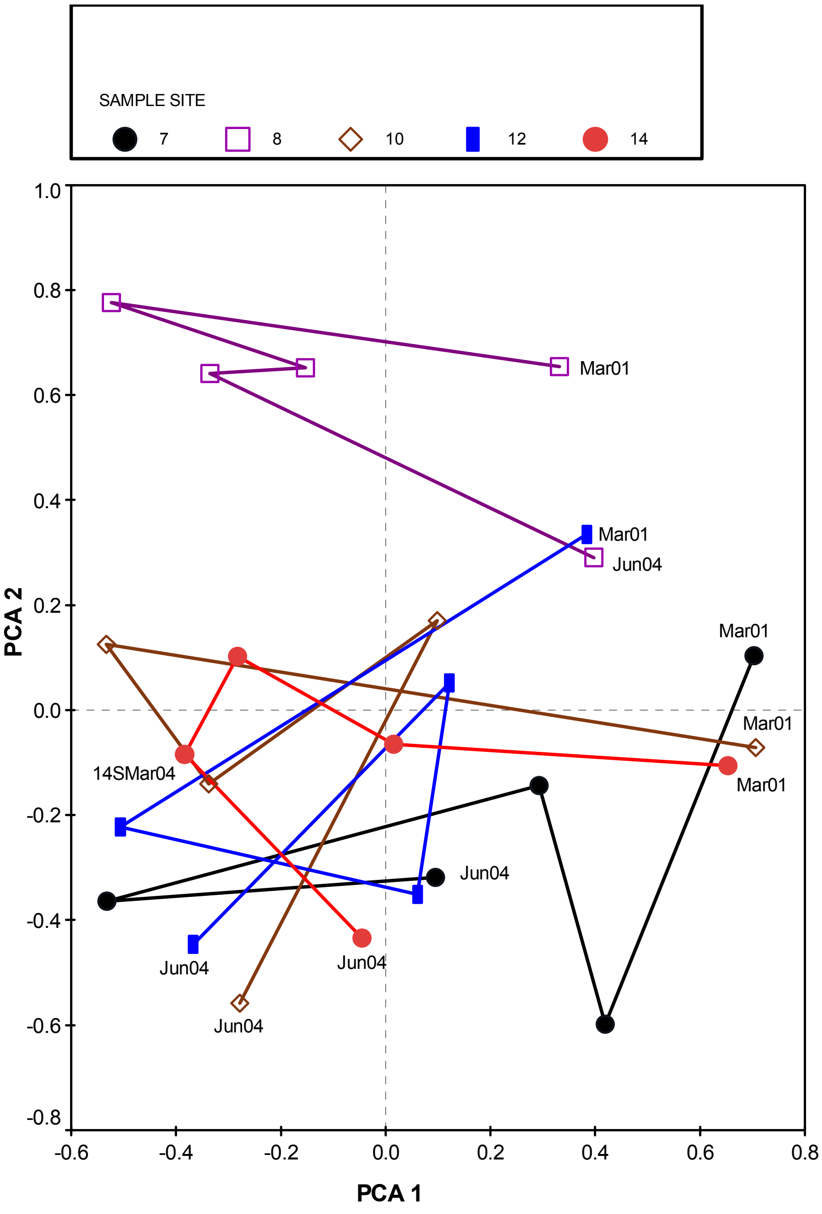

Figure 7.13: Stones biotope site trajectories along PCA axes 1 and 2 with labels for start and end sampling dates (based on log(X+1) for mid-class abundance data). Axes 1 and 2 accounted for 15.7% and 14.7% of the total species variance respectively.

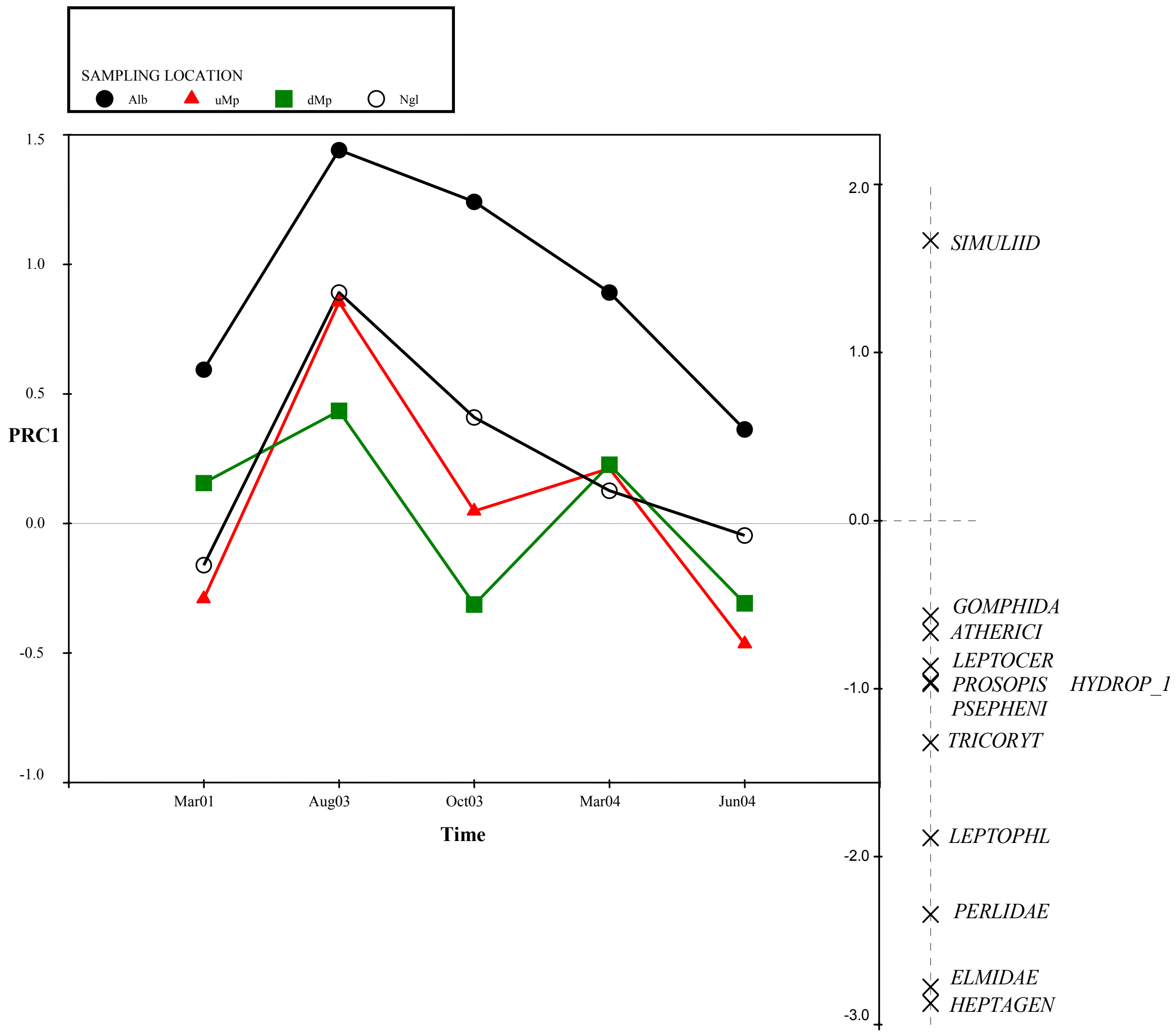

Figure 7.14: PRC for the Stones biotope and family level taxonomic identification (based on log(X+1) for mid-class abundance data. Only taxa with more than 10% of their variance accounted for by PRC1 are displayed). PRC1 accounted for 18.3% of the total species variance. [See Table 7.11 for full taxonomic names]

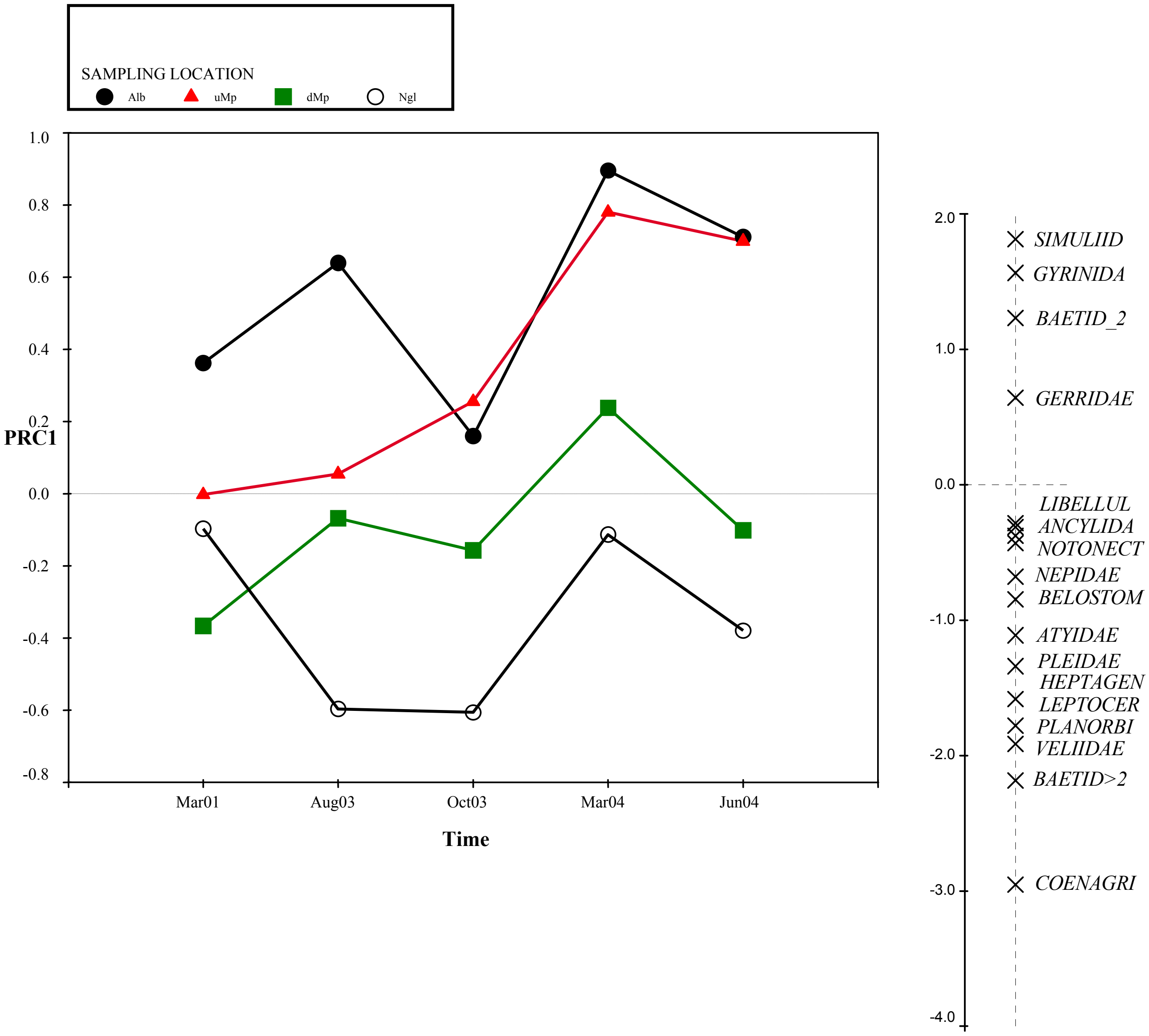

Figure 7.15: PRC for the Vegetation biotope and family level taxonomic identification (Based on log(X+1) for mid-class abundance data. Only taxa with more than 5% of their variance accounted for by PRC1 are displayed). PRC1 accounted for 21.2% of the total species variance. [See Table 7.11 for full taxonomic names]

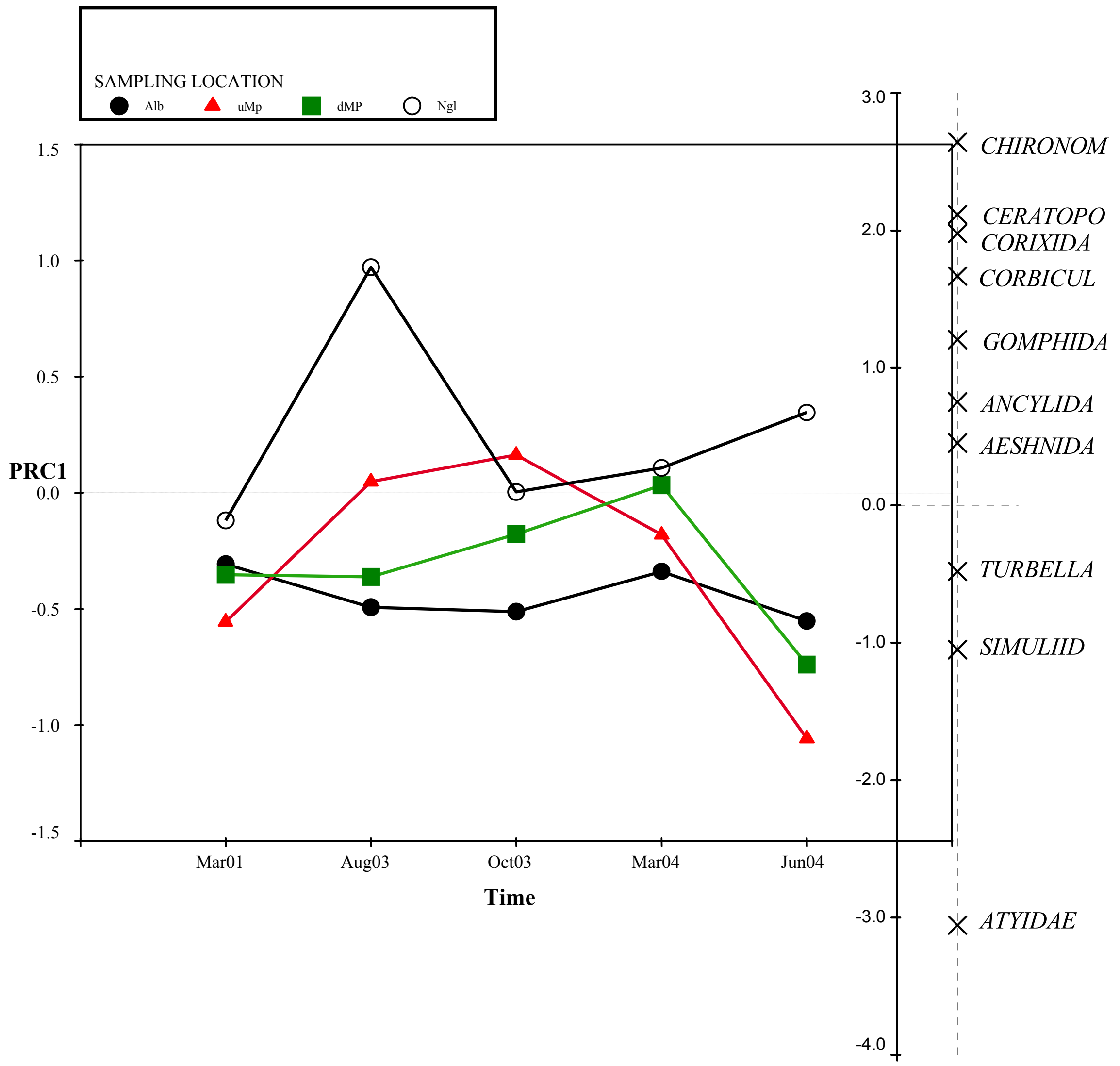

Figure 7.16: PRC for the GSM biotope and family level taxonomic identification (Based on log(X+1) for mid-class abundance data. Only 10 taxa with at least 15% of their variance accounted for by PRC1 are displayed). PRC1 accounted for 24% of the total species variance. [See Table 7.11 for full taxonomic names]

### Interpretation of PRC figures

In comparing the temporal patterns of sites observed with respect to the Karkloof River control, the Albert Falls and Nagle sites were prioritised in terms of interpretation as these are geographically furthest apart down the uMngeni River, and hence likely to be most distinct **if** the Albert Falls Dam was having a large effect on the aquatic fauna. The Albert Falls site was also least likely to be affected by other confounding effects of water quality changes from incremental subcatchments of the uMngeni downstream of the dam, and hence most likely to express the impact of the impoundment.

The most obvious feature of the PRC figures is how different the Albert Falls site (immediately below the dam) is from the Nagle site (furthest from the Albert Falls Dam), when compared to the Karkloof River reference site. This is most evident in the gravel, sand and mud (GSM) and vegetation (Veg) biotopes respectively (both on opposite sides of the Karkloof River horizontal line for the Veg biotope), with the Albert Falls site consistently different in composition from the Karkloof River in GSM (stays below the line), whilst Nagle appears to vary in dissimilarity from the Karkloof River. At times the Nagle site has almost the same composition (March 2001, October 2003 and March 2004), whilst at others it is distinctly different (e.g. August 2003). Interestingly for the GSM samples, the composition of the Nagle sites is most similar to the Karkloof River site during the "high" summer stream flow seasons (March 2001, October 2003 and March 2004) when it would be anticipated that the incremental flows from tributaries to the uMngeni between Albert Falls and Nagle Dam have had a chance to "reset" the biological condition of the lower reach of the river and make it more closely similar to that observed in the control site.

Another interesting feature of Figure 7.16 (PRC for GSM) is the generally wider separation of all sites away from the horizontal Karkloof River control line during the winter samplings (August 2003 and June 2004). Significantly this feature appeared to repeat itself for all biotopes examined (Figures 7.15 (Veg) & 7.14 (St)), whilst the converse appeared to hold, with generally minimal separation between sites and the Karkloof River control during the summer season. This implies the greatest difference in taxonomic composition between sites (relative to the Karkloof River control site) is during the unseasonal "high" winter flow season.

For the Veg biotope, the Nagle site starts out being almost the same composition as the control site in March 2001, but from then onwards is always different (below the line) until the March 2004 sampling. Again it appears that the late summer, high base flows during March in the lower portion of the uMngeni River above Nagle, resets the biota to being more like that noted in the control site on the Karkloof River, and hence during these periods the sites are closest to the horizontal (control site) line. It is also noteworthy that during the start of the study (March 2001) Albert Falls was spilling (Figure 7.17) and hence had probably "reset" the aquatic biota in the river downstream of the impoundment which may help explain the initially similar composition of most sites in the vegetation biotope.

A similar pattern emerges in the Stones biotope where the March monitoring on the Nagle sites is closely allied to the community observed in the control site on the Karkloof River. In the Stones biotope, Albert Falls is consistently different from the Karkloof River (stays above the line), whilst varying in degree of dissimilarity. Otherwise the pattern (shape of the PRC curve) in the Stones biotope for Nagle is similar to the Albert Falls site (both for example had peaks in Simulids in August 2003), but is closer to the Karkloof River generally (PRC curve not too distant from the horizontal) and as already noted very similar at certain times (e.g. March 2001 & 2004 and June 2004). August 2003 (during the unseasonal "high" winter flow season) and October 2003 (at the end of this same season of unseasonal high winter base flows) shows the widest separation of all sites around the horizontal Karkloof River control site, implying the greatest impact on taxonomic composition.

In terms of the taxonomic responses to differences between the control site and study sites, it appears that the Simuliidae are important in differentiating the Albert Falls site, particularly in the Stones and Vegetation biotopes (high positive species weights on the Y axis to the right of the PRC curves) and then to lesser degree (along with Atyidae) in the GSM biotope (high negative species weights). Coenagrionidae (amongst a range of others – see Figure 7.15) appear to distinguish the Nagle sites from the Karkloof River in the Vegetation biotope. However this data and its interpretation are expanded upon in the species level of analyses below.

We can therefore perhaps conclude that the environment at the Albert Falls site might be different in some way that causes the temporal pattern of community change there to differ consistently from that of the reference Karkloof River site (in a way that none of the other sites appear to do). This difference is also markedly different from the site furthest downstream (Nagle), particularly in the GSM and Veg biotopes. There appears to be no other systematic similarity in the pattern for the other sites examined on the uMngeni, above or below the Mpolweni confluence.

The question then is:

> How did the temporal pattern in stream physico-chemical and flow characteristics of Albert Falls differ from the Karkloof River, and the other sites, and what variable(s) could be causing the marked differences between sites noted in the PRC analyses?

In an attempt to answer this question, a similar analysis using PRCs was applied to the water physico-chemical and flow (environmental) data to determine if there were patterns or variations in the environmental data set which firstly:

- differentiated the surveyed sites from the Karkloof River control site; and secondly
- mirrored that observed in the biological data.

These results are presented in Figure 7.18 Again the Karkloof River control site is represented by the horizontal dotted line in the figure.

The first feature of these results is that there is a similar pattern of variation (compared to the Karkloof River control site) in water quality exhibited at all monitoring sites. This pattern is different to the environmental picture at the Karkloof River site and is most consistent with the pattern exhibited by the biota collected in the Stones biotope (Figure 7.14).

The results of this analysis also suggest that the temporal pattern of change in the water quality at Albert Falls, (and all other sites downstream of the dam), whilst differing most markedly from the Karkloof River in the late summer samples (March 2001 and 2004 – deviations from the horizontal line), was generally similar to the Karkloof River at other times. This implies that the greatest change in water quality between the Karkloof River control site and all other sites below Albert Falls Dam was most apparent during the late summer months. This was in contrast to the biological picture which emerged during the PRC analysis of aquatic macroinvertebrate data when the summer "reset" generally allowed sites to resemble more closely the composition displayed by the Karkloof River control site, particularly for sites some distance downstream from Albert Falls Dam.

The differences in the environmental picture between the impacted sites and the control site during summer could be largely attributable to the fact that in summer the flow (and hence water physico-chemistry) in the river below Albert Falls dam is likely to be radically different to that experienced in an unregulated river (or the control site on the Karkloof River). The modifying effects of a large dam on the "normal" river water physico-chemistry will also be contributing to the difference between the control and impacted sites.

The site on the uMngeni downstream of the confluence with the Mpolweni (dMp = RMG012) showed the same general trend as the others (shape of PRC curve), but much more enhanced (greater distance from the horizontal Karkloof River line) than the others in August & October 2003. The "species" (water quality) weights indicate that this is because of high levels of certain determinants, e.g. *E.coli*, $NO_3$, DO, SRP, TP, Turbidity, etc. These results are understandable from the point of view of higher organic enrichment and nutrient loads emanating from the Mpolweni catchment, which is typically more polluted than the uMngeni. Higher DOs may be an anomaly in this respect as DOs typically decline with increased pollution. Higher saturated dissolved oxygen (Sat DO), conductivity (Cond) and free (un-ionised) ammonia ($NH_3$ Fr) (all with high negative "species" weights) also appear to differentiate the surveyed sites on the uMngeni from the Karkloof River control. These determinants are also typically higher during the summer months (Figure 7.18, March 2001 and March 2004) and may be also attributed to pollution from the feedlots in the area below Albert Falls.

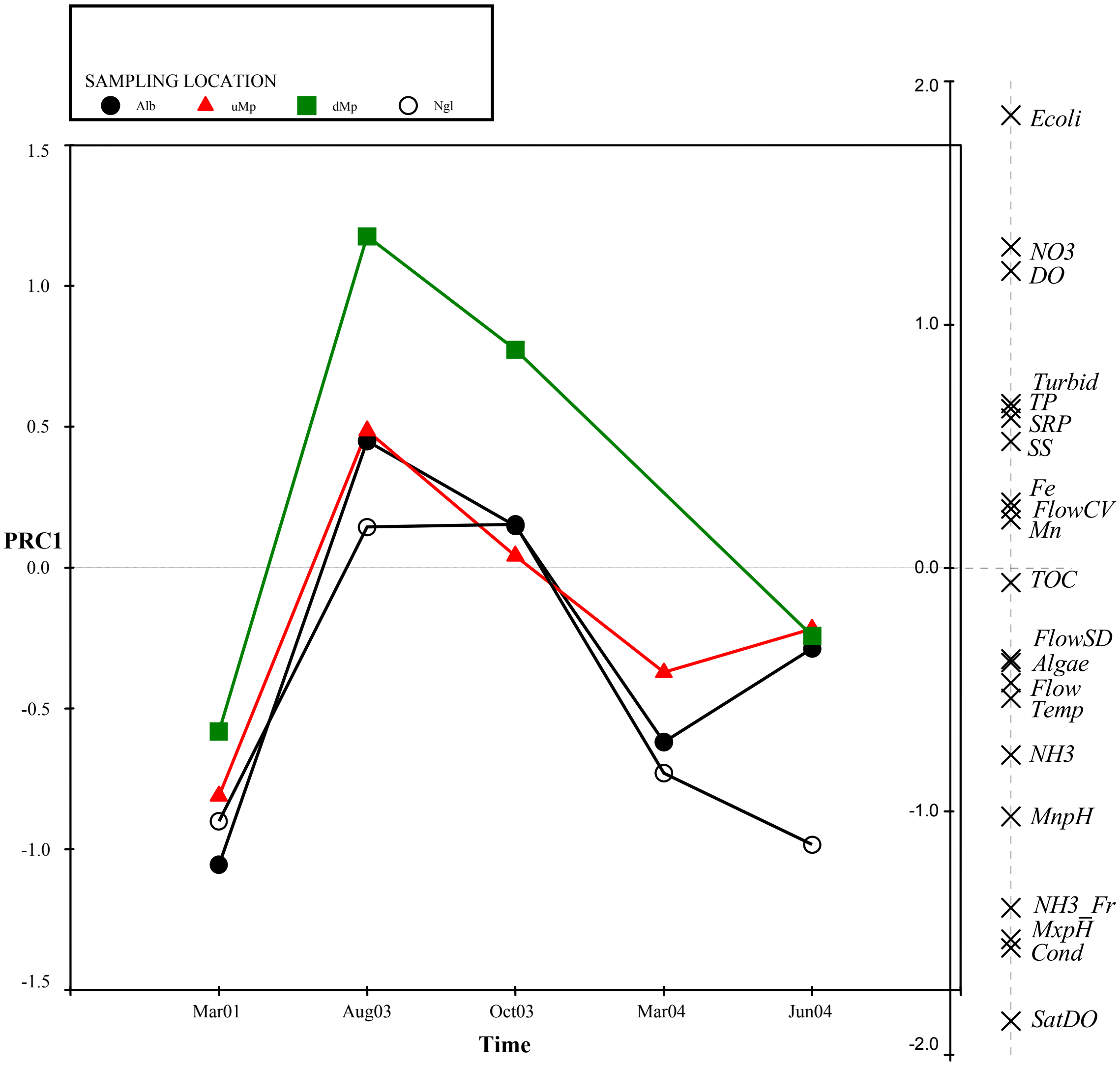

Figure 7.18: First principal response curves (PRC) for four sampling locations on the uMngeni River in relation to temporal changes in water chemical, physical and biotic variables observed at the Karkloof River reference/control site (dotted horizontal line above), and their "species" weights (vertical axis on the right) (data standardized (SD=1) and centred (mean=0)). The eigenvalue for PRC1 was 0.121, representing 19.8% of the total variability. See Table 7.8 for names and details of variables. Outlier site dMpMa04 excluded

A correlation analysis between the family level PRC1 site scores and measured environmental determinants was conducted to see which of these showed possible linkages with observed biological variability as characterised by the macroinvertebrates in respective biotopes. These data are summarised in Table 7.12 and shows very few of the determinants were statistically significantly correlated with the biological data. Temperature and the Max pH have a weak but significant correlation to the data in the GSM biotope with Min pH having a weak but highly significant correlation to the data in the Stones biotope.

Table 7.12: Partial Pearson's Product-Moment Correlations (r) between Family-level PRC1 site scores and measured environmental determinants

| **Biotope** | **GSM** | | **St** | | **Veg** |
|---|---|---|---|---|---|
| **Variable** | **r** | | **r** | | **r** |
| Flow | -0.143 | | 0.130 | | -0.168 |
| Mn | -0.224 | | -0.082 | | 0.126 |
| NH3 | -0.020 | | 0.154 | | 0.073 |
| NH3_Fr | 0.281 | | 0.311 | | 0.032 |
| NO3 | 0.055 | | -0.106 | | -0.132 |
| SRP | 0.078 | | -0.048 | | -0.096 |
| SS | 0.165 | | 0.216 | | -0.172 |
| TOC | -0.007 | | 0.243 | | -0.056 |
| TP | -0.011 | | -0.081 | | -0.022 |
| Temp | 0.442 | * | 0.163 | | -0.359 |
| Turbid | -0.007 | | 0.087 | | 0.078 |
| MxpH | 0.463 | * | -0.080 | | -0.169 |
| MnpH | 0.208 | | -0.508 | ** | -0.038 |
| SatDO | 0.391 | | 0.104 | | -0.176 |
| Algae | 0.005 | | 0.253 | | 0.117 |
| Cond | 0.263 | | -0.123 | | -0.342 |
| DO | -0.048 | | -0.110 | | -0.076 |
| *E. coli* | 0.115 | | -0.301 | | -0.213 |
| Fe | -0.037 | | -0.223 | | -0.295 |

* = $p<0.5$ (r to be significant 0.396)
** = $p<0.01$ (r to be significant 0.505)

Hence besides these two environmental determinants (temperature and pH) it appears that there is some as yet unmeasured environmental parameter(s) which occurs during the high unseasonal winter flow season which is impacting upon and accounting for the biological picture displayed by the macroinvertebrates. To better understand which specific species were responding to this regime, PRC analyses were repeated for respective biotopes but in this instance using the macroinvertebrate data identified down to the highest possible taxonomic resolution by the Albany Museum (in most cases species level data).

**Principal Response Curve (PRC) analysis of aquatic macroinvertebrate species data.**

Analysis of the species level data followed the same process as that applied to the family level data. Each biotope was analysed separately and the results summarised in Figures 7.19 to 7.21. In some cases species was a pseudonym for the highest possible taxonomic resolution possible from the aquatic macroinvertebrate material sent to the Albany Museum for identification purposes. As previously noted, the first set of Karkloof River samples collected in March 2001, were mislaid and hence no species level identification was possible. Hence valid PRC analyses of the species level data only covered the last four sampling occasions (viz. August 2003, October 2003, March 2004 and June 2004). Notwithstanding the absence of this sample a number of interesting trends and species responses to the changes below the Albert Falls Dam were illustrated in the PRC analyses.

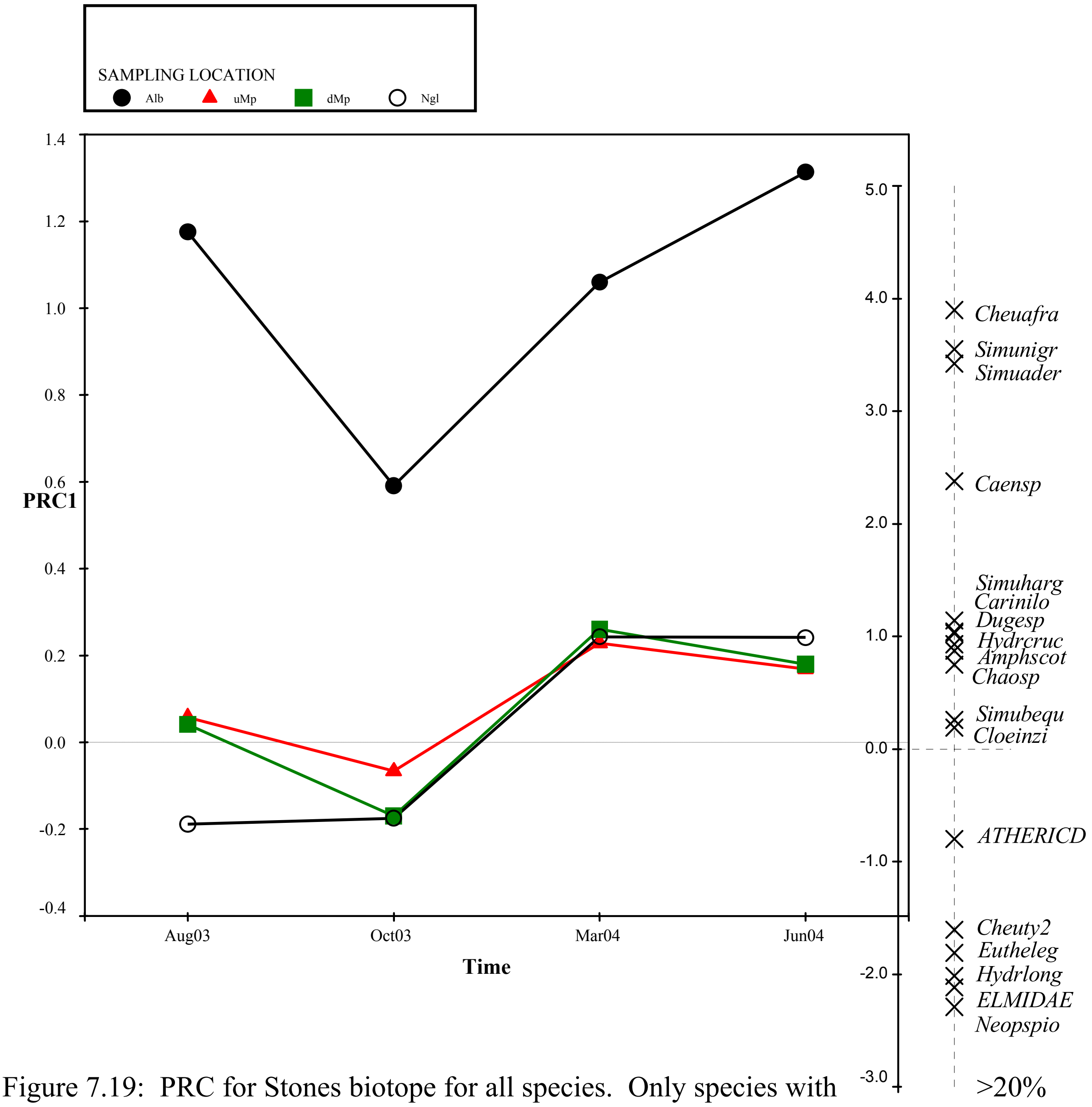

Figure 7.19: PRC for Stones biotope for all species. Only species with >20% of variance accounted for (species fit) shown. The eigenvalue for PRC1 was 0.245, representing 32% of the total species variability.

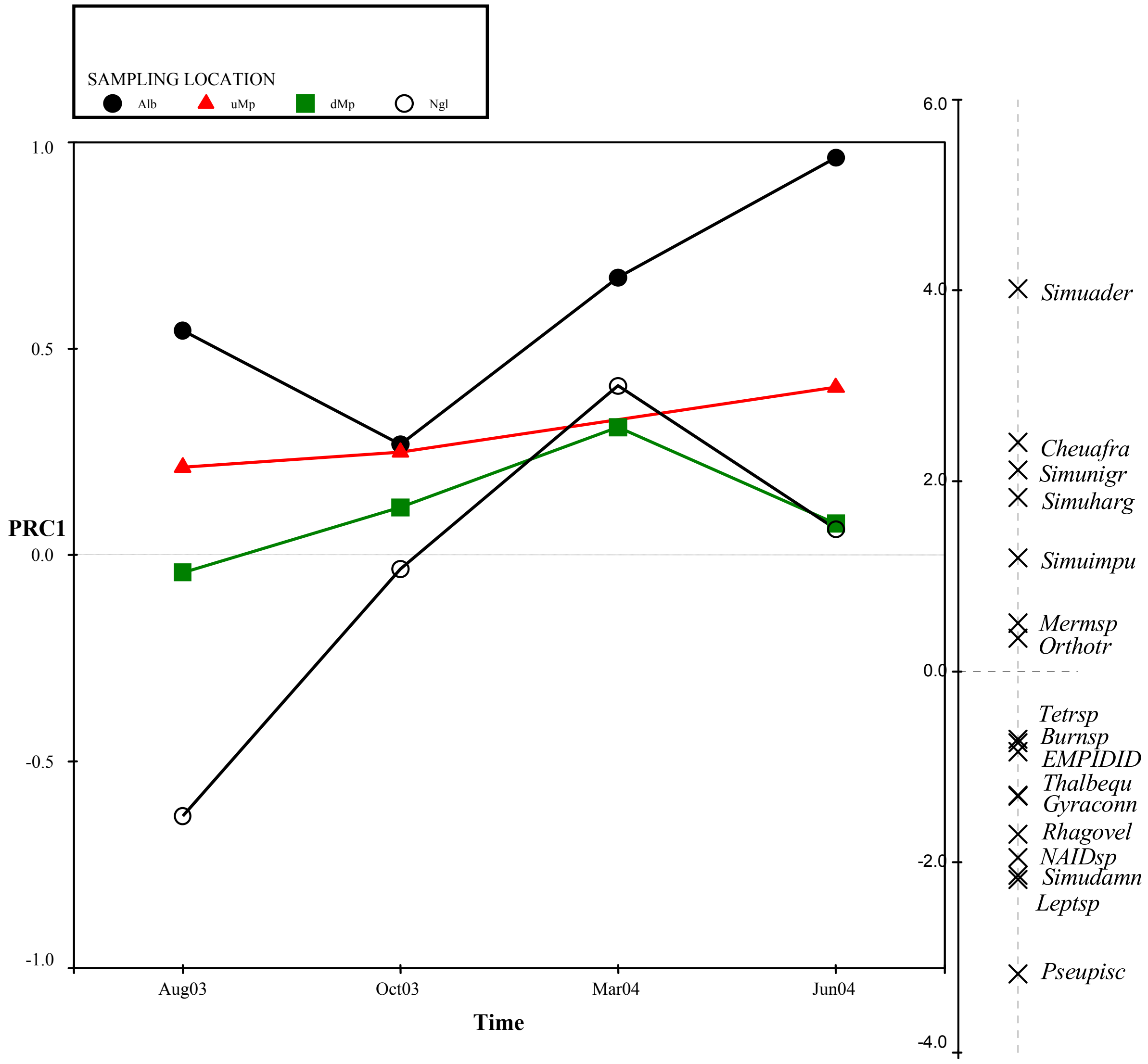

Figure 7.20: PRC for Vegetation biotope for all species. Species with >20% of variance accounted for shown. The eigenvalue for PRC1 was 0.153, representing 21.2% of the total species variability.

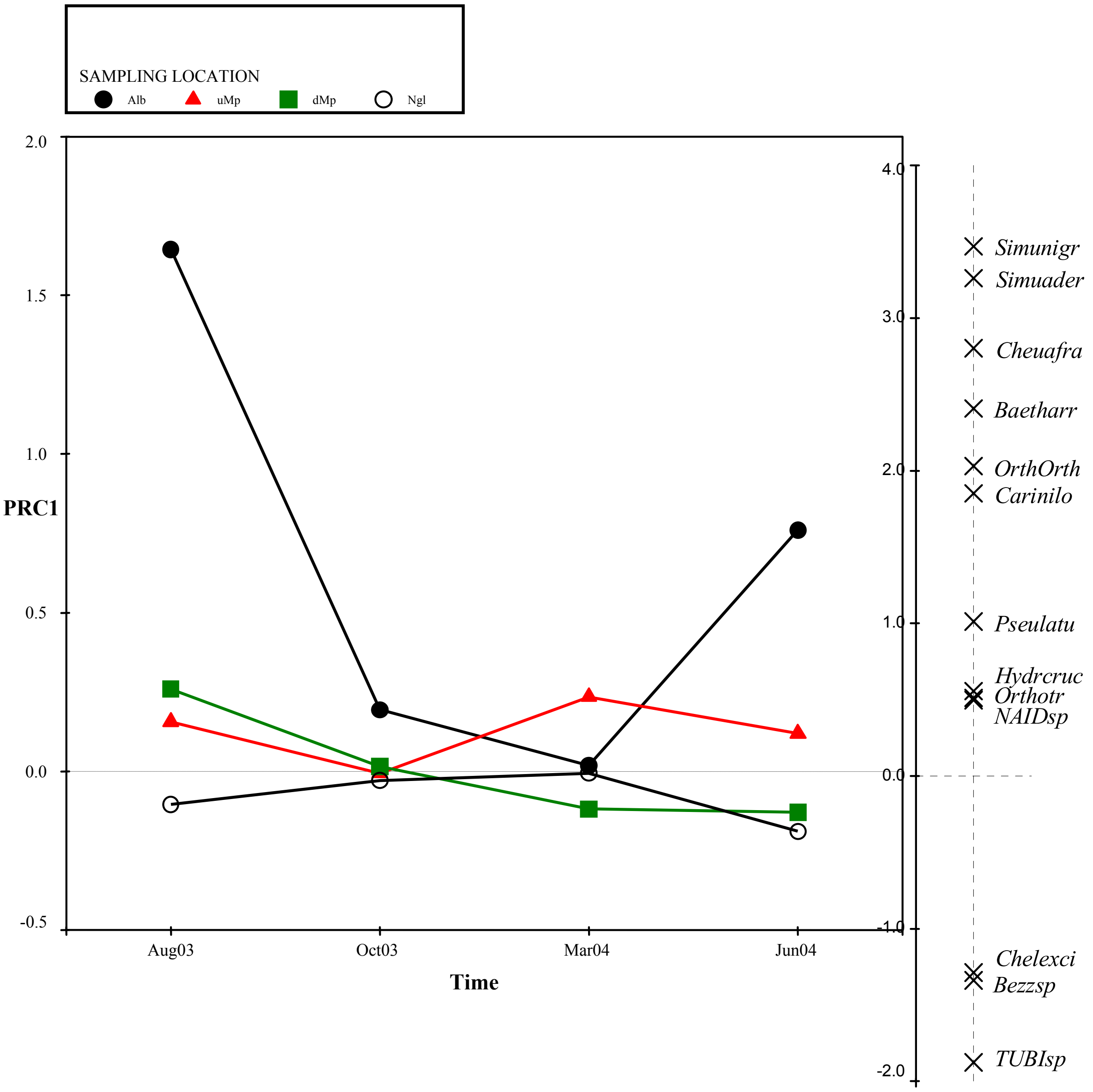

Figure 7.21: PRC for gravel/sand/mud (GSM) biotope for all species. Species with >20% of variance accounted for shown. The eigenvalue for PRC1 was 0.258, representing 36.1% of the total species variability.

**Discussion of results from PRC analysis of aquatic macroinvertebrate species data.**
Again a number of interesting features emerge from these PRC analyses.

For the Stones biotope (Figure 7.19) the greatest compositional variance with the Karkloof River control site was displayed by the Albert Falls site, and this most pronounced during the winter flow periods (August 2003 and June 2004). Within this biotope, most of the other sites studied downstream of Albert Falls Dam on the uMngeni appeared to have a very similar community composition to that displayed by the Karkloof River.

Besides the Albert Falls site, all other sites are generally very similar in their species composition both amongst themselves and with the Karkloof River control site (PRC curves largely together and centred around the Karkloof River horizontal line).

Of the three biotopes sampled, the vegetation biotope appears to show the greatest general variation (dispersion of PRC curves) across respective sampling sites down the uMngeni River, as compared to the Karkloof River control site. The stones and GSM biotopes were all much more consistent and similar to the Karkloof River in their composition across all uMngeni sites, except for the already mentioned Albert Falls site. Rapid and unseasonal flow changes in response to flow regulation below the Albert Falls impoundment may well be responsible for this effect - having the greatest impact on the marginal vegetation and least impact on the in-stream Stones and GSM biotopes. The probable mechanism for this impact is by either leaving the marginal vegetation “high and dry” during the summer (as the dam captures the normal spates and freshettes which would otherwise inundate the marginal vegetation) or inundating it out- of- season with high winter flow releases. This probably makes for a “harsh” and unpredictable habitat for marginal vegetation dependent macroinvertebrate species. On the other hand during flow regulation the available habitat for the Stones and GSM biotopes is probably least affected, as are species dependant on those biotopes.

For the Vegetation biotope (Figure 7.20) there appeared to be no seasonal pattern in the response of aquatic communities, other than perhaps the Nagle site which was most different from the Karkloof River control during winter (August 2003), and late summer (March 2004). At all other sampling occasions during the study the Nagle composition is virtually identical to the Karkloof River control (virtually on the same horizontal line and hence little deviation). This appears to imply that the unseasonal “high” winter flows may still be having some effect on the aquatic macroinvertebrates downstream of Albert Falls as far as Nagle Dam as well as possible influences from incremental catchments between Albert Falls and Nagle in summer. This is in contrast to the results obtained using the simple SASS indices. Within the Vegetation biotope the Albert Falls site is again consistently the most different from the Karkloof River reference site.

In many respects the GSM biotope showed a similar pattern to that exhibited by the Stones biotope. Namely, of all sites considered, the Albert Falls site was most different to the Karkloof River control, and this difference most pronounced during the winter periods (August 2003 and June 2004) (Figure 7.21). All other sites studied in this biotope were in many respects compositionally virtually the same as the Karkloof River control (small deviation around the horizontal line).

An examination of the species counts (richness) of each of the biotopes (Figures 7.22 to 7.24) further illustrates some of the differences between sites and between seasons. (Note that the scale on the Y axis (species counts) are all kept the same for comparative purposes).

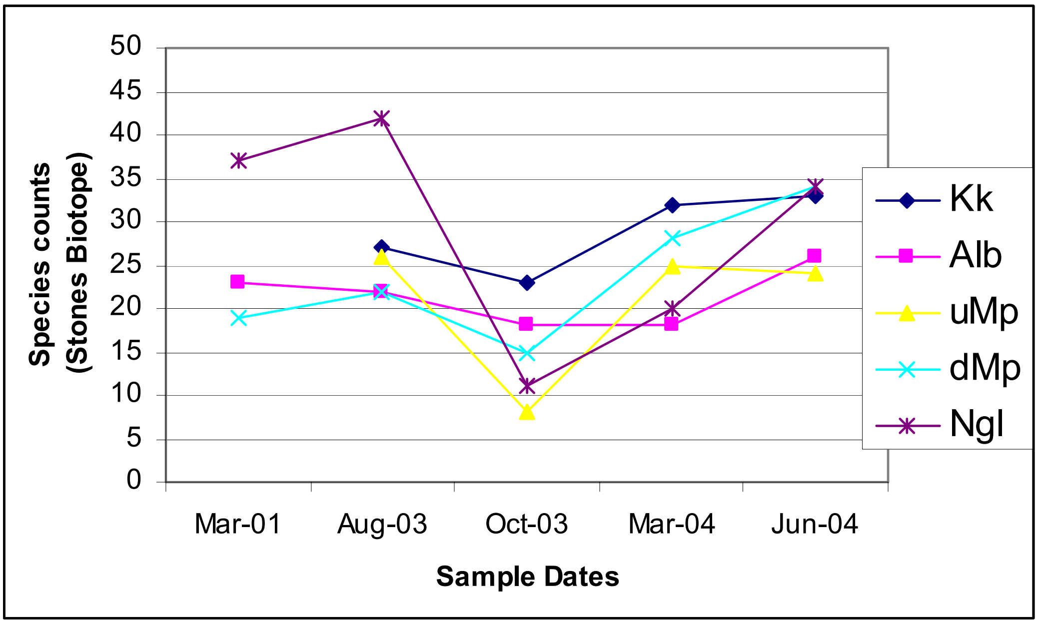

Figure 7.22: Species counts for all sites over all seasons sampled for the Stones biotope

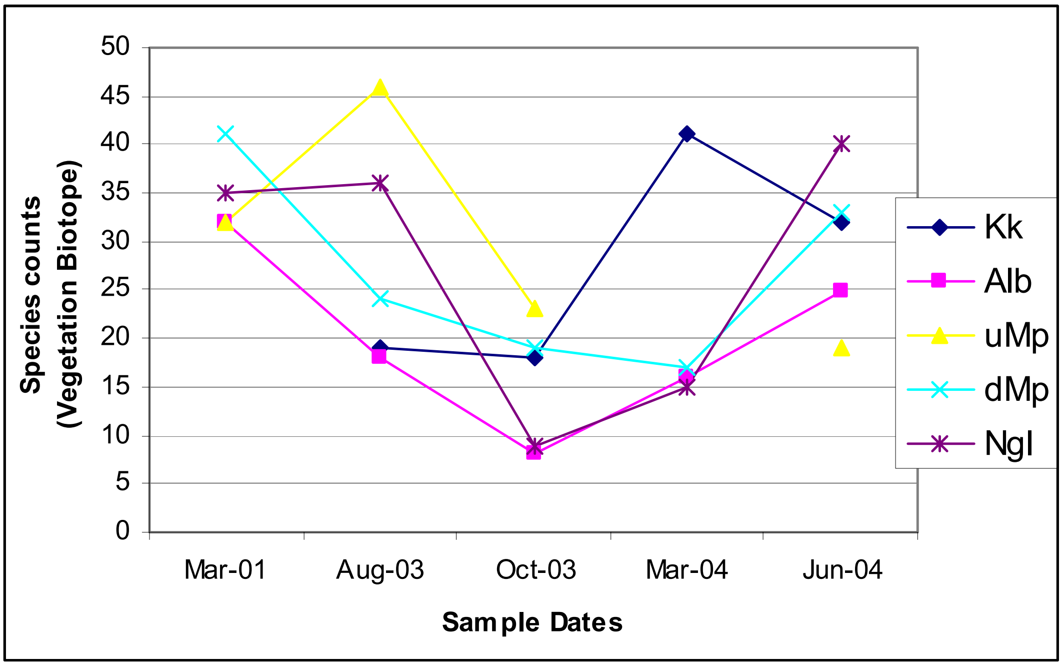

Figure 7.23: Species counts for all sites over all seasons sampled for the Vegetation biotope

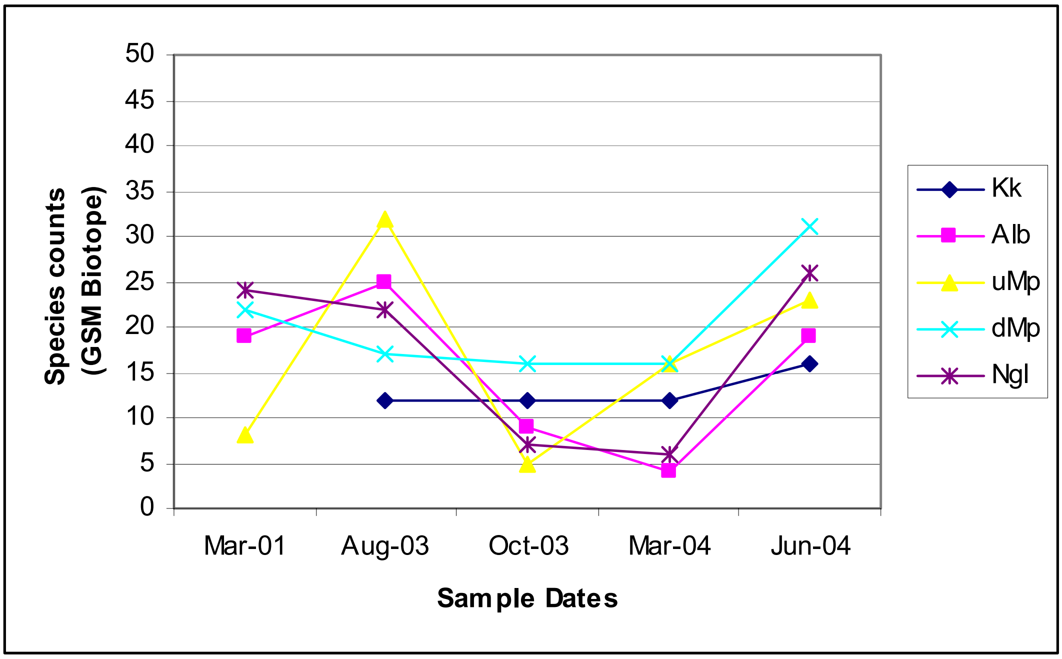

Figure 7.24: Species counts for all sites over all seasons sampled for the GSM biotope

Overall the Albert Falls sites generally show the lowest species counts (low diversity) of all sites monitored (particularly evident in the Vegetation biotope). On the other hand the Karkloof River control site tended to have the highest overall species counts, particularly in the Stones and Vegetation biotopes, although it only it displayed low to moderate diversity in the GSM biotopes. Winter (August 2003 and June 2004) appears to be the most species rich time of the year for all sites, with early summer showing the lowest diversity (October 2003) for the Stones and Vegetation biotopes and late summer (March 2004) the lowest for the GSM biotope. The higher species diversity in winter probably contributes to the sensitivity of these systems to flow modification in the winter months as illustrated by the PRC analyses.

### Species level interpretations of response to the Albert Falls impoundment on the uMngeni River

It is perhaps informative to examine which species were accounting for the clear distinction between Albert Falls and all other sites.

As previously mentioned, in the PRC analyses the accompanying species weights allow for an interpretation of which species are more likely to follow the actual pattern observed in the PRC curves. In the PRC analysis of the Stones biotope there is a clear grouping of species with high species weights. The Albert Falls sites have high positive weights (dominance) for Simulid species (*S. adersi, S. nigritarse* & *S. hargreavesi*) with some of the caddisfly species including, *Cheumatopsyche afra* and *Amphipsyche scottae,* also present, whilst they are lacking (high negative weights) the stonefly *Neoperla spio* and riffle beetles (Elmidae). To further illustrate this situation Figures 7.25 & 7.26 provide an alternative graphical picture.

In Figure 7.25 the clear abundance of the Simulids in the Albert Falls site compared to the Karkloof River site is obvious, as is the virtual lack of Elmids (Riffle Beetles) and *Neoperla spio* (Stoneflies) in the Albert Falls site whilst the Karkloof River has a greater relative abundance of planarians (*Dugesia* spp.) and Cain flies (*Caenis* spp.), compared to the Albert Falls site (Figure 7.26).

Clearly a large number of graphs would be needed to illustrate the same amount of information as shown by the PRC figures. Hence all further interpretations were based on the more efficient and respective PRC figures.

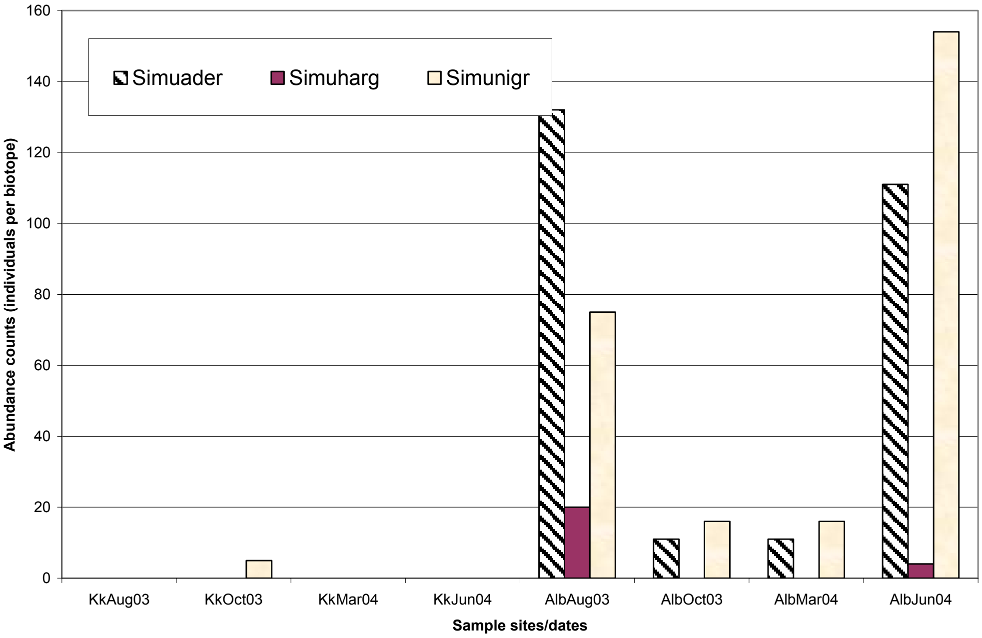

Figure 7.25: Summary abundance counts for Simulid species separating Albert Falls sites (Alb) from the Karkloof River reference site (Kk) in the Stones biotope.
Simuader = *Simulium adersi* ; Simuharg = *Simulium hargreavesi* ;
Simunigr = *Simulium nigritarse*.

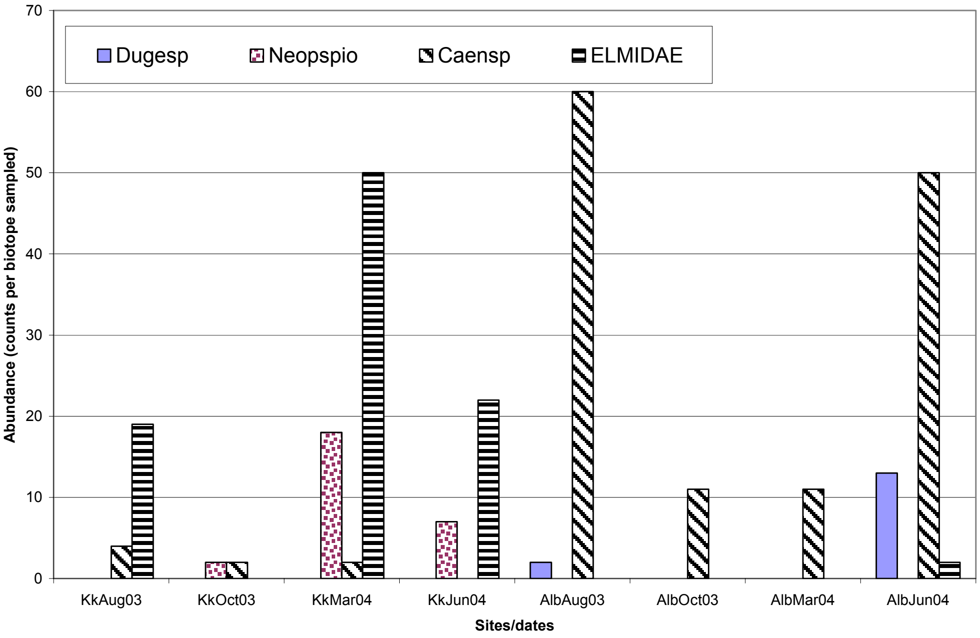

Figure 7.26: Summary abundance counts for Dugesia (planaria), stonefly (Neoperla spio), Caenis spp. and riffle beetles (Elmidae) separating Albert Falls sites (Alb) from the Karkloof River reference site (Kk) in the Stones biotope. Dugesp = *Dugesia sp*; Neopspio = *Neoperla spio*; Caensp = *Caenis sp.;* Elmidae = Riffle Beetle (no species identification made).

Examining the species in the Vegetation PRC analysis, shows that the Albert Falls sites again have high positive weights (dominance) for Simulid species (*S. adersi* & *S. hargreavesi*) with the same caddisfly species, *Cheumatopsyche afra,* also dominant as was noted in the Stones biotope. These sites were lacking (high negative weight) the caddisfly, *Leptocerina* spp. Similarly the GSM analysis also indicates that it is the Simulid species (*S. adersi, S. hargreavesi* & *S. nigritarse*) and again the caddisfly, *Cheumatopsyche afra* (amongst others taxa) which are responsible for the separation of the Albert Falls sites from the Karkloof River control.

What is significant about most of these species is that they are largely filter feeders during the larval stage of their life cycle, i.e. they obtain suspended food particles from the water column, either by a catchnet (the caddisfly larvae, e.g. Hydropsychidae) or by filter feeding mouth parts (the black fly, Simulium, larvae) (McCafferty, 1999). The regular and consistent winter flow releases from Albert Falls Dam, to maintain the water supply in the downstream Nagle Dam, will undoubtedly contribute a regular and consistent food source for these larvae present at the Albert Falls site.

Other studies (e.g. Palmer & O'Keeffe, 1990) have shown a similar response of simuliids increasing below an impoundment. Species identified in this study on the uMngeni, which were common to that reported by Palmer and O'Keeffe (1990) on the Great Fish (below the Elandsdrift Dam in the Eastern Cape), were *S. adersi* and *S. nigritarse*. Additionally, *S. hargreavesi* was noted in this study on the uMngeni to increase in response to the regulated flow regime below Albert Falls Dam.

Although there was a replacement of *Cheumatopsyche thomasseti* by *C. afra* on the Great Fish River study (Palmer & O'Keeffe, 1990), this did not appear to be the case in this uMngeni study. Even though the former species was present in the system, it never really dominated. However the latter species was one of the dominant species differentiating the Albert Falls site from all other sites monitored (and particularly from the Karkloof River reference site – Figure 7.19). This was again in accordance then with previous studies showing this species (*C. afra*) as a dominant caddisfly (trichopteran) below an impoundment with regulated flows. Chutter (1969) has shown that in the Vaal River *C. afra* usually occurs in large numbers in the eroding zone of a the river, with Scott (1974) reporting this species as occurring in fast-flowing water, generally in stony runs and cascades from the mountain torrent zone to the foothills. Additionally it is normally found in clear, clean streams (Scott, 1974). Most of these conditions correspond with those noted at the sample site below the Albert Falls impoundment, i.e. relatively fast, clear, clean water discharged from the dam, onto and through the Albert Falls falls and associated stony runs and cascades.

Harrison (1966) noted that *C. afra* (along with *C. thomasseti*) was amongst the last species to colonise a newly inundated river following a severe drought and at first reading appears to be in contrast to the assertion of Skoroszewski & de Moor (1999) that these species will be adversely affected in regions downstream of impoundments. This present study has shown in fact that *C. afra*, in particular, appears to favour the site immediately downstream of the Albert Falls dam, and in fact is one of the key species which distinguishes this site from all the other sample sites in this study. This is understandable from the point of view that its late appearance in the successional recovery reported by Harrison (1966) is at a point where the system has recovered and is showing consistent flows. This is exactly the same situation as illustrated in the consistent flow conditions demonstrated below Albert Falls dam.

The co-dominance by Simuliidae at this site below the Albert Falls dam is consistent with the feeding behaviour of *C. afra*, (preying on drifting organisms caught in their nets) as reported in previous studies, with Chutter (1968), Scott (1974 & 1983) and de Moor (1992) describing them preying on a variety of macroinvertebrates, particularly Simuliidae. Interestingly too, the dominance of the filter feeding Hydropsychidae (*C. afra*), and simuliid species is an indication that filter feeding is the major functional feeding component below the dam. Compared to the Karkloof River reference site, these two major macroinvertebrate groups (i.e. simuliids and *C. afra*) appear to consistently differentiate the Albert Fall sample site from the other sample sites downstream on the uMngeni River.

At the other end of the spectrum the absence of the predatory stonefly (*Neoperla spio*) is one of the species that characterises the stones biotope at sites some distance below the Albert Falls dam but is largely absent from the site immediately below the wall (e.g. high negative weights on Figure 7.19). This species has been reported by Skoroszewski & de Moor (1999) as being a good indicator of moderate to large flow discharge conditions as well as an umbrella species whose presence ensures other that other species requiring similar flow conditions will also be protected. Its presence in sufficient numbers is also reported as being essential to maintaining diversity of species and helping prevent a few species from dominating and becoming pests (Skoroszewski & de Moor, 1999). These latter authors also report on its dependence for very fast-flowing or cool water. It could be speculated that the flow regulation below Albert Falls may in part account for its absence below the dam.

Another interesting species interpretation made in Figure 7.19 was the characterisation of the Albert Falls sites by the *Caenis spp*. Within the Lesotho highlands this mayfly family (Caenidae) has been reported by Skoroszewski & de Moor (1999) as becoming more abundant after the completion of Katse Dam, probably reflecting a more stable substrate not influenced so frequently by flash floods. This too would be a classical response in a river below a regulated discharge as is happening in this Albert Falls study.

Colwell (1974), amongst others, has highlighted the importance that patterns of temporal fluctuation in physical phenomena have on biological systems. More recently, and in the context of aquatic systems, it appears to be a key driver of the Simuliidae and other filter feeding populations found on regulated rivers below impoundments (e.g. Rivers-Moore et al., 2006). Colwell (1974) defines various measures of the predictability and constancy of these phenomena but for the purposes of this study the coefficient of variation (CV%) of the flow for each survey period was used as a measure of the constancy of the flow at each sample site. Whilst the flow variability as an environmental determinant was not statistically significantly correlated to the pattern of variability in the species data (Table 7.10), it still appears to be worthy of examination to better understand the impact of flow regulation below the dam. This data is summarised in Table 7.13 and Figure 7.27 to illustrate the "constancy" of flow below the Albert Falls Dam, as compared to the unregulated Karkloof River reference site.

Table 7.13: Coefficient of variation in flow data for the month preceding biological sampling

| | Sample Sites | | | | |
|---|---|---|---|---|---|
| Sample Period | Karkloof (Kk) | Albert Falls (Alb) | Upstream Mpolweni (uMp) | Downstream Mpolweni (dMp) | Upstream of Nagle Dam (Ngl) |
| Mar-01 | 59.94 | 43.49 | 43.49 | 44.90 | 45.97 |
| Aug-03 | 21.10 | 6.40 | 6.40 | 7.58 | 10.10 |
| Oct-03 | 29.86 | 6.70 | 6.70 | 7.42 | 5.60 |
| Mar-04 | 88.13 | 18.00 | 18.00 | 52.01 | 51.17 |
| Jun-04 | 12.68 | 21.55 | 21.55 | 21.06 | 24.41 |

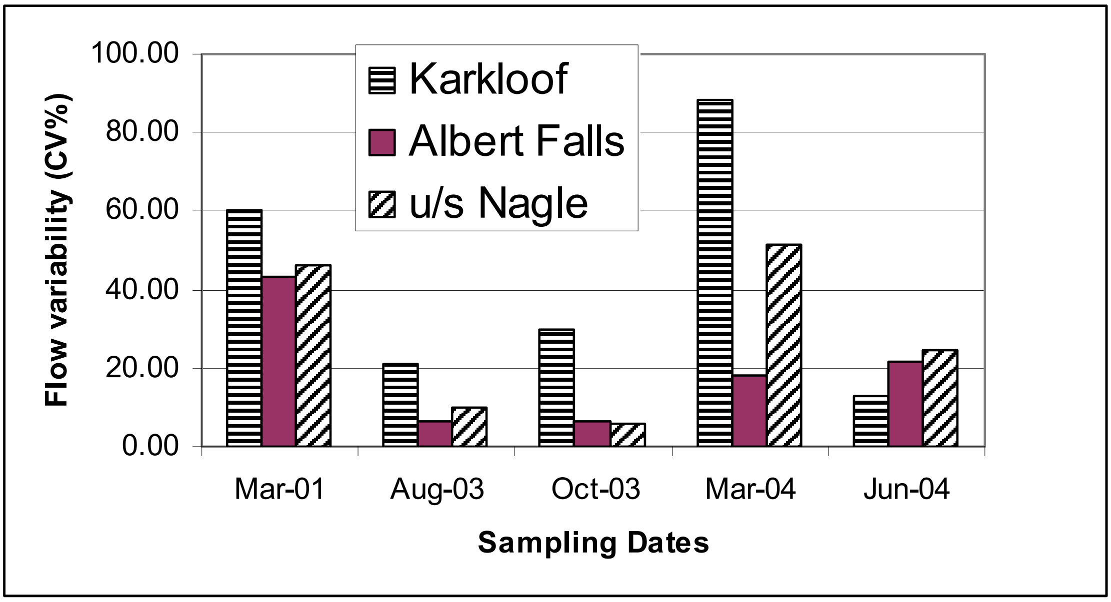

Figure 7.27: Flow variability (as measured by coefficient of variability - CV%) for selected sites in the month preceding biological sampling.

The graphical display (Figure 7.27) of selected sites (data) from Table 7.13 is informative as it shows the seasonal and geographical separation of flow variability in response to the Albert Falls impoundment. For ease of illustration only 3 sites were chosen to display – these were the Karkloof River reference, the uMngeni immediately downstream of Albert Falls and then the Nagle site, furthest from the Albert Falls impoundment.

A number of observations may be made from Figure 7.27.

- March consistently appears to have the highest flow variability. This would be expected in a summer rainfall area in response to natural rainfall events
- Winter (August and June) appears to have the lowest flow variability, probably in response to low rainfall and sustained/regular base flows.
- The Karkloof River control site consistently has the highest and most natural flow variability (other than in June 2004), again to be expected and in response to an unregulated catchment where river flows respond to episodic rainfall events.

- All sites during March 2001 had high flow variability due to Albert Falls Dam spilling during that period (see Figure 7.17) and reflecting a more natural and variable flow.
- Thereafter the sites below the dam had relatively low flow variability in response to regulated and consistent flows/releases from the dam.

The Albert Falls impoundment is clearly having a significant impact on the natural flow regime of the uMngeni River below the dam, and this particularly so when the dam is not full. Along with a consistent supply of suspended food this is probably contributing to the dominance of filter feeding macroinvertebrates below the dam.

A great variety of food items are reported in black fly larval diets: fungal spores and mycelia, silt, detritus, Rotifera, several species of algae and diatoms (Peterson, 1956; Kuznetsov, 1981). Chutter (1968) also suggests that *Simulium* numbers are linked to microplankton food supply as well as suitable current velocities. Coetzee (1982) similarly noted that the increase in black fly populations succeeding the completion of the inter-basin transfer (IBT) on the Great Fish River were likely to be due to the combined effects of permanent flows, faster current speeds and increased food supply, all factors likely to have “improved” in favour of the black fly below Albert Falls Dam. Coincidentally Simuliid (blackfly) numbers in the uMngeni River between Midmar Dam and Albert Falls were reported (Natal Witness 8/11/06) to be at very high nuisance levels. This could in part be attributed to the flow regulation in the uMngeni below Midmar and Albert Falls Dams.

In a study of streams downstream of hydroelectric schemes in Sweden, Zhang et al. (1998) found that regulated sites showed an increase in Simuliid numbers, and an associated decrease in predators and competitors. They further propose that under conditions of flow disturbance (un-natural flow regime) black fly larvae are better able to cope than their predators and competitors (Zhang et al., 1998). The results from this study on the Albert Falls Dam in many ways corroborate those findings, with black fly (and other filter feeders) the dominant taxa accounting for differences between the unregulated Karkloof River control site and the Albert Falls site.

However within a relatively short distance downstream of the dam the “natural” composition of the aquatic macroinvertebrate fauna is largely restored compared to that exhibited by the unregulated Karkloof river (Figures 7.19 to 7.21), particularly for the Stones and GSM biotopes. The Vegetation biotope appears to be more variable and takes longer (distance downstream) to return to the control type “natural” community (Figure 7.20).

## Summary Discussion of Aquatic Macroinvertebrate Results

### Analysis of historical SASS indices to determine if there is an impact in response to flow regulation below Albert Falls

Historical data (1993 to 2006) existed on three sites which allowed an examination of the possible impacts that flow regulation below Albert Falls may be having on aquatic macroinvertebrates. These sites were:

- On the Karkloof River, upstream of its confluence with the uMngeni River and Albert Falls Dam (RKK003 or Kk).
- On the uMngeni River downstream of Albert Falls Dam and immediately downstream of the confluence with the Mpolweni River (above the Wartburg road) (RMG012 or dMp)
- Immediately above the gauging station and weir at the inflow to Nagle Dam (RMG013 or Ngl)

The Karkloof River control (or reference) site (RKK003 or Kk) was compared with the two downstream sites.

Results of this analysis on the historical unpaired data firstly indicates that it is only on the basis of comparisons between the SASS ASPT index, is there a statistically significant difference between sites. In all cases the control site on the Karkloof River is found to be statistically significantly different from both the uMngeni downstream of the Mpolweni confluence and the uMngeni upstream of Nagle Dam. Exactly the same picture emerges with the analysis of the paired data. In all of these instances the mean of the SASS ASPT index for the control site on the Karkloof River is always higher than that measured on the uMngeni River sites. Interestingly too is the fact that of the two uMngeni River sites, the lowermost site (with the greatest chance of recovery from the impacts of the dam regulated flows) has the higher ASPT index (more similar to the Karkloof River control). Although there are statistically significant differences between the control and the "impacted" sites (as measured by the ASPT) the differences are relatively small in real terms (and as related to draft river health class boundaries) – changing from a "natural" on the Karkloof River to "good" on the two sites on the uMngeni.

To determine if there was a greater seasonal impact (due to the unseasonal high winter flows), paired seasonal data were next considered. Results showed:

- That in both site comparisons made (Karkloof River vs. uMngeni downstream of Mploweni, and Karkloof River vs. uMngeni upstream of Nagle Dam) there were statistically significant differences between the SASS ASPT indices in <u>both</u> summer and winter.
- Furthermore for the Karkloof River vs. uMngeni downstream of Mpolweni confluence site (closest to Albert Falls Dam) comparison there was a clearly non-significant difference between the paired SASS score data during summer but that in winter this difference was only marginally statistically significant.
- However by time the river has travelled down to Nagle Dam this difference has swung the other way around, i.e. the summer SASS score differences are marginally significant with the winter differences clearly not significantly different.

The reasons for this could be speculated as follows:

- The high and un-seasonal winter base flows below Albert Falls Dam are having an impact on the SASS scores during the winter months but the incremental summer flows from the Mpolweni are ameliorating this impact for sites monitored below the Mpolweni/uMngeni confluence.
- Once the river has reached Nagle Dam during winter the impact of the high winter base flows have been moderated by biophysical processes in the river and are hence not showing up as significant, whilst on the other hand summer flushing from polluted side tributaries (Mpolweni and feedlots around the upper/middle reaches of the river) could be influencing water quality at the lowermost site on the uMngeni.

A geographically more detailed, albeit temporally shorter investigation into SASS indices below Albert Falls compared to the Karkloof River control site showed a significant drop in the respective SASS indices below the Albert Falls Dam. However with increasing distance from the Albert Falls impoundment, down the uMngeni River towards the last site monitored at the weir above Nagle Dam, there were clear signs of recovery in the respective indices. To test if these differences were statistically significant appropriate statistical tests were applied and only the SASS score and number of taxa were shown to be statistically significantly different between the Karkloof River control site and the first site below the Albert Falls impoundment, with the ASPT comparison almost statistically significant.

In other words, by the time the river has travelled some 4 km downstream of the Albert Falls Dam, based on the SASS indices alone there appears to be no statistically significant difference between the results obtained on the Karkloof River control site and the paired monitoring sites on the uMngeni River (uMngeni u/s Mpolweni, uMngeni d/s Mpolweni & uMngeni u/s Nagle Dam).

To examine this picture further, the underlying taxa collected in the SASS analyses were investigated using multivariate statistical tools, primarily Principal Response Curves (PRC) analysis. The PRC figures represented the principal pattern in community response over time with respect to the Karkloof River reference or control site, i.e. how did the temporal changes in family level composition at each site differ from that at Karkloof River. Key results from those analyses are summarised as follows.

**Analyses of SASS taxa to determine if there is an impact in response to flow regulation below Albert Falls**

In comparing the temporal patterns of sites observed with respect to the Karkloof River control, the Albert Falls and Nagle sites were focused on in interpretation as these are geographically furthest apart down the uMngeni River and hence likely to be most distinct **if** the Albert Falls Dam was having a large effect. The Albert Falls site was also least likely to be affected by other confounding effects of water quality changes from incremental subcatchments of the uMngeni downstream of the dam, and hence most likely to express the impact of the impoundment.

The most obvious feature of the PRC figures is how different the Albert Falls site (immediately below the dam) is from the Nagle site (furthest from the Albert Falls Dam) when compared to the Karkloof River control. This is most evident in the gravel, sand and mud (GSM) and vegetation (Veg) biotopes respectively, with the Albert Falls site consistently different in composition from the Karkloof River in GSM whilst Nagle appears to vary in dissimilarity from the Karkloof River. At times the Nagle site has almost the same composition as the Karkloof River control whilst at others it is distinctly different (e.g. August 2003). Interestingly, for the GSM samples, the composition of the Nagle sites is most similar to the Karkloof River site during the "high" summer stream flow seasons, when it would be anticipated that the incremental flows from tributaries to the uMngeni between Albert Falls and Nagle Dam have had a chance to "reset" the biological condition of the lower reach of the river and make it more closely similar to that observed in the control site.

The unseasonal "high" winter flow season appears to be the time displaying the greatest taxonomic difference between the Karkloof River control site and all other sites sampled. This feature appeared to repeat itself for all biotopes examined (Stones, Vegetation & GSM), whilst summer had generally minimal separation between sites and the Karkloof River control.

Within the Vegetation biotope, the Nagle site initially has almost the same composition as the control site in March 2001, but from there onwards is always different until March 2004 again. It appears that the late summer, high base flows during March in the lower portion of the uMngeni River above Nagle, "resets" the biota to being more like that noted in the control site on the Karkloof River. It is noteworthy that at the start of the study Albert Falls was spilling and hence had probably "reset" the aquatic biota in the river downstream of the impoundment which may help explain the initial similar composition of most sites in the vegetation biotope.

A similar pattern emerges in the Stones biotope where the community composition in the March monitoring on the Nagle sites is closely allied to the community observed in the control site on the Karkloof River. In the Stones biotope, Albert Falls is consistently different from the Karkloof River. Again the unseasonal "high" winter flow season shows the widest separation (difference in community composition) between the Karkloof River control site and all other sites, implying the greatest impact on taxonomic composition.

In terms of the taxonomic responses to differences between the reference and study sites, it appears that the Simuliidae are important in differentiating the Albert Falls site, particularly in the Stones and Vegetation biotopes, and then to lesser degree in the GSM biotope. Coenagrionidae (amongst a range of others) appear to distinguish the Nagle sites from the Karkloof River in the Vegetation biotope.

We can therefore perhaps conclude that the environment at the Albert Falls site might be different in some way that causes the temporal pattern of community change there to differ consistently from that of the reference Karkloof River site (in a way that none of the other sites appear to do). This difference is also markedly different from the site furthest downstream (Nagle), particularly in the GSM and Veg biotopes. There appears to be no other systematic similarity in the pattern for the other sites examined on the uMngeni, above or below the Mpolweni confluence.

In order to determine the temporal pattern in stream physico-chemical (environmental) characteristics of Albert Falls and how these differ from the Karkloof River control, and the other sites, a similar analysis using PRCs was applied to the environmental data set. The key question was to determine if there were patterns or variations in the environmental data set which firstly:

- differentiated the surveyed sites from the Karkloof River control site; and secondly

- mirrored that observed in the biological data.

The results of this analysis suggest that the temporal pattern of change in the water quality at Albert Falls, (and all other sites downstream of the dam) whilst differing most markedly from the Karkloof River during the summer sampling, was generally similar to the Karkloof River at other times. This was in contrast to the biological picture which emerged during the PRC analysis of aquatic macroinvertebrate data when the summer "reset" generally allowed sites to resemble more closely the composition displayed by the Karkloof River site, particularly for sites some distance downstream from the Albert Falls Dam.

The site on the uMngeni downstream of the confluence with the Mpolweni (dMp = RMG012) showed the same general trend as the others, but much more enhanced in August & October 2003. The "species" (water quality) weights indicate that this is because of high levels of certain determinants, e.g. *E. coli*, $NO_3$, DO, SRP, TP, & Turbidity. Most of these results are understandable from the point of view of higher organic enrichment and nutrient loads emanating from the Mpolweni catchment which is typically more polluted than the uMngeni. Higher DOs may be an anomaly in this respect as it typically declines with increased pollution. Higher saturated dissolved oxygen, conductivity and free (un-ionised) ammonia also appear to differentiate the surveyed sites on the uMngeni from the Karkloof River control. These determinants are also typically higher during the summer months.

A correlation analysis between the biological family level data and measured environmental determinants showed none of the determinants were statistically significantly correlated with the biological data. Hence it appears that there is some as yet unmeasured environmental parameter(s) which occurs during the high unseasonal winter flow season which is impacting upon and accounting for the biological picture displayed by the macroinvertebrates. To better understand which specific species were responding to this regime, PRC analyses were repeated for respective biotopes but in this instance using the macroinvertebrate data identified down to the highest possible taxonomic resolution (in most cases species level data).

**Analyses of aquatic macroinvertebrate species data to determine if there is an impact in response to flow regulation below Albert Falls**

Analysis of the species level data followed the same process as that applied to the family level data. A number of interesting features emerge from these analyses.

Firstly, the Albert Falls site consistently (i.e. over all biotopes) showed the largest compositional variance compared to the control. This was particularly evident in the Stones biotope which showed the Albert Falls sites as being most compositionally distinct from the Karkloof River control. In other words the aquatic macroinvertebrate species in the Stones biotope at the Albert Falls sampling site was the most changed/impacted compared to the Karkloof River control.

For the Vegetation biotope there appeared to be no strong seasonal pattern in the response of aquatic communities, other than perhaps the Nagle site which was most different from the Karkloof River control during winter (August 2003). At all other sampling occasions during the study, the Nagle composition is virtually identical to the Karkloof River control. This appears to imply that the unseasonal "high" winter flows (at least during August 2003) may still be having some effect on the aquatic macroinvertebrates downstream of Albert Falls as far as Nagle Dam. This is in contrast to the results obtained using the simple SASS indices. Within the Vegetation biotope the Albert Falls site is again consistently the most different from the reference site, and this generally most strongly during the winter periods (August 2003 & June 2004).

Of the three biotopes sampled, the vegetation biotope appears to show the greatest general variation across respective sampling sites down the uMngeni River, as compared to the Karkloof River control site. This was most pronounced during the winter flow periods (August 2003 & June 2004). The stones and GSM biotopes were all much more consistent and similar to the Karkloof River in their composition across all uMngeni sites, except for the already mentioned Albert Falls site. Rapid and unseasonal flow changes in response to flow regulation below the Albert Falls impoundment may well be responsible for this effect, having the greatest impact on the marginal vegetation and least impact on the in-stream Stones and GSM biotopes. The probable mechanism for this impact is by either leaving the marginal vegetation "high and dry" during the summer (as the dam captures the normal spates and freshettes which would otherwise inundate the marginal vegetation) and/or inundating it out-of-season with high winter flow releases. This probably makes for a "harsh" and unpredictable habitat for marginal vegetation dependent macroinvertebrate species. On the other hand during flow regulation the available habitat for the Stones and GSM biotopes are probably relatively least affected, as are species dependant on those biotopes and who are able to migrate and "follow" suitable habitat with the changing water levels.

In many respects the GSM biotope showed a similar pattern to that exhibited by the Stones biotope. Namely, of all sites considered, the Albert Falls site was most different to the Karkloof River control, and this difference most pronounced during the winter periods. All other sites studied in this biotope were in many respects compositionally virtually the same as the Karkloof River control.

An examination of the species counts (richness) of each of the biotopes further illustrates some of the differences between sites and between seasons. Overall the Albert Falls sites generally show the lowest species counts (low diversity) of all sites monitored (particularly evident in the Vegetation biotope). On the other hand the Karkloof River control site tended to have the highest overall species counts, particularly in the Stones and Vegetation biotopes, although it only displayed low to moderate diversity in the GSM biotopes. Winter appears to be the most species rich time of the year for all sites, with early summer showing the lowest diversity for the Stones and Vegetation biotopes and late summer the lowest for the GSM biotope. The higher species diversity in winter probably contributes to the sensitivity of these systems to flow modification in the winter months as illustrated by the PRC analyses.

As previously mentioned, in the PRC analyses the accompanying species weights allow for an interpretation of which species are more likely to follow the actual pattern observed in the PRC curves. In the PRC analysis of the Stones biotope there is a clear grouping of species with high species weights. The Albert Falls sites have high positive weights (dominance) for Simulid species (*S. adersi, S. nigritarse* & *S. hargreavesi*) with some of the caddisfly species including, *Cheumatopsyche afra* and *Amphipsyche scottae,* also present, whilst they are lacking (high negative weights) the stonefly *Neoperla spio* and riffle beetles (Elmidae).

Within the Vegetation biotope analysed the Albert Falls sites again have high positive weights (dominance) for Simulid species (*S. adersi* & *S. hargreavesi*) with the same caddisfly species, *Cheumatopsyche afra,* also dominant as was noted in the Stones biotope. These sites were lacking the caddisfly, *Leptocerina* spp. Similarly the GSM analysis also indicates that it is the Simulid species (*S. adersi, S. hargreavesi* & *S. nigritarse*) and again the caddisfly, *Cheumatopsyche afra* (amongst others taxa) which are responsible for the separation of the Albert Falls sites from the Karkloof River control.

What is significant about most of these species is that they are largely filter feeders during the larval stage of their life cycle, i.e. they obtain suspended food particles from the water column, either by a catchnet (the caddisfly larvae, e.g. Hydropsychidae) or by filter feeding mouth parts (the black fly, Simulium, larvae) (McCafferty, 1999). The regular and consistent winter flow releases from Albert Falls Dam, to maintain the water supply in the downstream Nagle Dam, will undoubtedly contribute a regular and consistent food source for these larvae present at the Albert Falls site.

Other studies (e.g. Palmer & O'Keeffe, 1990) have shown a similar response of simuliids increasing below an impoundment. Species identified in this study on the uMngeni, which were common to that reported by Palmer and O'Keeffe (1990) on the Great Fish (below the Elandsdrift Dam in the Eastern Cape), were *S. adersi* and *S. nigritarse*. Additionally, *S. hargreavesi* was noted in this study on the uMngeni to increase in response to the regulated flow regime below Albert Falls Dam.

Although there was a replacement of *Cheumatopsyche thomasseti* by *C. afra* on the Great Fish River study (Palmer & O'Keeffe, 1990), this did not appear to be the case in this uMngeni study. Even though the former species was present in the system, it never really dominated. However the latter species was one of the dominant species differentiating the Albert Falls site from all other sites monitored (and particularly from the Karkloof River reference site – Figure 7.19). This was in accordance with previous studies showing this species (*C. afra*) as a dominant caddisfly (trichopteran) below an impoundment with regulated flows. Chutter (1969) has shown that in the Vaal River *C. afra* usually occurs in large numbers in the eroding zone of a the river, with Scott (1974) reporting this species as occurring in fast-flowing water, generally in stony runs and cascades from the mountain torrent zone to the foothills. Additionally it is normally found in clear, clean streams (Scott, 1974). Most of these conditions correspond with those noted at the sample site below the Albert Falls impoundment, i.e. relatively fast, clear, clean water discharged from the dam, onto and through the Albert Falls falls, and associated stony runs and cascades.

Harrison (1966) noted that *C. afra* (along with *C. thomasseti*) was amongst the last species to colonise a newly inundated river following a severe drought. At first reading this appears to be in contrast to the assertion of Skoroszewski & de Moor (1999) that these species will be adversely affected in regions downstream of impoundments. This present study has shown in fact that *C. afra*, in particular, appears to favour the site immediately downstream of the Albert Falls dam, and in fact is one of the key species which distinguishes this site from all the other uMngeni sample sites in this study. This is understandable from the point of view that its late appearance in the successional recovery reported by Harrison (1966) is at a point where the system has "recovered" and is showing consistent flows. This is exactly the same situation as illustrated in the consistent flow conditions demonstrated below Albert Falls dam.

The co-dominance by Simuliidae at the site immediately below the Albert Falls dam is consistent with the feeding behaviour of *C. afra*, (preying on drifting organisms caught in their nets) as reported in previous studies, with Chutter (1968), Scott (1974 & 1983) and de Moor

(1992) describing them preying on a variety of macroinvertebrates, particularly Simuliidae. Compared to the Karkloof River reference site, these two major macroinvertebrate groups (i.e. simuliids and *C. afra*) appear to consistently differentiate the Albert Fall sample site from the other sample sites downstream on the uMngeni River and their dominance is an indication that filter feeding is the major functional feeding component below the dam.

At the other end of the spectrum the absence of the predatory stonefly (*Neoperla spio*) is one of the species that characterises the stones biotope at sites some distance below the Albert Falls dam but is largely absent from the site immediately below the wall (e.g. high negative weights on Figure 7.19). This species has been reported by Skoroszewski & de Moor (1999) as being a good indicator of moderate to large flow discharge conditions, as well as an umbrella species whose presence ensures other that other species requiring similar flow conditions will also be protected. Its presence in sufficient numbers is also reported as being essential to maintaining diversity of species and helping prevent a few species from dominating and becoming pests (Skoroszewski & de Moor, 1999). These latter authors also report on its dependence for very fast-flowing or cool water. It could be speculated that the flow regulation below Albert Falls may in part account for its absence below the dam.

Another interesting species interpretation made was the characterisation of the Albert Falls sites by the *Caenis spp*. Within the Lesotho highlands this mayfly family (Caenidae) has been reported by Skoroszewski & de Moor (1999) as becoming more abundant after the completion of Katse Dam, probably reflecting a more stable substrate not influenced so frequently by flash floods. This too would be a classical response in a river below a regulated discharge as is happening in this Albert Falls study.

Colwell (1974), amongst others, has highlighted the importance that patterns of temporal fluctuation in physical phenomena have on biological systems. More recently, and in the context of aquatic systems, it appears to be a key driver of the Simuliidae and other filter feeding populations found on regulated rivers below impoundments (e.g. Rivers-Moore et al., 2006). Colwell (1974) defines various measures of the predictability and constancy of these phenomena but for the purposes of this study the coefficient of variation (CV%) of the flow for each survey period was used as a measure of the constancy of the flow at each sample site. Whilst the flow variability as an environmental determinant was not statistically significantly correlated to the pattern of variability in the species data, it still appeared worthy of examination to better understand the impact of flow regulation below the dam.

A number of observations may be made from that aspect of the study:

- March consistently appears to have the highest flow variability. This would be expected in a summer rainfall area in response to natural rainfall events
- Winter (August and June) appears to have the lowest flow variability, probably in response to low rainfall and sustained/regular base flows.
- The Karkloof River control site consistently has the highest and most natural flow variability (other than in June 2004), again to be expected and in response to an unregulated catchment where river flows respond to episodic rainfall events.
- All sites during March 2001 had high flow variability due to Albert Falls Dam spilling during that period (see Figure 7.17) and reflecting a more natural and variable flow.
- Thereafter the sites below the dam had relatively low flow variability in response to regulated and consistent flows/releases from the dam.

The Albert Falls impoundment is clearly having a significant impact on the natural flow regime of the uMngeni River below the dam, and this particularly so when the dam is not full. Along with a consistent supply of suspended food, this is probably contributing to the dominance of filter feeding macroinvertebrates below the dam.

A great variety of food items are reported in black fly larval diets: fungal spores and mycelia, silt, detritus, Rotifera, several species of algae and diatoms (Peterson, 1956; Kuznetsov, 1981). Chutter (1968) also suggests that *Simulium* numbers are linked to microplankton food supply as well as suitable current velocities. Coetzee (1982) similarly noted that the increase in black fly populations succeeding the completion of the inter-basin transfer (IBT) on the Great Fish River were likely to be due to the combined effects of permanent flows, faster current speeds and increased food supply, all factors likely to have “improved” in favour of the black fly below Albert Falls Dam. Coincidentally Simuliid (blackfly) numbers in the uMngeni River between Midmar Dam and Albert Falls were recently reported (Natal Witness 8/11/06) to be at very high nuisance levels. This could in part be attributed to the flow regulation in the uMngeni below Midmar and Albert Falls Dams.

In a study of streams downstream of hydroelectric schemes in Sweden, Zhang et al. (1998) found that regulated sites showed an increase in Simuliid numbers, and an associated decrease in predators and competitors. They further propose that under conditions of flow disturbance (un-natural flow regime) black fly larvae are better able to cope than their predators and competitors (Zhang et al., 1998). The results from this study on the Albert Falls Dam in many ways corroborate those findings, with black fly (and other filter feeders) the dominant taxa accounting for differences between the unregulated Karkloof River control site and the Albert Falls site.

However within a relatively short distance downstream of the dam the “natural” composition of the aquatic macroinvertebrate fauna is largely restored compared to that exhibited by the unregulated Karkloof River, particularly for the Stones and GSM biotopes. The Vegetation biotope appears to be more variable and takes longer (distance downstream) to return to the control type “natural” community.

### Summary of results in the context of meeting resource management and conservation planning targets

Currently, resource management targets within the South African context do not generally manage beyond the level of family taxonomic detail, and even this detail is often summarised to reflect a SASS index or score (being a summary again of macroinvertebrate family taxonomic detail). This is typically given effect to within Ecological Flow Requirements (EFR) determinations (such as the Ecological Reserve) as well as river health monitoring (as for example in the River Health Programme).

In the application of this type of monitoring data from this study, results of the analysis on the historical SASS data showed that there is a statistically significant difference between the reference site on the Karkloof River and both the uMngeni downstream of the Mpolweni confluence and the uMngeni upstream of Nagle Dam. In all instances the mean of the SASS ASPT index for the reference site is always higher than that measured on the uMngeni River sites below Albert Falls. Although there are statistically significant differences between the reference and the “impacted” sites (as measured by the ASPT) the differences are relatively small in “real” terms (and as related to draft river health class boundaries) – changing from a “natural” on the Karkloof River to “good” on the two sites on the uMngeni. In terms of resource management targets, it may be argued that this is an acceptable change (low impact) in water quality below the dam, and as such no reason for concern.

However, once a species level of analysis is undertaken on this same data, the results have shown there was a significant biological impact and change in community composition in response to the modified flow regime immediately below the dam. In terms of the National Environmental Management: Biodiversity Act of 2004, it may be argued that this change is not a ‘‘sustainable’’ activity, particularly in the light of one of the definitions of sustainability in the Act, i.e., “would not disrupt the ecological integrity of the ecosystem in which it occurs”. This potential inconsistency between, on the one level resource management targets, and on the other, biodiversity targets, is an area needing further applied research, particularly in the light of possible human and livestock health issues related to dominance by certain potential “pest” species in the site below the regulated flow zone. DWAF have gone part of the way to addressing this issue (Kleynhans *Pers comm*) by the conversion of SASS scores using the Ecostatus method (MARAI) into a species sensitive analysis, which make use of reference conditions, including species information, to determine the river status. Unfortunately, when SASS is the index used to collect the raw data, then there will be a dirth of species information to be able to do this.

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# Annexure C. Taxonomic and summary data of aquatic macroinvertebrates

| | Phylum, Class or Order | Class or Order | Family | Genus | species | Taxa codes | Frequency /count | Relative Frequency (%) | Maximum Abundance (%) | Median Abundance (%) | Mean Abundance (%) | Mean Local Abundance (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ANNELIDA | OLIGOCHAETA | LUMBRICULIDAE | | sp | LUMBsp | 2 | 3 | 3 | 2 | 0.06 | 2.00 |
| 2 | ANNELIDA | OLIGOCHAETA | NAIDIDAE | | sp | NAIDsp | 13 | 19 | 120 | 3 | 2.20 | 11.85 |
| 3 | ANNELIDA | | TUBIFICIDAE | | sp | TUBIsp | 25 | 36 | 70 | 4 | 4.74 | 13.28 |
| 4 | ANNELIDA | HIRUDINEA | | | | HIRUDIN | 8 | 11 | 10 | 1 | 0.29 | 2.50 |
| 5 | HYDROZOA | | HYDRIDAE | Chlorohydra | sp | Chlosp | 2 | 3 | 7 | 6 | 0.17 | 6.00 |
| 6 | ISOPODA | | | | | ISOPOPO | 5 | 7 | 6 | 1 | 0.14 | 2.00 |
| 7 | MYRIAPODA | | DIPLOPODA | | | Diplopo | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 8 | NEMATODA | | MERMITHIDAE | | sp | Mermsp | 4 | 6 | 4 | 2.5 | 0.14 | 2.50 |
| 9 | NEUROPTERA | | SISYRIDAE | Sisyra | sp | Sisysp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 10 | TURBELLARIA | TRICLADIDA | PLANARIIDAE | Dugesia | sp | Dugesp | 8 | 11 | 35 | 1.5 | 0.83 | 7.25 |
| 11 | CRUSTACEA | Decapoda | ATYIDAE | Caridina | nilotica | Carinilo | 45 | 64 | 3000 | 25 | 113.60 | 176.71 |
| 12 | CRUSTACEA | Cladocera | DAPHNIIDAE | | | Daphnid | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 13 | CRUSTACEA | Decapoda | POTAMONAUTIDAE | Potamonautes | dentatus | Potadent | 14 | 20 | 5 | 1.5 | 0.39 | 1.93 |
| 14 | CRUSTACEA | Decapoda | POTAMONAUTIDAE | Potamonautes | perlatus | Potaperl | 7 | 10 | 7 | 1 | 0.19 | 1.86 |
| 15 | CRUSTACEA | Copepoda | | | | Copepod | 1 | 1 | 3 | 3 | 0.04 | 3.00 |
| 16 | ARACHNIDA | | LYCOSIDAE | | sp | Lycosid | 4 | 6 | 21 | 4 | 0.43 | 7.50 |
| 17 | ARACHNIDA | | PISAURIDAE | Thalassius | sp | Thalsp | 9 | 13 | 22 | 2 | 0.57 | 4.44 |
| 18 | ARACHNIDA | | SALTICIDAE | | | Salticid | 2 | 3 | 7 | 4 | 0.11 | 4.00 |
| 19 | ARACHNIDA | | TETRAGNATHIDAE | Tetragnatha | sp | Tetrsp | 9 | 13 | 15 | 1 | 0.40 | 3.11 |
| 20 | ARACHNIDA | | THOMISIDAE | | | Thomisid | 2 | 3 | 3 | 2 | 0.06 | 2.00 |
| 21 | ARACHNIDA | "HYDRACARINES" | | | | Hydracar | 3 | 4 | 4 | 2 | 0.10 | 2.33 |
| 22 | PLECOPTERA | | PERLIDAE | Neoperla | spio | Neopspio | 32 | 46 | 60 | 3 | 4.79 | 10.47 |
| 23 | EPHEMEROPTERA | | BAETIDAE | Acanthiops | varius | Acanvari | 4 | 6 | 8 | 4.5 | 0.27 | 4.75 |
| 24 | EPHEMEROPTERA | | BAETIDAE | Afroptilum | sudafricanum | Afrosuda | 5 | 7 | 5 | 4 | 0.26 | 3.60 |
| 25 | EPHEMEROPTERA | | BAETIDAE | Small Baetids | sp | Baetsmal | 13 | 19 | 60 | 3 | 2.03 | 10.92 |
| 26 | EPHEMEROPTERA | | BAETIDAE | Baetis | harrisoni | Baetharr | 46 | 66 | 1040 | 17.5 | 49.76 | 75.72 |
| 27 | EPHEMEROPTERA | | BAETIDAE | Centroptiloides | bifasciata | Centbifa | 3 | 4 | 4 | 3 | 0.11 | 2.67 |
| 28 | EPHEMEROPTERA | | BAETIDAE | Cheleocloeon | excisum | Chelexci | 18 | 26 | 40 | 4.5 | 1.93 | 7.50 |
| 29 | EPHEMEROPTERA | | BAETIDAE | Cloeodes | inzingae | Cloeinzi | 2 | 3 | 5 | 3 | 0.09 | 3.00 |
| 30 | EPHEMEROPTERA | | BAETIDAE | Cloeon | sp | Cloesp | 5 | 7 | 18 | 5 | 0.50 | 7.00 |
| 31 | EPHEMEROPTERA | | BAETIDAE | Crassabwa | flava | Crasflav | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 32 | EPHEMEROPTERA | | BAETIDAE | Dabulamanzia | helenae | Dabuhele | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 33 | EPHEMEROPTERA | | BAETIDAE | Dabulamanzia | indusii | Dabuindu | 11 | 16 | 11 | 4 | 0.66 | 4.18 |
| 34 | EPHEMEROPTERA | | BAETIDAE | Dabulamanzia | media | Dabumedi | 7 | 10 | 11 | 3 | 0.53 | 5.29 |
| 35 | EPHEMEROPTERA | | BAETIDAE | Dicentroptilum | spinulosum | Dicespin | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 36 | EPHEMEROPTERA | | BAETIDAE | Demoulinia | crassi | Democras | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 37 | EPHEMEROPTERA | | BAETIDAE | Demoreptus | natalensis | Demonata | 1 | 1 | 7 | 7 | 0.10 | 7.00 |
| 38 | EPHEMEROPTERA | | BAETIDAE | Labiobaetis | piscis | Labipisc | 1 | 1 | 170 | 170 | 2.43 | 170.00 |
| 39 | EPHEMEROPTERA | | BAETIDAE | Nigrobaetis | bethunae | Nigrbeth | 14 | 20 | 10 | 2 | 0.53 | 2.64 |
| 40 | EPHEMEROPTERA | | BAETIDAE | Ophelmatostoma | sp | Ophesp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 41 | EPHEMEROPTERA | | BAETIDAE | Procloeon | africanus | Procafri | 2 | 3 | 5 | 3.5 | 0.10 | 3.50 |
| 42 | EPHEMEROPTERA | | BAETIDAE | Pseudocloeon | glaucum | Pseuglau | 24 | 34 | 60 | 6 | 4.20 | 12.25 |
| 43 | EPHEMEROPTERA | | BAETIDAE | Pseudocloeon | latum | Pseulatu | 18 | 26 | 100 | 7 | 5.41 | 21.06 |
| 44 | EPHEMEROPTERA | | BAETIDAE | Pseudocloeon | piscis | Pseupisc | 25 | 36 | 100 | 4 | 6.16 | 17.24 |
| 45 | EPHEMEROPTERA | | BAETIDAE | Pseudocloeon | vinosum | Pseuvino | 13 | 19 | 90 | 3 | 2.13 | 11.46 |
| 46 | EPHEMEROPTERA | | BAETIDAE | Pseudopannota | maculosa | Pseumacu | 10 | 14 | 7 | 2 | 0.36 | 2.50 |
| 47 | EPHEMEROPTERA | | CAENIDAE | Afrocaenis | sp nov. | Afrosp n | 1 | 1 | 6 | 6 | 0.09 | 6.00 |
| 48 | EPHEMEROPTERA | | CAENIDAE | Caenis | sp | Caensp | 55 | 79 | 100 | 4 | 9.46 | 12.04 |
| 49 | EPHEMEROPTERA | | CAENIDAE | Clypeocaenis | uMngeni | Clypumge | 8 | 11 | 70 | 9 | 1.83 | 16.00 |
| 50 | EPHEMEROPTERA | | HEPTAGENIIDAE | Afronurus | oliffi | Afroolif | 1 | 1 | 10 | 10 | 0.14 | 10.00 |
| 51 | EPHEMEROPTERA | | HEPTAGENIIDAE | Afronurus | peringueyi | Afroperi | 30 | 43 | 38 | 5 | 4.84 | 11.30 |
| 52 | EPHEMEROPTERA | | HEPTAGENIIDAE | Afronurus | scotti | Afroscot | 2 | 3 | 10 | 6 | 0.17 | 6.00 |
| 53 | EPHEMEROPTERA | | HEPTAGENIIDAE | Thalerosphyrus | bequaerti | Thalbequ | 11 | 16 | 26 | 4 | 1.40 | 8.91 |
| 54 | EPHEMEROPTERA | | LEPTOPHLEBIIDAE | Adenophlebia | sylvatica | Adensylv | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 55 | EPHEMEROPTERA | | LEPTOPHLEBIIDAE | Euthraulus | elegans | Eutheleg | 29 | 41 | 40 | 5 | 4.33 | 10.45 |
| 56 | EPHEMEROPTERA | | MACHADORYTHIDAE | Machadorythus | maculatus | Machmacu | 4 | 6 | 3 | 1.5 | 0.10 | 1.75 |
| 57 | EPHEMEROPTERA | | OLIGONEURIDAE | Elassoneuria | trimeniana | Elastrim | 5 | 7 | 12 | 2 | 0.29 | 4.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | EPHEMEROPTERA | | POLYMITARCYIDAE | Ephoron | savignyii | Ephosavi | 4 | 6 | 1 | 1 | 0.06 | 1.00 |
| 59 | EPHEMEROPTERA | | PROSOPISTOMATIDAE | Prosopistoma | sp | Prossp | 7 | 10 | 10 | 4 | 0.49 | 4.86 |
| 60 | EPHEMEROPTERA | | TRICORYTHIDAE | Tricorythus | sp | Tricory | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 61 | EPHEMEROPTERA | | TRICORYTHIDAE | Tricorythus | discolor | Tricdisc | 3 | 4 | 47 | 2 | 0.71 | 16.67 |
| 62 | EPHEMEROPTERA | | TRICORYTHIDAE | Tricorythus | reticulatus | Tricreti | 3 | 4 | 34 | 21 | 1.01 | 23.67 |
| 63 | ODONATA | | AESHNIDAE | Anax | sp | Anaxsp | 3 | 4 | 5 | 1 | 0.10 | 2.33 |
| 64 | ODONATA | | AESHNIDAE | Aesha | subpupillata | Aeshsubp | 6 | 9 | 2 | 1 | 0.10 | 1.17 |
| 65 | ODONATA | | CALOPTERYGIDAE | Phaon | iridipennis | Phaoirid | 4 | 6 | 5 | 2.5 | 0.16 | 2.75 |
| 66 | ODONATA | | CHLOROCYPHIDAE | Platycypha | caligata | Platcali | 11 | 16 | 3 | 1 | 0.23 | 1.45 |
| 67 | ODONATA | | COENAGRIONIDAE | Pseudagrion | spp. | Pseuspp. | 28 | 40 | 55 | 3 | 2.50 | 6.25 |
| 68 | ODONATA | | CORDULIIDAE | Hemicordulia | sp | Hemisp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 69 | ODONATA | | GOMPHIDAE | Ceratogomphus | sp | Ceratogom | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 70 | ODONATA | | GOMPHIDAE | Ictinogomphus | sp | Ictisp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 71 | ODONATA | | GOMPHIDAE | Notogomphus | sp | Notosp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 72 | ODONATA | | GOMPHIDAE | Paragomphus | sp | Paragomp | 11 | 16 | 4 | 2 | 0.33 | 2.09 |
| 73 | ODONATA | | LIBELLULIDAE | Diplacodes | sp | Diplsp | 3 | 4 | 1 | 1 | 0.04 | 1.00 |
| 74 | ODONATA | | LIBELLULIDAE | Chalcostephia | flavifrons | Chalflav | 1 | 1 | 4 | 4 | 0.06 | 4.00 |
| 75 | ODONATA | | LIBELLULIDAE | Orthetrum | sp | Orthsp | 3 | 4 | 3 | 1 | 0.07 | 1.67 |
| 76 | ODONATA | | LIBELLULIDAE | Tholymis | tillarga | Tholtill | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 77 | ODONATA | | LIBELLULIDAE | Tramea | sp | Tramsp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 78 | ODONATA | | LIBELLULIDAE | Zygonyx | sp | Zygosp | 2 | 3 | 4 | 2.5 | 0.07 | 2.50 |
| 79 | ODONATA | | SYNLESTIDAE | Chlorolestes | sp | Chlorols | 2 | 3 | 2 | 1.5 | 0.04 | 1.50 |
| 80 | LEPIDOPTERA | | CRAMBIDAE | Nymphula | sp | Nympsp | 7 | 10 | 4 | 1 | 0.16 | 1.57 |
| 81 | HEMIPTERA | | APHELOCHEIRIDAE | Aphelocheirus | sp | Aphesp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 82 | HEMIPTERA | | APHIDIDAE | | | APHIDID | 3 | 4 | 2 | 1 | 0.06 | 1.33 |
| 83 | HEMIPTERA | | BELOSTOMATIDAE | Appasus | sp | Appasp | 10 | 14 | 18 | 3.5 | 0.77 | 5.40 |
| 84 | HEMIPTERA | | CORIXIDAE | Micronecta | sp | Micrnect | 14 | 20 | 17 | 2.5 | 0.86 | 4.29 |
| 85 | HEMIPTERA | | CORIXIDAE | Sigara | sp | Sigasp | 1 | 1 | 6 | 6 | 0.09 | 6.00 |
| 86 | HEMIPTERA | | GERRIDAE | Eurymetra | sp | Eurymet | 5 | 7 | 22 | 1 | 0.41 | 5.80 |
| 87 | HEMIPTERA | | GERRIDAE | Eurymetropsis | sp | Eurymetr | 1 | 1 | 3 | 3 | 0.04 | 3.00 |
| 88 | HEMIPTERA | | GERRIDAE | Limnogonus | sp | Limnsp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 89 | HEMIPTERA | | GERRIDAE | Rhagadotarsus | sp | Rhagsp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 90 | HEMIPTERA | | MESOVELIIDAE | Mesovelia | sp | Mesosp | 1 | 1 | 7 | 7 | 0.10 | 7.00 |
| 91 | HEMIPTERA | | NAUCORIDAE | Laccocoris | sp | Laccsp | 3 | 4 | 4 | 1 | 0.09 | 2.00 |
| 92 | HEMIPTERA | | NEPIDAE | Ranatra | sp | Ranasp | 5 | 7 | 3 | 1 | 0.10 | 1.40 |
| 93 | HEMIPTERA | | NOTONECTIDAE | Anisops | sp | Anissp | 4 | 6 | 8 | 2.5 | 0.20 | 3.50 |
| 94 | HEMIPTERA | | NOTONECTIDAE | Enithares | sp | Enitsp | 1 | 1 | 4 | 4 | 0.06 | 4.00 |
| 95 | HEMIPTERA | | NOTONECTIDAE | Nychia | sp | Nychsp | 3 | 4 | 3 | 3 | 0.11 | 2.67 |
| 96 | HEMIPTERA | | NOTONECTIDAE | Notonecta | sp | Notonect | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 97 | HEMIPTERA | | PLEIDAE | Plea | sp | Pleasp | 7 | 10 | 3 | 1 | 0.14 | 1.43 |
| 98 | HEMIPTERA | | VELIIDAE | Microvelia | sp | Microvel | 7 | 10 | 38 | 4 | 0.93 | 9.29 |
| 99 | HEMIPTERA | | VELIIDAE | Rhagovelia | sp | Rhagovel | 13 | 19 | 21 | 5 | 1.59 | 8.54 |
| 100 | TRICHOPTERA | | DIPSEUDOPSIDAE | Dipseudopsis | simplex | Dipssimp | 4 | 6 | 2 | 1.5 | 0.09 | 1.50 |
| 101 | TRICHOPTERA | | ECNOMIDAE | Ecnomus | sp | Ecnosp | 17 | 24 | 11 | 2 | 0.67 | 2.76 |
| 102 | TRICHOPTERA | | HYDROPSYCHIDAE | Amphipsyche | scottae | Amphscot | 7 | 10 | 40 | 2 | 0.84 | 8.43 |
| 103 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | type 2 | Cheuty2 | 15 | 21 | 21 | 3 | 1.47 | 6.87 |
| 104 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | type 7 | Cheuty7 | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 105 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | type 10 | Cheuty10 | 2 | 3 | 11 | 6.5 | 0.19 | 6.50 |
| 106 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | afra | Cheuafra | 28 | 40 | 664 | 7 | 20.49 | 51.21 |
| 107 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | maculata | Cheumacu | 3 | 4 | 35 | 16 | 0.74 | 17.33 |
| 108 | TRICHOPTERA | | HYDROPSYCHIDAE | Cheumatopsyche | thomasseti | Cheuthom | 15 | 21 | 121 | 2 | 2.50 | 11.67 |
| 109 | TRICHOPTERA | | HYDROPSYCHIDAE | Macrostemum | capense | Macrcape | 21 | 30 | 33 | 7 | 2.81 | 9.38 |
| 110 | TRICHOPTERA | | HYDROPSYCHIDAE | Hydropsyche | longifurca | Hydrlong | 18 | 26 | 110 | 3 | 5.26 | 20.44 |
| 111 | TRICHOPTERA | | HYDROPTILIDAE | Catoxyethira | sp | Catosp | 3 | 4 | 6 | 1 | 0.11 | 2.67 |
| 112 | TRICHOPTERA | | HYDROPTILIDAE | Hydroptila | cruciata | Hydrcruc | 16 | 23 | 16 | 1 | 0.70 | 3.06 |
| 113 | TRICHOPTERA | | HYDROPTILIDAE | Hydroptila | sp | Hydropt | 8 | 11 | 6 | 1.5 | 0.26 | 2.25 |
| 114 | TRICHOPTERA | | HYDROPTILIDAE | Orthotrichia | sp | Orthotr | 7 | 10 | 7 | 1 | 0.20 | 2.00 |
| 115 | TRICHOPTERA | | HYDROPTILIDAE | Oxyethira | sp | Oxyesp | 3 | 4 | 7 | 2 | 0.14 | 3.33 |
| 116 | TRICHOPTERA | | LEPTOCERIDAE | Adicella | sp | Adicsp | 3 | 4 | 3 | 1 | 0.07 | 1.67 |
| 117 | TRICHOPTERA | | LEPTOCERIDAE | Athripsodes | corniculans | Athrcorn | 5 | 7 | 9 | 2 | 0.23 | 3.20 |
| 118 | TRICHOPTERA | | LEPTOCERIDAE | Athripsodes | sp | Athrsp | 3 | 4 | 1 | 1 | 0.04 | 1.00 |
| 119 | TRICHOPTERA | | LEPTOCERIDAE | Oecetis | sp | Oecesp | 26 | 37 | 13 | 2 | 1.49 | 4.00 |
| 120 | TRICHOPTERA | | LEPTOCERIDAE | Oecetis | lucipetens | Oeceluci | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 121 | TRICHOPTERA | | LEPTOCERIDAE | Leptocerina | sp | Leptsp | 21 | 30 | 202 | 5 | 6.21 | 20.71 |
| 122 | TRICHOPTERA | | LEPTOCERIDAE | Leptocerus | sp | Leptocer | 9 | 13 | 15 | 2 | 0.53 | 4.11 |
| 123 | TRICHOPTERA | | LEPTOCERIDAE | Ceraclea | sp | Cerasp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 124 | TRICHOPTERA | | LEPTOCERIDAE | Trichosetodes | sp | Tricsp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 125 | TRICHOPTERA | | LEPTOCERIDAE | Setodes | sp | Setosp | 18 | 26 | 40 | 3.5 | 1.69 | 6.56 |
| 126 | TRICHOPTERA | | PHILOPOTAMIDAE | Chimarra | sp | Chimsp | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 127 | TRICHOPTERA | | POLYCENTROPODIDAE | Paranyctiophylax | sp | Parasp | 9 | 13 | 3 | 2 | 0.23 | 1.78 |
| 128 | COLEOPTERA | | CHRYSOMELIDAE | TRIBE: Halticini | sp | Haltsp | 3 | 4 | 20 | 1 | 0.31 | 7.33 |
| 129 | COLEOPTERA | | CHRYSOMELIDAE | TRIBE: Hispini | sp | Hispsp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 130 | COLEOPTERA | | CURCULIONIDAE | | sp | CURCUL | 1 | 1 | 7 | 7 | 0.10 | 7.00 |
| 131 | COLEOPTERA | | DYTISCIDAE | Noterinae | | Noterin | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 132 | COLEOPTERA | | ELMIDAE | | sp | ELMIDAE | 48 | 69 | 50 | 4.5 | 6.41 | 9.35 |
| 133 | COLEOPTERA | | GYRINIDAE | Aulonogyrus | sp | Aulosp | 14 | 20 | 9 | 1 | 0.39 | 1.93 |
| 134 | COLEOPTERA | | GYRINIDAE | Dineutus | sp | Dinesp | 8 | 11 | 4 | 1 | 0.21 | 1.88 |
| 135 | COLEOPTERA | | GYRINIDAE | Orectogyrus | sp | Orecsp | 8 | 11 | 4 | 1.5 | 0.23 | 2.00 |
| 136 | COLEOPTERA | | HELODIDAE | | sp | HELODID | 8 | 11 | 37 | 5.5 | 1.19 | 10.38 |
| 137 | COLEOPTERA | | HYDROPHILIDAE | Berosus | sp | Berosp | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 138 | COLEOPTERA | | HYDROPHILIDAE | unidentified | sp | Hydrophsp | 2 | 3 | 1 | 1 | 0.03 | 1.00 |
| 139 | COLEOPTERA | | PSEPHENIDAE | | sp | PSEPHEN | 11 | 16 | 31 | 3 | 0.96 | 6.09 |
| 140 | DIPTERA | | ATHERICIDAE | | sp | ATHERICD | 16 | 23 | 8 | 2 | 0.54 | 2.38 |
| 141 | DIPTERA | | CERATOPOGONIDAE | Atrichopogon | sp | Atrisp | 2 | 3 | 2 | 2 | 0.06 | 2.00 |
| 142 | DIPTERA | | CERATOPOGONIDAE | Bezzia | sp | Bezzsp | 22 | 31 | 13 | 2 | 0.99 | 3.14 |
| 143 | DIPTERA | | CHAOBORIDAE | Chaoboris | sp | Chaosp | 3 | 4 | 25 | 20 | 0.83 | 19.33 |
| 144 | DIPTERA | | CHIRONOMIDAE | SUB FAM: Chironominae | | ChirChir | 42 | 60 | 200 | 6.5 | 9.23 | 15.38 |
| 145 | DIPTERA | | CHIRONOMIDAE | SUB FAM: Orthocladiinae | | OrthOrth | 35 | 50 | 250 | 6 | 10.61 | 21.23 |
| 146 | DIPTERA | | CHIRONOMIDAE | SUB FAM: Tanypodinae | | TanyTany | 33 | 47 | 20 | 3 | 1.89 | 4.00 |
| 147 | DIPTERA | | CHIRONOMIDAE | TRIBE: Tanytarsini | sp | Tanysp | 21 | 30 | 150 | 7 | 6.73 | 22.43 |
| 148 | DIPTERA | | CHIRONOMIDAE | Rheotanytarsis | sp | Rheosp | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 149 | DIPTERA | | CULICIDAE | Culicinae | sp | Culisp | 4 | 6 | 3 | 2 | 0.11 | 2.00 |
| 150 | DIPTERA | | DIXIDAE | | | DIXIDAE | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 151 | DIPTERA | | EMPIDIDAE | | sp | EMPIDID | 6 | 9 | 8 | 4 | 0.36 | 4.17 |
| 152 | DIPTERA | | MUSCIDAE | | sp | MUSCID | 10 | 14 | 6 | 1 | 0.26 | 1.80 |
| 153 | DIPTERA | | SCIOMYZIDAE | | sp | SCIOMZ | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 154 | DIPTERA | | SEPSIDAE | | sp | SEPSID | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 155 | DIPTERA | | SIMULIIDAE | Simulium | adersi | Simuader | 27 | 39 | 350 | 8 | 18.50 | 47.96 |
| 156 | DIPTERA | | SIMULIIDAE | Simulium | alocki | Simualoc | 3 | 4 | 4 | 2 | 0.10 | 2.33 |
| 157 | DIPTERA | | SIMULIIDAE | Simulium | bequaerti | Simubequ | 3 | 4 | 7 | 1 | 0.13 | 3.00 |
| 158 | DIPTERA | | SIMULIIDAE | Simulium | cervicornutum | Simucerv | 12 | 17 | 12 | 2 | 0.67 | 3.92 |
| 159 | DIPTERA | | SIMULIIDAE | Simulium | damnosum | Simudamn | 17 | 24 | 80 | 14 | 6.26 | 25.76 |
| 160 | DIPTERA | | SIMULIIDAE | Simulium | hargreavesi | Simuharg | 12 | 17 | 46 | 7 | 2.21 | 12.92 |
| 161 | DIPTERA | | SIMULIIDAE | Simulium | hirsutum | Simuhirs | 6 | 9 | 100 | 16 | 2.39 | 27.83 |
| 162 | DIPTERA | | SIMULIIDAE | Simulium | impukane | Simuimpu | 8 | 11 | 7 | 2 | 0.34 | 3.00 |
| 163 | DIPTERA | | SIMULIIDAE | Simulium | lumbwanum | Simulumb | 4 | 6 | 6 | 2 | 0.16 | 2.75 |
| 164 | DIPTERA | | SIMULIIDAE | Simulium | medusaeforme | Simumedu | 8 | 11 | 33 | 13 | 1.74 | 15.25 |
| 165 | DIPTERA | | SIMULIIDAE | Simulium | mcmahoni | Simumcma | 14 | 20 | 21 | 1.5 | 0.76 | 3.79 |
| 166 | DIPTERA | | SIMULIIDAE | Simulium | nigritarse | Simunigr | 20 | 29 | 700 | 3.5 | 15.24 | 53.35 |
| 167 | DIPTERA | | SIMULIIDAE | Simulium | rotundum | Simurotu | 22 | 31 | 75 | 6 | 3.87 | 12.32 |
| 168 | DIPTERA | | SIMULIIDAE | Simulium | vorax | Simuvora | 5 | 7 | 26 | 4 | 0.57 | 8.00 |
| 169 | DIPTERA | | TABANIDAE | | sp | TABANID | 7 | 10 | 5 | 2 | 0.24 | 2.43 |
| 170 | DIPTERA | | TANYDERIDAE | | sp | TANYDER | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 171 | DIPTERA | | TIPULIDAE | Antocha | sp | Antosp | 10 | 14 | 3 | 1 | 0.20 | 1.40 |
| 172 | DIPTERA | | TIPULIDAE | Limonia | sp | Limosp | 3 | 4 | 1 | 1 | 0.04 | 1.00 |
| 173 | DIPTERA | | TIPULIDAE | Limnophila | sp | Limnph | 6 | 9 | 3 | 2 | 0.16 | 1.83 |
| 174 | GASTROPODA | | ANCYLIDAE | Burnupia | sp | Burnsp | 9 | 13 | 20 | 2 | 0.53 | 4.11 |
| 175 | GASTROPODA | | LYMNAEIDAE | Lymnaea | columella | Lymncolu | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 176 | GASTROPODA | | LYMNAEIDAE | Lymnaea | natalensis | Lymnnata | 3 | 4 | 37 | 1 | 0.56 | 13.00 |
| 177 | GASTROPODA | | PHYSIDAE | Physa | acuta | Physacut | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 178 | GASTROPODA | | PLANORBIDAE | Gyraulus | sp | Gyrasp | 4 | 6 | 11 | 2 | 0.23 | 4.00 |
| 179 | GASTROPODA | | PLANORBIDAE | Gyraulus | costulatus | Gyracost | 4 | 6 | 10 | 2.5 | 0.23 | 4.00 |
| 180 | GASTROPODA | | PLANORBIDAE | Gyraulus | connollyi | Gyraconn | 2 | 3 | 27 | 14 | 0.40 | 14.00 |
| 181 | GASTROPODA | | PLANORBIDAE | Bulinus | africanus | Buliafri | 1 | 1 | 2 | 2 | 0.03 | 2.00 |
| 182 | GASTROPODA | | PLANORBIDAE | Bulinus | natalensis | Bulinata | 1 | 1 | 1 | 1 | 0.01 | 1.00 |
| 183 | PELECYPODA | | CORBICULIDAE | Corbicula | sp | Corbsp | 9 | 13 | 15 | 3 | 0.61 | 4.78 |
| 184 | PELECYPODA | | SPHAERIIDAE | Pisidium | sp | Pisisp | 5 | 7 | 1 | 1 | 0.07 | 1.00 |

# Chapter 8. Fish in the uMngeni River

## Introduction

Fish are naturally dominant inhabitants of rivers and the uMngeni is no exception. Because of their close association with society, as a source of food and recreation, they are valued more than some of the other inhabitants of rivers even if this is not based on any sound ecological judgment. It is partly for this reason that they are used internationally as primary indicators of ecological condition, as they gain strong public support whereas other less charismatic inhabitants may be ignored (Lazorchak, US EPA *pers com.*).

The fish of the uMngeni River occur with a poor diversity, having a maximum of only 13 natural species if the estuary is excluded. Three of these are eels whose numbers are likely to have declined since the construction of Inanda and Nagle Dams downstream as the juveniles are required to make the journey over these dams as they migrate upstream. That they do succeed has been recorded but undoubtedly in a much reduced number as Inanda in particular is insurmountable for much of the year.

The uMngeni River reach that has been studied in this project is well known for its angling, with the *Labeobarbus natalensis* (KZN Yellowfish) being common and sought after. This fish survives well in impoundments where it grows to a large size. Other angling fish include the Sharptooth Catfish and alien species including Carp and various Bass.

## Method

During each field survey fish were collected using two methods:

1. Electro-fishing using a DECCA portable shocker. Fishing effort was approximately 40 minutes roaming across all of the fish biotopes present at the site. Various combinations of pulse and voltage were used, varied to suite the occasion. While this method yielded good results there is no doubt that many fish escaped.
2. Gill-netting. Either one or two 20 m long gill nets, with mesh of 80 mm, were left installed in the river overnight. This could only be done at sites Kk and dMp, the limitations being access and a suitable deep-water habitat.

## Results

Fish collected were weighed and their length recorded. Most were released back to the river with the exception of specimens lodged with Ezemvelo KZN Wildlife and some large gravid Yellowfish. Samples of ovary with immature eggs were collected from these Yellowfish with the intention of recording their readiness to spawn. The size (diameter) of these eggs was recorded with the expectation that this would indicate maturity, but this was not the case and there was no trend over time. Unfortunately the entire ovary of each fish was not collected as this could have yielded more useful information.

Fish data collected in this project was too little and uneven to be analyzed statistically. Annexure D (at the end of this chapter) contains raw data in which fish species collected using both electroshocking and netting techniques on all the four surveys are presented.

Only eight fish species were collected during the four surveys, viz, *Labeobarbus natalensis, Amphillius natalensis, Barbus viviparous, Micropterus dolomieu, Micropterus salmoides, Clarias gariepinus, Oreochromis mossambicus, Tilapia sparrmanii* and *Tilapia rendalii* using the electro-fishing method. Only *L. natalensis* at site Kk and *M. dolomieu, C. gariepinus, L. natalensis* and *O. mossambicus* at site dMp were collected using gill nets.

**Site Kk - Karkloof River upstream of uMngeni confluence**

*A. natalensis* (Natal Mountain Catfish) were collected in numbers from site 7, the control site on the Karkloof River. The other fish species collected at the site includes *L. natalensis*, *C. gariepinus* and *B. viviparus* (Table 8.1).

Table 8.1: Fish species collected from Site Kk.

| **Site Kk** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** |
|---|---|---|---|---|---|---|---|---|
| | **Survey 1** | | **Survey 2** | | **Survey 3** | | **Survey 4** | |
| *Clarias gariepinus* | | | | | | | 290 | 1 |
| *Labeobarbus natalensis* | 51 | 4 | Failed equip. | | 280 | 3 | 115 | 1 |
| *Barbus viviparus* | | | | | 40 | 1 | 40 | 1 |
| *Amphillius natalensis* | 83 | 6 | | | 79 | 10 | 81 | 10 |

**Site Alb - uMngeni River below Albert Falls Dam**

Site Alb just below the Albert Falls Dam was marked by scores of *L. natalensis* (KwaZulu Natal Yellowfish) collected and observed. The other fish species collected includes *M. dolomieu* and *T. rendalii* (Table 8.2).

Table 8.2: Fish species collected from Site Alb.

| **Site Alb** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** |
|---|---|---|---|---|---|---|---|---|
| | **Survey 1** | | **Survey 2** | | **Survey 3** | | **Survey 4** | |
| *Labeobarbus natalensis* | 116 | 8 | Failed equip. | | 237 | 11 | 280 | 4 |
| *Micropterus dolomieui* | 125 | 2 | | | | | 105 | 1 |
| *Tilapia rendalii* | | | | | | | 80 | 1 |

**Site uMp - uMngeni upstream of the Mpolweni confluence**

Fish species collected at this site were *A. natalensis, M. dolomieu* and several juvenile tilapias (Table 8.3).

Table 8.3: Fish species collected from Site uMp.

| **Site uMp** | **Avg. Length** | **No.** | **Avg. Length** | **No.** | **Avg. Length** | **No.** | **Avg. Length** | **No.** |
|---|---|---|---|---|---|---|---|---|
| | **Survey 1** | | **Survey 2** | | **Survey 3** | | **Survey 4** | |
| *Labeobarbus natalensis* | 405 | 1 | 70 | 4 | 338 | 2 | 395 | 6 |
| *Micropterus dolomieui* | 93 | 1 | | | | | | |
| Tilapia juveniles | | | | | 39 | 4 | | |

**Site dMp - uMngeni downstream of the Mpolweni confluence**

Several fish species were collected at this site including *L. natalensis, O. mossambicus, T. sparrmanii and M. dolomieui* (Table 8.4).

Table 8.4: Fish species collected from Site dMp.

| **Site dMp** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** |
|---|---|---|---|---|---|---|---|---|
| | **Survey 1** | | **Survey 2** | | **Survey 3** | | **Survey 4** | |
| *Labeobarbus natalensis* | 437 | 3 | 435 | 6 | 347 | 10 | 405 | 6 |
| *Oreochromis mossambicus* | | | 305 | | | | | |
| *Tilapia sparrmanii* | | | | | 68 | 1 | | |
| *Micropterus salmoides* | 390 | | | | 440 | 1 | 380 | 1 |
| *Tilapia rendalii* | | | | | | | 65 | 1 |
| *Amphillius natalensis* | | | | | | | 90 | 1 |
| *Clarias gariepinus* | | | 630 | 3 | | | | |

**Fish kill on 18/1/04**

A fish kill as reported just below the dMp site on the 18th January 2004, unfortunately in the middle of the survey activities. An extensive investigation was made by Steve Terry of Umgeni Water who found large numbers of dead fish, mostly Yellowfish and Carp. Numerous large and small fish in good condition were also noticed and the invertebrate life also appeared to be normal, both suggesting that this was not due to a toxin. The cause could have been related to a severe storm a few days before but the events which led to the death of the fish could not be uncovered. Possible causes would be ammonia run-off from the surrounding feedlots and farms, or rapid temperature changes due to the rainwater.

**Site Ngl - uMngeni weir upstream of Nagle dam**

Five fish species, *C. gariepinus, L. natalensis, M. dolomieui, T. sparrmanii* and several more tilapia juveniles were collected at this site (Table 8.5).

Table 8.5: Fish species collected from Site Ngl.

| | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** | **Avg. length** | **No.** |
|---|---|---|---|---|---|---|---|---|
| **Site Ngl** | **Survey 1** | | **Survey 2** | | **Survey 3** | | **Survey 4** | |
| *Clarias gariepinus* | 256 | 1 | | | 153 | 4 | | |
| *Labeobarbus natalensis* | 138 | 7 | | | 200 | 1 | 140 | 2 |
| *Tilapia sparrmanii* | | | | | 75 | 7 | | |
| Tilapia juveniles | | | | | 43 | 6 | | |
| *Micropterus dolomieui* | 173 | 2 | | | 170 | 3 | | |
| *Micropterus salmoides* | 390 | 1 | 440 | 1 | | | 380 | 1 |

**Discussion**

The following information on the tolerance/preference of the fish found during the surveys is extracted from a NAEBP report. These ratings were the output of a workshop of the county's fish experts who ranked each species as presented below. This information is used to discuss the distribution of fish species and the impacts of the flow regulation on them.

Table 8.6: Tolerance ratings of fish found in the uMngeni River (derived from NAEBP)
1-2 = Tolerant; >2-3 = Moderately Tolerant; >3-4 = Moderately Intolerant; >4-5 = Intolerant

| Species | Trophic specialisation | Habitat specialisation | Flow requirement | Unmodified water quality requirement |
|---|---|---|---|---|
| *Amphillius natalensis* | 4.9 | 4.9 | 4.9 | 4.9 |
| *Barbus anoplus* | 2.8 | 2.8 | 2.3 | 2.6 |
| *Barbus viviparus* | 2 | 2.3 | 2.3 | 3 |
| *Clarias gariepinus* | 1.2 | 1.4 | 1.7 | 1 |
| *Labeobarbus natalensis* | 2.5 | 2 | 3.5 | 3 |
| *Oreochromis mossambicus* | 1.2 | 1.9 | 0.9 | 1.3 |
| *Tilapia sparrmanii* | 1.6 | 1.4 | 0.9 | 1.4 |
| *Tilapia rendalii* | 1.4 | 1.7 | 1.8 | 2.1 |

Tropic specialization – 1 = tolerant of any type of food source; Habitat specialization – 1 = tolerant of any type of habitat; Flow requirement – 1= tolerant of no-flow/pool situations; Unmodified water quality requirement – 1= tolerant of changes to water quality

Table 8.7: Preference ratings of fish for different flow/depth biotopes found in the uMngeni River (derived from NAEBP)
0 = no preference; >0-2 = Low preference; >2-3 = Moderate preference; >3-4 = High preference; >4-5 = Very high preference

| Species | Slow-deep (<0.3m/s;>0.5m) | Slow-shallow (<0.3m/s;<0.5m) | Fast-deep (>0.3m/s;>0.3m) | Fast-shallow (>0.3m/s;<0.3m) |
|---|---|---|---|---|
| *Amphillius natalensis* | 0.5 | 0.5 | 5 | 4.7 |
| *Barbus anoplus* | 4.1 | 4.3 | 0.9 | 2.5 |
| *Barbus viviparus* | 2.1 | 4.8 | 0.4 | 0.6 |
| *Clarias gariepinus* | 4.3 | 3.4 | 1.2 | 0.8 |
| *Labeobarbus natalensis* | 3 | 1.5 | 4.5 | 4 |
| *Oreochromis mossambicus* | 4.6 | 3.8 | 1.4 | 0.8 |
| *Tilapia sparrmanii* | 3 | 4.3 | 0.9 | 1.5 |
| *Tilapia rendalii* | 4.9 | 3.9 | 1 | 0.3 |

**Environmental requirements of the fish found in the uMngeni River.**

*Amphillius natalensis* (Natal Mountain Catfish)
The fish is intolerant of adverse conditions, having a tolerance rating of 4.9/5 and a requirement for fast flowing water (Tables 8.6 and 8.7)
The Natal Mountain Catfish was found in abundance in the Karkloof River where it was by far the dominant species. This situation is unusual in KZN as higher up in the catchment the fish is preyed on by trout which are not found at this site and nor were other predators. This fish actively feeds at night on benthic aquatic invertebrates such as mayfly and midge larvae. It occurs in fast flowing clear and well oxygenated water with rocks and cobles, as are found in mountain streams, but fish have been recorded as far down as Nagle Dam (rarely).

*Clarias gariepinus* (Sharptooth Catfish)
This fish is tolerant of most perturbations in the river and has a preference for slow moving water.
The Sharptooth Catfish was found in abundance at site dMp where large specimens were caught in the gill nets during the summer months, but none during winter. Only one fish was caught in the Karkloof River. It is possible that the reason that no Catfish were collected at sites upstream of dMp, could be due to the mode of fishing, as all fish caught at dMp were with gill nets and none with the electro-fishing apparatus. Gill nets were not used at the two sites upstream or at Nagle. Those Catfish that were caught with the electro-fishing apparatus at other sites were much smaller, so it is possible that the larger fish were able to evade the shock.

They occur in quite waters; lakes and pools but may also occupy fast flowing rivers and rapids but these are not favoured. The fish has well developed air breathing organs enabling it to breathe air during unfavorable conditions and or when searching for food on land or moving from one water body to another. They breed on shallow grassy grounds during summer when water level have risen to cover such areas. Catfish feed on the bottom, but occasionally on the surface, preying on a variety of invertebrates, plankton, and some vertebrates such as fish, frogs and birds, whereupon they can be voracious predators. They are also known to eat rotting meat and plants.

*Barbus viviparus* (Bowstripe Barb)
This fish is moderately tolerant of perturbations in the river and has a preference for slow shallow rivers (Tables 8.6 and 8.7)

It was only collected on one occasion in the Karkloof River but at no other sites. This was surprising as the fish is common in the uMsunduze, a major tributary of the uMngeni River. This latter river is enriched with nutrients, which is supported by the information in Table 8.6, that the fish has a liking for such conditions.

The Bowstripe Barb is distributed, but not confined to the east coastal rivers and fresh water lakes from the Ruvuma (Tanzania-Mozambique border) southwards to the Vungu in the southern KwaZulu-Natal in South Africa. It occupies vegetated pools and lake margins and feeds on aquatic insects and other small organisms. Breeding occurs in summer with eggs laid on the submerged roots and vegetation.

*Labeobarbus natalensis* (KwaZulu-Natal Yellowfish)

This fish is moderately intolerant of adverse habitat conditions, and has a fairly strong preference for fast and deep water (Tables 8.6 and 8.7 )

The fish species has a wide distribution from the uMkuze southwards to the uMtamvuna on the Transkei border and have been translocated to the Save in Zimbabwe. The fish occupy a wide variety of habitats ranging from pools and rapids of clear streams to deep turbid waters of larger rivers and impoundments. It however, prefers warmer areas of rivers and the fish often congregate at the inlets of smaller tributaries where the temperature is warmer than that of the main river. They feed on a variety of foods from algae and detritus to aquatic invertebrates insects larvae and crabs, leaving trails of scrape marks on the rocks behind them. Making use of their sensitive mouths, they are able to feed in water with zero visibility.

These Yellowfish search out shallow rivers with a gravel substrate on which to spawn, an activity that usually takes place in summer.

*Micropterus dolomieu* (Smallmouth Bass)

Smallmouth Bass is naturally distributed in the North America and were translocated into certain rivers in the Western and Eastern Cape and KwaZulu-Natal, South Africa and are known to have adverse ecological impact. They occupy shallow rocky habitats in lakes, clear and gravel-bottom runs and flowing pools of rivers, cool flowing streams and streams fed by such streams. Adult fish prey on crabs, fish and aquatic and terrestrial insects. Juvenile fish feed on plankton and immature aquatic insects. Breeding occurs in spring and early summer.

*Micropterus salmoides* (Largemouth Bass)

This fish is more frequently found in lakes where it thrives in deep still water. It is sometimes found in deep slow moving rivers, including parts of the uMngeni below Albert Falls.

*Tilapia rendalii* (Redbreasted Tilapia) (Tables 8.6 and 8.7)

This fish has a high level of tolerance for adverse conditions but prefers slow moving waters.

Redbreasted Tilapia occurs throughout KwaZulu-Natal and the highveld region in South Africa where it has been translocated for weed control and aquaculture purposes. In several other countries where introduced, it has been reported to have adverse ecological impacts. The fish prefers quite, well vegetated water along river littorals or backwaters, floodplains and swamps. Adults feed mainly on water plants and algae; they also take aquatic invertebrates and even small fish.

*Oreochromis mossambicus* (Mozambique Tilapia)
This fish is tolerant of adverse conditions but has a preference for slow moving waters (Table 8.6 and 8.7)

Mozambique Tilapia is distributed southwards to the Brak River in the Eastern Cape and in the Transvaal in the Limpopo system in South Africa. This fish has been widely (globally) introduced for aquaculture, but has often escaped and established itself in the wild in many countries, often outcompeting local species. It occurs in a variety of freshwater habitats including fast flowing and pools and is even tolerant of marine water. Generally they are omnivorous, but adults tend to be herbivorous. Breeding occurs in summer on nest constructed on a sandy bed.

*Tilapia sparrmanii* (Banded Tilapia)
This fish is tolerant of adverse conditions but has a preference for slow moving waters (Tables 8.6 and 8.7)

It occurs in widely diverse habitats, preferring areas where plant cover exists along the edges of rivers, lakes or swamps and shallow sheltered waters. It does not tend to colonize the open water of large lakes. Adults feed preferentially on filamentous algae, aquatic macrophytes and vegetable matter of terrestrial origin (leaves, plants, etc.). Juveniles feed on small crustaceans and midge larvae. They undertake seasonal upstream migration and breed before and during these migrations.

### Discussion of the impacts of flow regulation on fish populations

The dominant fish species collected at the control site on the Karkloof River was the Natal Mountain Catfish which is intolerant of aberrations in water flow and quality. Clearly the water quality and flow conditions are acceptable to this species as it thrives in abundance. It may be protected from trout moving downstream by the upstream Karkloof Falls as well as from the exotic bass species which proved to be uncommon. The reason for the low abundance of bass is not known, as in other similar rivers they can dominate the population.

The habitat in this river (cold clear water, rapid flow over cobbles) is clearly ideal for this species but it is possible that the location is approaching its lower boundary as they are not often found in rivers at a lower altitude. Accordingly, it would be difficult to conclude that this species should be found in abundance at Albert Falls even though this is only a few kilometers away.

Immediately below Albert Falls Dam, there were large numbers of the endemic KwaZulu-Natal Yellowfish at all times of the year. They were reported to spawn prolifically at this site during early summer (November) where they spawn over shallow fast-flowing gravel beds. The Albert Falls waterfall as well as the dam immediately above, provided a barrier for further upstream migration but this would be a natural situation. Fast flowing aggressive water from the dam probably clears silt from the gravel beds thus providing good breeding grounds. As has been shown in this project, the mean temperatures released by the dam during summer are not significantly different to what they would be in the natural condition, while the range (and thus maximum and minimum) are suppressed. It is most noteworthy that the release of cold bottom water (i.e. that does not heat up during the day) during summer from the Albert Falls Dam does not seem to affect the spawning period of this fish as breeding occurs during the normal summer period.

The investigation of the water quality in this project has indicated some perturbations in quality which, in comparison to the literature, may be toxic to fish. These perturbations are principally high ammonia, including the toxic un-ionized form and manganese, which can also be toxic to fish. There was no clear documentation of a relationship between toxic water and the presence or absence of fish although Clive Harries (local fisherman) reports that at times when iron oxides coat the rocks, accompanied by a strong $H_2S$ smell, the fish move out completely. Unfortunately such an event was not documented during this project. During this study, at those times when the water quality was poor, such as when the dam was stratified and not spilling e.g. in March, there were abundant Yellowfish to be found.

It is important to note that few other species, other than Yellowfish, were found at this site below Albert Falls. According to Clive Harries (local fisherman), *Tilapia rendalii,* as well as bass, used to be common at this site particularly before the 1987 floods but also thereafter. Numbers have recently declined so that these fish are now seldom seen. Unfortunately this project did not uncover any change in regime or water quality that would have given rise to this loss of diversity. A possibility is the extreme drought that occurred during the 1990s' which may have eliminated the species from the area. This may have been due to a rich scour water which could have been released at the time. Recolonization is difficult as the fish would have to scale the downstream weir, which Yellowfish do easily which may explain their presence.

A general conclusion for this site is that the river reach supports the presence of large numbers of *L. natalensis* (Yellowfish) but there is a general absence of *A. natalensis* and other species such as *Tilapia sp.* which could be expected. It is possible that the continuous high flows favour Yellowfish, supporting greater numbers than would be the case if the river were to be stressed during winter. In the uMsunduze River at a similar altitude, this species has been seen to suffer from extensive *Saprolegnia* fungus infections during August – September when flows are low but temperatures increase (*pers. obs.*), probably the result of stress. Numerous deaths occur under these conditions.

Further down the river, at the site above the Mpolweni River confluence, there remained a low diversity of fish but with good numbers of Yellowfish but low numbers of the other species (Smallmouth Bass and juvenile Tilapia). Deep water of fast and slow velocity with vegetated margins provide good habitat for fish, so it was surprising that such low numbers were collected, with the exception of Yellowfish which were abundant in June but not at other times. The riparian vegetation which was abundant along the margins of the river, was almost devoid of fish despite there being abundant invertebrate life. This strongly suggests periodic adverse water quality conditions.

Further downstream at the site below the Mpolweni confluence, there was a much greater diversity. Fish collected at this site were *L. natalensis*, *O. mossambicus*, *T. sparrmanii*, *M. dolomieu, M. salmoides*, *T. rendalii*, *A. natalensis* and *C. gariepinus*, making the site the most diverse in terms of fish species. *O. mossambicus* was collected only from this site and this was the only site where *A. natalensis* was collected below the Albert Fall Dam.

Large Yellowfish were collected year round at this site although they were most abundant in March as was the case further upstream. *C. gariepinus* was also abundant during March and less so during summer (October). They were absent during the winter months despite the higher flows of warmer water. It seems thus that *Clarias* retreat from this site during the winter for reasons other than temperature and flow volumes.

Above Nagle Dam the species of fish found were somewhat sporadic although diverse. Large numbers of *Tilapia sparrmanii* were found during late summer but at no other time. Similarly Yellowfish were found mostly during summer months. Unfortunately this site was a poor choice as it was bound between the upstream weir and the downstream Nagle Dam with its recent construction activities.

**Length/mass**

The length/mass ratio was only calculated for larger fish specimens in order to gain an indication of their condition. There were slight differences in length/mass ratios amongst the same fish species at different times of the year with the heaviest fish recorded during October (i.e. low length/mass ration) (Annexure D). Difference in mass could be associated with different physiological activities such as breeding and other environmental conditions. A breeding female fish will have slightly more weight as it carries eggs while unfavorable conditions may also affect weight. Unfortunately the data that was collected was inconclusive and could not be used for any interpretation.

**References**

NAEBP – Intolerance ratings, flow-depth and cover preference ratings for South African fish species. Report to the National Aquatic Ecosystems Biomonitoring Programme presented at a workshop on the use of fish in aquatic health assessment. *NAEBP Report series, Department of Water Affairs and Forestry (unpublished).*

## Annexure D. Fish data

**FISH DATA:** Summary of fish collected during the project. Fish indicated in italics (e.g. *340*) indicates those fish caught in gill nets.

| **Site Kk** | | | | |
|---|---|---|---|---|
| **Karkloof upstream of uMngeni confluence** | | | | |
| | 2003/08/01 | 2003/10/15 | 2004/03/30 | 2004/06/17 |
| | | missing data | | |
| | Length (mm) | Length (mm) | Length (mm) | Length (mm) |
| *Clarias gariepinus* | | | | 290 |
| | | | | |
| | | | | |
| *Labeobarbus natalensis* | 55 | | 40 | 115 |
| | 65 | | | |
| | 50 | | | |
| | 35 | | | |
| | | | ~400 | |
| | | | ~400 | |
| *Barbus viviparus* | | | 40 | 40 |
| *Amphillius natalensis* | 100 | | 95 | 95 |
| | 100 | | 105 | 90 |
| | 80 | | 95 | 58 |
| | 65 | | 90 | 62 |
| | 70 | | 93 | 88 |
| | 80 | | 85 | 95 |
| | | | 75 | 75 |
| | | | 50 | 80 |
| | | | 55 | 75 |
| | | | 50 | 90 |
| | | | 50 | 90 |
| | | | 50 | 90 |

| **Site Alb** | | | | |
|---|---|---|---|---|
| **uMngeni River below Albert Falls Dam** | | | | |
| | 2003/8/01 | 2003/10/15 | 2004/03/02 | 2004/06/17 |
| | | Equipment problem | | |
| | Length (mm) | Length (mm) | Length (mm) | Length (mm) |
| *Labeobarbus natalensis* | 93 | 0 | 380 | 370 |
| | 152 | | 365 | 340 |
| | 104 | | 265 | 270 |
| | | | 215 | 140 |
| | | | 235 | |
| | | | 255 | |
| | | | 233 | |
| | | | 200 | |
| | | | 105 | |
| | | | 175 | |
| | | | 175 | |
| *Micropterus dolomieui* | 121 | | 110 | 105 |
| | 128 | | | |
| *Tilapia rendalii* | | | | 80 |
| **Site uMp** | | | | |
| **uMngeni upstream of Mpolweni confluence** | | | | |
| | 2003/08/12 | 2003/10/15 | 2004/03/01 | 2004/06/17 |
| | | Equipment problem | | |
| | Length (mm) | Length (mm) | Length (mm) | Length (mm) |
| *Labeobarbus natalensis* | 405 | 70 | 350 | 460 |
| | | 70 | 325 | 420 |
| | | 70 | | 320 |
| | | 70 | | 380 |
| | | | | 370 |
| | | | | 420 |
| *Micropterus dolomieui* | 93 | | | |
| Tilapia juvs. | | | 55 | |
| | | | 40 | |
| | | | 30 | |
| | | | 30 | |

| **Site dMp** | | | | |
|---|---|---|---|---|
| **uMngeni downstream of Mpolweni confluence** | | | | |
| | 2003/08/12 | 2003/10/15 | 2004/03/01 | 2004/06/17 |
| | Length (mm) | Length (mm) | Length (mm) | Length (mm) |
| *Labeobarbus natalensis* | | | 300 | |
| | | | 340 | |
| | *440* | *420* | *240* | *480* |
| | *420* | *440* | *320* | *470* |
| | *450* | *490* | *435* | *360* |
| | | *470* | *375* | *370* |
| | | *400* | *350* | *350* |
| | | *390* | *360* | *400* |
| | | | *375* | |
| | | | *370* | |
| *Oreochromis mossambicus* | | *310* | | |
| | | *300* | | |
| | | | | |
| *Tilapia sparrmanii* | | | 95 | |
| | | | 40 | |
| | | | | |
| *Micropterus dolomieui* | | | 145 | 90 |
| *Micropterus salmoides* | *390* | *440* | | *380* |
| | | | | |
| *Tilapia rendalii* | | | | 65 |
| *Amphillius natalensis* | | | | 90 |
| *Clarias gariepinus* | | *710* | *550* | |
| | | *660* | *540* | |
| | | *520* | *520* | |
| | | | *560* | |
| | | | *560* | |
| | | | *510* | |
| | | | *510* | |

| **Site Ngl** | | | | |
|---|---|---|---|---|
| **uMngeni weir upstream of Nagle Dam** | | | | |
| | 2003/08/19 | 2003/10/15 | 2004/03/01 | 2004/06/17 |
| | | Equipment problems | | |
| | Length (mm) | Length (mm) | Length (mm) | Length (mm) |
| *Clarias gariepinus* | 256 | | 310 | |
| | | | 125 | |
| | | | 80 | |
| | | | 95 | |
| *Labeobarbus natalensis* | 163 | x | 200 | 190 |
| | 148 | | | 90 |
| | 159 | | | |
| | 143 | | | |
| | 105 | | | |
| | 135 | | | |
| | 115 | | | |
| *Tilapia sparrmanii* | | | 55 | |
| | | | 95 | |
| | | | 90 | |
| | | | 65 | |
| | | | 65 | |
| | | | 75 | |
| | | | 80 | |
| Tilapia juvs | x | | 80 | |
| | | | 45 | |
| | | | 30 | |
| | | | 35 | |
| | | | 35 | |
| | | | 35 | |
| *Micropterus dolomieui* | 172 | | 240 | |
| | 173 | | 160 | |
| | | | 110 | |
| *Micropterus salmoides* | *390* | *440* | | *380* |

**Fish length/mass ratios**

| | **Length (mm)** | **Mass (g)** | **L/M ratio** |
|---|---|---|---|
| **2003/08/12** | | | |
| *Labeobarbus natalensis* | 440 | 1500.0 | 0.29 |
| | 420 | 1375.0 | 0.31 |
| | 450 | 1475.0 | 0.31 |
| **2003/10/15** | | | |
| *Clarias gariepinus* | 710 | 3550.0 | 0.20 |
| | 660 | 3050.0 | 0.22 |
| | 520 | 1050.0 | 0.50 |
| *Labeobarbus natalensis* | 420 | 1250.0 | 0.34 |
| | 440 | 1275.0 | 0.35 |
| | 490 | 1775.0 | 0.28 |
| | 470 | 1725.0 | 0.27 |
| | 400 | 1500.0 | 0.27 |
| | 390 | 800.0 | 0.49 |
| **2004/03/01** | | | |
| *Clarias gariepinus* | 550 | 1450 | 0.38 |
| | 540 | 1500 | 0.36 |
| | 520 | 1130 | 0.46 |
| | 560 | 1375 | 0.41 |
| | 560 | 1375 | 0.41 |
| | 510 | 1250 | 0.41 |
| | 510 | 1150 | 0.44 |
| *Labeobarbus natalensis* | 240 | 250 | 0.96 |
| | 320 | 550 | 0.58 |
| | 435 | 1375 | 0.32 |
| | 375 | 875 | 0.43 |
| | 350 | 740 | 0.47 |
| | 360 | 850 | 0.42 |
| | 375 | 830 | 0.45 |
| | 370 | 875 | 0.42 |
| **2004/06/17** | | | |
| *Labeobarbus natalensis* | 480 | 1850 | 0.26 |
| | 470 | 1625 | 0.29 |
| | 360 | 850 | 0.42 |
| | 370 | 850 | 0.44 |
| | 350 | 675 | 0.52 |
| | 400 | 1200 | 0.33 |