C.A.P.E. ERI Programme

Environmental Water Requirements of the Koekedouw River:

Evaluation of Ecological Reserve Implementation and Monitoring downstream of the Greater Ceres Dam

FINAL REPORT

Prepared by

NINHAM SHAND
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CONSULTING SERVICES

in association with

The Freshwater Consulting Group

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For Ninham Shand Consulting Services

Compiled by	V Jonker		
	Initials & Surname	Signature	Date

For The Freshwater Consulting Group

Compiled by	G Ractliffe & D Ollis		
	Initials & Surname	Signature	Date

EXECUTIVE SUMMARY

In July 2008, as part of the C.A.P.E. Ecological Reserve Implementation (ERI) Programme, CapeNature appointed Ninham Shand (Pty) Ltd, in association with The Freshwater Consulting Group, to undertake an auditing of EWR compliance of the Koekedouw River downstream of Greater Ceres Dam, and an evaluation of how effective EWR releases have been in meeting the management objectives for the river. In essence, the study entailed three key tasks viz.:

1. A biophysical assessment of the state of the Koekedouw River downstream of the Greater Ceres Dam and an evaluation of current practice with regard to dam operation aimed at implementation of and compliance with the Ecological Reserve.
2. Recommendations on improved operating rules for the Greater Ceres Dam.
3. Design of a draft EWR monitoring programme for the Koekedouw River downstream of Greater Ceres Dam.

Assessment of compliance in meeting the EWR flows

The EWR determination for the Koekedouw River was one of the earliest reserve determinations to be undertaken and has some drawbacks that have been refined during later studies. For example, the EWR is not linked to climatic variation that would allow for wet and dry years to reflect in the imposed hydrological regime downstream of the dam. A second drawback of the EWR is that it was developed without adequate hydrological data, and some questions remain about the possible inadequacy of the floods which were specified: the larger flood in the EWR as it stands was supposed to reflect the naturally occurring annual flood event, but spillage records would suggest that this event is in fact far larger. A compounding problem is the fact that the outlet works at the dam impose release limitations with regard to high flows and the release of larger floods is therefore not easily achieved.

Based on an assessment of historical flow records in the Koekedouw River downstream of the Greater Cerse Dam for the decade since completion of the dam, it is obvious that the implementation of environmental protection, the accepted legal responsibility of the Koekedouw Irrigation Board and the Municipality, has been poor to the point of dereliction of duty. Although the *Ceres Koekedouw Dam Operation and Maintenance Manual (SRK Report 216111/7, Aug 2001)*, which specifies minimum low flow and high flow EWRs on a monthly basis, is supposed to guide the current operation of the dam in terms of EWR releases, the assessment of historical flow records indicates that this is not the case. In general, the evaluation of historical flow records in the Koekedouw River for the period between October 1999 and September 2006, indicate non-compliance in terms of EWR releases. Although the record suggests that intermittent low flow EWR releases were made during the period immediately after dam construction (1999 to 2001), these became more sporadic and less frequent from 2002 onwards. Furthermore, flood releases have been attempted in only three years during the decade following dam construction.

What is also extremely worrying is that the obviously inaccurate flow measurements at Weir 3 from April 2003 onwards were not noted and corrected by the Koekedouw Irrigation Board. A comparison of the observed flows at Weir 3 with the concurrent flow record at DWAF Gauge H1H103 should have been made and should have alerted the dam operators to the anomalies in the Weir 3 record. The fact that recorded flows at Weir 3 exceeded the EWR low flow by up to three times, over extended periods of time, is further confirmation that the monitoring of EWR releases from the dam has probably not been a priority.

The majority (75%) of non-compliant months fall within the wet season, with only 25% of non-compliant months occurring during the dry season. This is echoed by the monthly percentages of non-compliance for individual calendar months, which shows that the wet season months display much higher percentages (25% to 100%) of non-compliance than the dry season months (0% to 40%). It is also interesting to note that four months characterised by some of the highest percentages of non-compliance (November, April, June and August) represent months with high flow EWRs, which require elevated EWR volumes during these months.

In general, most of the Class “a” and “b” freshes (small flood pulses) were complied with in terms of flood peak (0.5 m^3/s). However, the prescribed flood duration were not always met. The peak flow (3 m^3/s) of the Class “c” flood was exceeded on four occasions (50% of the time). However, the required duration (three days) of this flood was never complied with, except in one year. Finally, the largest of the EWR floods, the 6-day Class “d” flood, was never observed at Weir 3. As far as the record shows, therefore, flood releases have been attempted in only three years since closure of the dam in 1998. These were the years 2000, 2001 and 2002. In the last year of the previous monitoring programme (2003) no floods were released, despite this being a requirement of the permit. Since that programme ended, the records (using the data from DWAF Gauge H1H013) shows that flows in the river downstream of the dam have rarely exceeded 0.2 $m^3\ s^{-1}$. Dam spillage occurred in three of these years (2001, 2002 and 2006) augmenting these paltry releases and providing on occasion significant flow in the river.

Biophysical assessment of the consequences for the Koekedouw River of non-compliance with the EWR

<u>Sediment</u>

The sediment depth analyses indicate that there has been some scouring of sediments in the upper reaches of the study area, between the Greater Ceres Dam wall and Bridge 3, although large accumulations of sediment still remain in some of the pools and backwater areas in this section of river. Flood releases in 2001 and 2002 with maximum discharges of 4 – 5 $m^3\ s^{-1}$ were not sufficient to mobilise sediment even at sites close to the dam. This was despite the fact that the hydrological data provided to specialists at the original IFR (EWR) workshop indicated that this size of flood approximated the annual return period event, in which case it might be expected to perform sediment movement more effectively. The change in sediment depths observed in this 2008 study indicates that, at least on one occasion, flows in the river must have reached discharges that did mobilise these sediments. Indeed, in 2007, a flood with a peak daily discharge of 20 $m^3\ s^{-1}$ was recorded at the DWAF gauge H1H013 (no flow record was available from Weir 3 for that time period). Whilst this flood would have had a smaller peak at Weir 3, it nevertheless is three times the magnitude of any flood releases specified in the EWR documentation.

It may be, therefore, that the EWR specifications are inadequate to deal with the flushing requirements of the sorts of sediment loads that were allowed to enter the river during the construction of the new dam.

Other, smaller floods – one of 7 $m^3\ s^{-1}$ in November 2006, two of 5 $m^3\ s^{-1}$ in June / July 2007 and three of 7 – 8 $m^3\ s^{-1}$ in August 2008 may have helped to move some of the accumulated sediments in other less protected areas, such as the runs, but significant portions of some of the naturally sediment-free biotopes were still covered in a layer of sediment. This substantially reduces the quality of habitat used by aquatic macroinvertebrates and indigenous fish, in some places rendering it too poor to support these animals.

Lower down the river, between Bridge 3 and the DWAF Weir H1H013, there has been a slight increase in the accumulation of sediments at most sampling points.

Vegetation

The following is a summary of the findings:

- In terms of plant species and vegetation, the river section studied is substantially different from mountain streams within the general region.
- There appears to be some evidence from on-site observations that sandy banks might well be more prevalent than natural in the Koekedouw River downstream of the Ceres Dam, as has been suggested in Ractliffe & Ewart-Smith (2004). Species encountered along the Koekedouw River represent a mix of rocky and sandy substratum-dependant species.
- Whilst sand-loving species were prevalent, and dominated in the river reaches close to the dam, the species complement included generally equal numbers of species characteristic of sand and rocky habitats.
- Dominant habitat signatures were either riverine or riverine and wetland, indicating that the Koekedouw is perennial but that its winter flushes are inadequate to remove sediment. However, the upper banks of the channel are mostly free of sediment deposits and this sustains rocky riverine endemics, with some rocky upper bank species including *Erica caffra* and *Brabejum stellatifolium* (the latter in the lower sections only).
- There was a general absence of certain graminoids which normally characterise wetter banks closer to the water's edge, which suggests that the river lacks strong perennial flow, and water levels are not maintained at periodically higher levels, for example those that would be expected of winter baseflows.
- Conspicuous by its absence is the midstream rocky endemic sedge, *Isolepis digitata*. This is present in most of the montane rivers in the subregion and requires strongly perennial to perennial conditions, generally with periodically high water levels, to survive. This suggests that there needs to be more regular flushes throughout the year to keep the midstream habitat clear of sediment and seasonally wetter / deeper.
- The aquatic plant species *Nymphoides indica* geelwateruintjie,which was recorded along the river is not typical of fast-flowing mountain streams in the Cape but prefers lowland reaches where flows have largely dissipated and the substratum is generally sandy or even clayey. This underscores the absence of flushing flows in the river.

These features of the vegetation are considered to be the result of the construction process as well as inappropriate flow rates and timing, this despite the limited scouring of sandy banks that was probably associated with a single large (20 cumec) flood event coinciding with dam spillage. An increase in the extent of sandy banks will result in concomitant colonisation by a small suite of lower and upper sandy bank species. Unnatural increase in extent of sandy banks and their vegetation cannot be conclusively demonstrated due to lack of comparative spatial data such as vegetation cover taken at specific vegetation plots.

Water quality

There has been an increase in the concentration of nutrients at DWAF Weir H1H013 since 1977, much of which occurred prior to the construction of the Greater Ceres Dam, probably largely as a result of agricultural activities upstream of the dam and in the immediate vicinity of the weir. The statistically significant increase in inorganic nitrogen and orthophosphate concentrations since the construction of the dam is probably mostly due to this incremental increase in nutrient loading of the system over the period of record rather than an effect of the dam. It is not possible to determine how much of this change is attributable to flow-related impacts associated with the dam. The present condition, however, is one where mesotrophic conditions periodically prevail at DWAF Weir H1H013, between periods of oligotrophy. Once-off nutrient data collected in December 2008 suggest that conditions may be better between the dam wall and the DWAF Weir, implicating farming practices closer to Site W in nutrient enrichment rather than the activities higher in the catchment or the operation of the dam.

Periphyton

The periphyton data provide considerable insight into the effects of changes in ecosystem processes that have ensued with the flow regime that has been imposed on the river in the past decade. The following is a summary of the findings:

- Chlorophyll *a* (Chl *a*) on stone surfaces as an indicator of periphyton biomass was high compared with values obtained from natural streams in the broader region for the same time of year. Periphyton biomass accumulation is enhanced by low and constant flow, but may be restricted by the availability of nutrients.
- The extremely high ash-free-dry mass of surface biofilms (AFDM), an indicator of organic matter accumulation, indicates that the Koekedouw River is severely impacted with regards to flow. This accumulation of surface material has a large negative impact on habitat quality for riverine organisms adapted to free-flowing and well scoured substrata.
- Although Chl *a* did not differ significantly between sites, the AFDM was considerably higher at the DWAF weir site, relative to the other two sites. This could be a consequence of localised conditions at each of the three sites which, in the absence of scouring floods would promote inter-site variability.
- Similarly, the periphyton community structure varied between sites, further suggesting that, in the absence of floods that act to control periphyton communities at the reach level, localised conditions assume greater importance in structuring periphyton communities. This situation has been shown to be typical of climax communities after long periods of constant low flow and should not naturally pertain in early summer.
- Despite differences in both Chl *a* and taxon composition between these sites, the periphyton community at each site had a relatively high richness and was generally indicative of an oligotrophic system, impacted by an altered (or non-existent) flow regime.

Invertebrates

The invertebrate data presented here indicate without any doubt that the condition of the instream environment has deteriorated further than the already poor state recorded at the end of the first monitoring programme in 2004. The following is a summary of the findings:

- The index of “river health” based on invertebrate composition places the river in a low Class D or Class E/F Ecological State, which means serious loss of habitat, biodiversity and ecosystem function. The Management objective identified in setting the EWR was for a Class B river, in terms of invertebrate assemblages.
- Historical data indicate that the invertebrate assemblages were more diverse and included more of the sensitive groups of insects expected of mountain streams in the years when baseflow releases from the dam were made in line with the EWR and when some flood releases were attempted.
- Physical conditions in the river, which constitute the major features of invertebrate habitat, are presently characterised by high levels of sediment and organic matter both on the bedrock / cobble surfaces and in the interstitial spaces, severely reducing the quality of habitat for more sensitive insects, whilst providing for an abundant supply of organic matter on the bed and in transport in faster-flowing portions, favouring the detritivores and collector-gatherers like chironomids, simuliids and hydropsychids.
- Abundances of invertebrates are relatively high, compared with regional data, but are highly skewed toward three groups: chironomids, simuliids and hydropsychids which comprise up to 90% of the sample numbers.
- The scarcity of fast-flowing, well scoured riffle habitat means that groups such as plecopterans, leptophlebiids, heptageniids, aeschnids, riffle beetles and megalopterans that inhabit upper stone surfaces and especially the under-surfaces or interstitial spaces in this habitat are largely absent from the Koekedouw River.
- Besides the indirect effects of flow, the more or less permanent lowflows in the river appear to have created conditions that favour a mix of lotic and lentic species which are tolerant of high organic loads, such as chironomids, where species diversity is high.
- Based on the historical invertebrate data as well as the results of water quality and periphyton analysis, it is concluded that flow, rather than nutrient enrichment is the major factor implicated in the loss of natural invertebrate communities in the Koekedouw River. Both the constant low flows, the absence of elevated winter baseflows and particularly the failure to provide scouring floods to the river will need to be addressed if recovery of a more natural condition is desired.

Fish

The results of the preliminary fish survey is the first to find indigenous fish species upstream of the DWAF weir since 1989. This may be a consequence of a more extended survey, covering reaches between Bridge 1 and the DWAF weir, which were not included in the surveys of the more recent past, but is nevertheless exciting and encouraging. The following is a summary of the findings:

- Degradation of fish habitat in the Koekedouw River, as documented in the preceding report sections, is also directly implicated in low population densities and dwarfism in trout, which is the dominant species in the Koekedouw River, having been introduced after closure of the dam as an angling species.
- Key aspects of this loss of habitat quality is in the physical smothering of large parts of the river bed and interstitial spaces, as well as the knock-on effects of this on fish prey items, specifically mobile invertebrates.
- Breede River redfin were found in the gorge section of the Koekedouw, where they appear to be coexisting with trout, possible largely due to food resource limitation of the latter, which

restricts population size and therefore competition and predation pressure on the redfins. Redfin populations were small, but it is unclear as to whether this is influenced by sub-optimum habitat conditions which are flow-induced, or simply the result of the presence of alien trout.

- Similarly, Cape kurper were collected in relatively high numbers from the lower portions of the study area, up- and downstream of the DWAF gauge. The poor habitat quality in this stretch of river appears not to have major deleterious effects on the species. However, it might as well be that this reach, where trout appear to be effectively excluded by habitat and very poor prey availability, is a refugium for the species despite habitat characteristics not being ideal.
- A single largemouth bass was observed in a pool just below the gorge, near the downstream end of the study reach. It is possible that spillages from the dam in recent years may have been sufficient to move wash this species from the river as it is poorly adapted to fast-flowing rivers. This is an area of uncertainty, however, and what is certain is that failure to release floods, and the decline in spillage events as demand grows, pose the threat of allowing this species to establish along the river with disastrous consequences for the remaining indigenous fish populations.

Recommendations for implementation of the environmental flow requirements for the Koekedouw River

In light of the findings of this study, the following issues are highlighted for consideration during the possible refinement of the operating rules of the Greater Ceres Dam:

The existing low flow EWR prescribes constant monthly minimum flow values. However, these flows do not take into account the actual inflows into the Greater Ceres Dam and as such are not always realistic in terms of flow variability and natural climatic conditions. More realistic EWRs based on monthly rule curves would address this problem. Based on the latest hydrology for the Koekedouw catchment, as simulated during the recent Berg Water Availability Assessment Study, the RESDSS Desktop Model was used to derive monthly rule curves for the low flow component in accordance with specified EWR flows. The rule curves are displayed in the table below and should be easy to implement by using observed flows at the existing flow gauge (Weir 2) on the Witzenberg Stream, which is already fitted with a telemetry system, as an indication of the reference (natural) flow at the dam. The Weir 2 catchment represents about 8% of the catchment area upstream of the dam and can therefore be scaled up proportionally each month, to estimate the total natural monthly inflow into the dam. This natural flow can then be used in conjunction with the values in the table, to determine the required EWR low flow release.

Similarly, the use of the observed flow record at Weir 2 as an indicator (reference) catchment for EWR releases during flood events, will ensure that the release flood hydrograph emulates the natural condition and that artificial flood releases are linked to natural flood or high flow conditions in the river. Release restrictions imposed by the existing outlet works at the dam should also be re-considered and, if necessary, the high flow EWR should be modified to accommodate the current release restrictions.

The fact that the data indicate that annual EWR volume has been exceeded most of the time, even when the dam did not spill, is probably an **artefact of inaccurate data**. This is supported by the observation that, from 2002 onwards, the observed baseflow at Weir 3 was consistently higher than the minimum EWR low flow and was substantially higher than that recorded at DWAF weir H1H013. As a matter of urgency, improvements to the calibration of the gauge (Weir 3) and the collection of hydrological data must be made. It is recommended that the local authority be provided with an independent consultant to undertake this work, to ensure that what should be routine monitoring and the delivery of trustworthy data is fast put back on track.

Proposed EWR Rule Curve (Low flows):

% Exceedence	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
% Exceedence	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Reserve Flows without High Flows (m3/s mean monthly flow)										
Oct	0.294	0.294	0.292	0.288	0.279	0.261	0.229	0.18	0.12	0.082
Nov	0.255	0.255	0.254	0.25	0.242	0.227	0.199	0.156	0.105	0.072
Dec	0.17	0.17	0.168	0.165	0.157	0.143	0.119	0.089	0.062	0.049
Jan	0.097	0.097	0.096	0.094	0.089	0.081	0.067	0.049	0.033	0.025
Feb	0.068	0.068	0.068	0.066	0.061	0.048	0.041	0.03	0.017	0.01
Mar	0.052	0.052	0.051	0.05	0.046	0.034	0.028	0.018	0.012	0.003
Apr	0.068	0.068	0.067	0.066	0.063	0.058	0.049	0.035	0.018	0.006
May	0.119	0.119	0.118	0.116	0.111	0.102	0.085	0.059	0.027	0.007
Jun	0.206	0.206	0.205	0.203	0.198	0.189	0.171	0.139	0.086	0.033
Jul	0.266	0.266	0.265	0.263	0.257	0.247	0.228	0.192	0.134	0.075
Aug	0.31	0.31	0.309	0.306	0.3	0.288	0.265	0.223	0.156	0.086
Sep	0.331	0.331	0.328	0.324	0.313	0.293	0.257	0.202	0.135	0.092
Natural Duration curves (m3/s mean monthly flow)										
Oct	1.88	1.555	1.329	1.145	1.026	0.857	0.677	0.566	0.441	0.245
Nov	1.323	1.047	0.81	0.677	0.563	0.433	0.383	0.313	0.25	0.168
Dec	0.744	0.548	0.401	0.34	0.236	0.202	0.162	0.132	0.107	0.058
Jan	0.349	0.233	0.174	0.135	0.11	0.089	0.074	0.055	0.046	0.034
Feb	0.274	0.169	0.102	0.088	0.061	0.048	0.041	0.034	0.02	0.01
Mar	0.413	0.168	0.116	0.08	0.046	0.034	0.028	0.018	0.015	0.003
Apr	0.832	0.519	0.332	0.266	0.196	0.142	0.092	0.06	0.029	0.006
May	1.858	1.203	0.98	0.735	0.643	0.49	0.41	0.282	0.107	0.009
Jun	2.936	2.094	1.806	1.582	1.386	1.158	0.981	0.737	0.364	0.101
Jul	3.052	2.658	2.26	1.84	1.678	1.476	1.237	1.044	0.643	0.19
Aug	3.019	2.455	2.168	2.054	1.846	1.574	1.316	1.096	0.79	0.517
Sep	2.613	2.202	1.892	1.724	1.541	1.351	1.177	1.11	0.845	0.443

Recommendations of management steps to be undertaken in the immediate future

Based on the previous 5-year monitoring programme and this once-off assessment of conditions in the river, there is little doubt that failure to release adequate flows in the Koekedouw River have been responsible for much of the deterioration in ecosystem integrity. Continued monitoring of the implementation of an arbitrary flow regime will not help to improve matters, and emphasis must be placed on the recommendations made in respect of actual implementation of the EWR.

A number of questions remain, however, regarding whether the stipulated environmental flows are sufficient to achieve some of the environmental objectives. Also, some non flow-related issues require exploration. These are discussed below.

Sediment scouring requirements

As recommended at the end of the initial monitoring programme, from an ecological perspective it is very important that sufficiently large floods are released down the Koekedouw River below the Greater Ceres Dam to facilitate the removal of the sediment deposits that have accumulated since the construction of the dam. This requirement was of course never anticipated when the initial EWR was established (prior to the construction of the dam and its impacts on the downstream environment). No quantitative information exists on the sorts of flows that would be required to move sediments from the river, given the channel features and hydraulic environment that is the river. If the flood releases stipulated in the EWR are released down the river at the required magnitude, duration and frequency, this would help to shift sediment deposits that have accumulated in the faster-flowing, shallower habitats in the river, but probably not effect scouring of pools, which is only likely to occur if larger flood releases were possible or during periods of dam spillage that coincide with incoming floods.

The lack of annual monitoring of this aspect of the river means that there are no flow-linked sediment movement data that will help to guide management steps. It is proposed therefore that a study be commissioned to determine what size floods will move sediment. Linked to this is a requirement to clarify the actual maximum release that can be made from the dam, and under what conditions.

If the release of larger floods is not possible, some consideration is required of the sorts of interventions that are possible that would improve habitat quality in the river. Improving the condition of shallow habitats, for example, could be seen as a priority for flow management in the next five years. Management of the dam to ensure maximising this, for example making releases that coincide with spillage, may increase the effectiveness of sediment movement. This is a long-term goal, which can only be met by a commitment on the part of the dam management to perfect flood release techniques.

Nutrient data

Regular collection of nutrient (and other water quality) data should be collected from at least two of the sampling sites used for the December 2008 survey, together with data from upstream of the dam, to identify potential non flow-related impacts on the river emanating from the upstream catchment. A sampling programme should be implemented now to build up an historical record which is necessary for statistical analysis of this ecosystem component.

Management of trout and bass

It is recommended that, along with the implementation of the required environmental flows, efforts be made to reduce trout density and remove any bass from the system, and steps be taken to prevent future stocking, which was an unfortunate management decision. Since the impact of trout is likely to be density-dependant, it may be possible to promote co-existence with indigenous fish, however, by keeping trout density as low as possible. Under such circumstances, re-introduction of indigenous species upstream of the gorge would be advantageous. This programme will require buy-in and the collaboration of local anglers and the community utilising the nature reserve, but should not be difficult given the biodiversity rewards that could be associated with it: a visually “cleaner” river, more natural food webs, restoration of insect biodiversity, protection of red-data fish species and the restoration of a natural asset that it well utilised by the local townspeople

Recommendations for future monitoring programme to evaluate the efficacy of environmental flow releases in the Koekedouw River

To date monitoring of the river has used the desired state as described in the original EWR documentation as the basis for evaluation of success or otherwise. However, based on the current situation with regard to sediment deposits, the maximum possible flood releases, the issues or choices relating to the management of alien and indigenous fish in the river, and, most importantly, the seeming lack of commitment to making environmental flow releases, it may be a pertinent time to establish a revised and detailed set of objectives and requirements regarding management objectives for the Koekedouw River.

It is therefore recommended that:

- A public participation process be undertaken by an independent and appropriately qualified consultant to re-state the desired condition to which the river should now be restored, and in the future maintained.
- To translate this desired or target condition into measurable Resource Quality Objectives for each ecosystem component (e.g. water quality, fish etc). RQOs are indices, or ranges or mean values for variables that can be measured, or the presence or absence of features that can be recorded, that would indicate that a specific ecological goal was being met.
- This process involve river scientists and water resource managers who are able to interpret the consequences of particular choices of management or the target condition (e.g. what would the consequence be of a choice to manage the river as a pristine system and how feasible would that be).
- The interested parties should include both local users, users of the water resource (irrigation boards) as well as statutory bodies like DWAF, CapeNature and SANBI.

The future monitoring programme must be able to track changes in ecosystem condition that are not flow related, separately from those that are, by the placing of monitoring sites and activities. In this case the water quality monitoring proposals would adequately indicate possible impacts from upstream vs. the dam.

The following section presents a proposed monitoring protocol for the Koekedouw River downstream of the Greater Ceres Dam, as a product to take forward for funding and implementation in the future.

Monitoring objectives:

- To determine how well the pattern of daily flows in the river meets the hydrological conditions expected of the EWR, maintains desirable habitat and provides for the ecological processes required to sustain ecosystem function.
- To provide an interpretation of the major aspects of ecosystem condition and function, including *inter alia* changes in physical attributes, biodiversity, trophic status, water chemistry and sediment dynamics.
- To measure biotic responses to the implementation of the EWR, to establish if they are meeting the water resource quality objectives (target ecological condition).
- Through an analysis of biotic responses to flow related changes in the system, to make recommendations where necessary about the need to adjust baseflow requirements and / or

refine the pattern of flood and fresh releases to meet the target ecological condition identified for the Koekedouw River.

Monitoring activities

Monitoring should be conducted on a site or reach basis, depending on the component monitored (e.g. invertebrate sampling occurs on a site level; fish are assessed along reaches). In order to gain from the historical data, the three sites and the different reach sections used in this study are recommended.

The following are the major components envisaged as part of a future monitoring programme.

a Geomorphology and hydraulics

This component is not developed here, as it will be informed by the sediment transport study and eventual management actions taken, as recommended in section 9 of this report.

b Water chemistry

The most useful water chemistry data are those from regular recording at frequent (e.g. weekly or fortnightly) intervals.

- The water quality dataset maintained by DWAF at H1H013 is useful, but additional data should be collected from at least one location within the section of river passing through the nature reserve, together with data from upstream of the dam, to identify potential non flow-related impacts on the river emanating from the upstream catchment.
- System variables (temperature, pH, conductivity, and oxygen), together with nutrients (PO_4^+-P, NO_3^+-N, NO_2^+-N and NH_4^+-N) should be sampled *in situ* at these monitoring sites on at least a monthly basis. These records should be analysed to show trends in water quality in the Koekedouw River, as a whole and by season, and to identify if necessary any sources of nutrient enrichment.

c Riparian botanical assessment

Rivers generally show a shift in plant species composition with lateral / vertical distance away from the water's edge because of a gradient in moisture. Bank vegetation may thus comprise a number of plant communities, and in many Western Cape rivers these communities have been correlated with vertical inundation levels associated with the natural flow regime. Changes in the flow regime can result in changes in the species composition and / or community zonation, with some zones expanding and other becoming progressively replaced. The following are proposed:

- A detailed assessment of all plant species present is required to establish floristic gradients more accurately.
- Changes in river habitat need to be monitored every two years through the establishment of permanent plots and flora sampling; this should be linked with assessment of change in proportion of sandy to rocky substratum in preselected areas. The re-establishment of key riverine endemics such as *Isolepis digitata* would be a vital indicator of positive change in the river.
- All woody alien species mentioned in the study need to be eradicated as matter of urgency. The acacias in particular are aggressive invaders and can choke river channels with

deleterious effects to the riverine habitat. *Populus canescens*, only occurring in the lower parts, also needs to be monitored carefully and removed.

d Periphyton biomass and taxon composition assessment

Since seasonal patterns of biomass accrual and loss, and of community structure are driven by the disturbance regime to a significant degree, patterns consistent with those observed on a regional basis should emerge once appropriate flows are restored to the river.

- Periphyton biomass, as Chlorophyll *a,* and the density of total organic matter on the stream bed (AFDM) have shown patterns that implicate flow-related impacts, and should form a component of the monitoring programme. The frequency of monitoring should be aimed at identifying biomass changes at key times to allow biomass estimates to be compared with natural seasonal cycles found elsewhere in the region, namely August (winter low), October (spring peak), December (early summer low) and March (late summer peak).
- The collection of periphyton and AFDM from five replicate samples from run biotopes appears to be sufficient in this present study to identify patterns in periphyton, and is proposed for future monitoring.
- Continued collection of periphyton community data should be included in a future monitoring programme, to track both changes in richness and community structure against the proper implementation of the required flow regime. Community data would be assessed by subsampling the five replicate biomass samples. If budget constraints apply, it is possible to combine the community data subsamples to obtain a single species list for each site / sampling time.

e Macroinvertebrate faunal assessment

Invertebrates are considered to be very useful indicators of change, and are a core component of the River Health Programme. As shown in this study, the evaluation of the SASS5 scores and ASPTs has become an extremely convenient way in which to summarise ecosystem condition, at least in naturally strongly perennial systems, partly because of the wealth of historical and reference data from western Cape rivers.

- It is thus proposed that the standard SASS5 protocols be implemented at the three monitoring sites on a bi-annual basis, in August and March.
- In addition, however, semi-quantitative community data – abundance estimates of major groups – and information on biodiversity at the species level have both been shown in this study to provide valuable insight into the sorts of changes in ecosystem processes that are occurring, for example in relation to trophic relationships. Species-level data collected semi-quantitatively, such as by preserving and processing the SASS samples, is a very cost-effective way in which to gather community data, and should be continued. The frequency of monitoring could readily be reduced from that initially indicated to bi-annual with August (winter) and March (summer) sampling.

f Fish assessment

A recommendation has been made for a management intervention aimed at reducing trout densities, removing any bass present, and at an appropriate stage to re-introduce indigenous fish to the upper reaches of the river. Such a programme should begin immediately, and the first component be implemented alongside any training and institutional arrangements that are required to be made in order to give effect to the stipulated EWR. Future fish surveys will be dictated to some extent by the programme that is implemented. In the medium-term, however, annual surveys could be scaled back to take place bi-annually or at even longer-intervals, once fish populations are no longer being actively managed.

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1. INTRODUCTION

The Koekedouw River is a tributary of the upper Breede River system in the Western Cape Province. It has its source in the Hartebees Valley, and is fed by runoff from the Skurweberg Mountains to the east and the Witzenberg Mountains to the west. The river flows through farming areas before entering the relatively unspoiled Koekedouw Valley, within the Ceres Nature Reserve. Here, some 9 km from its source, the river is dammed by the Ceres Dam, originally built in 1954, but demolished and reconstructed entirely in 1998. From the dam, the river flows in a south-easterly direction for approximately 4 km within a gorge with a fairly steep gradient, also within the Ceres Nature Reserve, before the gradient flattens out again where the Koekedouw River joins the Dwars River, immediately upstream of the town of Ceres (Figure 1.1). The area is described in some detail in Ractliffe & Brown (1995).

The earthquake-damaged Ceres Dam was replaced in 1998. The new dam was approved subject to the release of Environmental Water Requirements (EWR), then known as the Instream Flow Requirements or IFR. The operation of the dam, including EWR releases into the Koekedouw River was monitored for a five year period thereafter, ending in 2004

In July 2008, as part of the C.A.P.E. Ecological Reserve Implementation (ERI) Programme, Ninham Shand (Pty) Ltd, in association with The Freshwater Consulting Group, was appointed by CapeNature to undertake an auditing of EWR compliance of the Koekedouw River downstream of Greater Ceres Dam, and an evaluation of how effective EWR releases have been in meeting the management objectives for the river. In essence, the study entailed three key tasks viz.:

- A biophysical assessment of the state of the Koekedouw River downstream of the Greater Ceres Dam and an evaluation of current practice with regard to dam operation aimed at implementation of and compliance with the Ecological Reserve.
- Recommendations on improved operating rules for the Greater Ceres Dam.
- Design of a draft EWR monitoring programme for the Koekedouw River downstream of Greater Ceres Dam.

This report presents the outcome of the above tasks.

1.1 APPROACH TO THIS AND PREVIOUS EWR ASSESSMENTS

Any EWR recommendation is tailored to meet certain ecological goals for the receiving river. In general the closer to the natural condition required for a river, the greater the EWR is, as a percentage of the annual flow in the river. Assessment of the EWR then, includes both an assessment of whether the flows that were stipulated have indeed been released, but also whether these have met the ecological goals for the river. Both need to be achieved in order to conclude that there is compliance with the EWR.

A fairly detailed statement regarding the objectives for the ecological condition of the Koekedouw River was compiled through public consultation during the EIA phase of the Greater Ceres Dam. The desired future state for the river reaches within the reserve identified as the basis for the IFR process was that they be managed as near-natural habitat (Management Class B), inhabited only by indigenous species of fish, macroinvertebrates and plants. It was specifically desired to create conditions that would permit the introduction of the indigenous fish species *Pseudobarbus burchelli, Barbus andrewi* and *Galaxias zebratus*. It is noteworthy that these features did not exist in the river at the time – no fish were collected in the reaches downstream of the old dam, and the operation of the dam resulted in the complete loss of invertebrates during winter, although in summer a fairly representative invertebrate population was able to re-establish itself in the river.

The construction of the Greater Ceres Dam had a dramatic effect on the water quality, habitat integrity and invertebrate communities of the Koekedouw River, further exacerbating the existing impacts of the old dam. Massive sediment loads were transported to and deposited out on the river bed downstream of the dam wall. These river reaches, within the Ceres Nature Reserve, were altered from a boulder-bedrock channel characterised by a high biotope diversity to one dominated by sand and fine silts. Riffle and stony run biotope all but disappeared. Fine deposits in the marginal and instream vegetation caused clogging of this biotope and some plant deaths were noted as a result of sediment deposition. In addition, frequent elevations in both the pH of the water and the concentration of fine suspended solids (including at times actual cement fines) were associated with the construction period.

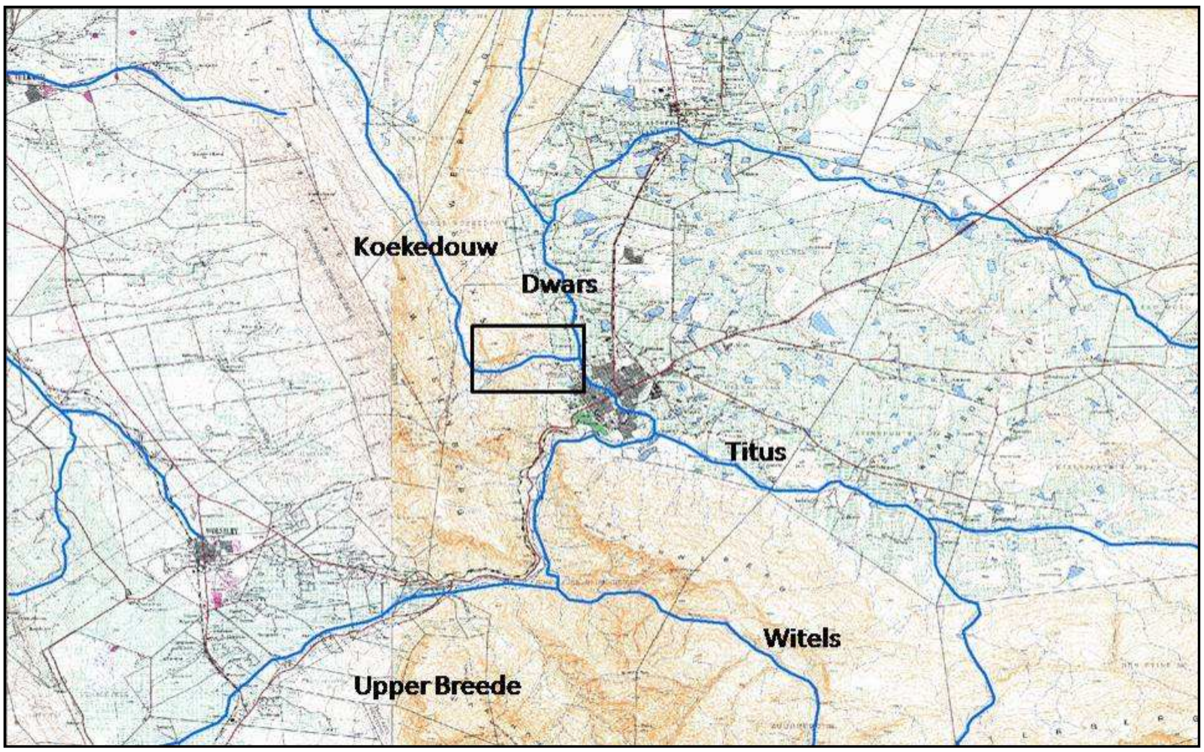

Figure 1-1. Location of Koekedouw River, with the study area (box). The rivers in the general area also shown.

The approach to the EWR monitoring after completion of the dam was altered therefore from checking whether the ecological goals had been met, to one that evaluated recovery of the system. The hypothesis adopted was that given implementation of the EWR flows, and in the absence of further impacts like those from construction activities, the river should gradually exhibit a recovery from its degraded state to one where natural channel features, good water quality and healthy invertebrate assemblages would persist. This then would be a basis for re-introducing the indigenous fish populations desired for this river.

In this study, an assessment is made therefore, of a) the compliance with implementing the flows designed during the IFR process, that would restore and maintain the ecological goals and b) the extent to which the river has progressed in its recovery toward the desired state.

1.2 CONTRIBUTORS TO THIS REPORT

Dean Ollis and Geordie Ractliffe (Freshwater Consulting Group) and Verno Jonker (Ninham Shand) compiled the information in this report, with the exception of the Vegetation report which was compiled by Barrie Low (COASTEC) and the Fish report which was compiled by Sean Marr and Jeremy Shelton. Denise Schael provided the invertebrate species list and comments on the species complement at each site. Phumelele Gama did the same for algal species.

2. KEY CHARACTERISTICS OF GREATER CERES DAM

In the mid 1990s, the old Ceres Dam on the Koekedouw River was declared to be unsafe by the Department of Water Affairs and Forestry (DWAF) and a decision was taken to construct a new, larger dam to augment the water supply to the Ceres area. The construction phase of the new dam, known as the Greater Ceres Dam, extended from January 1996 to the start of impoundment in September 1998. The locations of the dam and weirs are shown in Figure 2-1.

The new structure is a 64 m high, asphalt core rockfill dam with a Full Supply Capacity of 17.2 Mm^3 and a FSL of 642 masl. Water from the dam is supplied to a composite group of domestic, industrial and agricultural users via a pipeline. The dam has the following outlet arrangements:

- one 600 mm diameter multi-level outlet stack, which can abstract water from three levels.
- two 900 mm diameter bottom outlets, which can be cross connected.
- one 600 mm diameter and one 250 mm diameter sleeve discharge valve.

The estimated maximum flow that can be released via the discharge valves into the downstream river channel is in the order of 5 to 6 m^3/s depending on the water level in the dam.

As part of the Greater Ceres Dam Project, three weirs were constructed to monitor inflows into the dam as well as releases and spills from the dam. With flow recording commencing in March 1999. These include:

- a weir on the Koekedouw River upstream of the dam (Weir 1). The catchment upstream of this weir is impacted by irrigation and farm dams.
- a weir on the Witzenberg Stream upstream of the dam (Weir 2). The catchment upstream of this weir is relatively unimpacted (natural).
- Weir 3, situated in the Koekedouw River, just over 1 km downstream of the dam

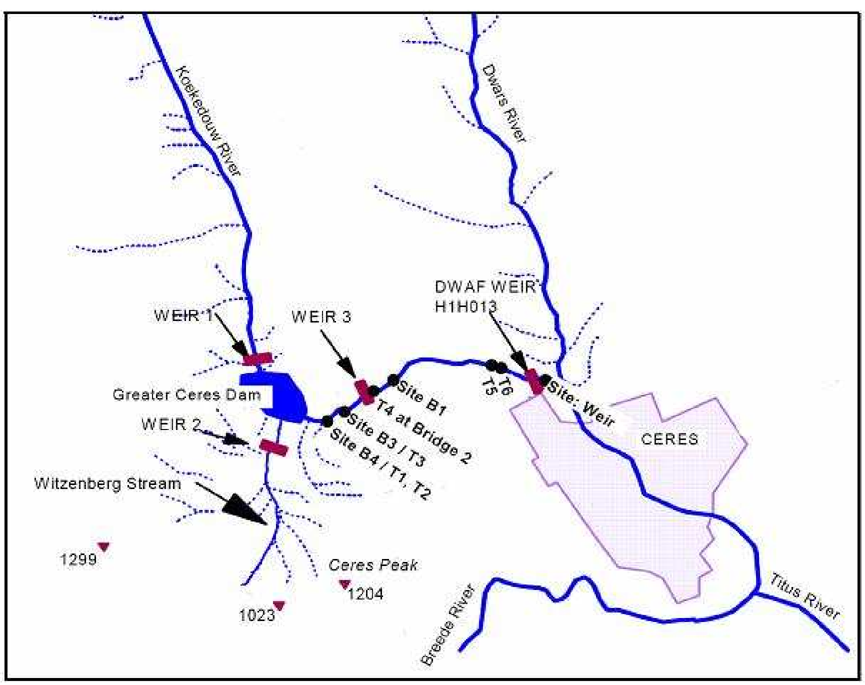

Figure 2-1. Study area showing the Greater Ceres Dam, gauging weirs and monitoring sites.

3. ENVIRONMENTAL WATER REQUIREMENTS OF THE KOEKEDOUW RIVER

Concurrent to the engineering feasibility studies for the new dam, an EIA was undertaken, which included an assessment of the EWR for the Koekedouw River downstream of the dam, in accordance with the National Water Act (Act 36 of 1998). After consultation with interested parties during the EIA phase a statement of the "desired future state" and the management objectives for the ecological condition of the Koekedouw River was compiled, upon which the EWR deliberations were based. The desired future state for the river reaches within the reserve was that they be managed as near-natural habitat, inhabited only by indigenous species of fish, macroinvertebrates and plants. It was specifically desired to create conditions that would permit the introduction of the indigenous fish species *Pseudobarbus burchelli, Barbus andrewi* and *Galaxias zebratus*.

The water use authorisation issued by DWAF for the Greater Ceres Dam stipulated that the EWR as determined by the river scientists during the EIA process should be implemented. Table 3-1 summarises the EWR for normal and drought years, as detailed in the Water Permit issued by DWAF.

Table 3-1: Minimum EWR daily flows and flood flows for the Koekedouw River

m^3/s	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Normal Base flows	0.1	0.1	0.1	0.07	0.06	0.06	0.08	0.2	0.3	0.3	0.3	0.2
Normal Floods		a					b		c		d	
Drought Low flow	0.1	0.05	0.03	0.01	0.01	0.01	0.05	0.08	0.1	0.1	0.1	0.1
Drought Floods							e				f	

Normal Year Condition Floods:

a 1-day flood 0.5 m^3 /sec for 24 hours

b 2-day flood 0.5 m^3 /sec for 24 hours; 0.5 m^3 /sec for 24 hours

c 3-day flood 1 m^3 /sec for 24 hours; 3 m^3 /sec for 24 hours; 1 m^3 /sec for 24 hours

d 6-day flood 1 m^3 /sec for 24 hours; 2 m^3 /sec for 24 hours; 5 m^3 /sec for 11 hours, 7 m^3 /sec for 2 hours, 5 m^3 /sec for 11 hours; 3 m^3 /sec for 24 hours; 1.5 m^3 /sec for 24 hours; 1.0 m^3 /sec for 24 hours

Drought Year Condition Floods:

e 1-day flood 0.3 m^3 /sec for 24 hours

f 3-day flood 0.5 m^3 /sec for 12 hours 1,0 m^3 /sec for 12 hours; 3.0 m^3 /sec for 24 hours; 1.5 m^3 /sec for 12 hours; 1,0 m^3 /sec for 12 hours

Under normal conditions, the total annual EWR volume equals 6.15 Mm^3, which equals approximately 23% of the natural MAR. The EWR releases are divided into continuous baseflows (differing in magnitude according to season) and into floods: two small floods (0.5 m^3/s) in November and April respectively and two larger floods in June and August respectively. The peak flow of the June flood was set at 3 $m^3 s^{-1}$ for 24 h, whilst that for the August flood was set at 7 m^3/s for two hours. In addition to peak flows, the EWR also prescribes a release hydrograph for each flood event.

The EWR assessment also provided a "drought release" EWR, which essentially entails a significant reduction in baseflows as well as a reduction in the annual number, peak magnitude and duration (volume) of flood releases as shown in Table 3-1. This drought condition was deemed to be applicable when natural flows are within the lowest 10% of the long-term hydrological record. Note that for the purpose of this study, the "normal" year EWR was considered to be applicable to the period under consideration.

The DWAF Permit prescribes that discharge in the river must be recorded at the low flow gauging station at Weir 3, via the telemetry system or read manually. Additional requirements stipulated in the Permit, include that all EWR releases from the dam need to be made from the upper and middle water layers to satisfy temperature and dissolved oxygen requirements, that the release pattern for each flood should ensure that the flood hydrograph emulates the natural condition and that floods should be linked as far as possible to natural flood or high flow conditions in the river.

The water use authorisation issued by DWAF also stipulated that a monitoring programme be conducted for a 5-year period in order to assess the effectiveness of the flow releases in meeting the management / ecological objectives set out. The monitoring programme, which was implemented between 1999 and 2004, assessed compliance with the stipulated EWR and also examined changes in the physical conditions (i.e. extent of sediment scour, physical habitat availability and water chemistry) and biological characteristics (i.e. aquatic invertebrates, algae and riparian vegetation), making use of hydrological records from gauges upstream and downstream of the dam.

4. CURRENT OPERATION OF GREATER CERES DAM

The allocation and distribution of water from the Greater Ceres Dam is managed by the Ceres Koekedouw Management Committee, which is a joint venture between the Witzenberg Municipality and the Koekedouw Irrigation Board. The bulk of the municipal and irrigation use from Greater Ceres Dam is by means of direct abstraction via a pipeline.

During a site visit in May 2009, Mr B Skipper, the dam operator, indicated that the current operation of the Greater Ceres Dam, in terms of both low flow and high flow EWR releases, is in accordance with the *Ceres Koekedouw Dam Operation and Maintenance Manual* (SRK Report 216111/7, Aug 2001). According to Mr Skipper, low flow releases are being made at a constant monthly rate in accordance with the minimum EWR baseflow requirements as set out in Table 3-1, while high flow releases aim to meet the EWR flood specifications as listed in Table 3-1. Mr Skipper also indicated that, although the high flow releases attempt to mimic the occurrence of natural floods, this is not always implemented successfully.

Both the 600 mm diameter and 250 mm diameter sleeve valves are used for EWR releases. However, the capacity of the existing outlet works is not sufficient for making large high flow EWR releases, while the outlet works also impose release limitations with regard to temperature and dissolved oxygen linked to the specific layer of water from which releases are made.

5. EWR COMPLIANCE

5.1 HISTORICAL FLOW RECORDS

In order to assess the extent to which flows downstream of the Greater Ceres Dam have met the requirements of the previously determined EWR since dam completion, observed flow data in the Koekedouw River at Weir 3 (see Figure 5-1) were compared with the low flow and high flow EWR for the hydrological years 1998 to 2006 (no flow data were available for hydrological year 2007). A historical daily flow record at Weir 3 was obtained from the Koekedouw Irrigation Board Control Centre in Ceres. However, based on initial analyses, it was evident that the observed record significantly overestimated flows at Weir 3 from April 2003 onwards. This was confirmed by comparing the Weir 3 flow record to the DWAF flow record at Gauge H1H013, which is situated further downstream along the Koekedouw River. After consultation with the Koekedouw Irrigation Board, it emerged that this overestimation might be ascribed to the installed telemetric system at Weir 3. Based on a comparison of concurrent manually recorded water level readings and water level readings as registered by the telemetric system, it was possible to determine a correction factor. This factor was subsequently applied to the original observed flow record from 2003 onwards. However, a furher comparison with the DWAF flow record at Gauge H1H013 showed that, even after the correction was made, the Weir 3 flow record still appeared to overestimate flows significantly. For the purpose of this study, it was decided to continue with the analysis based on the corrected Weir 3 data, but, taking cognisance of the fact that these flows are probably substantially inflated from April 2003 onwards.

Figure 5-1: Weir 3 on the Koekedouw River

Annexure A summarises the results of the compliance assessment and provides the following information per hydrological year:

- A graph which displays:
    - the observed daily average flow at Weir 3. This weir effectively measures the releases and spills from the Greater Ceres Dam, as well as flows from the incremental catchment downstream of the dam.
    - the observed daily average flow in Witzenberg Stream (Weir 2), representing runoff from a relatively unimpacted, natural catchment into the Greater Ceres Dam. Unfortunately, very limited data are available at this station.
    - the observed daily average flow in the Koekedouw River at DWAF Gauge H1H013.
    - the minimum EWR low flow value, which varies on a monthly basis.
- A table which, on a monthly basis, presents the following information at Weir 3:
    - the number of days in each month (expressed as a percentage) during which the observed daily average flow at Weir 3 was less than the minimum EWR flow.
    - the high flow EWR compliance in terms of peak EWR flow vs. observed instantaneous peak flow.
    - the monthly EWR total flow volume (low flow and high flow) and volume surplus or deficit based on observed flow volume.
    - an indication of whether Greater Ceres Dam spilled during a particular month.

5.2 INTERPRETATION OF FLOW DATA

From the information presented in **Annexure A**, the following key observations are made for the eight-year period between October 1999 and September 2006 in terms of EWR compliance at the site of Weir 3. (Hydrological years 1998 and 2006 were excluded from the analysis due to significant periods of missing data at Weir 3 - 8 months and 9 months of missing data respectively). Although it is difficult, due to the extent and frequency of missing data, to investigate trends with regard to EWR compliance, the limited data that are available seem to suggest that there is no clear chronological pattern with regard to EWR compliance or non-compliance since dam construction.

5.2.1 EWR Volume

Table 5-1 displays the average proportion of EWR non-compliance at Weir 3 in terms of monthly observed flow volumes, i.e. for each calendar month it shows the average percentage of months during the analysis period for which the observed flow volume at Weir 3 was less than the total prescribed EWR volume (for low flows and high flows combined).

What is interesting from Table 5-1 is the seasonality of non-compliance, i.e. the majority (75%) of non-compliant months fall within the wet season, with only 25% of non-compliant months occurring during the dry season. This is echoed by the monthly percentages of non-compliance for individual calendar months, which shows that the wet season months display much higher percentages (25% to 100%) of non-compliance than the dry season months (0% to 40%). It is also interesting to note that four months characterised by some of the highest percentages of non-compliance (November, April, June and August) represent months with high flow EWRs, which require elevated EWR volumes during these months. The implication of this is that the EWR volumes during these months are probably not being met, due to high flow EWRs not being released.

Finally, it is worthwhile pointing out that January and February are characterised by 0% non compliance, i.e. the total EWR volume was met during these months. On the contrary, the month of June displayed a non-compliance of 100%.

Table 5-1. EWR non-compliance: Monthly volume at Weir 3

Season	Month	% Months : Obs. Flow Volume < Total EWR Volume	% Months: Seasonality of non-compliance
Dry	Oct	25%	25%
	Nov	40%	
	Dec	33%	
	Jan	0%	
	Feb	0%	
	Mar	40%	
Wet	Apr	67%	75%
	May	25%	
	Jun	100%	
	Jul	50%	
	Aug	67%	
	Sep	40%	

Table 5-2 displays the observed annual flow volume at Weir 3. Although the flow record at Weir 3 was characterised by extensive periods of missing data, the data presented do provide some insight in terms of compliance with the required total annual EWR volume of 6.15 Mm^3. From the table, the very poor implementation of the EWR in the first two hydrological years after completion of the dam (1998 and 1999) and the substantial improvement in the 2000 hydrological year (Oct 2000-Sep 2001), as reported in Ractliffe (2003), is demonstrated by the large increase in annual volume from 1999 to 2000. This performance, in terms of annual EWR volume, declined again in 2001, improved in 2002 and 2003, and declined again in 2004 and 2005. In the case of 2000 and 2002, the relatively high flow volumes at Weir 3 were probably caused by the overtopping of Greater Ceres Dam. Flow data for the period 2003 (Hydro-year 2003) onward are not trustworthy, and considered to be inflated, based on comparison with data from the DWAF Gauge H1H013: these then suggest greater compliance with the EWR than is suspected to be true.

5.2.2 Low Flows

The data presented in **Annexure A** show that low flows released from the dam during May to September 1999 were significantly less than the prescribed EWR low flow. This situation improved during the dry period between October 1999 and March 2000, but deteriorated again during the winter of 2000 (May to

Sep 2000). The seasonality of low flows released from the dam during the 2000 and2001 hydrological years was clear and pronounced, a critical and essential requirement for natural ecosystem functioning.

Table 5-2. Observed Annual Volume at Weir 3. Shaded cells represent data that are considered to be inflated (substantially higher than the DWAF weir downstream).

Hydro Year	Observed Volume (Mm^3)	No. months missing data	Dam Spill
1998 (Oct 1998-Sep 1999)	1.32	8	No
1999 (Oct 1999-Sep 2000)	3.82	3	No
2000 (Oct 2000-Sep 2001)	8.49	3	Yes (Sep 2001)
2001 (Oct 2001-Sep 2002)	2.80	8	Yes (Oct, Nov 2001) (Sep 2002)
2002 (Oct 2002-Sep 2003)	7.29	5	Yes (Oct, Nov 2002)
2003 (Oct 2003-Sep 2004)	6.21	3	No
2004 (Oct 2004-Sep 2005)	3.48	4	No
2005 (Oct 2005-Sep 2006)	5.30	0	No
2006 (Oct 2006-Sep 2007)	Missing Data	N.A.	Yes (Jul 2007)

For the first year since the start of the programme, low flow releases in the 2000 hydrological year met the EWR requirements for the summer and nearly all of the autumn / winter period. The only failure was that the incremental increases required in autumn were delayed by a month, with April 2001 flows remaining at the summer minimum levels. By mid-May 2001 the winter lowflow requirement of 0.3 m^3 s^{-1} was implemented. The spilling of the dam in later winter of 2001 also maintained elevated flows in the river during September and October. This combination of late autumn increases and extended spring spillage resulted in a slight shift in the winter season – a “lag” of approximately one month.

Between 2001 and 2005 the data show summer low flows released from the dam as being higher than the EWR requirement (between 0.08 and 0.3 m^3 s^{-1}, the latter being three times the EWR requirement). This usually occurred in the months of December and January, but sometimes extended through to March. In itself, this is not problematic – the limited data points from the weir upstream of the Greater Ceres Dam suggest that summer low flows inflowing into the dam are around 0.4 m^3 s^{-1}, so the flows above the minimum EWR recorded during summer were well within a natural range could only improve habitat availability. In the more recent past, summer low flows have been just below the 0.06 m^3 s^{-1}. **However, from 2003 onward, the data from Weir 3 indicate low flows up to three times the values recorded at H1H013, downstream. This discrepancy is shown in Figure 5-2.**

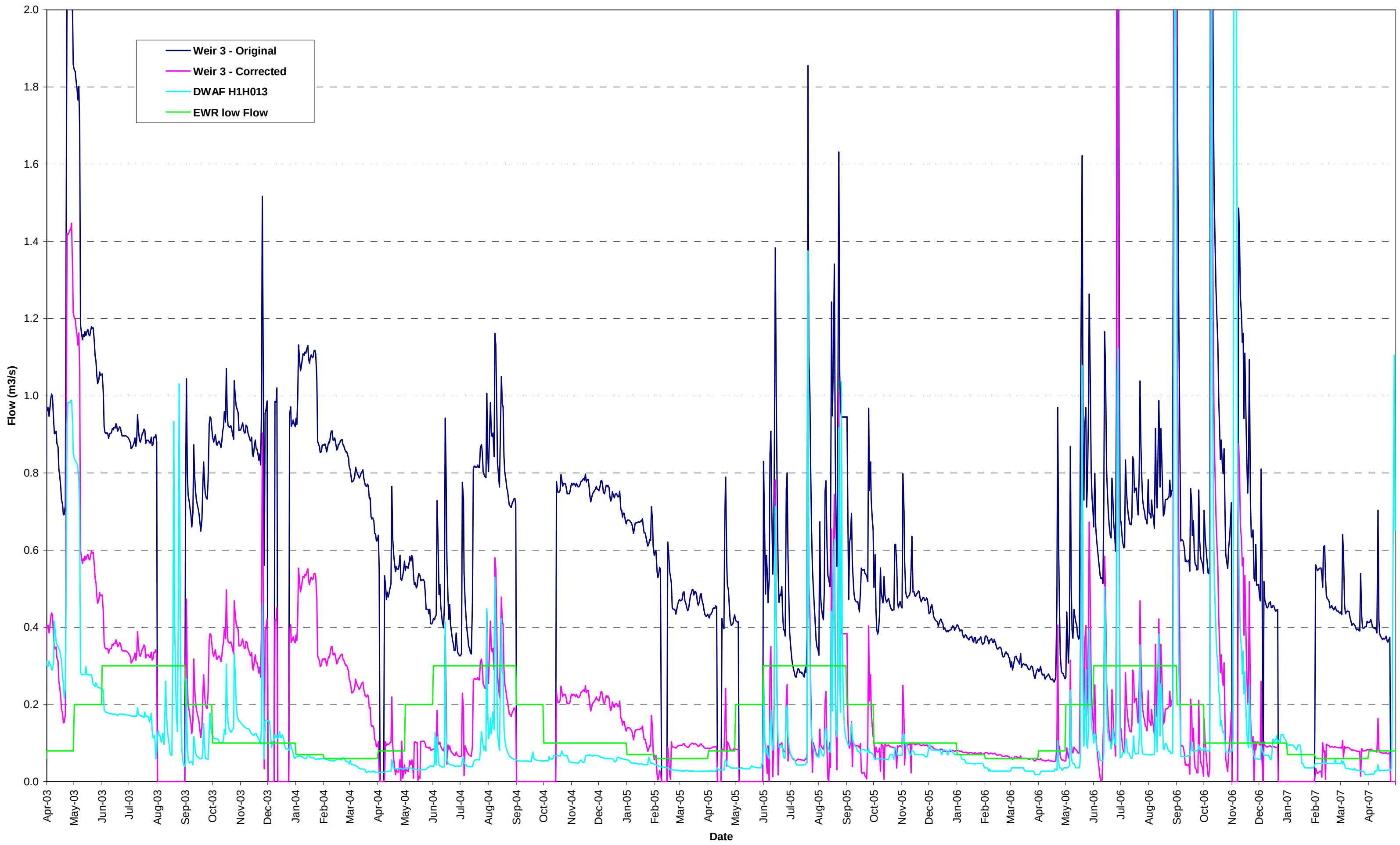

Figure 5-2: Comparison of daily average flows in Koekedouw River at Weir 3 and H1H013. Note the substantially elevated flows provided for both original data set and "corrected" data for Weir 3 compared with the downstream DWAF Gauge H1H013, indicating the discrepancy in flow records collected by the dam managers.

Winter EWR low flows were short of what was required by a very wide margin for the duration of the post-dam period, aside from the 2000 year mentioned above as well as the 2003 winter. In the 2001 hydrological year (June – August 2002), they were maintained as low as 0.2 $m^3 s^{-1}$, and this deteriorated in subsequent years – winter discharges as low as 0.10 $m^3 s^{-1}$ (June 2004), and 0.05 $m^3 s^{-1}$ (July 2005) illustrate this, whilst overall, winter low flow releases for the available record fluctuated about the 0.1 $m^3 s^{-1}$ mark, equivalent to the drought EWR scenario. Again, Figure 5-2 shows that even these data provided appear inflated, compared with recorded data from H1H103.

The combination of low flow releases has resulted in a reversal of seasonality in low flows in the 2002, 2003, and 2004 hydrological years. In the 2005 year, a normal seasonality was evident, but based on summer flow levels of around 0.06 $m^3 s^{-1}$ and winter levels (winter 2006) of around 0.1 $m^3 s^{-1}$, the latter about half of the winter drought EWR! No data for winter 2007 or 2008 were available.

The findings that EWR compliance in terms of low flows, was significantly better during the dry season than during the wet season, is highlighted in Table 5-3, which summarises the average proportion of days per month (expressed as a percentage) for which the observed daily average flow at Weir 3 was less than the minimum EWR low flow during the hydrological period 1998 to 2006. The table shows that, on average, only 28% of dry season days were characterised by daily average flows that are less than the minimum prescribed EWR flow. However, during the wet season, this percentage increased to 59%. A possible explanation for this phenomenon could be that the release of EWR low flows during the dry season is currently viewed as more “acceptable” from a dam management perspective than releasing EWR low flows during the wet season, because the wet season low flows are an order of magnitude higher than the dry season low flows, which translates into higher release volumes. The table also shows that, on average, the lowest non-compliance percentage occurred during the month of January (9%), while the highest percentage of non-compliance occurred in June and July (67% and 65% respectively). These data should be considered to be unreliable, given the discrepancies between Weir 3 and H1H013. The main conclusion that should be reached. however, is that there has been poor performance with regard to implementation of low flows, especially during the transitional and wet months.

Table 5-3. EWR non-compliance: Average daily flow at Weir 3

Season	Month	% Days that observed flow < Minimum Low Flow EWR, per month and average for wet and dry seasons	
Dry	Oct	35%	28%
	Nov	29%	
	Dec	37%	
	Jan	9%	
	Feb	20%	
	Mar	41%	
Wet	Apr	62%	59%
	May	46%	
	Jun	67%	
	Jul	65%	
	Aug	61%	
	Sep	52%	

5.2.3 High Flows (Floods)

High flow EWR compliance at Weir 3 was assessed by means of a comparison of the prescribed flood peaks and flood hydrographs (durations), as set out in Table 3-1, with observed instantaneous flood peaks and flood hydrographs during the period 1999 to 2006. Note that, for the purpose of this comparison, observed floods which occurred in months on either side of the months in which the EWR flood was required were also considered. The results of this comparison are presented in Table 5-4.

Table 5-4. High flow EWR compliance at Weir 3.

Floods per Hydro Year		A (Nov)	B (Apr)	C (Jun)	D (Aug)
1999	Peak:	Yes (Oct ’99)	Yes (Apr ’00)	Yes (Jul ’00)	No (Sep ’00)
	Duration:	No	No	No	No
2000	Peak:	Missing data (no flood at H1H013)	Yes (May ’01)	Yes (Jun ’01) (daily peak not met)	No (Aug / Sep ’01 plus spillage)
	Duration:		Yes	Yes	Yes
2001	Peak:	Missing data (no flood at H1H013)	Yes - Late (Jun ’02)	Yes (Jun ‘ 02) (daily peak not met)	No - Late (Sep ’02 plus spillage)
	Duration:		Yes	No	No
2002	Peak:	Yes (Oct ’02 spillage)	Yes (Apr ’03)	No	Missing data (no flood at H013)
	Duration:	No	Yes	No	
2003	Peak:	?Yes (Nov ’03) (no flood at H1H013)	?Yes (Apr ’04) (no flood at H1H013)	No	No
	Duration:	No	No	No	No
2004	Peak:	No	Yes - Late (Jun ’05)	Yes (Jul ’05)	No (Aug ’05)
	Duration:	No	Yes	No	No
2005	Peak:	?Yes (Nov ’05) (no flood at H1H013)	Yes (May ’06)	Yes (Jun ‘06) (daily peak not met)	No (Aug ‘06)
	Duration:	No	Yes	Yes	No
2006	Peak:	Yes (Oct and Nov ’06 spillage)	Yes (Apr ’07) (daily peak not met)	Missing data H1H013 peak daily flow of 5.58 m^3/s - ? spill	Missing data H1H013 peak daily flow of 20 m^3/s - ? spill
	Duration:	Yes	No		

Note: The successful implementation of the peak flood flow is indicated separately from implementation of the required flood duration. The month of the flood release is given in parenthesis. Where releases were made that did not meet peak flow requirements the date of release is nevertheless indicated. Shaded entries indicate that results are doubtful, as the data are not trustworthy. A “?” indicates discrepancies where the Weir 3 data indicate a flood but this is not reflected at H1H013.

The above table shows that, in general, most of the Class “a” and “b” floods were complied with in terms of flood peak (0.5 m^3/s). However, the prescribed flood duration (24 h and 48 h respectively for the “a” and “b” floods) were not always met. The peak flow (3 m^3/s) of the Class “c” flood was exceeded on four occasions (50% of the time). However, the required duration (three days) of this flood was never complied with, except in one year. Finally, Table 5-4 shows that the largest of the EWR floods, the 6-day Class “d” flood, was never observed at Weir 3. Based on flow data at H1H013, spillage of the dam from 3-8 November 2006 caused a flood which registered a peak daily flow of 7.57 m^3/s at this gauge (dam level and flow data from Weir 3 for this period were both missing). In June 2007 and late July 2007 sustained high flows with a daily peak of 5.58 m^3/s and an 8-day flood with peak daily flows of 20 m^3/s, respectively, were also recorded at this gauge, although the dam level data did not indicate a period of spillage, and Weir 3 data were missing. This suggests that in these latter years the EWR high flow requirement may have been met as a result of higher than average rainfall and dam spillage, rather than EWR releases.

Also indicated in **Annexure A** are the months during which the Greater Ceres Dam spilled, based on an interpretation of historical dam levels (the dam was considered to spill when the maximum dam level exceeded the FSL of 642 masl) and anecdotal evidence. The Annexure shows that the dam spilled during September to November 2001, during September, October and November 2002 and during July 2007. Unfortunately, due to the extent of missing data at Weir 3, it is not possible to draw definitive conclusions regarding the correlation between spills and EWR flood compliance at Weir 3. However, although the 2002 spill resulted in relatively large floods at Weir 3, the observed flood hydrographs still did not comply with the 6-day flood specifications.

Finally, in order to assess whether the release pattern for floods emulated natural flood events, the relation between runoff events in the catchment upstream of the Greater Ceres Dam and observed floods at Weir 3 was investigated. The observed flow record at Weir 2 on the Witzenberg Stream upstream of Greater Ceres Dam, which represents a natural catchment, was used for this purpose (see **Annexure A**). Unfortunately, the flow record at Weir 2 is characterised by significant periods of missing data. Still, based on the limited records which were available, it does appear as if there is a relation between observed floods at Weir 3 and natural flood events. However, the extent to which this may be attributed to dam releases or storm runoff generated in the incremental catchment downstream of the dam is not clear.

The flood releases that were made, two in each year of 2000, 2001, 2002, are shown graphically in Figure 5-3, using quarter-hourly data. For the 5 cumec flood in 2000, the releases were cut off mid-way, and thus a second parcel of water was released after intervention by DWAF. The most successful flood releases were made in 2001. Here the June/July flood exceeded the IFR requirement both in volume and duration, reaching up to 5 $m^3 s^{-1}$ for a couple of hours at its peak. The fact that the flood release coincided with a natural runoff event is clearly demonstrated by the fluctuations in discharge during days 2 and 3 of the event, and the gradual tapering off of the flow. The floods in 2002 clearly show that the peak discharges, above 2 $m^3 s^{-1}$, were not provided for sufficient time to meet the EWR.

As far as the record shows, flood releases have been attempted in <u>only three years</u> since closure of the dam in 1998 i.e. of the decade since the dam has been completed. These were the years 2000, 2001 and 2002. **In the last year of the previous monitoring programme (2003) no floods were released, despite this being a requirement of the permit. Since that programme ended, the records (using the data from DWAF Gauge H1H013) shows that flows in the river downstream of the dam have rarely exceeded 0.2 $m^3 s^{-1}$**. Dam spillage occurred in three of these years (2001, 2002 and 2006) augmenting these paltry releases and providing on occasion significant flow in the river.

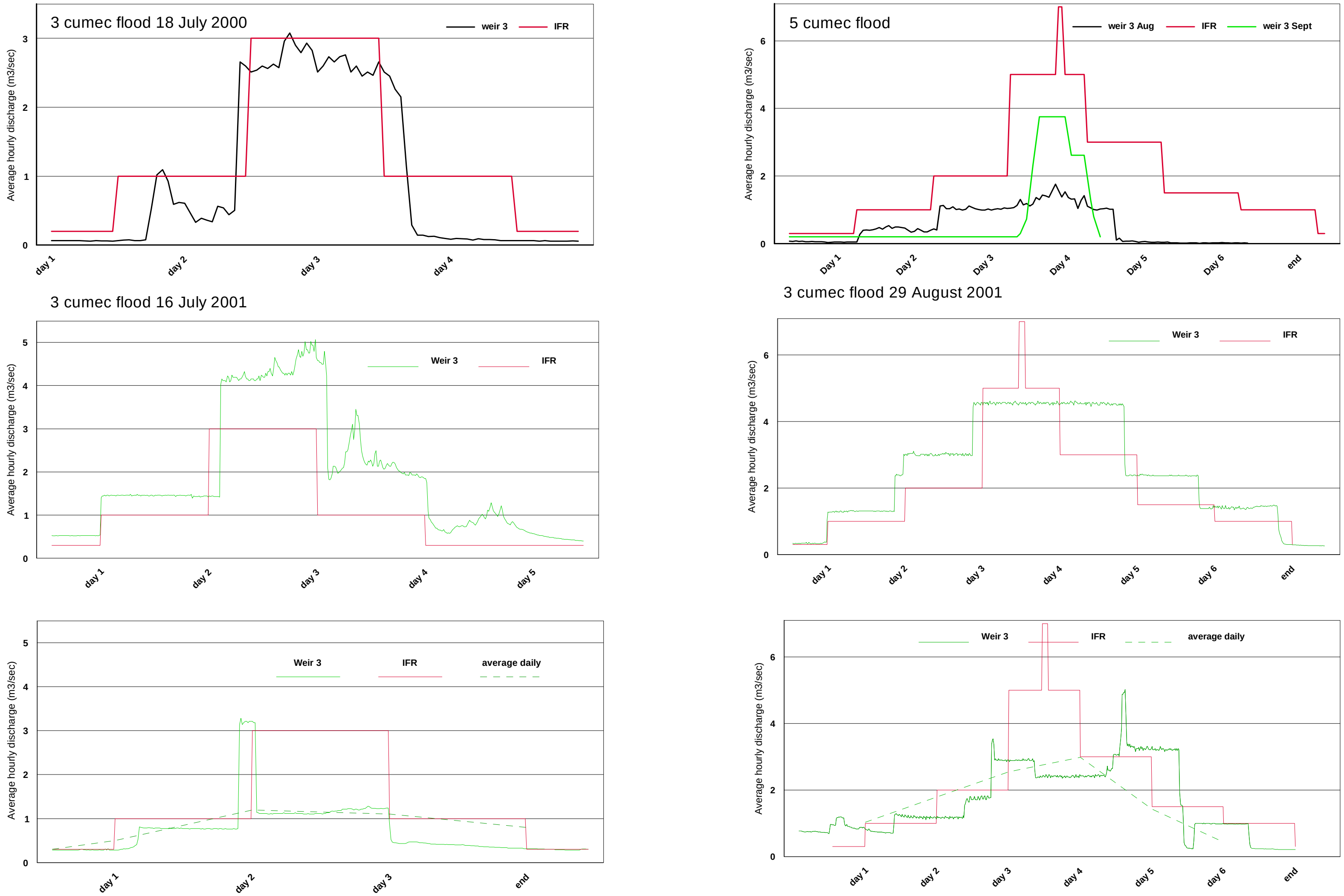

Figure 5-3. Comparison of EWR flood releases in 2000, 2001 and 2002 (1999 to 2001 hydrological years). No flood releases were made in subsequent years. 26 June 2002 September 10 2002.

5.3 CONCLUSION

The evaluation of historical flow records in the Koekedouw River for the period between October 1999 and September 2006, indicate non-compliance in terms of EWR releases. Although the record suggests that intermittent low flow EWR releases were made during the period immediately after dam construction (1999 to 2001), these became more sporadic and less frequent from 2002 onwards. Furthermore, flood releases have been attempted in only three years during the decade following dam construction. It is also extremely worrying that the obviously inaccurate flow measurements at Weir 3 from April 2003 onwards were not noted or corrected by the Koekedouw Irrigation Board. A comparison of the observed flows at Weir 3 with the concurrent flow record at DWAF Gauge H1H103 should have been made and should have alerted the dam operators to the anomalies in the Weir 3 record. The fact that recorded flows at Weir 3 exceeded the EWR low flow, by up to three times and over extended periods of time, is further confirmation that the monitoring of EWR releases from the dam has probably not been a priority.

6. BIOPHYSICAL ASSESSMENT

6.1 INTRODUCTION

Construction of the Greater Ceres Dam was completed in 1999 and monitoring of the Ecological Reserve in the Koekedouw River was conducted by the Freshwater Consulting Group (FCG) from July 1999 to February 2004, as one of the conditions of approval in the permit from DWAF. During this time the EWR was not implemented adequately in any of the five years monitored, and the monitoring programme, far from being able to assess the efficacy of the EWR, simply measured the effects of the actual (far lower) flows that were released into the river (Ractliffe & Ewart-Smith 2004).

One of the primary tasks of the current project was to conduct an assessment of the present biophysical state of the Koekedouw River downstream of the Greater Ceres Dam, largely to determine whether there have been any changes since the completion of the initial 5-year monitoring programme that might suggest better compliance with the ecological objectives outlined as part of the EWR process (refer to section 1.1 of this report).

The key objective of the baseline biophysical survey was to establish, in some detail, the current condition of the river at selected locations, and interpret the extent to which this condition is influenced by the actual water release practices and operating rules that have been applied over preceding years, as documented in Section 5.

The approach taken for the biophysical baseline assessment closely followed the methods used during the 5-year monitoring programme that was completed in 2004. Data were collected to assess the following components of the riverine ecosystem:

- Sediment accumulation and scour;
- Botanical assessment;
- Water quality;
- Algae / periphyton;
- Aquatic macroinvertebrates; and
- Fish.

Most of the data for the biophysical assessment were collected during a two-day site visit in December 2008 (summer). Follow-up surveys for the fish component of the study were undertaken in January 2009.

In addition to the field data, the data collected during the 5-year monitoring programme from 1999 to 2004 (as summarised in Ractliffe & Ewart-Smith 2004 and previous annual reports) as well as long-term flow and water quality data from DWAF gauging weir H1H013 from 1977 to the present were used to assess the ecological condition of the Koekedouw River below the Greater Ceres Dam. Detailed methods for each component are provided in the respective sections (6.2 to 6.7) below.

6.1.1 Sampling sites

Sediment accumulation, water quality, algal and aquatic macroinvertebrate data were collected from sampling sites established during the previous 5-year monitoring programme (Figure 2-1). All the sampling sites are located on the *ca*. 3 km stretch of river between the Greater Ceres Dam and the confluence of the Koekedouw River with the Dwars River. A list of the sampling sites used for the baseline assessment is provided in Table 6-1.

Table 6-1: List of sampling sites used in biophysical baseline assessment of the Koekedouw River for the CAPE EWR compliance assessment study. Coordinates are in decimal degrees (WGS84 datum).

Site name		Coordinates		Data collected*	
Full name	**Abbrev.**	**Latitude (°S)**	**Longitude (°E)**	**Current survey**	**1999-2003**
DWAF weir	W	33.360	19.300	WQ, algae, inverts	WQ, algae, inverts
Bridge B1	B1	33.360	19.283	WQ, algae, inverts	WQ, algae, inverts
Bridge B3	B3	33.363	19.279	WQ, algae, inverts	WQ, algae, inverts
Bridge B4	B4	33.363	19.277	WQ, inverts	WQ, algae, inverts
Transect T2	T2	33.364	19.278	sed (x-section)	sed (x-section)
Transect T3	T3	same as B3		sed (long-section)	sed (x-section)
Transect T4	T4	same as B4		sed (x-section)	sed (x-section)
Transect T6	T6	33.359	19.294	sed (x-section)	sed (x-section)

* WQ = water quality; inverts = aquatic macroinvertebrates; sed = sediment depth survey (x-section = cross-section)

Details regarding the sampling sites or reaches of river used for the collection of vegetation and fish data are provided in the relevant sections below (i.e. sections 5.3 and 5.7, respectively).

6.2 SEDIMENT ACCUMULATION AND SCOUR

6.2.1 Introduction

One of the most severe impacts of the construction of Ceres Dam on the Koekedouw River has been the accumulation of sediment in the river bed (Ractliffe 1999). This sediment has resulted in extensive alteration of natural riverine habitats, with former bedrock pools being partially filled with sand deposits, and riffle and backwater areas being partially, in some areas wholly, submerged by sediment. These effects drastically alter the quality and quantity of habitats that are available for aquatic macroinvertebrates. In addition, in-channel sandbars provide areas of colonisation for riverine vegetation, including exotic species. Vegetation serves to stabilise accumulated sediment, making these sandbars and other deposits permanent features, the removal of which will require progressively stronger discharges to scour.

One of the functions that the recommended EWR flood regime was designed to perform is that of channel maintenance, including the scouring of sediment that has accumulated in the channel during low flow periods. In the case of the Koekedouw River after the completion of dam construction, this function is particularly important, given the quantity of sediment that has previously accumulated in the channel. Release of floods down the river is expected to result in the gradual movement of sediment downstream, and the associated restoration of more natural riverine habitats in the reaches below the dam. The larger floods prescribed in the EWR are of particular importance in this regard.

In order to track the anticipated sediment movements, and to monitor the effectiveness of EWR flood discharges in scouring sediment from the river channel, sediment monitoring in the river reaches downstream of the dam wall was included in the 5-year EWR monitoring programme undertaken by FCG between 1999 and 2004. Sediment data were collected from six fixed cross-sectional transects, established between Bridge 4 and the DWAF gauging weir (see locations of these transects in Figure 2-1).

For the current biophysical baseline assessment, follow-up surveys of sediment accumulation were undertaken to determine whether there had been any significant scouring and removal of sediments from the river since the completion of the initial monitoring programme in early 2004.

6.2.2 Methods

Sediment surveys were undertaken in December 2008 at four of the initial transects, namely T2, T3, T4 and T6. The transects T1 and T5 were not sampled. T1 had been largely scoured clean during the previous monitoring phase as a result of floods released in 2001, and the location of the transect was not clearly recorded, making re-survey along the same alignment impossible. During the previous monitoring programme T5 was also considered to be generally inappropriate for this monitoring, because of its very large bed elements, which was the reason for T6 being introduced. It was thus not used for the 2008 study.

The sediment surveys were carried out using similar methods to those used during the initial 5-year EWR monitoring programme. At Transects T2, T4 and T6, water depth and the depth of sediment on the river bed were measured perpendicularly across the bankful river channel, at 0.5 m intervals, using a tape measure and a 1.5 m metal rod, using the same transect alignment as was used in the 1999-2004 sampling period. The length of the metal rod dictated the maximum depth of sediment that could be measured, that is 1.5 m.

At Transect T3, a slightly different approach to the measurement of sediment accumulation was taken. Here the original monitoring transect extended across a mid-channel bar that had formed by deposits during the dam construction. During the 2008 field visit it was evident that this bar has become stabilised with dense vegetation and the cross-sectional transect would simply have shown an increase in the depth of sediment on this mid-channel bar. Instead, an estimate was made of the amount accumulated sediment in the main channel at this sampling site, a more useful measure of the habitat quality available to instream biota. To do this, sediment depth was measured at 0.5 m intervals along a *longitudinal* transect extending for 15 m along the main channel upstream of Bridge B3. The channel here was less than 2 m in width, but sampling line nevertheless followed the thalweg rather than measure sediment depth at the channel margins.

6.2.3 Findings and discussion

The sediment depth transects for sampling points T2, T4 and T6, as recorded in December 2008, are presented in Figure 6-1. These cross-sectional profiles show the depth of sediment relative to the river bed, with both of these depicted as a depth below the water surface which was set to a datum of zero. Also shown are the sediment levels at the end of the previous monitoring, in January 2003.

The sediment depth profiles for transect T2 (Figure 6-1) show that considerable scouring has taken place there since 2003. The width of the channel without sediment increased by some 2 m, and the deep sediment deposits in the pool on the left hand side of the channel which created an exposed side bar was considerably eroded and mostly submerged. Nevertheless, substantial quantities of sediment remained.

At T3, the main braid of the channel is narrow (< 2m wide), cobble- and boulder-dominated, and during low flow levels would be characterised as run biotope. During the summer sampling the flow depth

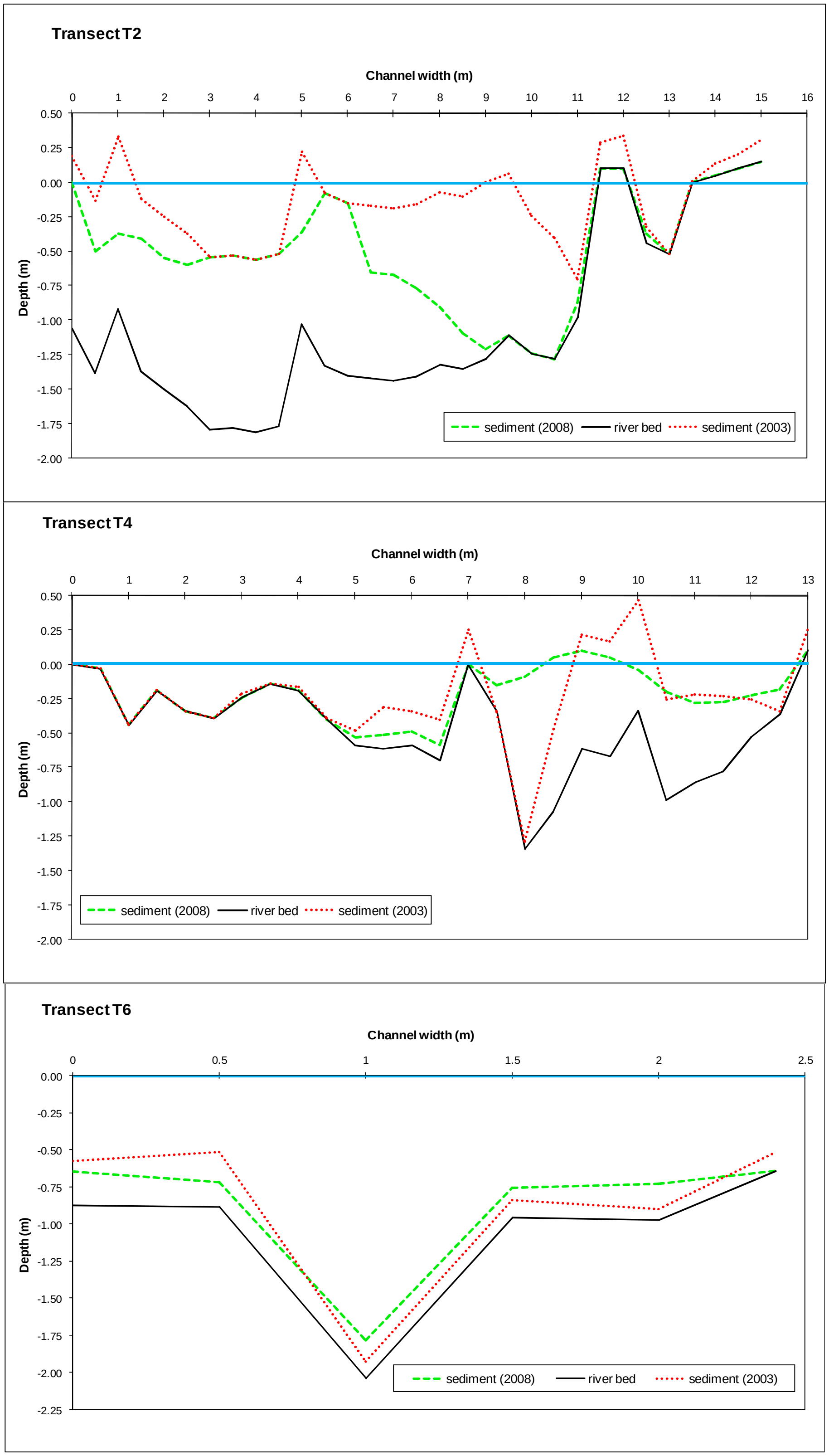

Figure 6-1 **Transects of sediment depth relative to the river bed at sampling points T2, T4 and T6, plotted across the channel from left bank to right bank (facing downstream). Water surface is represented by zero-depth line at the top of the graph. Note that maximum recordable sediment depth was 1.5 m.**

averaged 15.9 ± 12.0 cm, with a maximum of 37.5 cm. This sort of habitat should naturally be characterised by little or no visible sediment cover. Sediment accumulations of up to 40–50 cm were recorded here in January 2003, an increase from the 10 – 20 cm in years prior to that, possibly as a resultof the downstream displacement of sediment from the reaches above this site. Between 2003 and the current 2008, sampling, sediment removal appeared to have taken place again, with all sediment depths measured during the 2008 study being under 10 cm. Notwithstanding, approximately one-third of measurements taken along the longitudinal transect recorded sediment with a depth of 3.5 to 8.5 cm, indicating that habitat quality remained impaired.

At T4 minor shifts in sediment depths were apparent between the 2003 and 2008 sampling periods. The left portion of the channel, between the stake values 1 and 5 m in Figure 6-1, comprises shallow cobble fast-flowing run. This area was blanketed in sediment at the very start of the previous monitoring period, but has generally remained clear to date. Sand deposits between stake values 5 and 15 m were filled the pool on the right hand side of the channel, and this has remained more or less unchanged.

Sediment depths at Transect T6 declined progressively in the past monitoring programme– from 20 to 40 cm in 2000 to 20 cm in March 2001 to some 10 cm recorded in January 2002 and January 2003. In December 2008 this had increased to approximately 20 cm, a reversal of this trend.

6.2.4 Conclusions

Overall, the sediment depth analyses indicate that there has been some scouring of sediments in the upper reaches of the study area, between the Greater Ceres Dam wall and Bridge 3, although large accumulations of sediment still remained in some of the pools and backwater areas in this section of river. As described in reports from the previous monitoring programme, flood releases in 2001 and 2002 with maximum discharges of 4 – 5 m^3 s^{-1} were not sufficient to mobilise sediment at T2. This was despite the fact that the hydrological data provided to specialists at the original IFR (EWR) workshop indicated that this size of flood approximated the annual return period event, in which case it might be expected to perform sediment movement more effectively. The change in sediment depths at T2 observed in this 2008 study indicates that, at least on one occasion, flows in the river must have reached discharges that did mobilise these sediments. Indeed, in 2007 a flood with a peak daily discharge of 20 m^3 s^{-1} was recorded at the DWAF gauge H1H013 (no flow record was available from Weir 3 for that time period). Whilst this flood would have had a smaller peak at Weir 3, it nevertheless is three times the magnitude of any flood releases specified in the EWR documentation.

It may be, therefore, that the EWR specifications are inadequate to deal with the flushing requirements of the sorts of sediment loads that were allowed to enter the river during the construction of the new dam.

Other, smaller floods – one of 7 m^3 s^{-1} in November 2006, two of 5 m^3 s^{-1} in June / July 2007 and three of 7 – 8 m^3 s^{-1} in August 2008 may have helped to move some of the accumulated sediments in other less protected areas, such as the runs, but significant portions of some of the naturally sediment-free biotopes were still covered in a layer of sediment. This substantially reduces the quality of habitat used by aquatic macroinvertebrates and indigenous fish, in some places rendering it too poor to support these animals. Lower down the river, between Bridge 3 and the DWAF Weir H1H013, there has been a slight increase in the accumulation of sediments at most sampling points.

As recommended previously (e.g. Ractliffe 1999, Ractliffe & Ewart-Smith 2004), from an ecological perspective it is very important that sufficiently large floods are released down the Koekedouw River below the Greater Ceres Dam, to facilitate the removal of the sediment deposits that have accumulated since the construction of the dam. The lack of annual monitoring of this aspect of the river means that there are no flow-linked sediment movement data that will help to guide management steps. If the flood releases stipulated in the EWR are released down the river at the required magnitude, duration and frequency, this would help to shift sediment deposits that have accumulated in the faster-flowing, shallower habitats in the river, but probably not effect scouring of pools, which is only likely to occur during periods of dam spillage that coincide with incoming floods. Improving the condition of shallow habitats, however, should be seen as a priority for flow management in the next five years. Management of the dam to ensure maximising this, for example making releases that coincide with spillage, may increase the effectiveness of sediment movement. This is a long-term goal, which can only be met by a commitment on the part of the dam management to perfect flood release techniques.

6.3 BOTANICAL ASSESSMENT

(Author: Barrie Low, COASTEC)

6.3.1 Introduction

The Koekedouw River forms part of a complex of rivers in the south-western Cape which is characterised by relatively high rainfall and strong winter flows. Whilst not according full vegetation type status to Cape mountain stream vegetation, Mucina & Rutherford (2006) nevertheless do recognise a separate azonal vegetation unit: Fynbos Riparian Vegetation. This is the vegetation of sandstone base rivers of the Cape flora within the Northern, Western and Eastern Cape regions, with typical dominants including *Prionium serratum* palmiet, *Metrosideros angustifolia* smalblad, *Brachylaena neriifolia* waterwitels, *Erica caffra* waterheide, *Calopsis paniculata* besemriet and *Berzelia lanuginosa* kolkol. This vegetation is found on alluvium (Mucina & Rutherford 2006) as well as colluvium and bedrock. Substratum type plays a critical role in flora variation, with many of the graminoids and other herbaceous species confined to sandy stretches, particularly in the lower wetbank zone (*sensu* Boucher, 2002). Personal observation shows there to be a general trend from sandy banks in the upper reaches, to rocky channels in the upper to middle reaches, and sandier banks in the lower reaches where rivers widen and flows dissipate.

Riparian flora and vegetation is as strongly influenced by distance from the river, as it is by substratum type. The riparian zones of rivers generally show a lateral shift in plant species composition from the water's edge outwards. Due to moisture gradients, at times very subtle, these shifts are influenced by lateral and vertical distance from the water's edge. In many Western Cape rivers, plant communities have been correlated with vertical inundation levels associated with the natural flow regime. These have been referred to, in order of distance from the water, as rooted aquatic, the lower and upper wetbank zones, and the dynamic and tree / shrub drybank zones (Boucher 2002). Changes in flow regime can thus result in changes in both plant species composition and/or community zonation.

The broad aim of this study was to evaluate the overall condition of the vegetation along a portion of the Koekedouw River downstream of the Greater Ceres Dam. The terms of reference were restricted to a botanical scan with collection of sufficient information to assess whether the ecological condition of the riparian vegetation along the river has changed over time. The terms of reference precluded collection of data, for example along vegetation transects or sampling plots, because of budget constraints.

6.3.2 Methods

The Koekedouw River was visited on 7 December 2008, and observations made of the resident flora and vegetation. For convenience the river stretch being studied (i.e. from the dam wall to the outskirts of Ceres) was divided into a number of sections, based more upon the presence of structures, such as bridges, rather than any natural changes in riverine plant life. The six sections, S1 to S6 are shown in Figure 6-2. A record was made of all species occurring in each river section, which could be identified in the field (this amounted to most species encountered).

A group of computer-based programs specifically developed for multivariate and statistical analyses of multispecies data was used to investigate the relationships between the plant assemblages in the Koekedouw and other local rivers. These programs collectively form the software package PRIMER (Plymouth Routines in Multivariate Ecological Research) Version 6, developed at the Plymouth Marine Laboratory, United Kingdom (Clark & Warwick 1994). Multivariate analysis has an advantage over univariate methods (e.g. ANOVA) of maintaining much of the complexity of community-based biological data, as the comparisons of samples are based on the extent to which they have particular taxa in common and at the same levels of abundance. PRIMER is particularly useful as a tool to display the relationships between biological samples when the taxa-by-samples arrays are large, and thus patterns in community data not readily apparent (Clarke & Warwick 1994).

The PRIMER routines follow an initial computation of similarity coefficients between each pair of samples to produce a triangular similarity matrix. In this study, the Bray-Curtis similarity measure was used, as recommended for biological data (Clarke & Warwick 1994). A 4^{th}-root transformation of abundance data is recommended for comparison of samples where abundances may range from zero to very high numbers, in order to dampen the effect of the most dominant taxa on the similarity matrix, whilst also being invariant to scale change (Field *et al.* 1982). Whilst such a transformation was used for the invertebrate and algal studies, the vegetation analysis used a abundance scale of 1 to 3, where 3 = dominant, high cover; 2 = occasional to frequent, moderate cover; 1 = rare, very low cover.

The CLUSTER analysis and MDS ordination routines in the PRIMER package were used to represent relationships between the Koekedouw River flora and that of neighbouring rivers, based on their species complements. Classification involved hierarchical, agglomerative clustering with group-average linking, as recommended by Field *et al*. (1982) and Clarke & Warwick (1994). As cluster analysis may force data into artificially distinct classes when, in reality, continua exist, a complementary method of analysis is advisable to confirm groupings (Field *et al*. 1982). Ordination by means of non-metric multi-dimensional scaling (MDS), which was used in this investigation, is one such method. Advantages of MDS include its flexibility and its basis on very few underlying assumptions (see Field *et al*. 1982 and Clarke & Warwick 1994 for a thorough discussion of MDS). All MDS ordinations were generated using 25 restarts. Distortions of the underlying data in two-dimensional MDS ordinations (and the subsequent reliability of the ordinations) were determined by the respective 2-D stress values (Table 6-2).

6.3.3 Findings and discussion

Field observations and comments

Species lists for the various sections are shown in Appendices C1 (individual sections) and C2 (composite species list).

Total species numbers for individual sections range from 11 (Section 5) to 24 (Section 3), with a total of 35

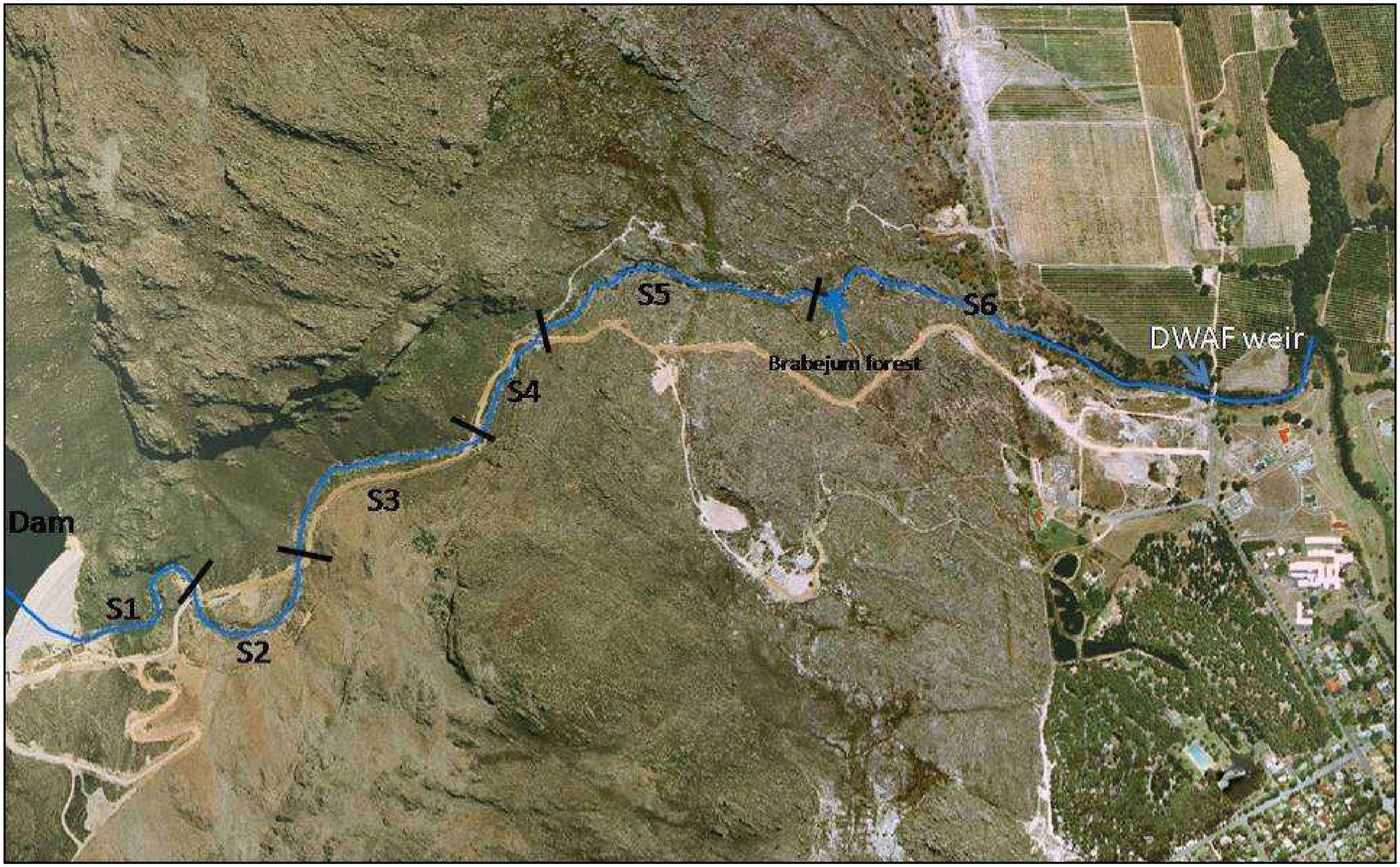

Figure 6-2. Koekedouw River in the study area, showing sections S1 to S6. Scale approximately 1:10 000 at A4 page format.

Table 6-2. Guidelines for interpretation of 2-D stress values for MDS diagrams (from Clarke & Warwick 1994)

2-D stress value	Interpretation
< 0.05	Excellent representation with no prospect of misinterpretation
0.05 – 0.1	Good ordination with no real prospect of misleading interpretation
0.1 – 0.2	Potentially useful 2-D ordination, but too much reliance should not be placed on the plot for values at upper end of range
0.2 – 0.3	2-D ordination should be treated with great deal of scepticism and discarded in upper half of range, especially with <50 data points
> 0.3	2-D ordination should be treated with great deal of scepticism and discarded in upper half of range, especially with <50 data points

species for the whole stretch of river surveyed (Table 6-3). This compares well with the mean species richness for the Witels River which joins the Dwars to form the upper Breede, some 10 km downstream of the confluence of the Koekedouw and Dwars Rivers. In the Witels, the average species number for river reaches of similar length is 38 (range of 22 to 53) (Low, unpubl. data; SaSFlora, 1998 - 2009). The Koekedouw species number is likely to be somewhat higher if a full year's collecting were to be undertaken and would likely eclipse this mean.

The results of MDS analysis was based on the full species complement for all six river sections of the Koekedouw River combined, along with reach-averaged data for different longitudinal zones of four other rivers (Low, unpublished data) are provided in Figure 6-3. The distance between samples in the plot indicates the strength of their dissimilarity. Two aspects are apparent from the plot: the gradient of change along the horizontal axis appears to reflect a shift from upper to lower longitudinal zones in these rivers. Secondly, the individual river catchments separate out fairly well along the vertical axis, with the Koekedouw River reach most different from the Witte (WL) and Elandspad (EP) Rivers and most similar to the middle reaches of the Twenty Four Rivers indicates that the Koekedouw River in the study reach is different from the surrounding rivers.

The positioning of the Koekedouw River study reach within this regional river reach classification indicates that the Koekedouw is not a river which flows at pace for long periods of the year, where most of the species would require rocky or rocky/sandy substrates for rooting, but rather a system more characteristic of lower gradients and lower energy, where sand banks and finer particles are prevalent. Indeed, Table 6-3 indicates a dominance of species with a preference for sandy habitats, as is discussed in the following section.

Changes in the composition of vegetation characteristic of lateral zones

It has been asserted in Ractliffe and Ewart-Smith (2004) that, due to the construction of the Greater Ceres Dam, vegetation patterns in the Koekedouw River downstream of the dam have been negatively affected by reduced flow rates and altered seasonality of flow. Changes reported in Ractliffe and Ewart-Smith (2004) included colonisation of backwater side channels by herbaceous plants that are characteristic of the lower wetbank zone, such as *Isolepis prolifera* and *Juncus lomatophyllus,* in, this following the accumulation of sand in these backwaters. In addition, wetbank herbaceous plants such as *Elegia capensis*, *Lobelia anceps* vleilobelia (not encountered in the present study), *Juncus lomatophyllus*, *Erica*

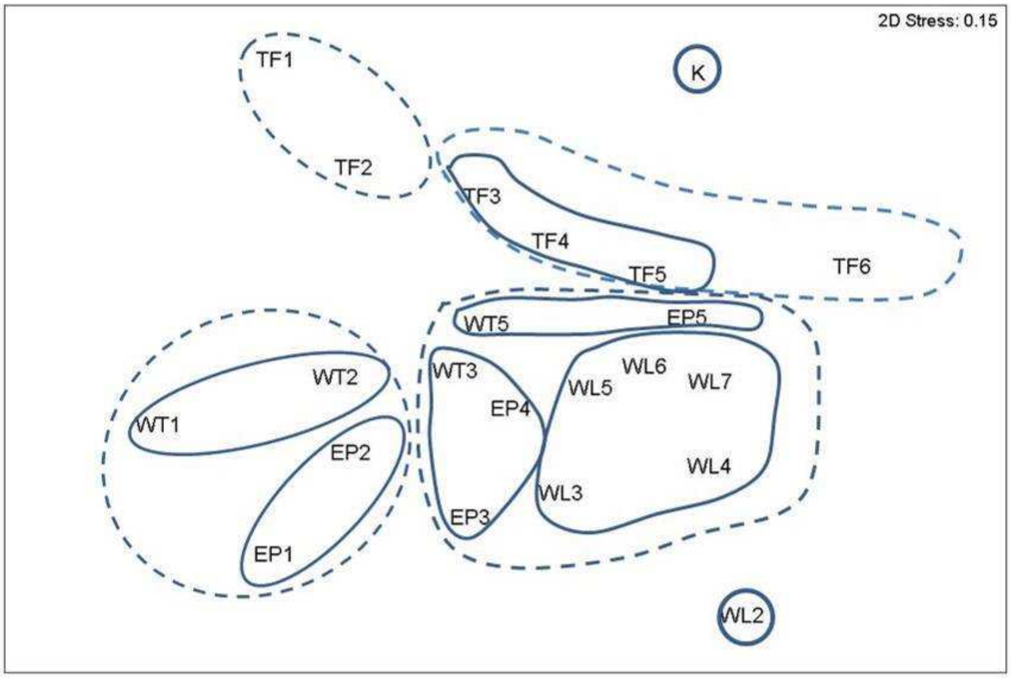

Figure 6-3. MDS analysis of the floras of river reaches at a subregional level - from the Twenty Fours (TF), Witels (WL), Witte (WT) and Elandspad (EP) Rivers. Numbers indicate river sections, 1 and 2 = upper river reaches and 3 – 7 = lower reaches.

cf. *versicolor* (not encountered), *Metrosideros angustifolia* and *Pseudobaeckia africana* were reported to be encroaching into the rooted aquatic zone.

As there appears to be no vegetation reference condition for the river prior to construction of the dam and without established vegetation monitoring plots from the 2004 study it is difficult to test this assertion. In terms of both plant species and vegetation, the river section studied is substantially different from mountain streams within the general region (i.e. Groot Winterhoek to Du Toits Kloof Mountains) as illustrated in Figure 6-3, but less so of the middle reaches of the Twenty Fours and Witte Rivers. Sandy banks are natural features of rivers such as the Koekedouw River and their position and extent will vary over time. However, the clear documentation of the sediment washing into the river, chiefly when the old dam was decommissioned, means that this habitat more prevalent now than would have been the case under natural conditions, and this is a key factor in separating this system from other rivers in the subregion (Figure 6-3).

Nevertheless, species encountered along the Koekedouw represent a mix of rocky and sandy substratum-dependant species (Table 6-3). Whilst sand-loving species were prevalent, and dominated in the river reaches close to the dam, the species complement included generally equal numbers of species characteristic of sand and rocky habitats. There is at present little evidence to suggest that a mature (climax) lower wetbank community is developing as this not supported by the low number of species and low cover observed.

The species complement recorded in the Koekedouw River indicates there are sufficient low flows during the year to provide moisture to the sandy bank habitats for key wetbank species such as *Drosera cistiflora* sundew, *Cyperus sphaerospermus* matjiesgoed, the sedges *Fuirena hirsuta* and *Isolepis prolifera*, the rush *Juncus lomatophyllus*, *Pennisetum macrourum* beddinggras, and *Elegia capensis* katstert. In light of the over-supply of sediment from the dam construction phase, however, this habitat is likely to be present under most low-flow regimes, especially when very low flows persist. Colonisation of sandy deposits then gives rise to a greater chance of sediment persisting.

However, some key species characteristic of the rocky midstream and lower wetbank environments, such as the sedge *Isolepis digitata*, the orchid *Disa caulescens*, the prostrate, creeping species *Lycopodiella caroliana* (a fern), *Laurembergia repens* and *Villarsia capensis* yellow bogbean appeared to be absent from this system. There was a general absence of certain graminoids which normally characterise wetter banks. These include *Chrysithrix capensis* kwasbiesie, the sedge group *Epischoenus* spp. and a number of rush or *Juncus* spp., as well as floating aquatics such as *Isolepis fluitans* watergras. Their absence suggests that the river lacks strong perennial flow, and water levels are not maintained at periodically higher levels, for example those that would be expected of winter baseflows. The flow data reported in Section 5 demonstrate that, except during periods of dam spillage, implementation of winter baseflows and floods has been extremely poor, with flows remaining at or lower than the <u>summer minimum levels</u> for most winter months over the past five years, and the flora and vegetation composition reflects this change in the flow regime.

The floating aquatic plant species *Nymphoides indica* geelwateruintjie,which was recorded along the river is not typical of fast-flowing mountain streams in the Cape but prefers lowland reaches where flows have largely dissipated and the substratum is generally sandy or even clayey. Again this underscores the absence of flushing flows in the river.

Climax riverine thicket/forest species were also absent. These include *Ilex mitis*, *Cunonia capensis* and *Platylophus trifoliatus* witels, with the only tall thicket, rather than forest, developed by *Brabejum stellatifolium* wild almond over a very short length of river. This suggests that strongly perennial conditions, which are essential for the development of tall thicket or forest, are absent from the site. Their absence is not related to the dam operation, however, since this community is not recently absent.

Analysis of species habitat signatures (Table 3-6) shows that most species are sand-loving and this relates directly to the build up of sediment along the river course. Key species with both high cover as well as frequency of occurrence (six or more sections) are: the shrubs *Cliffortia strobilifera*, *Leucadendron* cf. *salicifolium*, *Morella* cf. *integra*, and the graminoids *Calopsis paniculata*, *Elegia capensis*, *Merxmuellera cincta* and *Prionium serratum* (sandy), and the shrubs *Erica caffra*, *Metrosideros angustifolia*, and *Psoeudbaeckea africana* (rocky). Dominant habitat signatures (Table 3-6) are either riverine or riverine and wetland, indicating that the Koekedouw is perennial but that its winter flushes are inadequate to remove sediment. However, the upper banks of the channel are mostly free of sediment deposits and this sustains rocky riverine endemics such as *Pseudobaeckea africana*,, with some rocky upper bank species including *Erica caffra* and *Brabejum stellatifolium* (the latter in the lower sections only). Conspicuous by its absence is the midstream rocky endemic sedge, *Isolepis digitata*. This is present in most of the montane rivers in the subregion (SaSFlora, 1998 – 2009) and requires strongly perennial to perennial conditions, generally with high water levels to survive. This suggests that there needs to be more regular flushes throughout the year to keep the midstream habitat clear of sediment and seasonally wetter / deeper.

Table 6-3. Total species numbers in each section of the Koekedouw River and in the different habitats within each section. Species habitat signature indicated by R = riverine, W = wetland, R/W = riverine and wetland, T = terrestrial. Local habitat preference indicated by R = rock, S = sand. Numbers represent weighted presence (1 = rare, 2 = moderate cover, occasional to frequent; 3 = high cover, common).

Species	Habitat signature	Main habitat	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Lower weirs	DWAF Weir	Frequency of occurrence
Dicotyledons											
Brabejum stellatifolium	R	R & S						3	3	3	2
Brachylaena neriifolia	R	S & R		2	1	2			1	1	5
Cassine schinoides	T	R & S				1					1
Cliffortia ruscifolia	T	R & S			1					1	2
Cliffortia strobilifera	R/W	S	3	3	2		3	3	2	3	8
Diospyros glabra	T	R & S	1	1	2	1			1	1	5
Drosera cf. *cistiflora*	R/W	S	1	1	1						3
Erica abietina subsp. *aurantiaca*	T	S & R		1	1	1			1	1	5
Erica caffra	R	R & S	1		1	1		2	1	1	6
Erica cf. daphniflora	R/W	S & R		1	1	1		1	1		5
Freylinia lanceolata	R	S			2						1
Gnaphalium cf. *capense*	R/W	S	1		1						2
Grubbia rosmarinifolia	R/W	S				1					1
Leucadendron cf. *salicifolium*	R/W	S	2	2	1		2	2		1	7
Morella integra	R	S & R	2	2	2		2	2	3	1	8
Metrosideros angustifolia	R	R & S	3	3	2		3	3	3	3	8
Nymphoides indica	R/W	S								1	1
Pseudobaeckea africana	R	R	2	2	2	2	2	2	2		7
Rhus angustifolia	R/W	S & R								1	1
Salix mucronata cf. *subsp. capensis*	R	S & R			1						1
No. species	20	20	9	10	15	8	5	8	10	12	
Monocotyledons											
Askidiosperma chartaceum	R/W	S		1							1
Calopsis paniculata	R/W	S & R	3	3	3	3	3	3	2	3	8
Cannomois cf. virgata	R/W	S		2	2				1		3
Carpha glomerata	R/W	S		1		1				1	3
Cyperus cf. *sphaerospermus*	R/W	S	2		1					1	3
Elegia capensis	R/W	S	2	2	2	2		2	1	1	7
Elegia cf. *asperiflora*	R/W	S			1						1
Fuirena cf. *hirsuta*	R/W	S	2	2	2	2	2				5
Isolepis prolifera	R/W	S	2							2	3
Juncus lomatophyllus	R/W	S	2	2							3
Merxmuellera cincta	R/W	S	2	2	2		2	2	2	2	7
Panicum cf. *schinzii*	R/W	S	2		2	1	1	2		2	5
Pennisetum macruorum	R/W	S	2	2	1		2			1	5
Prionium serratum	R/W	S & R	3	3	3	3	3	3	3	3	8
Watsomia cf. *meriana*	R/W	S								1	1
No. species	15	15	10	10	10	6	6	5	5	10	

Woody alien vegetation

Both *Acacia longifolia* golden wattle and *A. mearnsii* black wattle were recorded sporadically along the river. These species are aggressive invaders, the latter predominantly of riverine systems, and are classified as Transformer invasive and Category 2 invader respectively (Henderson, 2001). *Hakea sericea* silky hakea is also present, although this is principally an invader of dryland habitats. Both *Acacia* spp. need to be removed from the system as their presence has and will lead to stifling of river flow. Once removed, regular (once a year) follow ups are essential.

6.3.4 Conclusions

The following is a summary of the findings:

- In terms of plant species and vegetation, the river section studied is substantially different from mountain streams within the general region.
- There appears to be some evidence from on-site observations that sandy banks might well be more prevalent than natural in the Koekedouw River downstream of the Ceres Dam, as has been suggested in Ractliffe & Ewart-Smith (2004). Species encountered along the Koekedouw River represent a mix of rocky and sandy substratum-dependant species.
- Whilst sand-loving species were prevalent, and dominated in the river reaches close to the dam, the species complement included generally equal numbers of species characteristic of sand and rocky habitats.
- Dominant habitat signatures were either riverine or riverine and wetland, indicating that the Koekedouw is perennial but that its winter flushes are inadequate to remove sediment. However, the upper banks of the channel are mostly free of sediment deposits and this sustains rocky riverine endemics, with some rocky upper bank species including *Erica caffra* and *Brabejum stellatifolium* (the latter in the lower sections only).
- There was a general absence of certain graminoids which normally characterise wetter banks closer to the water's edge, which suggests that the river lacks strong perennial flow, and water levels are not maintained at periodically higher levels, for example those that would be expected of winter baseflows.
- Conspicuous by its absence is the midstream rocky endemic sedge, *Isolepis digitata*. This is present in most of the montane rivers in the subregion and requires strongly perennial to perennial conditions, generally with periodically high water levels, to survive. This suggests that there needs to be more regular flushes throughout the year to keep the midstream habitat clear of sediment and seasonally wetter / deeper.
- The aquatic plant species *Nymphoides indica* geelwateruintjie,which was recorded along the river is not typical of fast-flowing mountain streams in the Cape but prefers lowland reaches where flows have largely dissipated and the substratum is generally sandy or even clayey. This underscores the absence of flushing flows in the river.

These features of the vegetation are considered to be the result of the construction process as well as inappropriate flow rates and timing, this despite the limited scouring of sandy banks that was probably associated with a single large (20 cumec) flood event coinciding with dam spillage. An increase in the extent of sandy banks will result in concomitant colonisation by a small suite of lower and upper sandy bank species. Unnatural increase in extent of sandy banks and their vegetation cannot be conclusively demonstrated due to lack of comparative spatial data such as vegetation cover taken at specific vegetation plots.

Recommendations

- A detailed assessment of all plant species present is required to establish floristic gradients more accurately.
- Changes in river habitat need to be monitored every two years through the establishment of permanent plots and flora sampling; this should be linked with assessment of change in proportion of sandy to rocky substratum in preselected areas. The re-establishment of key riverine endemics such as *Isolepis digitata* would be a vital indicator of positive change in the river.
- All woody alien species mentioned in the study need to be eradicated as matter of urgency. The acacias in particular are aggressive invaders and can choke river channels with deleterious effects to the riverine habitat. *Populus canescens*, only occurring in the lower parts, also needs to be monitored carefully and removed.

6.4 WATER QUALITY

An assessment of the water quality of a river ecosystem not only provides a direct measure of ecosystem condition but also provides vital information for interpreting biological data, particularly on algae, macroinvertebrates and fish. Water quality is affected by the flow regime, but the relationship between flow and different chemical variables is complex. For example, very low flows can lead to higher temperatures and low concentrations of oxygen, a problem for many biotas, but can also reduce the rate of nutrient supply to algae and thus result in lowered algal biomass. Catchment effects such as nutrient enrichment from farming practices most often exacerbate the stress on riverine fauna and flora caused by altered flows, reducing ecosystem integrity.

6.4.1 Methods

System variables (temperature, pH, and conductivity) were measured *in situ* at all four biological sampling points during the December 2008 survey, using a Crison portable multimeter, while water samples were collected at the three primary sites (i.e. Sites B1, B3 and W (DWAF Weir H1H013)) for the analysis of nutrients (PO_4^+-P, NO_3^+-N, NO_2^+-N and NH_4^+-N). Nutrient samples were processed at the water quality laboratory in the Oceanography Department, University of Cape Town.

A comparison was made between the pH, temperature and conductivity data collected in December 2008, and the same data that were collected seasonally from the same sampling sites during the initial (1999-2004) 5-year monitoring programme.

In addition, long-term water quality data from DWAF Weir H1H013 were used to analyse historic trends in the water quality of the Koekedouw River downstream of the Greater Ceres Dam, as well as seasonal patterns, linked to flow releases from the dam. The trends over the entire sampling record that was available (i.e. July 1977 to March 2008) were compared to the situation since the completion of the dam (i.e. 1999 to 2008). Differences between the period 1977 – 1998 and 1999-2008, representing before and after the construction of the dam, were analysed statistically. The nutrient data were not normally distributed, thus precluding parametric statistical tests. Statistical testing for differences between the time periods 1977-1998 (i.e. before completion of the dam) and 1999 – 2008 were performed using 1-way Kruskal-Wallis ANOVA by ranks, with $P<0.05$ used as a threshold to indicate significant differences. The variables selected for these long-term water quality analyses were pH, conductivity, total inorganic nitrogen (NO_3-N + NO_2-N + NH_4-N) and orthophosphate concentrations (PO_4-P), and silica concentration. Seasonal differences before and after 1998/99 were also explored, with the following months taken to represent each season:

- Autumn = March, April May
- Winter = June, July, August
- Spring = September, October, November
- Summer = December, January, February

6.4.2 Findings and discussion

The *in situ* measurements recorded during December 2008 are presented in Table 6-4 and are compared with the average quarterly measurements recorded at the same sampling sites during the initial 5-year monitoring programme (expressed as the mean ± standard deviation). A broader perspective is provided by the long-term water quality data at the DWAF gauge H1H013 covering the period from July 1977 to March 2008.

Table 6-4. pH, electrical conductivity (EC) and temperature (T) measurements recorded in the Koekedouw River downstream of the Greater Ceres Dam in December 2008, compared with, for EC and pH, the average quarterly measurements recorded at the same sampling sites between March 1999 and February 2004 (mean ± standard deviation), and for temperature the maximum value recorded in summer at each site.

		Sampling sites			
		B4	**B3**	**B1**	**W**
pH	Dec '08	6.4	6.4	6.4	5.4
	Mar '99 - Feb '04	6.5 ± 0.7	6.5 ± 0.4	6.7 ± 0.3	6.3 ± 0.4
EC (mS/m)	Dec '08	3.0	2.9	2.8	3.7
	Mar '99 - Feb '04	3.3 ± 0.7	3.5 ± 0.9	3.4 ± 0.8	4.0 ± 1.1
T (^{o}C)	Dec '08	19.1	21.8	19.4	25.3
	Mar '99 - Feb '04	14.7 ± 3.2	16.1 ± 3.7	16.0 ± 4.0	16.9 ± 4.8

pH

pH measurements were similar at Sites B4, B3 and B1, where they were within the range of values recorded during the initial 5-year monitoring programme and towards the upper end of the natural range of values for Western Cape rivers. The pH of 5.4 recorded at Site W (downstream of DWAF Weir H1H013), while still within the range of naturally acidic values for Western Cape rivers, was below the minimum pH of 5.8 recorded during the initial 5-year monitoring programme.

These values represent an instantaneous measurement in the river, which for pH can be quite variable, affected by such other conditions as water temperature, time of day, and particularly the degree of photosynthetic activity or respiration in the system.

There was a noticeable increase in pH values at DWAF Weir H1H013 between the late 1970's and 2008, mainly as a result of a noticeable jump in values around 1989 (Figure 6-4). This shift in values appears in other pH time series data in the Western Cape (e.g. Molenaars River) and is an artefact of a change in DWAF's sampling techniques. At the very least, this date was not associated with dam activities, which took place a decade later. To avoid false conclusions, the statistical analysis of differences in pH in the period before and after the dam construction was based on the data sets 1989 – 1997 and 1998 – 2008. No significant differences were found. Since the completion of the Greater Ceres Dam in 1998/99, pH values have generally remained consistently between 6 and 7, with few values in the 5 – 6 or 7 – 8 range in the almost ten-year period between 1999 and 2008 (Figure 6-5).

The H1H013 data show only slight but non-significant seasonality in pH (Figure 6-6), whereas the natural seasonal range would be expected to be greater. No seasonal signature is apparent in the post-dam period. Seasonal variation in pH is often attributed to increased leaching during winter of organic acids which lowers the pH, chiefly from areas where organic matter is retained and decomposed, such as seeps. The lack of seasonality in pH in the Koekedouw River may be a consequence of a low incidence of these sorts of wetlands in the catchment.

Conductivity

Conductivity values recorded at all four sampling sites in December 2008 (Table 6-4) were within the ranges recorded between 1999 and 2004, and were within the expected natural range for Mountain Stream sites in the Western Cape (Dallas *et al*. 1998). As in the case of the quarterly measurements recorded during the initial 5-year monitoring programme, the conductivity was slightly elevated at the

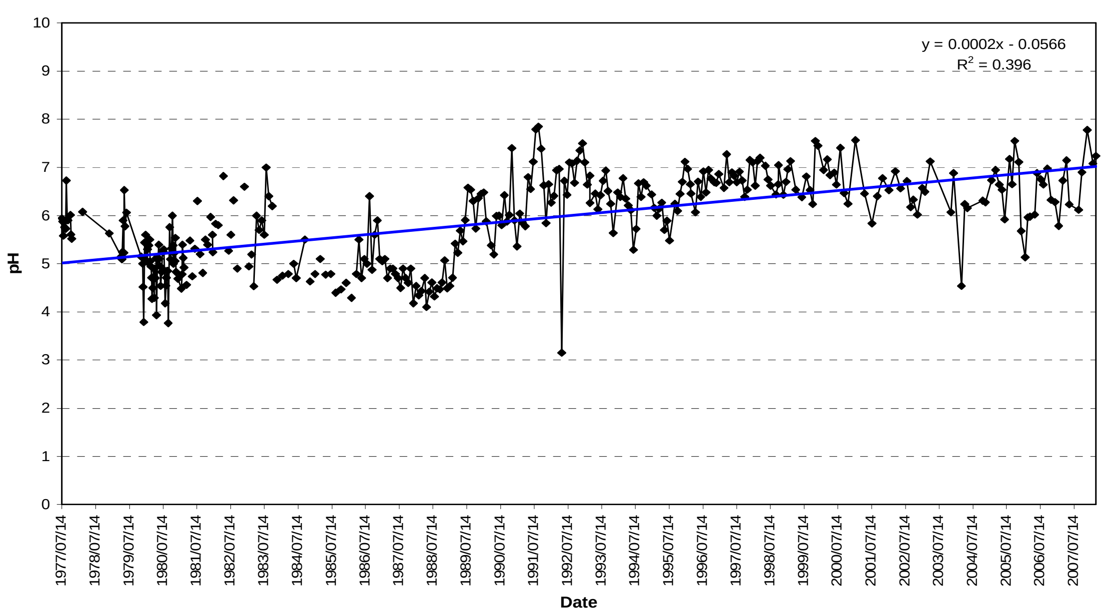

Figure 6-4: pH values recorded at DWAF Weir H1H013 between 1977 and 2008, with the linear trend line shown in blue (and associated equation and R^2 value given).

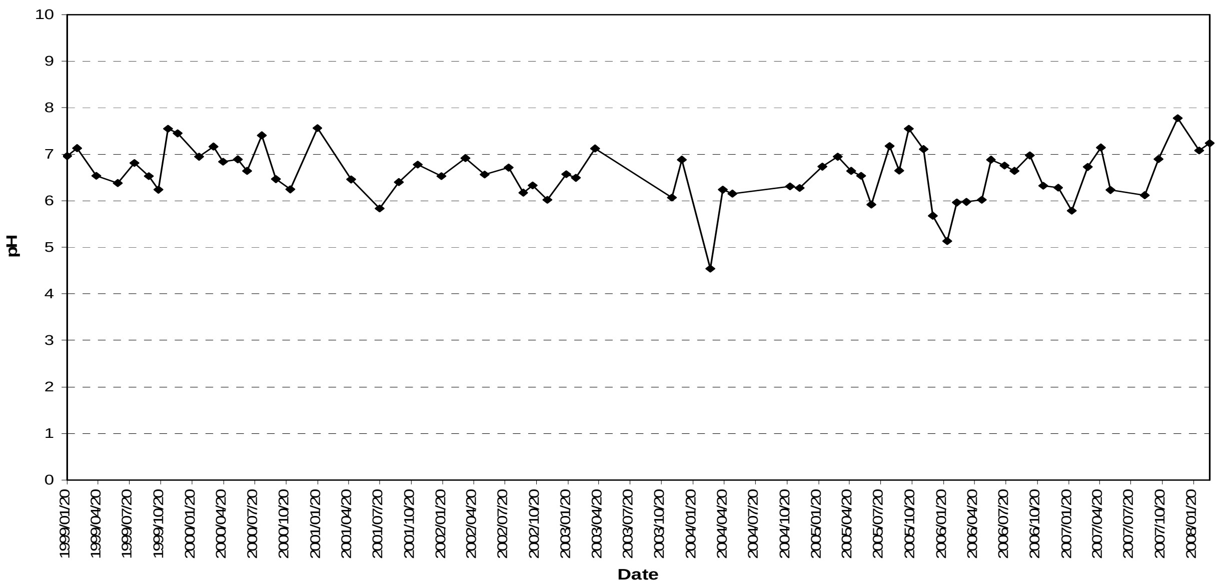

Figure 6-5. **pH values recorded at DWAF Weir H1H013 between January 1999 and March 2008.**

DWAF Weir (W) relative to the other three sampling sites, but nevertheless still reflect values typical of very pure waters. Contributing factors to this increase could be the shift in land use from nature reserve to farming activities just upstream of the weir (refer to Figure 6-2), hydropower releases, as well as frequent use of the river for recreational activities in the reaches upstream, that includes ablutions like washing with soaps (personal observation).

No distinct trend was evident in the EC values recorded at H1H013 from 1977 to 2008, although there was a noticeable less variability in EC measurements from the mid-1980's onward (Figure 6-7). EC values

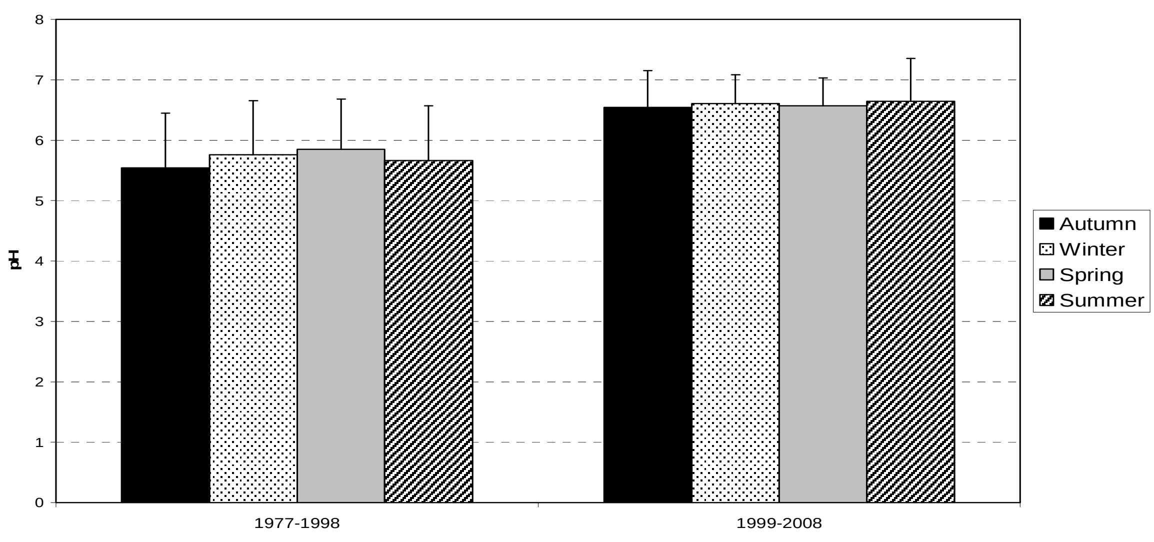

Figure 6-6. **Mean seasonal pH values recorded at DWAF Weir H1H013 from 1977–1998 compared with mean seasonal values recorded from 1999–2008, the post-dam period. Error bars show standard deviation in measurements for each season.**

recorded at DWAF Weir H1H013 from 1999 to 2005 were particularly stable and relatively low, remaining between approximately 3 and 7 mS/m. More variation is evident in the data in recent years, with spikes of approximately 10 mS/m in September/October 2005 and December 2007 (Figure 6-7). These do not appear to be related to periods either of dam releases or spillage, and may reflect occasional impacts associated with the recreational activities upstream of the gauge.

Seasonal differences in conductivity were not pronounced, especially for the post-dam period (Figure 6-8). Although spring and summer values were somewhat higher in the 1977-1998 period, these were not significant. No seasonality was evident in the post dam period.

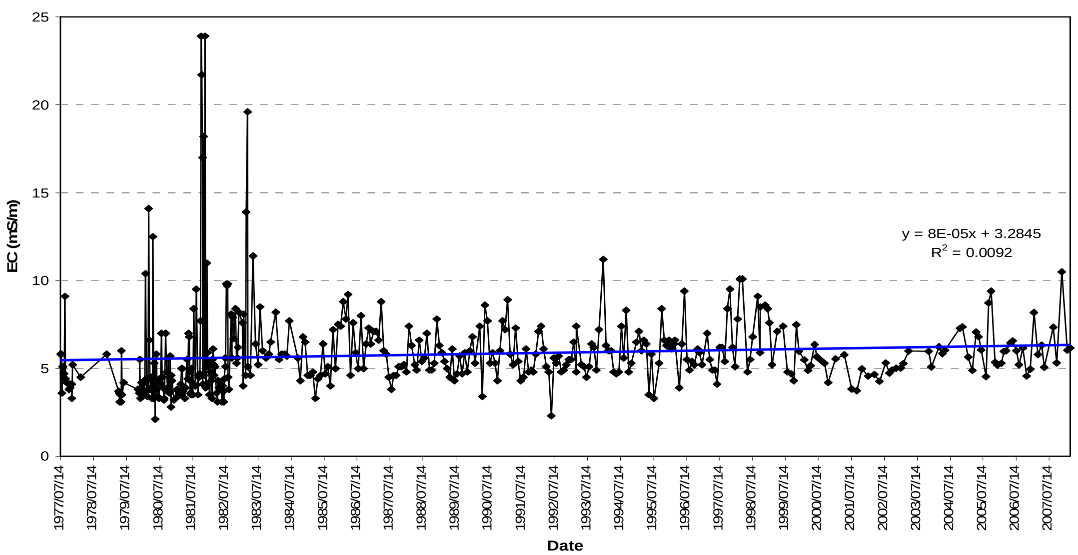

Figure 6-7. Electrical conductivity (EC) values recorded at DWAF Weir H1H013 between 1977 and 2008, with the linear trend line shown in blue (and associated equation and R^2 value given).

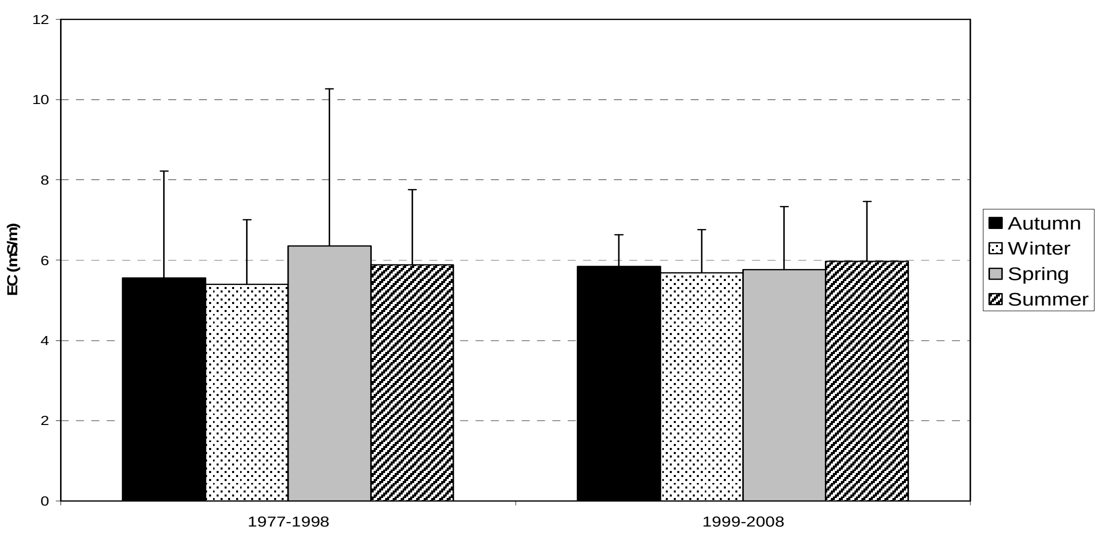

Figure 6-8: Mean seasonal electrical conductivity (EC) values recorded at DWAF Weir H1H013 from 1977–1998 compared with mean seasonal values recorded from 1999–2008. Error bars show standard deviation in measurements for each season.

Temperature

The water temperature results presented in Table 6-4 are based on instantaneous measurements that were recorded at different times of the day, making them unsuitable as a basis for making any firm assessment of trends. During the previous monitoring programme, however, it was noted that B4, closest to the dam had markedly lower temperatures than the other sites, and the difference in temperature between this site and the ones downstream were more marked during summer than winter. This is probably the result of contributions made by cool seepage water from the aquifer below the dam wall. A cooler temperature was recorded here than the other sites again during this survey.

All values recorded at each site were lower than the mean site value recorded during the previous monitoring programme, with the exception of the Weir site H1H013, which had a temperature substantially higher than the mean of the previous monitoring period, but which nevertheless was lower than the maximum value recorded here.

Nutrients

Nitrate is usually the dominant form of inorganic nitrogen in unpolluted rivers, and typically occurs at concentrations below 0.2 mg l^{-1} (Dallas & Day 1994) whilst nitrite is normally a minor component of Total Inorganic Nitrogen (TIN). Ammonium occurs naturally in acidic waters as a product of the breakdown of nitrogen-containing organic matter, but is usually also a minor component of dissolved nitrogen compounds, especially in flowing systems, because it is converted to nitrite and nitrate through aerobic bacterial activity.

The DWAF determination of boundary values between nutrient status categories for inland waters is based on measurements of Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (DWAF 1996). Whilst the boundary between oligotrophic and mesotrophic conditions for Nitrogen is quoted as 0.5 mg/l, and between meso- and eutrophic conditions is 2.5 mg/l, inorganic phosphorus levels associated with different trophic states have been revised over the past decade. Two iterations of the benchmark boundaries of soluble phosphorus nutrient categories (DWAF 1996) and an independent review (Malan & Day 2005) are presented in Table 6-5. In the latter study, the distinction between oligo- and mesotrophic (medium) nutrient status categories of SRP was suggested as 0.02 mg/l (rather than 0.005 mg/l) provided that the results of tests are greater than the detection limits. This threshold was based on actual values recorded in a range of ecosystems, albeit with a limited data set. The use of orthophosphate measurements (PO_4-P) to determine nutrient status is now preferred to that of Total Phosphorus, which was used previously (DWAF 1996).

Table 6-5 Iterative reviews of benchmark SRP category boundaries for trophic levels in inland aquatic systems (values in mg/l) (after Malan & Day 2005)

DWAF 1996	Malan & Day 2005
Median SRP (ortho-phosphate or PO_4) (mg/l)	
Oligo- ≤ 0.005 Meso- 0.005 - 0.025 Eutro- 0.02501 - 0.25	Oligo- ≤0.02 Meso- 0.0201 - 0.125 Eutro- > 0.125

The concentration of inorganic nitrogen and phosphorus compounds measured at three of the sites downstream of the Greater Ceres Dam in December 2008 are presented in Table 6-6. No nutrient data were collected from the monitoring sites during the initial 5-year EWR monitoring programme.

Nutrient concentrations in 2008 were all relatively low, and close to values expected for the oligotrophic (i.e. nutrient-poor) conditions that comprise the natural state of Western Cape rivers. TIN concentrations at B1 and B3 were below the range for oligotrophic conditions and nitrates were close to natural. Elevated nitrates at the H1H013 weir (W) are suggestive of slightly enriched conditions, but are only marginally above the mesotrophic threshold of 0.5 mg/l.

Table 6-6 Nutrient concentrations (in mg/l) recorded in the Koekedouw River downstream of Greater Ceres Dam in December 2008. Nutrients analysed were Nitrate (NO_3-N), nitrite (NO_2-N) ammonium (NH_4-N) which together comprise Total Inorganic Nitrogen (TIN), as well as Phosphate (PO_4 –P) and Total Phosphorus (Total P). Shaded values are indicative of concentrations above the threshold between oligotrophic and mesotrophic conditions (DWAF 1996).

	NO_2 - N	NO_3 - N	NH_4 - N	TIN	Total P	PO_4 - P
B3	0.006	0.309	0.015	0.330	0.003	0.002
B1	0.005	0.262	0.010	0.278	0.005	0.004
W	0.007	0.624	0.007	0.638	0.004	0.002

Total Phosphorus and orthophosphate concentrations were all considerably lower than the 0.02 mg/l threshold between oligotrophic and mesotrophic conditions according to the ranges provided in Table 6-5, with even Total P being in the 0.005 mg/l range, characteristic of unimpacted headwater streams in the Western Cape.

The spot-data collected in December 2008 indicate that water quality in the Koekedouw River downstream of Greater Ceres Dam was good, with very slight enrichment at H1H013 (W), as indicated by marginally elevated nitrate concentrations. However, a more accurate perspective is provided by analysis of the long-term data collected by DWAF from H1H013 which is located at the weir site (W in Table 6-6).

Total inorganic nitrogen concentrations at H1H013 increased slightly between 1977 and 2008, with mesotrophic or near-mesotrophic concentrations being prevalent since the mid-1980's (Figure 6-9), although the correlation coefficient for the linear regression is very low (R^2 = 0.3, implying that the linear equation explains significantly less than 50% of the actual variability in the data). Recorded measurements were most erratic, with significant spikes (e.g. >4 mg/l), during the period when the Greater Ceres Dam was under construction (1996-1998). Since the completion of the dam, TIN concentrations have fluctuated quite substantially around the mesotrophic threshold level (0.5 mg/l), with higher values (between 0.5 and 1.5 mg/l) being recorded more frequently since 2004. The spot value recorded in December 2008 at the weir site is in agreement with these data, suggesting mesotrophy in this portion of the river.

TIN concentrations recorded before the completion of the Greater Ceres Dam (1977-1998) were significantly different from (Kruskal Wallis H = 91.5; $p<0.001$) and substantially lower than the period from 1999 to 2008 (Figure 6-10). Seasonal differences were not significantly different in either time period

(Kruskal-Wallis tests, $p<0.05$), probably because of the variability in the data. Despite this, increases in TIN in the recent period appear to have been greatest in autumn and winter months.

Orthophosphate concentrations appear to have increased gradually, from oligotrophic conditions in the early part of the record to periodic mesotrophic levels in the 1990's, thereafter fluctuating around the mesotrophic threshold (Figure 6-11), although once again it is important to bear in mind that regression coefficient for the linear trend-line is very low ($R^2 = 0.13$). Using the more stringent threshold of 0.005 mg/l, elevated phosphate levels are present from the mid 1980s. The high variability in the data suggests that phosphate is mobilised periodically, which might be due to increases in discharge, changes in pH or reduction in oxygen levels. Flow-linking of the water quality variables was beyond the scope of this project.

The Total Phosphorus concentration in December 2008 at this site was double the orthophosphate, but both of these were very low, and substantially lower than the mean summer concentration in the post-dam period. Low values like this have been recorded in the recent DWAF record, albeit only periodically. Such a result emphasises the importance of time series rather than spot measurements of water quality.

Orthophosphate concentrations were significantly lower in the period 1977-1998 than they were in the period 1999-2008 (Kruskal-Wallis H = 10.664, p = 0.014), where orthophosphate in the latter period was nearly double that of the former and frequently in the range suggesting mesotrophic conditions, especially in spring (Figure 6-12). Again the high variability in the data precluded the identification of significant differences between seasons.

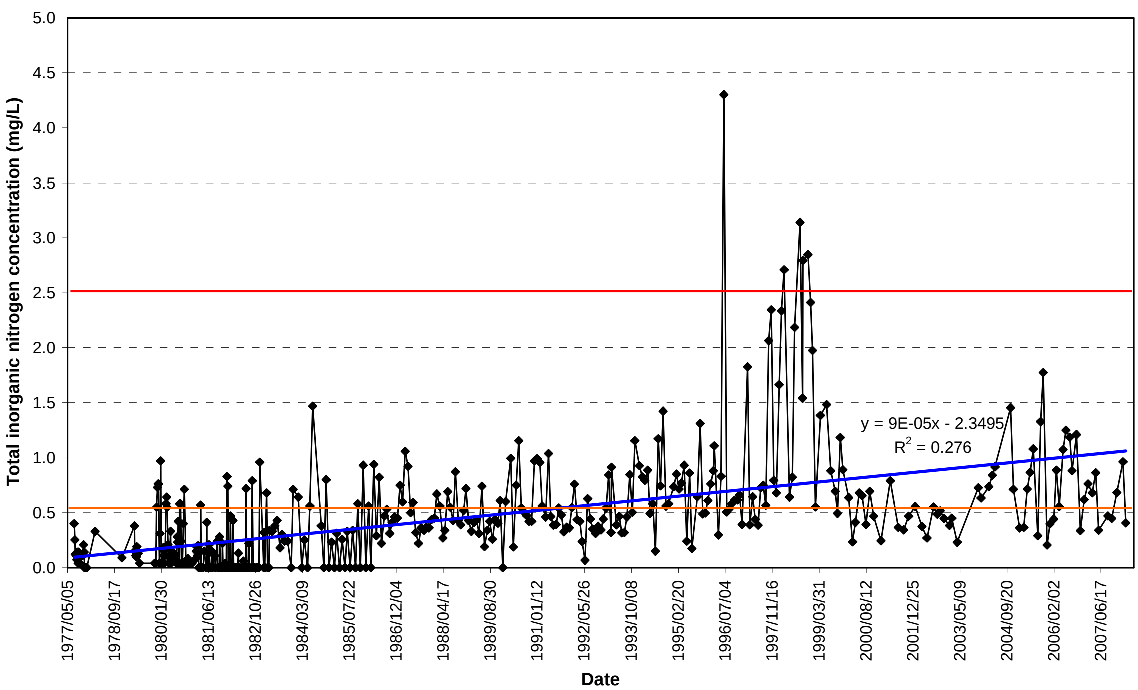

Figure 6-9: Total inorganic nitrogen (TIN) concentrations recorded at DWAF Weir H1H013 between 1977 and 2008, with the linear trend line shown in blue (and associated equation and R^2 value given). Orange (lower) and red (upper) horizontal lines represent DWAF threshold values for mesotrophic and eutrophic TIN concentrations, respectively.

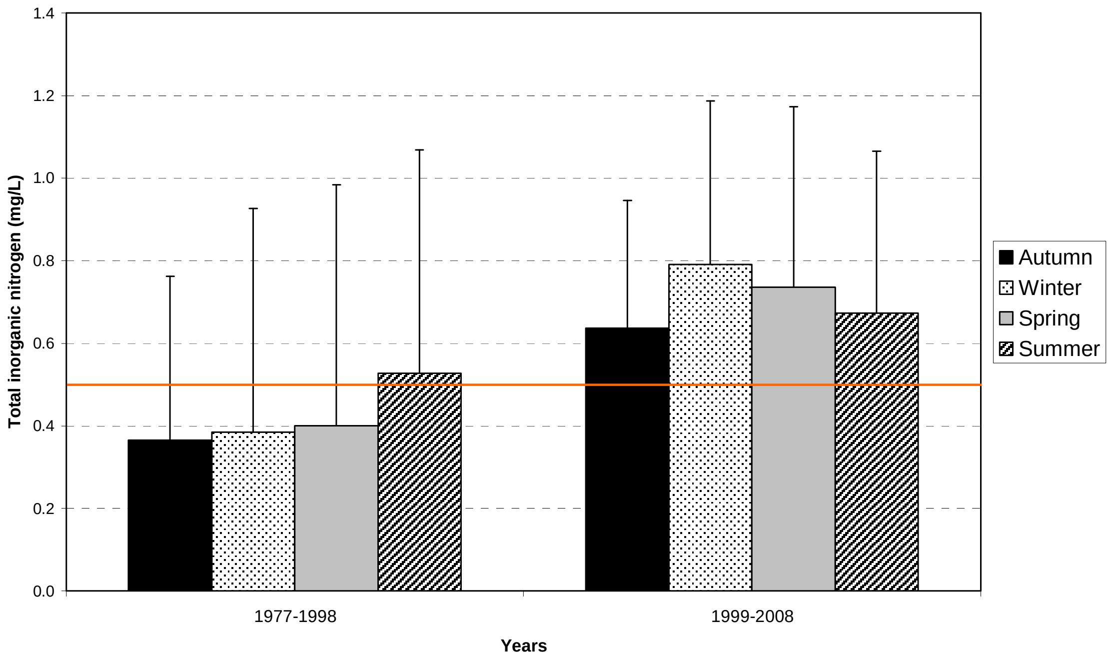

Figure 6-10: Mean seasonal Total Inorganic Nitrogen (TIN) concentrations recorded at DWAF Weir H1H013 from 1977–1998 compared with mean seasonal values recorded from 1999–2008. Error bars show standard deviation in measurements for each season. Orange horizontal line represents DWAF's (1996) threshold value for mesotrophic TIN concentrations.

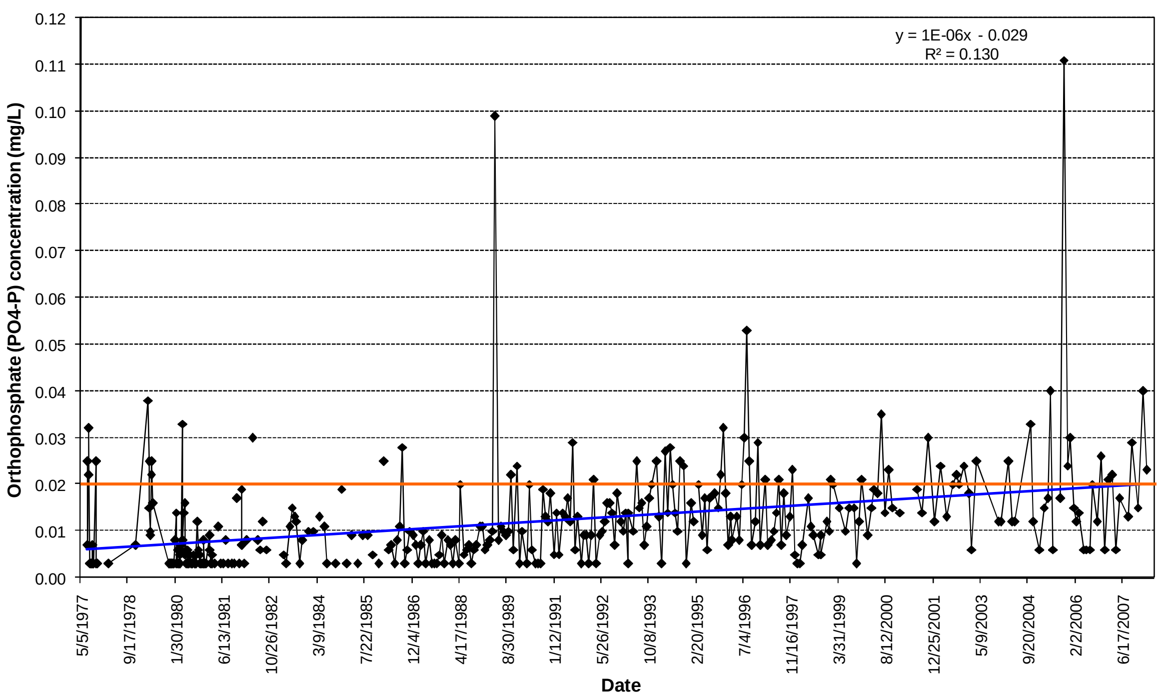

Figure 6-11: Orthophosphate concentrations recorded at DWAF Weir H1H013 between 1977 and 2008, with the linear trend line shown in blue (and associated equation and R^2 value given). The red horizontal line represents Malan and Day (2005)'s threshold value for mesotrophic concentrations.

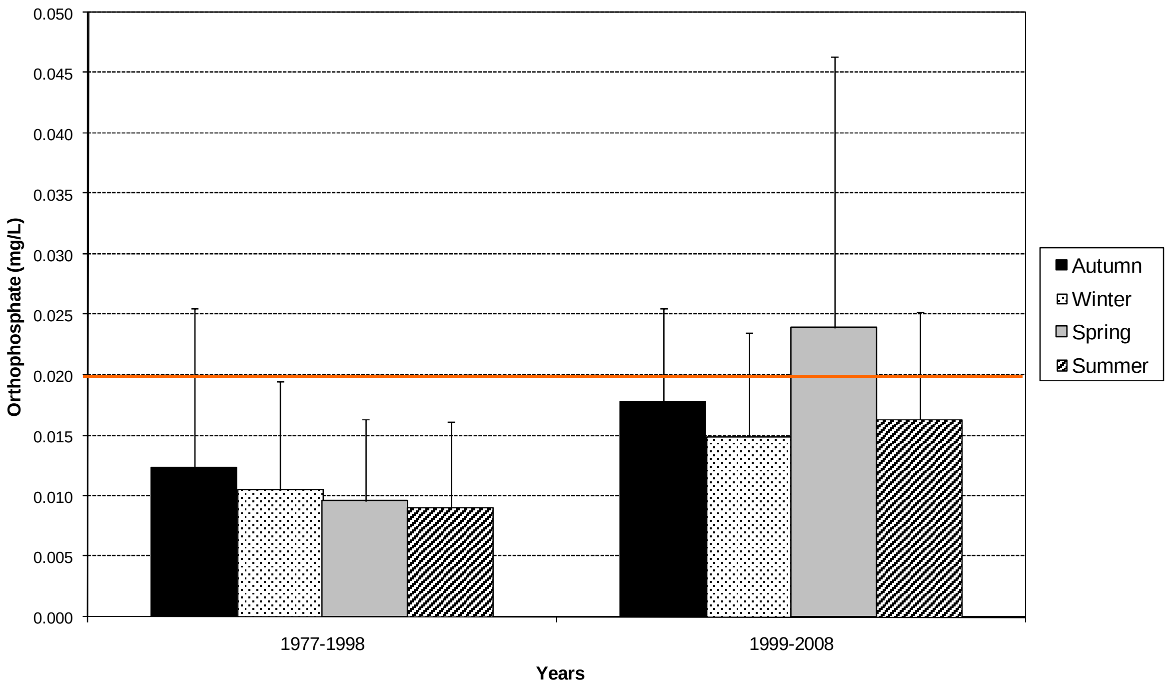

Figure 6-12: Mean seasonal orthophosphate concentrations recorded at DWAF Weir H1H013 from 1977–1998 compared with mean seasonal values recorded from 1999–2008. Error bars show standard deviation in measurements for each season. The red horizontal line represents Malan and Day (2005)'s threshold value for mesotrophy.

Silica

A trend of slowly decreasing silica (Si) concentrations at DWAF Weir H1H013 since 1977 is apparent from the data (Figure 6-13). Since 1999, Si concentrations have fluctuated between 2 and 3 mg/l, with a few spikes (up to >5 mg/l) recorded between March 1999 and March 2000, and a period characterised by low values (< 0.15 mg/l) between July 2001 and September 2002.

Seasonally averaged Si concentrations were generally higher in the period 1977-1998 than they were in the post-dam period 1999-2008 (Figure 6-14), a trend that is opposite to those found for the nutrient data. Because the data were not normal, parametric 2-way ANOVA could not be conducted. Instead, Kruskal-Wallis analysis of variance by ranks found significant differences between time period ($H = 15.99$, $p < 0.001$) and within each time period, seasonal differences were also significant ($H = 15.99$, $p < 0.001$ for the time period 1977 – 1998 and $H = 34.49$, $p < 0.001$ for the period 1999 – 2008; Dunn's test showing significant differences between each pair of seasons). From Figure 6-14, it can be seen that seasonal patterns in silica availability were relatively similar in both time periods, with autumn and summer Si concentrations being generally higher than winter and spring concentrations.

Elevated densities of diatomaceous algae in the Koekedouw River downstream of the Greater Ceres Dam, especially towards Site W (see Section 6.5) may, in part, explain a trend of decreasing silica concentrations, largely since the completion of the dam. Alternatively, the decline in silica after closure of the dam may simply represent the increased influence of surface flows in meeting the EWR, rather than only groundwater seepage which is higher in silicon. The dip in silica during 2000 – 202, when the best flows were released from the dam, supports this explanation. Increases in silica in the very recent period are consistent with the failure of dam management to release even the required baseflows from the dam, and suggest a return to the dominance of groundwater seepage. The decrease in silica concentrations at

DWAF Weir H1H013 during winter and spring is more than likely a consequence of increased dilution in the river associated with increased surface runoff: even if the required EWR releases from the dam are not being met, dilution would happen to some extent in these seasons through direct rainfall and catchment runoff, as well as through spillage from the dam.

6.4.3 Conclusions

There has been an increase in the concentration of nutrients at DWAF Weir H1H013 since 1977, much of which occurred prior to the construction of the Greater Ceres Dam, probably largely as a result of agricultural activities upstream of the dam and in the immediate vicinity of the weir. The statistically significant increase in TIN and orthophosphate concentrations since the construction of the dam is probably mostly due to this incremental increase in nutrient loading of the system over the period of recordrather than an effect of the dam. It is not possible to determine how much of this change is attributable to flow-related impacts associated with the dam. The present condition, however, is one where mesotrophic conditions periodically prevail at DWAF Weir H1H013, between period of oligotrophy. Once-off nutrient data collected in December 2008 suggest that conditions may be better between the dam wall and the DWAF Weir, implicating farming practices closer to Site W in nutrient enrichment rather than the activities higher in the catchment or the operation of the dam.

Recommendations

More frequent nutrient (and other water quality) data should be collected from the sampling sites used for the December 2008 survey, together with data from upstream of the dam, to identify potential non flow-related impacts on the river emanating from the upstream catchment.

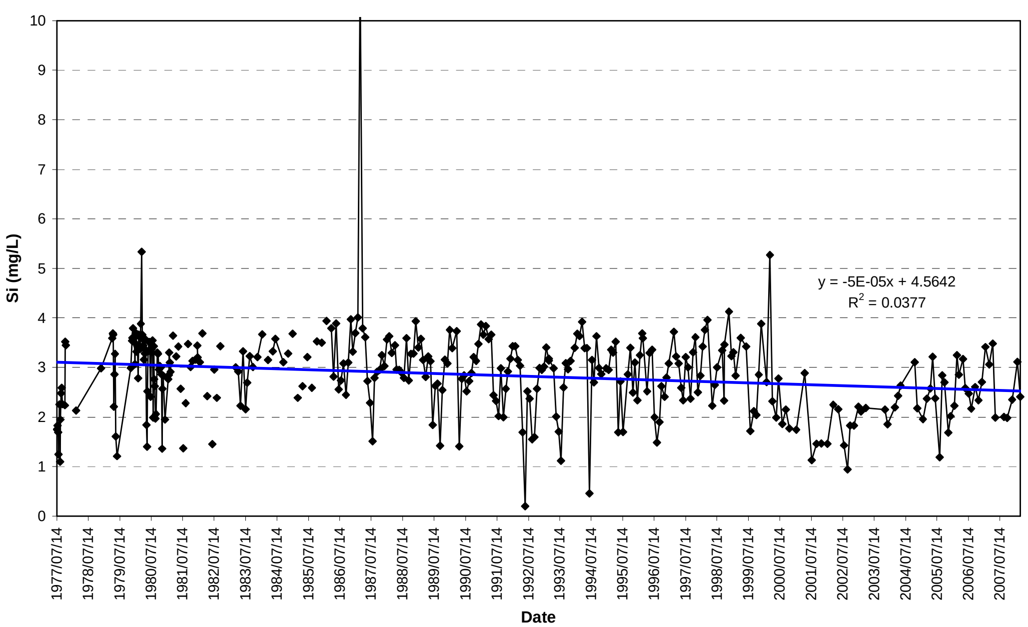

Figure 6-13: Silica (Si) concentrations recorded at DWAF Weir H1H013 between 1977 and 2008, with the linear trend line shown in blue (and associated equation and R^2 value given).

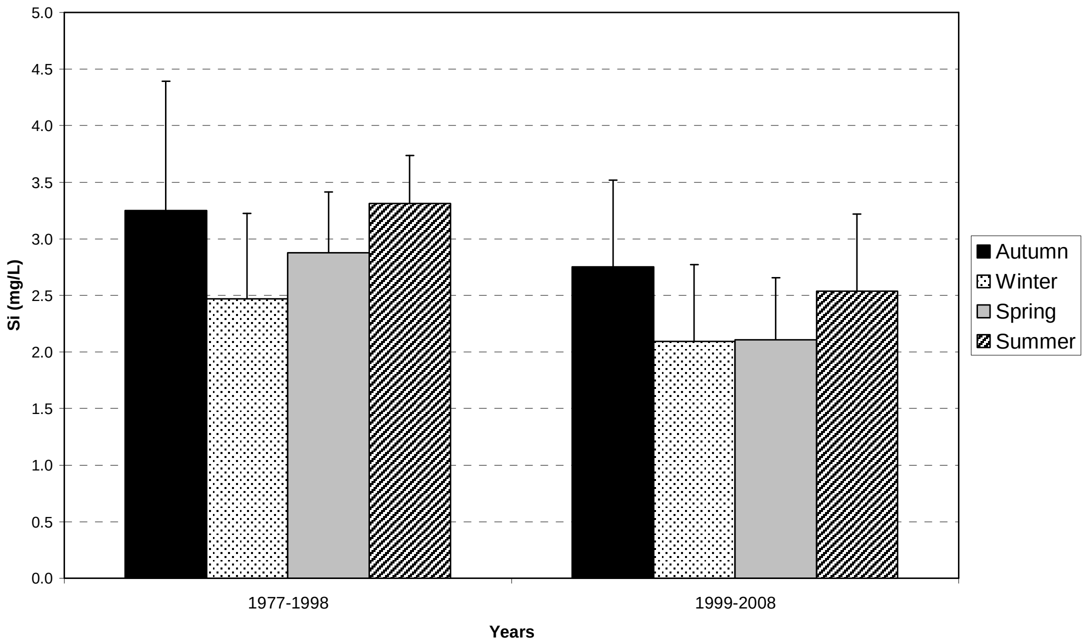

Figure 6-14: Mean seasonal silica (Si) concentrations recorded at DWAF Weir H1H013 from 1977–1998 compared with mean seasonal values recorded from 1999–2008. Error bars show standard deviation in measurements for each season.

6.5 ALGAE / PERIPHYTON

Periphyton is the slimy coating found on riverine substrates that consists mainly of algae but includes fungal and bacterial matter. Periphyton accumulation is affected by flow rates, particularly fluctuations in flow, as well as by the availability of nutrients and by temperature (Biggs & Kilroy 2000, Biggs 1995, Hildrew & Giller 1994). Periphyton is the base of many food chains, including those of open-canopied shallow rivers, maintaining the higher trophic levels of organisms such as macroinvertebrates, and fish that feed on these invertebrates. At high densities, however, periphyton may reduce habitat quality to the extent that it no longer supports the biota that inhabit these reaches.

In riverine ecosystems, international and local studies have shown that seasonal cycles of biomass accrual and loss typically occur in benthic algae, with peak biomass in late summer / early autumn (i.e. February to March or April) and again during the spring (i.e. October), with intervening periods of moderate to low biomass (e.g. Ewart-Smith 2007, Biggs 2000, Biggs *et al.* 1998, Biggs 1996, Young and Huryn 1996). Community structure is also expected to show seasonal change, from a dominance of diatoms during the winter when flood disturbance is frequent and temperatures are low, through to a dominance by green algae and a significant contribution by blue-green algae during the summer when temperatures are higher, day length is at a maximum and flow is stable, a pattern demonstrated in the upper Berg River (Ewart-Smith 2007).

A change in low flows may affect algae in a number of ways, for example by influencing the supply rate of nutrients to algae, determining water depth and turbidity which affect light penetration, and by altering biotope characteristics. These are all factors which determine algal productivity and community composition. Mean, maximum and minimum daily temperatures may also be affected by changes in low flows, which in turn affect the rate of metabolic processes and thus algal growth rates.

Although in its infancy in South Africa, study of the structure and taxonomic composition of the periphyton assemblage may provide additional insights into the overall ecological integrity of a river reach and is considered internationally as an important component river monitoring. For example, some algae proliferate more than others under enriched conditions; some groups are more palatable to grazers and thus the relative proportions of these groups will determine the quality of resources supporting macroinvertebrate fauna.

The recorded presence or absence of periphyton taxa in the Koekedouw River during the previous 5-year monitoring programme provided useful clues of flow and water quality changes in the system downstream of the dam that were not always apparent from the other bioassessment indicators. However, the lack of both biomass data and a more quantitative data relating to the taxon composition complicated the interpretation of these biotic responses to flow-related changes downstream of the dam. Consequently, the need for a more quantitative approach to establishing periphyton biomass and composition was identified, which will act as an early indicator of the efficacy of the Ecological Reserve in maintaining higher levels of the food chain (such as macroinvertebrates and fish that feed on these invertebrates). The biophysical baseline assessment of the Koekedouw River downstream of the Greater Ceres Dam that was undertaken in December, therefore, included a quantitative evaluation of the periphyton communities at three sampling sites. One of the key indicators of flow related changes in periphyton community structure and biomass characteristics is a change in the seasonal pattern of biomass accrual and loss in response to the hydrological regime. Although this assessment should ideally have included multiple sampling occasions over more than one season to address this issue more appropriately, the biophysical baseline assessment of the Koekedouw River downstream of the Greater Ceres Dam was limited to a once-off quantitative evaluation of the periphyton communities at three sampling sites in December 2008.

6.5.1 Methods

Replicate samples of the periphyton covering submerged stones in run biotopes were collected by brushing and scraping five stones at each of three main sampling sites (Sites B3, B1 and W, as described in Table 6-1). Periphyton was removed from each stone by scrubbing until no change was seen in the colour of the rinsing water. Samples were stored on ice in the field. In the laboratory, each sample was blended, and a 30 ml sub-sample extracted and preserved in 0.5 ml of Lugol's solution for identification and enumeration of algal taxa. The remainder of each sample was divided into two portions for the measurement of two biomass indicators (standardised to mg/m^2), namely the ash free dry mass (AFDM), which represents the total organic matter associated with the biofilm layer, and Chlorophyll *a* (Chl *a*), which represents the biomass of photosynthetic component of the biofilm, namely periphyton. Methods used for these processes and the relevant equations are described in detail by Biggs & Kilroy (2000).

The total dry mass of the biofilm was measured on filtered samples dried at 60 ºC for 1 hour. The samples were then ashed in a furnace at 400 ºC for 4 hours. The difference between the dry mass and the mass of the ashed sample is the organic component (i.e. AFDM) of the biofilm.

For each sample, chlorophyll was extracted with methanol, and boiled at 70 ºC for 3 minutes to increase extraction efficiency and to fix the chlorophyll by destroying the enzymes. Absorbance was measured at a wavelength of 665 nm with a spectrophotometer, corrected for phaeopigments. Background absorbance was measured at 750 nm. The difference between the absorbance at 665 nm and background absorbance was used to calculate Chl *a* content.

An improved Neubauer Haemocytometer with chamber depth of 0.1 mm was used for enumeration of periphyton during identification. A glass cover slip was placed on the grid areas of the haemocytometer ensuring that one edge of the cover slip was just over the lip of the haemocytometer furrow. A portion of each subsample was drawn into a Pasteur pipette and spread under the cover slip by capillary action when the tip of the pipette was placed on the furrow near the edge of the cover slip. The cells in a total of four complete 9 mm^2 grids were identified using the keys in Taylor *et al*. (2007), Bate *et al*. (2004), Cox (1996), Prescott (1970), and Collins (1918). Cells were counted using a compound light microscope at 400 times magnification, and enumerated using the following equation:

$$\text{Cells per ml} = [(\text{Counted cells}/(\text{area counted} \times \text{depth of chamber})) \times 1000] \times \text{Dilution}$$

The total number of algal cells per taxonomic group per sample was calculated by multiplying the number of cells per ml by the total volume of the periphyton sample collected in the field.

A regression equation for stone surface area has been developed (Freshwater Consulting CC, unpublished data) which relates surface area to the x, y and z axes of stones, since the latter are more easily measured in the field. The regression equation between surface area and stone dimensions used in this study was:

$$y \text{ (surface area in cm}^2) = 0.014x + 33.819\,(xy + xz + yz)$$

The dimensions of each stone were measured as the longest axis (i.e. x), the longest horizontal axis perpendicular to x, (i.e. y) and the longest vertical axis of the stone (i.e. z). Surface areas in cm^2 were converted to m^2 for further analysis.

The statistical significance of differences in the mean AFDM and Chlorophyll *a* <u>densities</u> between the three periphyton sampling sites was evaluated by means of ANOVA, or where normality could not be achieved, Kruskal-Wallis analysis of variance, with a probability value of $P<0.05$ taken to indicate statistical significance. The statistical significance of the differences in the mean densities of the main algal Divisions was also evaluated at the three sampling sites using these statistical tests.

The relationships between the algal <u>communities</u> collected at three sampling sites (i.e. Sites B1, B3 and W) were investigated using the Primer package, described in Section 6.3.2. Patterns in community structure were represented in two-dimensional space by means of cluster analysis (classification) and ordination (multi-dimensional scaling, or MDS), both based on the triangular matrix of similarity/dissimilarity coefficients computed between pairs of samples for each data set analysed. In addition to these basic Primer analyses, the ANOSIM routine in PRIMER was used to test for significant differences between groups of samples identified *apriori*, and the SIMPER routine was used to identify species contributing to these differences. SIMPER is computed on the initial triangular similarity matrix in PRIMER. This analysis produces a breakdown of average s*imilarity within* groups (i.e. representative species of each group), as well as a breakdown of average *dissimilarity between* groups, into differential contributions from the various species, ordered in decreasing contribution. In this way the ‘n’ species contributing the first 50 % of dissimilarity between two groups of samples, for example, could be identified. The SIMPER results also include a term indicating, for each discriminating species, the ratio between the average dissimilarity of that taxon between the two groups, and the standard deviation of that dissimilarity. In other words, a taxon with a high ratio of average / standard deviation would indicate that it is consistently dissimilar (across all the samples within a group) and thus a good discriminating species between the two groups.

6.5.2 Findings and discussion

Biomass

Periphyton AFDM is not a very reliable indicator of benthic algal biomass, since it incorporates any organic matter accumulating on the stone surfaces, both living and dead, including bacteria, fungi and potentially tiny insects that were not first removed before the stones were scrubbed. This variable should, therefore, be regarded more as a measure of the overall organic matter associated with stone surfaces than as a measure of the algal biomass. The Chlorophyll *a* (Chl *a*) concentration, on the other hand, provides a better estimate of the amount of live algal matter present and was therefore used in this assessment to report on biomass characteristics measured in December 2008.

Although Chl *a* concentrations were not significantly different from site to site (ANOVA $p > 0.2$), mean Chl *a* concentrations recorded in the Koekedouw River ranged between 5.0 mg/m^2 at site B3 and 9.0 mgm^{-2} at B1 (Figure 6-15) during December 2008. Compared with the unimpacted upper Berg River where mean Chl *a* concentrations for December are consistently around 1.5 mg/m^2 (J. Ewart-Smith, Freshwater Research Unit, UCT, pers. comm.), these results suggest that the system is severely impacted by algal proliferation. Even the Molenaars River, which has a natural flow regime but is enriched by trout farm effluent shows Chl *a* concentrations around 2 mg/m^2 during December. Higher values for Chl *a* are recorded, but only in late summer in these systems, with maxima in the Molenaars River of 12 mg/m^2 (J. Ewart-Smith, Freshwater Research Unit, UCT, pers. comm.), whilst in mountain and foothill streams across the region, Chl *a* values measured at the time of peak biomass (i.e. March, not December) never exceeded 5 mg/m^2 (Freshwater Consulting Group, TMG aquifer monitoring, unpublished data).

The DWAF water chemistry data demonstrate increases in nutrient concentration over the past two decades, but despite this the Koekodouw River below the dam is generally unenriched with generally low

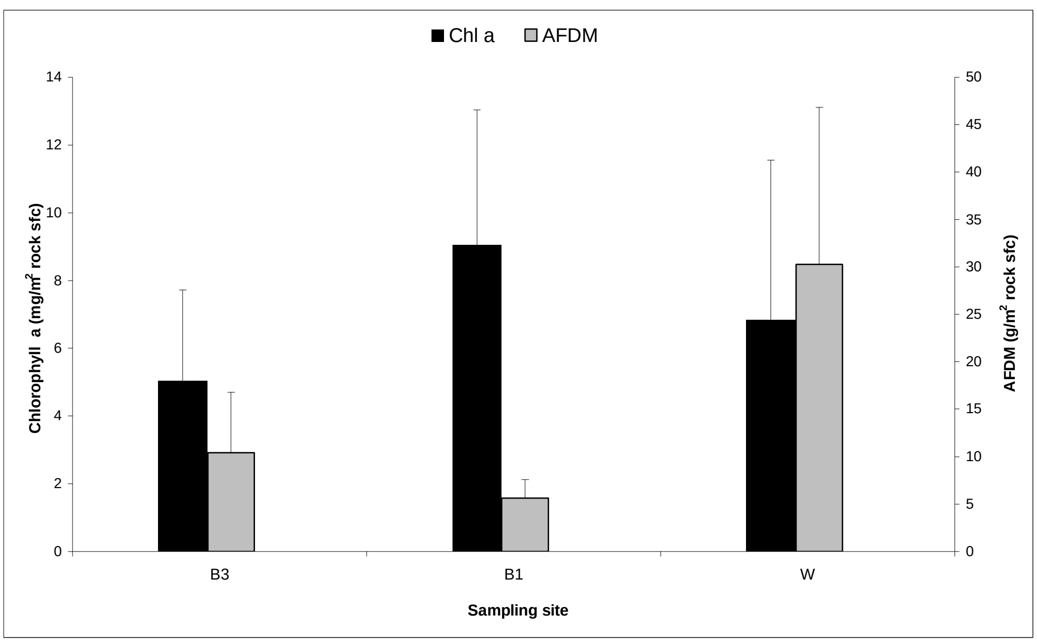

Figure 6-15: Chlorophyll a (Chl *a*) concentration and ash free dry mass (AFDM) of periphyton samples collected along the Koekedouw River in December 2008, expressed as mean ± standard deviation for each site. Note the different units used for the Chl *a* and AFDM.

SRP and TIN (see section 6.4). Algae cannot proliferate excessively under low nutrient conditions, and this may explain why the Chl *a* values are still within the range for oligotrophic systems, based on New Zealand Guidelines as illustrated in Table 6-7.

Table 6-7 Median Chlorophyll *a* (mg/m^2) and AFDM (mg/m^2) calculated from monthly samples for a year in four oligotrophic, six mesotrophic and six eutrophic gravel/cobble bed rivers in New Zealand (taken from Biggs 1995).

	Median Chlorophyll *a* (mg/m^2)	Median AFDM (mg/m^2)
Oligotrophic	1.7	150
Mesotrophic	21	480
Eutrophic	84	1500

Despite falling within the range of oligotrophic systems, the algal biomass is high relative to pristine systems because some biomass can accrue with low levels of nutrient enrichment where flood frequency is also low. It is therefore postulated that the higher than expected Chlorophyll a, representing unnaturally high algal biomass, is a reflection of a lack of scouring flows rather than reflecting a water quality problem in the river.

While Chl *a* may be a better measure of algal biomass and therefore a useful indicator of trophic state per se, AFDM provides a measure of the accumulation of organic matter, which is largely controlled by the flow of a system. AFDM may therefore be a useful indicator of the effects of the flow patterns that have been released from the dam. Significant differences in the biofilm ash-free dry mass (AFDM) were found between sites in December 2008 (ANOVA $F = 7.779$, $p = 0.007$). AFDM at Site W was some threefold that at B3 (closest to the dam) or B1, the latter recording the lowest AFDM (Figure 6-15). Average periphyton AFDM values ranged from 5 to 30 g/m^2. These values are between ten and thirty times the typical late spring to early summer values that have been recorded for organic matter in unimpacted mountain stream sites on the Berg and Molenaars Rivers which vary between 0.5 and 1.0 g/m^2 AFDM. While proliferations of algal biomass may be somewhat limited by the availability of nutrients in the Koekedouw River, the excessive accumulation of AFDM recorded in December 2008, provides a key indication that the system is severely impacted in terms of flow alternation and specifically, by the loss of small to medium sized floods which are responsible for removing excess accumulations of organic matter.

While Chl *a* and AFDM measured at all three sites generally suggest that the Koekedouw is impacted with regards to flow alterations, inter-site differences may be a consequence of localised substratum and base flow conditions that vary between these sites. For example, the channel dimensions at Site B1 may account for the lower AFDM and somewhat higher Chl *a* at this site: at Site B3 the river is braided, flowing in two or more channels between small vegetated instream bars. This increases the surface area of the flow, simultaneously reducing flow rates and therefore scour. The cobble substrata at Site W occur generally in more sheltered flow areas, whilst the fastest flow there is over bedrock, whilst at Site B1 the river is a single thread, cobble channel, and this may account for its somewhat more scoured bed. Also, the concentration of flow into a narrower channel means that velocities – which determine the rate of supply of nutrients – would be higher at Site B1. This might then stimulate better algal growth under low flow conditions.

These and possibly other localised differences in habitat may take on a higher level of importance in determining periphyton biomass and community where reach-level processes such as floods are removed. Under natural flow conditions where organic matter accumulation is controlled by periods of high flows, these inter-site differences in organic matter would probably be overridden by the effects of these scouring floods. In more natural systems, increased differentiation of both biotope-level and inter-site biomass and community occurs over the summer flood-free period, but is absent during winter and early summer (J. Ewart-Smith, Freshwater Research Unit, UCT, pers. comm.). These differences in the Koekedouw River in December provide further evidence of the negative effects of cessation of flood events.

Community composition

Periphyton communities may be comprised of taxa from several major taxonomic divisions including the Chlorophyta (green algae), Chrysophyta (diatoms), Cyanophyta (blue-greens or cyanobacteria), and Euglenophyta. High algal species richness and a lack of dominance by one or two species are features that are generally considered to be consistent with unenriched waters, although a number of other factors may contribute to diversity.

The list of algal species collected from the three periphyton sampling sites during the December 2008 survey is presented in Annexure D. Forty-six species in all were recorded, with a somewhat poor overlap of species across sites: only eight of the 46 species were recorded at all three sites, despite their close proximity. At all three sampling sites in December 2008, the diatoms (Chrysophyta) had the highest number of species (richness) of the three or four algal divisions recorded (Figure 6-16), although absolute species number (for the Chrysophyta at Site W was double that at Site B3, closest to the dam. Site W also had a more species-rich green algal (Chlorophyta) community than the other sites and more species overall, although Site B1 supported a more diverse suite of blue-green algae (Cyanophyta) and Euglenophytes (Figure 6-16).

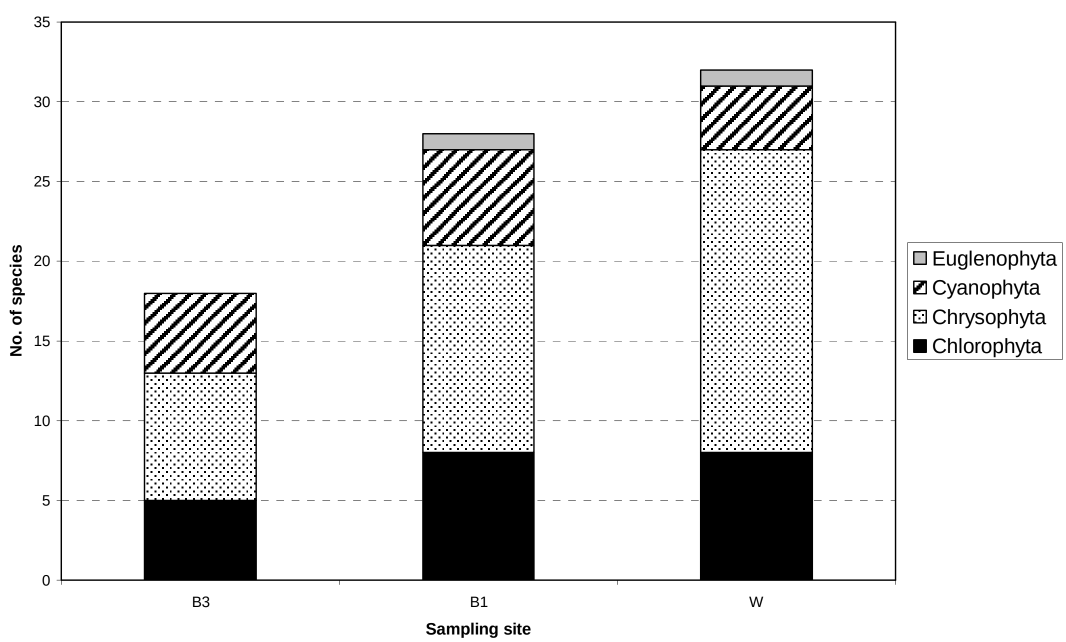

Figure 6-16: Algal species richness of periphyton samples collected along the Koekedouw River in December 2008, showing contributions by the four main algal Divisions.

In terms of algal densities, Figure 6-17 shows a different pattern: here there were significant differences in densities of the different algal divisions at Site W (ANOVA $F = 22.345$; $p < 0.001$) with strong dominance by Chrysophytes, and equal representation of Chlorophytes and Cyanophytes. Blue-greens tended to be more numerous at Site B1 than other algal divisions, although differences in cell densities were not significantly different from one algal division to another at this site. At Site B3, the green algae dominated, although differences in abundance between algal divisions were again not significant. This trend, from (non-significant) green algal dominance closer to the dam to diatom dominance at the Site W, is likely to be the consequence of an interplay of multiple factors, including flow rates, nutrient levels, and invertebrate assemblage dynamics. It emphasises the finding in the previous section of the heightened importance of localised factors in determining the biomass and composition of algae / biofilms in the absence of reach-level processes.

The individual species that comprise the samples at each of the sites were examined through multivariate analysis, in order to illustrate community differences between sites, and their possible relevance to the evaluation of the environmental flow releases.

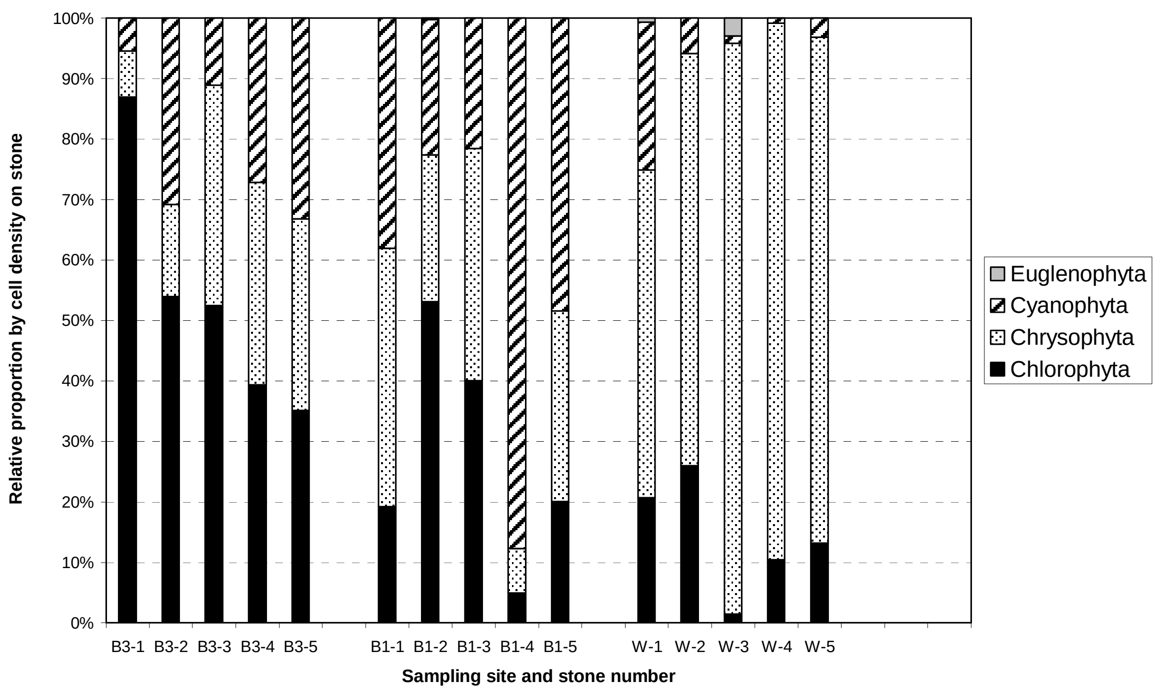

Figure 6-17: Percentage composition of the four main algal Divisions (by cell density) on stones collected at the three periphyton sampling sites (B1, B3 and W) along the Koekedouw River in December 2008. Individual replicate stones are shown rather than site averages to illustrate variability.

The results of the multivariate analyses of the algal species data are presented in Figure 6-18, a plot of the relationship between individual samples, based on multidimensional scaling (MDS). The MDS plot is fairly representative of the underlying patterns, indicated by a moderate 2-D stress value (refer to Table 6-2), but should be interpreted along with the Cluster analysis results.

Cluster analysis groupings are thus overlaid on the MDS plot, indicating groups of samples generated at similarity levels of 40% and 45%. These combined results show that the replicates from each site grouped closely together, clearly differentiating sites according to algal species community, and also that the algal community at Site W was more different from those of the upper sites B1 and B3.

SIMPER analysis identifies the taxa most characteristic of any chosen group of samples, as well as those which best discriminate between groups (see methods, section 6.5.1 for full explanation). Since the replicates from each site clustered closely together, the SIMPER groups represented each of the three sites. The SIMPER results are summarised in Table 6-8, showing average within-site similarities at Sites B3, B1 and W of 55%, 49% and 52%, respectively. This similarity was made up of the contributions of individual species as a result of their occurrence across all samples at a site. At Site B3, closest to the dam, the colonial chlorophyte *Desmococcus* sp. on its own accounted for 30% of the similarity between replicates, indicating that species was consistently present in all samples at the site. This species is generally associated with flowing, well-oxygenated habitats with low to moderate nutrient levels. *Tabellaria flocculosa*, a chrysophyte known to flourish in nutrient poor, slightly acid conditions (Taylor *et al.* 2007) accounted for a further 18% of the similarity within the site replicates, followed by the blue-green *Oscillatoria* sp.1 which is tolerant of low nitrogen conditions. The dominance of green algae, rather than diatoms at the time of the study (December) and the generally high algal biomass, compared with mid-summer data from other rivers in the region, may be a result of a long period of low and stable flow in the Koekedouw River: the fact that floods have not been released, and that spillage in 2008 did not occur, means that conditions giving rise to peak algal production and late-summer community structure, are likely to be reached earlier than would be the case naturally. Despite the fact that species richness at this site was lower than the other two sites, the particular suite of species present suggests that water quality is relatively good.

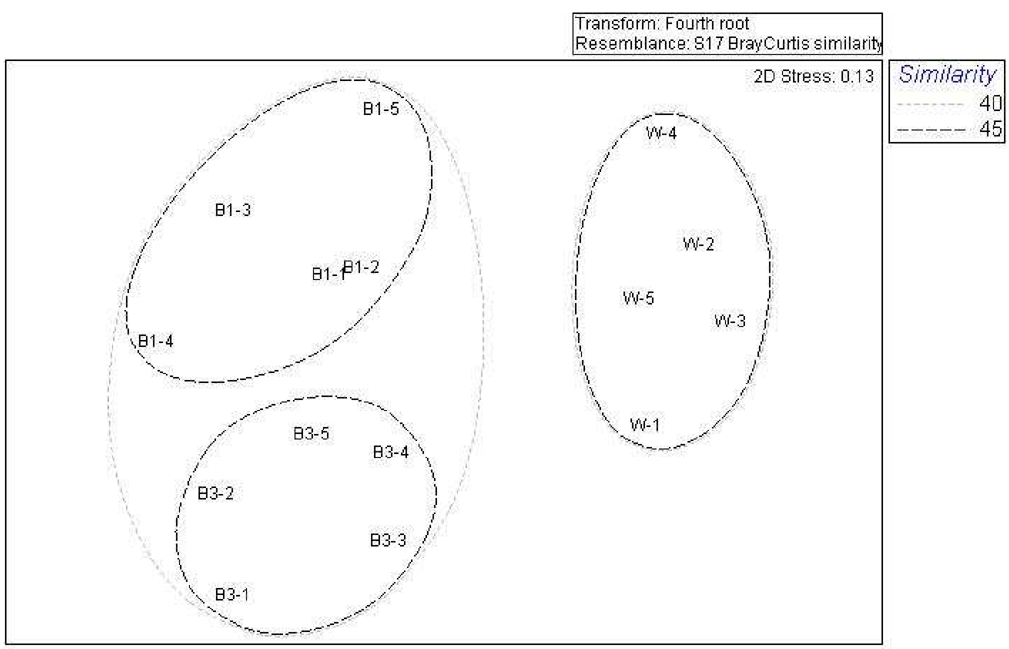

Figure 6-18: MDS diagram for algal samples collected from three sampling sites (B1, B3, W) along the Koekedouw River in December 2008, generated on the basis of the (fourth-root transformed) abundance of algal species and grouped according to the results of hierarchical cluster analysis (at similarity levels of 40% and 45%).

Although blue-greens were dominant in some samples at Site B1 (refer to Figure 6-17), the species that best characterised the community overall comprised diatoms and green algae. As with Site B3, *Tabellaria flocculosa* and *Desmococcus* sp. were prevalent across samples, along with a number of other green algae (Table 6-8). These were *Bulbochaete* sp., a filamentous chlorophyte which has the potential to proliferate under increased nutrient levels and *Cosmarium* sp., a desmid chlorophyte which is not generally found in nutrient-enriched waters. The blue-green contributing most to similarity between samples at this site was *Aphanothece* sp., a species which can thrive in nitrogen-poor waters because it is able to fix atmospheric nitrogen.

Table 6-8: Condensed SIMPER results for each group of samples, representing sites, as defined by MDS and cluster analysis. The average similarity between samples within each site group is given in brackets, as well as the taxa contributing to 60 % of within-site similarity. The taxa that were best discriminators between sites are shown as the result of pairwise comparisons. Colour-coding indicates the algal division to which each species belongs: green = Chlorophyta, Blue = Cyanophyta, brown = Chrysophyta.

Sample groups from MDS	Taxa contributing to *ca*. 60% of within-site similarity
Site B3 (55 %)	*Desmococcus* sp.
	Tabellaria flocculosa
	Oscillatoria sp.1
Site B1 (49 %)	*Tabellaria flocculosa*
	Desmococcus sp.
	Bulbochaete sp.
	Cosmarium sp.1
	Aphanothece sp.
Site W (DWAF weir) (52 %)	*Tabellaria flocculosa*
	Eunotia incisa
	Frustulia saxonica
	Gomphonema sp.1
	Frustulia vulgaris

Pairwise comparisons (average % dissimilarity between sites)	Top discriminator taxa between pairs of sites	Average density at each site (4th root transformed)		Diss / SD ratio
Site B3 vs. Site B1 (58 %)		Site B1	Site B3	
	Bulbochaete sp.	18.4	1.8	3.3
	Achnanthidium sp.	16.9	2.2	1.9
	Aphanothece sp.	21.7	0.0	1.8
	Tabellaria flocculosa	25.4	17.0	1.6
Site B3 vs. Site W (69 %)		Site B3	Site W	
	Gomphonema sp.1	0.0	17.5	4.5
	Frustulia saxonica	3.5	18.7	2.8
	Chroococcus minutus	13.0	0.0	1.9
	Frustulia vulgaris	0.0	16.8	1.8
	Eunotia bilunaris	0.0	11.8	1.7
	Tabellaria flocculosa	17.0	27.1	1.7
	Eunotia rhomboidea	7.6	16.1	1.7
Site B1 vs. Site W (67 %)		Site B1	Site W	
	Bulbochaete sp.	18.4	0.0	5.0
	Gomphonema sp.1	0.0	17.5	4.3
	Cosmarium sp.1	17.2	2.7	1.9
	Frustulia saxonica	5.3	18.7	1.7
	Frustulia vulgaris	8.2	16.8	1.7
	Aphanothece sp.	21.7	4.4	1.5

The species that best differentiate between the community at two sites (those where the ratio of Diss / SD is high) are shown in Table 6-8. For Sites B1 vs. B3, most of the differentiation came from a similar suite of chrysophyte and chlorophyte species at both sites, but with substantially higher densities prevalent at Site B1. Site B1 also supported the blue-green *Aphanothece* sp.

At Site W the top 60% of the similarity between samples was attributable to chrysophyte (diatom) species (Table 6-8). *Tabellaria flocculosa* and *Eunotia incisa* were the most dominant species, with densities that were double those of the other species. Green and blue-green algae were present but in very low densities, with the exception of the colonial *Desmococcus* sp. which was present in moderate quantities, although still only half of the densities at which it occurred at Site B1 and B3. Pairwise comparisons of the species contributing most to the differences in community structure between Site W and Site B1 and B3 respectively (Table 6-8) emphasis that the differences here are related to changes in species composition, not simply differences in relative density, e.g. *Gomphonema* sp. Indeed eight of the 18 diatom species recorded at Site W were not recorded from either of the upstream sites.

Thus whilst the shifts in community structure from Site B3 (close to the dam) to Site B1 were related largely to increases in species' densities at the latter, as was also indicated greater periphyton biomass (Chlorophyll *a* measurement) there, a qualitative shift occurred downstream at Site W. Here the species complement was substantially different, and the site was also characterised by having a AFDM three to six times greater than at the other sites, and very high by comparison with international literature (refer to Figure 6-15), a feature which *suggests* organic pollution. Despite this, Site W did record the highest number of species of all sites, and the presence of a diverse diatom community could be considered to indicate relatively good water quality, despite the periodically mesotrophic levels of nutrients in the system.

The previous monitoring programme (Ractliffe 2001) found the periphyton flora to be exclusively comprised of diatoms in the first year following dam construction, when the river received only seepage flows from below the dam, and there were no releases. As releases replaced seepage flows, green algae replaced diatoms as the dominant algal group. The return to diatom dominance at Site W in 2008 may thus be flow-related rather than suggest changes in water quality. Sampling at this site takes place immediately downstream of a weir, and flow upstream of the weir is slowed in the weir pool, spilling uniformly over a wide spillway and bedrock shelf, into a well vegetated channel. The particular site characteristics thus appear to produce slower low-flow velocities than at the other two sites.

The composition of the non-photosynthetic component of the AFDM was not examined in this study. However, flagellated protozoans were found to dominate the periphyton samples at Site W during March 2001, following two years of low flows (below the required EWR) in the Koekedouw River. Where invertebrate consumers are very low in density and / or biomass, as was the case at the weir site, then protozoans may form the dominant consumer group. This phenomenon has been observed elsewhere (downstream of the Berg River Dam, Justine Ewart-Smith, pers. comm.), but not quantified. Clearly, a failure to release adequate baseflows provides the optimum conditions for proliferation of this material – which presents as a semi-gelatinous cover centimetres-thick on the substratum particles at Site W.

6.5.3 Conclusions

The periphyton data presented here provide considerable insight into the effects of changes in ecosystem processes that have ensued with the flow regime that has been imposed on the river in the past decade. The following is a summary of the findings:

- Chl *a* as an indicator of biomass and AFDM as an indicator of organic matter accumulation both indicate that the system is impacted with regards to flow but are somewhat moderated by the availability of nutrients.
- Although Chl *a* did not differ significantly between sites, the AFDM was considerably higher at the DWAF weir site, relative to the other two sites. This could be a consequence of localised conditions at each of the three sites which, in the absence of scouring floods would promote inter-site variability.

- Similarly, the community structure varied between sites, further suggesting that, in the absence of floods that act to control periphyton communities at the reach level, localised conditions, are probably more important at structuring periphyton communities.
- Despite differences in both Chl *a* and taxon composition between these sites, the periphyton community at each site has a relatively high richness and is generally indicative of an oligotrophic system, impacted by an altered (or non-existent) flow regime.

Recommendations

Whilst the periphyton biomass / organic total density data have shown patterns that implicate flow-related impacts, continued collection of periphyton community data, with seasonal representation, should be included in a future monitoring programme, to track both changes in richness and community structure against the proper implementation of the required flow regime. Since seasonal patterns of biomass accrual and loss, and of community structure are driven by the disturbance regime to a significant degree, patterns consistent with those observed on a regional basis should emerge once appropriate flows are restored to the river.

6.6 AQUATIC MACROINVERTEBRATES

Invertebrates are an important component of biodiversity within river ecosystems, particularly within the Cape Floral Kingdom where 64% of the 300 recorded species of aquatic fauna are endemic to the region (Picker and Samways, 1996). In addition, river macroinvertebrates perform important functional roles in maintaining ecosystem integrity, including the provision of food to other faunal groups, both aquatic and terrestrial, and the removal of organic loads from the river. Most insects have an aquatic larval life stage, which is spent developing body mass and reproductive tissue from the available food resources on the stream bed, but a terrestrial adult stage. Thus the maturation of most insects is associated with an export of organic matter from the river.

Aquatic macroinvertebrates occupy a myriad of habitats within the riverscape. Their presence, survival and reproduction is predicated on the unique combination of structural features (e.g. substratum composition and flow), ambient conditions (e.g. chemistry or temperature), and biotic conditions (such as the availability of food or prey, the density of competitors or the presence of predators). All of these factors comprise each species' habitat.

Different species living within an area will always have slightly different habitats – no two species utilise the resources or respond to the conditions pertaining in a place in precisely the same way. As a result, changes to ecosystems (such as those associated with pollution, flow alteration or physical interference) represent differential shifts in the character, quality and suitability of species' habitats. Such changes, subtly or otherwise, alter the presence, survival and reproduction of one or more species, often leading to the proliferation of one species to the detriment of another.

There are several advantages to using aquatic macroinvertebrates for bioassessment (as summarised by Ollis *et al*. 2006). Briefly, aquatic macroinvertebrates are largely non-mobile, ubiquitous and relatively abundant inhabitants of rivers, occupying most habitats. There are often many species within a community with varying sensitivities to stresses and relatively quick reaction times, resulting in a spectrum of graded, recognisable responses to environmental perturbation. Macroinvertebrates have life cycles that are long enough for temporal changes caused by perturbations to be detected, but their life spans are also short enough to enable the observation of recolonisation patterns following perturbation. Therefore, aquatic macroinvertebrates are generally considered to be particularly useful organisms for monitoring programmes.

The main findings of the macroinvertebrate sampling undertaken for the initial 5-year EWR monitoring programme (1999-2004) were that the invertebrate community in the Koekedouw, already severely impacted by the combination of the old dam and its operation which reduced invertebrate densities to near zero in winter, was further degraded during dam construction as a result of heavy silt loads and other pollution. With the completion of the dam and implementation of environmental releases, there was some recovery of macroinvertebrate community structure between 2000 and 2002, which was the only period during which the EWR requirements were relatively well implemented (see this report section 5). Aside from this, the river suffered even further deterioration, between 2002 and 2004, in both the overall representation of taxa and the expected seasonal pattern in taxon richness (Ractliffe & Ewart-Smith 2004). These results coincided with periods of inadequate flow releases from the Greater Ceres Dam, particularly the winter base flows and flood/freshet events.

The December 2008 survey for this report included the collection of aquatic macroinvertebrates at the same sampling sites established for the earlier 5-year monitoring programme, using similar sampling methods, so that an indication could be obtained as to whether the integrity of the macroinvertebrate communities has improved or deteriorated further. These sites were the same as for the periphyton sampling, but including a site even closer to the dam, Site B4, where SASS5 data only were collected for comparison with the historical data. In addition, collected samples from Sites B3, B1 and W were returned to the laboratory for species enumeration, so that species lists and a semi-quantitative record of abundance could be initiated and for analysis of community structure.

6.6.1 Methods

Both the original situation assessment of the Koekedouw River undertaken as part of the EIA in 1995 and the 5-year monitoring programme undertaken subsequent to the construction of the new dam made use of the rapid macroinvertebrate-based bioassessment method known as the South African Scoring System (SASS). While the macroinvertebrate sampling for these earlier assessments was not undertaken according to biotope, the baseline survey undertaken in December 2008 was conducted according to the stipulated protocol for SASS Version 5 (or SASS5) whereby separate samples are collected from three biotope groups, namely (1) stones, (2) vegetation and (3) gravel/sand/mud (GSM).

The SASS5 method is described in detail in Dickens & Graham (2002). SASS5 involves kick-sampling to disturb the stream bed so that invertebrates are dislodged from the substratum and vegetation, and retained in a hand-held 950 µm-mesh net (attached to a 300mm x 300mm frame). The sample from each of the three biotope groups is placed in a basin and all the taxa identified, at the level of invertebrate family. Each invertebrate taxon has a pre-asigned SASS “sensitivity score” based on its general susceptibility to or tolerance of pollution, on a scale of 1 to 15, with sensitive taxa being assigned higher scores. Interpretation of the sample results is based on two values: the SASS5 Score, which is the summed sensitivity scores of all taxa present, and the average score per taxon (ASPT), which is the SASS5 Score divided by the number of taxa.

SASS5 results from the December 2008 survey were interpreted and compared with previous summer sampling results using the draft SASS data interpretation guidelines developed by Dallas (2007). These interpretation guidelines assign a site into one of five “Ecological Categories” (from A to E/F) on the basis of the combination of its SASS5 Score and ASPT. The thresholds of SASS5 Score and ASPT used to defined categories are different for each Ecoregion, with upland and lowland sites for most Ecoregions treated separately. The ecological categories align with the ecological status categories used by DWAF (Table 6-9), to facilitate generalisations regarding the state of the river. The relevant data interpretation guideline values in the case of the Koekedouw River within the study area were those generated for upland sites in the Western Folded Mountains Ecoregion.

Because the collection of SASS samples follows a reasonably strict protocol, the samples are regarded as semi-quantitative, and allow for comparison of abundance differences and species assemblage structure changes between sites. The samples were processed under microscope in the laboratory for identification and enumeration of the species present. This information is useful in long-term monitoring programmes, as it provides more detailed insight into the changes in species, which might occur before major changes in the coarser-level SASS data are identified. Analysis of invertebrate assemblage data was undertaken using the PRIMER multivariate statistical package, described in Section 6.3.2.

Table 6-9: Description of Ecological Categories (from Dallas 2007)

Ecological Category	Ecological State	Description
A	Natural	Unmodified natural
B	Good	Largely natural with few modifications
C	Fair	Moderately modified
D	Poor	Largely modified
E/F	Seriously to critically modified	Seriously to critically/extremely modified

An assessment of the quality and diversity of habitat available for macroinvertebrates was undertaken at each sampling site using a slightly modified version of the Invertebrate Habitat Assessment System (IHAS) (McMillan 1998), as included in the Site Characterisation Manual developed for the River Health Programme (Dallas 2005). The IHAS scoring system provides individual scores for the stones-in-current (SIC) and vegetation biotopes, as well as for “other habitats” including stones-out-of-current, and gravel, sand and mud.

6.6.2 Results and discussion

SASS5 assessment

The SASS5 results from the December 2008 survey are summarised in Table 6-10, with separate scores for the various indices provided for each of the three SASS5 biotopes and for each site as a whole. The designated Ecological Category for each site, based on the interpretation guidelines (Table 6-9) is also given. Overall, these results indicate largely modified conditions at Sites B1 and W (Ecological Category D, but bordering on Category E/F), and seriously to critically modified conditions closer to the dam, at Sites B3 and B4 (Ecological Category E/F).

A comparison with the historical (summer only) data collected during the first monitoring period is presented in Figure 6-19. This shows very poor SASS results in the initial years (2000) after dam construction, when the aquatic macroinvertebrate fauna were more than likely still recovering from the

Table 6-10: SASS5 results from December 2008 survey, showing scores recorded for individual biotopes and overall scores at each sampling site

		Sampling site			
		B4	**B3**	**B1**	**W**
Stones	SASS5 Score	38	46	64	34
	# Taxa	8	10	14	7
	ASPT	4.8	4.6	4.6	4.9
Vegetation	SASS5 Score	32	28	28	39
	# Taxa	6	7	8	7
	ASPT	5.3	4.0	3.5	5.6
GSM	SASS5 Score	-	4	7	7
	# Taxa	-	1	3	2
	ASPT	-	4.0	2.3	3.5
Overall	SASS5 Score	50	56	71	54
	# Taxa	10	12	15	10
	ASPT	5.0	4.7	4.7	5.4
	Ecological Category	**E/F**	**E/F**	**D**	**D**

construction impacts associated with the new dam. A marked improvement was recorded at all sites during 2001 and 2002, when the river regained a high Class D or a Class C ecostatus, which coincide with the years that flow releases were attempted in earnest. Those results suggested than that the Koekedouw had the potential to recover if adequate flows were maintained in the river, but that recovery to the reference condition (Site C in Figure 6-19) observed in 1995 was far from complete.

The years 2003 and 2004, however, were associated with declining SASS5 Score : ASPT ratios, and all sites feel into a Class D or even a Class E/F Ecostatus. It is noteworthy that the latter is not considered an acceptable standard for the management of any water resource, in terms of the South African Water Act, and is certainly far from the Class B that was set as the required ecosystem management class when the EWR was devised.

Worse still, the 2008 data indicate scores that are commensurate with those right at the start of the initial monitoring programme, immediately after the impacts associated with dam construction, and prior to any environmental flows being released into the river. The entire study reach of the Koekedouw River was shown to be in a severely degraded ecological state, with a highly impoverished macroinvertebrate fauna, both in terms of overall diversity and in terms of the complement of taxa recorded, with few of the more sensitive families represented in the samples. Site B1 was associated with the highest SASS5 Score and Site W the highest ASPT, although both of these sites fell into a low Class D Ecostatus (Figure 6-19).

Physical conditions in the river constitute the major features of invertebrate habitat, and both directly and indirectly are strongly influenced by flow. The habitat at Site B1 was of higher quality than at the other three sampling sites, with more areas of faster flow and slightly less embeddedness of riffle habitat by sediment and organic matter. Indeed, the SASS5 Score and number of taxa recorded within the Stones biotope were significantly greater at Site B1 than they were within this biotope at the other sites (Table 6-10). Notwithstanding, both site observation and IHAS scores indicate that instream habitat in the Koekedouw River is presently characterised by high levels of sediment and organic matter both on the

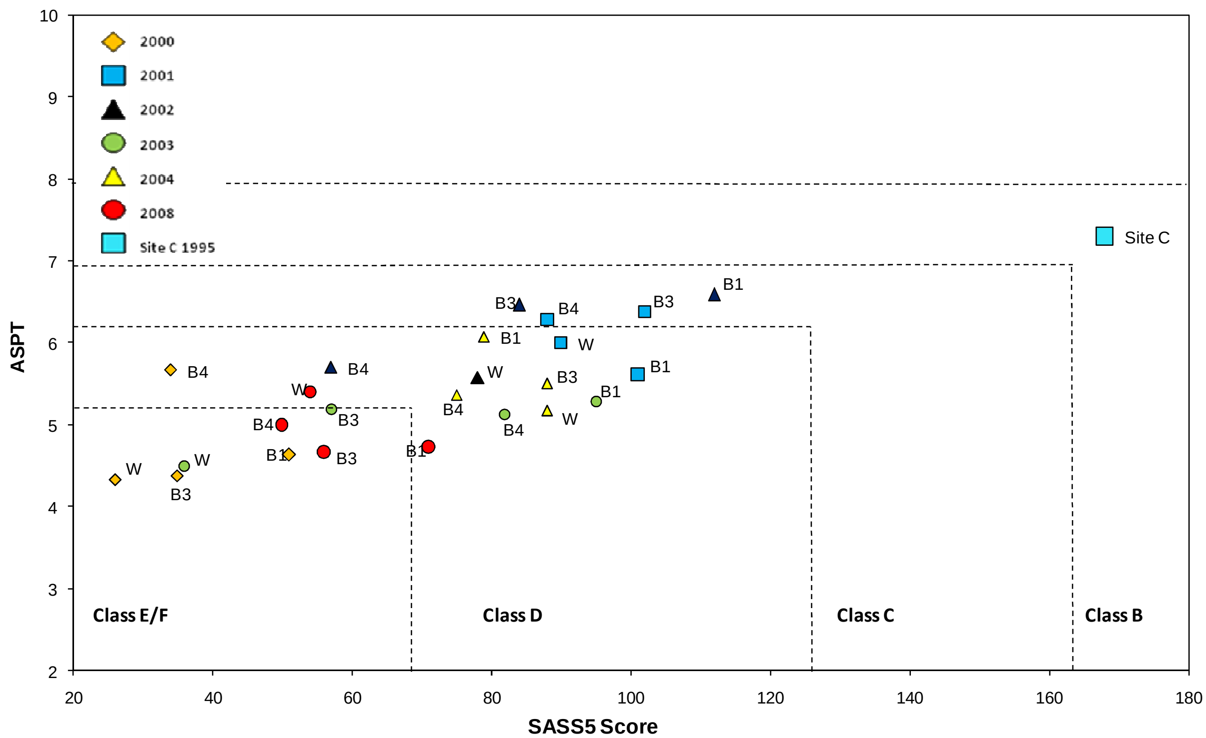

Figure 6-19: Summer SASS5 Scores and ASPT values recorded at sampling sites along the Koekedouw River between 1994 and 2008. The years of sampling are colour coded and sites labelled. The bands associated with Ecological Categories (A to E/F) for upland sites in the Western Folded Mountains Ecoregion are also shown. Site C = a site in the river downstream of the dam between B3 and B1, sampled prior to construction of the Greater Ceres Dam.

bedrock / cobble surfaces and in the interstitial spaces, severely reducing the quality of habitat for more sensitive insects, whilst providing for an abundant supply of organic matter on the bed and in transport in faster-flowing portions.

Assessment of macroinvertebrate community structure

At three of the four SASS5 sampling sites along the Koekedouw River, macroinvertebrate samples were collected from each SASS5 biotope group for identification down to the lowest taxonomic level possible (generally species or morpho-species). These were Sites B1 (at Bridge 1), B3 (at Bridge 3) and W (at the DWAF Weir). Across all three sites there were 50 different taxa (combining larval and pupal forms of some taxa), which represents a moderate degree of species richness. If the Chironomidae taxa are excluded, however, the overall species richness drops to 35, which is not very high. The full species list is included in Annexure E.

The results of multivariate analysis of the species data from each of the biotopes sampled in December 2008 are presented in Figure 6-20. Cluster analysis groupings are overlaid on the MDS plot, indicating groups of samples generated at similarity levels of 20% (green line) and 40%(blue line). Samples from each biotope grouped fairly closely together, although at Site B1 the Veg biotope sample was more similar to the Stones samples than the other Veg samples, and the GSM at Site B3 formed an outlier

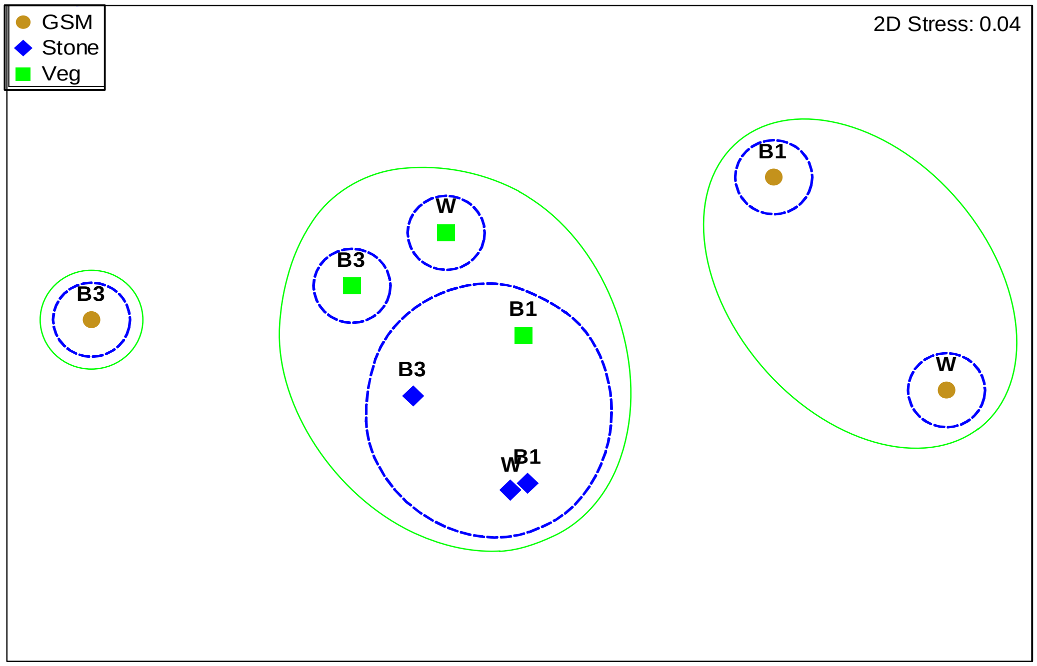

Figure 6-20: MDS diagram of aquatic macroinvertebrate species recorded in the stones, vegetation (veg) and gravel/sand/mud (GSM) biotope groups at sampling sites B1, B3 and W in December 2008, generated on the basis of (4th root) transformed abundances. Groups are delineated according to the results of hierarchical cluster analysis (at levels of 20% and 40% similarity, as indicated by the solid green and dashed blue lines, respectively).

The factors contributing most to the observed groupings, based on SIMPER analysis were the higher levels of diversity and greater abundances of all taxa differentiating these groups in samples from the Stones biotope at all sites and the Veg biotope at Site B1, with very low numbers in the GSM biotope (Figure 6-21). Figure 6-21 shows the estimated abundances of invertebrates from each biotope at each site. In comparison to data collected in the same manner, from 17 natural mountain streams between Tulbagh and Kleinmond in December 2008, the abundance values recorded in the Koekedouw River were higher than anticipated (abundance in that data set were on average 180 individuals per sample) but not greater than the maximum values recorded in that study (TMG_EMA 2009 in prep) and similar to abundance values obtained in the Palmiet River downstream of Arieskraal Dam (Ractliffe 2009). An important aspect of these numbers, however, was the composition of the samples. In the TMG_EMA study, for example, Dipterans (true flies, the hardiest of the insect orders) accounted for on average only 10% of the total abundance, whilst in the Koekedouw River this was much greater. Figure 6-22 shows the composition by major invertebrate Order of the samples from the Stones biotope at each site. Here Site W was noteworthy for the dominance there of Diptera which comprised 92 % of the sample. The other two sites were more even in composition, with better representation of especially Coleoptera and Trichoptera (Figure 6-22). Ephemeroptera, usually a well-represented group in upland rivers, were conspicuous by their low numbers and diversity. Both Simuliidae (blackfly) and Chironomidae (non-biting midges) contributed predominantly the Diptera at all sites. These are groups which may reach pest proportions where suspended or deposited organic matter respectively is abundant, and their increase in representation with distance from the dam correlates well with the increases observed in organic matter in Section 6.5.

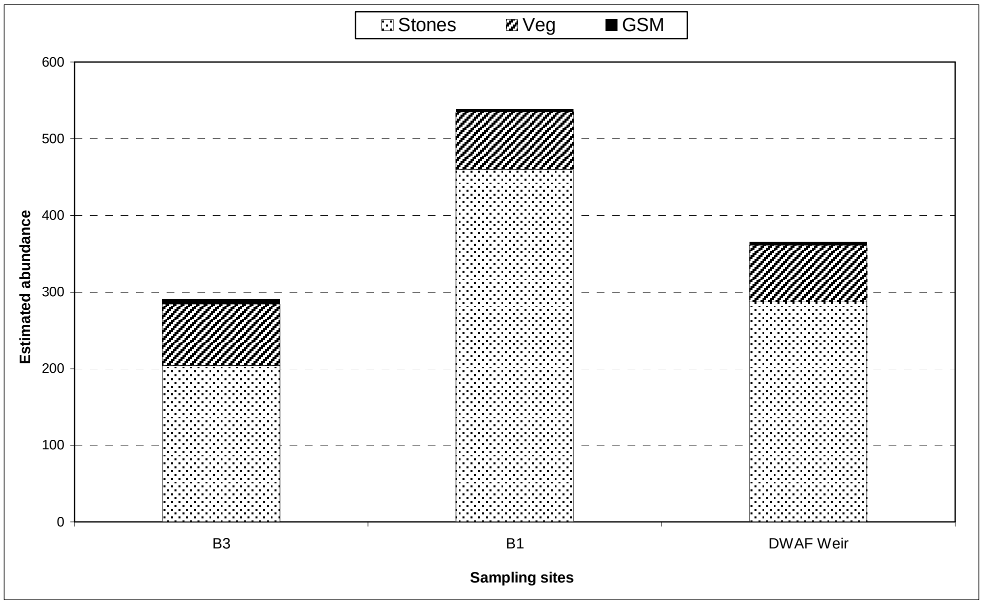

Figure 6-21: Estimated abundance of aquatic macroinvertebrates in the Stones, Vegetation (Veg) and Gravel/Sand/Mud (GSM) samples collected from Sites B1, B3 and DWAF Weir in December 2008

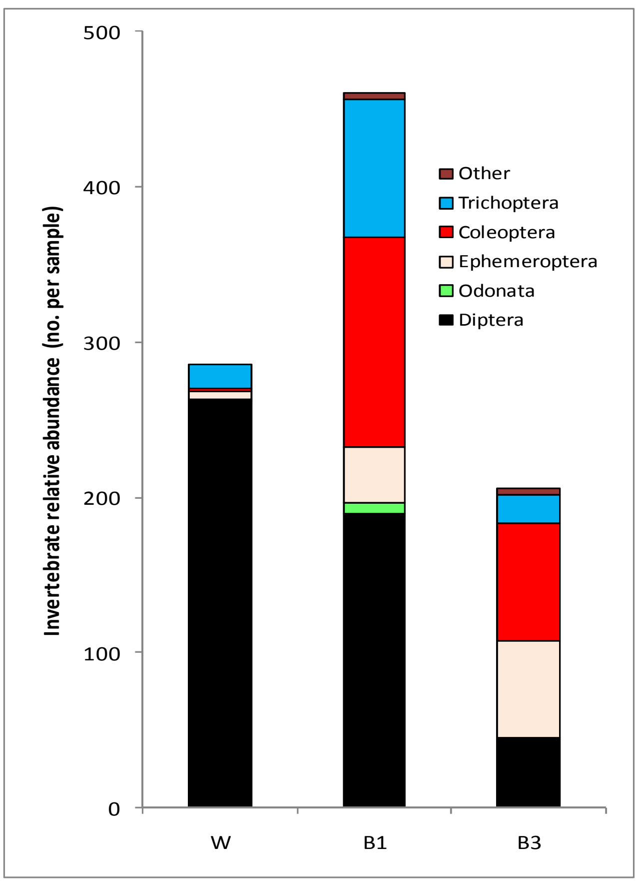

Figure 6-22: Relative abundance of aquatic macroinvertebrates in the Stones biotope, by insect Order.

The Koekedouw River samples had between 22 and 31 species, with richness greatest in the Stones biotope, followed by the Vegetation biotope, with the GSM biotope having the lowest diversity by far. The Chironomidae (Diptera) were the most species-rich family at all three sites, with 14 different taxa in total, followed by beetles (Coleoptera) and caddisflies (Trichoptera), with nine and six taxa respectively. The diversity of chironomid species is high – for example in comparison with the TMG_EMA (in prep) study, where total dipteran species accounted for under 30 % of the sample. This could be the result of a greater amount of lentic (i.e. standing water) habitat being prevalent for large parts of the year, relative to the natural state of the river, as a result of significantly reduced flows in the Koekedouw River. This would provide an opportunity for populations of chironomid species that are more commonly associated with lentic habitats to establish themselves, together with populations of species more commonly associated with lotic (i.e. running water) habitats but that tend to dominate in systems with low to moderate flows and low levels of seasonal flow variability. Also, where algal growth and organic matter are high, periodically low oxygen levels may result, to which many species of chironomid are well adapted. Coleoptera (beetle) species were only collected from the Stones and Vegetation biotopes, with none in the GSM samples.

Most of the Trichoptera taxa were from the Hydropsychidae family (fixed shelter caddis flies), which were abundant in samples from the Stones biotope but, as would be expected, were sparse in the Vegetation samples and absent from the GSM samples. These animals are net-spinning filter-collectors, which thrive in areas where suspended materials such as dead algae, colloidal material and detritus which make up the bulk of their diet are abundant. As such, they are often present in relatively high numbers below dams because dams are generally exporters of such material. However, where flows are very low, this may inhibit transport of organic matter in suspension, which will limit hydropsychid numbers. *Cheumatopsyche* tends to prefer slightly slower current speeds than most other hydropsychid species, and the failure to release any but the lowest flows in the Koekedouw River from the dam may therefore explain the dominance of *Cheumatopsyche maculata* in the samples, whilst *Macrostemum capense*, previously encountered along the full length of the river, was restricted to the Weir site. Abundances at all sites were nevertheless high.

Table 6-11 is reproduced from the final report of the first 5-year monitoring programme (Ractliffe & Ewart-Smith 2004). This indicates the changes in some of the more sensitive insect families that took place over the period 1998 to 2004, tracking both recovery after the dam construction phase as a result of the release of flows close to the required EWR, and subsequent decline as these efforts petered out. The 2008 species list (Annexure E) is based on processing of whole samples, not simply individual specimens picked from the field, and thus would automatically have a substantially better representation of particularly the more cryptic species, for example among the Chironomidae, and of small animals that would be overlooked in field-based collections (rather than laboratory-sorted samples). Despite this, the data show a continuation of this decline in condition, evidenced by the absence of sensitive taxa characteristic of mountain stream and foothill river, such as Plecoptera, Telogonodidae, Leptophlebiidae, and Athericidae. Only two species of Baetidae were present, these the only species of mayfly (order Ephemeroptera) represented. The Leptoceridae, although its members are not of high sensitivity, have always been a significant presence in the samples from almost all sites (per obs.) and these were reduced to only two individuals during the 2008 sampling. Very few predator taxa were recorded in the samples collected from the Koekedouw River in December 2008. For example, across all three sampling sites, there were very low numbers or no Corydalidae (Order Megaloptera), Hemipterans (“true bugs”) in general, predaceous trichopterans such as Philopotamidae and Ecnomidae. This further highlights the severely impacted current ecological state of the aquatic macroinvertebrate communities downstream of the Greater Ceres Dam.

Two species of the Platycnemididae family of damselfies (order Odonata) were collected at Site W in December 2008, considered to be *Metacnemis angusta* and *Platycnemidae* sp. The former is listed in the IUCN Red Data List as Vulnerable (Samways 2007), and was thought to be extinct until a population was identified in the DuToits River near Villiersdorp. The “Ceres Featherlegs”, as the name suggests, has been found in the Ceres region and is under threat because of water abstraction through dams, and invasive species such as alien riparian trees and introduced fish (particularly trout). The identification of one individual of this species suggests that a population of *Metacnemis angusta* may be present in the Koekedouw River, but this requires confirmation.

Table 6-11 **Summary of key taxa that indicate the extent of recovery or deterioration in macroinvertebrate community structure in the Koekedouw River between 1998 and 2004, where - = deterioration, 0 = no change from previous year and + = recovery.**

Key Taxa expected (based on species list prior to dam construction)		**Autumn 98 - Summer 99**		**Autumn 99 - Summer 00**		**Autumn 00 - Summer 01**		**Autumn 01 - Summer 02**		**Autumn 02 - Summer 03**		**Autumn 03 - Summer 04**	
LEPTOPHLEBIDAE	MAYFLIES	Not present	-	Not present		Present at B1 in autumn & winter	+	Present at B1 in autumn	+	Not present	-	Not present	0
TELAGANODIDAE		Single individual at B3 & B1 respectively in winter	-	Single individual at B3 in spring	0	Single individual at B4 in spring	0	Present at B4 & B3 in Spring 2001	+	Not present	-	Not present	0
BAETIDAE		Only 1 sp. throughout season at B3 & weir only except summer when 2 species present at B3.	-	2 spp. widespread in all seasons at all sites with 3 spp in autumn & winter at B1	+	3 or 4 spp. widespread in all seasons at most of the sites	+	4 or 5 spp. widespread in all seasons at all sites	+	3 or 4 spp. widespread in all seasons at most of the sites	0	2 or 3 spp widespread in all seasons except winter when 4 spp at B1 & weir and 5 spp at B3	-
CHORYDALIDAE	TOE BITERS	Not Present	-	Not Present		Not Present	-	Widespread in all seasons at all sites	+	Present at B1 only, except autumn when present at B1 & B4	-	Present at B1 only, except summer when present at B1 & B4	0
PLECOPTERAN	STONE FLIES	Not present	0	Not present	0	Not present	0	Not present	0	1 individual present at B1 in autumn	~ +	Not present	-
ATHERICIDAE	TRUE FLIES	Present at B1	+	Not present	-	Not present	-	Present at B3 in Spring	+	Not present	-	Not present	-

6.6.3 Conclusions

The invertebrate data presented here indicate without any doubt that the condition of the instream environment has deteriorated further than the already poor state recorded at the end of the first monitoring programme in 2004. The following is a summary of the findings:

- The index of "river health" based on invertebrate composition places the river in a low Class D or Class E/F Ecological State, which means serious loss of habitat, biodiversity and ecosystem function. The Management objective identified in setting the EWR was for a Class B river, in terms of invertebrate assemblages.
- Historical data indicate that the invertebrate assemblages were more diverse and included more of the sensitive groups of insects expected of mountain streams in the years when baseflow releases from the dam were made in line with the EWR and when some flood releases were attempted.
- Physical conditions in the river, which constitute the major features of invertebrate habitat, are presently characterised by high levels of sediment and organic matter both on the bedrock / cobble surfaces and in the interstitial spaces, severely reducing the quality of habitat for more sensitive insects, whilst providing for an abundant supply of organic matter on the bed and in transport in faster-flowing portions, favouring the detritivores and collector-gatherers like chironomids, simuliids and hydropsychids.
- Abundances of invertebrates are relatively high, compared with regional data, but are highly skewed toward three groups: chironomids, simuliids and hydropsychids which comprise up to 90% of the sample numbersThe scarcity of fast-flowing, well scoured riffle habitat means that groups such as plecopterans, leptophlebiids, heptageniids, aeschnids, riffle beetles and megalopterans that inhabit upper stone surfaces and especially the under-surfaces or interstitial spaces in this habitat are largely absent from the Koekedouw River.
- Besides the indirect effects of flow, the more or less permanent lowflows in the river appear to have created conditions that favour a mix of lotic and lentic species which are tolerant of high organic loads, such as chironomids, where species diversity is high.
- Based on the historical invertebrate data as well as the results of water quality and periphyton analysis, it is concluded that flow, rather than nutrient enrichment is the major factor implicated in the loss of natural invertebrate communities in the Koekedouw River. Both the constant low flows, the absence of elevated winter baseflows and particularly the failure to provide scouring floods to the river will need to be addressed if recovery of a more natural condition is desired.

6.7 FISH

Authors: Sean Marr and Jeremy Shelton, Freshwater research Unit, University of Cape Town

6.7.1 Background information

In a previous survey of the study area that took place shortly after completion of the dam, Clark (2000) found only a single rainbow trout in the river between the dam and the DWAF weir (August 2000). It was suggested then that the operation of the old dam had flushed all fish species from the study area. Discussions with a Ceres resident confirmed that Cape galaxias are present in one of the tributaries above the Ceres Dam and thus naturally should occur throughout the river. Cape kurper were reported by Clark (2000) below the DWAF gauging weir at the lower limit of the study site. No redfin were recorded from the study area during Clark's (2000) survey, and none upstream of the DWAF Weir in earlier studies as far back as 1989 (Clark 2000).

Indigenous Freshwater Fish

Five species of indigenous freshwater fish are characteristic of the Breede River System may historically have occurred in the study area: longfin eel (*Anguilla mossambica*), Cape galaxias (*Galaxias zebratus*), Breede River redfin (*Pseudobarbus burchelli*), Cape kurper (*Sandelia capensis*), and Berg Breede whitefish (*Barbus andrewi*) (Skelton 2001). The longfin eel is a diadromous species that breeds at sea and lives in freshwater (Skelton 2001). They do occur in the upper Breede catchment but it is uncertain whether this species could traverse the substantial waterfall barriers in Mitchell's Pass. The Koekedouw River does not have suitable habitat for the Berg Breede whitefish (*Barbus andrewi*), a lowland species which predominantly inhabits long, deep, warm pools (Skelton 2001). It is thus unlikely that these two species would have occurred in the Koekedouw River. Based on what is known about the ecological requirements of Breede River redfin (Cambray and Stewart 1985, De Wet 1990), Cape kurper (Harrison 1952, Cambray 1990) and Cape galaxias (Gore *et al.* 1991, Shelton *et al.* 2008,) the habitat in the study area is broadly suitable for these species, and they would be expected to be present.

All three species appear to be generalists in diet and habitat choice, although their habitat preferences may differ. Redfin occur widely throughout tributaries in the Breede River system (Gaigher *et al.* 1980), although populations have likely been fragmented as a result of habitat destruction and predation by alien fish species (Cambray and Stuart 1985) and habitat destruction (Skelton 2001). They prefer slightly faster water flow and are found in riffles and pools in the current (Skelton 2001). Their diet is mostly invertebrates and organic matter containing invertebrates (De Wet 1990). Redfin tend to school and breed during summer in riffles (Cambray and Stewart 1985, Skelton 2001). The upper limit of redfin distribution is usually defined by temperature between 14 and 16 ºC summer temperature), although they are known to survive below these temperatures (Dean Impson, pers. comm.).

Cape Kurper were historically widespread in the Breede River system (Gaigher *et al*. 1980), but populations have been negatively impacted by predatory alien fish (Harrison 1952, Woodford and Impson 2004) and habitat destruction (Skelton 2005). They tend to prefer calmer water than redfin, and areas with extensive cover (Harrison 1952). Their diet is predominantly invertebrates but larger individuals are known to take small fish including redfin juveniles and Cape galaxias (Skelton 2001). Kurper are aggressive towards other species and other kurper. They are brood guarders and breed in pools in summer (Harrison 1952, Skelton 2001). In open habitat, kurper are often found in low density with large numbers of juveniles in the marginal vegetation (Cambray 1990). In highly vegetated streams, especially in palmiet dominated reaches, or complex habitats, kurper can be found in high densities (Harrison 1952). Kurper appear to have similar temperature limitations to the redfins (Dean Impson, pers. comm.).

Cape galaxias are the smallest of the three species and have been poorly studied (Shelton *et al.* 2008). They are hardy fish that can tolerate a wide range of environmental conditions (Skelton 2001), but may be detrimentally impacted by introductions of predatory alien fish (Woodford and Impson 2004, Woodford *et al*. 2005 and Shelton *et al.* 2005). They breed in summer or winter depending on local conditions (Skelton 2001). Their distribution often extends further upstream than kurper or redfin, but they are often also found in the lower reaches of rivers (Skelton 2001). The taxonomy of this species is under review, but up to 14 species may be recognised, including two from the Breede catchment (Dr. Bob McDowall, National Institute of Water and Atmospheric Research, Christchurch, New Zealand, pers comm.). One putative species is widespread and can be found in a variety of habitats from very fast water to stagnant pools.

The second putative species is only known from one locality in the Hex River (Breede River catchment). The galaxias present in the Koekedouw River catchment is likely the widespread putative species although this needs to be confirmed. The diet of galaxias is recorded as consisting of small invertebrates (Skelton 2001). It is a very cryptic and difficult to detect using snorkelling, especially where other species are present (Sean Marr, pers.obs).

Alien Fish Introductions

Two alien freshwater fish species have been introduced into the Koekedouw River: Largemouth bass (*Micropterus salmoides*) and Rainbow trout (*Oncorhynchus mykiss*). Largemouth bass were introduced into the upper Koekedouw River while the old dam was in operation. CapeNature have no record of the date of this introduction and it seems likely that it was illegal. The bass population in the old dam persisted above the dam during the construction of the new dam wall.

Largemouth bass is a warm-water, piscivorous species that prefers slow-flowing, deep pools, and are susceptible to being flushed from systems during high flows (de Moor and Bruton 1988). They are brood-guarders and breed in pools or slow flowing reaches during early summer, once the temperature reaches 18ºC (Skelton 2001). Largemouth bass are ambush-hunters (McMahon and Holanov 1995) and are listed among the top 100 invasive species in the Global Invasive Species database (ISSG 2006). They have been widely introduced for sport fishing, both in the Western Cape and elsewhere, and are often implicated in severe declines in indigenous fish populations (Skelton 1993, Skelton 2001).

Subsequent to the closure of the new dam wall on the Koekedouw River in 1998, the Cape Piscatorial Society approached CapeNature for permission to stock the dam and river with trout. On the basis that the dam already contained a population of largemouth bass, permission to stock trout into the Dam was granted. Rainbow trout were then stocked in the Dam and spread into the river. This population has possibly been supplemented by illegal stockings or by escapees from a nearby hatchery. Rainbow trout are a popular target for flyfishermen and of commercial value as an aquaculture species. The species has been widely introduced into natural water courses around the world, and implicated in the decline of numerous native cold water species. Like the largemouth bass, it is included in GISP's list of the world's 100 worst invasive species (ISSG 2006). The diet of trout consists predominantly of invertebrates but they are known to become more piscivorous as they grow larger (Woodford and Impson 2004). Trout are a cold-water species that do not do well in waters warmer than 20ºC, although they can survive in water as warm as 28-29ºC (Lee and Rinne 1980). Trout spawn in winter (Skelton 2001) which provides an advantage to the young-of-the-year in that they are larger than the other species and can thus out-compete them for resources. Rainbow trout introductions to streams can result in ecosystem-wide effects (Townsend 2003). Brown trout (*Salmo trutta*) were introduced into the Greater Ceres Dam in August 2008 (M.C. Coetzer CPS Pers Comm.) but were not detected in the river below the dam and are thus not discussed further in this report.

6.7.2 Terms of reference

The study area for this survey included an approximately 4 km reach of the Koekedouw River, from the Greater Ceres Dam to the DWAF Gauge H1H013, a short distance upstream of the river's confluence with the Dwars River (Figure 6.23). The purpose of the survey was threefold:

1. To determine the suitability of the habitat in the study area to sustain fish populations,
2. To determine the fish species present in the study area, and

3. To determine the potential of restoring indigenous species to create an indigenous fish sanctuary in the study area.

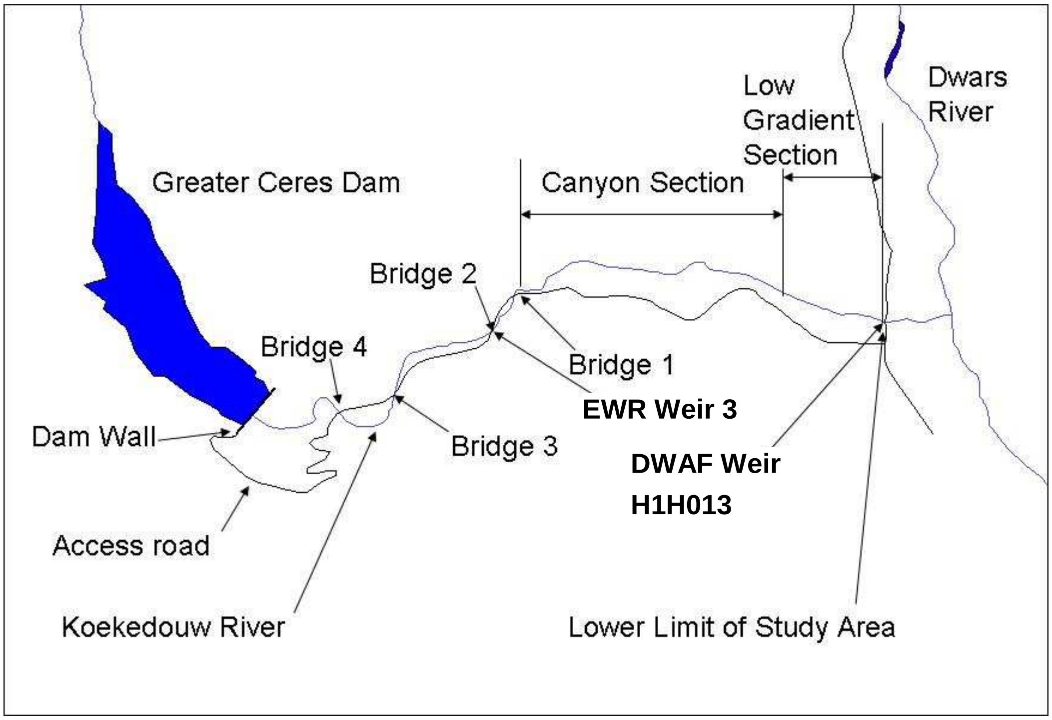

Figure 6-23. Study area from DWAF Weir (H1H013), showing the bridge crossings and the EWR gauging weir (Weir 3) at Bridge 2, which were used to differentiate study segments.

6.7.3 Methods

Fish and available aquatic habitat were surveyed during two visits to the Koekedouw River; the first on the 7-8 December 2008 and the second on 6 February 2009.

Habitat survey

Habitat constitutes a number of factors including the flow of water and the resultant hydraulic conditions within the river. Other elements include the substratum type, in-stream and riparian vegetation, and the food items available to fish. The condition of fish present in the river can also be used to determine whether any limitations in the habitat components are driving the structure of the fish populations.

Due to logistical constraints, it was not possible to conduct a full, quantitative habitat survey of the study reach. The habitat assessment was largely qualitative and focussed on determining visually whether the aquatic environment was broadly suitable for the native fish species expected to be found there. A visual

assessment was made of whether key habitat variables such as flow, substratum conditions, and nature of food items available to fish within the study area were comparable to other sites where the indigenous species occur in the Breede River System. This assessment of habitat was conducted by systematically moving down stream from the dam wall. Additionally, any major habitat degradation evident within the study area was noted.

Fish survey

Due to logistical constraints, visual observation from the bank and in-water (snorkelling) were the main techniques used to determine the fish distributions. Limited electro-fishing was performed at selected sites (Bridge 1, 2 and 3, and just above the DWAF gauging weir, Figure 6-24). These methods provide reliable information on the presence and absence of fish species at various locations throughout the study area. These methods also provide limited insight into population size structure and habitat use for the different species, as well as gauging whether species distributions overlap in the study area.

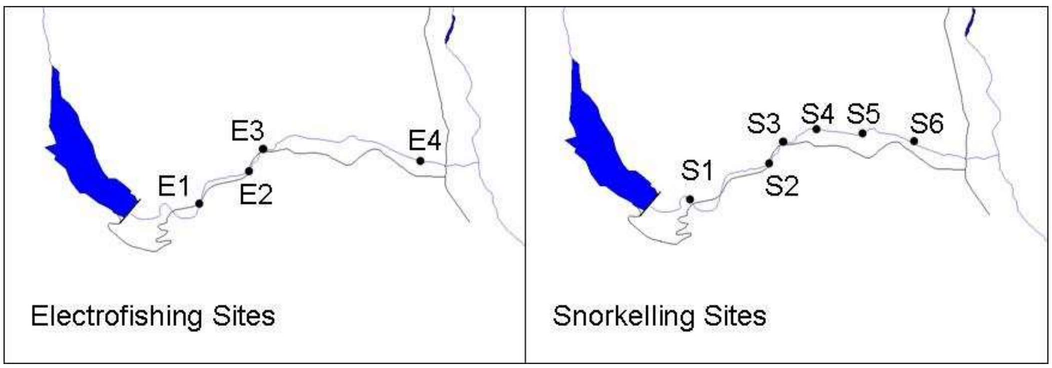

Figure 6-24. Location of sites where snorkel surveys and electrofishing were conducted.

6.7.4 Findings and discussion

Habitat survey

The reach immediately below the dam wall is a shallow, cobble-bed run, typical of the Western Cape streams. Small (~25cm in diameter) cobbles dominate the substratum, and whilst no in-stream vegetation was present, marginal vegetation was recorded along the entire section. Further downstream, just up-

stream of Bridge 4 (the closest bridge to the dam) a complex matrix of pools and short runs over boulders and sand was the main habitat, extending to just below Bridge 2 (Figure 6-23), with patches of instream and marginal vegetation. This habitat type contains ample hydraulic cover for both indigenous and alien species, but much of the cobble areas were impacted by sedimentation, with clear patches only occasionally where flow was concentrated along a narrowed channel or braid. Between Bridge 2 and 1, the channel comprises a series of bedrock steps and deep pools with limited hydraulic cover and neither in-stream nor marginal vegetation. Below Bridge 1 the river passes through a canyon with bedrock pools alternating with shallow runs, similar to the section above Bridge 2, but with a greater presence of palmiet-enclosed stream sections. With the exception of sediment-smothered patches, this stretch provides excellent habitat for the native fish species, as well as for trout. This section also had the steepest gradient within the study area.

Below the gorge, the river has a low gradient and contains deep pools with abundant in-stream vegetation interlaced with palmiet stands. The substratum is predominantly sand.

a) Flow

During the first visit (7-8 December 2008), the flow in the river was similar to that which would be expected for a tributary of that size in the Breede River system at that time of the year. During the second visit (6 February 2009), water was being released from the sluice gate in the dam wall at a flow similar to that of the previous visit. Downstream of Bridge 1, however, almost all of the flow appeared to be diverted into a furrow system at a low weir, and indeed a number of low weirs were noted along the canyon stretch of the river. It appeared that a portion of this flow was returned to the river between 50 and 100m below the weir. The section between the off-take and the return was receiving minimal flow at this time, and this habitat is considered to be largely unsuitable for fish. However, flows over most of the study area were visually similar to other Breede River tributaries that support redfin, kurper and galaxias (e.g. the Jan du Toits and Sandriftkloof Rivers).

b) Substratum

The substratum through much of the study area is smothered with sand, filamentous algae or detritus. This is of concern as the scouring flows do not appear to be clearing this material from the river bed as is found in other similar rivers in the upper Breede catchment. Sediment deposits like those observed in the study area can cause homogenisation of the substratum, and can drastically reduce the diversity of available habitats for both fish and invertebrates (Davies and Day 1998, Skelton 2001). Substratum homogenisation may reduce or destroy suitable habitat for indigenous fish which require different substratum types like boulders, cobbles and gravels for a range of activities like feeding, spawning and sheltering (Cambray and Stewart 1985, Cambray 1990, Shelton *et al.* 2008). There were patches where sediment has not smothered the bed which may be allowing fish populations to persist at relatively low densities.

c) Food items

Whilst invertebrate abundances were relatively high in the Koekedouw River (see section 6.6) they comprised largely chironomids, simuliids and fixed-shelter cased caddis. These groups are comparatively sessile and thus poor prey items for trout which feed predominantly on surface or drifting insects. Even for indigenous fish, their size, location in the swiftest microhabitats (e.g. simuliids in trailing palmiet fronds or small chutes) and / or their predator defences (shelters built by hydropsychids) make them less favoured prey. Organic matter and algae associated with invertebrates and often ingested during feeding have little value for fish. In extreme cases like the Koekedouw River where organic deposits are massive, relative to the invertebrate biomass, this only serves to reduce the efficiency of prey capture - to the point that there may be very little value in the ingested material. The very low abundance of the ephemeropteran grazer / collector trophic group is implicated both in the low abundance of invertebrate predators, and also constitutes a food shortage for the insectivorous fish species (probably all fish species present – see Skelton (2001)), which is a major limiting factor in terms of the number of fish that the study area can support.

Previous studies have shown that the invertebrate community in the river had been adversely impacted by the operation of the old dam and that particular groups of invertebrates like mayflies, stoneflies, megalopterans and odonates have not recovered to the population levels found in similar sized streams in the Breede catchment (see Section 6.6). In streams where trout have been introduced, and indigenous fish populations reduced or extirpated, the grazer community has been shown in many instances to thrive, with consequential reduction in algal biomass (Townsend 2003). The invertebrate data indicate that the Koekedouw River does not appear to be following this trend in the reaches where trout, but not indigenous fish, were found.

Fish Survey

Rainbow trout were observed throughout the study area, to just below the gorge (Figure 6-25). It is expected that this species is present all the way to the gauging weir even though it was not detected in this area. All the trout observed were small (<25cm) and evidence of dwarfism in the trout population was detected (Figure 6-26). Fully formed trout of less than 7cm were observed below Bridges 3 and 4 and one specimen was captured by electrofishing above Bridge 3. Dwarfism has been observed in salmonid populations, and can result from metal deficiency (Satoh *et al*. 1987), overstocking, and the lack of suitable food resources in rivers (Pichugin *et al*. 2006). In the case of the Koekedouw River, it is

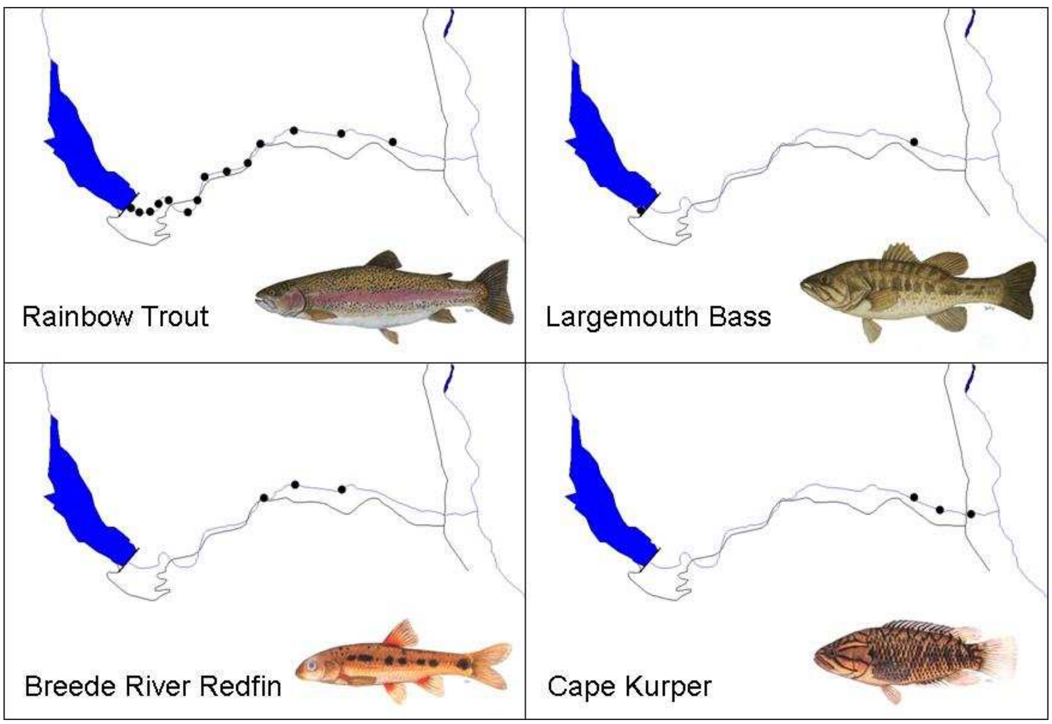

Figure 6-25. Location of sites where rainbow trout, largemouth bass, Breede River redfin and Cape Kurper were recorded in the Koekedouw River.

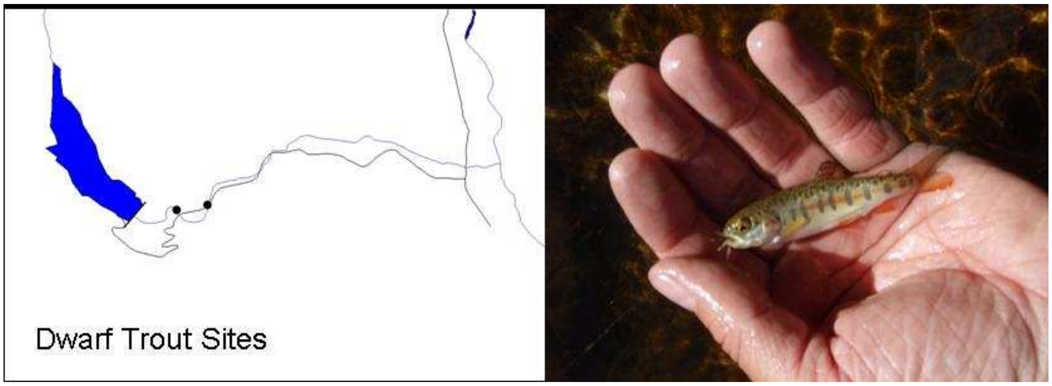

Figure 6-26. Location of sites where dwarf rainbow trout were observed. Photo of dwarf rainbow trout par (courtesy of MC Coetzer)

suspected that food resource limitations have resulted in dwarfism of cohorts of trout. The ongoing lack of larger, more mobile insects in the river may thus be at least in part explained by top-down control of the food web by trout, in addition to the obvious constraints posed by inadequate habitat quality, as suggested in section 6.6 of this report. Should this be the case, the recovery of the invertebrate population may not be possible without removal of the trout from the study area. It is acknowledged that the trout population in the reservoir will provide propagules and the trout population will be re-established, but by this time, the invertebrate population may have sufficiently recovered to provide a balanced food web in the river. Large numbers of largemouth bass were observed in the dam close to the wall. It is expected that hydraulic conditions in the river during spates would prevent permanent establishment in the study area, with the exception of the low gradient section of the river below the gorge. However, such flows, as indicated in the record, have been very limited. A single largemouth bass was observed in a pool just below the gorge (Figure 6-26). Discussions with a Ceres resident confirmed that largemouth bass have been observed in this pool previously. Bass have negatively impacted the three indigenous species in other streams in the Western Cape (de Moor and Bruton 1998). The presence of indigenous species is usually an indication that bass are not present or have only recently been introduced, whilst the presence of bass heralds the demise of indigenous species, within five years. The presence of bass in the dam is thus a major obstacle to establishing a sanctuary for indigenous species in the Koekedouw River. The hydraulic conditions in the upper sections appear to be unsuitable for largemouth bass and the likelihood of establishing a permanent population in these reaches is low. Bass are only likely to be flushed into the study area during high winter flows, and will probably pass through to the lower reaches, below the gorge. (Smallmouth bass would pose a more serious problem, since they are a river species and would be able to survive the high winter flows.)

Breede River redfin were captured by electrofishing below Bridge 1 and observed through most of the gorge by snorkelling (Figure 6-25). The lower portion of the gorge was not sampled but it is expected that redfin would be present in this area. The habitat between the gorge and the DWAF gauging weir at the lower limit of the study area is suitable for redfin and they would be expected there despite the fact that they were not collected by electrofishing in this reach. This reach was not surveyed by snorkelling and should be surveyed further using additional sampling techniques such as snorkelling and fyke netting. Only adult redfin were observed in pools containing trout, while juvenile and adult redfin were observed in pools that did not contain trout. Trout predation on redfin, especially juveniles has been reported anecdotally, but has not been discussed in scientific literature.

It is notable that redfin density was far lower than would be expected in a Breede River tributary the size of the Koekedouw, although it is nevertheless encouraging that they were collected upstream of the DWAF weir at all, and both as juveniles and adults. It is suspected that interactions between the alien fish present (notably trout) and habitat degradation (smothering by sediment and water abstraction at the low weir in the gorge section) are major causes their low densities in the river and their absence from some reaches.

Cape kurper were observed below the DWAF gauging weir below the study site and in the low-gradient section between the gorge and the weir. Large numbers were observed and collected by electrofishing in the abundant in-stream vegetation (Figure 6-25). It is likely that the in-stream vegetation provides shelter from foraging trout, allowing relatively high kurper population numbers to persist in vegetated river reaches. The upper limit of kurper distribution was not established precisely but the presence of largemouth bass in the pool below the gorge is accepted as the upper limit. The lower portion of the gorge has a number of steps that constitute barriers to fish movement upstream. It is possible that kurper survive in the gorge along with the redfins, but this can only be determined in subsequent surveys.

No Cape galaxias were detected in the survey, although this species is difficult to detect in preliminary surveys. It is possible that a population of galaxias persists in the study area since it is adept at surviving high flows. Being a small species, it is also susceptible to trout predation and would not be expected to be found in the resource-limited area of trout dwarfism. Since galaxias is a hardy fish that can tolerate a wide range of environmental conditions, it is probably the presence of trout, rather than unsuitable habitat that explains its absence from the study area.

6.7.5 Conclusions

The results of the preliminary fish survey is the first to find indigenous fish species upstream of the DWAF weir since 1989. This may be a consequence of a more extended survey, covering reaches between Bridge 1 and the DWAF weir, which were not included in the surveys of the more recent past, but is nevertheless exciting and encouraging. The following is a summary of the findings:

- Degradation of fish habitat in the Koekedouw River, as documented in the preceding report sections, is also directly implicated in low population densities and dwarfism in trout, which is the dominant species in the Koekedouw River, having been introduced after closure of the dam as an angling species.
- Key aspects of this loss of habitat quality is in the physical smothering of large parts of the river bed and interstitial spaces, as well as the knock-on effects of this on fish prey items, specifically mobile invertebrates.
- Breede River redfin were found in the gorge section of the Koekedouw, where they appear to be coexisting with trout, possible largely due to food resource limitation of the latter, which restricts population size and therefore competition and predation pressure on the redfins. Redfin populations were small, but it is unclear as to whether this is influenced by sub-optimum habitat conditions which are flow-induced, or simply the result of the presence of alien trout.
- Similarly, Cape kurper were collected in relatively high numbers from the lower portions of the study area, up- and downstream of the DWAF gauge. The poor habitat quality in this stretch of river appears not to have major deleterious effects on the species. However, it might as well be that this reach, where trout appear to be effectively excluded by habitat and very poor prey availability, is a refugium for the species despite habitat characteristics not being ideal.
- A single largemouth bass was observed in a pool just below the gorge, near the downstream end of the study reach. It is possible that spillages from the dam in recent years may have been sufficient to move wash this species from the river as it is poorly adapted to fast-flowing

rivers. This is an area of uncertainty, however, and what is certain is that failure to release floods, and the decline in spillage events as demand grows, pose the threat of allowing this species to establish along the river with disastrous consequences for the remaining indigenous fish populations.

6.7.6 Recommendations for rehabilitation

The authors believe that, although the presence of trout and bass compromise the establishment of a sanctuary in the study area, rehabilitation measures could be implemented to improve the status of the indigenous fish populations there.

A number of rehabilitation options are presented as intervention scenarios and are outlined below. The expected outcomes based on the authors' understanding of the ecological interactions of the proposed intervention options are discussed. Rehabilitation options are presented in order of increasing implementation commitment and complexity, beginning with the take no action, option.

1. Take no action

Option: Take no action and manage the river in the same way that it has been since completion of the dam wall in 1998.

Predicted outcome: The fish population and species distributions are likely to remain similar to the current pattern, at least in the medium term, with indigenous species persisting in the gorge and below the gorge. Trout will continue to be in low density above Bridge 1 and dwarfism in this species would be expected to continue in the absence of plentiful food. Trout and redfin will likely continue to co-exist below bridge 1, although over time trout may extirpate redfins there. The river appears to have avoided recruitment of bass in the reaches close to the dam and in the gorge, but this finding is based on a preliminary once-off survey and cannot be guaranteed. Winter flooding could prevent bass from establishing above the gauging weir, but currently occurs only fortuitously when the dam spills, and in the longer term would be less likely as demand grows. Cape kurper are likely to persist below the gorge.

2. Institute environmental flows

Option: Releases from the dam be managed to implement the environmental releases recommended for the Koekedouw River. The weir off-take and furrow in the gorge section should be investigated – abstraction of the EWR releases should not be allowed.

Predicted outcome: Improved baseflows and flushing flow releases from the dam should transport sediment out of the study area, which should improve habitat heterogeneity and fish and aquatic invertebrate populations, the food base for most of the fish species, which in turn may stimulate population growth. This may be of greater benefit to trout than to the indigenous species present in the study area, however, since the current flow regime ensures low population densities of trout which might otherwise pose more threat to indigenous species; ensures the isolation of pools in the gorge; and possibly promotes the development of conditions marginal for trout in these pools, such as near-zero flow rates and possibly increased temperatures (although no data to this end have been collected). It is anticipated, however, that the current situation will continue should environmental flows be implemented, since flows greater than those required to meet the EWR have been implemented without affecting the redfins in the past.

3. Reduce trout density the over the study area

Option: Use appropriate removal techniques (such as angling, netting or electrofishing) to reduce trout density in the area. It is unlikely that eradication of the trout population will be achieved, even with the use of piscicides (such as rotenone), given the ready supply of new recruits from upstream. Since the impact of trout is likely to be density-dependant, it may be possible to promote co-existence with indigenous fish, however, by keeping trout density as low as possible (Woodford and Impson 2004).

Predicted outcome: Competition with, and predation on indigenous species by trout will decrease, enabling stronger populations of indigenous species to establish.

Recommended Enhancement: Under such circumstances, re-introduction of indigenous species upstream of the gorge would be advantageous. It may be prudent to introduce the indigenous species in phases. Redfin and kurper should only be introduced after the invertebrate community of the study area has been restored. Efforts of this nature would be severely compromised by new trout stocking from any source, however. It is therefore recommended that every effort be made to prevent new introductions, e.g., by making sure no escapees enter the river from the hatchery in the lower catchment, and by enforcing the prevention of new stockings. Local anglers could be recruited to this end.

4. Removal of all alien fish from the Koekedouw River

Option: Removal of all alien fish from the Koekedouw River, including the section above the dam, as well as from the dam itself. Potential options include the use of piscicides (such as rotenone) and/or mechanical removal (such as angling or depletion electrofishing). Whitefish could be introduced to the Ceres Dam and redfin, galaxias and kurper introduced above the dam. Gaining stakeholder support for such a project is essential as the re-introduction of alien species by disgruntled stakeholders would reset the project to the current situation or worse – smallmouth bass or Sharptooth catfish could be introduced into the Koekedouw River.

Predicted outcome: Alien fish could be successfully removed from the Koekedouw River catchment. This would be the ultimate solution and create a sanctuary could be established in the Koekedouw River. The threat of new, illegal introductions may perpetually compromise this intervention. Stakeholder support is vital to the success of such an intervention and the community is probably not ready for it.

It is recommended that, along with the implementation of the required environmental flows, efforts be made to reduce trout density and steps be taken to prevent future stocking, which was an unfortunate management decision. This will require buy-in and the collaboration of local anglers and the community utilising the nature reserve, but should not be difficult given the biodiversity rewards that could be associated with it: a visually “cleaner” river, more natural food webs, restoration of insect biodiversity, protection of red-data fish species and the restoration of a natural asset that it well utilised by the local townspeople.

7. SUMMARY STATEMENT OF THE IMPLEMENTATION OF ENVIRONMENTAL WATER REQUIREMENTS FOR THE KOEKDOUW RIVER AND ITS ECOLOGICAL CONSEQUENCES

Based on the preceding analyses of observed flow records in the Koekedouw River for hydrological years 1999 to 2006 and the biophysical assessment of the state of the river, this section provides a summary statement with regard to the implementation of Environmental Water Requirements for the Koekedouw River within the Ceres Nature Reserve and to its confluence with the Dwars River, in terms of flows as well as the current biophysical state of the river.

7.1 IMPLEMENTATION OF FLOWS

The Environmental Water Requirements for the Koekedouw River were determined by river scientists by identifying those low flows and floods that were considered to perform various functions in the river, such that the desired condition of the river would be maintained into the future. This EWR determination was one of the early such water allocations to be undertaken and has some drawbacks that have been refined during later studies. For example, the EWR is not linked to climatic variation that would allow for wet and dry years to reflect in the imposed hydrological regime downstream of the dam. A second drawback of the EWR is that it was developed without adequate hydrological data, and some questions remain about the possible inadequacy of the floods which were specified: the larger flood in the EWR as it stands was supposed to reflect the naturally occurring annual flood event, but spillage records would suggest that this event is in fact far larger. A compounding problem is that the fact that the outlet works at the dam impose some release limitations with regard to high flows, so releasing larger floods will not easily be achieved.

Based on an assessment of historical flow records in the Koekedouw River downstream of the Greater Cerse Dam for the decade since completion of the dam, it is obvious that the implementation of environmental protection, the accepted legal responsibility of the Koekedouw Irrigation Board and the Municipality, has been poor to the point of dereliction of duty. Although the *Ceres Koekedouw Dam Operation and Maintenance Manual (SRK Report 216111/7, Aug 2001)*, which specifies minimum low flow and high flow EWRs on a monthly basis, is supposed to guide the current operation of the dam in terms of EWR releases, the assessment of historical flow records indicates that this is not the case. In general, the evaluation of historical flow records in the Koekedouw River for the period between October 1999 and September 2006, indicate non-compliance in terms of EWR releases. Although the record suggests that intermittent low flow EWR releases were made during the period immediately after dam construction (1999 to 2001), these became more sporadic and less frequent from 2002 onwards. Furthermore, flood releases have been attempted in <u>only three years</u> during the decade following dam construction.

What is also extremely worrying is that the obviously inaccurate flow measurements at Weir 3 from April 2003 onwards were not noted and corrected by the Koekedouw Irrigation Board. A comparison of the observed flows at Weir 3 with the concurrent flow record at DWAF Gauge H1H103 should have been made and should have alerted the dam operators to the anomalies in the Weir 3 record. The fact that recorded flows at Weir 3 exceeded the EWR low flow by up to three times, over extended periods of time, is further confirmation that the monitoring of EWR releases from the dam has probably not been a priority.

7.2 ECOLOGICAL CONSEQUENCES

In the environmental flows process outlined in Department of Water Affairs' manuals, the aim of biological monitoring is intended to be to evaluate whether the Environmental Water Requirements that were stipulated are sufficient to give effect to the desired management objectives for the river, namely the instream and riparian condition. Post-evaluation steps would be a refinement of EWR releases, including the possibilities that flows are augmented where deemed insufficient, or reduced where they may be superfluous in achieving a particular goal.

In the Koekedouw River EWR process, however, assessment has to be made of a flow regime imposed on the river that a) is not well quantified, b) is substantially less than the stipulated EWR and c) where most of the “work” performed by floods has been the result of occasional spillage, which cannot be guaranteed in the longer term. The biological assessment has provided some evidence that implicates the absence of regular scouring and the constancy of very low baseflows in the decline of river condition to one which is “seriously modified”, based on currently accepted indices of river health. Changes in ecosystem characteristics start at the level of inadequate sediment movement and massive accumulation of organic biofilms, and include loss of insect groups which perform important functional roles in removal of algae and detritus and as prey for higher-order insects and fish, and the proliferation of collector feeders and semi-lentic species. Lack of suitable prey for trout which is the dominant species in the river, has resulted in both dwarfism and small population sizes, which inadvertently may have had positive effects on indigenous fish populations by lowering competition and predation pressure, since the effects of trout on indigenous fish are density dependent. Indigenous fish populations were recorded in the lower reaches of the study area for the first time since 1989 through a more extensive survey. Here small population size is deemed to be affected by suboptimal habitat conditions, including sediment and organic smothering of bed substrata and feeding inefficiency as a consequence of high detrital intake and low densities of suitable prey. These are, again, linked back to the lack of adequate flow in the river.

In relation to the vegetation along the river, dominant habitat signatures of the species encountered were either riverine or riverine and wetland, indicating that the Koekedouw is perennial but that its winter flushes are inadequate to remove sediment. The absence of species which normally characterise wetter banks closer to the water’s edge suggests that the river lacks strong perennial flow, and water levels are not maintained at periodically higher levels, for example those that would be expected of winter baseflows. The upper banks of the channel, however, are mostly free of sediment deposits and this sustains a more natural suite of riverine endemics, with some rocky upper bank species. Alien vegetation is sparse, and does not appear to have been influenced by the flow regime, but requires management attention.

The direct influence of flow on one of the major determinants of river organisms – the physical habitat – and indirect effects on food web structure is thus demonstrated through this study. Implementing the EWR as stipulated for the Koekedouw River is likely to improve matters. Whether it achieves the ultimate management objectives stipulated for the river can only be evaluated once the correct flows are released.

8. PROPOSED IMPROVEMENTS TO OPERATING RULES

In light of the findings of this Study, the following issues are highlighted for consideration during the possible refinement of the operating rules of the Greater Ceres Dam:

The existing low flow EWR prescribes constant monthly minimum flow values. However, these flows do not take into account the actual inflows into the Greater Ceres Dam and as such are not always realistic in terms of flow variability and natural climatic conditions. More realistic EWRs based on monthly rule curves would address this problem. Based on the latest hydrology for the Koekedouw catchment, as simulated during the recent Berg Water Availability Assessment Study (DWAF, 2007), the RESDSS Desktop Model (Hughes and Münster, 1999) was used to derive monthly rule curves for the low flow component of the EWR in accordance with Table 3-1. The rule curves are displayed in Table 8-1 and should be easy to implement by using observed flows at the existing flow gauge (Weir 2) on the Witzenberg Stream, which is already fitted with a telemetry system, as an indication of the reference (natural) flow at the dam. The Weir 2 catchment represents about 8% of the catchment area upstream of the dam and can therefore be scaled up proportionally each month, to estimate the total natural monthly inflow into the dam. This natural flow can then be used in conjunction with Table 8-1, to determine the required EWR low flow release.

Table 8-1: Proposed EWR Rule Curve (Low flows)

% Exceedence	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Reserve Flows without High Flows (m3/s mean monthly flow)										
Oct	0.294	0.294	0.292	0.288	0.279	0.261	0.229	0.18	0.12	0.082
Nov	0.255	0.255	0.254	0.25	0.242	0.227	0.199	0.156	0.105	0.072
Dec	0.17	0.17	0.168	0.165	0.157	0.143	0.119	0.089	0.062	0.049
Jan	0.097	0.097	0.096	0.094	0.089	0.081	0.067	0.049	0.033	0.025
Feb	0.068	0.068	0.068	0.066	0.061	0.048	0.041	0.03	0.017	0.01
Mar	0.052	0.052	0.051	0.05	0.046	0.034	0.028	0.018	0.012	0.003
Apr	0.068	0.068	0.067	0.066	0.063	0.058	0.049	0.035	0.018	0.006
May	0.119	0.119	0.118	0.116	0.111	0.102	0.085	0.059	0.027	0.007
Jun	0.206	0.206	0.205	0.203	0.198	0.189	0.171	0.139	0.086	0.033
Jul	0.266	0.266	0.265	0.263	0.257	0.247	0.228	0.192	0.134	0.075
Aug	0.31	0.31	0.309	0.306	0.3	0.288	0.265	0.223	0.156	0.086
Sep	0.331	0.331	0.328	0.324	0.313	0.293	0.257	0.202	0.135	0.092
Natural Duration curves (m3/s mean monthly flow)										
Oct	1.88	1.555	1.329	1.145	1.026	0.857	0.677	0.566	0.441	0.245
Nov	1.323	1.047	0.81	0.677	0.563	0.433	0.383	0.313	0.25	0.168
Dec	0.744	0.548	0.401	0.34	0.236	0.202	0.162	0.132	0.107	0.058
Jan	0.349	0.233	0.174	0.135	0.11	0.089	0.074	0.055	0.046	0.034
Feb	0.274	0.169	0.102	0.088	0.061	0.048	0.041	0.034	0.02	0.01
Mar	0.413	0.168	0.116	0.08	0.046	0.034	0.028	0.018	0.015	0.003
Apr	0.832	0.519	0.332	0.266	0.196	0.142	0.092	0.06	0.029	0.006
May	1.858	1.203	0.98	0.735	0.643	0.49	0.41	0.282	0.107	0.009
Jun	2.936	2.094	1.806	1.582	1.386	1.158	0.981	0.737	0.364	0.101
Jul	3.052	2.658	2.26	1.84	1.678	1.476	1.237	1.044	0.643	0.19
Aug	3.019	2.455	2.168	2.054	1.846	1.574	1.316	1.096	0.79	0.517
Sep	2.613	2.202	1.892	1.724	1.541	1.351	1.177	1.11	0.845	0.443

Similarly, the use of the observed flow record at Weir 2 as an indicator (reference) catchment for EWR releases during flood events, will ensure that the release flood hydrograph emulates the natural condition and that artificial flood releases are linked to natural flood or high flow conditions in the river. Release restrictions imposed by the existing outlet works at the dam should also be re-considered and, if necessary, the high flow EWR should be modified to accommodate the current release restrictions.

The fact that the data indicate that annual EWR volume has been exceeded most of the time, even when the dam did not spill, is probably an **artefact of inaccurate data**. This is supported by the observation that, from 2002 onwards, the observed baseflow at Weir 3 was consistently higher than the minimum EWR low flow and was substantially higher than that recorded at DWAF weir H1H013. As a matter of urgency, improvements to the calibration of the gauge (Weir 3) and the collection of hydrological data must be made. It is recommended that the local authority be provided with an independent consultant to undertake this work, to ensure that what should be routine monitoring and the delivery of trustworthy data is fast put back on track.

9. RECOMMENDATIONS OF MANAGEMENT STEPS TO BE UNDERTAKEN IN THE IMMEDIATE FUTURE

Based on the previous 5-year monitoring programme and this once-off assessment of conditions in the river, there is little doubt that failure to release adequate flows in the Koekedouw River have been responsible for much of the deterioration in ecosystem integrity. Continued monitoring of the implementation of an arbitrary flow regime will not help to improve matters, and emphasis must be placed on the recommendations made in respect of actual implementation of the EWR.

A number of questions remain, however, regarding whether the stipulated environmental flows are sufficient to achieve some of the environmental objectives. Also, some non flow-related issues require exploration. These are discussed below.

Sediment scouring requirements

As recommended at the end of the initial monitoring programme, from an ecological perspective it is very important that sufficiently large floods are released down the Koekedouw River below the Greater Ceres Dam to facilitate the removal of the sediment deposits that have accumulated since the construction of the dam. This requirement was of course never anticipated when the initial EWR was established (prior to the construction of the dam and its impacts on the downstream environment). No quantitative information exists on the sorts of flows that would be require to move sediments from the river, given the channel features and hydraulic environment that is the river. If the flood releases stipulated in the EWR are released down the river at the required magnitude, duration and frequency, this would help to shift sediment deposits that have accumulated in the faster-flowing, shallower habitats in the river, but probably not effect scouring of pools, which is only likely to occur if larger flood releases were possible or during periods of dam spillage that coincide with incoming floods.

The lack of annual monitoring of this aspect of the river means that there are no flow-linked sediment movement data that will help to guide management steps. It is proposed therefore that a study be commissioned to determine what size floods will move sediment. Linked to this is a requirement to clarify the actual maximum release that can be made from the dam, and under what conditions.

If the release of larger floods is not possible, some consideration is required of the sorts of interventions that are possible that would improve habitat quality in the river. Improving the condition of shallow habitats, for example, could be seen as a priority for flow management in the next five years. Management of the dam to ensure maximising this, for example making releases that coincide with spillage, may increase the effectiveness of sediment movement. This is a long-term goal, which can only be met by a commitment on the part of the dam management to perfect flood release techniques.

Nutrient data

Regular collection of nutrient (and other water quality) data should be collected from at least one location within the section of river passing through the nature reserve, together with data from upstream of the dam, to identify potential non flow-related impacts on the river emanating from the upstream catchment and / or from the dam. A sampling programme should be implemented now to build up an historical record which is necessary for statistical analysis of this ecosystem component.

Management of trout and bass

It is recommended that, along with the implementation of the required environmental flows, efforts be made to reduce trout density and remove any bass from the system, and steps be taken to prevent future stocking, which was an unfortunate management decision. Since the impact of trout is likely to be density-dependant, it may be possible to promote co-existence with indigenous fish, however, by keeping trout density as low as possible. Under such circumstances, re-introduction of indigenous species upstream of the gorge would be advantageous. This programme will require buy-in and the collaboration of local anglers and the community utilising the nature reserve, but should not be difficult given the biodiversity rewards that could be associated with it: a visually “cleaner” river, more natural food webs, restoration of insect biodiversity, protection of red-data fish species and the restoration of a natural asset that it well utilised by the local townspeople

10. DRAFT EWR MONITORING PROGRAMME

10.1 RE-ESTABLISHMENT OF MANAGEMENT OBJECTIVES

To date monitoring of the river has used the desired state as described in the original EWR documentation as the basis for evaluation of success or otherwise. However, based on the current situation with regard to sediment deposits, the maximum possible flood releases, the issues or choices relating to the management of alien and indigenous fish in the river, and, most importantly, the seeming lack of commitment to making environmental flow releases, it may be a pertinent time to establish a revised and detailed set of objectives and requirements regarding management objectives for the Koekedouw River.

It is therefore recommended that:

- A public participation process be undertaken by an independent and appropriately qualified consultant to re-state the desired condition to which the river should now be restored, and in the future maintained.
- To translate this desired or target condition into measurable Resource Quality Objectives for each ecosystem component (e.g. water quality, fish etc). RQOs are indices, or ranges or mean values for variables that can be measured, or the presence or absence of features that can be recorded, that would indicate that a specific ecological goal was being met.
- This process involve river scientists and water resource managers who are able to interpret the consequences of particular choices of management or the target condition (e.g. what would the consequence be of a choice to manage the river as a pristine system and how feasible would that be).
- The interested parties should include both local users, users of the water resource (irrigation boards) as well as statutory bodies like DWAF, CapeNature and SANBI.

The future monitoring programme must be able to track changes in ecosystem condition that are not flow related, separately from those that are, by the placing of monitoring sites and activities. In this case the water quality monitoring proposals would adequately indicate possible impacts from upstream vs. the dam.

The following section presents a proposed monitoring protocol for the Koekedouw River downstream of the Greater Ceres Dam, as a product to take forward for funding and implementation in the future.

10.2 MONITORING OBJECTIVES:

- To determine how well the pattern of daily flows in the river meets the hydrological conditions expected of the EWR, maintains desirable habitat and provides for the ecological processes required to sustain ecosystem function.
- To provide an interpretation of the major aspects of ecosystem condition and function, including *inter alia* changes in physical attributes, biodiversity, trophic status, water chemistry and sediment dynamics.
- To measure biotic responses to the implementation of the EWR, to establish if they are meeting the water resource quality objectives (target ecological condition).
- Through an analysis of biotic responses to flow related changes in the system, to make recommendations where necessary about the need to adjust baseflow requirements and / or

refine the pattern of flood and fresh releases to meet the target ecological condition identified for the Koekedouw River.

10.3 MONITORING ACTIVITIES

Monitoring should be conducted on a site or reach basis, depending on the component monitored (e.g. invertebrate sampling occurs on a site level; fish are assessed along reaches). In order to gain from the historical data, the three sites and the different reach sections used in this study are recommended.

The following are the major components envisaged as part of a future monitoring programme.

a Geomorphology and hydraulics

This component is not developed here, as it will be informed by the sediment transport study and eventual management actions taken, as recommended in section 9 of this report.

b Water chemistry

The most useful water chemistry data are those from regular recording at frequent (e.g. weekly or fortnightly) intervals.

- The water quality dataset maintained by DWAF at H1H013 is useful, but additional data should be collected from at least one location within the section of river passing through the nature reserve, together with data from upstream of the dam, to identify potential non flow-related impacts on the river emanating from the upstream catchment.
- System variables (temperature, pH, conductivity, and oxygen), together with nutrients (PO_4^+-P, NO_3^+-N, NO_2^+-N and NH_4^+-N) should be sampled *in situ* at these monitoring sites on at least a monthly basis. These records should be analysed to show trends in water quality in the Koekedouw River, as a whole and by season, and to identify if necessary any sources of nutrient enrichment.

c Riparian botanical assessment

Rivers generally show a shift in plant species composition with lateral / vertical distance away from the water's edge because of a gradient in moisture. Bank vegetation may thus comprise a number of plant communities, and in many Western Cape rivers these communities have been correlated with vertical inundation levels associated with the natural flow regime. Changes in the flow regime can result in changes in the species composition and / or community zonation, with some zones expanding and other becoming progressively replaced. The following are proposed:

- A detailed assessment of all plant species present is required to establish floristic gradients more accurately.
- Changes in river habitat need to be monitored every two years through the establishment of permanent plots and flora sampling; this should be linked with assessment of change in proportion of sandy to rocky substratum in preselected areas. The re-establishment of key riverine endemics such as *Isolepis digitata* would be a vital indicator of positive change in the river.
- All woody alien species mentioned in the study need to be eradicated as matter of urgency. The acacias in particular are aggressive invaders and can choke river channels with

deleterious effects to the riverine habitat. *Populus canescens*, only occurring in the lower parts, also needs to be monitored carefully and removed.

d Periphyton biomass and taxon composition assessment

Since seasonal patterns of biomass accrual and loss, and of community structure are driven by the disturbance regime to a significant degree, patterns consistent with those observed on a regional basis should emerge once appropriate flows are restored to the river.

- Periphyton biomass, as Chlorophyll *a,* and the density of total organic matter on the stream bed (AFDM) have shown patterns that implicate flow-related impacts, and should form a component of the monitoring programme. The frequency of monitoring should be aimed at identifying biomass changes at key times to allow biomass estimates to be compared with natural seasonal cycles found elsewhere in the region, namely August (winter low), October (spring peak), December (early summer low) and March (late summer peak).
- The collection of periphyton and AFDM from five replicate samples from run biotopes appears to be sufficient in this present study to identify patterns in periphyton, and is proposed for future monitoring.
- Continued collection of periphyton community data should be included in a future monitoring programme, to track both changes in richness and community structure against the proper implementation of the required flow regime. Community data would be assessed by subsampling the five replicate biomass samples. If budget constraints apply, it is possible to combine the community data subsamples to obtain a single species list for each site / sampling time.

e Macroinvertebrate faunal assessment

Invertebrates are considered to be very useful indicators of change, and are a core component of the River Health Programme. As shown in this study, the evaluation of the SASS5 scores and ASPTs has become an extremely convenient way in which to summarise ecosystem condition, at least in naturally strongly perennial systems, partly because of the wealth of historical and reference data from western Cape rivers.

- It is thus proposed that the standard SASS5 protocols be implemented at the three monitoring sites on a bi-annual basis, in August and March.
- In addition, however, semi-quantitative community data – abundance estimates of major groups – and information on biodiversity at the species level have both been shown in this study to provide valuable insight into the sorts of changes in ecosystem processes that are occurring, for example in relation to trophic relationships. Species-level data collected semi-quantitatively, such as by preserving and processing the SASS samples, is a very cost-effective way in which to gather community data, and should be continued. The frequency of monitoring could readily be reduced from that initially indicated to bi-annual with August (winter) and March (summer) sampling.

f Fish assessment

A recommendation has been made for a management intervention aimed at reducing trout densities, removing any bass present, and at an appropriate stage to re-introduce indigenous fish to the upper reaches of the river. Such a programme should begin immediately, and the first component be implemented alongside any training and institutional arrangements that are required to be made in order to give effect to the stipulated EWR. Future fish surveys will be dictated to some extent by the programme that is implemented. In the medium-term, however, annual surveys could be scaled back to take place bi-annually or at even longer-intervals, once fish populations are no longer being actively managed.

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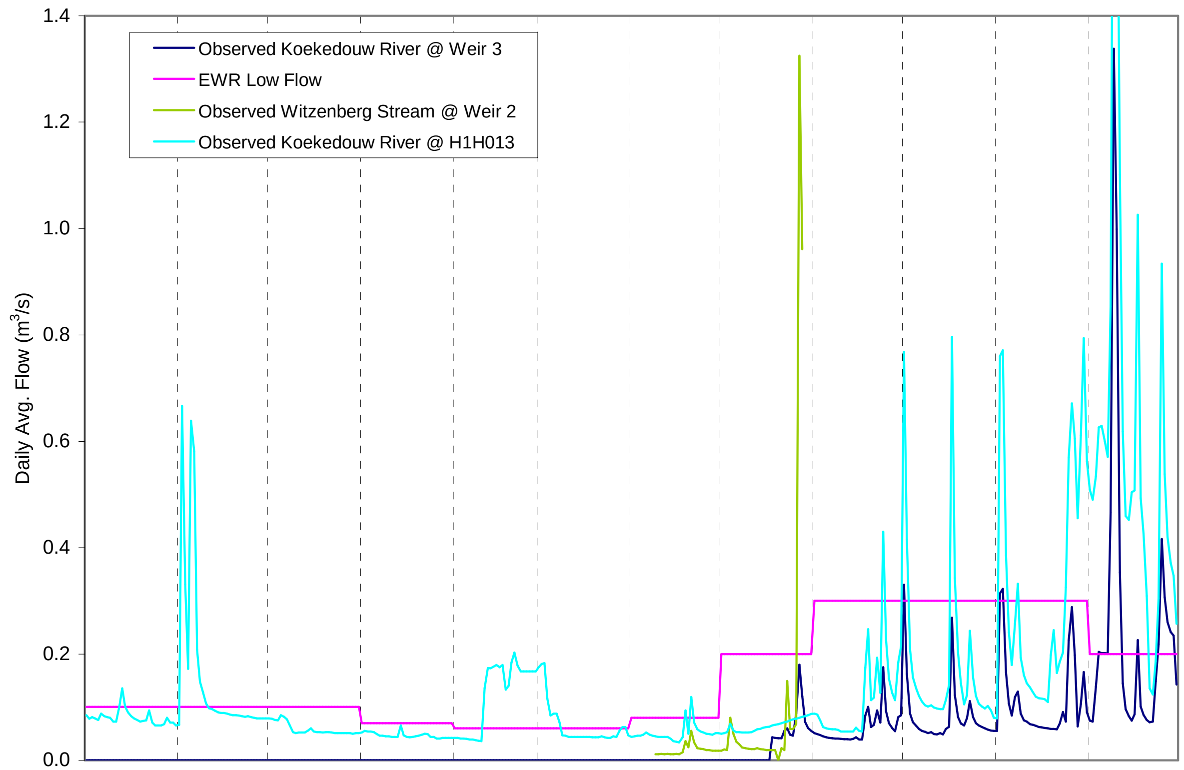
ANNEXURE A

ASSESSMENT OF EWR COMPLIANCE AT WEIR 3 IN THE KOEKEDOUW RIVER

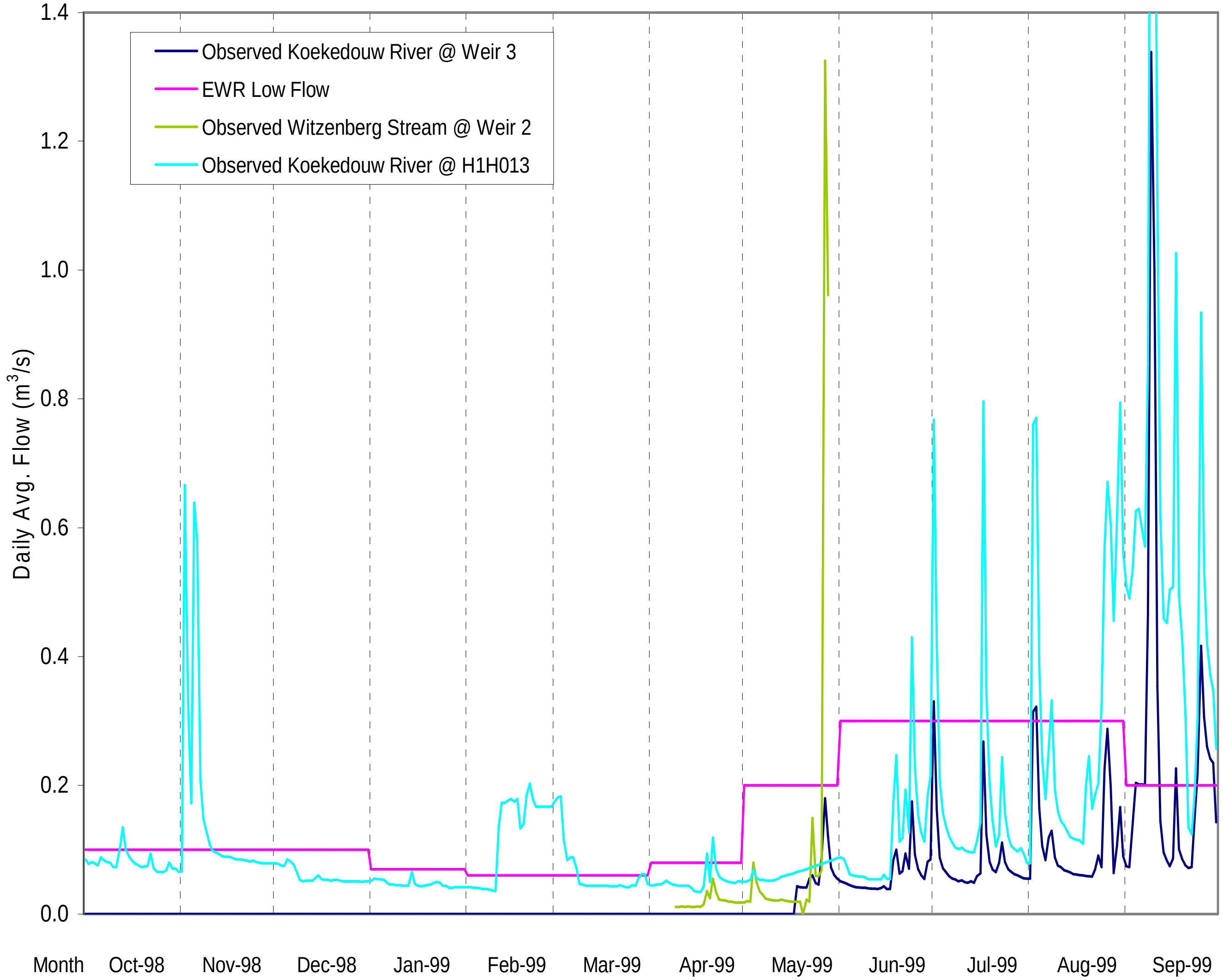
Koekedouw River: EWR Compliance (Normal Year) **1998 (Hydrological Year)**



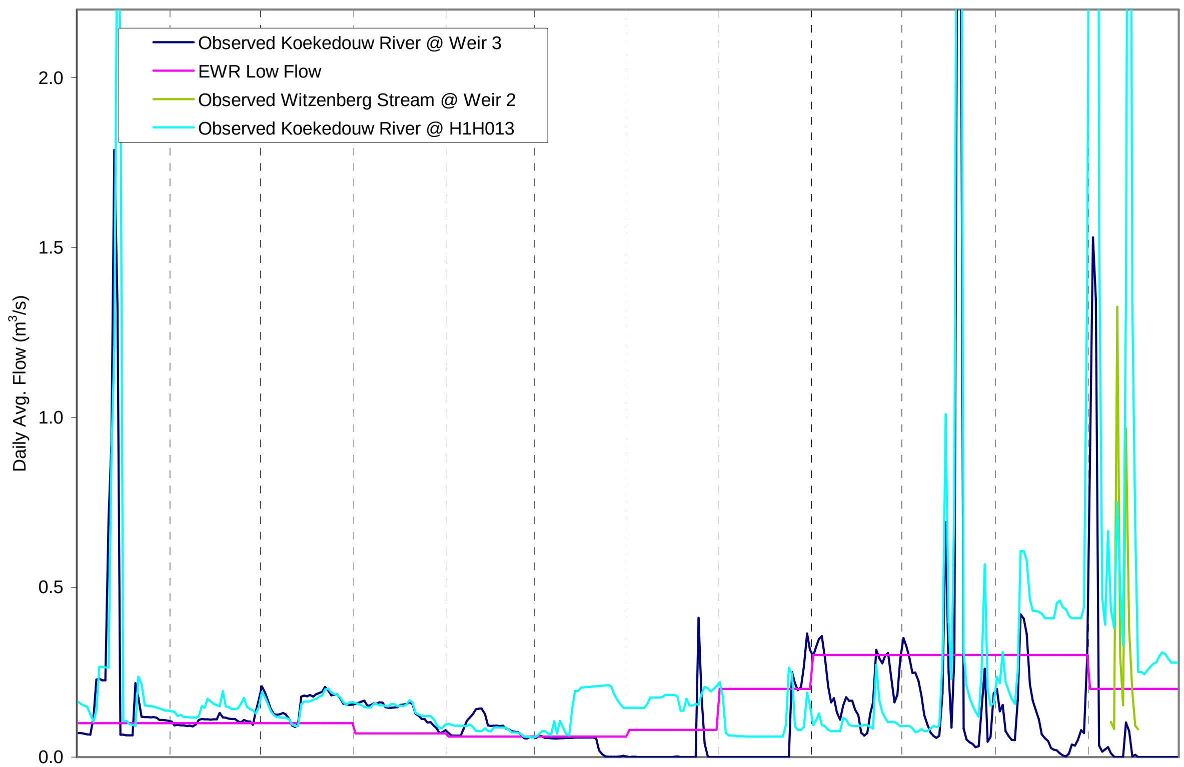
Month	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	Jun-99	Jul-99	Aug-99	Sep-99	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	Flow gauges not in operation yet					Missing Data			100%	97%	94%	50%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	Flow gauges not in operation yet					Missing Data							
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	Flow gauges not in operation yet					Missing Data			0.157	0.226	0.304	0.634	
Vol. deficit / surplus (Mm^3)	Flow gauges not in operation yet					Missing Data			-1.053	-0.578	-1.680	0.115	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	No	Spills

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) 1998 (Hydrological Year)



Koekedouw River: EWR Compliance (Normal Year) **1999 (Hydrological Year)**

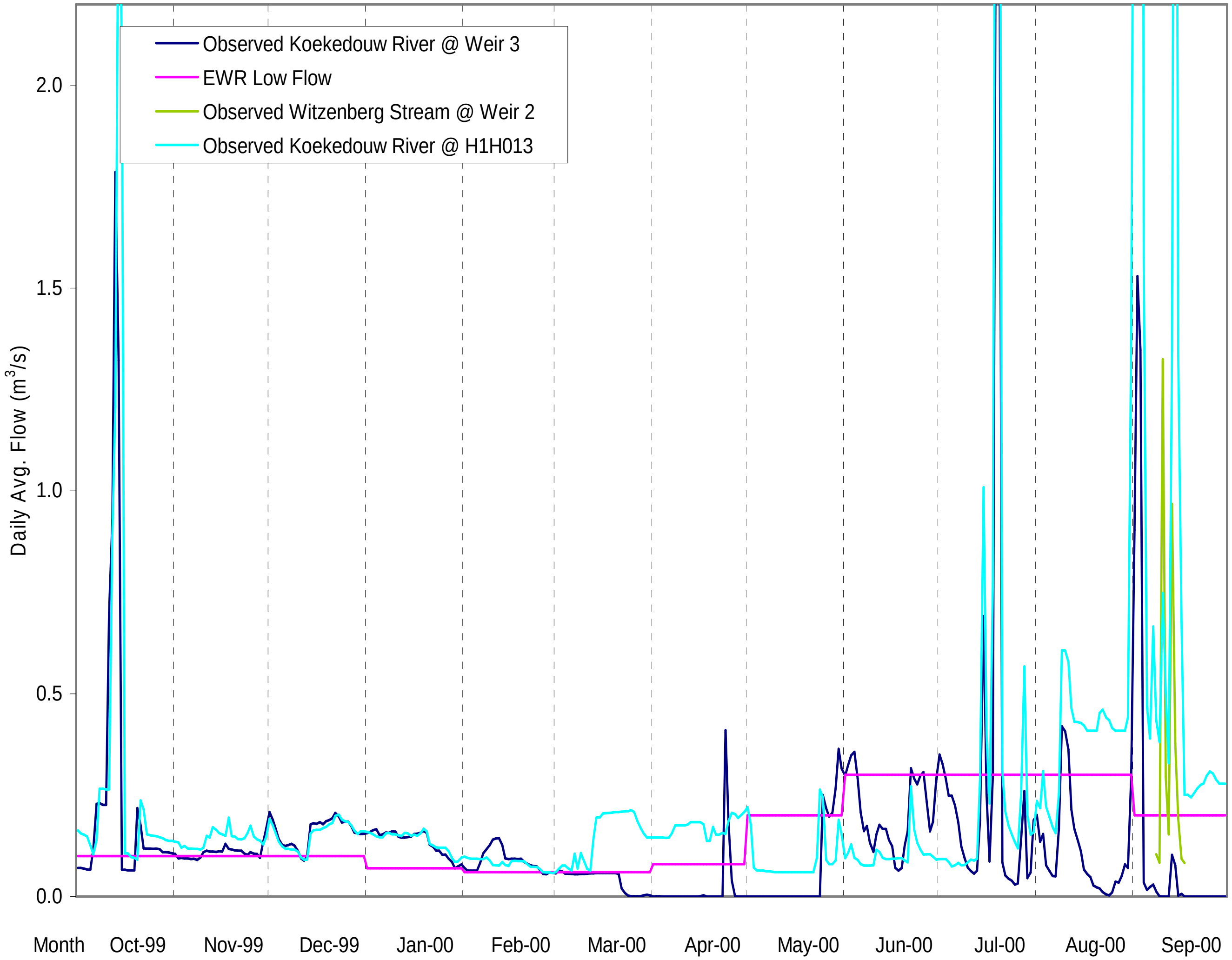


Month	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	32%	30%	10%	3%	14%	94%	Missing Data		83%	84%	90%	Missing	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	Missing Data		0.404	0.188	0.146	0.074	3.09*	0.569*	0.48	4.795	0.61	2.836*	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	0.688	0.281	0.427	0.361	0.220	0.107	Missing Data		0.533	0.896	0.307	Missing	
Vol. deficit / surplus (Mm^3)	0.420	-0.022	0.159	0.173	0.075	-0.053	Missing Data		-0.676	0.092	-1.678	Missing	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	No	Spills

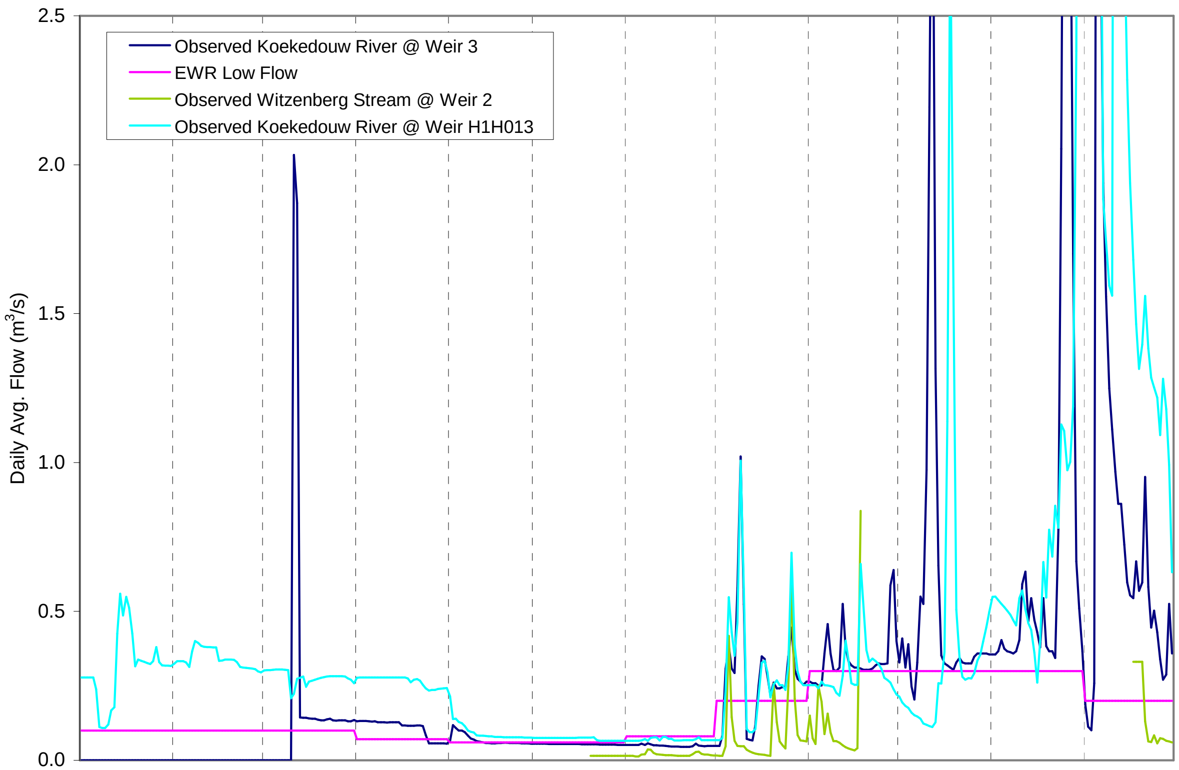
* Record incomplete

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) 1999 (Hydrological Year)



Koekedouw River: EWR Compliance (Normal Year) **2000 (Hydrological Year)**

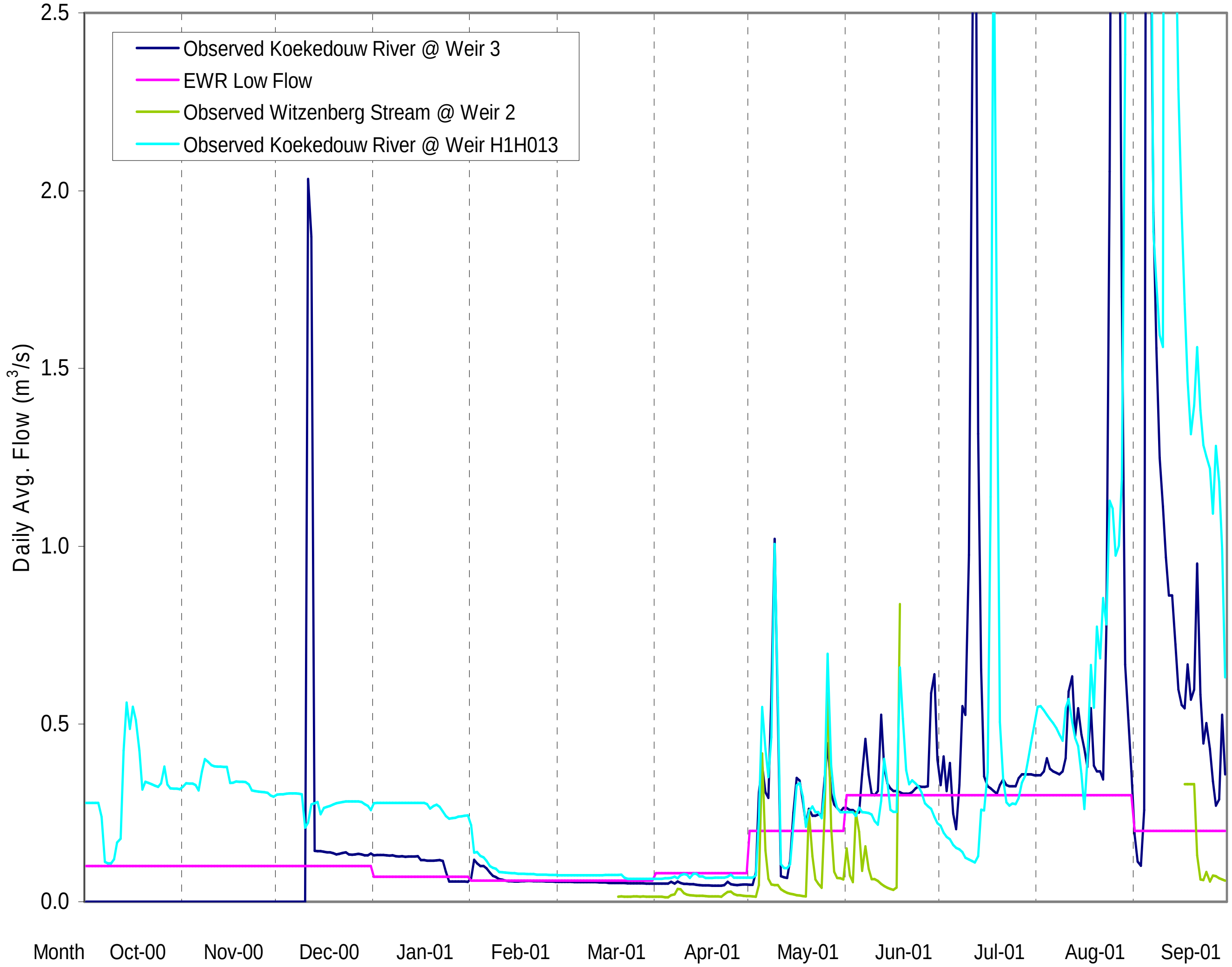


Month	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	Missing Data			23%	61%	100%	100%	23%	20%	6%	0%	10%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	Missing Data		2.084*	0.143	0.174	0.059	0.101	1.357	0.750	3.510	4.480	3.960	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	Missing Data			0.290	0.166	0.144	0.128	0.756	0.892	1.522	2.322	2.268	
Vol. deficit / surplus (Mm^3)	Missing Data			0.102	0.020	-0.016	-0.166	0.220	-0.318	0.719	0.338	1.750	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	Yes	Spills

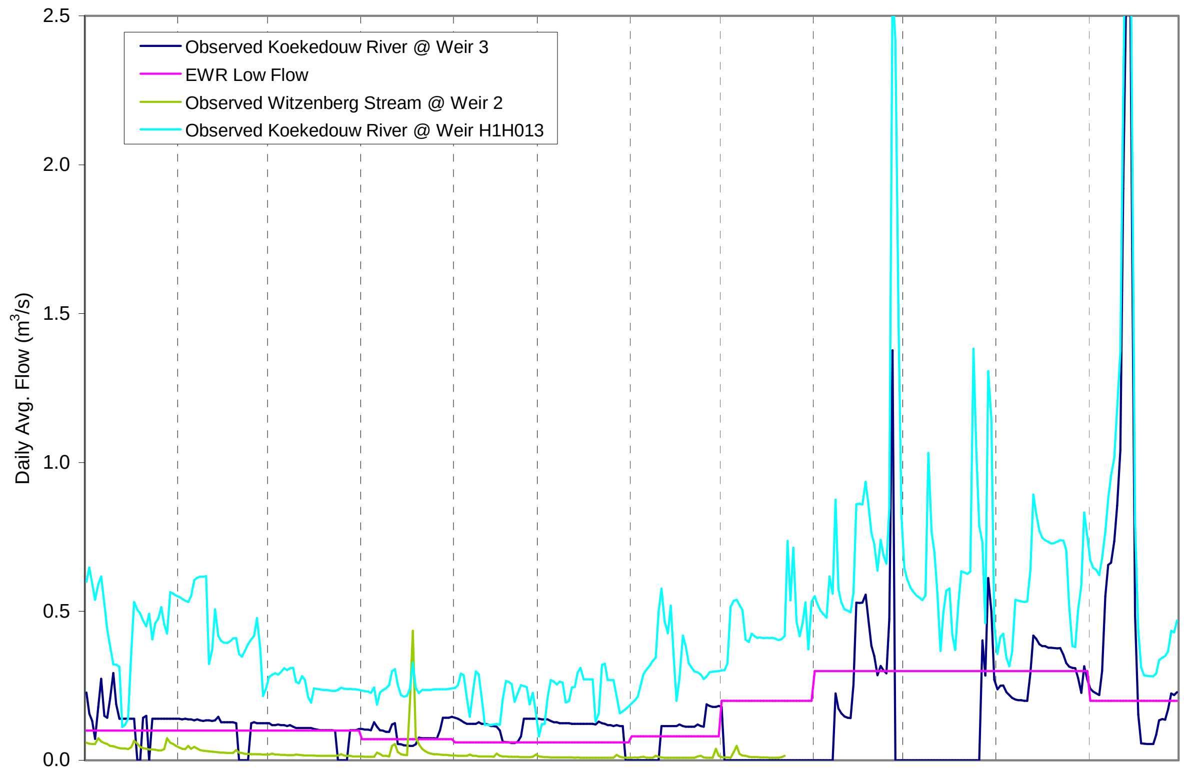
* Record incomplete

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) **2000 (Hydrological Year)**



Koekedouw River: EWR Compliance (Normal Year) **2001 (Hydrological Year)**

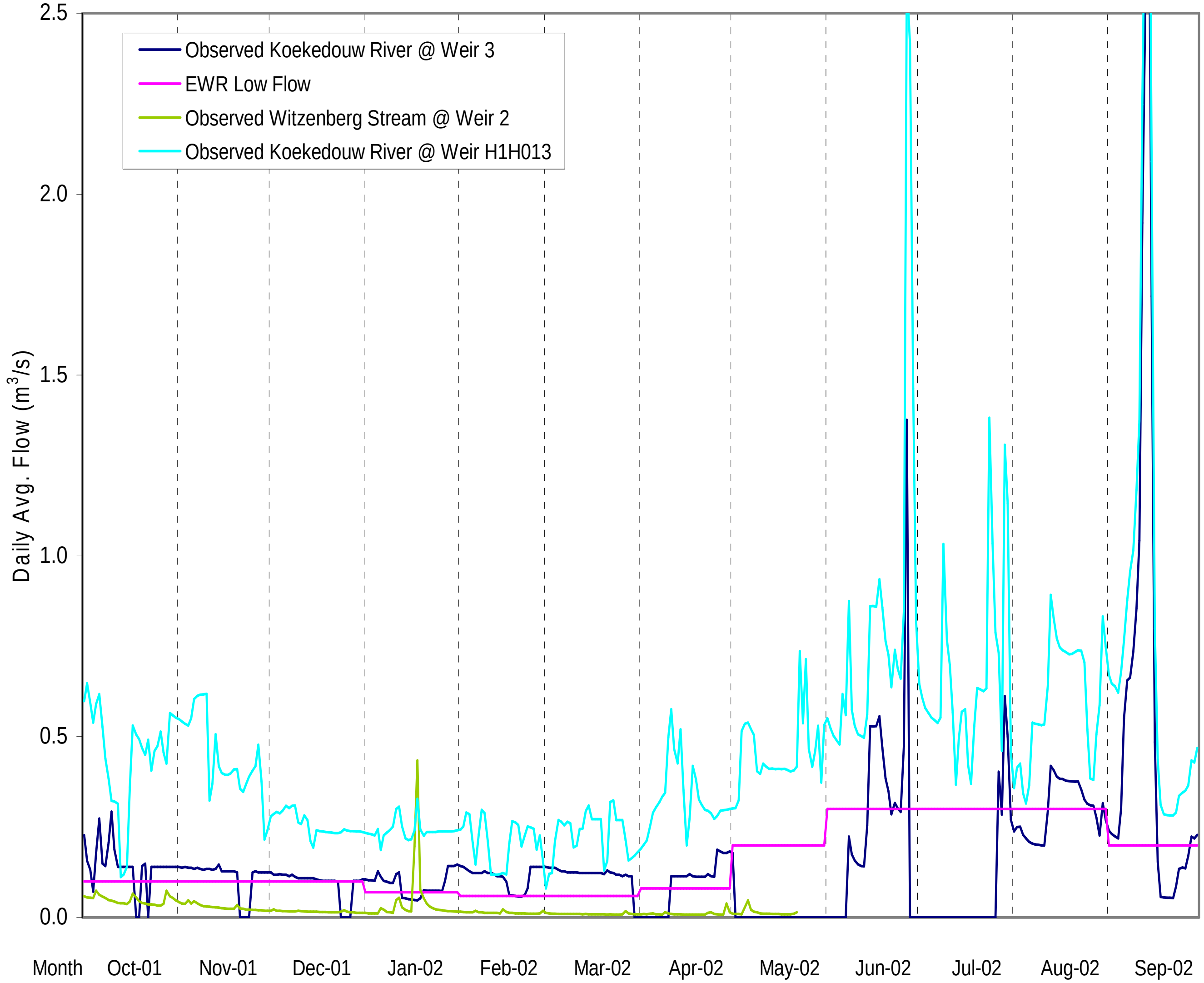


Month	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02	Sep-02	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	Missing Data			23%	11%	Missing Data					48%	37%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	Missing Data								3.277*	1.845*	0.48	5.02	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	Missing Data			0.246	0.269	Missing Data					0.801	1.485	
Vol. deficit / surplus (Mm^3)	Missing Data			0.058	0.124	Missing Data					-1.184	0.967	
Koekedouw Dam Spill	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	Spills

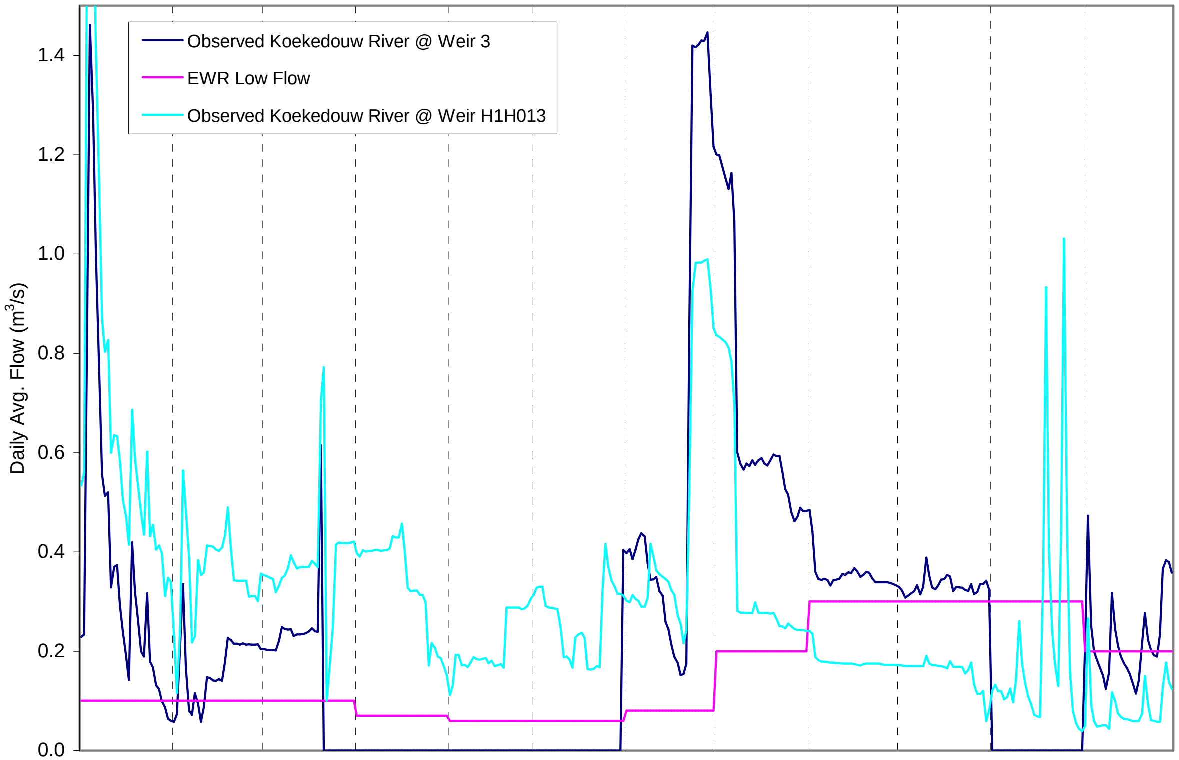
* Record incomplete

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) 2001 (Hydrological Year)



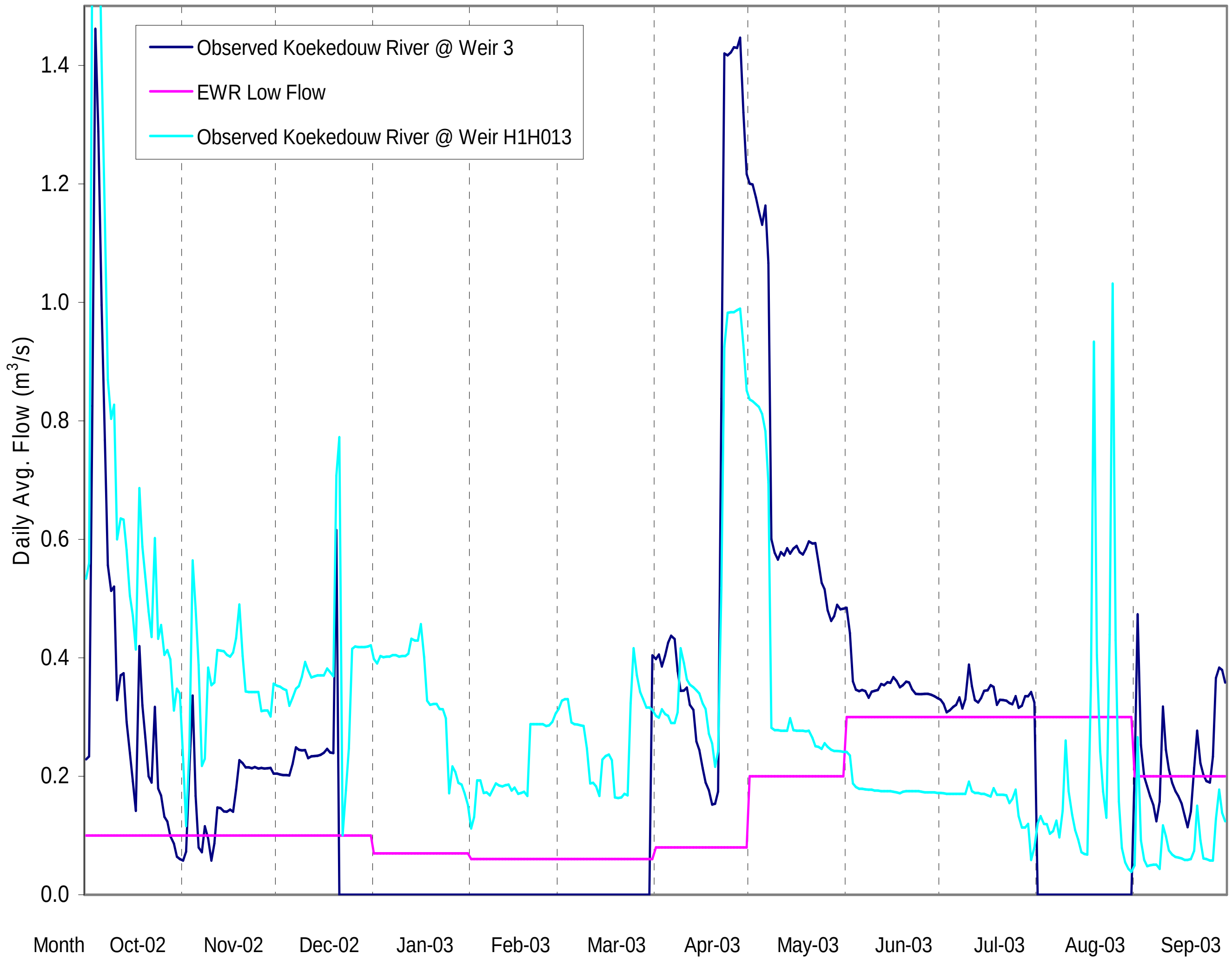
Koekedouw River: EWR Compliance (Normal Year) 2002 (Hydrological Year)



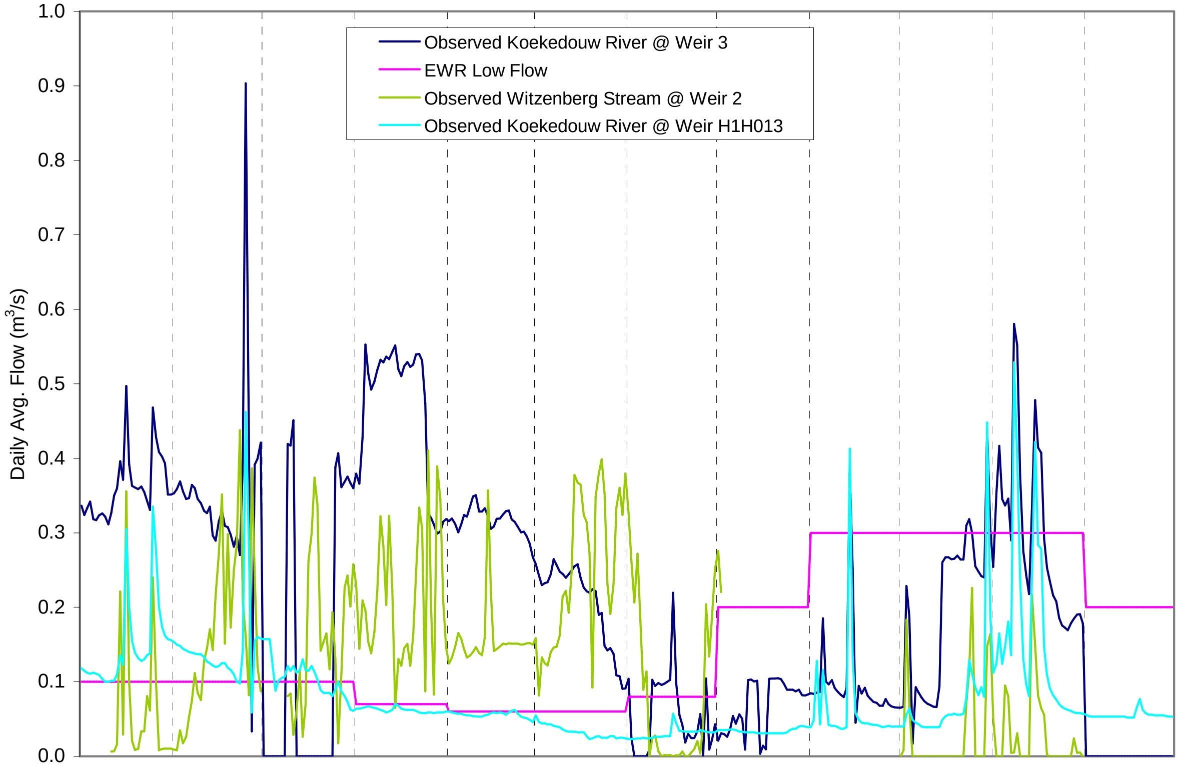
Month	Oct-02	Nov-02	Dec-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	13%	23%	Missing Data				0%	0%	0%	0%	Missing	50%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	2.276	0.957	Missing Data				1.534	1.266	0.53	0.648	Missing	0.813	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	1.033	0.429	Missing Data				1.593	1.841	0.921	0.887	Missing	0.586	
Vol. deficit / surplus (Mm^3)	0.765	0.127	Missing Data				1.299	1.305	-0.289	0.083	Missing	0.067	
Koekedouw Dam Spill	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Spills

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) **2002 (Hydrological Year)**



Koekedouw River: EWR Compliance (Normal Year) **2003 (Hydrological Year)**

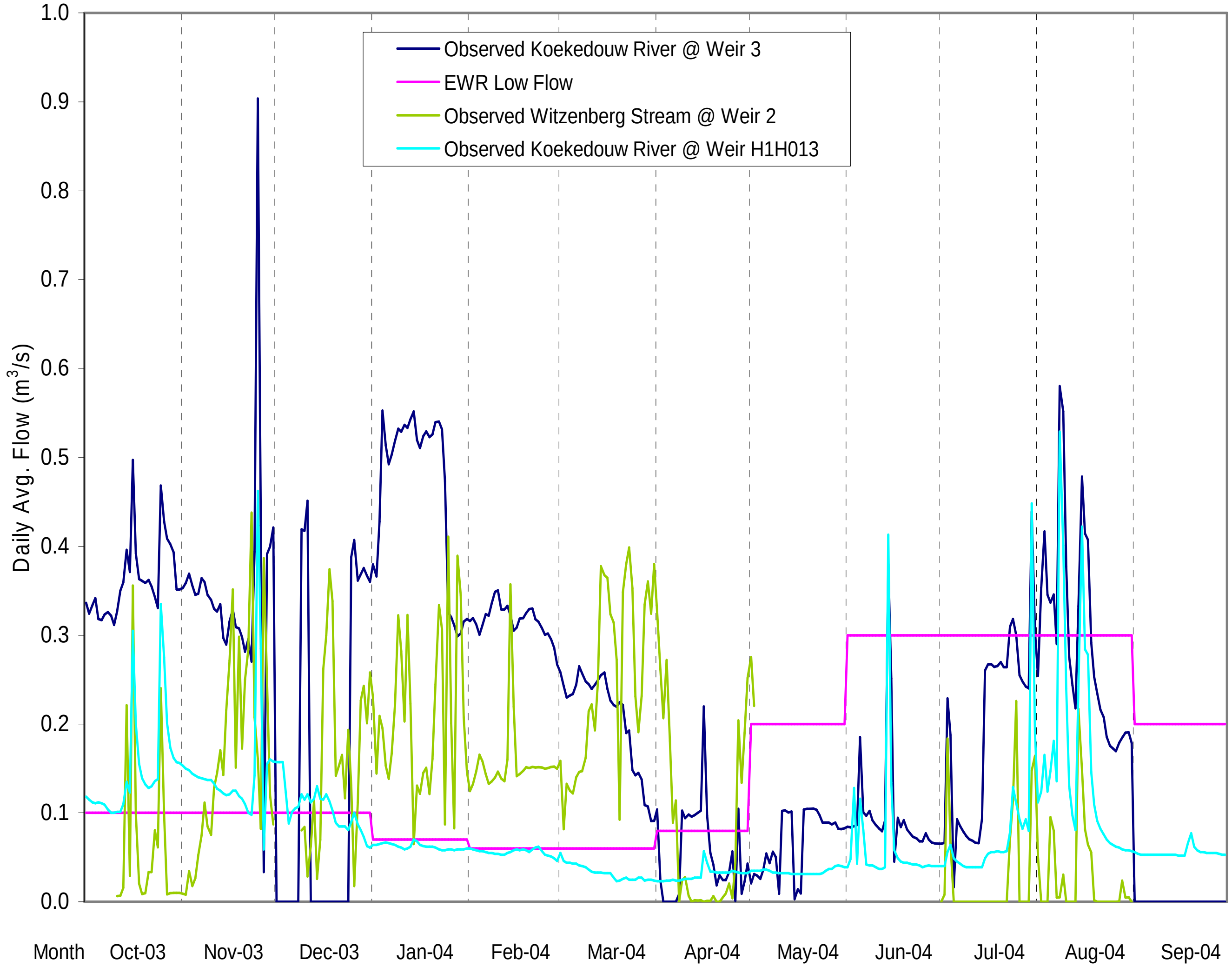


Month	Oct-03	Nov-03	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	0%	3%	Missing	0%	0%	0%	Missing	100%	97%	87%	61%	Missing	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	0.856	0.940	0.734*	0.769	0.411	0.308	.524*	0.120	1.065	0.745	1.126	Missing	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	0.970	0.906	Missing	1.243	0.793	0.554	Missing	0.181	0.258	0.522	0.782	Missing	
Vol. deficit / surplus (Mm^3)	0.702	0.604	Missing	1.055	0.648	0.393	Missing	-0.354	-0.951	-0.282	-1.202	Missing	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	No	Spills

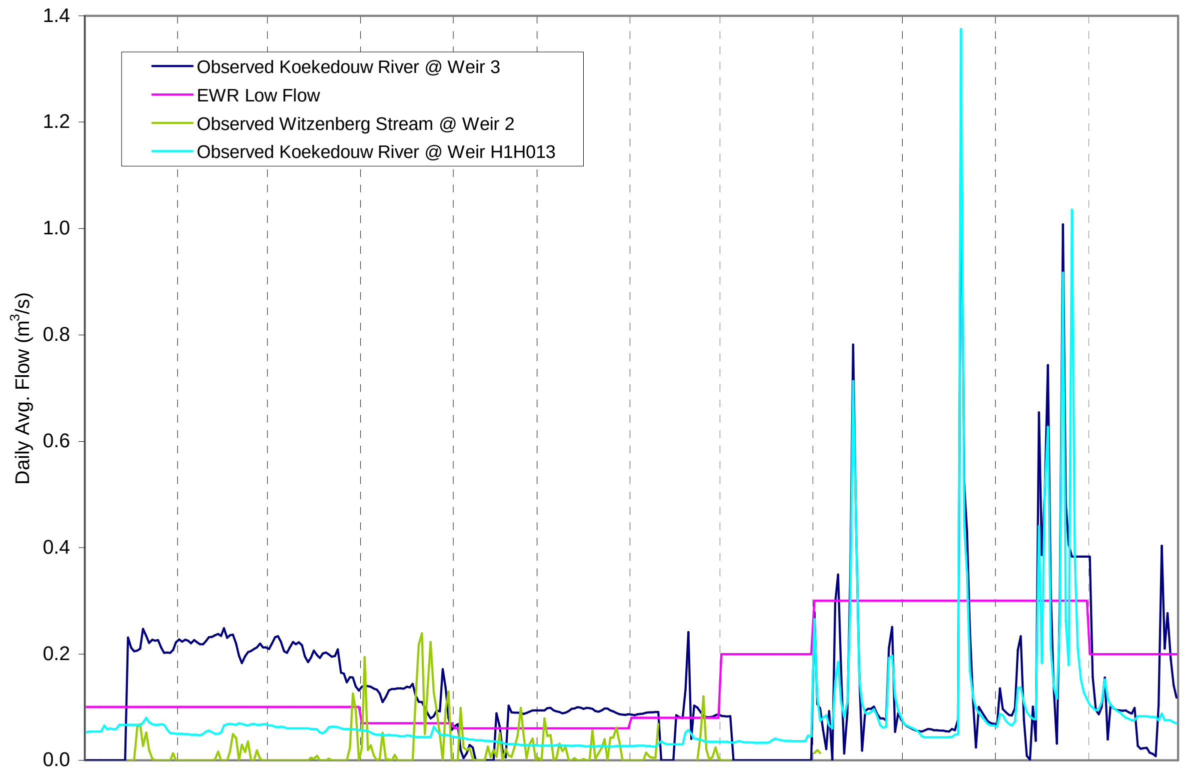
* Record incomplete

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) **2003 (Hydrological Year)**



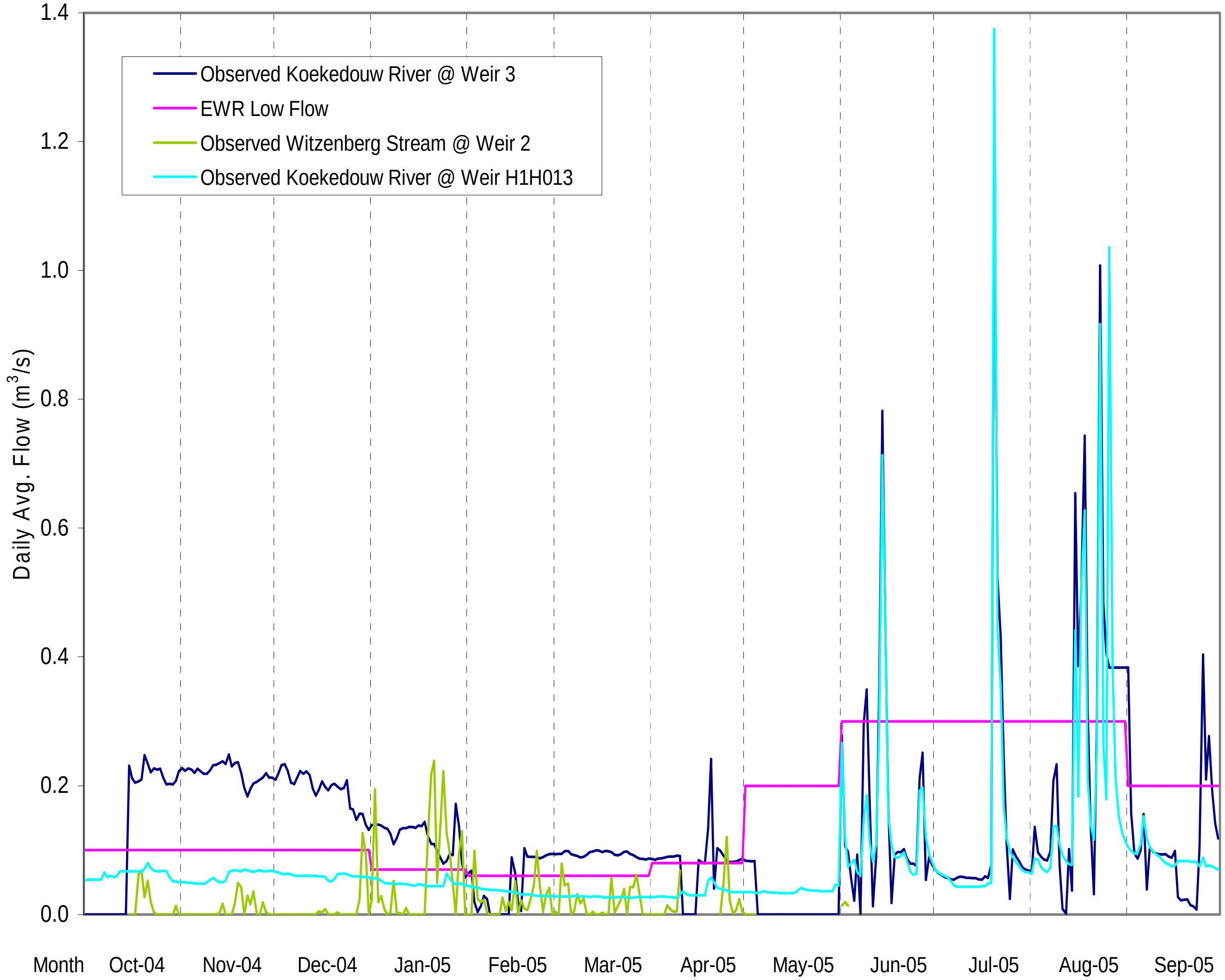
Koekedouw River: EWR Compliance (Normal Year) 2004 (Hydrological Year)



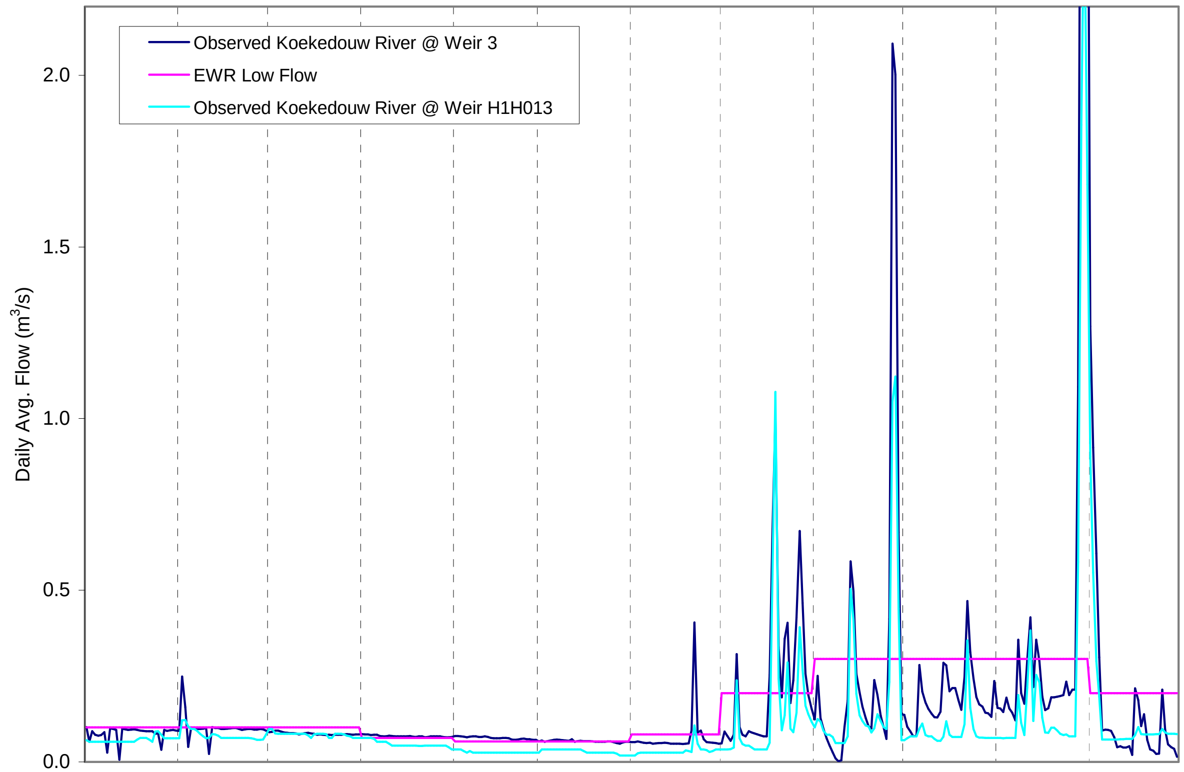
Month	Oct-04	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	Missing	0%	0%	3%	Missing	0%	Missing Data		87%	90%	55%	87%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	Missing	0.282	0.273	0.49	Missing	0.11	Missing Data		1.502	3.239	1.68	0.586	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	Missing	0.57	0.52	0.32	Missing	0.250	Missing Data		0.410	0.360	0.740	0.300	
Vol. deficit / surplus (Mm^3)	Missing	0.270	0.254	0.134	Missing	0.089	Missing Data		-0.800	-0.444	-1.244	-0.218	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	No	Spills

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) **2004 (Hydrological Year)**



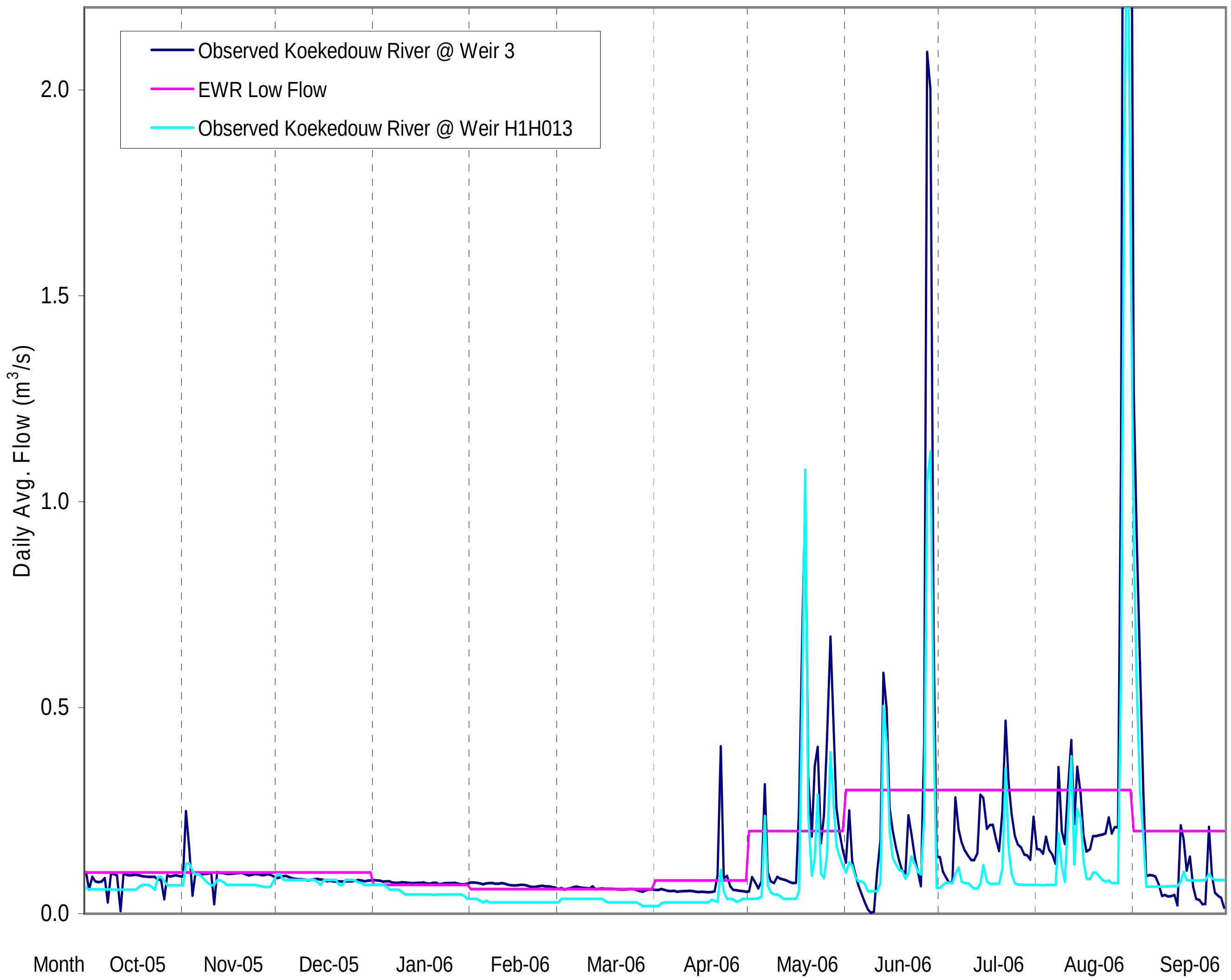
Koekedouw River: EWR Compliance (Normal Year) **2005 (Hydrological Year)**



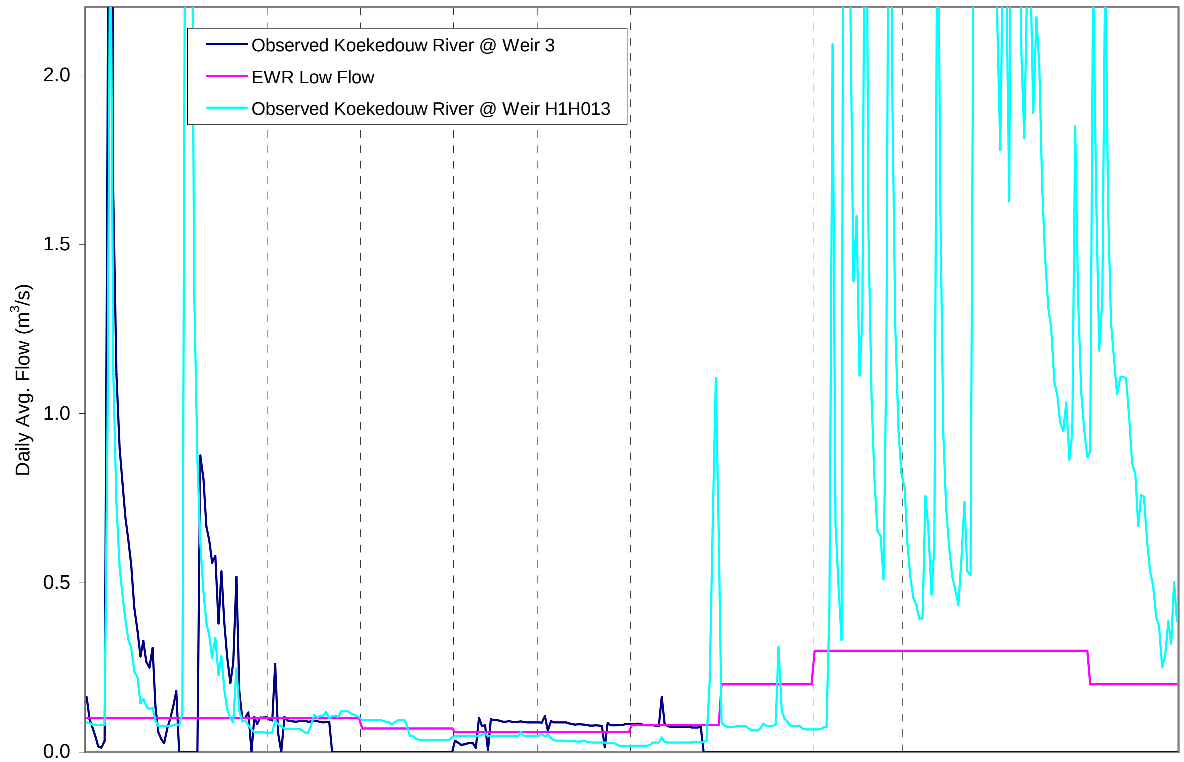
Month	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	97%	90%	100%	0%	0%	52%	87%	61%	80%	94%	77%	80%	
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	0.586	0.666	0.120	0.094	0.079	0.097	0.927	1.570	3.422	0.648	5.078	1.329	
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	0.221	0.257	0.220	0.201	0.169	0.161	0.183	0.629	0.788	0.503	1.538	0.435	
Vol. deficit / surplus (Mm^3)	-0.047	-0.046	-0.048	0.013	0.024	0.000	-0.111	0.093	-0.421	-0.301	-0.446	-0.083	
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	No	No	No	Spills

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) 2005 (Hydrological Year)



Koekedouw River: EWR Compliance (Normal Year) — 2006 (Hydrological Year)

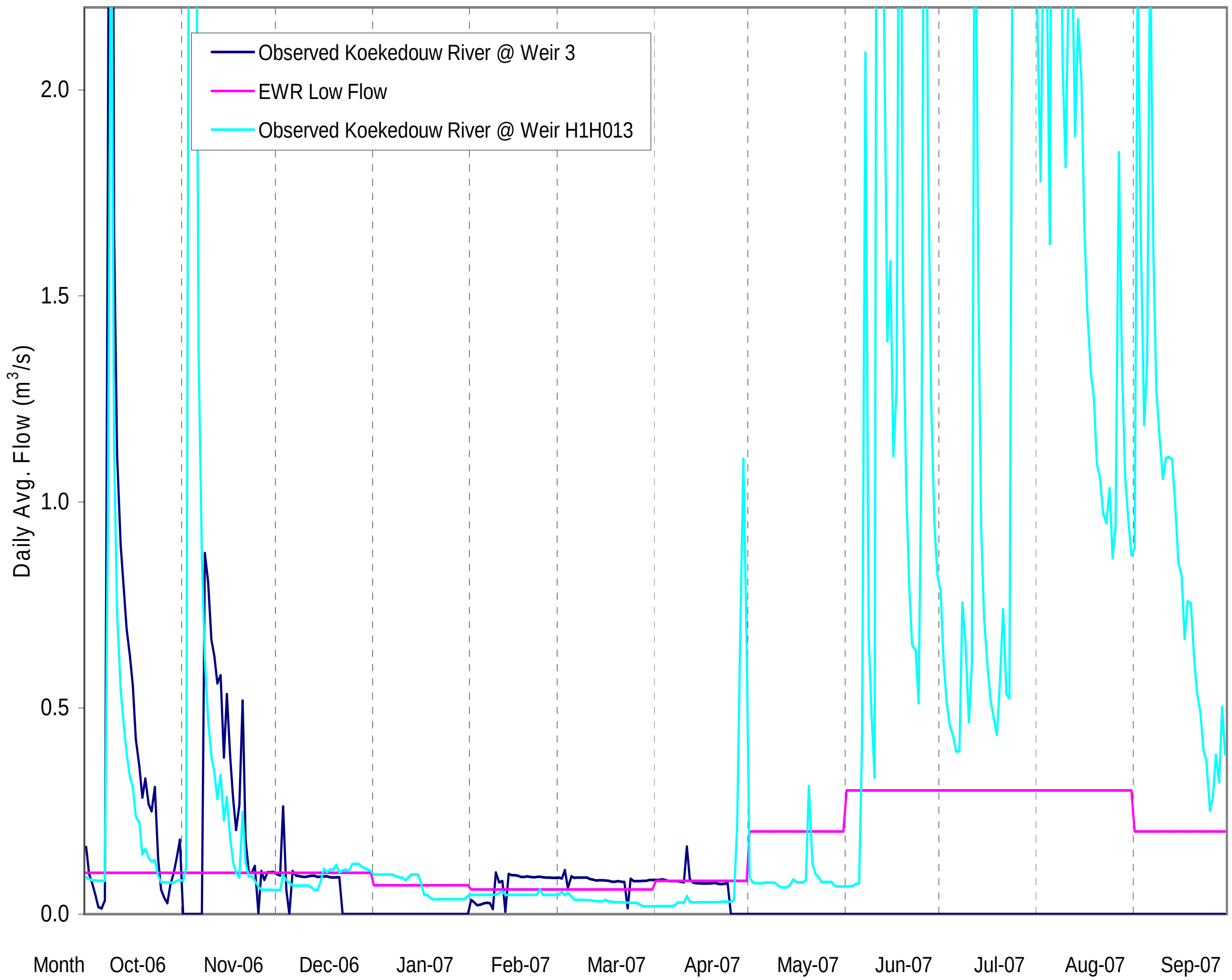


Month	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	
Min. EWR daily flow (m^3/s)	0.10	0.10	0.10	0.07	0.06	0.06	0.08	0.20	0.30	0.30	0.30	0.20	Low flows
% Days Flow < Min. EWR	32%	Missing Data			32%	3%	Missing Data						
EWR Peak (m^3/s)	-	0.5	-	-	-	-	0.5	-	3.0	-	7.0	-	High flows
Max. obs. Inst. Peak (m^3/s)	6.687	1.546*	0.301*	Missing	0.16	0.237	0.530*	Missing Data					
Total EWR Vol. (Mm^3/month)	0.268	0.302	0.268	0.187	0.145	0.161	0.294	0.536	1.210	0.804	1.984	0.518	EWR Volume
Observed Vol. (Mm^3)	1.359	Missing Data			0.165	0.217	Missing Data						
Vol. deficit / surplus (Mm^3)	1.091	Missing Data			0.020	0.056	Missing Data						
Koekedouw Dam Spill	No	No	No	No	No	No	No	No	No	Yes	No	No	Spills

* Record incomplete

Indicates volume deficit

Koekedouw River: EWR Compliance (Normal Year) **2006 (Hydrological Year)**



ANNEXURE B

SEDIMENT DEPTH TRANSECTS FROM THE 1999-2004 MONITORING PERIOD

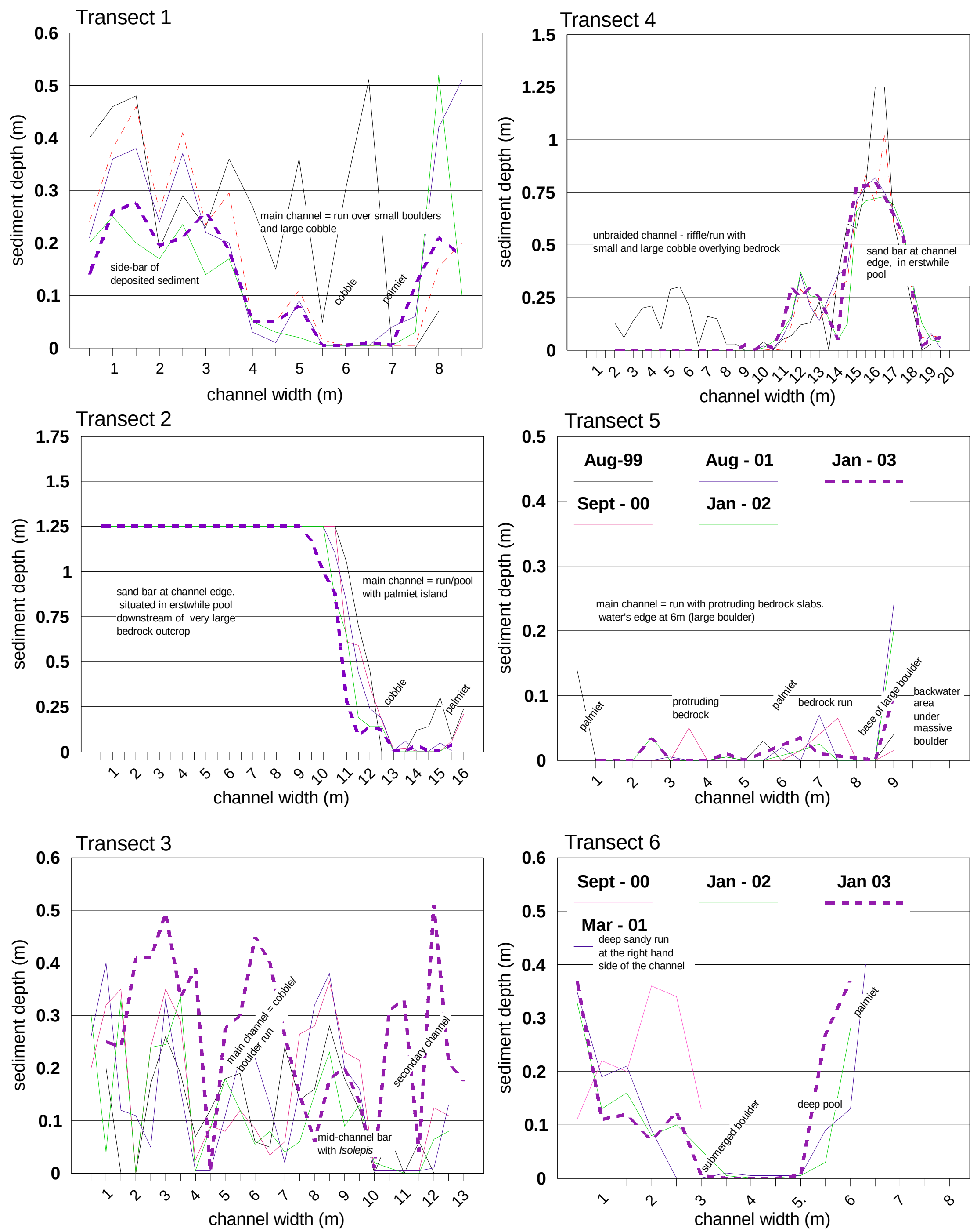


Figure AnnexB-1: Graphs showing the results of the sediment monitoring programme between July 1999 and January 2003, for six transects across the Koekedouw River (no sediment monitoring was undertaken for the 2003 to 2004 sampling period). Transects are plotted left bank to right bank (facing downstream). The legend shown in T5 refers to T1-T4 also.

ANNEXURE C

PLANT SPECIES LISTS FOR THE DECEMBER 2008 BOTANICAL ASSESSMENT

ANNEXURE C1
PLANT SPECIES RECORDED FROM SECTIONS OF THE KOEKEDOUW RIVER: INDIVIDUAL LISTS

Report produced by the SaSFLORA database: data (C) Coastec; database design and structures (C) Reuben Roberts 1998-2009

E: endangered, Ex: extinct, I: indeterminate, K: insufficiently known, R: rare, Us: unspecified, V: vulnerable

DWAF WEIR

Total named species:	**21**
Total genera:	**19**
Total families:	**15**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones
ANACARDIACEAE
Rhus
angustifolia
ASTERACEAE
Brachylaena
neriifolia
DROSERACEAE
Drosera
cf. cistiflora
ERICACEAE
Erica
abietina subsp. aurantiaca LC
caffra
MENYANTHACEAE
Nymphoides
indica
MYRICACEAE
Morella
cf. integra LC
MYRTACEAE
Metrosideros
angustifolia
PROTEACEAE
Leucadendron
cf. salicifolium LC
ROSACEAE
Cliffortia
ruscifolia
strobilifera

Division: Anthophyta **Class:** Monocotyledones
CYPERACEAE
Carpha
glomerata
Cyperus
cf. sphaerospermus
Isolepis
prolifera
IRIDACEAE
Watsonia
cf. meriana
JUNCACEAE
Juncus
lomatophyllus
POACEAE
Merxmuellera
cf. cincta
Pennisetum
macrourum
PRIONIACEAE
Prionium
serratum De
RESTIONACEAE
Calopsis
paniculata
Elegia
capensis

LOWER WEIRS

Total named species:	**15**
Total genera:	**13**
Total families:	**11**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones
ASTERACEAE
Brachylaena
neriifolia
BRUNIACEAE
Pseudobaeckea
africana
EBENACEAE
Diospyros
glabra
ERICACEAE
Erica
abietina subsp. aurantiaca LC
caffra
cf. daphniflora
MYRICACEAE
Morella
cf. integra LC
MYRTACEAE
Metrosideros
angustifolia
PROTEACEAE
Brabejum
stellatifolium LC
ROSACEAE
Cliffortia
strobilifera

Division: Anthophyta **Class:** Monocotyledones
POACEAE
Merxmuellera
cf. cincta
PRIONIACEAE
Prionium
serratum De
RESTIONACEAE
Calopsis
paniculata
Cannomois
cf. virgata
Elegia
capensis

SECTION 1 - DAM WALL TO BRIDGE 4

Total named species:	**19**
Total genera:	**19**
Total families:	**14**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones

ASTERACEAE
- Gnaphalium
  - cf. capense

BRUNIACEAE
- Pseudobaeckea
  - africana

DROSERACEAE
- Drosera
  - cf. cistiflora

EBENACEAE
- Diospyros
  - glabra

ERICACEAE
- Erica
  - caffra

MYRICACEAE
- Morella
  - cf. integra LC

MYRTACEAE
- Metrosideros
  - angustifolia

PROTEACEAE
- Leucadendron
  - cf. salicifolium LC

ROSACEAE
- Cliffortia
  - strobilifera

Division: Anthophyta **Class** Monocotyledones

CYPERACEAE
- Cyperus
  - cf. sphaerospermus
- Fuirena
  - hirsuta
- Isolepis
  - prolifera

JUNCACEAE
- Juncus
  - lomatophyllus

POACEAE
- Merxmuellera
  - cf. cincta
- Panicum
  - cf. schinzii
- Pennisetum
  - macrourum

PRIONIACEAE
- Prionium
  - serratum De

RESTIONACEAE
- Calopsis
  - paniculata
- Elegia
  - capensis

SECTION 2 - BRIDGE 4 TO BRIDGE 3

Total named species:	**21**
Total genera:	**20**
Total families:	**14**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones

ASTERACEAE
- Brachylaena
  - neriifolia

BRUNIACEAE
- Pseudobaeckea
  - africana

DROSERACEAE
- Drosera
  - cf. cistiflora

EBENACEAE
- Diospyros
  - glabra

ERICACEAE
- Erica
  - abietina subsp. aurantiaca LC
  - cf. daphniflora

MYRICACEAE
- Morella
  - cf. integra LC

MYRTACEAE
- Metrosideros
  - angustifolia

PROTEACEAE
- Leucadendron
  - cf. salicifolium LC

ROSACEAE
- Cliffortia
  - strobilifera

Division: Anthophyta **Class:** Monocotyledones

CYPERACEAE
- Carpha
  - glomerata
- Fuirena
  - hirsuta
- Isolepis
  - prolifera

JUNCACEAE
- Juncus
  - lomatophyllus

POACEAE
- Merxmuellera
  - cf. cincta
- Pennisetum
  - macrourum

PRIONIACEAE
- Prionium
  - serratum De

RESTIONACEAE
- Askidiosperma
  - chartaceum
- Calopsis
  - paniculata
- Cannomois
  - virgata
- Elegia
  - capensis

SECTION 3 - BRIDGE 3 TO BRIDGE 2

Division: Anthophyta **Class:** Dicotyledones

ASTERACEAE
- Brachylaena
  - neriifolia
- Gnaphalium
  - cf. capense

BRUNIACEAE
- Pseudobaeckea
  - africana

EBENACEAE
- Diospyros
  - glabra

ERICACEAE
- Erica
  - abietina subsp. aurantiaca LC
  - caffra
  - cf. daphniflora

MYRICACEAE
- Morella
  - cf. integra LC

MYRTACEAE
- Metrosideros
  - angustifolia

PROTEACEAE
- Leucadendron
  - cf. salicifolium LC

ROSACEAE
- Cliffortia
  - ruscifolia
  - strobilifera

SALICACEAE
- Salix
  - cf. mucronata subsp. capensis

SCROPHULARIACEAE
- Freylinia
  - lanceolata

Division: Anthophyta **Class:** Monocotyledones

CYPERACEAE
- Cyperus
  - cf. sphaerospermus
- Fuirena
  - hirsuta

POACEAE
- Merxmuellera
  - cincta
- Panicum
  - cf. schinzii
- Pennisetum
  - macrourum

PRIONIACEAE
- Prionium
  - serratum De

RESTIONACEAE
- Calopsis
  - paniculata
- Cannomois
  - cf. virgata
- Elegia
  - cf. asperiflora
  - capensis

Total named species:	**24**
Total genera:	**20**
Total families:	**14**
Total red data species:	**1**

SECTION 4 - BRIDGE 2 TO BRIDGE 1

Total named species:	**18**
Total genera:	**16**
Total families:	**14**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones
ASTERACEAE
Brachylaena
neriifolia
BRUNIACEAE
Pseudobaeckea
africana
CELASTRACEAE
Cassine
schinoides
EBENACEAE
Diospyros
glabra
ERICACEAE
Erica
abietina subsp. aurantiaca LC
caffra
cf. daphniflora
GRUBBIACEAE
Grubbia
rosmarinifolia
MYRICACEAE
Morella
cf. integra LC
MYRTACEAE
Metrosideros
angustifolia
PROTEACEAE
Leucadendron
cf. salicifolium LC
ROSACEAE
Cliffortia
strobilifera

Division: Anthophyta **Class:** Monocotyledones
CYPERACEAE
Carpha
glomerata
Fuirena
hirsuta
POACEAE
Panicum
cf. schinzii
PRIONIACEAE
Prionium
serratum De
RESTIONACEAE
Calopsis
paniculata
Elegia
capensis

SECTION 5 - BRIDGE 1 TO BRABEJUM "FOREST"

Total named species:	**11**
Total genera:	**11**
Total families:	**9**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones

BRUNIACEAE
- Pseudobaeckea
  - africana

MYRICACEAE
- Morella
  - cf. integra LC

MYRTACEAE
- Metrosideros
  - angustifolia

PROTEACEAE
- Leucadendron
  - cf. salicifolium LC

ROSACEAE
- Cliffortia
  - strobilifera

Division: Anthophyta **Class:** Monocotyledones

CYPERACEAE
- Fuirena
  - hirsuta

POACEAE
- Merxmuellera
  - cf. cincta
- Panicum
  - cf. schinzii
- Pennisetum
  - macrourum

PRIONIACEAE
- Prionium
  - serratum De

RESTIONACEAE
- Calopsis
  - paniculata

SECTION 6 - BRABEJUM "FOREST" TO LOWER WEIRS

Total named species:	**13**
Total genera:	**12**
Total families:	**9**
Total red data species:	**1**

Division: Anthophyta **Class:** Dicotyledones
BRUNIACEAE
Pseudobaeckea
africana
ERICACEAE
Erica
caffra
cf. daphniflora
MYRICACEAE
Morella
cf. integra LC
MYRTACEAE
Metrosideros
angustifolia
PROTEACEAE
Brabejum
stellatifolium LC
Leucadendron
cf. salicifolium LC
ROSACEAE
Cliffortia
strobilifera

Division: Anthophyta **Class:** Monocotyledones
POACEAE
Merxmuellera
cf. cincta
Panicum
cf. schinzii
PRIONIACEAE
Prionium
serratum De
RESTIONACEAE
Calopsis
paniculata
Elegia
capensis

ANNEXURE C2
PLANT SPECIES RECORDED FROM SECTIONS OF THE KOEKEDOUW RIVER: COMPOSITE LIST

Report produced by the SaSFLORA database: data (C) Coastec; database design and structures (C) Reuben Roberts 1998-2009

E: endangered, Ex: extinct, I: indeterminate, K: insufficiently known, R: rare, Us: unspecified, V: vulnerable

Division: Anthophyta
Class: Dicotyledones
ANACARDIACEAE
Rhus
angustifolia
ASTERACEAE
Brachylaena
neriifolia
Gnaphalium
capense
BRUNIACEAE
Pseudobaeckea
africana
CELASTRACEAE
Cassine
schinoides
DROSERACEAE
Drosera
cistiflora
EBENACEAE
Diospyros
glabra
ERICACEAE
Erica
abietina subsp. aurantiaca LC
caffra
daphniflora
GRUBBIACEAE
Grubbia
rosmarinifolia
MENYANTHACEAE
Nymphoides
indica
MYRICACEAE
Morella
integra LC
MYRTACEAE
Metrosideros
angustifolia
PROTEACEAE
Brabejum
stellatifolium LC
Leucadendron
salicifolium LC
ROSACEAE
Cliffortia
ruscifolia
strobilifera
SALICACEAE
Salix
mucronata subsp. capensis
SCROPHULARIACEAE
Freylinia
lanceolata

Division: Anthophyta
Class: Monocotyledones
CYPERACEAE
Carpha
glomerata
Cyperus
sphaerospermus
Fuirena
hirsuta
Isolepis
prolifera
IRIDACEAE
Watsonia
meriana
JUNCACEAE
Juncus
lomatophyllus
POACEAE
Merxmuellera
cincta
Panicum
schinzii
Pennisetum
macrourum
PRIONIACEAE
Prionium
serratum De
RESTIONACEAE
Askidiosperma
chartaceum
Calopsis
paniculata
Cannomois
virgata
Elegia
asperiflora
capensis

Total named species:	**35**
Total genera:	**31**
Total families:	**21**
Total red data species:	**1**

ANNEXURE D

ALGAL SPECIES LIST FOR THE DECEMBER 2008 SURVEY

Table AnnexD-1: List of algal taxa (to genera/species) recorded in samples collected from three sites along the Koekedouw River in December 2008, grouped according to Division.

DIVISION	GENERA/SPECIES	Sampling sites		
		DWAF Weir	B1	B3
Chlorophyta	*Ankistrodesmus* sp.	X		
	Bulbochaete sp.		X	X
	Chlorococcum sp.	X	X	X
	Cosmarium sp.1	X	X	X
	Cosmarium sp.2		X	X
	Cylindrocystis sp.	X		
	Desmococcus sp.	X	X	X
	Moegeotia sp.	X		
	Scenedesmus sp.	X	X	
	Sphaerocystis sp.	X	X	
	Unknown sp.		X	
Chrysophyta	*Achnanthes* sp.		X	X
	Achnanthidium sp.	X	X	X
	Diadesmis sp.	X		
	Dinobryon sp.	X	X	
	Encyonopsis sp.		X	
	Eunotia bilunaris	X	X	
	Eunotia incisa	X	X	X
	Eunotia pectinalis			X
	Eunotia rhomboidea	X	X	X
	Eunotia sp.1	X		
	Eunotia sp.2	X		
	Fallacia sp.	X		
	Frustulia saxonica	X	X	X
	Frustulia vulgaris		X	
	Gomphonema sp.1	X		
	Gomphonema sp.2	X		
	Navicula cincta		X	
	Navicula gregaria	X		
	Navicula minima	X	X	
	Navicula sp.	X		X
	Nitzschia sp.	X	X	
	Placoneis sp.	X		
	Tabellaria flocculosa	X	X	X
	Tabellaria sp.			
Cyanophyta	*Anabaena* sp.	X		
	Aphanocapsa sp.	X		
	Aphanothece sp.	X	X	
	Chroococcus minutus		X	X
	Chroococcus sp.			X
	Lyngbya sp.		X	
	Oscillatoria sp.1	X	X	X
	Oscillatoria sp.2		X	
	Scytonema sp.		X	X
	Unknown sp.			X
Euglenophyta	*Euglena* sp.	X	X	

ANNEXURE E

AQUATIC MACROINVERTEBRATE SPECIES LIST FOR THE DECEMBER 2008 SURVEY

Table AnnexE-1: List of aquatic macroinvertebrate taxa from samples collected at three sites along the Koekedouw River in December 2008 (all biotope groups combined), with an estimate of the abundance of each taxon in each sample (abundance codes: A = 1; B = 2–10; B = 11–20; C = 21–100; E = >100). Taxa organised by taxonomic group, order, family and then species. Taxa with "c.f." mean that taxon keyed out to this point in the taxonomic reference used (typically a key from another region of the world) and is the closest designation - may or may not be within this genus; "?" denotes an uncertainty of a generic or species designation, but thought to be near the designation based on identification keys and distribution notes available.

Group	**Order**	**Family**	**Taxon**	**Common Name**	**Sampling sites**		
					B1	**B3**	**W**
Crustacea	Amphipoda	Paramalitidae	*Paramelita nigroculus*	scuds	B		
	Decapoda	Potamonautidae	*Potamonautes perlatus*	Cape river crab		B	
Insecta	Coleoptera	Dytiscidae: Hydroporinae: Hydrovatini	*Hydrovatus* sp. adult	predacious diving beetles	B	A	
		Elmidae: Elminae	Elminae sp. larvae	riffle beetles	A		A
			Elpidelmis capensis adult		B	A	A
		Gyrinidae: Orectochilini	*Orectogyrus* sp. adult	whirligig beetles			A
		Hydraenidae: Hydraeninae	*Hydraena monikae?* adult	minute moss beetles	B	B	A
		Hydraenidae: Prosthetopinae	*Mesoceration* sp. adult		E		
			Parasthetops sp. adult			D	
		Hydrophilidae: Hydrophilinae	*Anacaena* sp. Adult	water scavenger beetles		B	
			Enochrus sp. adult		B		
			Enochrus sp. larvae		A		
	Diptera	Ceratopogonidae: Forcipomyiinae	*Atrichopogon* sp. larvae	biting midges	A		
		Chironomidae	Chironomidae sp. adult	non-biting midges		A	
		Chironomidae: Chironominae: Chironomini	*Poypedlium* sp. larvae				B
		Chironomidae: Chironominae: Tanytarsini	*Rheotanytarsus fuscus* sp. larvae		B	B	D
			Stempellina sp. larvae		A		
			Tanytarsus sp. larvae		C		C
			Tanytarsus sp. pupae		A		
		Chironomidae: Orthocladiinae	*Cardiocladius* sp. larvae		D	A	C
			Cricotopus sp. larvae		D		C
			Metriocnemus sp. larvae		A		
			Metriocnemus sp. pupae		B	A	
			Nanocladius sp.larvae				A
			Rheocricotopus sp. larvae		B	B	D
			Tvetenia sp. larvae		A		B
		Chironomidae: Tanypodinae	*Ablabesmyia* sp. larvae				B
			Conchapelopia sp. larvae		C		B
			Conchapelopia sp. pupae		B		
			Nilotanypus sp. larvae				A
			Nilotanypus sp. pupae				B
			Paramerina sp. larvae		A		B
			Paramerina sp. pupae				A
		Empididae	*Clinocera* sp. larvae	dance flies		B	C
			Clinocera sp. pupae		A		A
		Simuliidae	*Simulium (Anasolen) dentulosum* larvae	black flies			B
			Simulium (Metomphalus) sp. larvae			B	
			Simulium (Nevermannia) nigritarse? larvae		E	D	E
			Simulium (Pomeroyellum) alcocki group sp. pupae		A		
			Simulium (Pomeroyellum) sp. larvae		C	B	B
		unknown	Diptera adult	flies	A	A	

Table AnnexE-1 (cont.)

Group	Order	Family	Taxon	Common Name	Sampling sites		
					B1	B3	W
Insecta (cont.)	Ephemeroptera	Baetidae	*Baetis harrisoni*	minnow mayflies	D	D	C
			Baetis sp.		C		
	Hemiptera	Notonectidae	*Anisops* sp. nymph	backswimmers		A	
		unknown	Hemiptera sp. nymph?				A
	Megaloptera	Corydalidae: Corydalinae	*Chloroniella peringueyi*	dobson flies	B		
	Odonata: Anisoptera	Gomphidae	*Notogomphus praetorius?*	Yellowjack longlegs dragonflies	B		
		Libellulidae	Libellulidae sp.	Dropwing dragonflies		A	
			Trithemis sp.		B		A
	Odonata: Zygooptera	Platycnemididae	*Metacnemis angusta?* sp.	Featherlegs damselflies			A
			Platycnemidae sp.				B
	Trichoptera	Hydropsychidae: Hydropsychinae	*Cheumatopsyche afra* larvae	fixed-shelter caddisflies	A		
			Cheumatopsyche maculata larvae		D	C	C
			Cheumatopsyche? sp. pupae		B	B	
		Hydropsychidae: Macronematinae	*Macrostemum capense* larvae				B
		Leptoceridae	leptocerid gen. nov. sp. nov. larvae	transportable case caddisflies		A	
		Leptoceridae: Leptocerinae: Athripsodini	*Athripsodes* sp. Larvae				A