CHANGES IN THE ABUNDANCE OF INVERTEBRATES IN THE STONES-IN-CURRENT BIOTOPE IN THE MIDDLE ORANGE RIVER OVER FIVE YEARS

by

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Report to the Water Research Commission on the project K8/276 entitled

"Analysis of invertebrate samples from the Orange River"

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This report emanates from two 3-year projects, funded by the Water Research Commission, on the control of pest blackflies along the middle and lower Orange River (Palmer 1994, Palmer 1997). In the course of this work data were collected on various aspects of the ecology of the Orange River. These data were used as baseline information for the control of pest blackflies, but had wider potential application, such as for the assessment of Ecological Flow Requirements and the National River Health Programme. It was therefore considered important to make these data available to a wider audience than the Blackfly Control Programme.

This report provides a detailed account of the temporal (monthly) changes in the abundance of invertebrates at a single site near Upington (Gifkloof rapids) over 5 years (1992-1996). This is the longest and most detailed study of invertebrates in a South African river. Conditions during this period were highly variable, and this provided an opportunity to examine the relations between river conditions and the abundance and species composition of invertebrates over time.

Aims of this report

The aims of this report were to:

- examine the responses of invertebrates to temporal changes in river conditions the middle Orange River.
- examine the important ecological processes occurring in the middle Orange River.
- Provide baseline data that could be used in future assessments of Ecological Flow Requirements and/or biomonitoring in the middle Orange River.

Study area

Sampling was conducted in rapids downstream of Gifkloof Weir, in the vicinity of Upington.

Methods

Flow data

Flow data for this study were based on readings from Buchuberg Dam (Zeekoebaart Weir: D7H008), situated 145 km upstream of the study site. After 1993 flow data were also obtained from the newly constructed weir at Neusberg (D7H014), situated 92 km downstream of the study site.

Water temperature

Spot water temperatures were recorded at the time of sampling, and weekly temperature fluctuations were recorded from a maximum-minimum thermometer placed in a pool near the Gifkloof rapids.

Total Suspended Solids

Concentrations of Total Suspended Solids (TSS) and Secchi depth were measured weekly using standard methods.

Benthic and planktonic algae

The abundance of benthic (epilithic) algae in the rapids was ranked weekly in terms of percentage cover. Concentrations of planktonic algae were also estimated weekly, starting in March 1993.

Benthic invertebrates

Benthic invertebrates (excluding crabs) were sampled monthly between January 1992 and December 1996 (n=60). On each occasion ten stones, ranging in size from 10 to 20 cm diameter, were sampled from the stones-in-current biotope. For comparative purposes, the results were also analysed using the South African Scoring System version 4 (SASS4). The results are not directly comparable to SASS results, as these are usually collected from a range of biotopes, including marginal vegetation and sediments. However, the results provided useful insights into invertebrate biomonitoring.

Summary of results

Flow

An analysis of historical flow data from Buchuberg Dam, in the middle reaches of the Orange River, showed that before upstream impoundment, lowest flows were usually in September, and these flows were less than 15 m^3/s in nearly 40 % of the years between 1933 and 1969. The first spring freshet (flow pulse) was most often (60 % of years) in November, and was usually over 1000 m^3/s in size. Frequency analysis of daily average flows prior to major impoundment was used to categorise flows in the Orange River into five categories, ranging from very low flow to very high flow. The categories were based on the probability of exceedance of the daily average flow at Buchuberg Dam at the 10th, 40th, 60th and 90th percentiles before impoundment (1944-1966).

Taxa identified

A total of 74 invertebrate taxa was identified from the stones-in-current biotope at Gifkloof. Significant differences in invertebrate abundance and species composition were noted between visits and between years. Some of these changes had no obvious explanation, but others were related to changes in river conditions, and in particular, changes in flow and water temperature. The average number of taxa recorded per stone ranged from 6.0 to 18.4. The lowest value was recorded in August 1992, 19 days after an aerial application of temephos for blackfly control. The highest value was recorded during low-flow conditions in July 1995. The average number of taxa recorded per visit (27) represents 36 % of the taxa finally recorded.

Functional Feeding Groups

The majority of taxa were predators (23) or gatherers (18), but the most abundant trophic group were filter-feeders, followed by gatherers. The abundance of scrapers started increasing after 20 days of constant flow.

SASS Scores

The lowest SASS4 score (indicating poor conditions) was recorded in June 1994, following a mid-winter period of unseasonally high flow. Likewise, the lowest Average Score Per Taxon (ASPT) (5.9) was recorded in July 1996, four months after a flood. SASS scores and the ASPT were lower at temperatures less than 15°C compared to warmer temperatures.

The highest SASS4 score, by contrast, was recorded in November 1996, eight months after a flood, while the highest ASPT (5.9) was recorded during low flow in February 1995. On average, the highest SASS4 scores were recorded under conditions of very low flow (<16 m^3/s). This was usually in October or November, when the water temperatures was greater than 15°C, and when benthic algae was moderately scarce (<25 % cover). By contrast, the highest ASPTs were usually recorded during moderate flow (60 to 142 m^3/s), in January or February, when the water was warm (> 25°C), and when benthic algae were scarce (<10 % cover).

Very low flow

During very low flow (<16 m^3/s) the river was characterised by clear water (Secchi depth > 47 cm) and low concentrations of planktonic algae. The average number of taxa (29), the average number of SASS4 families (18), and the average total abundance of invertebrates (157) was highest during these flow conditions. Taxa typically associated with very low flow included the filter-feeding midge *Rheotanytarsus fuscus*, the sponge *Ephydatia fluviatilis* and the blackflies *Simulium adersi* and *S. ruficorne*.

Low flow

During low flow (16 to 59 m^3/s) the river was characterised by moderate clarity (Secchi depth 25 to 47 cm) and moderate concentrations of planktonic algae. Numerous taxa were associated with low flows, including the mayflies *Afronurus peringueyi, Baetis glaucus* and *Euthraulus elegans*, and the blackflies *Simulium damnosum* s.l. and *S. mcmahoni.*

Moderate flow

During moderate flow (60 to 142 m^3/s) the probability of planktonic algal blooms was high. Taxa typically associated with moderate flows were the caddisfly *Amphipsyche scottae* and the blackflies *Simulium chutteri* and *S. gariepense*. The Average SASS4 Score per Taxon (ASPT) was highest under moderate flow conditions.

Very High flow

Dramatic changes in species composition and abundance were recorded after a flood in January 1996. Species whose abundance increased after the flood included the blackfly *S. chutteri*, the mayfly *Tricorythus discolor*, and the caddisflies *Cheumatopsyche thomasseti* and *Aethaloptera maxima*. Species that disappeared after the flood included the mayfly *A. peringueyi*, the caddisfly *Ecnomus thomasseti*, the sponge *E. fluviatilis*, the blackfly *S. mcmahoni* and the midge *R. fuscus.*

Fluctuating flows

Taxa whose abundance increased when flows fluctuated were the leech *Salifa perspicax*, the mayflies *T. discolor* and *B. glaucus*, the caddisflies *A. scottae* and *A. maxima* and the blackfly *S. chutteri*. The number of SASS4 families and total SASS4 scores were unaffected by flow variation, but invertebrate abundance dropped as flow variation increased.

Stable flows

The pest blackfly *S. damnosum* became abundant during a long period of stable, low-flow conditions in 1993. Other taxa whose abundance increased during stable flow conditions were the stonefly *Neoperla spio*, Turbellaria and the midges *Cardiocladius africanus* and *R. fuscu,* the muscid fly *Xenomyia* sp. and the sponge *E. fluviatilis*. The overall abundance of caddisflies and predators started declining after 20 days of constant flow, whereas the abundance of gatherers started declining after 15 days of constant flow.

Water temperature

Water temperature had a significant impact on invertebrates. The abundances and number of mayfly and caddisfly taxa, the total number of taxa, the average number of taxa per stone, and the ASPT all increased as temperatures increased. Of particular interest was an inverse relation between the abundance of blackflies and caddisflies as water temperatures changed: blackflies were more abundant than caddisflies during cold conditions, whereas caddisflies were more abundant than blackflies during warm conditions. There was no obvious seasonal change in the dominance of filter-feeding invertebrates, although there were significant seasonal changes in the species composition of filter feeders.

Benthic algae

Benthic algae were usually abundant in late winter to early spring (July to September). They were was most abundant when the water was moderately clear (Secchi depth >18 cm) or when the flow was less than 130 m^3/s. There was a corresponding increase in the abundance of scrapers (mostly the midge *Cardiocladius africanus*) between August and October in most years. The ASPT was usually highest during low algal cover (<10 %). The middle and lower Orange River is mostly wide and the rapids are shallow. This means that primary production in most rapids in the Orange River is not limited at flows less than 130 m^3/s.

Planktonic algae

The abundance of planktonic algae was highly seasonal, with lowest values in winter (June to August), and highest values in autumn (March to May). The abundance of invertebrates increased as the abundance of planktonic algae increased. These changes had no significant influence on the SASS4 scores or the ASPT. However, in some years blooms of the blue-green algae *Microcystis* sp. developed in Lake Vanderkloof, particularly in autumn. There was a slight decline in the total number of invertebrate taxa as the abundance of *Microcytis sp.* increased, but these changes did not greatly affect SASS4 scores or the ASPT. Highest numbers of the pest blackfly *S. damnosum* were recorded in June 1995 following a *Microcystis* sp. bloom in the previous month. By contrast, the abundance of *S. chutteri* consistently declined during *Microcystis* blooms.

Conclusions

Natural flow fluctuations are important

This study has shown that many invertebrates in the Orange River have life-history characteristics that buffer against unfavourable conditions. These include desiccation-resistant stages and rapid rates of development. Such characteristics are likely to promote the coexistence of species in fluctuating environments. This highlights the importance of disturbance in maintaining a diverse river ecosystem. Stable flows caused by impoundment are detrimental to taxa adapted to either low or high flow. However, unseasonally high flows were shown to be detrimental to aquatic invertebrates.

Unusual invertebrate taxa prefer high flows

Taxa present during low flow were found throughout southern Africa, and were of little conservation importance. Taxa present during high flow, by contrast, included unusual species, endemic to large, turbid rivers. The maintenance of a healthy invertebrate fauna in the middle Orange River therefore depends on maintaining, or at least simulating, natural flow fluctuations. Simulating natural flow fluctuations would also help to conserve threatened species, such as the blackfly *S. gariepense*, and help reduce population outbreaks of the pest *S. chutteri*.

Timing of droughts and freshets

Simulating natural flow fluctuations in the middle Orange River requires a simulated drought in August/September and a controlled freshet or flood in November. The recommended size and duration of flood and drought events were not considered in this project, although there was an inflection in the abundance and species composition of invertebrates at 70 m^3/s. The reasons for this are not understood, but it is likely that light limitation and habitat availability play a role.

Many factors may affect SASS scores

This study has also shown that biomonitoring results based on SASS scores in the stones-in-current biotope are sensitive to long-term wet and dry cycles, the recent flow history, the time of year, water temperature and the abundance of benthic algae. The National River Health Programme should consider these aspects when defining reference conditions.

A single survey misses many species

During this study a single snap survey usually missed over 60% of the taxa that were eventually recorded at the site. This highlights the limitations of one-off surveys.

Fine organic material drives the middle Orange River ecosystem

This study also serves to highlight that the main source of energy that is driving the ecology of the middle Orange River is fine particulate organic material (FPOM). The sources of FPOM are unknown. The materials could be derived from heterotrophic bacteria, or primary production within Lake Vanderkloof, or primary production on the river bed, or the decomposition of *Phragmites* sp. reeds, or some other unknown source. An understanding the origins and fates of these material would provide a fundamental basis of how this river ecosystem functions.

Microcystis sp. appears toxic to certain invertebrates

The suspected toxicity of *Microcystis* sp. to certain aquatic invertebrates may have important implications for the distribution and abundance of certain species, and this may have important implications for the National River Health Programme.

Draining sediments from Buchuberg Dam has detrimental impacts

The draining of Buchuberg Dam released large quantities of fine silt. This has a detrimental impact on the downstream environment, although it did not have a major impact on invertebrates at Gifkloof, 145 km downstream.

Recommendations

A comprehensive assessment of the Ecological Flow Requirements is recommended

Given the changes that are likely to occur following the developments and proposed developments in Lesotho, as well as the agricultural developments which are taking place along the lower Orange River, it is recommended that a detailed study of the ecological flow requirements of the middle and lower Orange River should be conducted as soon as possible. Particular attention should be paid to the unexplained inflection in the abundance and species composition of invertebrates at 70 m^3/s.

Long-term biomonitoring at selected sites is recommended

Long-term biomonitoring at selected sites provides useful insights into natural ecosystem dynamics, and is essential for obtaining a better understanding of ecosystem processes and change.

Annual Biomonitoring at Gifkloof is recommended

This study has shown that sampling during low flow in winter (June to August) would provide the highest resolution of biomonitoring results in the middle Orange River. It is therefore recommended that invertebrates should continue to be monitored on an annual basis at the Gifkloof rapids at this time. Furthermore, when interpreting biomonitoring results, particular attention should be given to long-term wet and dry cycles, the recent flow history, the season, the water temperature, the abundance of benthic algae and the presence of the blue-green algae *Microcystis*.

Unseasonal winter releases should be avoided

This study has shown that unseasonal winter releases from Vanderklof Dam can have detrimental impacts on aquatic invertebrates situated over 600km downstream. Releases of this nature should be avoided.

Future Research should focus on the role of Fine Particulate Organic Matter

It is suggested that future research should investigate the sources, fates and management significance of FPOM in rivers in South Africa. Particular attention should be given to the effects of *Microcystis* sp. toxins on selected aquatic invertebrates, particularly the blackfly *S. chutteri.*

Draining of Buchuberg Dam should be controlled

The detrimental environmental impacts of periodically draining Buchuberg Dam should be recognised, and steps to mitigate these impacts should be taken. It is recommended that sediments should be flushed regularly, and this should be done when the flow is moderate to high (if possible).

Archiving of data

Data collected during this study are housed in the Department of Entomology, Onderstepoort Veterinary Institute, Pretoria. Data include maps, aerial slides of the Orange River, and raw data of experiments and weekly monitoring. Invertebrates collected during this study are housed in the National Collection of Freshwater Invertebrates, Albany Museum, Grahamstown.

Publications

(arising from this and the previous two blackfly projects)

International journals

Palmer, R. W. 1993. Short-term impacts of formulations of *Bacillus thuringiensis* var. *israelensis* de Bajarc and the organophosphate temephos, used in blackfly (Diptera: Simuliidae) control, on rheophilic benthic macroinvertebrates in the middle Orange River, South Africa. *Southern African Journal of Aquatic Sciences*. 19(1): 14-33.

Palmer, R. W. 1994. A rapid method of estimating abundance of immature blackflies (Diptera: Simuliidae). *Onderstepoort Journal of Veterinary Research*. 61: 117-126.

Palmer, R. W. 1994. Detrimental effects of fenthion (Queletox®), used to control red-billed quelea (*Quelea quelea*), on rheophilic benthic macroinvertebrates in the Orange River. *Southern African Journal of Aquatic Sciences*. 20(1&2): 33- 37.

Palmer, R. W. 1996. Invertebrates in the Orange River, with emphasis on conservation and management. *Southern African Journal of Aquatic Sciences* 22(1/2): 3-51.

Palmer, R. W., Edwardes, M. & E. M. Nevill 1996. Downstream carry of larvicides used in the control of pest blackflies (Diptera: Simuliidae) in the Orange River, South Africa. *Journal of Vector Ecology*. 21(1): 37-47.

Palmer, R. W., Edwardes, M. & E. M. Nevill 1996. Timing of larvicide treatments for the control of the pest blackflies (Diptera: Simuliidae) in a semi-arid environment in South Africa. *Journal of Vector Ecology*. 21(1): 48-59.

Palmer, R. W., Edwardes, M. & E. M. Nevill 1996. Control of pest blackflies (Diptera: Simuliidae) along the Orange River, South Africa: 1990-1995. *Onderstepoort Journal of Veterinary Research*. 63(4): 289-304.

Palmer, R. W. & A. R. Palmer 1995. Impacts of repeated applications of *Bacillus thuringiensis* var. *israelensis* de Barjac and temephos, used in blackfly (Diptera: Simuliidae) control, on macroinvertebrates in the middle Orange River, South Africa. *Southern African Journal of Aquatic Sciences*. 21(½): 35-55.

Contract reports

Palmer, R. W. 1995. Biological and chemical control of blackflies (Diptera: Simuliidae) in the Orange River. Water Research Commission Report No 343/1/95.

Palmer, R. W. 1997. Principles of integrated control of blackflies (Diptera: Simuliidae) in South Africa. Water Research Commission Report No 650/1/97.

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ALLOCHTHONOUS	Generated from outside the system in question.
ASPT	Average Score per Taxon. Calculated by dividing the SASS4 Score by the number of SASS4 taxa.
AUTOCHTHONOUS	Generated within the system in question.
BENTHIC	Bottom-dwelling.
BENTHOS	Bottom-dwelling biota.
BIOMONITORING	The use of BIOTA to assess the ecological "health" of an area.
BIOTA	Organisms.
BIOTOPE	The place where a group of organisms live. (See HABITAT.)
FPOM	Fine Particulate Organic Matter.
FRESHET	Flow pulse.
HABITAT	The place where a specific organism lives. (See BIOTOPE.)
HETEROTROPHIC	Using organic carbon as the principle source of carbon.
INVERTEBRATE	Animals without backbones - includes insects, snails, sponges, worms, crabs and shrimps.
METRIC	Variable.
TAXON (plural: TAXA)	General term for a taxonomic group, whatever its rank.
TEMEPHOS	An organophospate used to control blackflies.
TROPHIC	Pertainng to nutrition.
TURBIDITY	An optical property of water that courses light to be scattered and absorbed.
SASS4:	South African Scoring System version 4. A rapid method of assessing water quality, based on the presence of aquatic invertebrate families, each of which have been assigned a sensitivity value. The values are summed to provide a Total Score, and then divided by the total number of taxa to provide an Average Score per Taxon (ASPT).
SECCHI DEPTH	The depth at which a SECCHI DISC disappears from visibility when lowered into water.
SECCHI DISC	A standard black and white disc, 16 cm in diameter, used to evaluate the transparency of water.
SUSPENSOIDS	Fine particulate material suspended in the water column.
TROPHIC	Pertaining to nutrition.
UNIVOLTINE	A life history in which there is one generation each year.
TSS	Total Suspended Solids. In this project, TSS was defined as the mass of organic and inorganic material suspended in the water column and retained by a Whatman[R] GF/C filter (pore size approximately 0.6 µm). Major constituents of TSS include clay, phytoplankton and zooplankton.

1. INTRODUCTION

Background

In 1991 a programme to control population outbreaks of the pest blackfly *Simulium chutteri* along the middle Orange River was initiated by the Department of Agriculture (Palmer 1994, 1997, Palmer et al. 1996). Part of the control programme involved monitoring river conditions and the abundance of non-target fauna (Palmer 1993, Palmer & Palmer 1995). This provided the first opportunity to monitor medium-term (five year) changes in the abundance of invertebrates in a South African river. These data were used to analyse the responses of invertebrate populations to changes in river conditions. The results were used as baseline information for the control of pest blackflies, but had wider use, particularly in understanding the important driving variables and ecological processes in the Orange River. Such information could be of potential use in quantifying ecological flow requirements for the middle and lower Orange River, and for the National River Health Programme. It was therefore considered important to make these data available to a wider audience than the Blackfly Control Programme.

Problems facing the middle Orange River

One of the major challenges facing river management world-wide is the allocation of compensation flows which satisfy not only water demands of downstream users, but also maintain the river as a viable and healthy ecosystem. In the Orange River conflict arises between the water demands of (1) agriculture, (2) the generation of hydroelectricity and (3) the perceived ecological requirements (van Vuuren and Erasmus 1992). Agriculture requires stable flows so as not to flood or strand irrigation pumps, and highest demands are in summer. By contrast, the generation of hydroelectricity releases short-term (bi-daily) pulses of water during peak demands, mainly in winter. Both requirements are in conflict with the perceived ecological requirement, which is to simulate natural summer floods and winter droughts (Orange River Environmental Task Groups 1990, Benade 1993a&b).

Ecological Flow Requirements

Although water requirements of agriculture and the generation of hydroelectricity can be quantified reasonably accurately, the amount of water needed to simulate natural conditions is difficult to determine. Methods which have been used to quantify ecological flow requirements range from analyses of historical flow records to detailed studies of the flow and habitat requirements of specific organisms (King and Tharme 1994). With the introduction of the new Water Law in South Africa, the assessment of ecological flow requirements has become a legal requirement for all rivers and for all major water resource developments. Because of time constraints, the methods used to assess ecological flow requirements are usually based on available information, and this is usually limited to flow data and whatever can be extrapolated from other studies.

Biomonitoring

An important consideration in assessing ecological flow requirements is the present ecological condition of a river. The National River Health Programme uses the presence of aquatic invertebrates, among other criteria, to provide a rapid assessment of the present ecological conditions of a river. A procedure for doing this was formalised in the South African Scoring System (SASS) (Chutter 1994, Uys et al. 1996). The interpretation of SASS results relies on several factors, such as the particular biotopes sampled, the historical flow record and the reference conditions that may be expected for a particular area. Reference conditions are usually unknowable because conditions along most rivers are no longer pristine. However, it is possible to provide some indication of the natural variation that may be expected, although this requires long-term monitoring.

Ecological processes

A fundamental consideration in understanding how an ecosystem works is to understand how energy passes through the system. In most ecosystems, sunlight provides the initial source of energy, and then the processes of photosynthesis converts this energy into something that can be eaten. For rivers, the composition of invertebrate functional feeding categories (*sensu* Cummins 1973) is predicted to change with seasonal changes of inputs of energy (Vannote et al. 1980). Impounding of the Orange River trapped large amounts of silt, and this increased water clarity both within and downstream of the impoundments (Bremner et al. 1990). This converted the middle and lower Orange River from a light-limited system, reliant on allocthonous inputs of energy, into a system in which the main source of energy was autochthonous primary production (Palmer 1996).

Algae

A detailed study of the fisheries potential of Lake Vanderkloof showed that planktonic algal production and species composition was highly seasonal, with peaks in summer and autumn (Allanson & Jackson 1983). Observations on the production of benthic algae in the Vaal River (Chutter 1968) and this study showed that highest algal production occurred during clear conditions in winter. It was therefore likely that the invertebrate functional feeding categories in the Orange River would change from a dominance of filterers during summer and autumn, to a dominance of scrapers during winter.

1.1 Aims of this report

The aims of this report were to:

- examine the responses of invertebrates to temporal changes in river conditions the middle Orange River.
- examine the important ecological processes occurring in the middle Orange River.
- Provide baseline data that could be used in future assessments of Ecological Flow Requirements and/or biomonitoring in the middle Orange River.

The report describes temporal (monthly) changes in the abundance of aquatic invertebrates in the stones-in-current biotope in the vicinity of Upington over five years. Spatial changes in the distribution and abundance of invertebrates in the middle and lower Orange River are reported elsewhere (Palmer 1996).

General description

The study area is located in a 6 km stretch of river downstream of the Gifkloof Diversion Weir (28°26S; 21°45'E; 805 m amsl), in the vicinity of Upington. The river at Gifkloof is 200 to 800 m wide, and is characterised by numerous islands colonised mainly by *Phragmites* spp. reeds. There are long stretches of pool separated by small rapids. The gradient is gentle, and drops 9.5 m over 6 km in a series of four rapids.

Sites sampled

The specific site sampled each time varied as flows changed. Initially sampling was conducted at Site G2, about 200 m downstream of the Gifkloof Diversion Weir (**Fig. 1**). This site was chosen because of the abundance of loose rocks left from the construction of a dyke, built to protect the canal that carries water from the diversion weir to downstream agricultural lands. These rapids dried up during low flow, and sampling was moved to G3, where substrates consisted of a cobbles and large stones. These rapids dried up during very low flow, and sampling was moved to G4. During high flow there were no accessible stones-in-current to sample except at G2. On one occasion sampling was conducted below the Upington Railway Bridge (G5) because of transport problems. Therefore the specific rapids sampled varied from time to time depending on the flow and logistical considerations.

Blackfly Control Programme

The rapids downstream of Gifkloof Weir were used as a control area for the Blackfly Control Programme, and the river 20 to 70 km upstream of Gifkloof was excluded from larvicide treatment, depending on flow volumes. However, on the 4th of August 1992, the downstream 'carry' of the organophosphate temephos was further than expected, and Gifkloof was treated unintentionally (**Appendix A**).

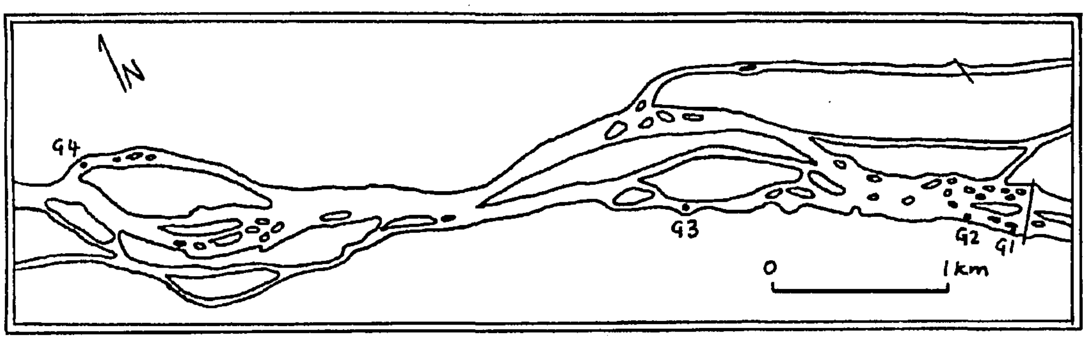

Figure 1. Map of the Orange River downstream of the Gifkloof Diversion Weir, showing sites used from regular sampling, numbered G1 to G4. The river is flowing from right to left.

3. METHODS

3.1 Flow

The Department of Water Affairs and Forestry, Upington and Pretoria, supplied daily average flow data. Flow readings were taken near Buchuberg Dam (Zeekoebaart Weir: D7H008), situated 145 km upstream of Gifkloof. After 1993 flow data were also obtained from the newly constructed weir at Neusberg (D7H014), situated 92 km downstream of the study area.

Flow data for the middle Orange River were inaccurate, particularly during low flow. For example, the canal at Gifkloof had a capacity of 10 m^3/s, and opening and closing of this canal during low flow caused major changes in river flow. The gauge at Buchuberg did not register these changes. Nevertheless, the gauge at Buchuberg was the closest and most accurate gauging weir to the study site when this study began in 1991. Furthermore, Buchuberg is the oldest gauging weir in the Orange River, and data were analysed more for temporal trends rather than specific quantities.

3.2 Flow variation

An arbitrary measure of flow variation was obtained from the coefficient of variation of daily average flow over 21 days prior to sampling. The choice of 21 days was based on the assumption that aquatic invertebrates are likely to respond to changes in river flow within 2 to 3 weeks. Likewise, an arbitrary measure of change in flow was obtained from the slope of the linear regression of daily average flow over 21 days prior to sampling. An arbitrary measure of flow constancy was obtained from the number of days that flow did not exceed, or was not less than, 20 % of the daily average flow on the day of sampling.

3.3 Water temperature

Spot water temperatures were recorded at the time of sampling. Weekly temperature fluctuations were recorded from a maximum-minimum thermometer placed in a pool near the Gifkloof rapids.

3.4 Total Suspended Solids

Concentrations of Total Suspended Solids (TSS) were measured weekly by filtering 50 to 600 ml of river water (depending on clogging) through pre-weighed Whatman® GF/C filters which were dried for at least 24 hrs at 60°C, and reweighed. Turbidities were estimated weekly using a 16 cm diameter Secchi disc, starting in September 1993.

3.5 Benthic and planktonic algae

Abundance of benthic (epilithic) algae in the rapids was ranked weekly on an 8-point visual scale, based on percentage cover as follows: 0, 1, 5, 10, 25, 50, 75 & 100 %. Starting in March 1993, the concentrations of planktonic algae were estimated weekly as follows: A known quantity of river water was filtered through a Whatman® GF/C filter. The filter was then cut to size, and placed on a glass microscope slide containing a drop of cane [Golden®] syrup. A cover slip was put in place, and the slide examined at 400 × magnification. Algal cells in each of ten fields were counted, and common taxa were identified using the descriptions in Truter (1987).

3.6 Benthic invertebrates

Benthic invertebrates (excluding crabs) were sampled monthly between January 1992 and December 1996 (n=60). On each occasion ten stones, ranging in size from 10 to 20 cm diameter, were removed from the stones-in-current biotope (current speed 0.7 to 1.5 m/s, depth 10 to 60 cm) and placed on a white tray. A net with a mesh size of 360 µm was held downstream of each stone to collect animals that dislodged when the stones were removed. Representative specimens of all taxa present were bottled in 80 % ethanol for further identification. For comparative purposes, the results were also analysed using the South African Scoring System version 4 (SASS4). Specimens are housed in the National Collection of Aquatic Invertebrates, Albany Museum, Grahamstown, under the catalogue series "ORP" (Orange River Palmer).

3.7 Invertebrate abundance

Invertebrate abundance of each taxon was ranked on a 4-point scale (0=absent; 1=present; 2=common; 3=abundant). Initially, an overall score for each taxon was given for all ten stones. This method did not allow for statistical comparison, and was therefore changed in May 1993 (and for 2 months following temephos application in July 1992), when the taxa on each stone were ranked separately. The scores for all ten stones were then added to provide an overall index of abundance for each taxon. The maximum score for a taxon was therefore 30 (i.e. 3 × 10). Taxa found in the stones-in-current biotope at times other than during regular monthly were also recorded. These taxa were excluded from SASS calculations, but for graphical purposes they scored 0.5. The method of quantifying invertebrate abundance was subjective because different taxa scored differently. For example, ten leeches on a stone scored 3, whereas 10 blackfly larvae on a stone scored 1. Nevertheless, the method was suitable because it provided a semi-quantitative index of abundance for minimal effort.

3.8 Functional Feeding Groups

In order to assess the role of invertebrates in ecological processes, taxa were assigned to functional feeding categories (*sensu* Cummins 1973) based on educated guesses and the work of Merritt and Cummins (1984). Several species were opportunistic feeders, and therefore fell into more than one feeding category. In such cases scores were divided equally between the categories.

4.1 Flow

Frequency analysis of daily average flows prior to major impoundment (1944-1966) was used to categorise flow in the middle Orange River into five operational categories (**Table 1**). The categories were based on the probability of exceedance of the daily average flow at Buchuberg at the 10th, 40th, 60th and 90th percentiles before impoundment (1944-1966). Flows less than 16 m^3/s were considered "very low", whereas flow greater than 670 m^3/s were considered "very high" (**Table 1**).

Table 1. Flow categories for the middle Orange River, based on frequency analysis of daily average flows at Buchuberg prior to major impoundment (1944-1966). A rough estimate of average current speeds that may be expected within each category was based on the time taken for various volumes of water to travel from Vanderkloof Dam to Upington. [Data: Department of Water Affairs and Forestry, Upington.]

Category	1. Very low	2. Low	3. Moderate	4. High	5. Very high
Probability of exceedance before impoundment	>90	90-59	40-60	10-39	<10
Flow (m^3/s)	<16	16-59	60-142	143-670	>670
Av. Current speed (m/s)	<0.3	0.3-0.6	0.6-0.8	0.8-1.4	>1.4

In November 1991, before this study began, flow was high (**Fig. 2a**). Sampling for this study started in January 1992, when flow was moderate. Flow then dropped steadily, reaching very-low (14 m^3/s) in September 1993. Flow then gradually increased, reaching moderate flow in January 1994. In June 1994 an aseasonal pulse of water was released from Vanderkloof Dam, after which flow was low for the rest of the year. In 1995 flows were low to moderate. In the early part of 1996 the river came down in flood. The flood was characterised by two flow peaks, the first of which reached a maximum of 1,492 m^3/s at Buchuberg Dam on the 5th February, and the second reached a maximum of 2,013 on 5th March (**Fig. 2b**). Most sampling was undertaken when the flow was low (55 %; n=33) or moderate (27 %; n=16). Five samples (8 %) were taken at very low flow, five at high flow, and one sample only was taken at very high flow (**Table 3**).

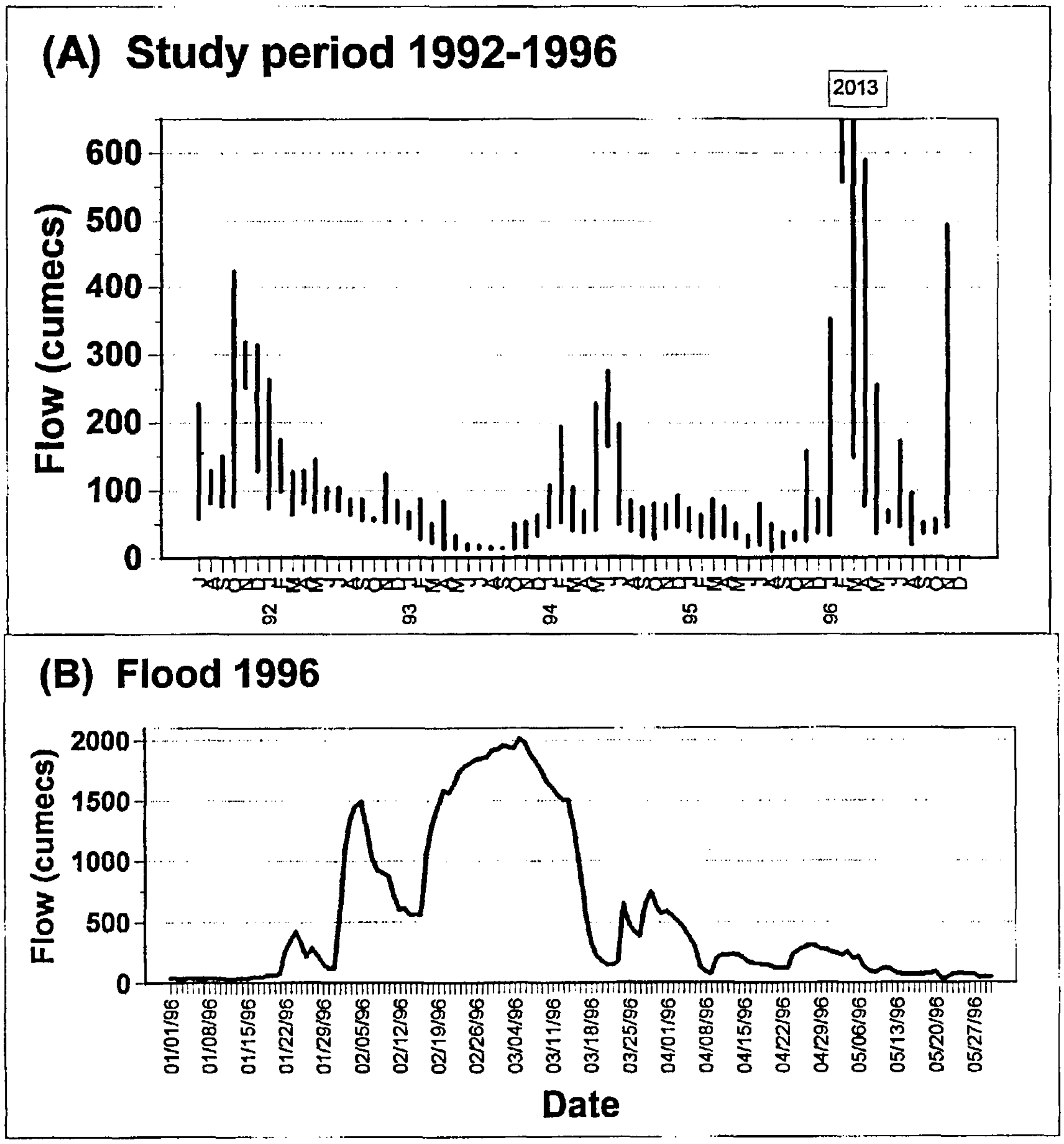

Figure 2. Monthly maximum and minimum daily average flow at Buchuberg Dam D7H008) during the study period 1992-1996 (A), and daily average flow during a flood in 1996 (B). [Data: Department of Water Affairs and Forestry, Upington.]

4.2 Invertebrates

A total of 74 invertebrate taxa was identified, of which 30 were considered common at least once, and 11 were considered abundant at least once (**Appendix A**). The average number of taxa recorded per stone ranged from 6.0 to 18.4. The lowest value was recorded in August 1992, 19 days after an aerial application of temephos for blackfly control. Taxa that were detrimentally affected by temephos included *Simulium* spp., certain Ephemeroptera, Trichoptera and Chironomidae. The next sample was taken 34 days after temephos application, and the total number of taxa recovered from 16 to 23 (**Fig. 3**). The highest number of taxa was recorded during low-flow conditions in July 1995.

After the first year of monthly sampling, 52 taxa were recorded (Fig. 3). **This represents 70 % of the taxa finally recorded. The average number of taxa recorded per visit (27) represented 36 % of the taxa finally recorded. In March 1993 a sudden increase in the cumulative number of taxa coincided with a drop in flow.**

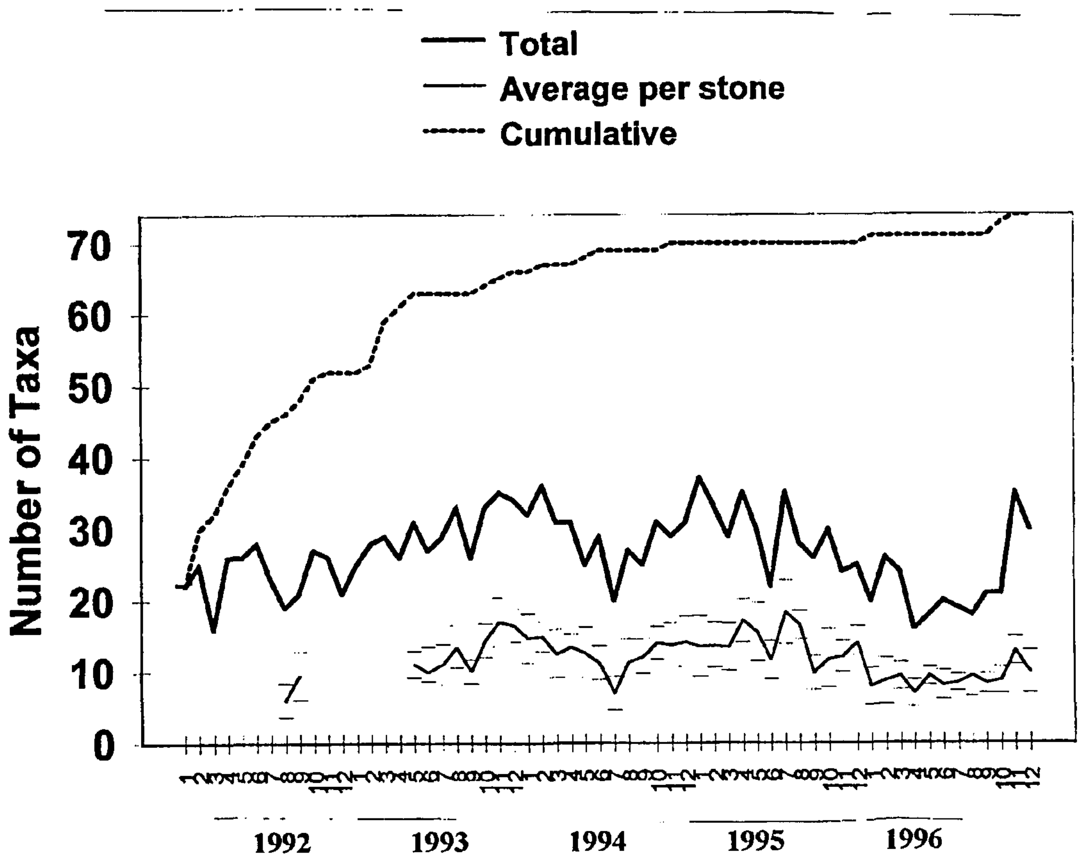

Figure 3. Number of taxa recorded monthly between January 1992 and December 1996 from rapids downstream of Gifkloof Weir, Orange River. The graph shows the cumulative number of taxa recorded, the total number of taxa recorded each month, and the average number of taxa found on each stone. Bars indicate one standard deviation (n=10).

Total SASS4 scores ranged from 65 to 159 (**Appendix A**). The lowest SASS4 score was recorded in June 1994, following a mid-winter period of high flow. The highest score was recorded in November 1996, eight months after a flood. The Average Score Per Taxon (ASPT) ranged from 5.9 to 7.9. The lowest score was recorded in July 1996, four months after a flood, and the highest score was recorded during low flow in February 1995.

The only species that was always present was the caddisfly *Cheumatopsyche thomasseti* (**Fig. 4**). The species that was most often abundant was the pest blackfly *S. chutteri*, followed by the filter-feeding mayfly *Tricorythus discolor* and the midge *Cardiocladius africanus* (**Fig. 4**). The stonefly *Neoperla spio* complex and the caddisfly *Ecnomus ?thomasseti* were never considered common or abundant, but were present more often than not (68 and 64 % of the samples respectively).

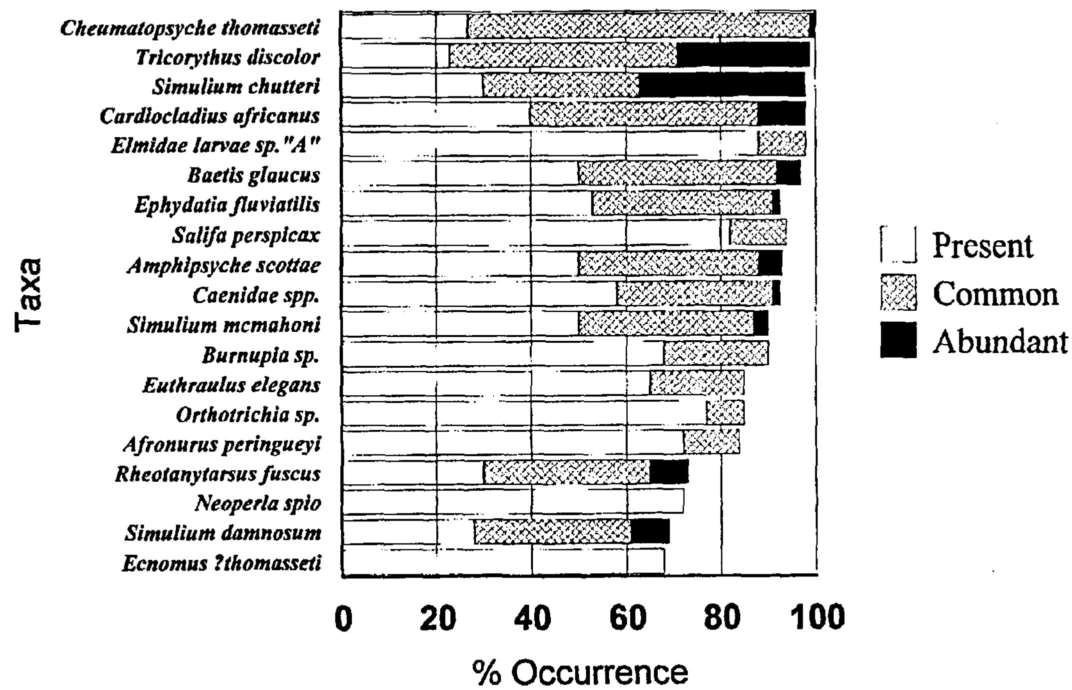

Figure 4. **Percent of time (samples) in which invertebrate taxa from the stones-in-current biotope at Gifkloof, Orange River, were present, common or abundant in monthly samples between** January 1992 and December 1996 (n=60). The most commonly occurring taxa only are listed.

The majority of taxa were predators (23) or gatherers (18) (**Fig. 5a**). However, the most abundant trophic group was filter feeders, followed by gatherers (**Fig. 5b**). The most abundant filterers were *S. chutteri, T. discolor* and *R. fuscus,* and the most abundant gatherers were the mayflies *B. glaucus* and *A. peringueyi* (**Table 2**).

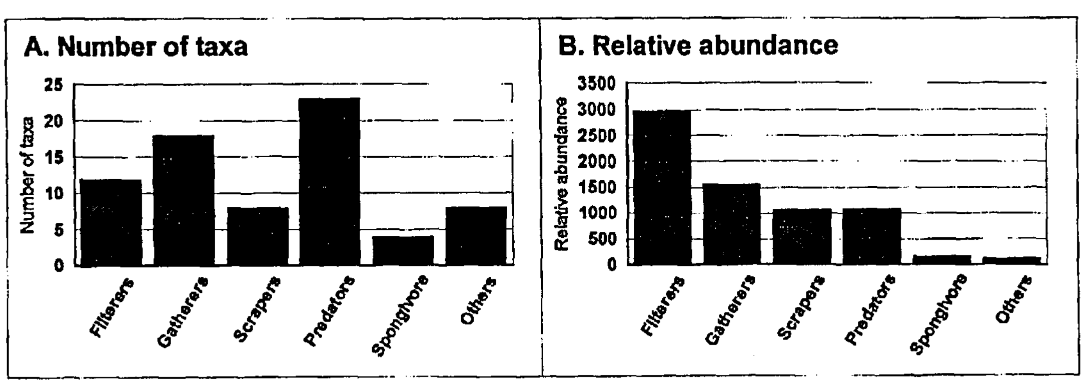

Figure 5. **The number of taxa (A) and the relative abundance (B) of the main trophic groups** in the Orange River.

Table 2. Numerically dominant taxa within each of the man functional feeding groups.

Feeding Category	**Dominant Taxa (% of total within each category)**
Filterers	*Simulium chutteri (17)* *Tricorythus discolor (16)* *Rheotanytarsus fuscus (13)*
Gatherers	*Baetis glaucus (33)* *Afronurus peringueyi (13)*
Scrapers	*Cardiocladius africanus (51)* *Burnupia sp. (29)*
Predators	*Cheumatopsyche thomasseti (28)* *Amphipsyche scottae (17)* *Salifa perspicax (17)*
Shredders	*Potomadytes ?brincki (85)*
Spongivores	*Pseudoleptocerus ?schoutedeni (29)* *Sisyra afra (29)*

Significant differences in invertebrate abundance and species composition were noted between visits and between years. For example, in July 1994 and January 1996 the abundance of invertebrates dropped suddenly (**Fig. 6**). The invertebrate fauna in 1993 was characterised by high numbers of the midge *R. fuscus*, whereas in 1996 the fauna was characterised by high numbers of the blackfly *S. chutteri* (**Fig. 6**). The caddisfly *Oecetus* sp. was seldom encountered but was present for three consecutive months (December 1994 to February 1995) during which river conditions were not obviously unusual (**Appendix A**). Likewise, on several occasions the abundance of the sponge *Ephydatia fluviatilis* changed suddenly for no apparent reason. Changes in the abundance of other taxa, however, were related to changes in river conditions, and in particular, changes in flow and water temperature.

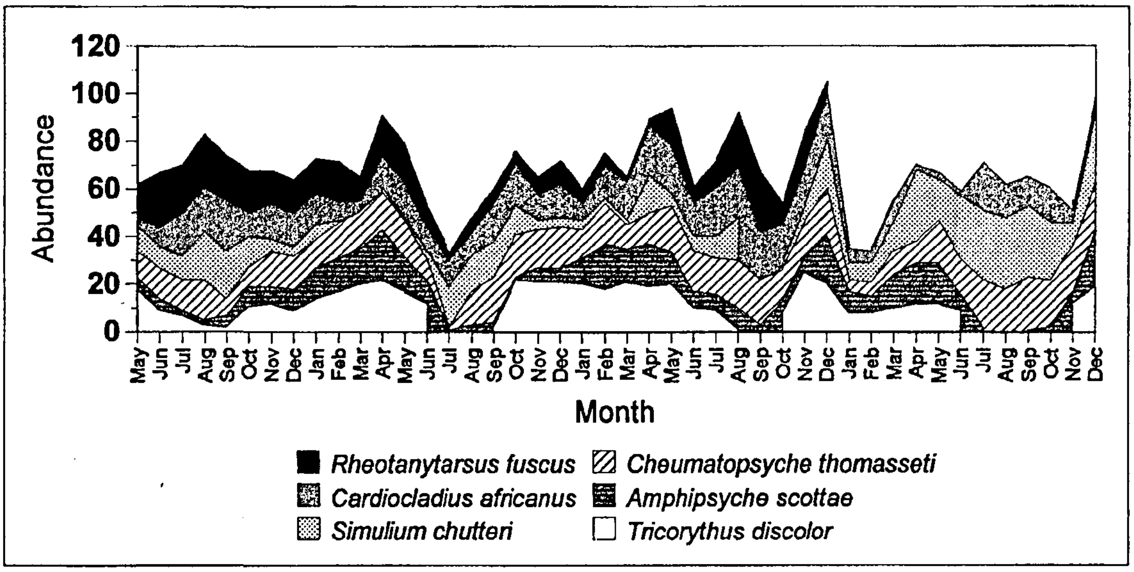

Figure 6. **Abundance of six commonly occurring invertebrates recorded monthly between May 1993 and December 1996 in the rapids downstream of Gifkloof, Orange River.** (Methods used to quantify abundance are described on page 5.)

During very low flow the river was characterised by clear water (Secchi depth >47 cm) and low concentrations of planktonic algae (**Table 3**). The average current speed was <0.3 m/s. The average number of taxa (29), average number of SASS4 families (18) and the average total abundance of invertebrates (157) was highest under these conditions. Taxa typically associated with very low flow included the filter-feeding midge *R. fuscus*, the sponge *Ephydatia fluviatilis* and the blackflies *S. adersi* and *S. ruficorne* (**Table 3**). The last species is usually associated with small trickles, but was found in the main channel of the Orange River. The most abundant trophic groups during very low flow were filterers and spongivores.

Table 3. River conditions and invertebrates in the Orange River typically associated with each of five flow categories, and the scores of selected metrics in each category. Shading indicates high values.

Flow category	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Sample size (n)	5	33	16	5	1
Typical Secchi depth (cm)	> 47	47-25	25-17	17-8	<8
Typical TSS (mg/l)	>16	16-42	42-80	80-260	>260
Median Planktonic algal abundance (cells/ml)	270	1,300	3,900	500	-
Average Total number of taxa	29	26	26	22	24
Average No. of SASS4 families	18	16	15	13	15
Average Total invertebrate	157	134	97	76	107

abundance					
Average SASS4 score	114	109	107	94	97
Average Score per Taxon	6.8	6.7	7.2	6.9	6.5
Trophic groups	Filterers Spongvores	Filterers Gatherers	Filterers Predators	Filterers Predators	Filterers Predators
Typical invertebrates	*R. fuscus* *S. adersi,* *S. ruficorne* *E. fluviatilis*	*C. africanus* *A.peringueuyi* *B. glaucus,* *E. elegans* *S. damnosum* *S. mcmahoni* *E. fluviatilis*	*A. scottae* *S. chutteri* *T. discolor*	*A. scottae* *S. chutteri,* *S. gariepense*	*A. maxima,* *A. scottae* *S. chutteri,* *S. gariepense*

During low-flow conditions the river was characterised moderate clarity (Secchi depth 25 to 47 cm) and moderate concentrations of planktonic algae (**Table 3**). The average current speed was 0.3 to 0.6 m/s. Numerous taxa were associated with these flows, including the mayflies *Afronurus peringueyi* and *Euthraulus elegans*, and the blackflies *S. damnosum* s.l. and *S. mcmahoni*. The mayfly *B. glaucus* was present under a wide range of flow conditions, but highest numbers were recorded during low flow. The most abundant trophic groups during low flow were filterers and gatherers. Although scrapers were uncommon in the Orange River, they were most abundant during low flow.

During moderate flow the probability of planktonic algal blooms was high. The average current speed was 0.6 to 0.8 m/s. Taxa typically associated with moderate flows were the caddisfly *A. scottae* and the blackflies *S. chutteri* and *S. gariepense*. The most abundant trophic groups during moderate flow were filterers and predators.

During high and very high flows the probability of planktonic algal blooms was minimal, and taxa typically associated with these conditions included the blackflies *S. chutteri* and *S. gariepense*, and the caddisflies *A. scottae* and *A. maxima*. The most abundant trophic groups during high and very high flows were filterers and predators.

An interesting result of this study was that the highest total number of taxa, number of SASS4 families, abundance of invertebrates and SASS4 scores most often occurred at very low flow, and values decreased as flows increased (**Table 3**; **Appendix A**). However, the highest ASPT was most often recorded during moderate flow. Furthermore, the abundance of several taxa dropped when flows exceeded 70 m^3/s (**Appendix C**). These included the mayflies *A. peringueyi* and *B. glaucus*, the blackflies *S. adersi* and *S. damnosum* s.l., the midge *R. fuscus*, the elmidae larva sp. 'B' and the sponge *E. fluviatilis*. However, the ASPT increased significantly when flows exceeded 70 m^3/s.

Within the beetle family Gyrinidae there appeared to be a replacement of genera along a flow gradient: The genus *Gyrinus* was most abundant during very low flow, *Aulonogyrus* was most abundant during low flow, and *Orectogyrus* was most abundant during moderate flow. However, the data were insufficient to be conclusive.

4.3 Flow variation

The abundance of several taxa responded to variations in flow, measured as the coefficient of variation of daily average flow over 21 days prior to sampling. Taxa whose abundance increased when flows fluctuated were the leech *Salifa perspicax*, the mayflies *T. discolor* and *B. glaucus*, the caddisflies *A. scottae* and *A. maxima* and the blackfly *S. chutteri* (**Appendix D**). The pest blackfly *S. damnosum* became abundant during a long period of stable, low-flow conditions in 1993. Other taxa whose abundance increased during stable flow conditions were the stonefly *Neoperla spio*, Turbellaria and the midges *C. africanus* and *R. fuscus* and the sponge *E. fluviatilis*. The number of SASS4 families and total SASS4 scores appeared unaffected by flow variation, but invertebrate abundance dropped as flow variation increased. The abundance of gatherers, scrapers and spongivores decreased as flow variation increased, whereas the abundance of predators increased as flow variation increased.

4.4 Flow slope

The direction and intensity of changes in flow were measured as the slope of the linear regression of daily average flow over 21 days prior to sampling. No metrics responded to a drop in flow (indicated by a negative slope), but several metrics responded to an increase in flow. In 1994 the abundance of common taxa was fairly constant until July, when there was a significant increase in the abundance of the pest blackfly *S. chutteri*, an almost complete disappearance of the midge *R. fuscus*, and a significant drop in the abundance of the predaceous caddisfly, *C. thomasseti*. These changes coincided with the mid-winter release of water in June (**Fig. 2a**). Interestingly, taxa took time to disappear. The June sample was taken at the peak of the release, and the average number of taxa was similar to previous months. The following month the average number of taxa was considerably lower. The June sample was also taken 22 days after the initial increase in flow, and for this reason the "flow slope" did not reflect the extent of the pulse.

Dramatic changes in species composition and abundance were also recorded after a flood in January 1996. Species whose abundance increased after the flood included *S. chutteri*, the mayfly *T. discolor*, and the caddisfly *A. maxima*. Species that disappeared after the flood included the mayfly *A. peringueyi*, the caddisfly *Ecnomus thomasseti*, the sponge *E. fluviatilis*, the blackfly *S. mcmahoni* and the midge *R. fuscus*.

These trends were reflected in the graphs of invertebrate abundance plotted as a function of positive flow change (**Appendix E**). Taxa whose abundance decreased following a sudden increase in flow included the blackflies *S. damnosum* and *S. mcmahoni*, the midge *R. fuscus*, the sponge *E. fluviatilis*. The abundance and number of scraper and spongivore taxa decreased as flow-slope increased.

Taxa whose abundance increased following a sudden increase in flow included the blackfly *S. chutteri*, the elmid adult species "B", the mayfly *B. glaucus*, the caddisfly *A. scottae*. There was a drop in the total abundance of invertebrates as flow-slope increased, but the total SASS4 scores and the ASPT remained unchanged.

4.5 Flow constancy

An arbitrary measure of flow constancy was obtained from the number of days that flow did not exceed, or was not less than, 20 % of the daily average flow on the day of sampling. There was no change in the overall SASS4 scores, total number of taxa or ASPT with changes in flow constancy. However, several metrics responded to flow constancy. Taxa whose abundance declined during extended periods of constant flow included the caddisflies *A. scottae* (after 20 days) and *C. thomasseti* (after 30 days), the leech *S. perspicax* (after 20 days) and the stonefly *N. spio* complex (after 30 days) (**Table 4**). The overall abundance of caddisflies and predators started declining after 20 days of constant flow, whereas the abundance of gatherers started declining after 15 days of constant flow. Taxa whose abundance increased during periods of constant flow included sponge (Porifera) gemmules (after 5 days), and the muscid fly *Xenomyia* sp. (after 30 days). The abundance of scrapers started increasing after 20 days of constant flow.

Table 4. Number of days taken for selected metrics to show a response following prolonged periods of constant flow conditions.

Metrics which increased	**Number of days**	**Metrics which decreased**	**Number of days**
Amphipsyche scottae	20	Porifera gemmules	5
Cheumatopsyche thomasseti	30	Abundance of scrapers	20
Salifa perspicax	20	*Xenomyia* sp.	30
Neoperla spio	30		
Abundance of Trichoptera	20		
Abundance of Gatherers	15		
Abundance of Predators	20		

4.6 Season

Two important considerations in the assessment of ecological flow requirements are the seasonal periods of drought, and the timing and size of the first spring freshet. An analysis of historical flow data from Buchuberg Dam showed that before impoundment the driest month was September, during which flows were less than 15 m^3/s in nearly 40 % of the years between 1933 and 1969. The first spring freshet was most often (60 % of years) in November, and was usually over 1000 m^3/s in size (**Fig. 7**). After impoundment there was no winter drought and no consistent spring freshet, and high flows were most often in March. This was at the end of the rainy season, when water was released from Lake Vanderkloof to provide buffering capacity for floods, anticipated the following season.

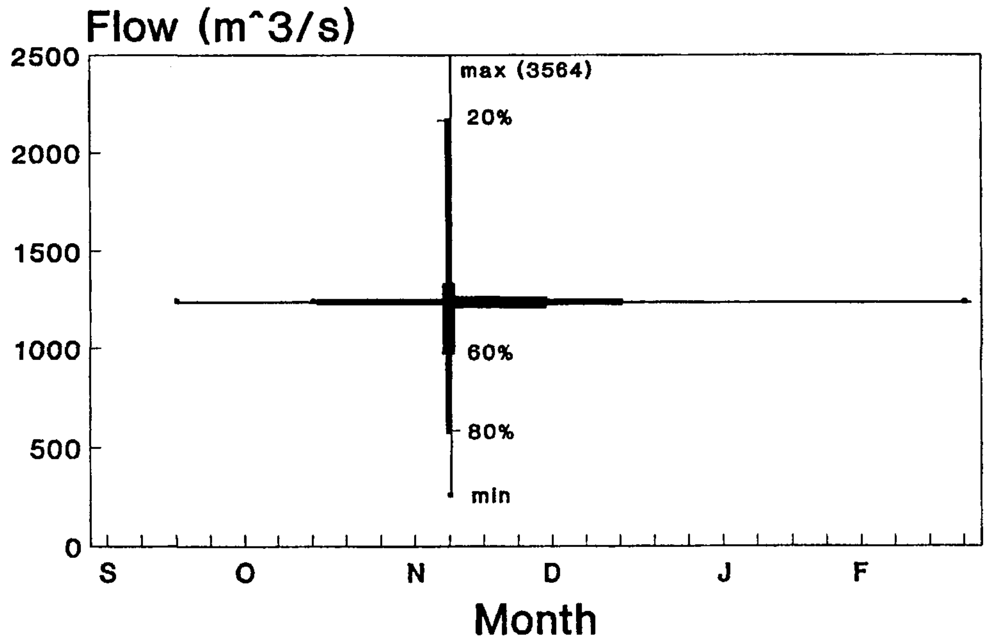

Figure 7. Timing and size of the first spring freshet recorded at Buchuberg Dam (D7H008) before major impoundment (1933-1966). Data are presented as percentiles, and include the ranges. [Data: Department of Water Affairs and Forestry, Pretoria.]

Highest total numbers of taxa and highest SASS4 scores were usually recorded in October or November, whereas the highest ASPT was usually recorded in January or February (**Appendix B**). The total abundance of filterers and gatherers showed no obvious seasonal trends, but scrapers were most abundant from August to October, whereas predators were most abundant in December.

Several taxa were common or abundant at certain times of the year only (**Appendices B & F**). The mayfly *A. peringueyi* and the caddisfly *Pseudoleptocerus ?schoutedeni* were most abundant in October, whereas the mayfly *E. elegans* was most abundant in mid-winter to early spring (July to September). The mayfly *T. discolor* was abundant during warmer months, and was consistently scarce in August and September. In both 1992 and 1993, large numbers of recently hatched *T. discolor* were noticed in the last week of September.

Taxa typical of the summer and autumn fauna included the caddisfly *Amphipsyche scottae* (December to May) and *Aethaloptera maxima* (March to April). The mayfly *P. maculosum* was present in December and February only. The leech *Helobdella conifera* was only once recorded during regular monthly sampling, but was found repeatedly between February and March during ad-hoc sampling.

The blackfly *S. mcmahoni* was present throughout the year, with highest numbers in October and November, whereas *S. adersi* was most abundant in late autumn to early winter (April to July). Larvae and pupae of the muscid fly *Xenomyia* sp. were common or abundant in spring only (mostly October). Taxa whose abundance showed no seasonal trends included the sponge *Ephydatia fluviatilis* and the caddisfly *C. thomasseti.*

4.7 Water temperature

Water temperature recorded during this study ranged from 8 to 30°C (**Appendix A**). Several metrics increased with increases in water temperature. These included the abundances and number of mayfly and caddisfly taxa, the total number of taxa, the average number of taxa per stone and the ASPT (**Table 5**). Numerous taxa were associated with warm water (**Appendix G**). The mayfly *T. discolor* was common only when water temperatures exceeded 22°C, and hatching in September 1992 and 1993 took place at water temperatures of 21 and 19°C respectively. The caddisfly *Aethaloptera maxima* was never found at temperatures less than 18°C. Other taxa which showed a preference for warm water were the caddisfly *Ecnomus* sp. and the mayfly Baetidae sp. 'C'.

A few taxa were more numerous during cold conditions. Taxa typically associated with cold water (less than 15°C) included the blackflies *S. adersi* and *S. damnosum* and larvae of the beetle *Aulonogyrus* sp. (**Appendix G**). Of particular significance was the inverse relation between the abundance of blackflies and Trichoptera (mostly predators of blackflies) as water temperatures changed.

Of significance for biomonitoring was that the number of SASS4 families and the SASS4 scores were lower only at temperatures less than 15°C.

Table 5. Median values of selected metrics within four water temperature categories, and taxa typically associated with each category. Shading indicates highest values.

Temperature (C)	<15C	15-19C	20-25C	>25C
Sample size (n)	13	14	19	14
Number of Ephemeroptera taxa	5	5	7	7
Abundance of Ehemeroptera	26	30	40	54
Number of Trichoptera Taxa	4	5	6	7
Abundance of Trichoptera	24	28	38	41
Number of Simuliidae species	3	4	3	4
Abundance of Simuliidae	36	32	22	18
Total number of taxa	23	27	27	29
Number of taxa per stone	10	12	14	14
Number of SASS4 families	15	17	16	16
SASS4 Score	93	108	109	108
Average Score per Taxon	6.6	6.7	6.9	7.2
Typical taxa	*S. adersi* *S. damnosum* *Aulonogyrus*	*B. glaucus* *E. elegans* *C. bifasciata* *R. fuscus*	*A. maxima* *E. thomasseti*	*A. peringueyi* *Baetidaae C* *P. maculosum* *T. discolor* *A. scottae* *Hydroptila* *Orthotrichia* *X. ugandae* *P. ?brincki*

4.8 Turbidity

Secchi depths recorded during this study ranged from 8 to 65 cm. At the beginning of this study water was turbid, and concentrations of suspended solids exceeded 50 mg/l (**Appendix A**). As river levels dropped the water became clear, and the lowest concentration of suspended solids (5 mg/l) was recorded during very low flow (14 m^3/s) in August 1993. Highest values (777 mg/l) were recorded during a flood in March 1996. However, occasional thunderstorms contributed localised inputs of highly turbid water which were unrelated to flow levels in the river.

Draining of Buchuberg Dam in April 1993 and again in July 1995 contributed to increased concentrations of suspended solids. These were not measured, but were once seen from the air, and the river for several kilometres downstream looked like liquid mud. Water temperatures at Gifkloof dropped following the releases by 5°C. However, the effects of these releases on invertebrate abundance at Gifkloof were undetected. Likewise, construction work at Gifkloof prior to the April 1992 sample had no major impact on invertebrate abundance.

Taxa whose abundance increased with increased turbidity included the mayflies *T. discolor* and *B.glaucus*, the leech *S. perspicax* and the caddisfly *A. scottae* (**Appendix H**). Taxa whose abundance increased during clear water included the blackfly *S. adersi*, the caddisfly Orthotrichia sp., the mayfly *Euthraulus elegans*, the stonefly *N. spio* and larvae of the beetle *Aulonogyrus* sp.. The filter-feeding midge *R. fuscus* was most abundant at a time when the water was very clear (TSS 10 mg/l). The abundance of Caenidae spp. was highest at intermediate concentrations of suspended solids.

4.9 Benthic algae

Benthic algae, consisting mainly of *Cladophora glomerata* and *Stigeoclonium tenue*, were usually abundant in late winter to early spring (July to September). In 1994 algal abundance remained low throughout winter because of high river levels and associated high turbidity (Secchi depth 9 to 10 cm) (**Appendix A**). Benthic algae were most abundant when the Secchi depth exceeded 18 cm (**Fig. 8a**), and when the flow was less than 130 m^3/s (**Fig. 8b**). However, the relation between turbidity (Secchi depth) and the abundance of benthic algae was weak, partly because sampling was done in shallow (accessible) water. The middle and lower Orange River is mostly wide and the rapids are shallow. This means that primary production in most rapids in the Orange River is not limited at flows less than 130 m^3/s.

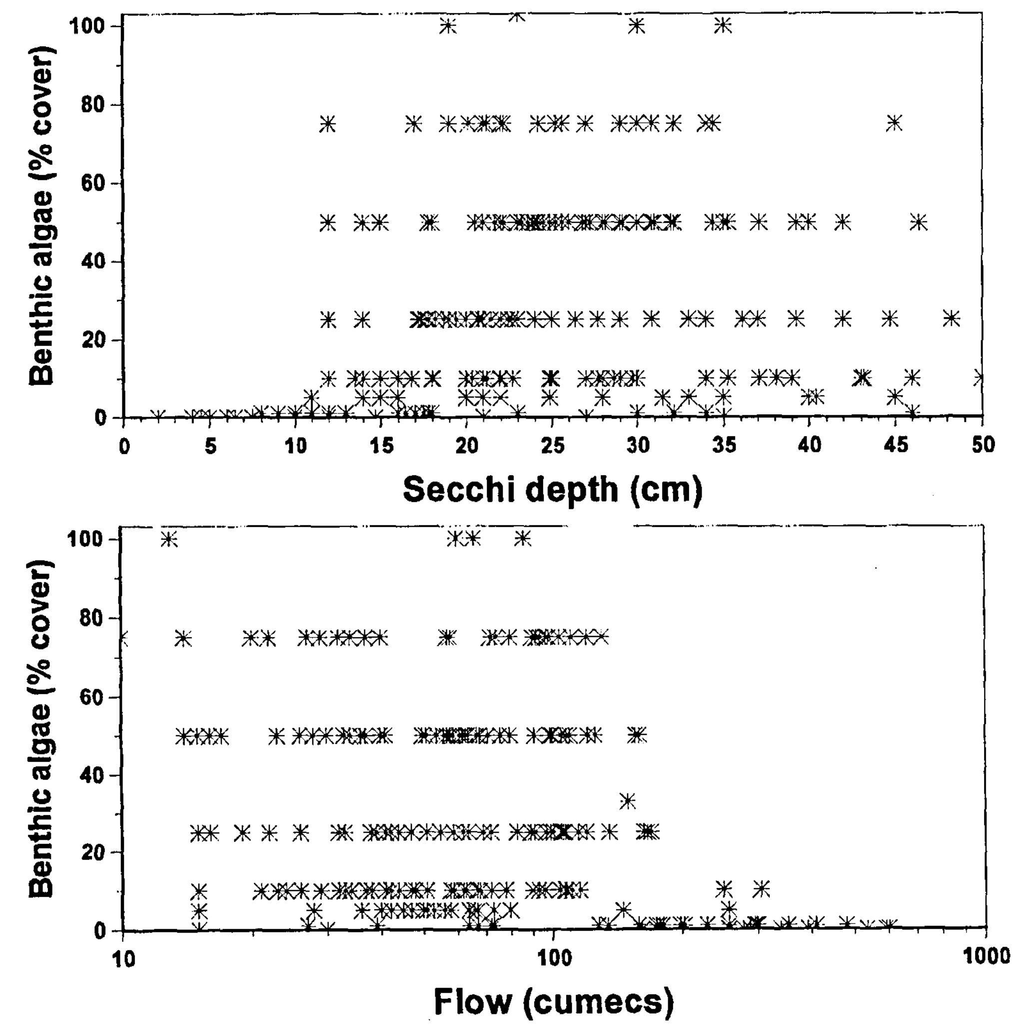

Figure 8. Abundance of benthic algae as a function of Secchi depth (A) and flow (B), recorded weekly between July 1991 and December 1996 in the rapids at Gifkloof, Orange River.

Construction work at Gifkloof Weir on 10-16 March 1992 caused an increase in silt loads and a sudden drop in the abundance of benthic algae. Taxa whose abundance dropped following construction included the mayfly *T. discolor*, the caddisfly *A. scottae* and the midge *C. africanus*. However, construction activities had no impact on the overall abundance and species composition of invertebrates.

During periods of low algal cover the abundance of the caddisfly *Ecnomus* sp. and the mayflies *B. glaucus* and Baetidae sp. 'C' was higher than during periods of high algal cover (**Appendix I**). By contrast, the abundance of the midge *C. africanus* and the abundance of blackflies increased during periods of high algal cover. The abundance of mayflies and caddisflies, the total number of taxa and the average number of taxa per stone were usually highest at intermediate levels of algal cover (10 to 25%).

Of particular significance for biomonitoring was that the ASPT was usually highest during low algal cover (<10 %) (**Table 6**).

Table 6. Median values of selected metrics within four benthic algal abundance categories, and taxa typically associated with each category. Shading indicates high values.

	<10 %	10-25 %	26-50 %	>50 %
Number of Ephemeroptera taxa	6	6	7	5
Abundance of Ephemeroptera	36	51	30	25
Number of Trichoptera Taxa	6	5	5	4
Abundance of Trichoptera	34	38	28	28
Number of Simuliidae species	4	4	3	2
Abundance of Simuliidae	19	24	34	38
Total number of taxa	26	29	26	19
Average number of taxa per stone	11	14	12	9
Number of SASS4 families	16	16	15	14
SASS4 Score	108	109	104	92
Average Score per Taxon	7.2	6.7	6.7	6.6

4.10 Planktonic algae

The concentration of planktonic algae was highly seasonal, with lowest values in winter (June to August), and highest values in autumn (March to May). Taxa whose abundance appeared to increase with increases in abundance of planktonic algae included the mayflies *B. glaucus* and Baetidae sp. C., the blackflies *S. adersi* and *S. mcmahoni*, the Elmid larvae sp. 'B' and the leach *S. perspicax* (**Appendix J**). However, these relationships were not strong. What was clear was that total invertebrate abundance, and the abundance of individual trophic groups increased as the abundance of planktonic algae increased. These changes had no major influence on the SASS4 scores or ASPT.

Blooms of the planktonic blue-green algae *Microcystis* sp. developed in Lake Vanderkloof from time to time, particularly after destratification of the thermocline in autumn (**Fig. 9**) (Allanson and Jackson 1983). There was a slight decline in the total number of taxa as the abundance of *Microcytis sp.* increased

(**Appendix K**). These changes did not greatly affect SASS4 scores or the ASPT. Taxa whose abundance declined during *Microcystis* sp. blooms included the blackfly *S. chutteri*, the limpet *Burnupia* sp., the beetle *Aulonogyrus* spp., the flatworm Turbellaria and the stonefly *N. spio*. By contrast, the abundances of the mayfly *T. discolor*, *S. damnosum* s.l. and the caddisfly *C. thomasseti* were unaffected by *Microcystis* sp. blooms. Indeed, highest numbers of *S. damnosum* were recorded in June 1995 following a *Microcystis* sp. bloom in the previous month. By contrast, the abundance of *S. chutteri* declined during *Microcystis* blooms.

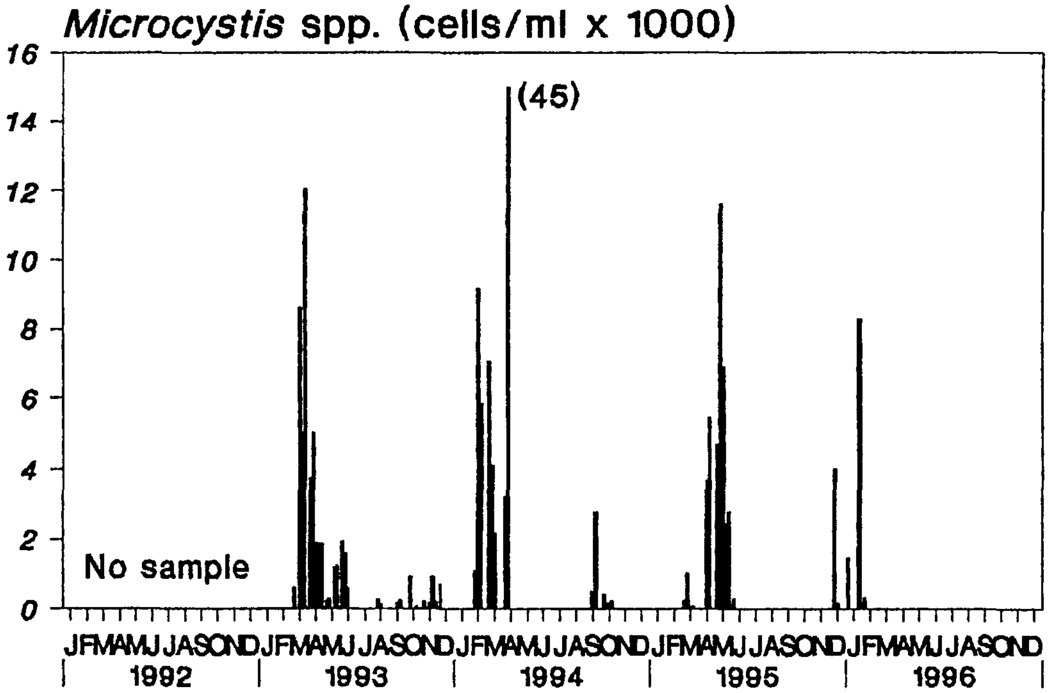

Figure 9. Abundance of the blue-green algae *Microcystis* sp., recorded weekly between March 1993 and December 1996 in the rapids at Gifkloof, Orange River.

5. DISCUSSION

The results of this study showed that the differences in invertebrate species composition and abundance between years were related mainly to long-term wet and dry cycles. This serves to highlight the importance of long-term monitoring in understanding the factors affecting changes in aquatic invertebrate populations, and supports the conclusions of Chutter et al. (1986).

During low flow, water was usually clear, and this led to an increase in the abundance of benthic algae. Invertebrate taxa whose abundance increased during low flow were typical of invertebrates found throughout southern Africa, and were therefore of little conservation importance. During high flow, light limitation led to reduced abundance of benthic and planktonic algae. Invertebrate taxa present following high flow included unusual species, endemic to large, turbid rivers, such as the blackflies *S. gariepense* and *S. chutteri*. Extended periods of constant flow was favourable to certain species, whereas fluctuating conditions were favourable to a different suite of species.

Although little is known about the life-history characteristics of aquatic invertebrates in South Africa, it is clear that many invertebrates in the Orange River have evolved life-history characteristics that buffer against extreme conditions. Such characteristics are likely to promote coexistence of species in fluctuating environments. Typical examples include:

- the desication-resistant eggs of certain Caenid mayflies and *Polypedilum* sp. Chironomidae,
- the suspected diapause of *S. chutteri* eggs,
- the ability of the bivalve *Corbicula fluminalis* to remain alive in damp sand,
- the desication-resistant stages of the sponge *Ephydatia fluviatilis* and the Bryozoa *Plumatella* sp.,
- the rapid rates of development of many species,
- the ability to withstand high current speeds and high turbidity.

The poor relation between functional feeding groups and trophic conditions reflects the problems associated with categorising invertebrates into specific feeding categories. Many taxa in the Orange River are opportunistic, and will feed on what is most readily available. Despite this problem, there was an increase in the abundance of scrapers (mostly the midge *Cardiocladius africanus*) during winter, supporting the seasonal changes in Functional Feeding Groups predicted by Vannote et al. (1980). However, there was no obvious seasonal change in the dominance of filterers, although there were significant seasonal changes in the species composition of filterers.

The Orange River is noted for its low numbers of invertebrate species (Palmer 1996). The level of resolution of the present study in detecting important driving variables and important ecological processes was therefore low. This simplified data analysis, but the conclusions may have been different, and certainly more complicated, had the study been undertaken in a river with a diverse fauna.

A further limitation of this study was that few samples were taken at very low flow and at high flow, and only one sample was taken during very high flow. Statistical comparisons between all flow categories were therefore not possible, and some of the conclusions of this report were based on circumstantial evidence rather than statistically valid tests. For example the blackfly *S. gariepense* was seldom encountered, but the structure of the larval mouth parts and its localised distribution leads one to suspect that it has a preference for high flow, turbid conditions which typically occurred in the Orange River before impoundment. Likewise, the mayfly *P. maculosum* was encountered in February 1994, February 1995 and

December 1996 only, and together with information from other studies, this leads one to suspect that *P. maculosum* is a warm-water species.

Like many studies of natural systems, the data collected during this study was plagued by various sources of "noise". Low numbers of *S. chutteri* in September and October 1995 may have been attributed to reduced recruitment because of the success of the blackfly control programme, rather than any natural event. Furthermore, sudden changes in water level caused by the opening and closing of the Gifkloof Canal may have affected invertebrate populations, but there was no record of when these occurred. Another source of variation was that the particular rapids sampled changed from time to time, and this may have resulted in artificial changes in invertebrate abundance. In addition, many aquatic invertebrates have an aerial phase, and populations may be therefore have been affected by conditions unrelated to conditions in the river. It is therefore not surprising that aquatic invertebrate populations are notoriously variable, and this further highlights the importance of long-term monitoring.

Another problem inherent in studying most natural systems is the close dependency between variables. For example, changes in flow may affect both water temperature and the availability of food resources, and these may influence hatching times, development rate, size and reproductive potential of aquatic invertebrates. Although this study ascribed changes in invertebrate abundance to changes in river conditions, these relationships are correlative only, and causative relationships need further testing. However, many changes in abundance recorded during this study were consistent with what is known about the environmental preferences of taxa, and causative relations may be suspected.

An interesting results of this study was the change in species composition and abundance at flows above or below 70 m^3/s. The reasons for this are not understood, but it is likely that light limitation plays a role. When the flow in the Orange River is 70 m^3/s, the Secchi depth is usually about 23 cm (Palmer 1997). The depth to which photosynthesizable radiation penetrates is not known, neither is the average depth of rapids in the Orange River known. However, the relation between flow and the abundance of benthic algae in the Orange River **(Fig. 8b)** shows clearly that light limitation starts to occur when flow is greater than 130 m^3/s. This suggests that factors in addition to light limitation are involved in the inflection of invertebrate abundance and species composition at 70 m^3/s. The most likely factor is the availability of habitat.

In 1995 the Department of Water Affairs and Forestry surveyed five profiles in the middle and lower Orange River. The surveys examined the relation between flow, depth and average water velocity. There was no obvious inflection in these parameters at 70 m^3/s.

Another interesting result of this study was the replacement of *S. chutteri* by *S. damnosum* s.l. during *Microcystis* sp. blooms. This suggests differential sensitivity of blackfly taxa to *Microcystis* spp. toxins. Laboratory trials elsewhere have shown that *Microcystis* spp. toxins are toxic to certain zooplankton (Lampert 1981, Jungmann and Benndorf 1994). In many reservoirs in South Africa, *Microcystis* spp. are abundant, usually in summer (Truter 1987). It is likely, therefore, that most rivers in southern Africa are periodically polluted by *Microcystis* spp. toxins. This may have important implications for the distribution and abundance of certain species, and by implication, have important implications for the National River Health Programme.

6. CONCLUSIONS

Natural flow fluctuations are important

This study has shown that many invertebrates in the Orange River have life-history characteristics that buffer against unfavourable conditions. These include desiccation-resistant stages and rapid rates of development. Such characteristics are likely to promote the coexistence of species in fluctuating environments. This highlights the importance of disturbance in maintaining a diverse river ecosystem. Stable flows caused by impoundment are detrimental to taxa adapted to either low or high flow. However, unseasonally high flows were shown to be detrimental to aquatic invertebrates.

Unusual invertebrate taxa prefer high flows

Taxa present during low flow were found throughout southern Africa, and were of little conservation importance. Taxa present during high flow, by contrast, included unusual species, endemic to large, turbid rivers. The maintenance of a healthy invertebrate fauna in the middle Orange River therefore depends on maintaining, or at least simulating, natural flow fluctuations. Simulating natural flow fluctuations would also help to conserve threatened species, such as the blackfly *S. gariepense*, and help reduce population outbreaks of the pest *S. chutteri*.

Timing of droughts and freshets

Simulating natural flow fluctuations in the middle Orange River requires a simulated drought in August/September and a controlled freshet or flood in November. The recommended size and duration of flood and drought events were not considered in this project, although there was an inflection in the abundance and species composition of invertebrates at 70 m^3/s. The reasons for this are not understood, but it is likely that light limitation and habitat availability play a role.

Many factors may affect SASS scores

This study has also shown that biomonitoring results based on SASS scores in the stones-in-current biotope are sensitive to long-term wet and dry cycles, the recent flow history, the time of year, water temperature and the abundance of benthic algae. The National River Health Programme should consider these aspects when defining reference conditions.

A single survey misses many species

During this study a single snap survey usually missed over 60% of the taxa that were eventually recorded at the site. This highlights the limitations of one-off surveys.

Fine organic material drives the middle Orange River ecosystem

This study also serves to highlight that the main source of energy that is driving the ecology of the middle Orange River is fine particulate organic material (FPOM). The sources of FPOM are unknown. The materials could be derived from heterotrophic bacteria, or primary production within Lake Vanderkloof, or primary production on the river bed, or the decomposition of *Phragmites* sp. reeds, or some other unknown source. An understanding the origins and fates of these material would provide a fundamental basis of how this river ecosystem functions.

Microcystis sp. appears toxic to certain invertebrates

The suspected toxicity of *Microcystis* sp. to certain aquatic invertebrates may have important implications for the distribution and abundance of certain species, and this may have important implications for the National River Health Programme.

Draining sediments from Buchuberg Dam has detrimental impacts

The draining of Buchuberg Dam released large quantities of fine silt. This has a detrimental impact on the downstream environment, although it did not have a major impact on invertebrates at Gifkloof, 145 km downstream.

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7. RECOMMENDATIONS

A comprehensive assessment of the Ecological Flow Requirements is recommended

Given the changes that are likely to occur following the developments and proposed developments in Lesotho, as well as the agricultural developments which are taking place along the lower Orange River, it is recommended that a detailed study of the ecological flow requirements of the middle and lower Orange River should be conducted as soon as possible. Particular attention should be paid to the unexplained inflection in the abundance and species composition of invertebrates at 70 m^3/s.

Long-term biomonitoring at selected sites is recommended

Long-term biomonitoring at selected sites provides useful insights into natural ecosystem dynamics, and is essential for obtaining a better understanding of ecosystem processes and change.

Annual Biomonitoring at Gifkloof is recommended

This study has shown that sampling during low flow in winter (June to August) would provide the highest resolution of biomonitoring results in the middle Orange River. It is therefore recommended that invertebrates should continue to be monitored on an annual basis at the Gifkloof rapids at this time. Furthermore, when interpreting biomonitoring results, particular attention should be given to long-term wet and dry cycles, the recent flow history, the season, the water temperature, the abundance of benthic algae and the presence of the blue-green algae *Microcystis*.

Unseasonal winter releases should be avoided

This study has shown that unseasonal winter releases from Vanderklof Dam can have detrimental impacts on aquatic invertebrates situated over 600km downstream. Releases of this nature should be avoided.

Future research should focus on the role of Fine Particulate Organic Matter

It is suggested that future research should investigate the sources, fates and management significance of FPOM in rivers in South Africa. Particular attention should be given to the effects of *Microcystis* sp. toxins on selected aquatic invertebrates, particularly the blackfly *S. chutteri.*

Draining of Buchuberg Dam should be controlled

The detrimental environmental impacts of periodically draining Buchuberg Dam should be recognised, and steps to mitigate these impacts should be taken. It is recommended that sediments should be flushed regularly, and this should be done when the flow is moderate to high (if possible).

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8. REFERENCES

ALLANSON, B. R. & JACKSON, P. B. N. (1983). Limnology and Fisheries Potential of Lake le Roux. *Council for Scientific and Industrial Research, South African National Scientific Programmes Report No.* 77: ix + 182 pp.

BENADE, C. (1993a). *Studies on fish populations in the regulated Orange River System within the borders of the Cape Province.* Unpublished M.Sc. thesis, University of the Orange Free State, Bloemfontein. Volume 1: iii + 185 pp; Volume 2: iii + 66 pp.

BENADE, C. (1993b). Management proposals for the regulated Orange River System within the borders of the Cape Province. *Internal report. Cape Nature Conservation, Kimberley.* v + 27 pp + appendixes.

BREMNER, J. M., ROGERS, J. & WILLIS, J. P. (1990). Sedimentological aspects of the 1988 Orange River floods. *Transactions of the Royal Society of South Africa* 47(3): 247-294.

CHUTTER, F. M. (1968). On the ecology of the fauna of stones in the current in a South African river suporting a very large *Simulium* (Diptera) population. *Journal of Applied Ecology* 5: 531-561.

CHUTTER, F. M. (1994). The rapid biological assessment of stream and river water quality by beans of the macroinvertebrate community in South Africa. In: Uys, M (ed). Classification of rivers and environmental health indicators. Proceedings of a joint South Africa/Australian workshop. February 7-14 1994, Cape Town, South Africa. *Water Research Commission Report No* TT 63/94.

CHUTTER, F. M., AGNEW, J. D., BRUWER, C. A. & FOWLES, B. K. (1986). Monitoring and surveillance. Chapter 6 in O'KEEFFE, J. H. (ed.). The conservation of South African Rivers. South African National Scientific Programmes Report No 131.

CUMMINS, K. W. (1973). Trophic relations of aquatic insects. *Annual Review of Entomology* 18: 183-206.

JUNGMANN, D. & BENNDORF, J. (1994). Toxicity to *Daphnia* of a compound extracted from laboratory and natural *Microcystis* spp., and the role of microcystins. *Freshwater Biology* 32: 13-20.

KING, J. M. & THARME, R. E. (1994). Assessment of the instream flow incremental methodology and initial development of alternative instream flow methodologies for South Africa. *Water Research Commission Report, Pretoria, No* 295/1/94.

LAMPERT, W. (1981). Inhibitory and toxic effects of blue-green algae on *Daphnia*. *Internationale Revue der Gesamten Hydrobiologie* 66(3): 285-298.

MERRITT, R. W. & CUMMINS, K. W. (1984). *An introduction to the aquatic insects of North America.* Second edition. Kendall/Hunt Publishing Company. Iowa. xiii + 722 pp.

ORANGE RIVER ENVIRONMENTAL TASK GROUP (1990). Orange River Ecology - assessment of environmental water requirement of the Orange River between PK le Roux Dam and the mouth. *Report on the Orange River Environmental workshop held at Golden Gate, August 1990, compiled by BKS Incorporated.*

PALMER, R. W. (1993). Short-term impacts of formulations of *Bacillus thuringiensis* var. *israelensis* de barjac and the organophosphate temephs, used in blackfly (Diptera: Simuliidae) control, on rheophilic benthic macroinvertebrates in the middle Orange River, South Africa. *Southern African Journal of Aquatic Sciences* 19(1/2): 14-33.

PALMER, R. W. (1994). Biological and chemical control of blackflies (Diptera: Simuliidae) in the Orange River. *Water Research Commission, Pretoria. Report No.* 343/1/94.

PALMER, R. W. (1996). Invertebrates in the Orange River, with emphasis on conservation and management. *Southern African Journal of Aquatic Sciences* 22(1/2): 3-51.

PALMER, R. W. (1997). Principles of integrated control of blackflies (Diptera: Simuliidae) in South Africa. *Water Research Commission, Pretoria, Report No.* 650/1/97.

PALMER, R. W., EDWARDES, M. & E. M. NEVILL (1996). Control of pest blackflies (Diptera: Simuliidae) along the Orange River, South Africa: 1990-1995. *Onderstepoort Journal of Veterinary Research* 63(4): 289-304.

PALMER, R. W. & PALMER, A. C. (1995). Impacts of repeated applications of *Bacillus thuringiensis* var. *israelensis* de Barjac and temephos, used in blackfly (Diptera: Simuliidae) control, on macroinvertebrates in the middle Orange River, South Africa. *Southern African Journal of Aquatic Sciences* 21(1/2): 35-55.

TRUTER, E. (1987). An aid to the identification of the dominant and commonly occurring genera of algae observed in some South African impoundments. Department of Water Affairs, *Technical Report No.* 135: vi + 101 pp.

UYS, M., GOETSCH, P. A., & O'KEEFFE, J. H. 1996. National Biomonitoring Programme for riverne ecosystems: Ecological indicators, a review and recommendations. Institute for Water Quality Studies, Department of Water Affairs and Forestry,Pretoria, South Africa. *NBP Report Series No. 4.*

VANNOTE, R. L., MINSHALL, W., CUMMINS, K. W., SEDELL, J. R. & CUSHING, C.E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 130-137.

VAN VUUREN, S. J. & ERASMUS, J. J. (1992). Hydro-power generation and the aquatic environment: a case study of the Orange River downstream of PK le Roux Dam. *Electricity + Control.* March: 11-15.

Appendix A. Data collected monthly at rapids downstream of Gifkloof Weir between January 1992 and December 1996. Flow refers to the daily average flow recorded at Buchuberg Dam (D7H008). 'TSS' refers to the concentration of Total Suspended Solids. Invertebrate abundance was initially ranked on a 3-point scale, but this was later changed to a 30-point relative abundance scale, described in the methods. Shading indicates sampling occasions in which abundance was ranked on a 3-point scale. Bold indicates maximum values.

Appendix B. Average scores (abundance) for invertebrate taxa recorded at Gifkloof rapids each month between January 1992 and December 1996.

Appendix C. Flow. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus flow (in m^3/s) recorded at Buchuberg Dam on the day of sampling.

Appendix D. Flow variation. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus flow variation, measured as the coefficient of variation over 21 days prior to sampling.

Appendix E. Flow slope. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus increase in flow, measured as the positive slope of the linear regression over 21 days prior to sampling. (Flow reductions are not shown because they showed no obvious trends).

Appendix F. Season. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus time of year (month).

Appendix G. Water temperature. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus water temperature (°C), measured as the average max-min temperature recorded in the week (7 days) prior to sampling.

Appendix H. Turbidity. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus turbidity, measured as the Secchi depth (cm).

Appendix I. Benthic algae. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus the abundance of benthic algae, measured visually as percentage cover.

Appendix J. Planktonic algae. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus the total abundance of planktonic algae, plotted as the square root of the number of cells/ml.

Appendix K. Microcystis sp.. Invertebrate abundance and selected metrics recorded at Gifkloof rapids versus the abundance of the blue-green algae Microcystis sp., plotted as the square root of the number of cells/ml.
