EXECUTIVE SUMMARY

The project was sub-divided into two parts. The title of the first part was "The preparation of a river water diatom identification database for use in South Africa". The title of the second part was "The use of diatoms in the assessment of water quality".

The initial hypothesis was that the database used in the Netherlands to assess water quality would be suitable for use in South Africa. For that reason, the aims in the first part were:

1. To produce a genus identification database consisting of all 238 genera described by Round et al. (1991). This was completed.
2. To obtain literature on the descriptions of all the 948 taxa of the Netherlands database. However, because the results of this study showed that the Netherlands database was not entirely suitable for use in South Africa (see later), descriptions were not confined to the Netherlands taxa. The available literature was obtained via interlibrary loans and purchases.
3. To produce a database and an identification system containing all the 948 diatom species used by van Dam et al (1994) to determine water quality in the Netherlands. For the reasons stated in 2 above this was not considered relevant to the study.
4. Construct identification systems for each genus of the Netherlands database. Because the study showed that the Netherlands database was not suitable for use in South Africa, this was not considered relevant to the study. Instead, the identification system was confined to all the genera as described in Round et al. (1990) because this is the latest text and it is in English.
5. Run a workshop for interested persons to test the system. A workshop has been run on two occasions for the staff of the CSIR (Durban). More workshops will be presented on demand.

The aims in the second part were:

1. To survey the benthic diatom flora of identified river systems and to relate the dominant taxa to the chemical water quality in those rivers. This was completed for rivers in the Eastern Cape, the Western Cape and Mpumalanga.

2. To determine the extent to which the diatom database developed in the Netherlands is relevant to South African rivers and their water quality. The conclusion was that the Dutch database was inadequate for South African use.

In the first part of the study, a Microsoft Excel spreadsheet was prepared from descriptions of each of the known diatom genera in Round et al. (1990) (see Appendix A). In the spreadsheet, all the possible characteristics (i.e. raphe, araphid, striae number, shape, etc.), were positioned across the page. The names of each of the possible genera were positioned down the LHS of the page and in each appropriate cell the genus was awarded a 1 if the characteristic applied or left blank if the characteristic did not apply. A visit was made to the University of Bristol, to Professor F.E. Round (senior author of the definitive text "The Diatoms") and, over a period of three days, each of the characteristics was checked. The table was then taken into a MS Access database system where a series of forms were produced, one for each genus. This database allows users to identify any diatom genus. The MS Access database was made available to the CCWR who placed it on the WRC web site.

The genus database is available to anyone interested in using it and can be accessed either from the CCWR web site or, by arrangement and a small charge to cover the cost, can be supplied as an MS Access database or as an MS Excel spreadsheet. These data have been supplied to the CSIR, Durban

The aims in the second part (literature) were achieved using Inter-library loans through the University of Port Elizabeth. Some of the aims of the second part very largely fell away as the project progressed. The number of taxa found was so small that the use of a species ID system was deemed to be more difficult for the potential user than to present each of the dominant taxa in visual format. Many of the more common dominant taxa are presented as plates in an Appendix C of this report.

Benthic epilithic and epipelic diatoms were sampled from 16 rivers in the Eastern Cape, the Western Cape, the Olifants River system (Mpumalanga) and, during a two-year survey every month in the Swartkops River, near Port Elizabeth. A species was considered dominant if it constituted the major number of specimens in a sample. Any species that was not dominant but constituted more than 10% of the total was included as a sub-dominant.

A total of 148 epilithic and 180 epipelic diatom taxa were studied. Of these, there were 102 species identified from all sites that came from only 31 genera. The total number of taxa when all future riverine data are available is likely to be less than 70 genera and 200 species. All the required information to enable future workers to identify all the taxa found should be easy to document. Only two genera are likely to require a system to enable species identification. These are *Navicula* and *Nitzschia.*

A water class index was constructed for the range of water qualities found from the 16 rivers sampled. Diatoms appear to be very suitable biomonitoring organisms. They give an accurate indication of the water chemistry within water quality classes. The system appears to be more specific than the system of van Dam et al. (1990) for the Netherlands. There are several possible explanations for the observed lack of correlation (in most instances) between the Van Dam index and observed conditions. Firstly, the species identifications are mostly based on European floras. Round (1993) pointed out that there might be subtle variations in appearance of diatoms collected in the Southern Hemisphere. Species are then identified to the nearest form in a European flora. This does not have to be a concern when the data are interpreted locally (e.g. calculating indicator values from the local data set). However, when comparisons are made that were developed in entirely different regions, the discrepancies in identification could interfere with the level of relevance.

The basis of the Van Dam index is that authors' own published and unpublished observations together with hundreds of other (international) publications. The index was specifically designed to be applied to watercourses and lakes in the Netherlands. Environmental conditions are likely to be quite different in South African rivers. Water quality is just one of the suite of variables (such as light, temperature or disturbance) affecting the structure of benthic diatom assemblages. These factors possibly override the water quality component when comparing the Van Dam index with South African conditions. This makes the calibration of a local diatom index necessary. The senior author of the Van Dam index was not surprised when he was advised that the application of the index in its present form did not result in a highly significant correlation with the South African data (H. van Dam, pers. comm.).

The data indicate that dominant diatoms do not change with season in the Swartkops River. The same diatom was dominant through all seasons at sites where the water quality was not influenced by pollution. This is an important finding because it means that the total number of taxa do not increase because of temperature (season) effects.

Water of a given quality will not result in a specific diatom being dominant. However, the presence of a dominant diatom will indicate the general quality of the water. The reason is that habitat characteristics other than water quality have an influence. Both epilithic and epipelic diatoms can be used as water quality indicators. Epipelic diatoms may be sampled with less operator influence than epilithic diatoms. However, epilithic diatoms may integrate water quality over a shorter time span.

The use of abbreviated names may be useful if the diatom system is applied as a biomonitoring tool. If the use of diatoms is adopted, the Environmentek division of the CSIR may be suitable to curate all the information. A single document containing the identification data for all dominant SA freshwater diatoms needs to be produced, preferably cheaply on a compact disk.

There is an urgent need for the information and techniques to be transferred to other professionals. There are no other researchers in South Africa at present that are specialising in the ecology of freshwater benthic diatoms.

The biological monitoring of water quality in river systems is beneficial if the variability of the conditions inferred from the organisms present is lower than the periodic chemical analysis of the water. Benthic diatoms have the potential to be used as biological indicators as they are ubiquitous members of riverine ecosystems, react rapidly and predictably to changes in water quality and their taxonomy has been well described. Diatoms are now being incorporated in standard protocols for water quality monitoring in various parts of the world. So far the use of benthic diatoms as indicators of river water quality in South Africa has been limited. There is, however, a demand for a biological indicator capable of integrating specific water quality conditions.

Benthic diatoms were collected in rivers located in the Eastern Cape, Western Cape, and the Olifants River (Mpumalanga) to assess the correlation between water quality and the relative abundance of epilithic and epipelic diatoms. The temporal variability between and within epilithic and epipelic assemblages was studied during a two-year survey along a pollution gradient in the Swartkops River in the Eastern Cape. Seasonal influences were not significant. The correlation between the relative abundance of benthic diatoms and water quality variables was investigated with Canonical Correspondence Analysis (CCA). Alkalinity, ammonium, conductivity, nitrite/nitrate, pH, phosphate and silicate had significant effects on the distribution of the diatom taxa in various rivers. Where the size of the data sets allowed it, weighted-averaging regression and calibration models were developed for these water quality variables. The models were tested with cross-validation (jack-knifing) and showed better performance with epilithic than with epipelic taxa, suggesting that the epilithon is the preferred habitat for biological monitoring of short-term (one-month) changes in water quality. The epipelon reflected long term integrated water quality patterns.

The variability of diatom inferred water quality values was significantly lower than the variability in measured water chemistry, indicating that diatoms are valuable indicators of water quality that give a time integrated assessment of prevailing water quality conditions. The application of the Van Dam diatom index, designed for lakes and watercourses in the Netherlands, showed a low correlation with observed water quality conditions in South Africa. This indicates that the calibration of a local diatom index, designed for specific regions, is the way forward.

The methods of field collection of diatom assemblages and processing techniques used during this study are straightforward and uncomplicated. With the development of a diatom species identification database, the use of diatoms for water quality monitoring in South Africa has the potential to become a valuable tool for local and national water authorities.

Diatoms were sampled from two distinct substrata: stones and sediments. The methods for diatom collection defined, to some extent, the boundaries for each habitat. The stones that were selected for the collection of an epilithic sample all had an obvious diatom growth, judged by their appearance and feel and lack of attached filamentous algae. Loosely attached algae were removed before the more tightly attached algae were sampled. This was done by rubbing the stone surface with a finger. The samples mainly contained prostrate (e.g. *Achnanthes*), stalked (e.g. *Cymbella*) and apically attached (e.g. *Synedra*) life forms. Mobile taxa (e.g. *Navicula* and *Nitzschia*) were also observed but usually in much lower relative abundance than in the epipelon.

Epipelic diatoms were collected with the 'cover slip method', which was particularly aimed at the collection of these mobile taxa. This was largely successful, although *Achanthes delicatula* and *A. engelbrechtii* (mono-raphid and therefore less mobile than their bi-raphid counterparts) were repeatedly found to be more abundant in the epipelon. Observations of live samples revealed that these species had actively attached to the cover slips and that they were not 'contaminants' originating from the epipsammon. Special care was taken to ensure that no, or very few sand grains, were collected along with the cover slips.

Species diversity was generally higher in epipelic than epilithic assemblages. This was mainly due to the larger number of mobile species in the epipelon. Most epilithic species were also found in the epipelon, although with lower relative abundance. The 'coverslip method' therefore seems fo not just be picking up mobile life forms but also other taxa that can actively attach to the glass surface within the six to eight hours of 'incubation'.

Physico-chemical data are, strictly speaking, representative of the conditions at the moment of sampling. The composition of a biological sample is an integration of the variation in physico-chemical conditions over a period. The 'snap-shot' data of water quality to which diatom distribution has been correlated in this study is therefore not ideal. Under the circumstances, however, it is the 'next-best-thing'. Where possible, historic data (2-3 weeks before diatom sampling) was taken into account, but most often, these data were not available. The only solution to this problem seems to be to increase the frequency of sampling sites, especially for nutrients (e.g. Pan *et al.*, 1996). This is because nutrients are taken up rapidly in shallow streams (e.g. Borchard, 1996) and their variability is high (e.g. France and Peters, 1992). The seasonal study of diatoms in the Swartkops River showed that the increased sample size and extensive gradient in water quality resulted in a strong correlation between water quality variables and diatom distribution. The weighted-averaging and calibration models showed a good performance, especially when based on epilithic diatoms. Water column variables explained the variance in epilithic assemblages better than the variance in the epipelon. Epipelic diatoms have resources supplied from the water column in addition to the sediments (McCormick, 1996). Resource supplies from the sediments could explain a considerable part of the variance.

Although diatoms have the potential to be indicative of general river health, efforts in this study were concentrated on water quality variables. No attempts have been made to give a full account of the ecological diversity of benthic diatoms in South African rivers. Other groups of organisms are already employed for the assessment of ecosystem integrity within the National Biomonitoring Programme (Uys *et al.*, 1996). Benthic diatoms could be a useful addition to this programme as they give a time-integrated indication of specific water quality components.

The use of weighted average indices of water quality conditions that are presented in this study, is just one of the ways of employing diatoms in environmental assessments. Lange-Bertalot (1979) classifies species according to their tolerance to certain stressors that improve the characterisation of environmental variability as well as integrated environmental conditions. The data sets on which those classifications are based are a result of many years of research.

No single group of organisms is always best suited for detecting the diversity of environmental perturbations associated with human activities. If the maintenance of ecosystem integrity is the aim of the environmental management of a river system, the need to monitor the status of different taxonomic groups is vital. Diatoms provide interpretable indications of specific changes in water quality, whereas invertebrate and fish assemblages may better reflect the impact of changes in the physical habitat in addition to certain chemical changes (McCormick and Cairns, 1994). Diatoms possess many desirable attributes as indicators of ecosystem integrity and water quality in particular:

- Diatoms are an ecologically important group in riverine ecosystems and occur throughout the river, throughout the year;
- Diatoms are sensitive to a wide range of water quality variables (e.g. pH, conductivity and nutrients);
- Diatoms respond rapidly and predictably to changes in water quality conditions.

The correlation that can be found between diatom distribution and water quality depends on the gradient that exists along the length of a river. In most instances pH, conductivity and nutrients could explain the variance in the distribution. Other variables of interest can possibly be investigated by constraining variables that have a known effect on the axes of ordination. If other variables can still explain a considerable part of the remaining variance, its influence on diatom distribution can be assessed (ter Braak and Šmilauer, 1998).

On a few occasions, river sites were sampled where the water quality conditions were considerably different from up and downstream sites. The diatom assemblages at these sites were also considerably different. These samples had to be classified as outliers as they would obscure the trends detectable with the multivariate analysis of the data sets. However, the information contained in the assemblage composition of these outlier sites, remains valuable. Only when these circumstances can be observed repeatedly, can this information become useful for the development of indicator values.

The technique of weighted-averaging and calibration has provided optimum values and tolerance ranges for individual diatoms species, specified for the habitat of origin. With this knowledge on the autecology of common diatoms, the analysis of (spatial or temporal) shifts in assemblage composition provides insight into the causes of such changes. The data in this

study have shown that changes in conductivity, nitrogen (nitrite/nitrate and ammonium), pH and phosphorus can be successfully inferred from the diatoms with a lower degree of variation than monthly monitoring of water chemistry. This is the result of the integration effects that changes in water quality conditions have on diatom assemblage composition.
The data sets used for the development of these models were not large enough to make reasonable comparisons between optimum values for taxa observed across regional boundaries. Indicator values based on the Swartkops dataset showed high r^2_{jack} and low RMSE, where the models based on the Olifants River data set performed less well. Few taxa that occurred in both rivers showed similar indicator values for pH, nitrite/nitrate or phosphate (the only variables for which models could be developed in both rivers). This is most probably a result of the relatively small amount of data on which the Olifants River model is based. It is probably also due to the fact that the Olifants was visited once whereas the Swartkops was sampled on a monthly basis during a two-year period, along a strong and persistent pollution gradient. Patterns in species distribution were observed repeatedly, increasing the performance of the calibration models.

So far, the lack of commonly accepted, standardised protocols for monitoring with diatom assemblages has limited the use of this group in South African rivers. In addition, the presently obscure state of diatom taxonomy in South Africa made the use of this group unfavourable. With the development of a species identification database during this study at the University of Port Elizabeth, the identification of benthic diatoms that have previously been observed in South African rivers will be facilitated. The methods for field collection of diatom assemblages and processing techniques used during this study are straightforward and uncomplicated. The use of diatoms for water quality monitoring therefore has the potential to become accessible for local and national water authorities.