ENVIRONMENTAL WATER QUALITY IN MAKANA MUNICIPALITY, EASTERN CAPE, SOUTH AFRICA: A CASE STUDY OF LOCAL GOVERNMENT RESPONSIBILITY FOR WATER RESOURCE MANAGEMENT

VON DER MEDEN CEO[1], PALMER CG [2], DAVIES-COLEMAN HD[#2], AND GOLA NP[2]
[1]Department of Environmental Sciences, Rhodes University, PO Box 94, Grahamstown, 6140, South Africa.
[2]Unilever Centre for Environmental Water Quality, Institute for Water Research, Rhodes University, PO Box 94, Grahamstown, 6140, South Africa.

Corresponding author

ABSTRACT

In South Africa there are two major pieces of water legislation, the National Water Act (No. 36 of 1998) (NWA), which governs water resource management, and the Water Services Act (No. 108 of 1997) (WSP), which legislates the provision of water and sanitation. Institutional arrangements to support the implementation of these Acts are devolved across three levels of government. At the local level, water resource management will be the responsibility of Water User Associations (WUA) and catchment forums (CF). In contrast, water service provision is actively devolved to the municipal level of local government. As there is little guidance for linkages between WUA and forums with municipal structures, there is little direction for municipal action in water resource management. This leaves the challenge of integrating sustainable management of water resources (which supports and limits water use) and effective water service provision to the municipality. Makana Municipality responded to this challenge through the initiation of a local environmental action plan (LEAP), which aims to implement sound environmental management as a first step towards sustainable development. In this paper we outline the LEAP process, report on a present ecological state (PES) assessment of environmental water quality in Makana and recommend implementation plans for the municipality. Water chemistry and biomonitoring data revealed the PES of most sites in the municipality to be Poor or Fair, while toxicity testing showed toxicity of out-flowing effluent from the Grahamstown sewage treatment works (STW) to be relatively high. Recommendations focus on risk assessment, communication, effective data management with decision-making links.

INTRODUCTION

South Africa is a semi-arid country and, as in the rest of Africa, “urbanization has led to deterioration in the quality of water in streams and lakes near urban centres” (Moyo and Phiri, 2002). Deteriorating water resource quantity and quality is likely to become a serious restriction to future socio-economic development (Peart and Govender, 2001). In South Africa there are two major pieces of water legislation: The South African National Water Act (No. 36 of 1998) (NWA), which deals with water resource management (WRM) and the South African Water Services Act (No. 108 of 1997) (WSA), which deals with water service provision (WSP). The institutional arrangements that support the implementation of this legislation are devolved across all three tiers of government: national, regional and local (DWAF, 2004).

At the National Government level, the Department of Water Affairs and Forestry (DWAF) acts as the “public trustee” to ensure that “water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons…” (NWA, Chapter 1:3(1)). The Act goes on to emphasize the promotion of environmental values and a focus on regulation (Chapter 1:3(2) and (3)). At a regional level, water resource management is currently undertaken by regional DWAF offices, but their powers and responsibilities are being transferred to Catchment Management Agencies (CMAs) (NWA, Chapter 7) which will administer 19 water management areas (WMAs) (DWAF, 2004). At the local level, water resource management will be undertaken by Water User Associations (WUA)(NWA, Chapter 8), with additional stakeholder input from Catchment Forums (CF). In contrast, the Constitution (Schedule L Part B) devolves responsibility for water service provision to local government in the form of municipalities. The Water Services Act establishes water services authorities (WSAs) to manage water services provision, and local authorities can act as WSAs. Added challenges are posed by municipal and WMA boundaries that do not coincide, the lack of attention to the linkages required for sustainable WRM to support water service provision, and lack of guidance provided for forging links between WUAs, Catchment Forums and municipalities. In this paper we explore the efforts of Makana Municipality to engage effectively with WRM issues.

Resource Directed Measures

In South Africa, water resource management (WRM) attempts to create a balance between the *protection* and *use* of water resources. This balance is essential for sustainable water use since both over protection and under protection are inefficient and expensive (Palmer *et al.,* 2004a). In order to find the most suitable level of protection, the NWA provides for the ecological Reserve, which comprises descriptive and quantitative definitions of the physical structure, water quality, and water quantity required by aquatic ecosystems to maintain a defined level of ecosystem integrity (Palmer, 1999; Palmer *et al.*, 2004a). Two main mechanisms are involved in implementing the ecological Reserve: Resource Directed Measures (RDM) (DWAF, 1997; 2003), which focus on setting objectives for the resource; and Source Directed Controls (SDC) (DWAF, 1997), which involve controlling impacts on the resource. Of these, RDM are the most pertinent to this study as they are directly concerned with the state of the resource. RDM not only provide descriptive and quantitative goals for the state of the resource in general, but also more specifically include the formulation of quantifiable and descriptive goals for ecosystem condition and user requirements, known as 'ecospecs' and 'userspecs' respectively (Palmer *et al.,* 2004a).

Present Ecological State

A major component of the RDM procedure (DWAF, 1999; 2003) is the present ecological state (PES) assessment (Palmer *et al*., 2004b). The purpose of the PES is to provide information on the current state of resource units in terms of ecological health, integrity and degree of difference from the natural state. These descriptions are formalized and categorized into a set of classes: Natural, Good, Fair, or Poor (DWAF, 2003; Palmer e*t al*., 2004b). The ecological components to be assessed include water quantity (the magnitude, duration, timing and reliability of the flow); water chemistry (system variables, which may include: total dissolved solids, pH, dissolved oxygen, temperature and total suspended solids; nutrients such as nitrogen and phosphorus; and toxic substances); and ecological state (bioassessment and geomorphology) (Hughes 2004). In this paper the focus is on environmental water quality (EWQ), an approach that links water chemistry, bioassessment and ecotoxicology (Palmer *et al*., 2004a). The PES is described in terms of nutrients (phosphate and total inorganic nitrogen), (Palmer *et al*., 2004b) salts (Jooste, pers. comm. 2004), macroinvertebrate bioassessments (Dickens and Graham, 2002), and aspects of ecotoxicity.

Once the PES has been classified and described, management objectives can then be selected. National water policy requires that water resources must be managed for at least a Fair state in order to avoid, and/or to rehabilitate, degraded water resources (DWAF 2004).

Water resource management decisions therefore involve choosing a state from Fair to Natural, based on the ecosystem functions/resources desired (Palmer *et al*., 2002).

Mechanisms for local water resource management

The vision for water resource management in South Africa has been described as progressive, forward thinking and ambitious (MacKay *et al*., 2003). As such, implementation of the country's novel water law and policy will require equally inventive ways to surmount the numerous problems which line the path to equity and sustainability. Given the logistical nature of several of these problems (such as limited finances, and a lack of qualified personnel) water quality and biomonitoring data monitoring methods need to be rapid, simple to use and inexpensive, whilst maintaining a reasonable level of accuracy (Malan and Day, 2003). In addition to this, MacKay *et al*. (2003) suggest that a broader and possibly greater challenge is that of "changing the mindsets of people, both officials and water users, to support a truly adaptive process of policy implementation". With the recent emphasis on local level empowerment, it is at this scale that such problems should be tackled.

Chapter 28 of Agenda 21 identifies "local authorities as the sphere of governance closest to the people, and calls upon all local authorities to consult with their communities and develop and implement a local plan for sustainability - a 'Local Agenda 21'. (DEH, 2004). With the transition to democracy in most countries has come a shift to decentralization of decision-making authorities, that allows environmental actions to be tailored to meet the specific needs and conditions of communities (Makana LEAP, 2004). Local Agenda 21 encourages newly empowered local government authorities to "develop local sustainable development action plans in cooperation with their citizens" (Makana LEAP, 2004). The Local Environmental Action Plan (LEAP) may be seen as a starting point for the creation of a sustainable community. A LEAP is concerned with two main components - the environment, and local government - and should provide a framework, which facilitates constructive interaction between local government infrastructure and communities, for environmental management. LEAP involves developing a community vision, assessing environmental issues, prioritizing concerns, identifying the most appropriate strategies for addressing these problems, and implementing actions that achieve real environmental and public health improvements (Makana LEAP, 2004). LEAP is based on the premise of meaningful public input in local governmental decision-making, achieving this by providing a forum that brings together stakeholders from all sectors and institutions in the community, in an attempt to reach a consensus on environmental priorities and the actions for addressing these.

In this paper we therefore present the present ecological state for aspects of environmental water quality in the Makana Municipality and discuss these in the context of responses of the municipality to this information.

STUDY AREA

The Makana Municipality (Fig. 1) is one of 9 Local Municipalities within the jurisdiction of the Cacadu District Municipality, which is the district local authority for the western third of the Province of the Eastern Cape, South Africa. Within the Makana region fall several small towns, namely Grahamstown, Riebeeck-East and Alicedale (Fig. 1). Informal settlements and low cost housing form significant portions of many of these areas. There are also a number of game reserves or private game farms within the municipality. These include Shamwari, Thomas Baines Nature Reserve, Kwandwe, Bayethe and the Andries Vosloo Nature Reserve. Several rivers are found within the Municipality, of which the Bloukrans, Bushmans, Great Fish, Kowie, Kariega and Palmiet/Berg Rivers were sampled in this study (Table 1, Fig. 1). The Bloukrans River rises near Grahamstown, then flows in a south-easterly direction, later joining the Kowie River. Although there are several sewage treatment works (STW) within the Makana region, the Grahamstown STW (which releases its outflow into the Bloukrans River) is of particular interest as it is the only STW in the municipality which has to deal with industrial effluent, this mainly coming from two tanneries. Given its location relative to the town of Alicedale (Fig. 1), the Bushmans River is another river at risk of human impact. The New Years Dam, one of the DWAF water chemistry monitoring sites included in this study, supplies Alicedale with water.

FIG. 1, TABLE 1.

METHODS

Determination of the Present Ecological State

The method of Palmer *et al.* (2004b) was followed. Data sources included the field and laboratory work conducted in this study, together with DWAF monitoring data, and existing local reports (De Moor *et al.*, 2002; Barber-James *et al.*, 2003). Sampling and/or experimental work using each of the techniques (data retrieval and analysis from the DWAF database, invertebrate biomonitoring and ecotoxicological testing) involved in the PES assessment were undertaken. The results from this work were then combined with all other data to produce the PES assessment.

Water Quantity (flow)

A lack of hydrological expertise and budget limitations did not allow analysis of data from the 12 DWAF monitoring weirs in the municipality. Environmental flows and water allocations for domestic, agricultural and industrial use still need to be determined. A more complete hydrological assessment was one of the main recommendations of the LEAP process.

Water Quality

Using the environmental water quality (EWQ) concept, water chemistry, biomonitoring and ecotoxicological information was gathered and integrated (Palmer *et al.*, 2004a).

Water chemistry

Water chemistry data sources were 1) DWAF data, and 2) field data. Analysis and interpretation of all data followed the ecological Reserve assessment method (Palmer *et al.*, 2004b).

Data analysis

Raw data were downloaded from the DWAF database for each water quality monitoring site in the municipality. Variables were then selected from two categories; system variables (salts and electrical conductivity) and nutrients (soluble reactive phosphorus (SRP) and total inorganic nitrogen (TIN) data) (DWAF, 1996). After EC screening (Palmer *et al.*, 2004c), ion and salt concentration evaluations were completed (Jooste, pers. comm. 2004). For the PES evaluation, only DWAF data from the last five years with a valid sample size (n) of 60 were included in the analysis (Palmer *et al.*, 2004b).

Step 1: Monthly median values for the entire available data set for each of the selected variables were plotted using the *Statistica* programme to produce both scatter-plots with trend lines and box-and-whisker plots showing the 25th and 75th percentiles.

Step 2: Temporal trend analysis of each of the variables was undertaken to determine whether water quality was changing over time (DWAF, 1999). For PES conditions, the median and quartile monthly data were used to identify seasonal water quality trends, which may have been flow related (Scherman *et al*., 2003). This was done using the box-and-whisker plots described above. For sites with incomplete data records, trend analysis was undertaken to

determine if the most recent data could be used as a surrogate for current data. In cases where the trend line remained level over the entire data set, it is likely that the situation will not have changed much in the intervening years and the most recent data in that record were used.
Step 3: Summary statistics for appropriate DWAF data, showing sample size, mean, median, and 5th and 95th percentile values for TIN, SRP and EC were extracted.

Basic water chemistry data EC (*CyberScan 200 Conductivity meter*), pH (*CyberScan 10 pH meter*), and water temperature (standard mercury thermometer) were gathered in the field during biomonitoring sampling. Most measurements were taken in the Bloukrans River. Biomonitoring is not routinely undertaken by DWAF in this area, and the data collected were limited in this case to "snap-shot" information.

Present Ecological State

Soluble Reactive Phosphorus (SRP) and Total Inorganic Nitrogen (TIN)

To establish the PES, the median (50th percentile) SRP and TIN values were calculated for each site and compared to the default benchmark category boundary concentrations (Table 2). Based on this, each site was classified according to the categories: Natural, Good, Fair or Poor. Using a precautionary approach, the worst category was assigned as the overall classification for the variable.

TABLE 2

Electrical Conductivity (EC) and Individual Salt Ions

EC data for each of the DWAF weirs were checked for completeness of the record. Suitability of data for a PES assessment was established based on scatter-plot trend analysis. Due to differential toxicity of salts, EC screening is used to provide a rapid measure of low salinities (Palmer *et al*., 2004b), and 85mS/m is the category boundary value for EC (Fair-Poor boundary), above which analysis of individual salts is required (DWAF, 2004). Thus, all sites at which the 95th percentile EC values were higher than 85mS/m, analysis of individual inorganic salts was undertaken. This was done by reconstituting DWAF ionic data for the salt ions: Ca, Mg, K, Na, Cl and SO_4^{2-}, using the Jooste model to obtain inorganic salt concentrations in mmols/l (Jooste, pers. comm., 2004). These concentrations were then converted to mg/l values by multiplying each by the respective salt's formula mass. Classification of the site as Natural, Good, Fair or Poor was done by comparing these values with the most recent default benchmark category boundary values, provided in the Palmer *et al.* (2004b) methods (Table 2). As with nutrient classifications, the worst case for inorganic salts at each site was assigned as the overall category.

Biomonitoring

Data

Biomonitoring sampling using SASS5 (Dickens and Graham, 2002) was undertaken in March and September 2004. SASS is a scoring system involving the use of benthic aquatic macroinvertebrates to assess water quality and river health in general (Chutter, 1998). Sampling was undertaken at seven sites along the Bloukrans River, at one site on the Great Fish River and at one site on the Berg/Palmiet River confluence (Table 1, Fig. 1). The sites on the Bloukrans River correspond to those sampled by De Moor *et al.* (2002) and Barber-James *et al.* (2003), while sites on the other rivers were selected on the basis of habitat availability. At each site, sampling of three habitats: stones in current; sand, gravel and mud; and vegetation, was undertaken for 5-6minutes (each), using a net of 1mm mesh size mounted on a square aluminium frame 300mm x 300mm.

The abundance of each taxon was estimated and recorded on the standard SASS score sheet. In this method each taxon is assigned a sensitivity/tolerance score according to the water quality conditions it is known to tolerate (Dallas and Day, 2004). The products of this SASS method are three different and complementary scores or values. These are the SASS score, the Average Score Per Taxon or ASPT, and the Number of Taxa (Chutter, 1998). The SASS score is the sum of the sensitivity/tolerance scores for taxa found at the site, while ASPT is the SASS score divided by the number of taxa (Dallas and Day, 2004). A fourth score, the Invertebrate Habitat Assessment System (IHAS) score was also calculated.

Present Ecological State

The data gathered in the present study were analysed in conjunction with the data reported in De Moor *et al.* (2002) and Barber-James *et al.* (2003). In order to establish the PES of water quality, the method of Palmer *et al.* (2004b) was followed. This involved comparing the calculated ASPT scores for each site with the default benchmark category boundaries for the biotic index (SASS) in order to categorize the water quality at each site as Natural, Good, Fair or Poor (Table 2). The Chutter (1998) interpretation using total SASS scores and ASPT was also undertaken.

Ecotoxicology

Experimental procedure

Whole effluent toxicity (WET) of the inflow and outflow of the Grahamstown sewage treatment works (STW) was assessed using the standard *Daphnia pulex* 48-hour acute toxicity method (Slabbert *et al.*, 1998).

Each test involved a series of different concentrations of effluent diluted with culture medium. Five concentrations (100%, 50%, 25%, 12.5%, 6.25%) were used for the influent and for the effluent (100%, 75%, 50%, 25%, 12.5%). A control of the culture medium was included in each test. Sewage effluent was collected from the STW inlet point, the outlet pipe into the stabilization dam, and the outlet point into the Bloukrans River; and filtered. Each concentration was prepared in a 100ml volumetric flask and divided into 25ml aliquot parts in beakers. Five *D. pulex* neonates were transferred into each beaker, with four beakers per concentration, (20 neonates per concentration). The standard *D. pulex* test procedure was followed (Slabbert *et al.*, 1998).

Mobile individuals were recorded at 1hr, 2hrs, 4hrs, 8hrs, 24hrs and 48hrs. LC_{50} values representing the effluent concentration at which 50% of the test organisms die, were calculated using the Probit or Trimmed Spearman-Karber models (in cases where the calculated chi-square value for heterogeneity was greater than the tabular value at 0.05 level for the Probit) (Rand, 1995).

Communication of the role of PES

In order to communicate the role of PES information to local government personell dealing with the management of water quality, a presentation was developed which explained the PES findings and their significance[1]. At a presentation to Makana municipal directors of Community & Social Services, Environmental Health and Cleansing, Parks and Recreation and Infrastructural Services, a short questionnaire given to each attendee was used to gauge the accessibility, usefulness and relevance of the presentation and the methods it attempted to explain[1].

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[1] Details available from corresponding author

RESULTS

Water chemistry

Due to incomplete data and/or a lack of appropriate data (no more than 5 years from present with n = 60), only seven of the twelve DWAF Water Quality monitoring sites in the study area were suitable for the present ecological state (PES) assessment. The results for each site are presented in the form of a summary table (Tables 3.1 – 3.5) and brief description.

TABLE 3.1

The Great Fish River (Table 3.1)

Site Q1 (Fig. 1)

Overall this site was classified at Fair for nutrients and Poor for salts, with high concentrations of the two most toxic inorganic salts magnesium sulphate and sodium sulphate.

Site Q2 (Fig. 1)

There were insufficient data for present ecological state assessment based on EC. However, in terms of the other variables, nutrients classified the site at Fair, while for inorganic salts it was Poor. Magnesium sulphate and sodium sulphate concentrations were again high.

Site Q10 (Fig. 1)

Like the other sites on the Great Fish River the overall category was Fair for nutrients but Poor in terms of inorganic salts. The TIN median value (0.29mg/l) exceeded the Natural category boundary value of 0.25mg/l by only 0.04mg/l. As was the case at sites Q1 and Q2 magnesium sulphate and sodium sulphate concentrations were elevated.

TABLE 3.2

The Kariega River (Table 3.2)

Site Q8 (Fig. 1)

Water quality in terms of nutrients was classed as Good overall but for inorganic salt data the site was Poor. The magnesium sulphate (the most toxic inorganic salt) concentration was more than five times the Fair category boundary value. Unlike the Great Fish River sites, concentrations of magnesium chloride, calcium chloride and sodium chloride also exceeded the Fair category boundary. The sodium chloride concentration (2517.3mg/l) was the highest found at any site.

TABLE 3.3

The Kowie River (Table 3.3)

Site Q17 (Fig. 1)

In terms of nutrients, this site was classified at Good. For inorganic salts the site was classified at Poor, with magnesium sulphate, magnesium chloride and sodium chloride concentrations significantly greater than the Fair boundary value.

TABLE 3.4

The Bushmans River (Table 3.4)

Site Q6 (Fig. 1)

Based on this nutrient data the site was Good. The inorganic salts magnesium sulphate, sodium chloride and calcium chloride each classify the site as Poor, while magnesium chloride classified the site as Natural. Using the precautionary approach, the overall category in terms of inorganic salts remains Poor.

TABLE 3.5

The New Years Dam (Table 3.5)

Site Q7 (Fig. 1)

Overall the site was classified as Fair for nutrients and Poor in terms of inorganic salts. The SRP value placed the site in the Fair category. Magnesium sulphate and sodium chloride concentrations were the lowest recorded at any site.

Biomonitoring

Table 4 summarizes all biomonitoring data collected on the Bloukrans, Great Fish and Palmiet/Berg Rivers. The average score per taxon (ASPT) values are compared to the default benchmark values given in the Table 2 in order to classify each site.

TABLE 4

Average Score Per Taxon (ASPT)

Site B1 (Fig. 1)

ASPT values did not exceed 5 (Table 4). This clearly classified the site as Poor. The value 4.5 was recorded in March 2004.

Site B2 (Fig. 1)

Data for site B2 were incomplete, however the ASPT values obtained in September 2003 and 2004 classify the site as Poor.

Site B3 (Fig. 1)

ASPT for November 2002 and September 2003 classed the site as Poor. However for March 2004 and September 2004 ASPT increased, allowing a Fair classification.

Site B4 (Fig. 1)

Except for September 2003, ASPT values were below 5 and classed the site as Poor. Based on the ASPT from September 2003 the site was Fair.

Site B5 (Fig. 1)

In terms of ASPT, in November 2002 the site was Fair, but for all other sampling times was Poor. It should be noted that ASPT decreased over time, showing worsening conditions.

Site B6 (Fig. 1)

Due to the absence of flowing water during sampling expeditions in 2004, biomonitoring was not undertaken. However, for November 2002 and September 2003, ASPT values of 6.1 and 5.7 classed the site as Good and Fair respectively.

Site B7 (Fig. 1)

The only data for site B7 is from September 2003, at which time ASPT was found to be 5.0, which classified the site as Fair.

Site B8 (Fig. 1)

Biomonitoring was not undertaken during 2002 or 2003, however ASPT values recorded in March and September 2004 decrease from 4.9 to 4.2, both placing the site in the Poor category.

Site B9 (Fig. 1)

Biomonitoring data for site B9 was only obtained for March 2004. Based on the ASPT at this time, a value of 4.5, the site was Poor.

Total SASS and IHAS Scores

Although only ASPT values have been used in the above classifications, total SASS score and IHAS percentage values are also useful. Classifications using the Chutter (1998) method in each case closely matched those calculated using the Palmer *et al.* (2004b) method. IHAS is a measure of habitat integrity and must be considered in conjunction with the total SASS scores. IHAS identifies whether biotic integrity is being affected by habitat availability. Sites B1, B2 and B9 had particularly low IHAS scores. Site B8 on the Kariega River was found to have the highest IHAS score. Overall biological condition improved with distance downstream of the STW.

Ecotoxicology

Table 5 shows the LC_{50} values obtained for each of the eight toxicity experiments, using either Probit or Trimmed Spearman-Kärber (TSK). The lower these values the more toxic the effluent.

TABLE 5

The LC_{50} values obtained for the inlet point ranged from 4.97% (1.41%-6.87%) to 58.8% (toxic). The tests for the outlet into the river returned lower percentages (43.1% and 39.43%), showing higher toxicity than the outlet pipe into the dam. These results indicate a concern for in-stream toxicity and are the basis of the recommendation for a toxicity risk assessment.

DISCUSSION

Local government

Under the NWA and National Water Resources Strategy (DWAF, 2004), local government is charged with water service provision (WSP) and local aspects of water resource management (WRM). At this level, WRM is effected institutionally through WUA and catchment forums. There is, as yet, little clarity on how municipalities and WUA will interact, but WUA will be represented on CMAs. Each level of government and the corresponding institutions become part of the cycle of action at a local scale (Fig. 2). Stakeholder involvement is an essential component of the SDC (Mtetwa and Schutte, 2002) and RDM approaches (Fig. 2).

FIG. 2

RDM requires stakeholder involvement in all aspects of the development of a catchment or community vision for their water resources. Communication of the environmental water quality PES to the Makana Municipality contributed to this process by providing the first step, “quantification of the current status”, which informed and will empower stakeholders in decision-making concerning their water resources.

Present Ecological State in Makana

Water Chemistry

Although water chemistry data are necessary for determining the type and concentration of pollutants, it is important to note that, unlike biomonitoring data, such assessment is limited to the period of sampling (Dallas and Day, 2004). Overall, water chemistry data show that the municipality's water resources are impacted. In terms of nutrients, the Great Fish River (where there is inter-basin transfer from the Orange River) was in a Fair state, while according to salt data it was Poor. Nutrient data at each of the other sites (excluding the New Years Dam which was Fair) classified water quality as Good. In terms of salts however, all these sites were Poor. Although no DWAF data were available for the Bloukrans River, algal growth was observed at many of the sites, suggesting nutrient enrichment.

Since the boundary values used were not derived from local reference conditions, there is some question as to the natural nutrient levels in the region. The geology of the area, dominated by sedimentary rock such as mudstones which are rich in phosphorus and salts (Rust, 1998), indicate that elevated nutrient and salt concentrations may be natural. However, even naturally levels seem to have been exacerbated by human activities such as irrigation return flows and domestic effluents. Nutrient enrichment and siltation of water resources are inevitable by-products of profitable crop production (Mtwetwa and Schutte, 2002). Sources of diffuse pollution are difficult to address due to their dispersed and variable nature (Pegram and Görgens, 2001). While sensitive fertilizer application may mitigate effects, Mtetwa and Schutte (2002) found in their study of the Muda River Catchment, Zimbabwe, that "pollutant loads were influenced to a greater extent by the changes in rainfall and run-off patterns than by the changes in agricultural practices." Urban point and non-point sources of pollution also often play a major part in raising nutrient concentrations.

Anthropogenic impacts which commonly influence salt concentrations are either direct, in the form of urban effluents and run-off, or indirect from decreasing water volume. In Makana the many small farm dams also increase the water body surface area and hence evaporation. Considering sites Q17 and Q6, (sodium chloride concentrations > 1900mg/l), anthropogenic impacts seem to be a plausible cause, since a common factor is their downstream location from the urban centres of Grahamstown and Alicedale respectively. In contrast to this, site Q8 (on the Kariega River), which had the highest NaCl concentration of any site, is not in close proximity to urban development, and other land-use impacts should be explored. Magnesium chloride was only detected at sites Q8, Q17 and Q6. Site Q6 was classified as Natural (in terms of magnesium chloride), suggesting the elevated $MgCl_2$ concentrations observed at Q17 and Q8, may be due to anthropogenic impacts. Correction of water chemistry imbalances will require long-term management actions that work to restore and maintain the water quality to at least the Fair class.

Biomonitoring

Biomonitoring data for the Great Fish and Bloukrans Rivers (Fig. 1) showed that they were degraded (Table 4). For the Great Fish River, these results validated the Poor classifications based on water chemistry data. Although the Bloukrans water chemistry indicated degradation, biomonitoring data suggested an improvement in water quality in a downstream direction, away from Grahamstown, from Poor to Fair.

Selection of management classes is dependent on trends, present state and desired future protection status (MacKay *et al*., 2003). Site B3, on the Bloukrans River was classed as Poor to Fair in terms of biomonitoring, and was the only site to improve over time. This may be due to the diluting effect of treated sewage effluent entering the Bloukrans River upstream of this site from the Grahamstown STW. Although there is a concern over toxicity in the STW outflow, such toxicity is likely to be temporally variable (Slabbert *et al*., 1998). Sites B5, B6 and B8 all showed decreasing ASPT scores over time. However, ASPT scores for site B6 were the highest recorded in the municipality.

On the Bloukrans River, the trend of improving water quality with increasing distance from Grahamstown may be explained in terms of the self-purifying property common to all rivers (Day and Davies, 1998). Assimilation of effluent from Grahamstown is taking place, albeit at a somewhat reduced level. Upstream agricultural runoff is also of concern.

The classification of site B8 as Poor was unexpected since this site, found at the confluence of the Palmiet and Berg Rivers in Thomas Baines Nature Reserve, is relatively isolated from human activity. The IHAS scores obtained in March and September 2004, suggest reasonable habitat availability at the site. This suggests that the poor ASPT scores may be due to poor water quality rather than inadequate habitat. A recent tar dump on the riverbank, upstream of the site, associated with road works on the nearby highway (Muller, pers. comm. 2004) may be the cause. Such results indicate the importance of environmental responsibility in all development undertakings in the municipality.

Despite an absence of government biomonitoring activity, work by local organizations such as the Kowie Catchment Campaign ensured biomonitoring data were available for at least the Bloukrans River. The difficulty in accessing and coordinating municipal physico-chemical monitoring data was problematic especially with the need to link biomonitoring results with physico-chemical data. The quality of much of the DWAF water chemistry data was poor, with missing values and incomplete data sets being commonplace. The chemistry data record for Grahamstown water supply dams ended in 1999 and such data cannot contribute to an accurate present state assessment.

In light of the difficulties and poor biodiversity indicated above, we suggest that additional chemical sampling along the Bloukrans River and regular biomonitoring at more sites on the Great Fish River and elsewhere would be valuable. Better water chemistry and biomonitoring data would enable appropriate use of ecotoxicology to inform causal links of prevailing water quality.

Ecotoxicology

In Makana, stakeholder concerns and the previous work of Hoohlo (2003) focused attention on the Grahamstown STW (toxicity and potential toxicities). In terms of WRM the positive toxicity of the effluent is of concern since this water enters the Bloukrans River. The LC_{50} effluent values (Table 5) indicate the likelihood of negative ecological impacts of STW effluent on the Bloukrans River as well as the potential to affect downstream water users.

Much work has been done towards the development and implementation of a protection-based classification system in which each ecological management class carries a specific level of protection or risk of damage to the sustainability of the ecosystem (Jooste and Rossouw, 2002). Under the NWA the “statutory end-point” for ecological risk assessment (ERA) is loss of sustainability. ERA can be performed at various levels of complexity depending on management needs and the quality of data input (Jooste and Claassen, 2001). The use of a risk assessment approach in Makana Municipality, for which risk is the likelihood that a loss of sustainable ecological function will occur (Jooste and Claassen, 2001), would be advantageous. “One of the key features of risk assessment, particularly in characterizing and evaluating the probability of effect, is information on stressor-response relationships” (Jooste *et al*., 2000). Toxicological information is the primary source for this. For the Bloukrans River, the poor biomonitoring results may also be explained by intermittent instream toxicity.

PES in Makana Municipality: an integrated picture

Integration of water chemistry and biomonitoring data for DWAF sites Q1, Q2 and Q10, and biomonitoring site B9 (all found on the Great Fish River) suggested that the PES of the Great Fish River was Poor. However, the low IHAS score of 24% recorded at site B9 indicates that this Poor classification may in part be due to a lack of appropriate habitat rather than just poor water quality.

Based on biomonitoring and ecotoxicology, the PES of site Q8 (Kariega River) and the upper reaches of the Bloukrans River was Poor, while further downstream, and with increasing distance from the Grahamstown STW, the river was considered Fair. Sites such as B6 showed that there were stretches of the river that were in a Good to Fair state at the times of sampling. The PES of some water resources in the municipality (for example the New Years Dam and Bushmans River sites) show that water chemistry was classified as Good, or even Natural.

Makana Municipality therefore now needs to manage and restore to a Fair, Good, or Natural (depending on the uses for which they are needed), those reaches classified in a Poor state.

Communication and implementation

Based on the questionnaire responses, the presentation of this paper’s findings to local municipal directors initiated positive action towards empowering local government to use PES information. A basic understanding of the PES concept and methods, and of the PES within Makana Municipality, were both crucial for local government decision makers to move towards the goal of sustainable water use. Although water quality management is effectively useless without changing the practices that contribute to pollution (Mtetwa and Schutte, 2003), communication that makes scientific information accessible to local government is the first step in getting governmental action and understanding with regards proper water resource management.

The LEAP process provided the medium for meaningful action as it integrated the PES information with other environmental aspects of the municipality in a comprehensive action plan. In this context, several implementation priorities have been put forward together with a hydrological monitoring requirement.

- a toxicity risk assessment;
- assessment of natural salt and nutrient levels;
- an integrated data management system; and
- hydrological modelling and a water resource plan.

If commitment and willing participation in collaborative partnerships (such as the LEAP) are to be successful, all stakeholders must be on the same trajectory and at the same level of understanding as the lead agent (MacKay *et al*., 2003). Hence, in addition to implementation priorities, data management and capacity building in the context of water resources and water resource management have been highlighted as areas in need of attention.

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	Site code	DWAF site number	Location/Description	Latitude : Longitude (Degrees)
Biomonitoring	B1	N/A	Bloukrans River	33.312667: 26.5413889
	B2	N/A	Bloukrans River	33.316555: 26.551
	B3	N/A	Bloukrans River	33.317777: 26.5680555
	B4	N/A	Bloukrans River	33.317388: 26.6
	B5	N/A	Bloukrans River	33.327777: 26.6430555
	B6	N/A	Bloukrans River	33.391111: 26.7069444
	B7	N/A	Bloukrans River	33.4547: 26.693333
	B8	N/A	Confluence Berg and Palmiet Rivers	33.3716666: 26.4763888
	B9	N/A	Great Fish River	33.0883333: 26.7808333
Water chemistry	Q1	Q9H001	Great Fish River	33.127778: 26.613889
	Q2	Q9H012	Great Fish River	33.098333: 26.445556
	Q10	Q9H018	Great Fish River	33.237778: 26.990278
	Q6	P1H003	Boesmans River	33.329167: 26.0775
	Q8	P3H001	Kariega River	33.554444: 26.603611
	Q7	P1R003	New Years Dam	33.303056: 26.113889
	Q17	P4H001	Kowie River	33.506: 26.745

TABLE 1.

Location and description of biomonitoring and Department of Water Affairs and Forestry (DWAF) water quality monitoring sites' in Makana Municipality, Eastern Cape, South Africa.

TABLE 2

The national default benchmark category boundaries for the 95th percentile inorganic salts, median nutrients concentrations and the biotic index (SASS) Average Score Per Taxon (ASPT) (Palmer *et al.*, 2004b)

	Variables	**Natural boundary**	**Good Boundary**	**Fair Boundary**
Inorganic salts 95th % (mg/l)	$MgSO_4$	16	27	37
	Na_2SO_4	20	36	51
	$MgCl_2$	15	33	51
	$CaCl_2$	21	63	105
	NaCl	45	217	389
	$CaSO_4$	351	773	1195
Nutrients (Median in mg/l)	SRP	<=0.005	0.0051 - 0.025	0.0251 - 0.125
	TIN	<=0.25	0.251 – 1.0	1.01 – 4.0
Biotic index	ASPT	7	6	5

TABLE 3.1

Summary results for sites Q1, Q2 and Q10 on the Great Fish River, north north-east of Grahamstown, containing the median values for Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (in mg/l), and the reconstituted concentrations for six inorganic salts (listed in descending order of toxicity).

Site Code: Q1		**Data Source:** DWAF weir Q9H001	**Site Descriptor:** Great Fish River, NNE of Grahamstown
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.62	Good
	SRP	0.12	Fair
FINAL	Fair		
Inorganic Salts 95% (mg/l)	$MgSO_4$	222.6	Poor
	Na_2SO_4	298.2	Poor
	$MgCl_2$	-	Undetectable
	$CaCl_2$	-	Undetectable
	NaCl	483.21	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

Site Code: Q2		**Data Source:** DWAF weir Q9H012	**Site Descriptor:** Great Fish River, NNW of Grahamstown
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.48	Good
	SRP	0.098	Fair
FINAL	Fair		
Inorganic Salts 95% (mg/l)	$MgSO_4$	249.02	Poor
	Na_2SO_4	323.76	Poor
	$MgCl_2$	-	Undetectable
	$CaCl_2$	-	Undetectable
	NaCl	555.75	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

Site Code: Q10		**Data Source:** DWAF weir Q9H018	**Site Descriptor:** Great Fish River, eastern boundary of the municipality
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.29	Good
	SRP	0.09	Fair
FINAL	Fair		
Inorganic Salts 95% (mg/l)	$MgSO_4$	245.4	Poor
	Na_2SO_4	262.7	Poor
	$MgCl_2$	-	Undetectable
	$CaCl_2$	-	Undetectable
	NaCl	582.1	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

TABLE 3.2

Summary results for site Q8 on the Kariega River, south of Grahamstown, containing the median values for Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (in mg/l), and the reconstituted concentrations for six inorganic salts (listed in descending order of toxicity).

Site Code: Q8		**Data Source:** DWAF weir P3H001	**Site Descriptor:** Kariega River, South of Grahamstown
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.155	Natural
	SRP	0.024	Good
FINAL	Good		
Inorganic Salts 95% (mg/l)	$MgSO_4$	252	Poor
	Na_2SO_4	-	Undetectable
	$MgCl_2$	365	Poor
	$CaCl_2$	575	Poor
	NaCl	2517.3	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

TABLE 3.3

Summary results for site Q17 on the Kowie River, south-east of Grahamstown, containing the median values for Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (in mg/l), and the reconstituted concentrations for six inorganic salts (listed in descending order of toxicity).

Site Code: Q17		**Data Source:** DWAF weir P4H001	**Site Descriptor:** Kowie River, SE of Grahamstown
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.07	Natural
	SRP	0.025	Good
FINAL	Good		
Inorganic Salts 95% (mg/l)	$MgSO_4$	222.6	Poor
	Na_2SO_4	-	Undetectable
	$MgCl_2$	221.1	Poor
	$CaCl_2$	315.2	Poor
	NaCl	1944	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

TABLE 3.4

Summary results for site Q6 on the Bushmans River, south of Alicedale, containing the median values for Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (in mg/l), and the reconstituted concentrations for six inorganic salts (listed in descending order of toxicity).

Site Code: Q6		**Data Source:** DWAF weir P1H003	**Site Descriptor:** Bushmans River, South of Alicedale
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.081	Natural
	SRP	0.025	Good
FINAL	Good		
Inorganic Salts 95% (mg/l)	$MgSO_4$	391	Poor
	Na_2SO_4	-	Undetectable
	$MgCl_2$	1.21	Natural
	$CaCl_2$	183.2	Poor
	NaCl	2042.82	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

TABLE 3.5

Summary results for site Q7 at the New Years Dam, north-east of Alicedale, containing the median values for Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) (in mg/l), and the reconstituted concentrations for six inorganic salts (listed in descending order of toxicity).

Site Code: Q7		**Data Source:** DWAF weir P1R003	**Site Descriptor:** New Years Dam, NE of Alicedale
Variables		**Value**	**Category**
Nutrients 50% (mg/l)	TIN	0.097	Natural
	SRP	0.028	Fair
FINAL	Fair		
Inorganic 95% (mg/l)	$MgSO_4$	50.64	Poor
	Na_2SO_4	-	Undetectable
	$MgCl_2$	-	Undetectable
	$CaCl_2$	40.3	Good
	NaCl	313.6	Poor
	$CaSO_4$	-	Undetectable
FINAL	Poor		

TABLE 4

ASPT, total SASS score and IHAS for each of the nine Bloukrans and Palmiet/Berg River sites

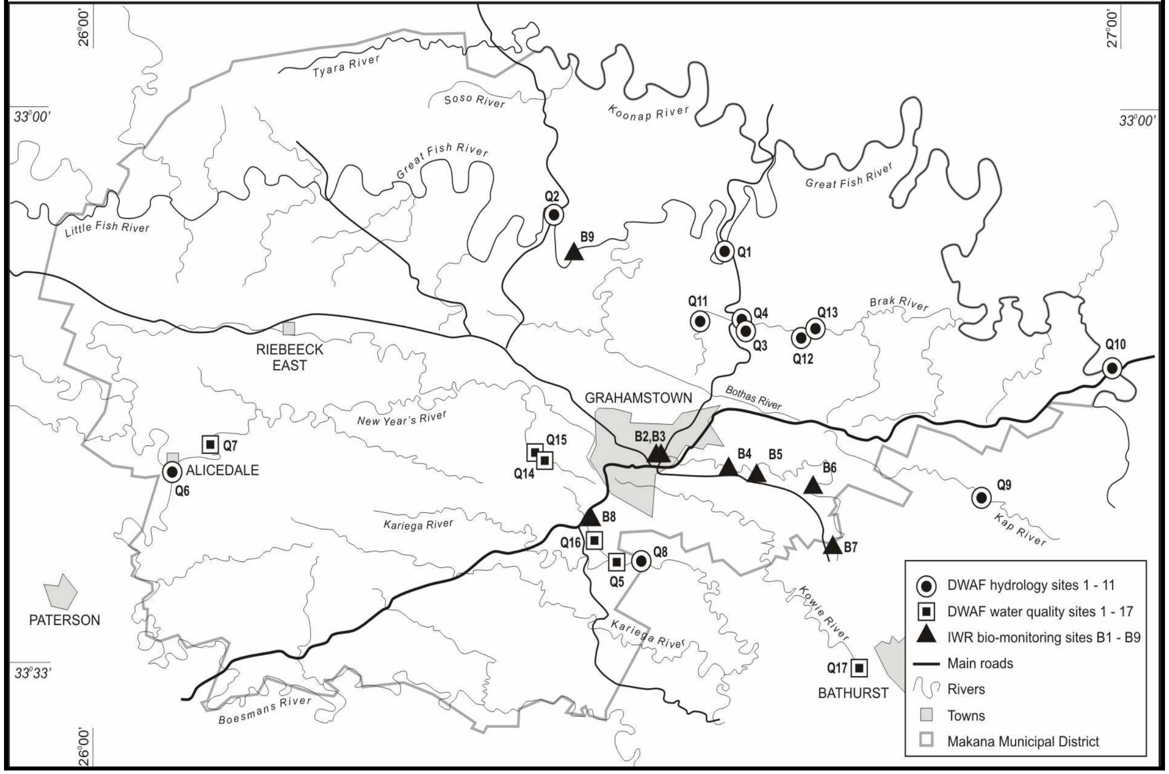
Total Scores	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**
ASPT NOV02	2.6		3.6	4.2	5.0	6.1			
ASPT SEP03	3.6	3.5	3.8	5.6	4.7	5.7	5.0		
ASPT MAR04	4.5		5	4.5	4.5			4.9	4.5
ASPT SEP04	2.5	3.1	5.3	4.3	4.4			4.2	
SASS NOV02	13		32	42	60	97			
SASS SEP03	25	14	23	51	42	120	50		
SASS MAR04	50		60	77	81			89	27
SASS SEP04	23	40	79	77	131			75	
IHAS(%) MAR04	50		51	52	53			65	24
IHAS(%) SEP04	29	37	43	43	48			50	

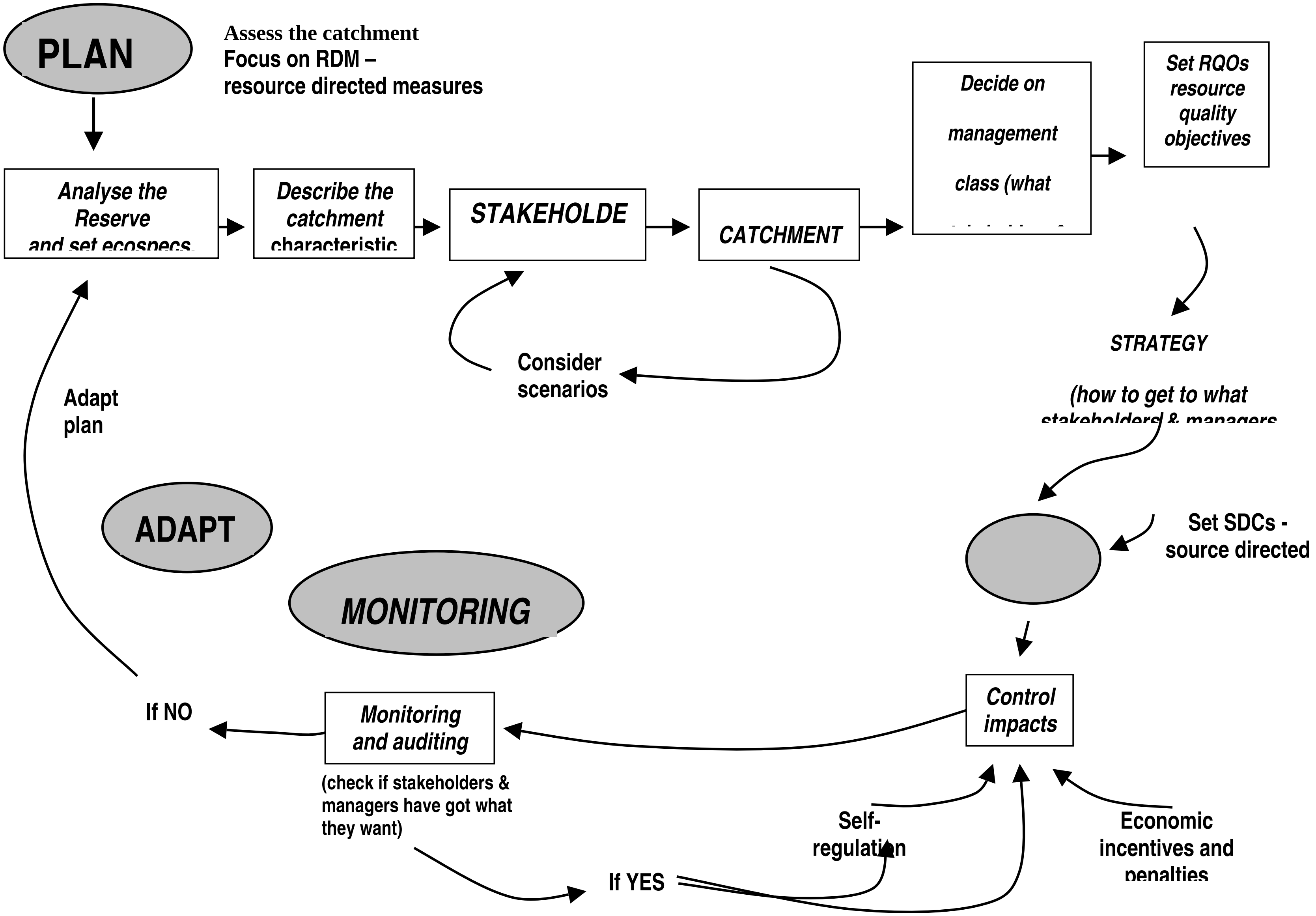
TABLE 5

LC50 (%) values from a 48-hour acute (*D. pulex*) toxicity test of sewage effluent, calculated using the EPA Probit analysis and the Trimmed Spearman- Kärber (TSK) analysis

Date	**Effluent**	**Method**	**48-hr LC50 (%)**	**Confidence limits**		**Chi square**	**% Trim**
				Lower	**Upper**		
26/04/2004	Inlet	Probit	23.86	19.99	28.48	0.8	
16/05/2004	Inlet	TSK	14.03	9.93	19.83		43.75
09/06/2004	Inlet	TSK	58.8	48.81	70.84		36.67
21/07/2004	Inlet	Probit	4.97	1.41	6.87	0.27	
01/09/2004	Inlet	Probit	30.02	23.87	37.91	6.68	
17/06/2004	Outlet pipe into dam	TSK	55.33	43.79	69.93		42.5
31/08/2004	Outlet into the river	TSK	43.1	31.09	59.74		15
06/09/2004	Outlet into the river	TSK	39.43	27.87	55.79		20

MAKANA WATER QUALITY MONITORING STATIONS




PLAN
Assess the catchment
Focus on RDM –
resource directed measures
Analyse the Reserve and set ecospecs
Describe the catchment characteristic
STAKEHOLDE
CATCHMENT
Decide on management class (what
Set RQOs resource quality objectives
STRATEGY
(how to get to what stakeholders & managers
Consider scenarios
Adapt plan
ADAPT
MONITORING
Set SDCs - source directed
Control impacts
If NO
Monitoring and auditing
(check if stakeholders & managers have got what they want)
If YES
Self-regulation
Economic incentives and penalties

List of Figure Captions

Figure 1

Makana Municipality, showing the Department of Water Affairs and Forestry (DWAF) water quality monitoring weirs and location of all biomonitoring sites.

Figure 2

A proposed strategy for undertaking integrated water resource management (IWRM) from a water quality perspective (Palmer et al., 2004a). Stage 1 (analyse the Reserve) and Stage 2 (deciding on the management class) of water resource classification are shown in the context of resource directed measures (RDMs) and source directed controls (SDCs) in order to achieve IWRM.