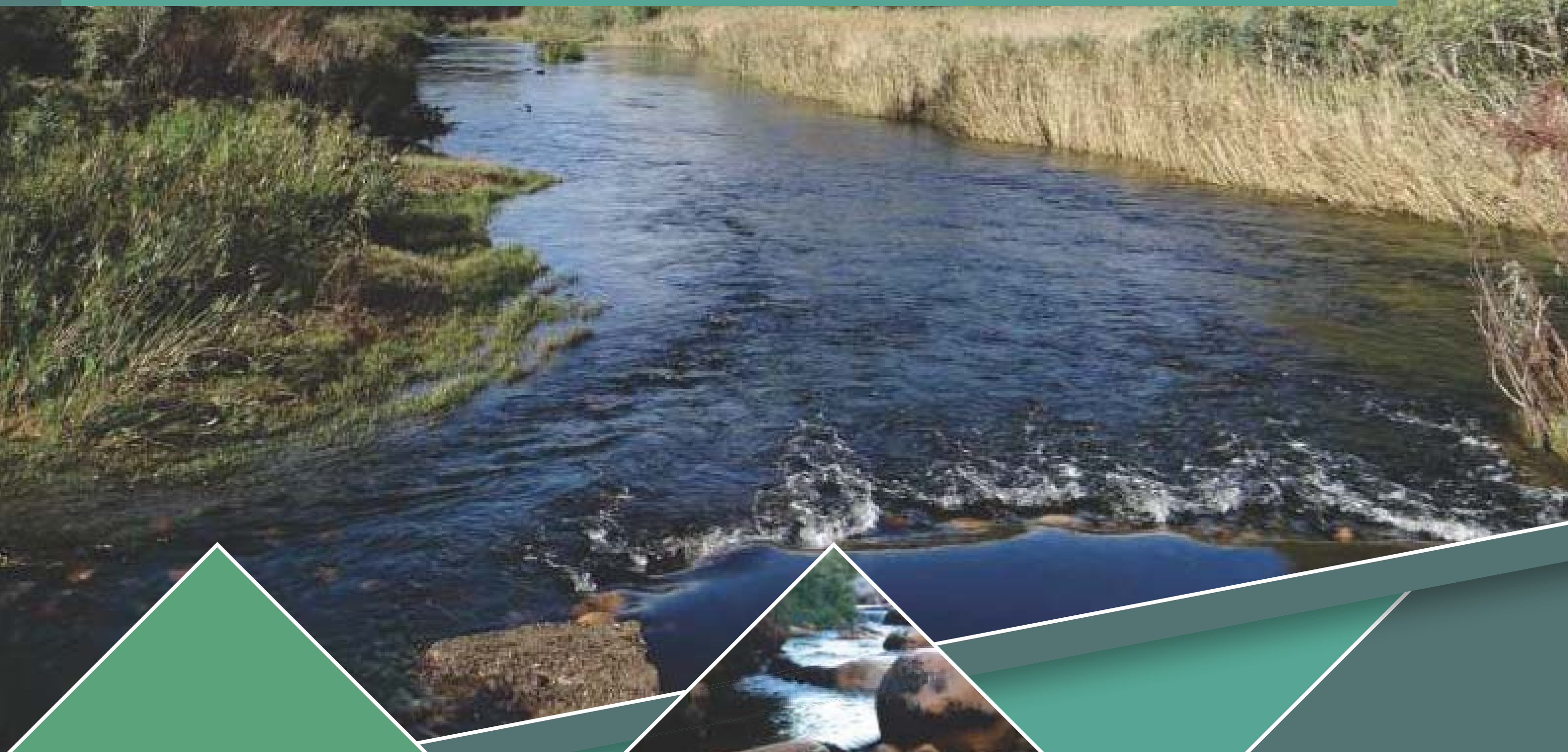
DEVELOPMENT OF AN INTEGRATED WATER QUALITY MANAGEMENTFRAMEWORK DECISION SUPPORT SYSTEM: PILOT STUDY IN THE BREEDE-GOURITZ WATER MANAGEMENT AREA

L Boyd, F Adams, Z Sithole, J Dateling and G Mc Conkey



WATER RESEARCH COMMISSION

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Development of an Integrated Water Quality Management Framework Decision Support System: Pilot study in the Breede-Gouritz Water Management Area

Report to the

WATER RESEARCH COMMISSION

by

L Boyd, F Adams, Z Sithole, J Dateling and G Mc Conkey

Golder Associates Africa

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EXECUTIVE SUMMARY

BACKGROUND

It is acknowledged that stresses on South Africa's water resources are affecting water quality, quantity and availability. There is therefore a need to protect, and not pollute, valuable freshwater resources. Rising demand for increasingly scarce water resources, as recently experienced in the 2015/2016/2017 droughts throughout the country, is leading to growing concerns about future access to water. This scenario is not unique to any of the country's nine water management areas (WMAs), as almost all of South Africa is experiencing water quality and quantity concerns at various levels. Importantly, it is recognised that deteriorating water quality not only affects aquatic ecosystems but also impacts economic growth, community health and empowerment. The National Water Resource Strategy: *Water for an equitable and Sustainable Future* (DWA, June 2013, Second Edition), states that an adequate water supply of suitable quantity and quality makes a major contribution to economic and social development.

Chapter 3 of the National Water Act (NWA) (RSA, 1998), prescribes the protection of water resources through resource directed measures and the classification of water resources. Together, these measures are intended to ensure the protection of water resources, prevention of pollution and the remedying of the effects of pollution, while balancing protection with the need to use water as a factor of production to enable socio-economic growth and development.

Human activities, such as mining, agriculture, and industrial, commercial and urban development, all result in waste disposal and air pollution, and can have major impacts on the quantity and quality of water available for human and environmental use, while the abstraction and storage of water and the discharge of waste into water resources can impact on the quality of the water resource. These interactions must therefore be addressed in the management of water resources.

An important milestone in the revision of water law in South Africa was the publication of the "White Paper on a National Water Policy for South Africa" which set out the overarching principles guiding policy regarding water resource management in South Africa. These principles were later taken up in the NWA (RSA, 1998) which recognises the need for the integrated management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to enable broader stakeholders to participate in water resources management.

RATIONALE

A major concern is the lack of proper reporting on data that is collected in the course of implementing various aspects of the NWA, such as reporting on compliance against water use licence conditions, and reporting of incidents such as sewer overflows or other land-use activities that could have an impact on a water resource. The lack of, or poor, reporting results in a lack of preventative action, or action that comes too late to be beneficial. There is therefore a need to develop a system that is simple to use and will allow reporting on targets, whether quantitative or qualitative, at various levels of management, as soon as data is received.

An Integrated Water Quality Management Framework (IWQMF) model has been developed which "breaks down" water management areas into smaller management units while establishing both a horizontal and vertical reporting framework. A benefit of the model is that responsibility for water quality is based on significantly smaller geographical areas, and accountability to the adjoining areas (horizontal accountability) and to the next level of management (vertical accountability) is established. This allows accountability for water quality to be focussed on smaller management units, rather than diffused up to ever higher levels of management, thereby ensuring that all water users are aware of their own responsibility in protecting South Africa's water resources and are accountable for the impacts that they have on the resource.

This multi-disciplinary research project proposed to link, and build on, among others, the various Water Research Commission (WRC) studies and industry and consultants' reports relating to this IWQMF model. The overall purpose of this project was to undertake technology transfer in the form of a case study of implementation of the Integrated Water Quality Management System (IWQMS) developed in WRC project K5/ 2159, and completed in April, 2014.

This pilot-scale project was aimed at refining the system in order to ensure that users are able to store data and draw reports in a simplified manner and on a more frequent basis, with the goal of improved understanding of what is happening in a catchment. The benefits include:

- Close to real-time water quality/quantity reporting by water users;
- Close to real-time access to water quality/quantity monitoring information;
- Simplified reporting for the regulators;
- Potential to include civil society organisations in the input of water quality data;
- Potential for spreading the monitoring footprint and reducing the cost of monitoring to the regulator.

This type of system can ultimately build towards assisting processes such as compulsory licensing and implementation of the waste discharge charge system.

OBJECTIVES AND AIMS

The overall aim of this project was to pilot the IWQMS that was developed in WRC project K5/ 2159, by introducing the proposed decision support system to an existing institution, and, secondly, to undertake a literature review on early warning systems (EWSs)and propose how the various EWS options could be incorporated into the IWQMS.

The aim has been achieved by holding numerous workshops and training sessions with, among others, the Western Cape Department of Water and Sanitation Regional Office, the Breede-Gouritz Catchment Management Agency (BGCMA), a water users association (WUA) and other interested water users.

METHODOLOGY

The methodology that was used focussed on identifying relevant stakeholders who would be intimately involved in learning the system and understanding the various components so to be able to make recommendations for improvements and refinements, including undertaking situational and risk assessments in their catchment areas, in order to identify relevant monitoring requirements and be able to set associated targets.

In addition, a literature review was undertaken on early warning systems and what type of links would be possible to a system such as the IWQMS.

RESULTS AND DISCUSSION

The report reviewed the principles and philosophy of integrated water resources management and the concepts of the integrated water quality management framework. Principles include the following: water must be properly valued; institutions responsible for managing water must be accountable for water quality; water quantity and water quality are inextricably linked; the Polluter Pays Principle must be applied to the true cost of water pollution; short-term economic gain at the cost of increasingly deteriorating water quality is not acceptable; and everyone should have access to water quality information that may not necessarily be in the form of technical data.

Figure i below graphically presents the IWQMF (Boyd et al., 2010) In order to achieve integrated water quality management (2), an assessment of the catchment, taking into consideration the elements of the water use cycle (1), needs to be undertaken. In this project defining principles (3) that underpin the background conditions (4) (an example being the proper valuing of water) led to the development of the management framework. The management framework (5) relates to the identification and registration of management units at various levels. It is for each of these management units, at the different levels, that the integrated water quality management business process (6) must be developed (including risk assessment, skills identification, and identification of critical control points (CCP) and reference factors (RF) and associated targets) and then implemented to achieve integrated water quality management.

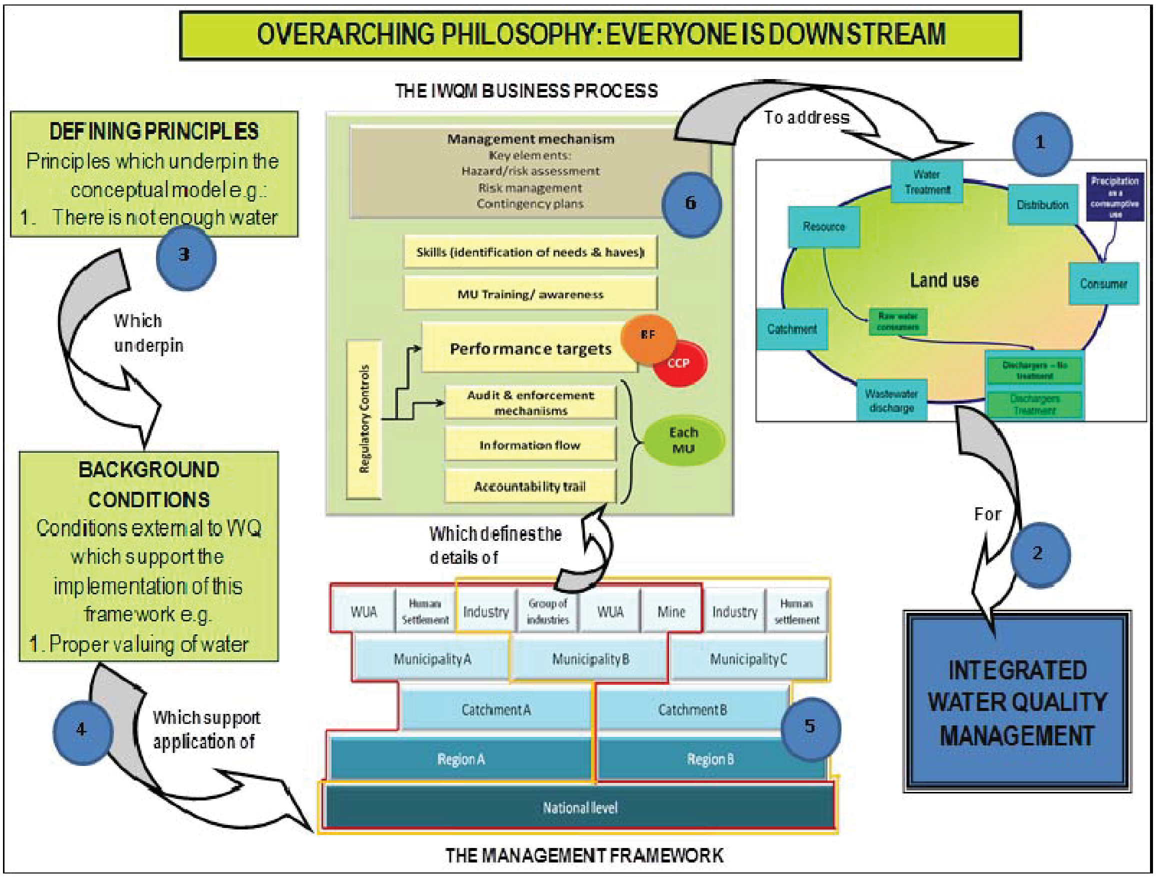

Figure i: The Integrated Water Quality Management Framework (Boyd et al., 2010)

The reporting component is an extremely important part of the framework. To adequately capture data and report on it in a timeous manner to allow actions to be taken, a decision support system was developed and includes:

- A system on which to record and store the data;
- A short-term reporting template that allows for data to be reported within minutes of inputting it;
- A longer-term report template that will allow for trend analysis.

Pilot results

The results have indicated a number of institutional constraints, as well as some exciting possibilities. The concept of ownership seems to be a large hurdle that will need to be removed. It is going to take a mind-set change to get personnel at all levels out of their comfort zone, as the immediate reporting may put them in the spotlight, where questions may be asked and answers will need to be given.

Participation at the various workshops and interim meetings ranged from 100% at the first workshop to around 20 to 30% at subsequent meetings. It was noted that this was seen as just another project; had it been part of their job description, the attendance is likely to have been better.

A further reason for poor commitment may be that the reporting requirements are not very stringent, the outcomes of data assessment are not used or communicated to effect change and no one is held accountable. It appears that data is seen as something that that only needs to be generated when asked for, rather than something that, as a standard procedure, should be collected and communicated to others within an institution, and to stakeholders.

Percentage data input ranged from 0% (monitoring points were added but no data was ever received to input) to 80%. In most cases, failure to input data happened because the samples were not taken. It was also noted that there was great enthusiasm when first seeing the product; however, the implementation seemed to stall when the official was left on their own. In several cases it was noted that this was due to the fact that the official did not have adequate computer knowledge, especially with programmes such as Excel.

The project has had some positive outcomes in that it has been taken up by the Breede-Gouritz Catchment Management Agency, with potential for use in the Olifants WMA as part of the development of an integrated water quality management plan for that area, and potentially in the Inkomati-Usuthu WMA. One important learning is that officials and water users at all levels will need to learn to be proactive rather than reactive, and will need to work as partners in implementing integrated water resources management.

Regarding the early warning systems assessed, the project relates to a model where water users (consumptive and non-consumptive) add data (qualitative or quantitative) to a system and immediately report on that data to up- and downstream users, as well as to management and regulators where applicable. This makes them *managers* of what they do on land that may pollute a water resource, and managers of what they may discharge to a water resource or abstract from that water resource.

The immediacy of the reporting is important to allow other users to be timeously informed of an incident. This in effect, could be a method of each user naming their own management, and be an incentive, where that management is shown to be poor, to improve and maintain a higher standard of land-based activities, as well as managing, in a beneficial manner, the discharges and abstractions that are under the user's control. While this in itself is a sort of

EWS, users may want to consider additional EWS. The report includes a brief description of various EWS such as on-line monitors, instream probes, predictive models, people-centred EWS (also known as citizen science), and other innovative measures that could be used, such as the use of historic data to determine ratios of specific variables that may indicate a tendency to, for example, that can be used as an indicator of, for example, acid mine drainage or eutrophic conditions. Some emerging technologies include biological monitors, fluorescence analysis and satellite remote sensing, such as has been tested for cyanobacterial blooms for standing water bodies.

An important aspect that has been noted in respect of using EWS, is that for an EWS to be effective, the system must be understandable, trusted by and relevant to the communities that it serves. Warnings have little value unless they reach the people most at risk, who need to be trained to respond appropriately to an approaching hazard. It is noted that a complete and effective EWS comprises four inter-related elements: knowledge of hazards; knowledge of vulnerabilities; preparedness; and capacity to respond.

In respect of the approach taken in the IWQM framework, and considering the various levels – community, municipal, catchment/regional, and national – the potential for EWS use was explored. At the community level, community-based monitoring may be feasible for densely populated areas; and on-line monitors may be feasible specifically for WUAs and industrial areas (stand-alone industries, industrial areas and mines). Municipalities may want to consider on-line monitoring at wastewater, and water treatment, works as an EWS for both water quality and quantity. Community-based monitoring and the implementation of a water-related smart phone application which the public could use to report issues such as sewer overflows and water leaks, while uploading the location and a photograph, would be useful.

In respect of larger catchment areas, there are currently nine WMAs described in the National Water Resource Strategy (DWA, 2013). Under the NWA, these areas are administered by catchment management agencies (CMAs), or DWS/proto CMAs, if a CMA has not yet been established. The CMA has institutional responsibility for managing water quality in its catchment(s) through the implementation of the reserve and resource quality objectives (RQOs) which should be identified for all the water resources in their area, once classification of the resources has taken place. However, RQOs will not be developed for each small catchment and, in this respect, water quality planning limits (WQPL) may need to be developed. The CMA, or regional management unit, is responsible for auditing the quality and quantity of water entering its geographical area, and management options implemented, as required, and reporting on the above to the next level of management, as well as to the adjacent upstream management unit, from where the water originated.

At this level, on-line/instream water quality monitoring is not likely to be feasible as the areas in which the monitors would be placed would be susceptible to theft of solar panels and instrumentation. Implementation of planning models and contaminant transport models will be more effective in determining and monitoring hotspots. Flow gauging at several points along major rivers and at the major dams gives a good indication of expected flood and drought flows and, in this respect, a good communication strategy just needs to be developed to warn downstream users. As at municipal level, a water-related smart phone application through which the public could report water-related concerns when travelling, uploading the location and a photograph, would be useful.

CONCLUSIONS AND RECOMMENDATIONS

The project experienced numerous constraints, including difficulties loading the software onto users' computers, receipt of data and ownership. It has been noted in interactions with various stakeholders that the latter may be due to users having limited experience in basic software products, such as Excel.

In several cases, the system could not be loaded onto the users' computers during a training session due to administrative permissions. In addition, it was noted that data is not backed up anywhere, it is only housed on the users' computers.

There would need to be an internal discussion with the relevant managers and IT departments to ensure that they are aware of what needs to be loaded, and what back-up needs to take plac, to ensure data is maintained and stored for historical purposes.

From the government department's side, a constraint is that contracts for sample collection and analysis are not renewed timeously. This means that data is not available for input. As sampling is most often part of an environmental official's job description, it should be the case that even if a laboratory contract is not in place, each official should have a field instrument that can measure some basic parameters such as pH and electrical conductivity. These values could then be immediately added to the system and reported on.

The concept of ownership seems to be a large hurdle that will need to be removed. It is going to take a mind-set change to get personnel at all levels out of their comfort zone, as the immediate reporting may put them in the spotlight, where questions may be asked and answers will need to be given. It will mean that officials and water users at all levels will need to be proactive rather than reactive. This also ties into the community-based monitoring described.

Importantly, some positive aspects are the use of the system by the Breede-Gouritz CMA and potential use by users in the Olifants WMA as well as the Inkomati-Usuthu CMA.

Recommendations

It is recommended that the Inkomati-Usuthu CMA is trained to use the technology in collaboration with the relevant departments within the CMA. The training should include:

- Data assessment to understand what the current situation is in respect of:
  - Data quality and quantity;
  - Other reporting requirements that are linked to the catchment management strategy;
- Participation by various levels of stakeholders and impactors that already have water use authorisations and who should be reporting to the CMA;
- Participation by other stakeholders in the WMA who may not have, and may not require, an authorisation, but who, however, have a stake in the catchment. This will allow for all communities to become intimately involved in the management of their catchment by assisting them to identify relevant management units, CCPs, RFs and targets specific to their community, thus making them part of the system and allowing them to be accountable for reporting on a target that they themselves will set; and
- Putting considerable effort into getting officials and relevant stakeholders comfortable with the system, so that it will be effectively used.

CAPACITY BUILDING

As part of the capacity building for the project included the following elements of capacity building:

- Farah Adams, who has an Honours in Environmental Management from the University of the Western Cape, was initially employed as a data capturer to help the project. She has now been given a longer-term contract with Golder based on the work and experience she has gained.
- Zinhle Sithole, a junior hydrologist at Golder Associates Africa (Pty) Ltd (GAA), started her GDE in Environmental Engineering, subject to change to an MSc depending on results, and has a bursary through GAA.
- Dikae Manchidi, 3rd year Wits University student studying for a BSc degree, carried out vacation work at GAA in 2015 and 2016 and helped with part of the literature review. She received a bursary for honours in 2017.
- Jeff Dateling (junior water resource modeller at GAA) undertook an Advanced Business Analysis Programme, incorporating the National Certificate: Business Analysis (NQF 6).

In addition, officials from the Department of Environmental Affairs, from Development Planning, Directorate: Pollution and Chemicals Management, Department of Water and Sanitation, and from the Breede-Gouritz Catchment Management Agency attended the workshops and training session.

The concepts were also presented at a short course held at the Centre for Environmental Management which is part of the North West University.

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Reference Group:

Mr Wandile Nomquphu	WRC
Dr Jennifer Molwantwa	Originally as WRC chairperson, and subsequently as representative from the Inkomati-Usuthu Catchment Management Agency
Mr Pieter Viljoen	Department of Water and Sanitation
Mr Sandile Dube	Dimension Data
Ms Unathi Jack	eManti
Ms Thabisa Manxodidi	eManti
Mr Fabion Smith	Breede-Gouritz Catchment Management Agency
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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
BGCMA	Breede-Gouritz Catchment Management Agency
BOD	Biochemical Oxygen Demand
CCP	Critical Control Point
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DWS RO	Department of Water and Sanitation Regional Office
EWS	Early Warning System
GIS	Geographic Information System
GWP	Global Water Partnership
GPRS	General Packet Radio Service
HSPF	Hydrological Simulation Program in Fortran
IFRC	International Federation of Red Cross and Red Sickle Associations
IWRM	Integrated Water Resources Management
IWQM	Integrated Water Quality Management
IWQMF	Integrated Water Quality Management Framework
IWQMS	Integrated Water Quality Management System
IWUL	Integrated Water Use Licence
MERIS	Medium Resolution Imaging Spectrometer satellite
MU	Management Unit
NEMP	National Eutrophication Monitoring Programme
NWA	National Water Act
NWRS	National Water Resource Strategy
RF	

RQO	Resource Quality Objectives
SCADA	Supervisory Control and Data Acquisition
SWAT	Soil and Water Assessment Tool
USEPA	United States Environmental Protection Agency
WMA	Water Management Area
WQPL	Water Quality Planning Limits
WRC	Water Research Commission
W2RAP	Wastewater Risk Abatement Plan
WUA	Water User Association
WWTW	Wastewater Treatment Works

GLOSSARY

Background conditions	Aspects external to water quality which support the implementation of the framework and therefore indirectly impact on water quality
Business process	A process for carrying out a particular activity, in this case, integrated water quality management
Critical control point (CCP)	A critical control point is defined as a point or process that requires technical target measures or parameter ranges to be met in order to continually assess the hazard potential of the water resource. The CCP is most often defined by regulatory controls, where a point includes a discharge point; point in a storm water system or a point in a water resource[1]; and a process may be a procedure, or a practice such as optimal fertiliser application rate; dam water levels measured or buffer strips in place
Risk factor (RF)	A risk factor is defined as a point or process at which, if a failure occurs, the CCP performance targets will not be met.
Defining principles	Generalisations that are accepted as true and that can be used as a basis for reasoning or conduct
Hazard potential	Susceptibility of the water resource[1].
ISO 14000	An environmental management system to help organisations to:(a) minimise how their operations negatively affect the environment (i.e. cause adverse changes to air, water, or land); (b) comply with applicable laws, regulations, and other environmentally oriented requirements, and (c) continually improve in the above.
Management unit	A management unit in the context of the IWQM model is a geographical area, not necessarily homogeneous or continuous; that could be managed as a unit owing to common water use characteristics at the "lower"

[1] As defined in the NWA a water resource includes a watercourse, surface water, estuary, or aquifer; and ``watercourse'' means -

(a) a river or spring;

(b) a natural channel in which water flows regularly or intermittently;

(c) a wetland, lake or dam into which, or from which, water flows; and

(d) any collection of water which the Minister may, by notice in the *Gazette,* declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;

levels and to institutional responsibilities with regard to the management of water quality at the “higher” levels.

1.0 INTRODUCTION

1.1 Background

It is acknowledged that stresses on South Africa's water resources are affecting water quality, quantity and availability. There is therefore a need to protect and not pollute valuable freshwater resources. Rising demand for increasingly scarce water resources, as experienced in the recent droughts throughout the country, is leading to growing concerns about future access to water. This scenario is not specific to any of South Africa's nine water management areas (WMAs), as almost all of South Africa is experiencing water quality and quantity concerns at various levels. Importantly, it is recognised that deteriorating water quality not only affects aquatic ecosystems but also impacts economic growth, community health and empowerment. The National Water Resource Strategy: *Water for an equitable and Sustainable Future* (DWA, June, 2013, Second Edition) states that an adequate water supply of suitable quantity and quality makes a major contribution to economic and social development.

Chapter 3 of the National Water Act (NWA) (RSA, 1998), prescribes the protection of water resources through resource-directed measures, and the classification of water resources. Together, these measures are intended to ensure the protection of water resources, prevention of pollution and the remedying of the effects of pollution, while balancing resource protection with the need to use water as a factor of production to enable socio-economic growth and development.

Human activities such as mining, agriculture and urban, industrial and commercial development, which all result in waste disposal and air pollution, can have major impacts on the quantity and quality of water available for human and environmental use, while the abstraction and storage of water and the discharge of waste into water resources can impact on the quality of the water resource. These interactions must therefore be addressed in the management of water resources.

An important milestone in the revision of water law in South Africa was the publication of the "White Paper on a National Water Policy for South Africa" which set out overarching policy principles regarding water resource management in South Africa. These principles were later taken up in the NWA (RSA, 1998) which recognises the need for integrated management of all aspects of water resources, and, where appropriate, the delegation of management functions to a regional or catchment level to enable broader stakeholder participation in water resource management.

A major concern in water resource management is the lack of proper reporting on data that is collected in the course of implementing various aspects of the NWA, such as reporting on compliance with water use licence conditions, and reporting incidents such as sewer overflows or other land-use activities that could have an impact on a water resource. The lack of, or poor, reporting results in a lack of preventative action, or action that may be too late to be beneficial. There is therefore a need to develop a system that is simple to use and will allow reporting on targets, whether quantitative or qualitative, at various levels of management, as soon as data is received.

An Integrated Water Quality Management Framework (IWQMF) model has been developed which “breaks down” water management into smaller management units, while establishing both a horizontal and vertical reporting framework. A benefit of the model is that responsibility for water quality is based on significantly smaller geographical areas, and accountability to the adjoining areas (horizontal accountability) and to the next level of management (vertical accountability) is established. This allows accountability for water quality to be focussed on smaller management units, rather than diffused up to ever higher levels of management, thereby ensuring that all water users are aware of their own responsibility for protecting South Africa’s water resources, and are accountable for the impacts that they have on the resource.

This multi-disciplinary research project proposed to link, and build on, among others, the various Water Research Commission (WRC) studies, industry and consultancy reports relating to this IWQMF. The overall purpose of this project was to undertake technology transfer in the form of a case study on implementing the Integrated Water Quality Management System (IWQMS) developed in WRC project K5/ 2159, completed in April, 2014.

The pilot-scale project was aimed at refining the system in order to ensure that users are able to store data and draw reports in a simplified manner and on a more frequent basis in order to have an idea of what is happening in a catchment. The benefits include:

- Close to real-time water quality/quantity reporting by water users;
- Close to real-time access to water quality/quantity monitoring information;
- Simplified reporting for the regulators;
- Potential to include civil society organisations in the input of water quality data;
- Potential for spreading the monitoring footprint and reducing the cost of monitoring to the regulator.

This type of system can ultimately build towards assisting processes such as compulsory licensing and implementation of the waste discharge charge system.

2.0 AIMS AND OBJECTIVES

The overall aim of this project was to pilot the IWQMS that was developed in WRC Project K5/2159, by introducing the proposed decision support system to an existing institution, and to undertake a literature review on early warning systems and propose how the various options could be incorporated into the IWQMS. The tasks that were undertaken to achieve the aims included:

- Conducting a workshop on the IWQMS with one Department of Water and Sanitation regional office (DWS RO), the Breede-Gouritz Catchment Management Agency (BGCMA), a Water Users Association (WUA) and the water users;
- Distributing the IWQMS on a CD to the above and training them on its use;
- Conducting monitoring of the system during the project, including monitoring the water users' ability to input the data and submit reports to the DWS RO/ CMA and other relevant water users identified during the setting up of management units for reporting;
- Having the DWS RO/ CMA draw reports from the system and utilise these for quarterly and annual reporting;
- Using the system to unlock the reporting bottlenecks in governance to ensure a swift flow of information;
- Refining the glitches on the IWQMS, based on implementation of the system by various water users;
- Reporting on the progress by the water users, DWS RO, CMA, municipality and province;
- Reviewing and assessing early warning systems (EWSs) to aid in protecting our source water from over abstraction and contamination;
- Developing response scenarios and conceptual tools and frameworks based on different water management levels;
- Developing ideas on how to effectively manage ongoing operation and maintenance of the EWS.

3.0 METHODOLOGY

The methodology that was used focussed on identifying relevant stakeholders who would be intimately involved in learning the system and understanding the various components, so as to be able to make recommendations for improvements and refinements. The stakeholders would have to undertake situational and risk assessments in their catchment areas, in order to identify relevant monitoring requirements, and be able to set associated targets. In addition, a literature review was undertaken on EWS and what type of links would be possible to a system such as the IWQMS.

The methodology included the components illustrated in Figure 1.

Figure 1: Summary of methodology used

4.0 THE INTEGRATED WATER QUALITY MANAGEMENT MODEL

4.1 The complex nature of water resource management

Water quality, quantity and the aquatic ecosystem are all interlinked and interdependent. For this reason, water resource management at catchment or regional level needs to be highly integrated.

The Global Water Partnership (GWP) defines IWRM as *a process which promotes the co-ordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems* (http://www.gwp.org/The-Challenge/What-is-IWRM/).

Considering this definition, fresh water resources vary in quantity and quality, and make up a complex system comprising rivers, springs, dams, aquifers and wetlands; and the impacts of rainfall, runoff from the land, infiltration into the ground and evaporation from the surface back to the atmosphere. Each of these components must be managed with regard to its inter-relationship with the others.

In addition, water must be managed with a good understanding of its importance for social and economic development. This study explores the question as to whether response scenarios and the implementation of early warning systems can help achieve this.

As described in WRC Report TT450/10 (Boyd et al., 2010), the IWQMF model (Figure 2) is comprised of:

- Defining principles;
- Background conditions;
- The management framework;
- The generic business process.

These are described below.

4.2 Defining principles

In the first phase of the project, the following principles were prioritised based on the frequency with which they were raised in the consultation process. Principles are defined as being generalisations that are accepted as true and that can be used as a basis for reasoning or conduct. These principles therefore underpin the conceptual model for integrated water quality management (IWQM) in the South African context. The following principles are described:

- Water must be properly valued;
- Institutions responsible for managing water must be accountable for water quality;
- Water quantity and water quality are inextricably linked;
- The Polluter Pays Principle must be applied to the true cost of water pollution;
- Short-term economic gain at the cost of increasingly deteriorating water quality is not acceptable;
- Everyone should have access to water quality information that may not necessarily be in the form of technical data.

4.2.1 Water must be properly valued

It is not only important to ascribe value to water based on water availability and increasing water scarcity. The concept of value in the context of water should include:

- Downstream costs of pollution;
- The social and economic value of water;
- The value of wastewater;
- The significance of clean water in terms of public health; and
- The price of not having water.

The principle of *"there is not enough" water* should encompass an understanding of the various values of water, and not be limited to the fact that there is not enough water.

4.2.2 Institutions responsible for managing water must be accountable for water quality

Accountability is the obligation to demonstrate and take responsibility for performance in light of commitments and expected outcomes. In the case of water quality, under our current framework, accountability is not clear because of the complex institutional framework and the current understanding of co-operative governance. Accountability implies that someone is accountable to someone else, for something. It is therefore important to ensure that responsibilities are clearly defined, and that those to whom institutions are accountable, clearly understand the standards at which water must be managed, in order that they can assess whether institutions are fulfilling their obligations with regard to water quality. Finally, commitment to management practices that will ensure good quality water must be evident at all levels, both within and across the spectrum of water management institutions.

4.2.3 Water quantity and water quality are inextricably linked

It is important to ensure that the above statement is consistently recognised in all aspects of water management.

Poor quality water will reduce the quantity of water available for use, and the significance of poor water quality is more pronounced where less water is available (concentration).

4.2.4 The Polluter Pays Principle must be applied to the true cost of water pollution

The "Polluter Pays Principle" is a well-known and widely accepted environmental policy principle which is applied internationally through various mechanisms. It does, however, raise the question: "pays what?" In the case of water pollution, there are always "downstream costs" of a pollution incident. The term "downstream costs" must be understood in both its literal and figurative sense. There may be costs to water users physically downstream of a pollution incident, and there may be significant costs over time owing to cumulative environmental deterioration at the site of an incident itself and physically downstream. Furthermore, "downstream costs" could refer to indirect costs such as the cost of a community not being able to develop as a result of a lack of clean water. It is important t that the Polluter Pays Principle encompasses the expanded definition of "pays what?"

4.2.5 Short-term economic gain at the cost of increasingly deteriorating water quality is not acceptable

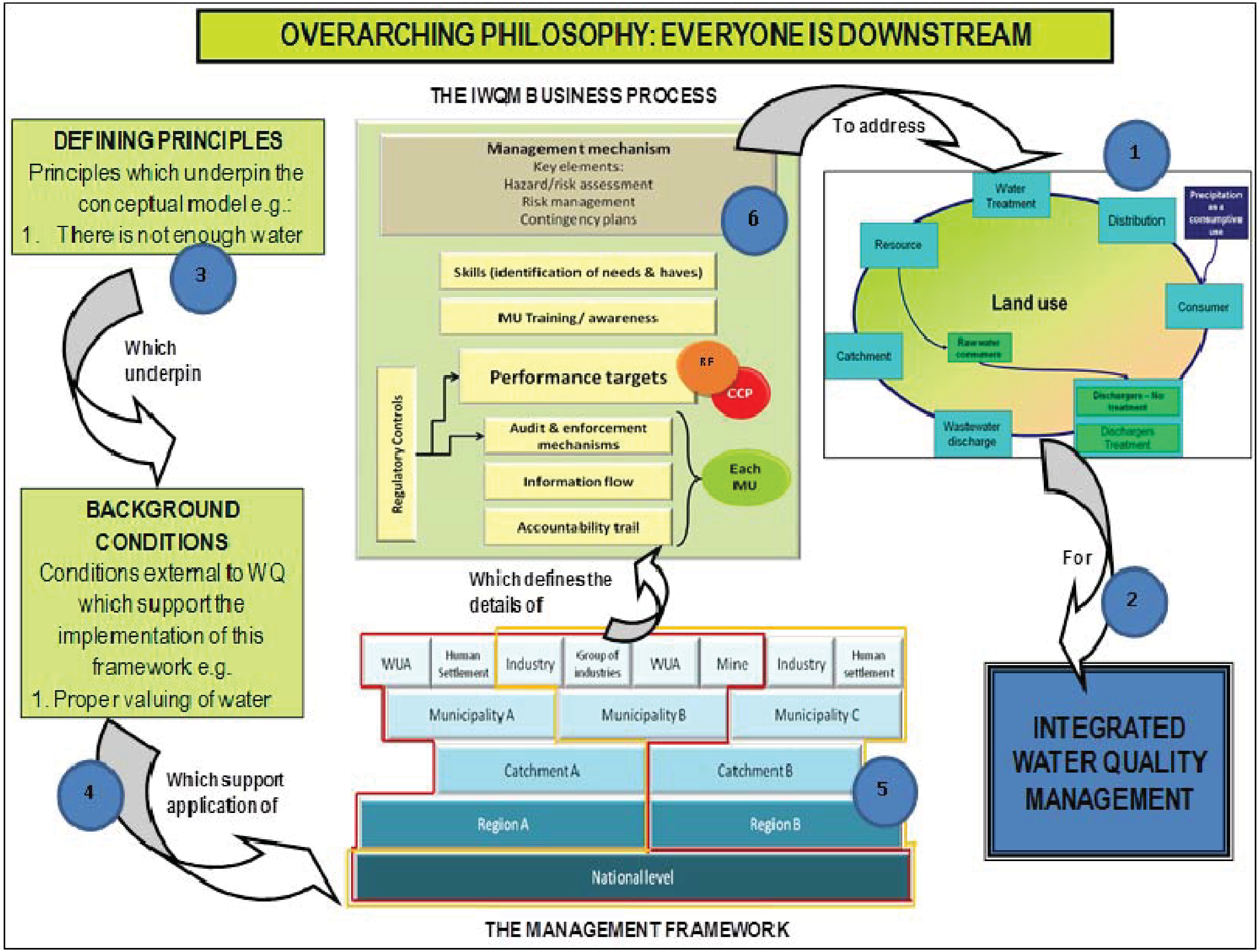
This principle refers mainly to the fees levied on users for discharge of wastewater to the sewer system, as the discharge has an impact on the wastewater treatment works (WWTW) and its capacity to operate optimally.

It is not acceptable that the discharger simply pays increasing fees without the relative cost of the downstream impact being understood when the "downstream" cost of discharging is creating a serious long-term impact on the water resource. The short-term economic gain received by those levying charges must be balanced against the total cost of wastewater entering the resource. This principle is closely related to the appropriate valuing of water.

4.2.6 Everyone should have access to water quality information that may not necessarily be in the form of technical data.

Everyone who uses water has a responsibility for water quality. Because water quality is a largely technical issue, most of the information disseminated about it is technical. While this is necessary at certain levels of responsibility, new and innovative ways to package information about water quality need to be found that will reach all audiences.

It is important that there is some understanding about water quality at all levels, and this will require a “rolling-up” of water quality data into more broadly understood formats.



In order to achieve IWQM (2), an assessment of the catchment, taking into consideration the elements of the water use cycle (1), needs to be undertaken.

In this project defining principles (3) (such as, there is not enough water) that underpin the background conditions (4) (an example being the proper valuing of water) led to the development of the Management Framework.

The Management Framework (5) relates to the identification and registration of MUs at the various levels. It is for each of these MUs that the IWQM BP (6) must then be developed and implemented to achieve IWQM.

Figure 2: The IWQM management framework (Boyd et al., 2010)

4.3 Background conditions

Background conditions are defined as those conditions external to water quality which support the implementation of the framework and therefore indirectly impact on water quality and include:

- The value of water (including wastewater) incorporating issues such as cost-benefit incentives and recycling initiatives;
- Management systems and tools (applicable to the various "levels") such as river health programmes and other existing water management systems or water safety plans;
- Communication between management units, as described in the section to follow, and also public access to information (which includes thinking about how to package water quality information for public consumption);
- Accountability, including aspects such as implementation of the Polluter Pays Principle, enforcement mechanisms and the implementation of a government watchdog;
- Improving institutional capacity;
- Education across the board on water issues, using the water use cycle as the basis for education and awareness;
- Effective strategic planning at various levels, which is an acknowledged challenge in most developing countries;
- Funding, which is seen as an important supporting condition for IWQM.

Two additional conditions that would have an impact on IWQM but do not fit into the eight main categories mentioned above are:

- Understanding the final catchment management structure within the nine water management areas (WMA) in South Africa and how it relates to roles and responsibilities; and
- Research which would include research into alternative and appropriate technologies, as well as assessment of certain established parameters such as Resource Quality Objectives (RQOs), which may be different in different parts of the catchment.

4.4 The management framework

A management unit (MU), as illustrated in Figure 3, in the context of the IWQM model, is a geographical area (not necessarily homogeneous or continuous) that could be managed as a unit owing to common water use characteristics at the "lower" levels and to institutional responsibilities with regard to the management of water quality at the "higher" levels (described in Section 4.4.1). Many of the MUs identified align with existing established institutions such as municipalities, catchment management agencies (CMA) or water user associations (WUAs). However, it is important to note that the establishment of a MU, at whatever scale, is not dependent on whether a legislatively established institution exists at that level.

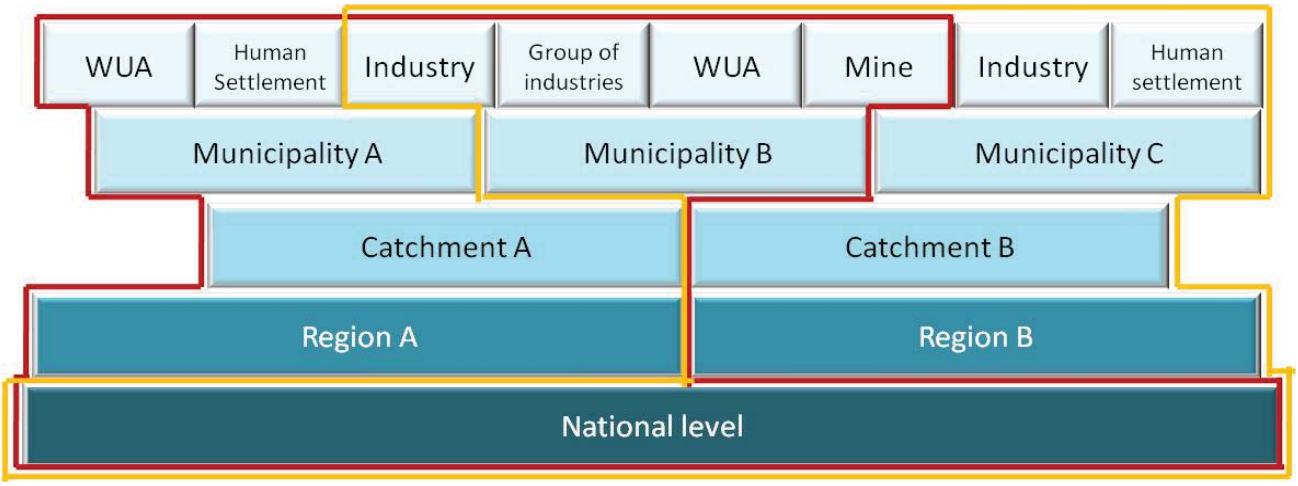


Figure 3: The IWQM Management Unit levels (Boyd et al., 2010)

4.4.1 Management levels

There are four management "levels" that would correspond to management unit types indicated in Figure 3. These are described below.

4.4.1.1 Community

Note that the word community is used to refer to a group of people or organisations with common interests regarding the quality and quantity of the water within a specific geographical area. A community-type management could be anything from a single factory to a small settlement (informal or otherwise) to a large group of farmers who participate in an irrigation scheme[1].

4.4.1.2 Municipality

Municipalities which have Water Services Authority status have the responsibility of ensuring a water supply to people in their area of jurisdiction, and many are also responsible for the treatment and discharge of wastewater.

[1] A group such as this is referred to as a Water User Association (WUA) and this is a statutory body established under the South African National Water Act (NWA) No. 36 of 1998 and must be established by a proposal to the Minister of Water Affairs. This means that there are specific provisions regarding what a WUA must undertake to put in place when they are established and also what must be reported on. However, the model presented does not require a group of farmers to be organised in an institution such as a WUA.

4.4.1.3 Catchment

South Africa has recently amended the division of WMAs from 19 WMAs to 9 WMAs, as described in the National Water Resource Strategy (DWA, 2013). Each WMA comprises several catchments. Under the NWA (RSA, 1998), these areas are administered by CMAs, or the Department of Water and Sanitation (DWS) if a CMA has not yet been established. The CMA has institutional responsibility for managing water quality in the catchment(s) through the implementation of RQOs, which should be identified for all the water resources in the catchment area, once classification of the resources has taken place. In the interim, while RQOs are still being developed, water quality planning limits (WQPLs) can be developed that will ultimately support the achievement of RQOs. A CMA, or even a group of water users at catchment level, which becomes a MU in this model, can therefore begin the process of managing water quality even if the legislative process is incomplete. The MU area can be one catchment or a group of catchments, as delineated by the WMA boundary.

4.4.1.4 Regional/ National

This level refers to the regional (or provincial) boundary (which does not always conform to catchment boundaries) and the national boundary. At this level there is definite institutional responsibility under both the NWA (RSA, 1998) and the Water Services Act (RSA, 1997), and at this level of the model the background conditions become increasingly important.

The management framework indicated in Figure 2 indicates how the various MUs (made up of water users or water user groups) relate to each other. This structure also addresses those instances where MUs may occur across municipal or catchment boundaries. Figure 2 further indicates how the water user groups (MUs) are represented in an integrated management context, and indicates the overlapping management “chains” from the smallest management unit (lower level) to the largest, at a national level (higher level). A single full IWQM management chain is highlighted by the red or yellow line.

The basic premise of the management framework is therefore to break down the challenge of IWQM into manageable areas, in order to reduce the reporting between management units to a simple “Yes” (quality and quantity parameters are being met) or “No” (they are not). This approach demands effective auditing, but is structured in such a way that adjacent MUs audit each other. That is, the MU is responsible for auditing the quality, quantity and management options implemented, as required, of water entering its geographical area and then reporting on that to the next level of management, as well as to the adjacent upstream management unit, from where the water originated.

It is at this point that the “how” becomes the focus of the model, through a simple generic business process which can be applied at every level of the model.

This framework ensures that each MU is accountable to its constituency, to the next/adjacent MU, and to the higher level MU, that could be a municipality, CMA or regulator at a national level.

4.5 The generic business process

The ultimate goal of IWQM is to realise specific objectives within a particular MU, taking into consideration the defining principles and background conditions relevant to that MU. This may be done through various tools, for example, a Water Safety Plan (WRC, 2012) for a municipality, or an Integrated Water and Waste Management Plan for an industry or mine (DWAF, 2010). The IWQM business process (Figure 4) is a generic process where various elements are applicable to every MU, and therefore each aspect of the business process must be in place in every MU. However, the detail of each element will vary according to the type of MU. Firstly, it is important to establish a management mechanism which must contain the specific elements of:

- Hazard assessment/risk analysis which includes identification of critical control points (CCP) and risk factors (RF);
- Risk management; and Contingency planning.

A CCP is defined as a point or process that requires technical target measures or parameter ranges to be met in order to continually assess the hazard potential of the water resource. The CCP is most often defined by regulatory controls.

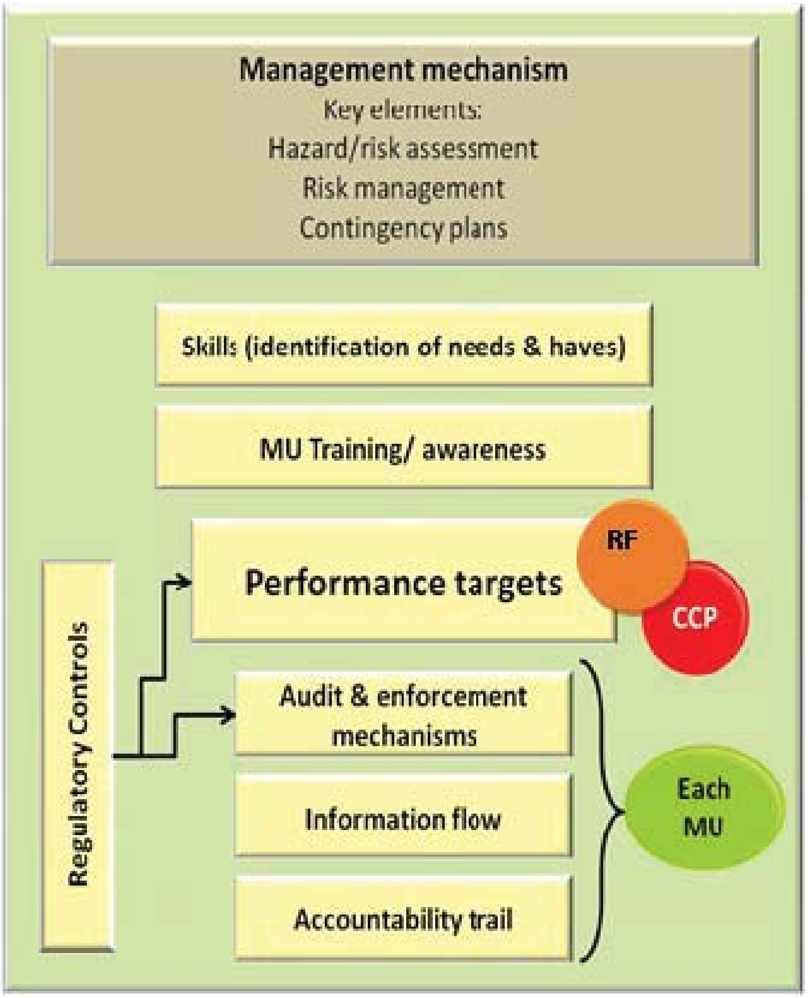


Figure 4: The generic business process (Boyd et al., 2010)

A risk factor *(RF)* is defined as a point or process at which, if a failure occurs, the CCP performance targets will not be met, where a ***point*** includes a discharge point; a point in a storm water system; or a point in a water resource[2]; and ***process*** may be a procedure or practice such as optimal fertiliser application rate; dam water levels measured or buffer strips in place; and ***hazard potential*** is defined as the susceptibility of the water resource. In this respect, meeting the targets of a RF can be mitigated for the CCP.

Implementing the IWQM business process within MUs would entail answering the following five questions (Table 1) in relation to the generic business process described above, and once the risk/hazard assessment had been undertaken, which would mean that the CCPs and RFs had been identified.

Table 1: Generic business process questions

Question		Notes
1	What do you (the management unit) need to know?	• Information/data flows from adjacent MUs, or smaller units within your MU; • Information/data requirements at each CCP: – performance targets; – management tools; – reporting requirements; – audit requirements; – regulatory requirements; and – contingency plans.
2	Who needs to tell you? What do they need to tell you?	• Information flow; • Organisations within MUs; • Information/data format; • Regulatory framework.
3	Who do you need to tell? What do you need to tell?	• Information flow from you (the MU) to adjacent or internal MUs; • Information content; • Information format.

[2] As defined in the NWA, a water resource includes a watercourse, surface water, estuary, or aquifer; and ``watercourse'' means - *(a)* a river or spring; *(b)* a natural channel in which water flows regularly or intermittently; *(c)* a wetland, lake or dam into which, or from which, water flows; and *(d)* any collection of water which the Minister may, by notice in the *Gazette,* declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks;

Question		Notes
4	What do we need to achieve this?	• Management tools (existing/new); • Relevant posts (existing/new); • Skills (existing/new); • Training/awareness programmes.

5.0 IMPLEMENTATION FRAMEWORK

As part of testing the IWQM framework (Boyd et al., 2011), an implementation framework was developed. The framework sets out a step-by-step process for the implementation of the IWQM model. Each step of the process is described and the necessary outcomes of each aspect of the process are also identified.

5.1 Establishing the outer boundary

The IWQM model applies at a number of different levels, in a number of different contexts, and there are a series of overlapping management chains in the management framework (Figure 3). Although ultimately the model can be applied at a national level, practically, the model should be applied at a smaller boundary such as a catchment or a municipality or even at community level. It is this practical outer boundary that must be initially defined. For example, will the boundary be just for one industry or will it be a whole industrial area with several industries all part of the MU?

It is also important to note that the MUs established do not have to cover the entire area, but obviously, the more area that is covered, the more effective implementation and positive impact on water quality will be.

5.2 Undertaking a risk assessment

In many instances there are already tools in place for undertaking a risk assessment, such as:

- An Integrated Water and Waste Management Plan for mines and industries as part of an integrated water use licence application;
- A Water Safety Plan for bulk water suppliers;
- A Wastewater Risk Abatement Plan (W_2RAP) for municipal wastewater treatment;
- Blue Drop assessment for water treatment works;
- Green Drop assessment for wastewater treatment works.

At catchment level, one way to identify the primary risks to the water quality would be to compile a matrix and undertake a risk assessment for the various sources of concern, an example of which is shown in Table 2. This should assist in prioritising the areas of concern and identifying the CCPs, RFs and associated targets that should be monitored, included in the IWQM model and be reported on. Such a tool would also assist in deciding whether an EWS would be a practical consideration and where.

Table 2: Example of a risk matrix that could be used as part of the catchment assessment

QUATERNARY DRAINAGE AREA W Q RISK ASSESSMENT			DRAINAGE AREA				H22A	
ACTIVITY - MINING, INDUSTRIAL, AGRICULTURAL, DOMESTIC, ENVIRONMENTAL								
Source of Concern	Description of Concern		Likelihood of WQ Problem		Severity of the Problem		RISK LEVEL	
			Highly Unlikely	1	Negligable	1	Negligible Risk	
			Unlikely	2	Minor	2	Low Risk	
			Possible	3	Major	3	Moderate Risk	
			Probable	4	Hazardous	4	High Risk	
			Certain	5	Catastrophic	5	Extreme Risk	
Paarl WWTW	No Trade waste By-laws	D		2		1		2
	Classification of the Works			1		1		1
	Classification of Process			2		1		2
	Design of the WWTW			3		3		9
	Maintenance of the Works			1		1		1
	License from DWS			3		2		6
	Quality of the Effluent			5		5		25
	Sludge Disposal			3		4		12
	Power Outage			3		3		9
Daspoort Informal	No formal Reticulation	D		5		5		25
	Buckets overflowing			4		5		20
	Solid Waste Management			3		3		9
	Stormwater Mngnt and			4		4		16
	Informal Roads			3		3		9
	2nd and 3rd Dwellings			4		4		16
Paarl Urban Areas	Management of Stormwater	D		3		3		9
	Stormwater Quality			3		3		9
	Solid Waste Disposal			3		2		6
	By Laws			3		2		6
Paarl Industrial	Industrial Effluent	I		4		4		16
	Stormwater Management			5		3		15
Distel Wine and Distillery	Compliance with By Laws	I		3		3		9
	Compliance with License/GA			1		1		1
	Stormwater Management			3		3		9
	Solid Waste Management			3		4		12
De Beers Piggery	License or GA	A		5		3		15
	WQ Compliance			4		4		16
	Irrigation Area			3		3		9
	Run-off from Irr. Area			3		3		9
	Stormwater Management			5		5		25

5.3 Identifying potential management units

The catchment assessment will support the identification of the MUs and specific potential areas of concern or "hot spots" within each MU. Once the outer boundary of the area is defined, water user groups, organisations or institutions which can potentially form MUs should be identified. It is important to note that the authority or management mandates for the outer boundary area generally exist at the level of the catchment or the municipality.

As described above, there are a number of "levels" of the management framework, the first level being the "community" level. Once again it is important to note that in the context of this framework, community is meant in the sense of a community of water users and not necessarily a community of people.

The outcome of this process should be a list of potential MUs and contact details for a person who represents or is responsible for the activities undertaken within the ambit of the MU.

5.4 Signing up management units

The IWQM model is based on individuals and organisations or institutions who use water being accountable for how they are using that water. Therefore, once potential MUs and their contact people are identified, each must be approached to "sign up" to be a management unit.

At this point, appointments should be made with the various representatives of the MUs to present the model and to begin identifying activities which could be a risk to water quality and quantity. It is very important to note that the RFs and CCPs, and the performance targets which will be applied in the model, must be established by the MUs themselves. This will support ownership of the model by the water users.

The approach needs to be tailored to the audience. For example, there is no need to create a presentation to give to a rural community on the IWQM model. Instead, the approach should be based around water use. This is something everyone can identify with rather than complicating the approach with talk of generic business processes and overarching philosophies.

WHAT IS MEANT BY "ACCOUNTABILITY"?

It must be noted that, in the context of implementation of the IWQM model, the term 'accountability' means:

- Taking responsibility to manage for those targets;
- Mitigating against risks; and, most importantly,
- Reporting to other management units in the framework when targets are not going to be met because a risk factor has been triggered and the CCP is not likely to meet its requirements.

Thus the "accountability" discussed in the context of this model is not legislative accountability where an institution has a mandate to meet certain requirements established by legislation and is therefore subject to the provision in the legislation if requirements are not met. It is, rather, voluntary accountability to meet the self-imposed requirements of the performance targets stated in the business process (BP) form discussed below, and signed off by an authorised representative of the MU. This is the critical aspect of the model, in that it confers management responsibility for water use on smaller groups who agree to be accountable for their actions with regard to the use of water.

IN THIS WAY, EVERY WATER USER IS A WATER MANAGER

This outcome of this process would be that MUs are signed up as committed to the principles of IWQM and take accountability for achieving the targets set for each RF or CCP and for reporting on these targets.

A spin-off benefit could be that these actions would support the establishment of a CMA as all stakeholders would ideally be represented.

5.5 The Business Process

The business process has been translated into two forms that are described further in the report as part of the system components and relates to the following information that is required:

- Management unit name;
- Management unit type;
- Management mechanism;
- Critical control points and risk factors;
- Existing management tools;
- Regulatory controls;
- Available skills;
- Training requirements;
- Reporting framework;
- Audit or enforcement mechanisms;
- Accountable person for the management unit.

5.6 Identifying risk factors and critical control points

The RFs and CCPs depend largely on the various ways in which water is used in the context of the water use cycle (

Figure 5) which forms the basic context for which the business process has been developed.

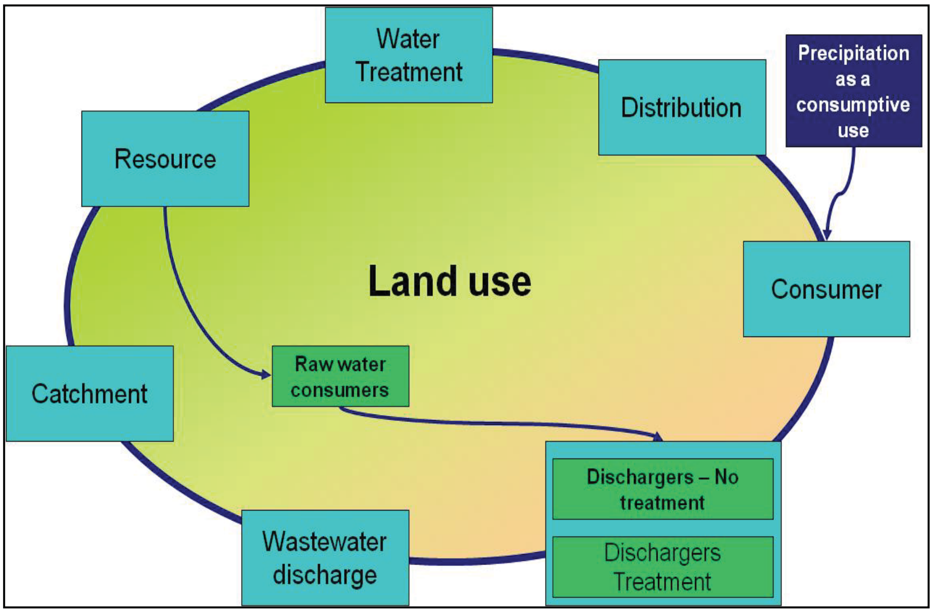


Figure 5: Water use cycle (Boyd et al., 2011)

For example, if the use of water is “Dischargers – Treatment”, the RFs and CCPs are based around the risks to water quantity and water quality (i.e. the fitness for use of that water) that this particular use of water will generate.

RFs and CCPs can, therefore, not be established without an examination of the uses of water in each management unit. Of course, once the CCPs and RFs have been determined, it is important to set targets for them, so that it is clear as to how the risks should be managed.

In many cases, the performance targets are set by national or local legislation such as municipal bylaws. For example, in the case of a MU abstracting water to be treated, distributed and provided to consumers, there are likely to be drinking water quality standards required by national legislation, or aligned with international standards under national policy. Often, the performance targets will already be there in the form of conditions set in a water use authorisation – for example, standards for treated wastewater discharge. In these cases, performance targets do not need to be established. However, where there are no regulatory controls, or quality limits, performance targets must be set.

6.0 THE IWQMS COMPONENTS

The IWQMS is the computer-based management information system. What follows below is a description of the system. The required installation files are contained in the CD included. The system comprises the following steps after installation that are described in further detail below:

- Step 1: Opening the application;
- Step 2: Adding an organisation;
- Step 3: Adding contacts;
- Step 4: Adding the management units;
- Step 5: Adding the business process list;
- Step 6: Adding monitoring points;
- Step 7: Adding targets for each monitoring point;
- Step 8: Adding actual monitored data.

Step 1: Opening the application

The system has been changed to be a stand-alone application for now. Figure 6 illustrates the page that will be displayed when running the application.

Figure 6: Opening page displayed when running the application

Step 2: Adding an organisation

The next step is to add organisations, as illustrated in Figure 7.

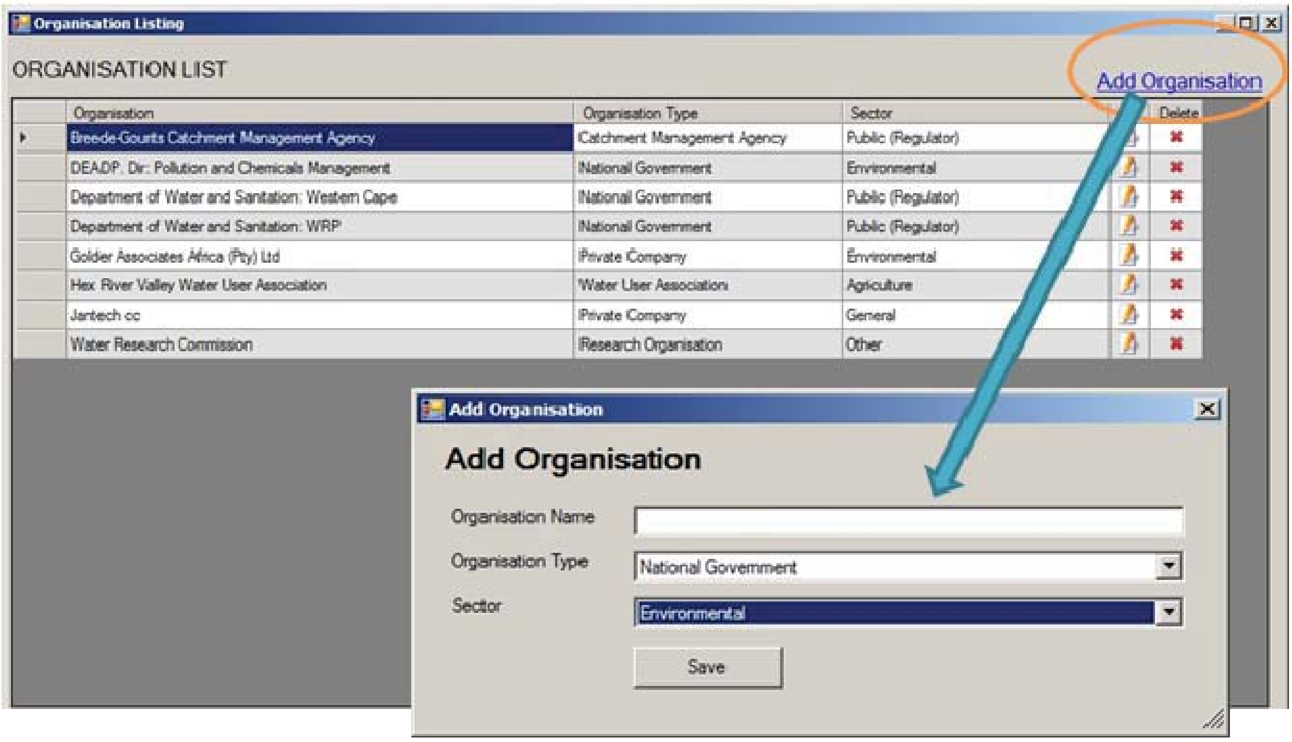


Figure 7: Adding an organisation

Step 3: Adding contacts

Adding a contact is done as illustrated in

Figure 8. Contacts would be all contacts that are related to the particular monitoring point. In other words, all who should receive a report regarding the achievement of certain targets at the point – remember the vertical and horizontal reporting philosophy.

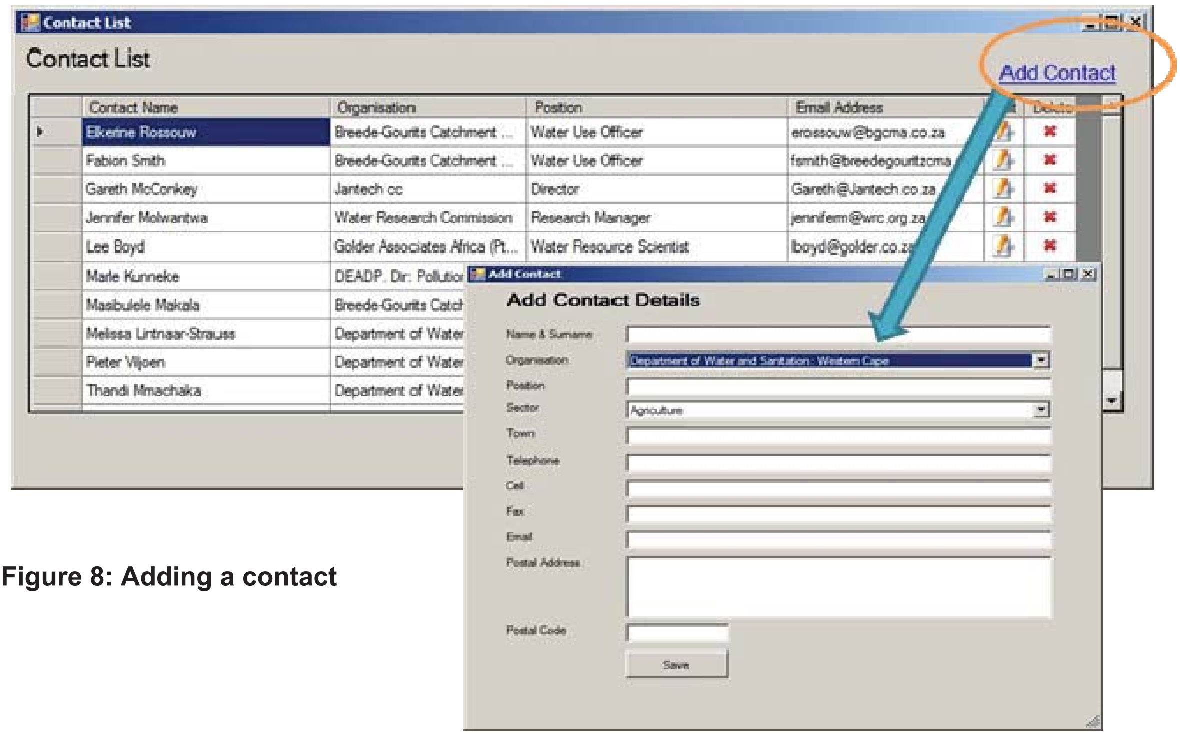


Figure 8: Adding a contact

Step 4: Adding the management units

MUs are added by firstly assigning a name to the MU, as well as an acronym that will be used as the first two letters for each monitoring point. The quaternary catchment in which the MU is located is also included here as well as the accountable person.

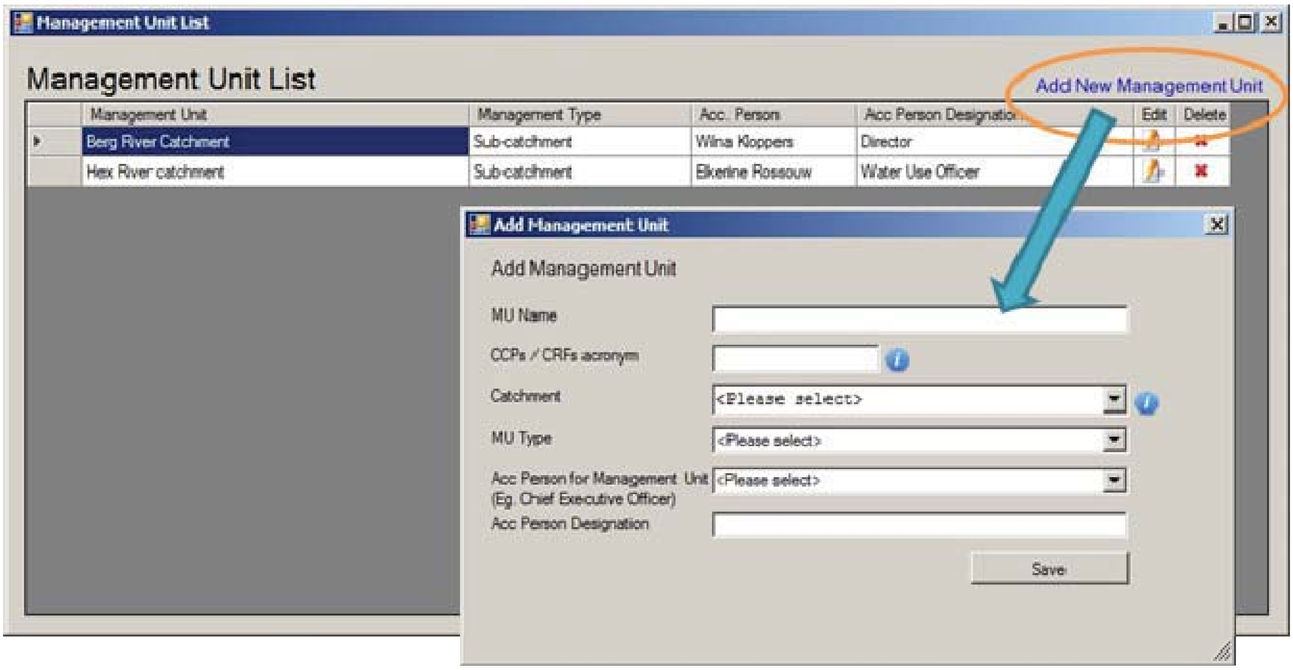


Figure 9: Adding a management unit

Step 5: Adding to the business process list

Adding to the business process list is done by selecting the MU you wish to work with (Figure 10).

There is the opportunity to add a reference to an existing management mechanism such as a catchment management strategy document or Integrated Water and Waste Management Plan, at the lower levels. It is, however, not mandatory.

The regulator control allows for a link (Figure 11) to a document or a web-page, and even allows the user to upload a document, such as an integrated water use licence, to the database. Adding a document to the database, however, would mean that the database would become very large, so this will need to be managed. Note that Manage links and documents only shows up when a *regulator control* item is added.

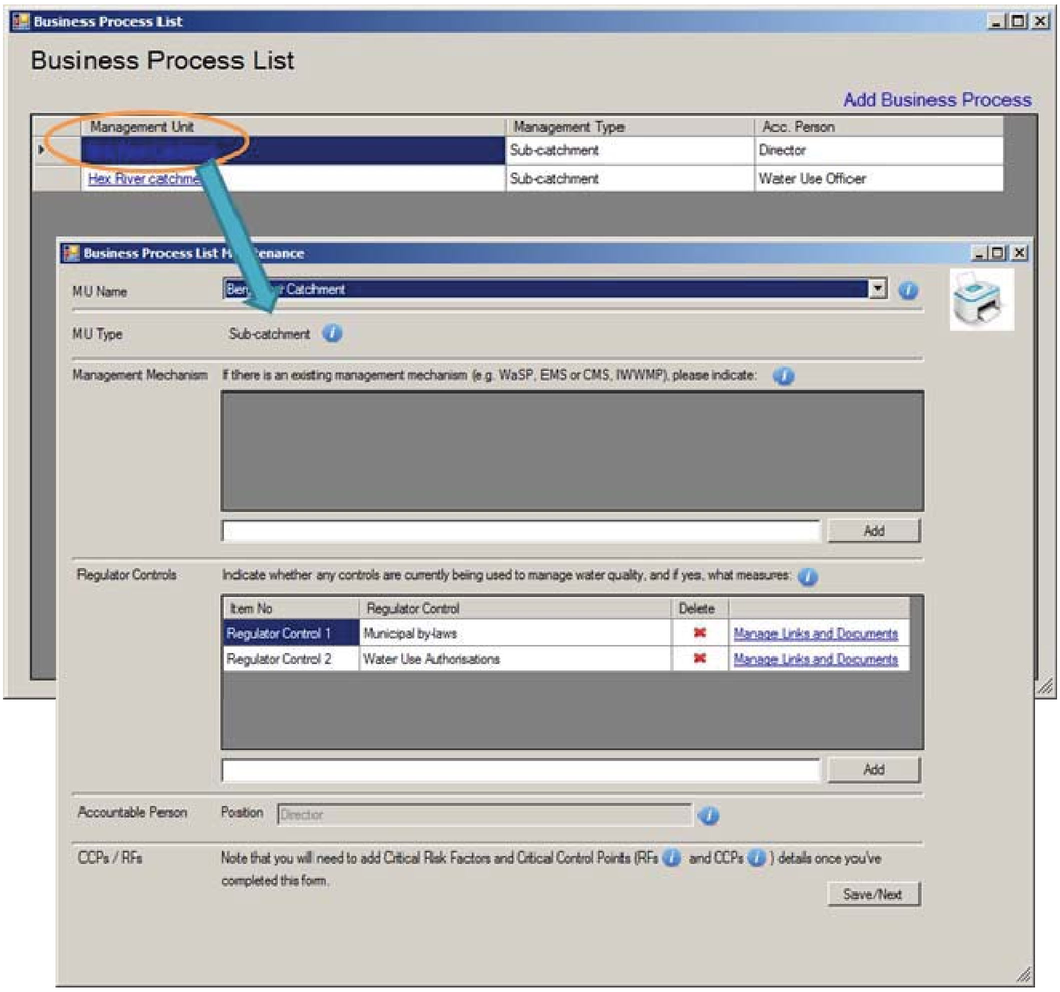


Figure 10: Adding to the Business Process List

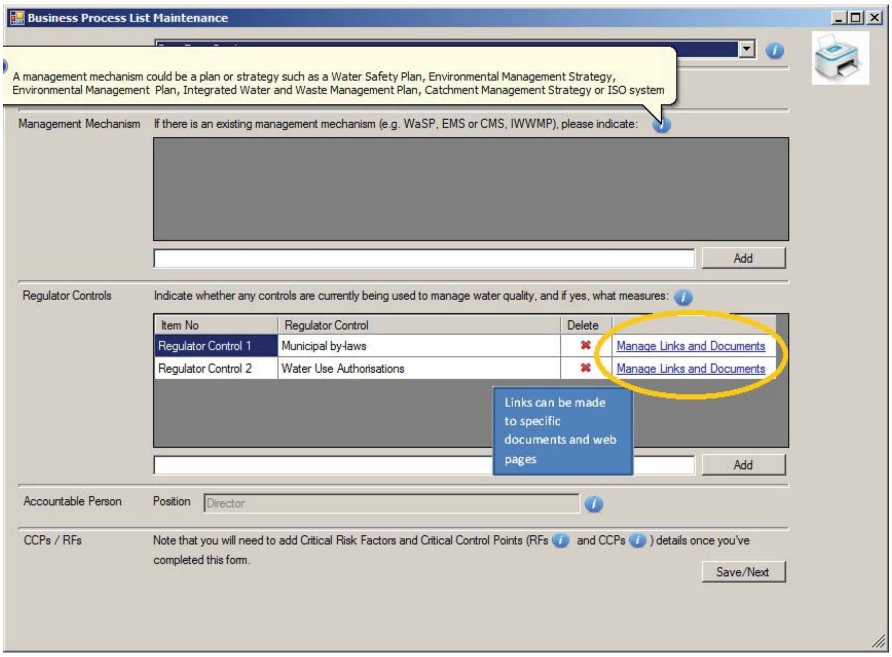
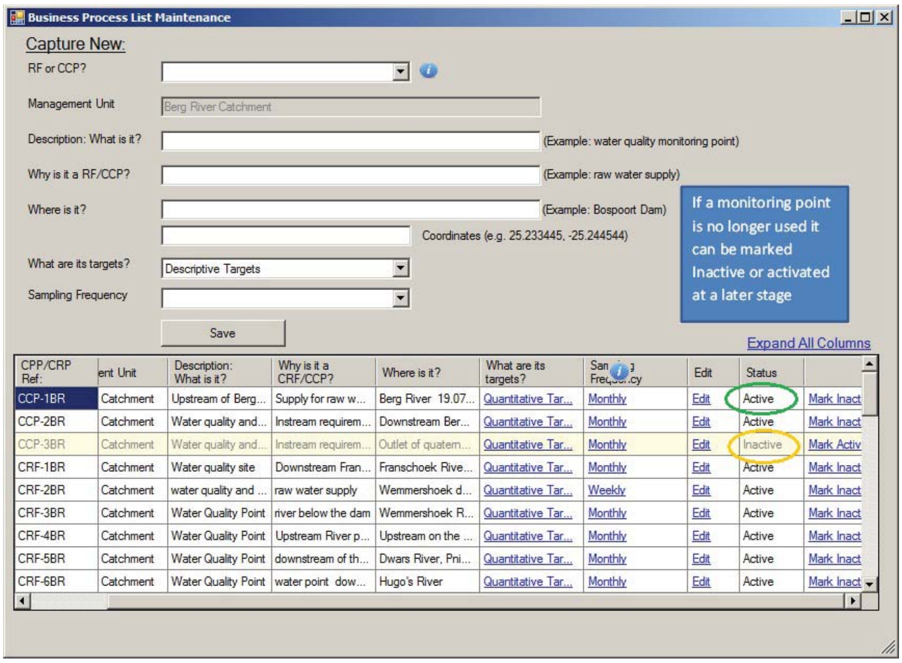


Figure 11: Opportunity to add links

Step 6: Adding monitoring points (CCPs and RFs)



Adding the critical control points (CCPs) and risk factors (RFs) is done by choosing the Save/ Next button. Should a monitoring point be added that is no longer applicable, it can be made inactive, and can be activated again at a later stage should it be required.

Figure 12: Adding monitoring points (CCPs and RFs)

Features of the CCP can also be edited should it be necessary (Figure 13).

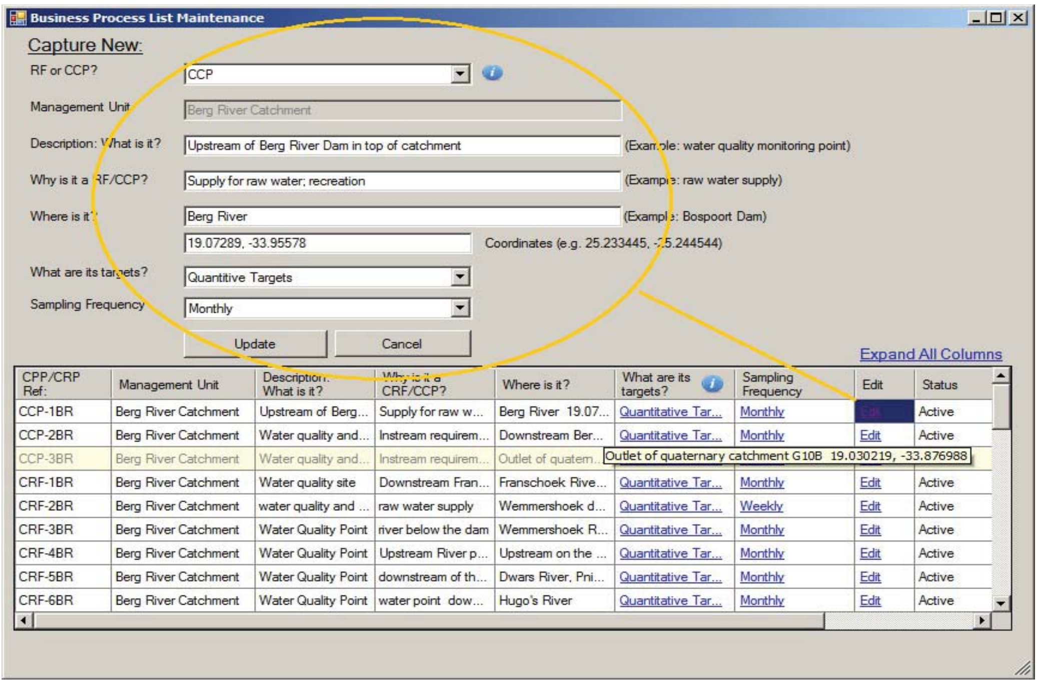


Figure 13: Edit function

Step 6: Adding targets for each monitoring point

The targets are added by clicking on the quantitative or descriptive targets that have been chosen. Parameters are chosen either from the list on the left-hand side or by adding to the empty field at the bottom of the page. Limits are added for each parameter chosen (Figure 14).

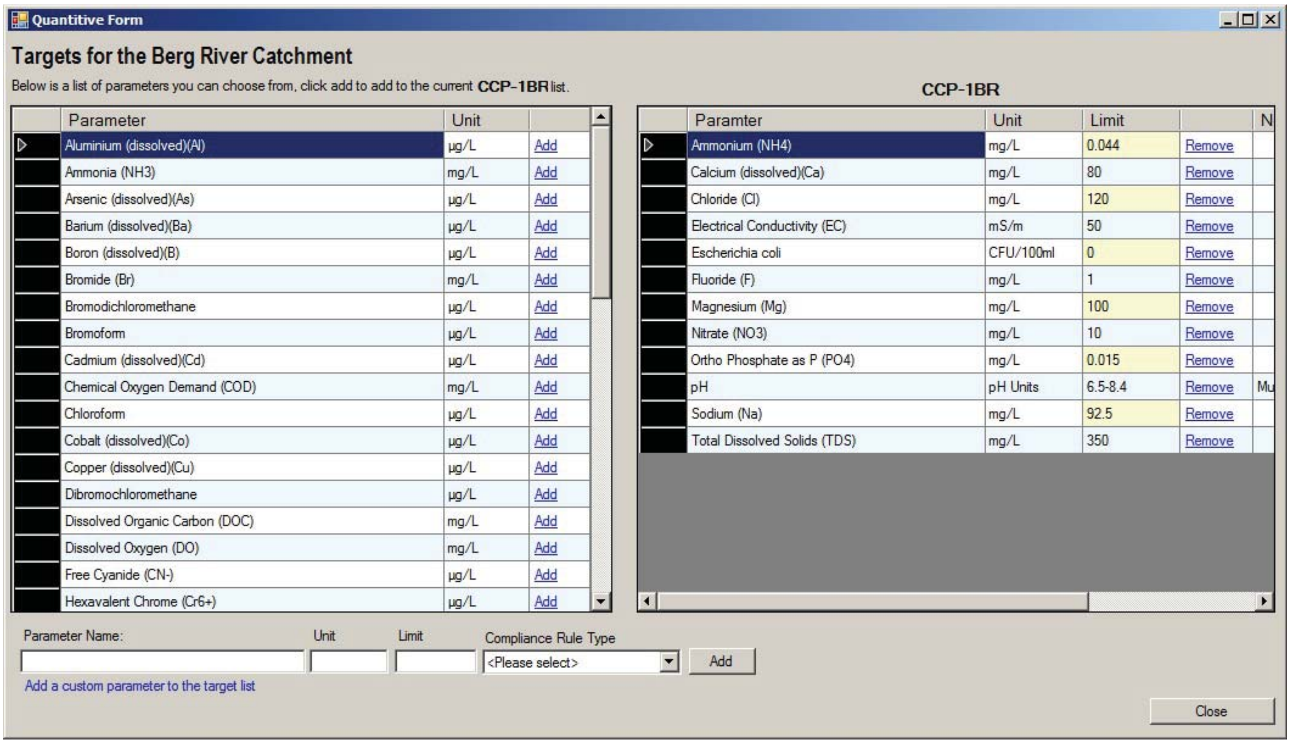


Figure 14: Targets page

Step 7: Adding actual monitored values

The actual monitored values are added by clicking on the sampling frequency link for each point. The addition of the measured value will then give a Y (yes) or N (no) answer in respect of compliance, and will be coloured green or red respectively. Once the sampling data for the period has been entered and the period expires, then further non-compliance, (N), will bring up a form at the bottom of the page where three questions will need to be completed.

- Why is there non-compliance?
- What has/will be done to remedy the situation?
- What are the timeframes for improvement?
- Once the data is added, click on Save data to csv file, to create a csv file and save it.

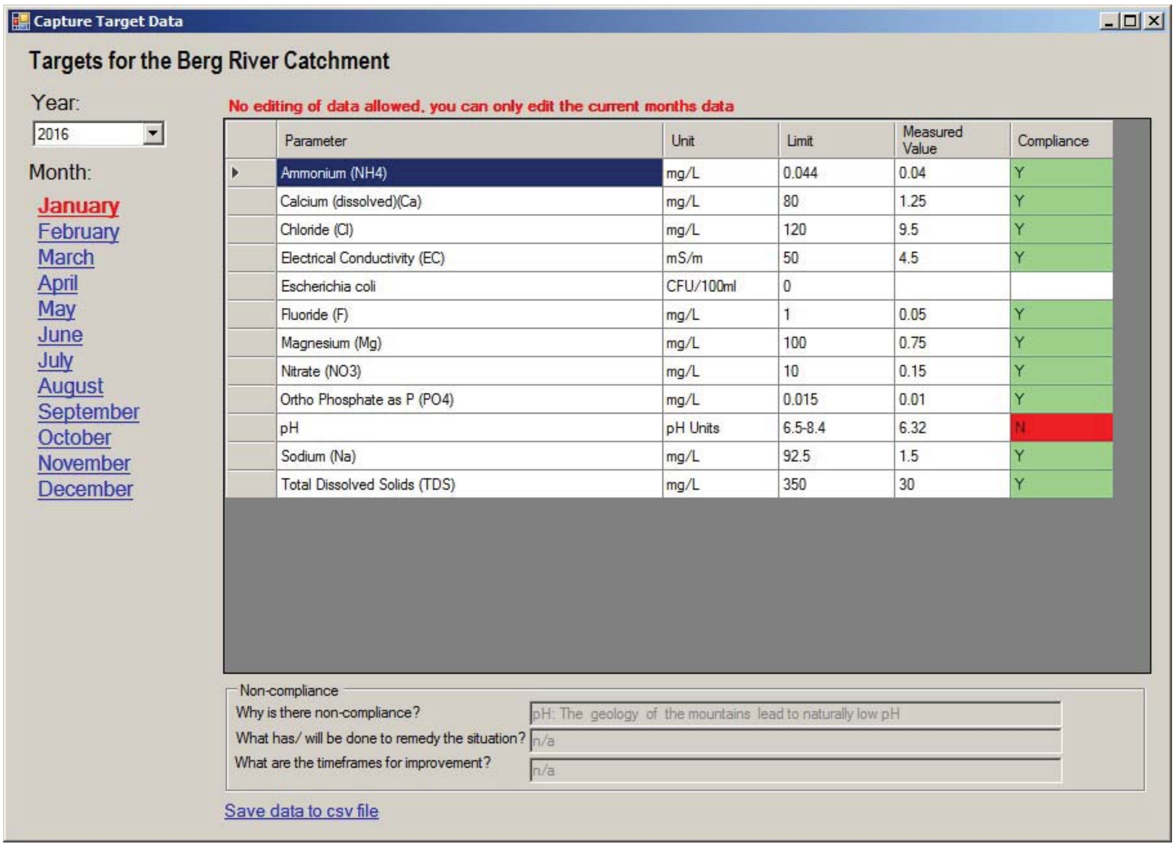


Figure 15: Results page

6.1 Reporting

There are two types of reports:

- Short-term or "immediate" reports that deal with data from one specific point at a time, i.e. individual monitoring data per monitoring event (Section 6.1.1);
- Longer term, for example, annual reports (Section 6.1.2).

6.1.1 Creating short-term reports

The following approach is proposed for immediate or short-term reporting requirements.

Set up the short-term/immediate reporting template

Set up your reporting template from the template included on the CD, which is an Excel spreadsheet entitled "Sampling point template", by following steps 1 to 4.

1. Step 1: Complete the cover page by adding to it as illustrated in Figure 16.

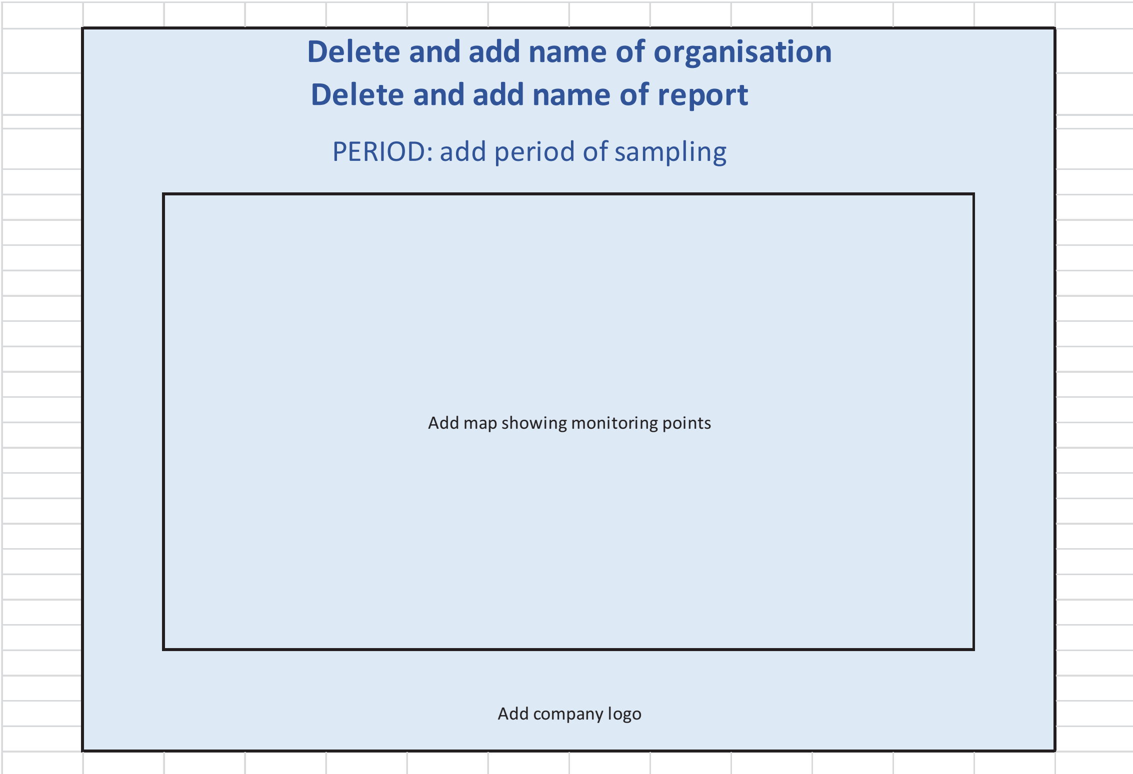


Figure 16: Complete the cover page

2. Step 2: Add monitoring points data to the spreadsheet with the tab: *Monitoring points;*
3. Step 3: Add contact details for those contacts who will be receiving the report. Remember the following:
    a. Those points identified as critical control points should go to all relevant organisations. Ask the question, who needs to see this report so that action can be taken, as needed, within the shortest possible time;
    b. Those points that have been identified as reference factors, may need to be reported internally only;
4. Step 4: Add the spreadsheets for the measured data - depending on the number of monitoring points, whether they are CCPs and RFs, and whether the data is descriptive or quantitative:
    c. Right-click on the tab titled CCP quantitative, CCP descriptive, RF quantitative or RF descriptive and then:
        i. Left-click on Move or Copy…;
        ii. In the move or copy box, left-click on Create a copy;
        iii. Copy as many sheets as needed for each monitoring point. It may be useful to colour the tabs depending on whether the monitoring points are critical control points or reference factors, as defined in the main

body of this report. To change the tab colour, right-click on it, then choose Tab colour and left-click on the colour you would like to use;

iv. Change the tab name for each monitoring point by right-clicking on the tab and then choosing Rename (left-click);

d. Save the worksheet as a report template; and

e. As data is entered each month, save a new worksheet with a relevant file name, for example: March 2016 surface water report.

Adding data from the csv file

- Keep the newly named report open;
- Copy the data exactly from the csv file as illustrated in Figure 17;

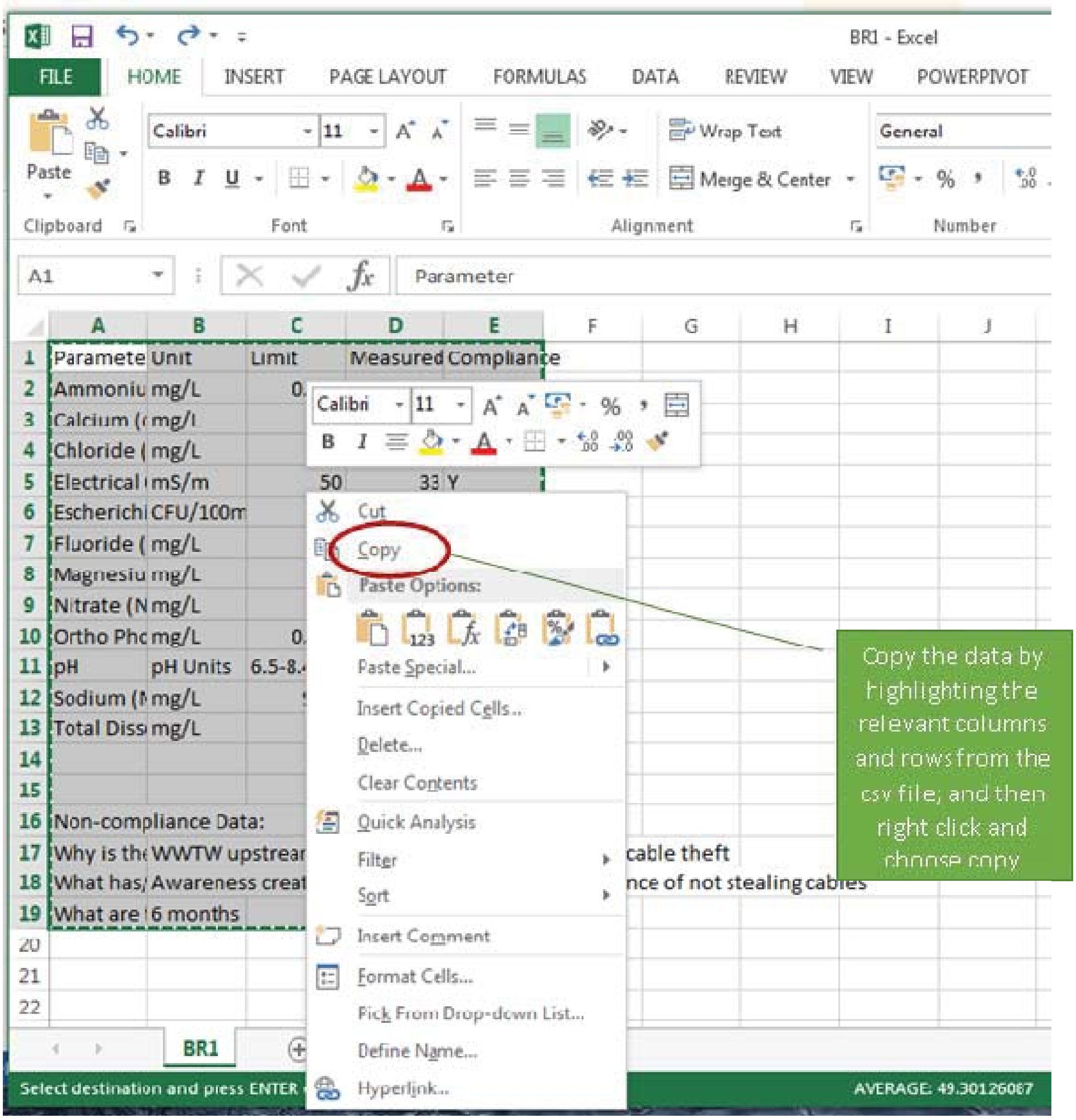


Figure 17: Copying from the csv file

- Choose the worksheet with the correct tab for the data from the monitoring point being entered;
- Paste the selection into the relevant spreadsheet with the monitoring point tab for the data downloaded (Figure 18); you can paste it directly by right-clicking in the top RH corner (A1) where it says: Parameter.

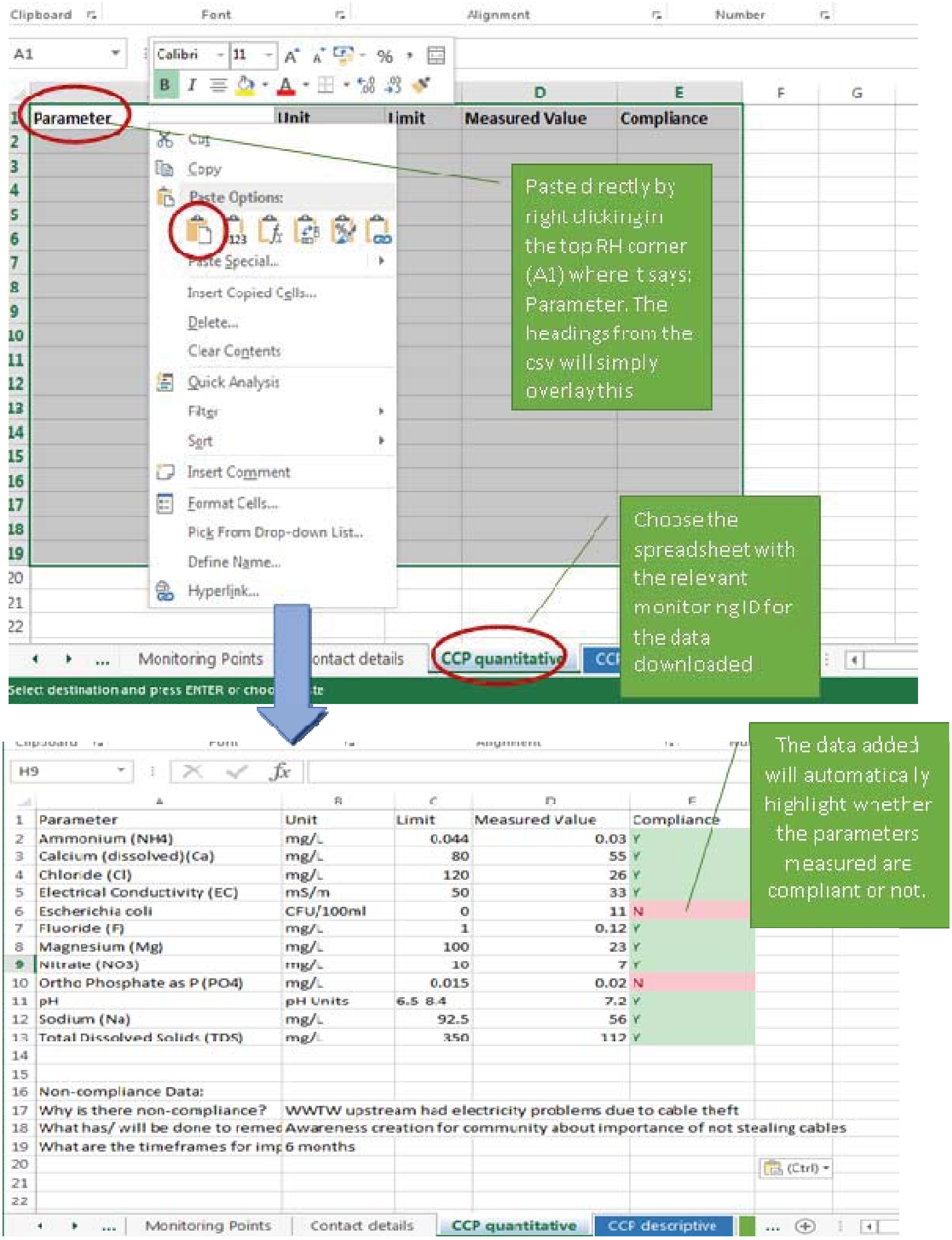
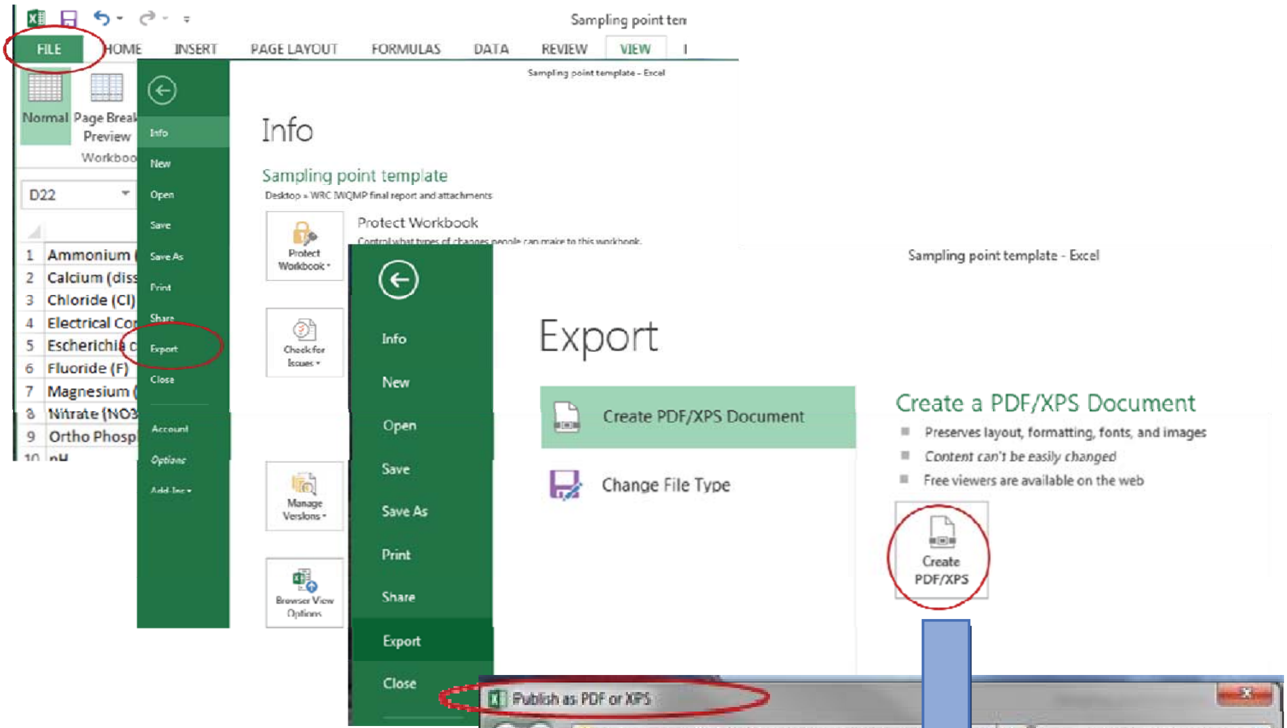


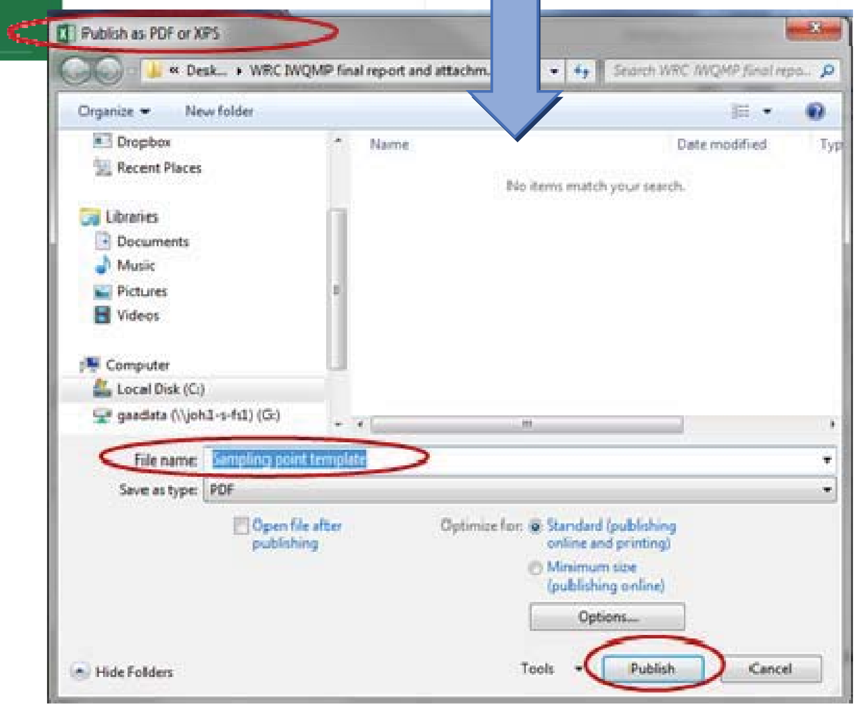
Figure 18: Insert into the report template

This worksheet can then either be saved as a pdf and e-mailed to relevant contacts, or it can be e-mailed directly as an Excel spreadsheet.

If you prefer to e-mail only those worksheets with data, then you will need to print to pdf.

- Highlight the relevant worksheets that you would like to send by holding down the Ctrl button and left-clicking on the relevant tabs;
- Choose File/Export/Create PDF/XPS document, by left-clicking on each of those as highlighted below. This will bring up the Publish as pdf page.





a) Update the file name, if necessary, and click on Publish.

b) The file will be saved to the folder in which the Excel report is saved. If the box: *Open file after publishing* is ticked, it will open automatically and can be e-mailed immediately to the relevant contacts.

6.1.2 Creating longer-term reports

The long-term report has been designed to assess the trends per monitoring point over a longer period.

1. Step 1: Complete the cover page by adding to it as illustrated in Figure 19.

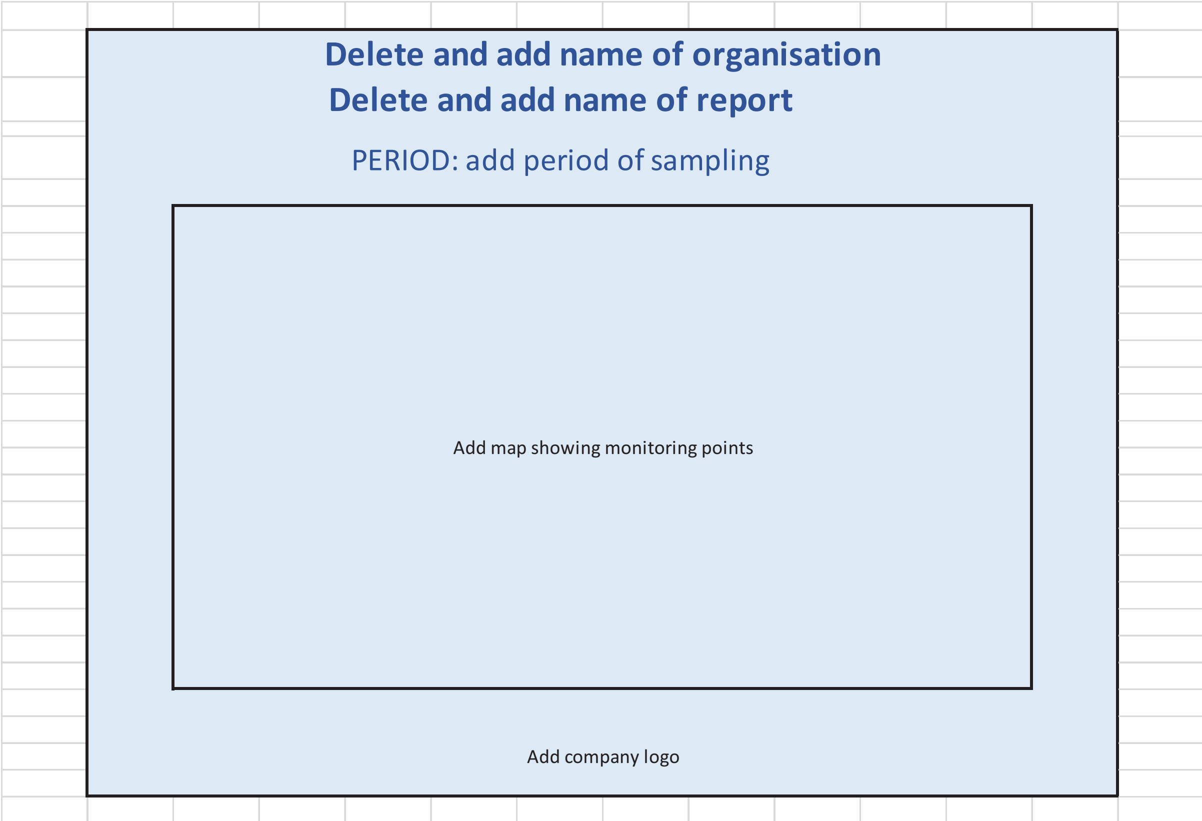
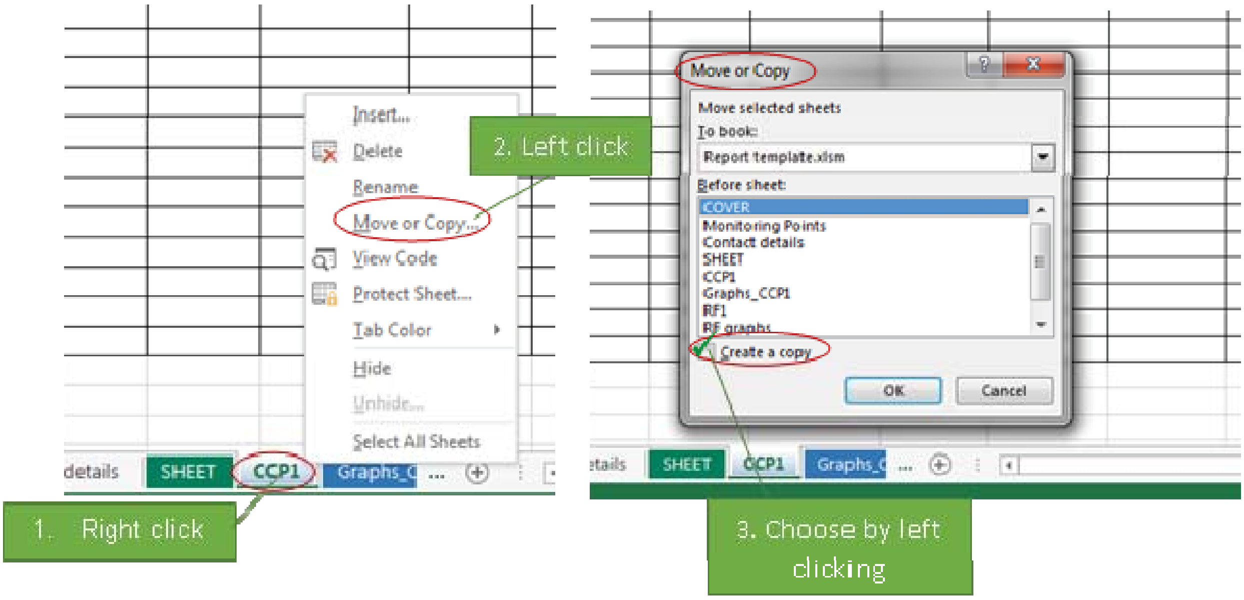


Figure 19: Complete the cover page

2. Step 2: Add monitoring points data to the spreadsheet with the tab: *Monitoring points;*
3. Step 3: Add contact details of those contacts who will be receiving the report;
   - NOTE: Steps 2 and 3 do not differ from the steps undertaken for the short-term reports and can therefore be copied and pasted into this report.
4. Step 4: Depending on the number of monitoring points:
   a. Right-click on the tab titled CCP 1, and then
      i. Left-click on Move or Copy…;
      ii. In the move or copy box, left-click on Create a copy;
      iii. Do the same for Graphs_CCP1;
      iv. Change the tab name for each monitoring point; and
      v. Do as many sheets as needed for each monitoring point. It may be useful to colour the tabs depending on whether the monitoring points are critical control points or reference factors as defined in the main body of this report.



5. Site 3: Edit Sheet Index (Figure 20) for easy reference

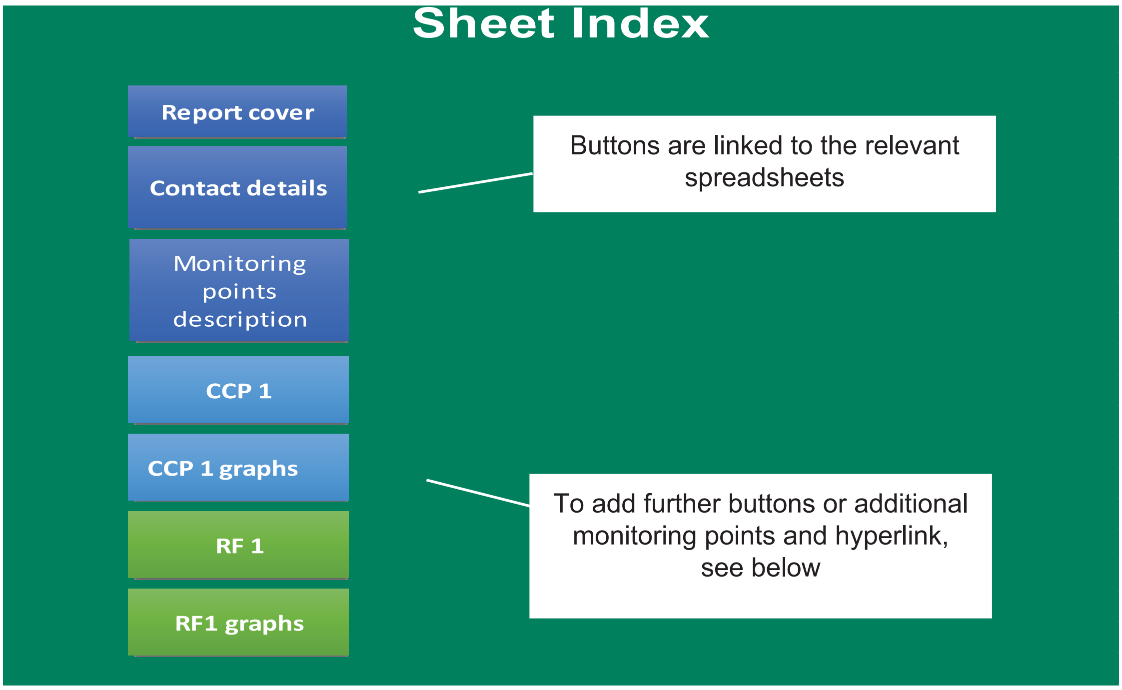


Figure 20: Sheet Index page

To add further buttons carry out the following steps:

a) In the top ribbon, click on Insert, choose Illustrations, Shapes and then the shape you would like to use (as illustrated in Figure 21).

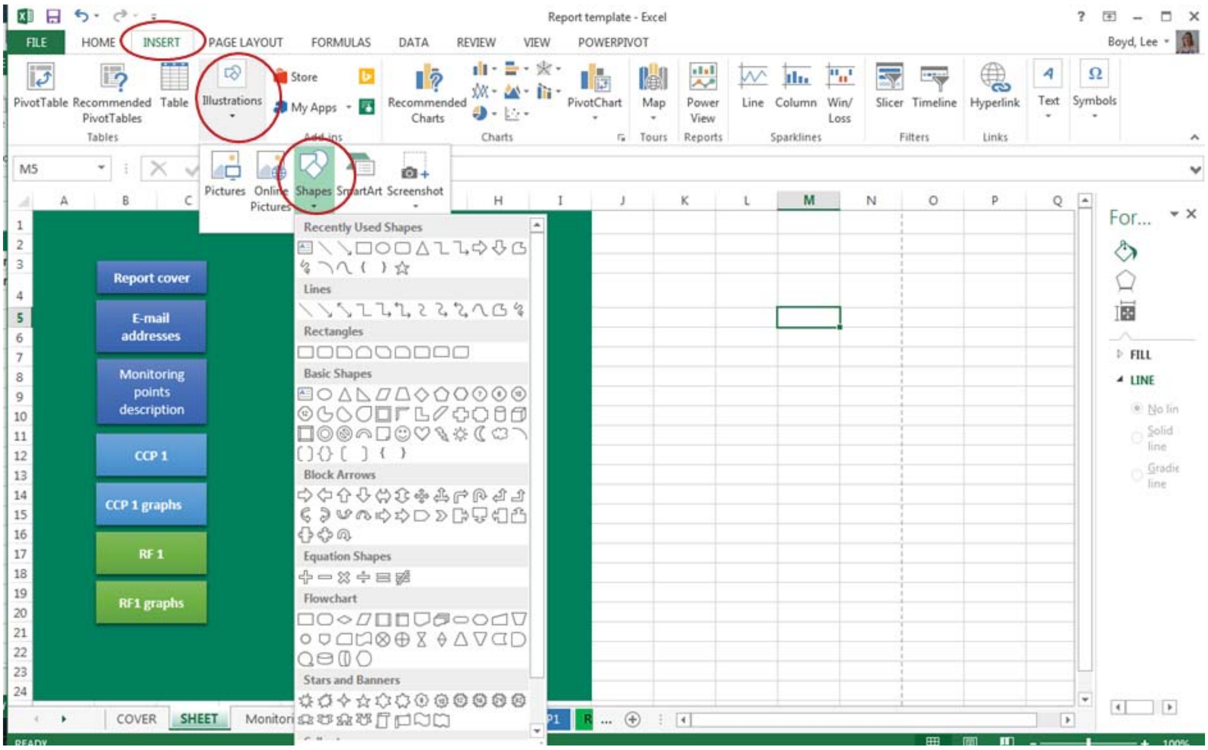


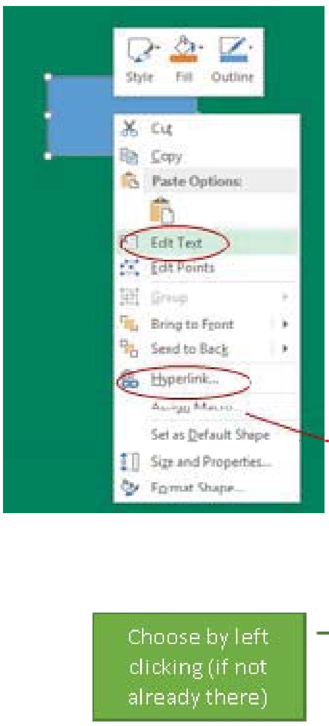
Figure 21: Adding buttons

b) Type the name of the spreadsheet that you want to link in the button.

c) Edit text in the button by right-clicking on the shape that you have inserted, then click on Edit text.

d) To hyperlink the buttons, click on Hyperlink which will open the Insert hyperlink box.

e) If not already there, choose Place in this document, and left-click on the relevant worksheet.



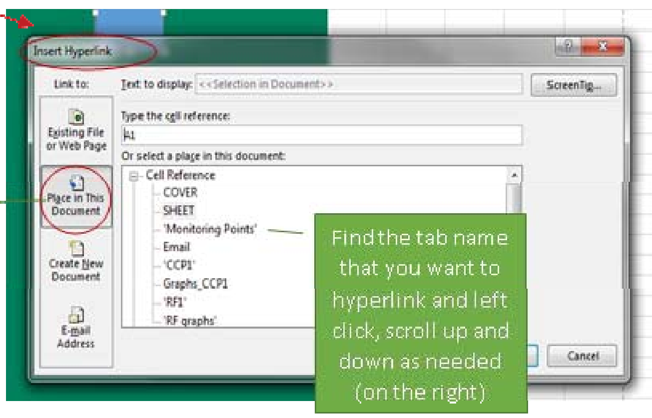


Figure 22: Editing text in the button, and adding a hyperlink

The button should now be hyperlinked to the spreadsheet for easy navigation. The Index sheet button, SHEET, should move as you navigate through the workbook.

Adding data

When adding data to the long-term report (it makes sense to do this at the same time as adding it to the short-term report):

1. Add the parameters in the top row;
2. Add the data from the short-term report – to do this easily for each point, you can try the following:
    a. Highlight the parameters listed in Column A, starting from the 2nd row (A2) (left-click and drag down the column); then right-click on the selection and left-click on Copy;
    b. have two highlighted/copied columns.

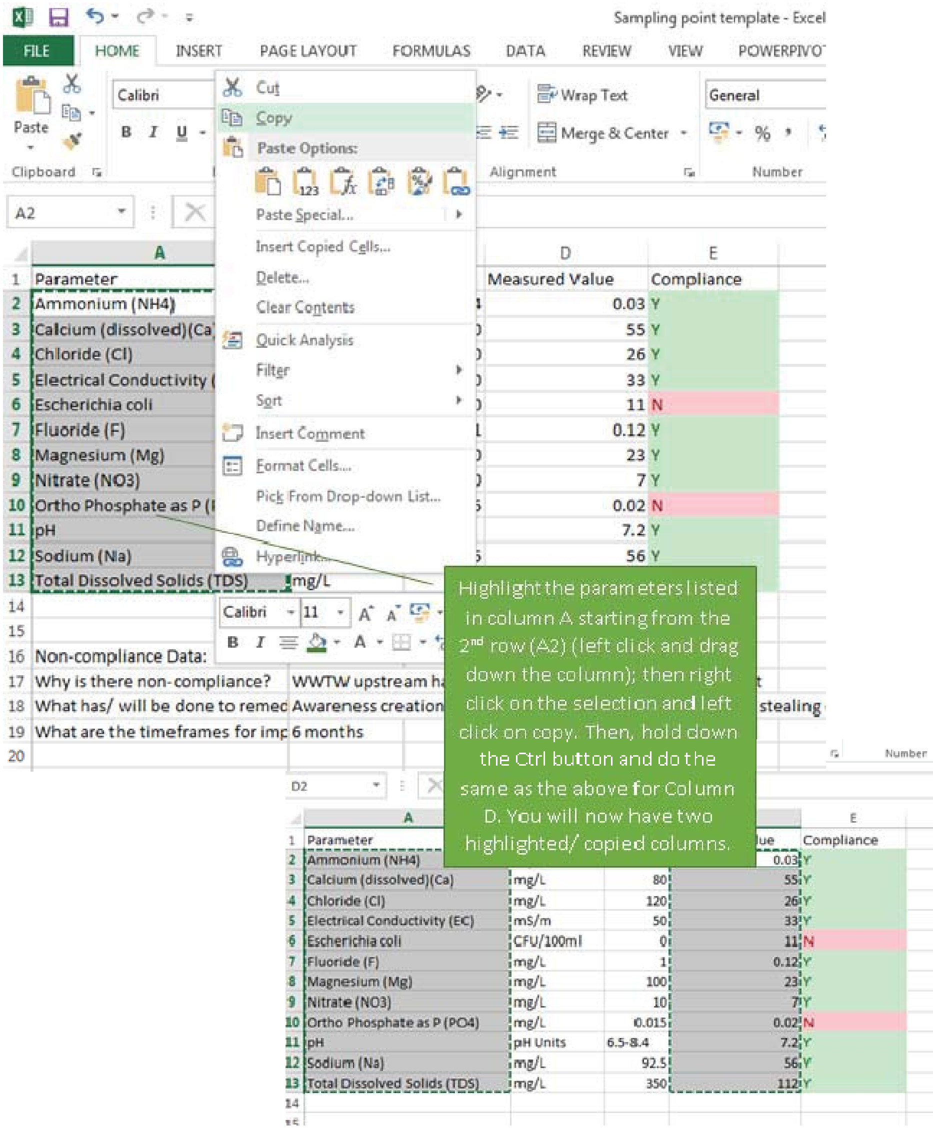


Figure 23: Copying data from the short-term workbook to the long-term workbook

c. Then, hold down the Ctrl button and do the same as the above for Column D. You will now, in the annual report template, in the worksheet that corresponds to the monitoring point, right-click in the Parameter 1 cell and in the ribbon that appears, under Paste options, choose Transpose, as highlighted in Figure 24. For the subsequent data as the year progresses, you will only need to add the measured values.

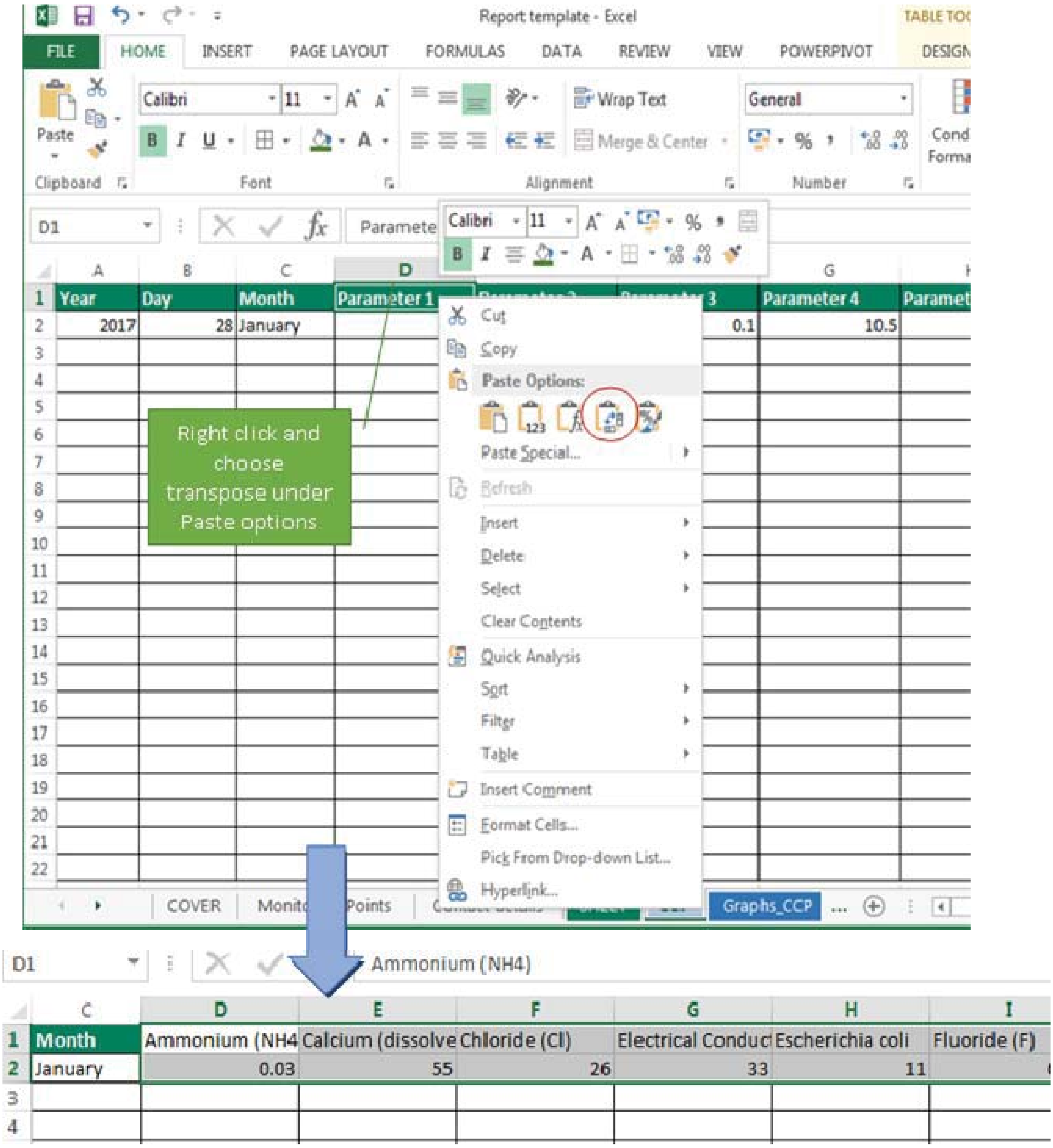


Figure 24: Pasting in long-term report

This will paste the data in the correct format for this report and you can just "pretty" it up if you think it necessary. The data will automatically update the graphs for the 12 parameters included in Columns D to O; however, the headings and units in each graph will need to be updated when first compiling the report (Figure 25).

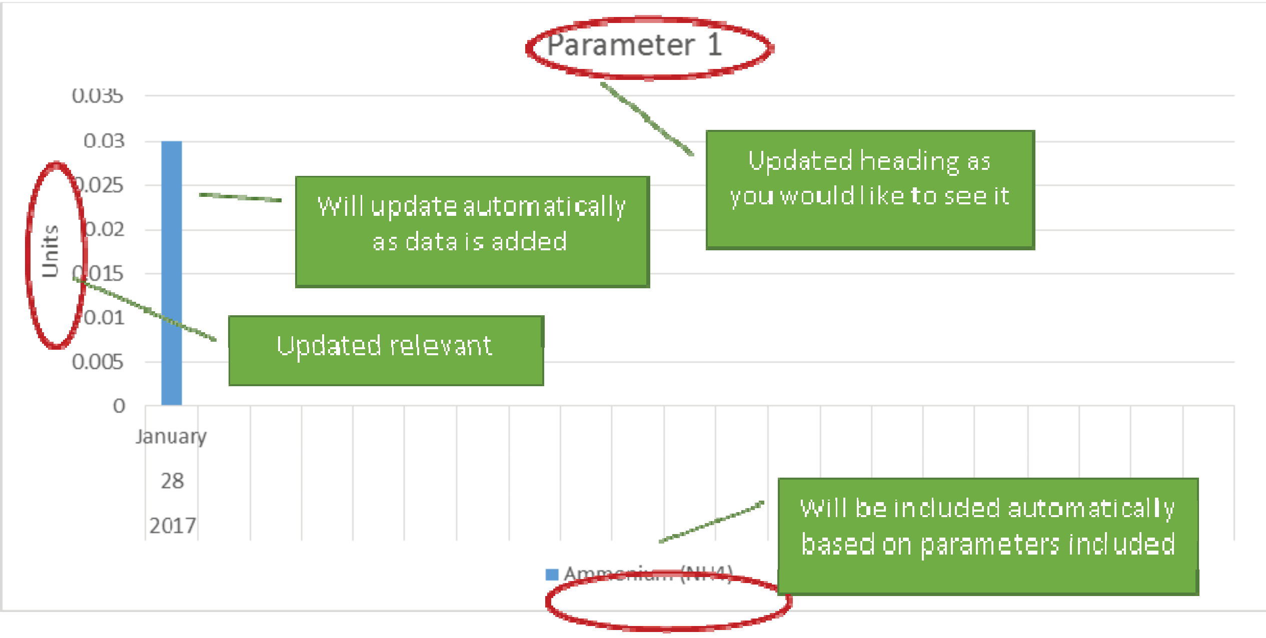


Figure 25: Changes to be made to the graphs

When the workbook has all the data for the report, such as at the end of a year, the report can be exported to pdf as previously described.

7.0 PILOT RESULTS

7.1 Parameters added

The following parameters have been added for the quantitative targets page, from which parameters can be chosen and targets added; there is, in addition, a function that allows for the addition of further parameters and targets. The same goes for the descriptive targets which would need to be added for each site.

- Aluminium (dissolved)(Al) μg/L
- Ammonia (NH_3) mg/L
- Arsenic (dissolved)(As) μg/L
- Barium (dissolved)(Ba) μg/L
- Boron (dissolved)(B) μg/L
- Bromide (Br) mg/L
- Bromodichloromethane μg/L
- Bromoform μg/L
- Cadmium (dissolved)(Cd) μg/L
- Chemical Oxygen Demand (COD) mg/L
- Chloroform μg/L
- Cobalt (dissolved)(Co) μg/L
- Copper (dissolved)(Cu) μg/L
- Dibromochloromethane μg/L
- Dissolved Organic Carbon (DOC) mg/L
- Dissolved Oxygen (DO) mg/L
- Free Cyanide (CN^-) μg/L
- Hexavalent Chrome (Cr^{6+}) μg/L
- Iron (dissolved)(Fe) μg/L
- Lithium (dissolved)(Li) μg/L
- Magnesium (dissolved)(Mg) μg/L
- Manganese (dissolved)(Mn) μg/L
- Mercury (dissolved)(Hg) μg/L
- Molybdenum (dissolved)(Mo) μg/L
- Nickel (dissolved)(Ni) μg/L
- Nitrite (NO_2) mg/L
- Oxygen Saturation %
- Potassium (K) μg/L
- Selenium (dissolved)(Se) μg/L
- Silica (dissolved)(Si) μg/L
- Sodium (dissolved)(Na) μg/L
- Sulphate (SO_4) mg/L
- Total Alkalinity mg/L
- Total Chromiun (Cr) μg/L
- Total Coliforms CFU/100ml
- Total Cyanide μg/L
- Total Faecal Coliforms CFU/100ml
- Total Hardness mg/L
- Total Kjeldahl Nitrogen (TKN) mg/L
- Total Oil and Grease mg/L
- Total Organic Nitrogen mg/L
- Total Phenols μg/L
- Total Suspended Solids (TSS) mg/L
- Turbidity NTU
- Uranium (dissolved)(U) μg/L
- Vanadium (dissolved)(V) μg/L
- Zinc (dissolved)(Zn) μg/L
- Ammonium (NH4) mg/L
- Calcium (dissolved)(Ca) mg/L
- Chloride (Cl) mg/L
- Electrical Conductivity (EC) mS/m
- Escherichia Coli CFU/100ml
- Fluoride (F) mg/L
- Magnesium (Mg) mg/L
- Nitrate (NO_3) mg/L
- Ortho-phosphate as P (PO_4) mg/L
- pH pH Units
- Sodium (Na) mg/L
- Dissolved Solids (TDS) mg/L

For the CCPs and CRFs added, the following parameters and limit values (Table 3) have been included as there are as yet no RQOs or WQPLs set for the catchment.

Table 3: Parameters and limits included for the compliance assessment

Parameter	Unit	Limit
Ammonium (NH4)	mg/L	0.044
Calcium (dissolved)(Ca)	mg/L	80
Chloride (Cl)	mg/L	120
Electrical Conductivity (EC)	mS/m	50
Escherichia coli	CFU/100ml	0
Fluoride (F)	mg/L	1
Magnesium (Mg)	mg/L	100
Nitrate (NO3)	mg/L	10
Ortho-phosphate as P (PO4)	mg/L	0.015
pH	pH units	6.5-8.4
Sodium (Na)	mg/L	92.5
Total Dissolved Solids (TDS)	mg/L	350

7.2 Berg River Catchment

The points set out in Table 4 were added for the Berg River Management Unit where the white rows refer to the critical control points (CCPs) and the green highlighted rows refer to the risk factor (RF) points.

Table 4: Monitoring points for the Berg River Management Unit

CCP/ RF	Why is it a CCP/RF?	Location description and co-ordinates	Type of target	Frequency of monitoring	Active/ Inactive site
CCP-1BR	Upstream of Berg River Dam at top of catchment; Supply for raw water; recreation	Berg River 19.07289, -33.95578	Quantitative Targets	Monthly	Active
CCP-2BR	Water Quality and Quantity Site Instream requirements; recreation	Downstream Berg River Dam 19.05478, -33.90494	Quantitative Targets	Monthly	Active
CCP-3BR	Water Quality and Quantity Monitoring Point Instream requirements; outlet of sub-catchment	Outlet of quaternary catchment G10B 19.030219, -33.876988	Quantitative Targets	Monthly	Inactive
RF-1BR	Water Quality Site Downstream Franschoek town, vineyards and WWTW	Franschoek River 19.055341; -33.884256	Quantitative Targets	Monthly	Active
RF-2BR	Water Quality and Quantity Point raw water supply	Wemmershoek dam -33.83222, 19.08333	Quantitative Targets	Weekly	Active
RF-3BR	Water Quality Point river below the dam	Wemmershoek River -33.8524, 19.04252	Quantitative Targets	Monthly	Active
RF-4BR	Water Quality Point upstream river point	Upstream on the Dwars River -33.95306, 18.97889	Quantitative Targets	Monthly	Active
RF-5BR	Water Quality Point downstream of the Dwars River and Pniel WWTW	Dwars River, Pniel -33.87258, 18.98214	Quantitative Targets	Monthly	Active

CCP/ RF	Why is it a CCP/RF?	Location description and co-ordinates	Type of target	Frequency of monitoring	Active/ Inactive site
RF-6BR	Water quality point water point downstream of emerging informal settlements	Hugo's River	Quantitative Targets	Monthly	Active
CCP-4BR	Water quality point water point	Outlet of catchment -33.7075, 18.97444	Quantitative Targets	Monthly	Active
RF-7BR	Water quality point water point downstream Paarl WWTW discharge	Paarl -33.67647, 1897639	Quantitative Targets	Monthly	Active
RF-8BR	Water quality point water supply downstream of informal settlements	Paarl -33.66667, 18.97889	Quantitative Targets	Monthly	Active
RF-9BR	Water quality point downstream Wellington WWTW discharge	Wellington -33.65047, 18.96783	Quantitative Targets	Monthly	Active
CCP-5BR	Water quality point weir at Wellington	Wellington -33.64214, 18.98364	Quantitative Targets	Monthly	Active
RF-10BR	Water quality point water point downstream on the Doring River	Doring River -33.54333, 18.9225	Quantitative Targets	Monthly	Active
RF-11BR	Water quality point water point downstream on the Kompanjies	Kompanjies River -33.47917, 18.97806	Quantitative Targets	Monthly	Active
CCP-6BR	Water quality point water point	outlet of sub-catchment -33.435, 18.95694	Quantitative Targets	Monthly	Active
RF-12BR	Water quality point downstream on Watervals	Watervals River -33.35222, 19.10111	Quantitative Targets	Monthly	Active
RF-13BR	Water quality point downstream on Knolvlei	Knolvlei River -33.39, 19.15972	Quantitative Targets	Monthly	Active
RF-14BR	Water quality point downstream on Brakkloof	Brakkloof River -33.39111, 19.17194	Quantitative Targets	Monthly	Active
RF-15BR	Water quality point upstream on Klein Berg	Klein Berg River -33.18472, 19.15528	Quantitative Targets	Monthly	Active
RF-16BR	Water quality point downstream on Klein Berg at outlet of sub-catchment	Klein Berg RIver -33.31389, 19.07472	Quantitative Targets	Monthly	Active
CCP-7BR	Water quality point raw water supply	Voelvlei Dam -33.34556, 19.02472	Quantitative Targets	Monthly	Active
RF-17BR	Water quality point downstream of Fish River	Fish River -33.35722, 18.95694	Quantitative Targets	Monthly	Active
CCP-8BR	Water quality point Sonkwas Drift weir on Berg River	Berg River -33.337982, 18.982397	Quantitative Targets	Monthly	Active
RF-18BR	Water quality point Berg River close to outlet of sub-catchment	Berg River -33.25614, 18.95311	Quantitative Targets	Monthly	Active
RF-19BR	Water quality point water point at the outlet of sub-catchment on the Vier-en-Twintig	Vier-en-Twintig River -33.13389, 19.06083	Quantitative Targets	Monthly	Active
RF-20BR	Water quality point water point on Krom River dowstream of Pyls, etc.	Krom River -33.04778, 18.83278	Quantitative Targets	Monthly	Active

CCP/ RF	Why is it a CCP/RF?	Location description and co-ordinates	Type of target	Frequency of monitoring	Active/ Inactive site
RF-21BR	Water quality point water point upstream of farms	Leeu River - 33.15667, 19.05222	Quantitative Targets	Monthly	Active
RF-22BR	Water quality point water point downstream on Sand River	Sand River - 33.16139, 18.89306	Quantitative Targets	Monthly	Active
CCP-9BR	Water quality point water point - Drieheuwels Weir	Berg River - 33.13083, 18.86278	Quantitative Targets	Monthly	Active
RF-23BR	Water quality point downstream water point Moorreesburgspruit	Moorreesburgspruit -33.06611, 18.75972	Quantitative Targets	Monthly	Active
CCP-10BR	Water quality point raw water supply - outlet of sub-catchment	Misverstand Dam - 33.0253, 18.78906	Quantitative Targets	Monthly	Active
RF-24BR	Water quality point water supply downstream of Misverstand Dam	Berg River - 32.996994, 18.77889	Quantitative Targets	Monthly	Active
RF-25BR	Water quality point (considered a groundwater point) discharge from quarry	Berg River (Piketberg) - 32.953392, 18.767677	Quantitative Targets	Monthly	Active
CCP-11BR	Water quality point inlet of sub-catchment	Berg River - 32.94583, 18.33667	Quantitative Targets	Monthly	Active
RF-26BR	Water quality point Berg River Estuary	Berg River - 32.90702, 18.33444	Quantitative Targets	Monthly	Active
RF-27BR	Water quality point Berg River Estuary	Berg River	Quantitative Targets	Monthly	Active
RF-28BR	Water quality point Berg River Estuary	Berg River	Quantitative Targets	Monthly	Active
RF-29BR	Water quality point Berg River Estuary	Berg River - 32.81667, 18.19417	Quantitative Targets	Monthly	Active
CCP-12BR	Water quality point Gauge station at Berg River Estuary	Berg River - 32.78704, 18.16828	Quantitative Targets	Monthly	Active

7.3 Breede-Gouritz Water Management Area

As part of the development of the catchment management strategy for the Breede-Gouritz Water Management Area, the area was divided into 11 sub-catchments that have been added as 11 MUs:

- BGCMA: Central Breede;
- BGCMA: Eastern Coastal Rivers;
- BGCMA: Gamka River;
- BGCMA: Groot River;
- BGCMA: Lower Breede;

- BGCMA: Olifants River;
- BGCMA: Overberg East;
- BGCMA: Overberg West;
- BGCMA: Riviersonderend;
- BGCMA: Upper Breede;
- BGCMA: Western Coastal Rivers.

The points described in Table 5 and Table 6 have been added under the various MUs. A further workshop was held with various staff at the BGCMA in Worcester, during January, 2017. Further work is being undertaken with the BGCMA to add new points that will be included on the system for 2017. The system will then be handed over to the BGCMA to use during March 2017.

Table 5: CCP/CRFs added to the Upper Breede Management Unit

Monitoring point	Description		Location
CCP-1UB	Water quality monitoring point - WMS 102019	Downstream Ceres Town - irrigation use	Breede River -33.3806, 19.30167
CRF-1UB	Water quality monitoring point - WMS 102024	Irrigation use	Koekedou River at Ceres -33.3589, 19.29833
CRF-2UB	Water quality monitoring point - WMS 1000009589	Irrigation use	Modder River - low water bridge at Fairfield Farm in Prince Alfred Hamlet -33.3167, 19.28912
CRF-3UB	Water quality monitoring point - WMS 1000009591	Irrigation use	Skaap River, Low water bridge on Fairfield Farm -33.3217, 19.2925
CRF-4UB	Water quality monitoring point - WMS 1000009591	Irrigation use,	Dwars River, Low water bridge at Klein Pruise Farm -33.3439, 19.2981
CRF-5UB	Water quality monitoring point - WMS 1000009594	Irrigation use	Dwars River, downstream irrigation area on Mazoe -33.3581, 19.3006
CRF-6UB	Water quality monitoring point - WMS 1000009604	Irrigation use, Ceres Town	Dwars River - Low water bridge in Hugo Street in Ceres -33.3656, 19.3036
CRF-7UB	Water quality monitoring point - WMS 1000009642	Irrigation use, runoff from CFG irrigation area	Dwars River -33.3772, 19.3203
CRF-8UB	Water quality monitoring point - WMS 1000009740	Overflow from last maturation pond	Dwars River -33.3814, 19.3206
CCP-2UB	Water quality monitoring point - WMS 102020	Irrigation use	Breede River -33.4217, 19.26833
CCP-3UB	Water quality monitoring point - WMS 192773	Rawsonville/ Worcester towns	Breede River -33.4144, 19.29227
CCP-4UB	Water quality and quantity monitoring - WMS 188483	Abstraction weir	Breede River -33.4217, 19.26721
CCP-5UB	Water quality monitoring point - WMS 192780	Irrigation use, downstream Rawsonville/ Worcester	Breede River -33.411, 19.25259

CRF-9UB	Water quality and quantity monitoring point - WMS 1000009676	Irrigation Board weir	Dwars River -33.4217, 19.2669
CCP-6UB	Water quality monitoring point - WMS 102026	Irrigation use	Breede River below Brandvlei Dam - 33.6842, 19.42194
CCP-7UB	Water quality and quantity - WMS 188484	Worcester East WUA Abstraction point	Breede River -33.6982, 19.45772

Table 6: CCP/CRFs added for the Central and Lower Breede, Overberg East and West and Riviersonderend Management Units

Monitoring point	Description		Location
Central Breede			
CRF-1CB	Water quality monitoring point	Raw water supply	Buffelsjag Dam 20.53389, -34.01861
CRF-2CB	Water quality monitoring point	Raw water abstraction for irrigation	Bree River 20.40417, -34.06583
Lower Breede			
CRF-1LB	Water quality monitoring point	Raw water supply	Duiwenhoks River 20.9925, -34.25056
Overberg East			
CRF-1OE	Water quality monitoring point	Raw water supply	Kars River 20.11611, -34.57167
CRF-2OE	Water quality management point	Raw water supply	Sout River 20.02361, -3429194
Overberg West			
CRF-1OW	Water quality monitoring point	Raw water supply	Uilenkraals River 19.4795, -34.5738
CRF-2OW	Water quality monitoring point	Raw water supply	Klein River 19.60056, -34.40583
Riviersonderend			
CRF-1RS	Water quality monitoring point	Raw water supply	Upper course of Riviersonderend River 19.29417, -34.09222
CRF-2RS	Water quality monitoring point	Raw water supply	Lower Course of Riviersonderend River 20.14556, -34.07556

Monitoring point	Description		Location
Groot River			
CRF-1GR	Water quality monitoring point	Raw water supply	Sand River 21.44083, - 33.76278
CRF-2GR	Water quality monitoring point	Raw water supply	Groot River 21.17472, - 33.98056

Monitoring point	Description		Location
		Olifants River	
CRF-1OR	Water quality monitoring point	Raw water supply	Kandelaars River 22.13333, -33.6775
CRF-2OR	Water quality monitoring point	Raw water supply	Olifants River 21.77389, -33.65889
		Gamka River	
CRF-1GA	Water quality monitoring point	Raw water supply	Gamka River 21.68333, -33.54583
CRF-2GA	Water quality monitoring point	Raw water supply	Huis River 21.48056, -33.49444
		Eastern Coastal River	
CRF-1EC	Water quality monitoring point	Raw water supply	Bloukrans River 23.64167, -33.9542
CRF-2EC	Water quality monitoring point	Raw water supply	Knysna River 23.02469, -33.89
		Western Coastal Rivers	
CRF-1WC	Water quality monitoring point	Raw water abstraction for irrigation; recreation	Goukou River 21.29528, -34.09222
CRF-2WC	Water quality monitoring point	Raw water abstraction for irrigation; recreation	Gourits River 21.65333, -33.98056

7.4 Reporting

The data, downloaded from the system as csv files, is incorporated into an Excel-based report for the sampling year and examples of the types of reports that can be expected are shown in Appendix A. Report templates, as described in Section 6.1, are included electronically on the attached CD.

7.5 Constraints with implementation

There have been numerous constraints to this project, some of which are highlighted below.

Adding the application to the users' computer

In several cases the system could not be loaded onto the users' computer during the training session due to administrative permissions. In addition, it was noted that data is not backed up anywhere except being housed on the users' computer.

There would need to be an internal discussion with the relevant managers and IT departments to ensure that they are aware of what needs to be loaded and what back-up needs to take place to ensure data is maintained and stored for historical purposes.

Participation in the various workshops and interim meetings ranged from 100% at the first workshop to 30% at subsequent meetings. It was noted that this was seen as just a project and, had it been part of their job description, the attendance is likely to have been better.

Receipt of data

From the government department's side, a constraint is that the contracts for sample collection and analysis are not renewed timeously. This means that data is not available for input. Percentage data input ranged from 0% (monitoring points were added but no data was ever received to input) to 80% for certain points along the coast. In most cases, it was because samples were not taken.

As sampling is most often included as part of an environmental official's job description, it should be that even if a laboratory contract is not in place, each official should have a field instrument that can measure some basic parameters such as pH and EC (from which TDS can then be calculated). These values could then be immediately added to the system and reported on.

Taking ownership

The concept of ownership seems to be a large hurdle that will need to be surmounted. It is going to take a mind-set change to get personnel at all levels out of their comfort zone, as the immediate reporting may put them in the spotlight, where questions may be asked and answers will need to be given. It will mean that officials and water users at all levels will need to be proactive rather than reactive. This also ties into the community-based monitoring described.

It was also noted that there was great enthusiasm when first seeing the product; however, the implementation seemed to stall when the official was left on their own. In several cases it was noted that this was due to the fact that the official did not have adequate computer knowledge, especially with programmes such as Excel.

A further reason may be that the reporting requirements are not very stringent and the outcomes of the data assessment are not used or communicated to effect change. It appears that data is seen as something that only needs to be generated when asked for, rather than something that, as a standard procedure, should be collected and communicated to others within an institution, and to stakeholders.

8.0 EARLY WARNING SYSTEMS AND RESPONSE SCENARIOS

As part of the project, a literature review was undertaken on early warning systems (EWS). The purpose of this research was to identify various EWS for water quality and has provided some general background to a generic EWS.

A response scenario may be defined as a reconstruction of past events or a hypothetical exploration of future ones (Alexander, 2002) to develop a response for such events in future. In other words, the aim is to assess and understand what has gone before so that systems may be put in place to prevent a similar incident in future. For example, how can one react timeously in the event of a pollution incident or flood event, to prevent or limit damage to the environment and downstream water users. Scenarios can be used for modelling all phases of the "disaster cycle" (Alexander, 2002) illustrated in Figure 26.

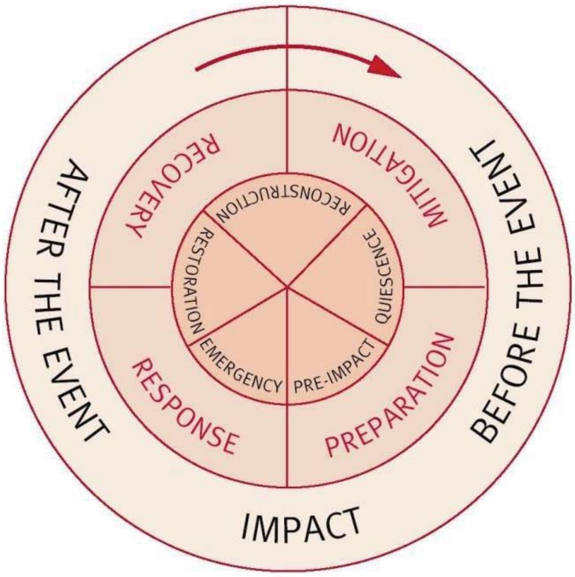


Figure 26: Phases of the "disaster cycle" (Alexander, 2002)

When scenario planning for responding to water disasters, it is important to understand the water resources management system in all its complexity.

8.1 Early warning systems and the IWQM model

The current project relates to a model where water users (consumptive and non-consumptive) add data (qualitative or quantitative) to a system and immediately report on that data to up- and downstream users, as well as to management and regulators as applicable. This makes them *managers* of what they do on land that may pollute the water resource, managing what they may discharge to a water resource or abstract from that water resource.

The immediacy of the reporting is important to allow other users to be timeously informed of an incident. This in effect, could be a method of each user naming their own management, and be an incentive, where that management is shown to be poor, to improve and maintain a higher standard of land-based activities, as well as managing, in a beneficial manner, the discharges and abstractions that are under the user's control. While this in itself is a sort of EWS, users may want to consider additional EWS to help prevent this situation.

For example, in respect of the IWQM model, a wastewater treatment works will have at least one critical control point: the final effluent, which is likely to have certain water quality and quantity targets set in the water use authorisation (NWA, 1998) that regulates the wastewater treatment works. These will therefore need to be reported on.

However, the works manager may like to have on-line monitors for specific indicator chemicals, such as ammonia, which would give a heads up before the laboratory results are out and reported on, and could allow action to be taken before the problem exacerbates. When the laboratory results are reported on, and if they show elevated ammonia levels because the sample was taken on the day of the incident, the report can already state that the issue has been resolved.

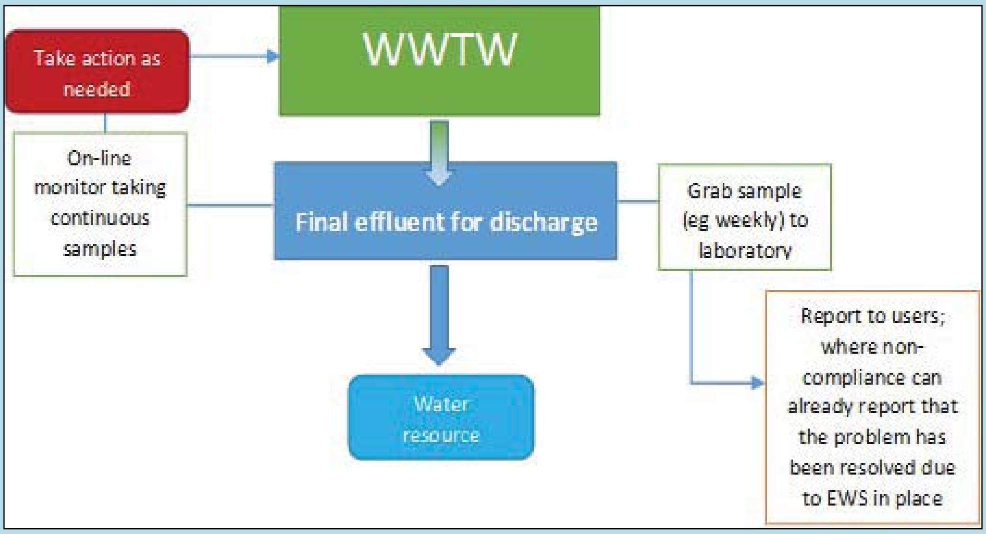


Figure 27: Example of how an EWS can complement the IWQM

The literature review undertaken earlier in the project highlighted the advantages and disadvantages of early warning systems. These are summarised in Table 7. Further possible early warning systems that could complement the IWQM model are discussed in the sections to follow.

Table 7: Advantages and disadvantages of an early warning system

Advantages	Disadvantages
• Improved monitoring can detect sudden changes in the river water quality and potentially identify the source; • Provide warning information that allows policy makers, and medical personnel to plan emergency response systems; • Identification of spills and releases that are unknown to the dischargers may help them to prevent similar releases in the future; • Improved communication of contamination events to water utilities; • Better information on contamination events for better response decisions; • Reduction of the overall risk to the public from spill events; • Increased sharing of information and better communication between water providers; • Better coordinated monitoring efforts on the river; • Promotion of greater diligence on the part of potential dischargers as the system can serve as a monitoring sentinel, thus leading to improved public confidence in water quality; • Additional information provided by the system can help in responding to the press during spill events; and • A central data warehouse may be beneficial to researchers studying the river.	• EWS can be expensive depending on the system that is required to be monitored; • EWS setups can be labour intensive and may be difficult to establish as automated systems; • Real-time data collection and transmission can pose challenges; • False negative and false positive readings could provide a false sense of security and lead to unpredicted disasters; and • EWSs that are not fully integrated may not provide accurate results.

8.2 People-centred early warning systems

When assessing scenarios after an event, participation by water users in the particular catchment is of utmost importance. Khalafzai and Niazi (2012) state that it is important to develop EWSs that meet local conditions. Lack of a suitable people-centred EWS, and failure to warn people at risk in advance, is one of the main causes for high levels of human, economic and environmental losses (Khalafzai and Niazi, 2012).

When developing a catchment management strategy, participation by communities in the catchment is a requirement of Chapter 2, Section 10(c)(i and ii) of the NWA (RSA, 1998). So when considering the implementation of an EWS which would form part of the implementation plans for the catchment management strategy, it is important to get local stakeholder knowledge and buy-in. This is also highlighted in the classification of water resources and determination of Resource Quality Objectives for the catchment under Chapter 3 of the NWA, entitled: Protection of Water Resources, and the associated guidelines (DWA, 2013).

In this respect, to be effective, an EWS must be understandable, trusted by and relevant to the communities that it serves. Warnings will have little value unless they reach the people most at risk, who need to be trained to respond appropriately to an approaching hazard (http://www.ifrc.org/en/publications-and-reports/general-publications/). The International Federation of Red Cross and Red Crescent societies (IFRC) stresses the importance of:

- Establishing local networks that can both receive and act on warnings and that raise awareness and educate communities to take action to ensure their safety;
- Utilizing local networks to develop warning systems progressively so that they meet the needs of the communities and situations for which they are designed; and
- Taking a multi-hazard approach to ensure sustainability by providing active alert, awareness and relevance.

The objective of people-centred EWS is therefore to empower individuals and communities threatened by hazards to act in sufficient time, and in an appropriate manner, to reduce the possibility of personal injury, loss of life and damage to property and the environment (EWS III, 2006). A complete and effective EWS comprises four inter-related elements:

- Knowledge of hazards;
- Knowledge of vulnerabilities;
- Preparedness; and
- Capacity to respond.

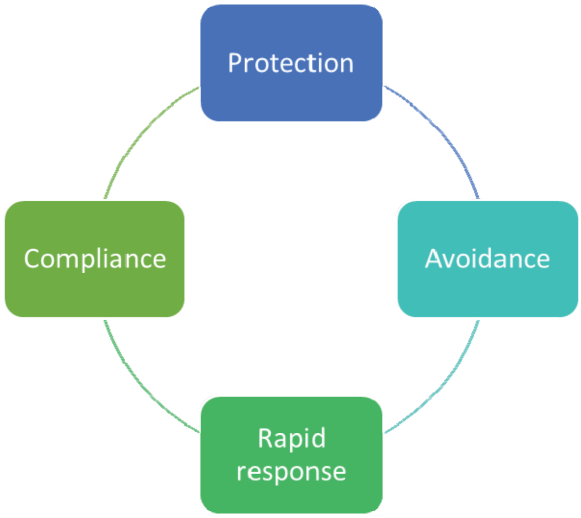
Best practice EWS also have strong inter-linkages and effective communication channels between the four elements (EWS III, 2006).

8.3 How can response scenarios be effectively used for IWRM?

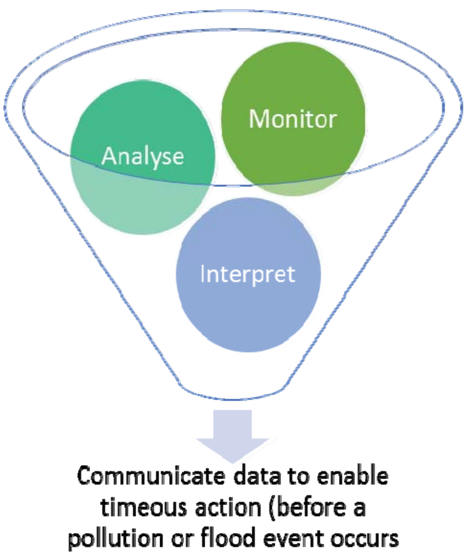
Risks arise from the combination of hazards and vulnerabilities at a particular location. Assessment of risk requires the collection and analysis of data and should consider the dynamic nature of hazards and vulnerabilities that arise from processes such as urbanisation, land-use change, environmental degradation and climate change (EWS III, 2006).

The United States Environmental Protection Agency (USEPA) describes an EWS as an integrated system for monitoring, analysing, interpreting and communicating monitored data to enable timeous action to take place before an event such as pollution or flooding occurs. In this respect, an EWS needs to be able to reliably identify low-probability, high-impact contamination, drought or flooding events in time to allow an effective local response.

When considering response scenarios and the implementation of an EWS, it needs to include the characteristics listed below.



- ***Detection mechanisms***: a detection mechanism system to identify an event such as chemical contamination, drought or flooding;
- A mechanism for ***data acquisition,*** as historical data is vital when considering the type of EWS to apply. An EWS will require a baseline of data in order to decide where to implement an EWS and to compare future results to determine changes in water quality and/or quantity;
- ***Characterisation and analysis*** of contaminant events which refers to the "what", "where" and "extent" of the event;



- ***Communication system*** which will include the data transmission between the monitoring sensor and a central database;
- ***Notifications and response actions***; and
- ***Data verification***.

In order to benefit and assist in IWRM, key elements of a response scenario and implementation of an EWS need to include:

Rapid response

For an EWS to be effective, downstream water users need to be timeously informed of an event. The type of response may need to be slightly different depending on whether it is related to a contamination event or a flood warning.

A wide range of contaminant detection mechanisms

As described earlier, land-use management is integral to water resource management. Depending on the land use, the contaminants of concern, and therefore the EWS requirements, may be different. For example, in the Breede River catchment in the Western Cape province, the dominant land use is agriculture – nutrients and pesticides from agricultural use are therefore of concern; whereas in the Upper Olifants River catchment in Mpumalanga Province, sulphate from the intensive coal mining is dominant. In both cases, contamination from urban areas, and specifically wastewater treatment works, would also be a concern.

Contaminants from both point and non-point sources need to be considered as these will also determine the types of “sensors” to be used and which institution would be responsible.

Identification of sources of contamination

Identifying the sources of contamination is critical to ensure that the points at which the EWS sensors are located will detect the events. This means that a detailed catchment assessment needs to be undertaken prior to making a decision as to what type of system to implement.

Minimal false positives and negatives

The system chosen needs to have detection limits that are sensitive enough to limit the number of false negatives and positives and there will need to be a good calibration system in place.

Function continuously

To be effective, an EWS needs to function continuously.

Affordability

Monitoring is expensive, especially of contaminants such as pesticides and metals. In this respect, an EWS can reduce costs if the sensors that are installed detect relevant “indicators” that prompt further sampling and analyses only when a certain concentration is reached.

In addition, the system should not be an economic burden on the institution implementing the system.

Low skill and training requirements

The system in place should require limited skill and training requirements, the reason being that in many areas in South Africa it would be good to employ local people for implementation. It is likely that better “buy-in” would occur and there is less chance of vandalism and theft of systems if the communities see that the system benefits them. To achieve the maximum benefit from EWS, and in line with IWQMS, the EWS could also be implemented at various management levels within a catchment. For example, a WWTW may have an on-line monitor for ortho-phosphate, while the catchment management agency may have aerial photography to detect algal blooms, as described further in Section 8.5.3.

A key component of undertaking response scenario analysis is the availability of a mathematical model for predicting the fate and transport of the contaminant. It is important to note that a model should only be seen as a guide to what will happen during contamination. Predictions of future events should be verified, and increased monitoring should occur before taking action. Historical data is therefore very important in response scenario analysis, when using a model to predict potential events.

Section 8.6 sets out some models used for water resource management that may be useful in response scenario analysis.

8.4 Framework for integrated water quality management in a catchment context

Water quality management in a catchment context is based on the principle that water quality management must be informed by the requirements of the Reserve; the water resource management class for the particular area; resource quality objectives; the National Water Resource Strategy; and if available for a particular catchment, the catchment management strategy and its associated sub-strategies, such as the reconciliation and water quality management plans. In combination, these establish the water quality, water quantity and aquatic ecosystem attributes that are required to ensure a given level of protection for the resource, to meet basic human needs, and to meet the requirements of strategically important water users (DWAF, 2003). The framework is based on identifying the stakeholders' needs with respect to use of the water resource over and above these requirements.

The framework for an EWS (Gullick et al., 2005) is illustrated in Figure 28, and does not differ fundamentally from the development of a catchment management strategy and its associated sub-strategies. The response scenario analysis prior to the implementation of an EWS should therefore not be done in isolation but needs to be informed by the catchment management strategy, and its sub-strategies if in place, as these would also highlight local concerns.

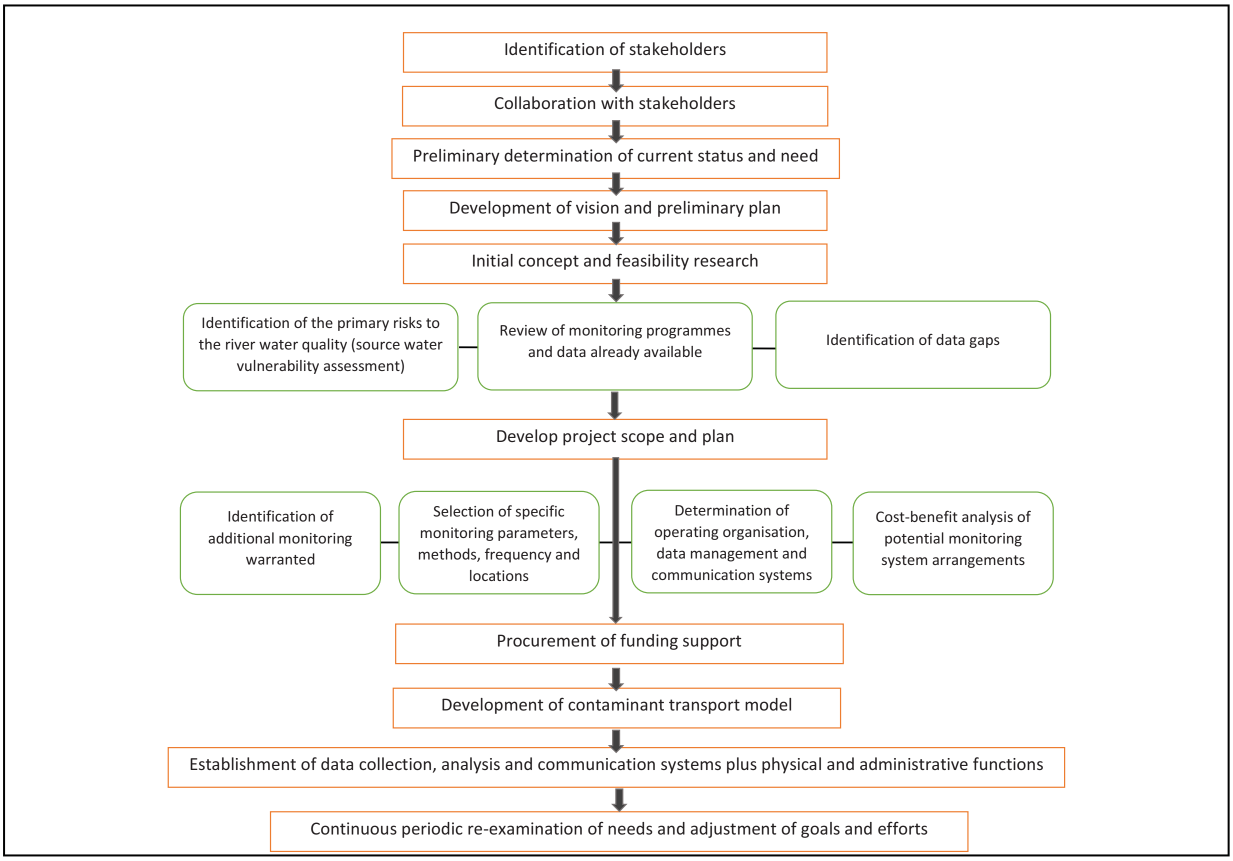


Figure 28: Framework for developing a plan for implementing an early warning system

8.4.1 Potential tools for assisting with response scenario analysis

Constituent ratios as indicators

In a CSIR project led by Dr Peter Ashton (Ashton et al., 2011), a calculation was included for the ratio of sulphate to chloride anions. The report stated that while sulphate on its own has insignificant health effects even at 400 mg/l, when the ratio of sulphate to other ions starts to change, this is often a warning that acid mine drainage (AMD) may be occurring upstream.

Dr Ashton used a SO_4/ Cl ratio; however, this was amended by Dr M Silberbauer from the Resource Quality Information Services (RQIS) section of the DWS, who uses SO_4/ [total anions]. Determining the SO_4/ [total anions] ratio provides a more convenient number, in the range 0.0 to 1.0, and avoids bias when total alkalinity is very high or low. A high SO_4/ [total anions] ratio is considered indicative of AMD and suggests that further investigation and analysis are needed, i.e. it is intended as a rough filter. Where hotspots are identified in this manner it follows that sampling and analysis should be done to confirm whether there has been a significant change in the water quality.

Based on the 95 percentile data, the following (arbitrary) ranges (Table 8) could be applied to produce a risk category.

Table 8: Example risk potential table

0 – <0.2	No risk potential	Blue
0.2 – <0.4	Small risk potential	Green
0.4 – <0.6	Perceptible risk potential	Yellow
0.6 – <0.8	High risk potential	Orange
0.8 – 1	Severe risk potential	Red

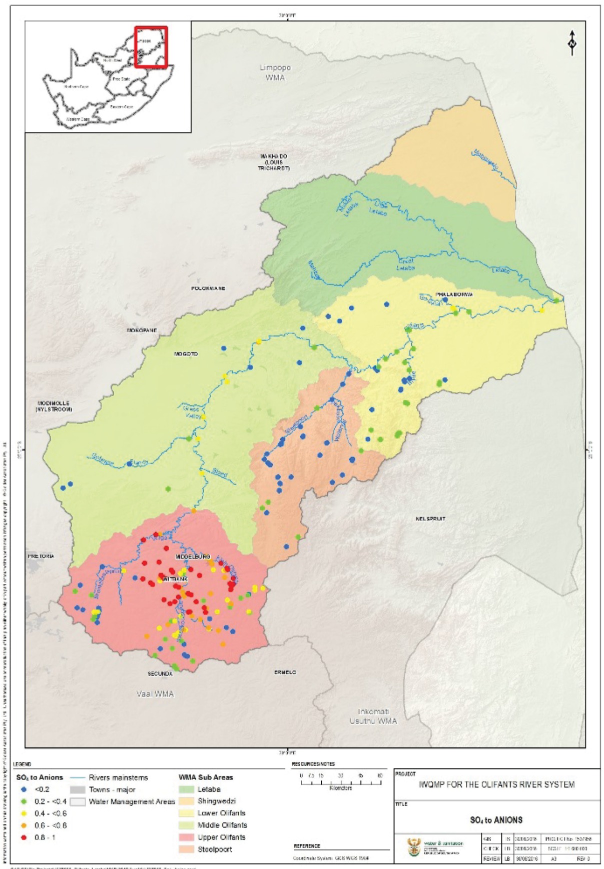


Figure 29: Example of sulphate to major anion ratios

An example of this is seen in the Olifants Water Management Area showing the AMD concerns in the upper catchments of the Olifants River and the perceptible risk along the main stem right into the Kruger National Park area (Figure 29) (DWS, 2016).

Trophic status of impoundments

Eutrophication is a process of nutrient enrichment of a system and it is used to classify the stage at which this process is at any given time in a particular water body (DWS, RQIS). The "trophic status" of a water body can therefore be used as a description of the water quality status of a water body with regard to nutrient enrichment. The following classification terms, and colour coding (Table 9), are provided by the DWS National Eutrophication Monitoring Programme (NEMP) site for easy reference.

Table 9: Colour codes, classification naming and description (DWS, NEMP[8])

Class	Description
Oligotrophic	Low in nutrients and not productive in terms of aquatic animal and plant life.
Mesotrophic	Intermediate levels of nutrients, fairly productive in terms of aquatic animal and plant life and showing emerging signs of water quality problems.
Eutrophic	Rich in nutrients, very productive in terms of aquatic animal and plant life and showing increasing signs of water quality problems.
Hypertrophic	Very high nutrient concentrations where plant growth is determined by physical factors. Water quality problems are serious and can be continuous.

Table 10 sets out a simplified method for classifying trophic status, as used by the DWS NEMP. Note the use of medians rather than means to reduce the effect of irregular monitoring and occasional outliers on the results.

Table 10: Simplified method for classifying trophic status classes (DWS, RQIS)

Statistic	Unit	Current trophic status:			
Median annual chlorophyll-a	µg/L	0<x≤10	10<x≤20	20<x≤30	>30
		Oligotrophic	Mesotrophic	Eutrophic	**Hypertrophic**
		(low)	(moderate)	(significant)	**(serious)**
		Potential for algal and plant productivity:			
Median annual total phosphorus (TP)	mg/L	x≤0.015	0.015<x≤0.047	0.047<x≤0.130	>0.130
		negligible	moderate	significant	**serious**

8.5 Types of early warning systems

Any early warning system must have a monitoring component linked to a warning system. There must be a sound scientific basis for predicting and forecasting hazards, and a reliable forecasting and warning system that operates 24 hours a day (EWS III, 2006). Continuous monitoring of hazard parameters and precursors is essential to generate accurate, timeous warnings. Warning services for different hazards should be coordinated, where possible, to gain the benefit of shared institutional, procedural and communication networks.

Types of EWS may differ depending on the water resource, the contaminants of concern, whether floods or droughts are common, and their feasibility at the different management unit levels (Boyd et al., 2009).

Groundwater, surface water (rivers, dams, springs and wetlands), rainfall, runoff and evaporation all need to be managed with regard to their interrelationship.

As described in the literature review, the most common types of EWS are those related to flood events. However, the implementation of EWS for contaminant detection is becoming more common.

Types of EWS may include:

- On-line/ continuous monitors/ sensors;
- Water resource modelling and specifically contaminant transport modelling;
- Community based monitoring; and
- Applications for smart phones.

8.5.1 On-line/ continuous monitors

Baseline sampling and monitoring of water quality will provide a record of changes in water quality over time (historical data). As surface water interacts with the atmosphere, groundwater, land, wetlands, estuaries, human activities, and seasonal changes, water quality is dynamic, changing with time (even over minutes to hours). An historical data record helps quantify change associated with best management practices and inform decisions that need to be made to effect a change in upstream water use.

Detecting water quality concerns in real time is an optimal way to ensure an appropriate and timely response. Given that existing laboratory-based methods are slow to develop an effective response, the need for on-line/ continuous monitoring systems to rapidly detect and respond to instances of either natural, artificial, accidental or deliberate contamination in real time is obvious. The use of these tools has the potential to improve management response to pollution events.

It should be noted, however, that the need for real-time monitors should be evaluated on a case by case basis depending on the requirements of a water management institution.

Urban water utilities world-wide make use of EWSs throughout the cycle of water intake (raw water), treatment operations and distribution systems. The use of these on-line monitoring tools allows the process controller to detect contaminants in a drinking water system in near or close to real time thereby allowing improved management responses to events.

On-line monitoring in river systems is not as common; however, they are finding application more often.

8.5.2 Types of on-line/ continuous monitors

An ideal on-line monitoring system should, once an event is detected, be able to connect from a phone/ laptop (telemetry1[3]) and transfer data from a battery-powered water quality sensor and automatically update the data collection spreadsheet. After the spreadsheet has updated itself, it will determine whether or not the new data is within the water quality guidelines. The record will also be updated on a database and a notice sent to all users (Dolphin and Freimund, 2007). It is therefore important to have a continuous monitor that will capture high temporal resolution data to assist in detecting events that could lead to situations such as algal blooms, fish kills, human health impacts, sediment plumes and floods.

System components

The on-line system would require two parts:

A water quality data collection system.

The system typically would include a solar panel and battery to power a multi-parameter water quality monitor/ sensors (to reflect the water quality parameters more comprehensively that if just using one sensor) and a GPRS[4] module.

- A monitoring centre:

This typically would consist of a computer to collect and store the data. Relevant models (examples of which are described in Section 8.6) would be included to run scenarios and interpret the data received, and then send a message (communicate the data) to the relevant person.

In most instances, a combination of monitors is likely to be beneficial as some may be more useful than others at a particular location. The most common sampling instruments for river water monitoring measure:

- Dissolved oxygen;
- Turbidity;
- Temperature;
- Conductivity;
- Chloride;
- Ammonia;

[3] Telemetry is an automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring

[4] GPRS: General Packet Radio Service

- Nitrate;
- pH;
- Oxygen reduction potential; and
- Salinity.

At a different scale, such as for a wastewater treatment works or water reclamation/ treatment plants, on-line analysers can measure chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrogen, nitrate and ortho-phosphate on a finer scale. A common on-line monitor is that used to monitor dosing with disinfection products such as chlorine or ozone.

8.5.3 Emerging technologies

Some emerging technologies being explored in the drinking water industry which may have potential for more widespread environmental monitoring include biological monitors and fluorescence.

Biological monitors

According to Storey et al. (2010), only a fraction of toxic compounds is covered by routine physical monitoring. A biological warning system could draw attention to physiological behavioural changes in organisms responding to sudden changes in the concentration of compounds in water. As much as physical monitoring gives well defined answers, the reaction of organisms will reflect the real biological harm which can be estimated very roughly.

A video camera may be used to visually monitor the movement of organisms, and the live images obtained may be evaluated on-line using digital image analysis with an integrated computer to analyse changes in the behaviour of organisms due to the concentration or potency of a substance. These changes may include movement of fish muscles, ventilation depth and rate, and gill purge frequency (Storey et al., 2010).

Some limitations of this method include maintenance time, the size required to house “fish” stocks, and adjustable high sensitivity which may lead to false positive alarms in some cases.

Fluorescence analysis

The fluorescence technique uses emitted light to measure the excitation spectra of specific compounds which may include chlorophyll, aromatic compounds, pesticides and humic acids. The technique can be used to identify compounds using a combination of the wavelength of the emitted light and the wavelength of the irradiated light.

In respect of increased water recycling, Henderson et al. (2009) explored the application of fluorescence as a monitoring tool for the detection of cross-connection in dual reticulation systems, where recycled water had been inadvertently introduced into a drinking water system. As there is a potential for accidental (or deliberate) cross-connection from recycled water to a potable water distribution system, there is a need for monitoring to ensure water safety and to maintain public confidence (Storey et al., 2007).

The fluorescence analysis technique uses emitted light to measure the excitation spectra of specific compounds. Fluorescence can be used to help estimate variation in dissolved organic matter, its varying chemical composition as well as the path that the water transporting it has followed with respect to time. Estimations of concentrations and source can also be traced (Jiang et al., 2009).

Other sensor-based technologies that rely on the optical properties of water and contaminants include infra-red spectroscopy. The technology relies on the ability of various organic functional groups, including proteins, carbohydrates, lipids and nucleic acids, to absorb infra-red light at specific wavelengths (Groves et al., 2006).

Innovative spectral fluorometers with integrated algal class differentiation enable the simultaneous determination of green algae, cyanobacteria, brown algae and cryptophytes.

Floating monitoring system

A floating monitoring system may be used for taking samples at different water level depths. The system should be able to continuously and autonomously monitor. Its energy supply will therefore need to be supplied by batteries and solar cells. Through GPRS connection, the multi-parameter water quality measurements will be sent to a central database. The database will have to be established with algorithms to detect subtle changes (Storey et al., 2010). Challenges include the maintenance requirements for each sensor to ensure optimised ongoing operation and vulnerability to floating debris.

Satellite remote sensing

Satellite remote sensing can make a significant contribution to monitoring water quality in South African standing water bodies (Matthews and Bernard, 2015). Eutrophication, defined as enrichment by nutrients that causes algal blooms in both rivers and impoundments, and toxin-producing cyanobacterial blooms, pose a significant threat to the quality of South African surface water bodies, the Hartbeespoort and Roodeplaat dams being just two dams notorious for this occurrence.

Between 2002 and 2012, the status and trends of chlorophyll-*a* (chl-*a*, a proxy for algal concentration), cyanobacterial blooms and cyanobacterial surface scum were determined for

South Africa's 50 largest water bodies (Matthews and Bernard, 2015). The method used was a recently developed algorithm and 10 years of data from the Medium Resolution Imaging Spectrometer (MERIS) satellite.

The research undertaken by Matthews and Bernard and published in 2015 has demonstrated the pivotal role that satellite remote sensing can play in greatly supplementing in-situ monitoring efforts such as the National Eutrophication Monitoring Programme (NEMP).

It is important to note that water quality assessments from satellite remote sensing are restricted to surface water that is visible from space. Parameters that can be directly retrieved from remote sensing are limited to those that effect a change in the colour of the water in the visible and near infra-red light spectrum (Matthews and Bernard, 2015). Variables defined in water quality guidelines that are directly retrievable from remote sensing include phytoplankton, measured by the concentration of chlorophyll-*a*, the dominant phytoplankton group, water clarity or turbidity, measured by Secchi disk, total non-dissolved suspended solids and nuisance plants (macrophytes).

The results of the study demonstrated both the power and efficiency of satellite remote sensing used on a sub-continental (national) scale. Matthews and Bernard were able to show how satellite remote sensing estimates compare closely with in-situ data from the NEMP. In this way they could be used to supplement monitoring programmes, to fill information gaps and provide new insights into the occurrence and seasonality of cyanobacterial blooms and surface scum (Matthews and Bernard, 2015). The method therefore has great potential as an EWS for predicting when a eutrophication event may occur.

8.5.4 Constraints to consider when selecting an on-line system

Aspects to consider when considering an on-line monitor include:

- To be effective, on-line monitors need to be able to withstand adverse weather conditions. In the South African context, electrical storms could interfere with the electronics;
- Rivers are often low flow for the majority of the year with rapid changes in flow level when a rain event happens;
- Accessibility will be important to allow the sensor/(s) to be changed and the instrument to be maintained, as necessary;
- Accessibility to electrical connections may be difficult and the use of a solar panel would be necessary;

- Theft and vandalism of saleable items, such as copper wire and the solar panel, is a real concern.

8.6 Water resource models

There are many models available for use in water resource modelling that could assist in assessing the water quality and quantity situation in respect of future trends.

Table 11 briefly describes various models that are being used globally, giving a brief description, including the water resource area that it can be used in, and the water quality constituents that it can model.

The use of these types of models would allow the relevant authority to get a good understanding of where the water quality hot spots are and at what level there should be an intervention.

It is important to note that all the models listed below require regular monitoring of the river system for quantity and quality parameters. Currently, collection of data is problematic, so this is likely to be a constraint. The relevant authorities/institutions need to prioritise data and information management to enable the effective use of these models.

Some of the advantages and disadvantages (where available) of the models are included in

Table 12.

Table 11: Models used in water resource management and planning

Model	Description	Constituents
AQUATOX	AQUATOX is a freshwater ecosystem simulation model. It predicts the fate of various pollutants, such as nutrients and organic toxicants, and their effects on the ecosystem, including fish, invertebrates, and aquatic plants. AQUATOX is a valuable tool for ecologists, water quality modellers, and anyone involved in performing ecological risk assessments for aquatic ecosystems. Can be used in streams, rivers, lakes, reservoirs and estuaries.	Nutrients, organic loadings, sediments, organic chemicals, temperature
BASINS Version 3 Better Assessment Science Integrating Point and Non-point Sources	BASINS provides a framework that brings together modelling tools and environmental spatial and tabular data into a geographic information system (GIS) interface. BASINS can be used for investigations and analysis on a variety of geospatial scales from small watersheds within a single municipality, to a large watershed across several states. This system makes it possible to quickly assess large amounts of point source and non-point source data in a format that is easy to use and understand. Installed on a personal computer, BASINS allows the user to assess water quality at selected stream sites or throughout an entire watershed. This invaluable tool integrates environmental data, analytical tools and modelling programs to support development of cost-effective approaches to watershed management and environmental protection. The watershed modelling is based on Hydrological Simulation Program in Fortran (HSPF). The model also includes the Soil and Water Assessment Tool (SWAT) which is a	Conservative and non-conservative pollutants

Model	Description	Constituents
	physically based, watershed-scale model which has been developed to predict the impact of land-use practices on water, sediment and agricultural chemical yields in large, complex watersheds. The water modelling includes conservative and non-conservative pollutant types.	
BIOMOC	BIOMOC is a two-dimensional, multispecies, reactive solute-transport model with sequential aerobic and anaerobic degradation processes. The model design is general and flexible, permitting simulation of biotransformation reactions for any combination of electron donor and acceptor. The program is general and flexible, allowing for any combination of biodegradation processes. Steady and transient state modelling is permitted. A number of expressions for biological transformation rates have been included as options in the code. These include single, multiple, and minimum Monod kinetics and competitive, non-competitive, and Haldane inhibition. The kinetic parameters can be formulated to simulate zero-order or first-order approximations of biodegradation rates. The growth and decay of several microbial populations performing the transformations is also accounted for. The microbial growth can be disabled, limited by biomass inhibition, or limited by the availability of a specified nutrient. Input data consists of initial conditions, boundary conditions, aquifer properties and biodegradation parameters.	
CE-QUAL-W2	CE-QUAL-W2 is a water quality and hydrodynamic model in 2D (longitudinal-vertical) for rivers, estuaries, lakes, reservoirs and river basin systems. W2 models basic eutrophication processes such as temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships. Longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems, nutrients-dissolved oxygen-organic matter interactions, fish habitat, selective withdrawal from stratified reservoir outlets, hypolimnetic aeration, multiple algae, epiphyton/ periphyton, zooplankton, macrophyte, CBOD, sediment diagenesis model (Version 4),and generic water quality groups, internal dynamic pipe/culvert model, hydraulic structures (weirs, spillways) algorithms including for submerged and 2-way flow over submerged hydraulic structures, dynamic shading algorithm based on topographic and vegetative cover.	Total Dissolved Solids, suspended solids, nutrients, dissolved oxygen and temperature
CORMIX	CORMIX is a water quality modelling and decision support system designed for environmental impact assessment of mixing zones resulting from wastewater discharge from point sources. The system emphasises the role of boundary interaction to predict plume geometry and dilution in relation to regulatory mixing zone requirements. As an expert system, CORMIX is a user-friendly application which guides water quality analysts in simulating a site-specific discharge configuration. To facilitate its use, ample instructions are provided, suggestions for improving dilution characteristics are included, and warning messages are displayed when undesirable or uncommon flow conditions occur.	

Model	Description	Constituents
DYRESM / CAYDIS DYnamic REservoir Simulation Model – Computation-al Aquatic Ecosystem DYnamics Model	Time step is one hour; input data either daily or hourly for dynamic variables. Fast-running, coupled, hydrodynamic-ecological model intended for simulation and prediction of water quality in lakes and reservoirs.	Nitrogen, phosphorous, microbes, sediment, other includes chlorophyll, dissolved oxygen and physical variables
FISUN	A flow and salinity routing model for both rivers and dams that is used to operate the water supply system in the Eastern Cape.	
FLOSAL	Predictive flow catchment salinity model which can switch between daily and monthly time steps.	Salinity
GenScn- **GENeration and analysis of model simulation SCeNarios**	Can be used to analyse and manage the high volumes of input and output of complex river basins. These models are used to simulate water quantity and quality for numerous scenarios of changes in land use, land-use management practices, and water management operations. To assist with the process, an interactive computer program, GENeration and Analysis of Model Simulation SCeNarios (GenScn), was developed to create simulation scenarios, analyse results of the scenarios, and compare scenarios. GenScn runs with the HSPF hydrological software for the analysis of the water resource scenarios.	
HEC-HMS	Rainfall-runoff model for flood peak determination for catchments.	Rainfall
HEC-RAS	BOD and ammonia (NH_3-N) can be monitored in a river through the use of the Streeter Phelps equation in HEC-RAS. Water quality modelling is applied as a supporting tool for water quality management. Modelling assists in assessing potential impacts and provides estimates of contamination concentrations, speed and direction of travel. A limitation of this method is that only limited parameters can be measured, and the transport formation equations are usually estimated with simplified assumptions. The Streeter Phelps equation is not able to accurately calculate the water quality of the lower section of tidal rivers, as the stream approaches the river mouth (Fan et al., 2012). This software allows the user to perform one-dimensional, steady flow calculations, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling. An advection-dispersion module is included with the latest version of HEC-RAS, adding the capability to model water temperature. This new module uses the QUICKEST-ULTIMATE explicit numerical scheme to solve the one-dimensional advection-dispersion equation using a control volume approach with a fully implemented heat energy budget. Transport and fate of a limited set of water quality constituents is now also available in HEC-RAS.	Dissolved nitrogen (NO_3-N, NO_2-N, NH_4-N, and Org-N); Dissolved phosphorus (PO_4-P and Org-P); Algae; Dissolved oxygen (DO); and Carbonaceous biological oxygen demand (CBOD).
HEC-RESSIM	Model used to examine reservoir operating rules and hydropower generation. The documentation reviewed indicated that water quality is not modelled. The software simulates reservoir operations for flood management, low flow	

Model	Description	Constituents
	augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support. HEC-ResSim can represent both large- and small-scale reservoirs and reservoir systems through a network of elements (junctions, routing reaches, diversion and reservoirs) that the user builds. The software can simulate single events or a full period or record, using available time steps. HEC-ResSim is a decision support tool that meets the needs of modellers performing reservoir project studies as well as meeting the needs of reservoir regulators during real-time events.	
HSPF Hydrological Simulation Program in Fortran	The HSPF model is a USEPA programme for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF model uses information such as the time history of rainfall, temperature and solar radiation, and land surface characteristics, such as land-use patterns and land management practices, to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. HSPF includes an internal database management system to process the large amounts of simulation input and output. This model typically runs at a daily time step and can be used for water resource planning if the database can support the input. The model supports both conservative and non-conservative pollutant types as well as the modelling of land-use segments.	Conventional and toxic organic pollutants
IMPAQ/ WRYM Impound-ment/River Management and Planning Assessment Tool for Water Quality Simulation	The IMPAQ model is a water quality model which simulates chemical, biological and mixing processes affecting conservative and non-conservative water quality constituents in wash off, in rivers and in dams. Stream flows, effluent point sources, abstractions and dam operations are imported from the WRYM, with which the IMPAQ model was designed to interface	The water quality constituents modelled are Total Dissolved Solids, SP, PP, TP, suspended solids, E-Coli and chlorophyll-a in impoundments
ISIS/ MIKE 11	Hydrodynamic, one-dimensional river models, modelling both conservative and non-conservative water quality constituents.	
Nacl01/ Nacl02 Naclbar/ Nacls	Like HSPF, this daily time step suite of models can be used for water resource management relating to salinity. Models catchment conservative pollutant balances as well as routing through reservoir and river systems	
NEAP	A first-level screening tool that allows the user to carry out fundamental phosphorus-based determinations related to the eutrophication of standing surface waters. It is a Web-based software toolbox, a relatively simple model, easy to use and user friendly. Used for estimating nutrient loads in a water body and in-lake nutrient and algal concentrations. NEAP consists of several submodules, e.g. the in-lake condition module takes the output from the phosphorus loading module, and predicts what the mean annual in-lake concentration of Total P is likely to be. NEAP also provides an indication of	

Model	Description	Constituents
	the trophic condition in two formats, i.e. Carlson indices and OECD boundary method. To run the basic analyses, only limited data is necessary and this tool can be used as a first step in the evaluation of the water quality of a water body.	
QUAL2K	One dimensional, steady state hydraulics, non-uniform, steady flow is simulated. Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale. Diurnal water quality kinetics. All water quality variables are simulated on a diurnal time scale. Heat and mass inputs. Point and non-point loads and abstractions are simulated. One-dimensional river and stream water quality model intended to represent a well-mixed channel both vertically and laterally with steady state hydraulics, non-uniform steady flow, and diel heat budget and water quality kinetics. It simulates bottom algae, macrophytes, binding of phosphorous onto suspended sediment, and settling, making it more applicable to turbid rivers, or rivers where large amounts of bottom algae and macrophytes act as an important sink for nutrients.	
SWBB	A field-scale crop model that models irrigation requirements as well as conservative and non-conservative water quality constituents.	
SWMM	Storm water management model developed for the prediction and management of the water quantity and quality of storm water drainage systems, for urban developments.	
WASP6	WASP is a generalised modelling framework based on the finite-volume concept for quantifying the fate and transport of water quality variables in surface waters. The three components of the model are WASP for mass transport; EUTRO for dissolved oxygen, nutrients, and algal kinetic; and TOXI for toxic substances. WASP is capable of analysing time-variable or steady state, one-, two-, or three-dimensional water quality problems. WASP5 is a DOS application and WASP6 is a Windows application. The WASP model has been widely applied to investigate dissolved oxygen, bacteria, eutrophication, suspended solids, and toxic substance problems.	The latest version includes kinetic algorithms for eutrophication/ conventional pollutants, organic chemicals/ metals, mercury, and temperature, faecal coliforms, and conservative pollutants.
Water Situation Assessment Model WSAM	The WSAM was developed by the DWS. It provides a decision support system for water resources planning, and access to national information for broad-scale resource management. The model uses the results of independent detailed analysis of storage/yield relationships to synthesise a picture of the status of water resources across the country. Based on the flexible compartment modelling approach, WASP6 can be applied in one, two, or three dimensions. It helps users interpret and predict water quality responses to natural phenomena and man-made pollution for various pollution management decisions. A water quality component to the WSAM model has been formulated. The water quality component will provide an index on the salinity state of the system	
WQ2000	WQ2000 is an interactive system for rapidly assessing quaternary catchment salinity for naturalised and developed conditions. This Water Research Commission product can also provide a regional overview of	Salinity

Model	Description	Constituents
WQ2000	salinity conditions. A simple to use but versatile interface links the user to an extensive database and facilitates interaction with the sophisticated WQT monthly time step hydro-salinity model. The database contains seventy-year monthly time series of rainfall, naturalised pervious and urban catchment runoff, calibrated WQT model hydro-salinity parameter values and a wide range of natural and present-day development characteristics. The initial implementation is for the 192 quaternary catchments of the Vaal River, ranging from undeveloped areas to some of the most developed catchments in South Africa.	
WQDOWN	WQDOWN is a user-friendly, self- calibrating stochastic model to simulate the impact of permit applications and other options on water quality in downstream river reaches. It is designed to deal with a range of chosen water quality variables.	
WQT/ WQS	WQT - Water quality total dissolved solids WQS – Water quality sulphate Monthly time step models which are often used for calibration purposes to generate the input files for the Water Resource Planning Model (WRPM)- see below.	TDS Salinity SO_4
WRPM	WRPM which models TDS and sulphate at a monthly time step	TDS and SO_4

Table 12: Model type, describing advantages, disadvantages and latest version available

Model	Advantages	Disadvantages
AQUATOX	General and site-specific application. Can model just the species and scenarios you need to understand. Contains sophisticated uncertainty and sensitivity analysis tools. Contains many example studies and data libraries. Available at no cost on EPA website. User-friendly interface.	
BASINS Ver 3 **Better Assessment Science Integrating Point and Non-point Sources**	BASINS is available on the EPA website and can be downloaded for free. Integration of environmental data, tools and modelling programmes.	
BIOMOC	BIOMOC is available on the USGS website and can be downloaded for free.	
CE-QUALW2	Suitable for reservoirs and rivers. Generally used for reservoir modelling. Supported by the EPA and is freely available.	Too detailed for planning purposes. Needs data such as flow, wind, temperature, light penetration, dissolved oxygen, nutrients, algal species, substrate, Chlorophyll-*a.*
CORMIX		Not suitable for planning purposes

Model	Advantages	Disadvantages
DYRESM / CAYDIS DYnamic REservoir Simulation Model - Computational Aquatic Ecosystem DYnamics Model	Wide breadth of users and can be picked up by users with limited expertise in modelling	Commercial use by arrangement
FISUN		Site specific (Catchment runoff)
FLOSAL		Not suitable for assessing management options
HEC-HMS		Does not include any water quality modelling component.
HEC-RAS	Routing pollutants down river. Interactions and reactions moving downstream	Does not model catchment runoff
HSPF (Hydrological Simulation Program in Fortran)	HSPF is EPA supported. It is a dynamic model that simulates a range of water quality variables.	The data requirements are high.
IMPAQ/ WRYM: Impoundment/ River Management and Planning Assessment Tool for Water Quality Simulation	Models a variety of water quality variables.	Nitrogen species are not simulated. The model has had limited application. Time series of monthly flows are required, usually provided by a preceding system analysis. Export coefficients needed for SA conditions
ISIS/ MIKE 11	Routing pollutants down river. Interactions and reactions moving downstream	Does not model catchment runoff
QUAL2K	This is a detailed model for non-conservative pollutants. QUAL-2E is supported by the EPA and is freely available. QUAl-2E is ideal for evaluating water quality impacts during critical low flow periods when the flow is more or less steady for extended periods of time. Also the case for regulated rivers where, for example, irrigation releases are more or less constant for several days on end.	QUAL-2E is unsuitable for modelling dynamically varying flow since it is a steady state model. It also cannot be used to model systems. Its use is limited to river reaches with relatively steady flow. Only a limited number of experts can use this model in South Africa.
SWBB and SWMM		Small scale
WASP6	Software and manual is freely available from internet.	Workshop training is necessary for effective use. Does not support watershed modelling. Requires external hydrodynamic model to provide flow file for solving advection.
Water Situation Assessment Model WSAM	Useful for macro planning; Processes a national dataset within seconds; requires very little effort to modify and run	

Model	Advantages	Disadvantages
WQDOWN	This model is designed specifically to meet the need for CMAs and DWS regional offices to assess the water quality impact of permit applications. WQDOWN accesses water quality data directly from files generated by the WMS and hydrology. A particular strength is that it is self-calibrating. The model complies with the expressed need of various DWS users for a simple model to assess a range of water quality variables.	WQDOWN is not a rigorous conceptual model. Hence it is most suitable for initial evaluation that may indicate the need for more detailed evaluation. WQDOWN is still in the development stage, which is currently stalled for lack of funding. The potential benefits to be derived from WQDOWN could be lost if the tool is not completed.

8.7 Community-based monitoring (volunteer monitoring)

It is essential that communities understand the risks related to water, respect the warning service and know how to react if a warning is issued. Education and preparedness programmes therefore play a key role. It is also essential that disaster management plans are in place, well-practised and tested. The community should be well informed on options for safe behaviour, available escape routes, and how best to avoid damage and loss to property (EWS III, 2006).

An EWS based on community monitoring (volunteer monitoring) is an aspect that may also have great value in integrated water resources management, especially in municipal areas where funding is limited. This type of monitoring would require community champions to drive the implementation as well as an institutional drive to solve the problems once identified.

What would be important is that the community know why they are monitoring – benefits to their health, ecological health, what they are monitoring, how to monitor, and critically who they will report to.

Examples of what could be monitored include:

- Changes in colour in a stream/river;
- Presence of odours;
- Water levels (increasing or decreasing);
- Observation of a discharge that is not normally present in a certain area;
- Water leaks;
- Sewer overflows;
- Presence of litter; and

- Presence of algae (stringy or clumps).

Being alerted to any of these before it becomes a large concern would allow the CMA, local authority or other relevant institution to take action timeously and with less cost than if the problem were to be allowed to continue until it becomes a crisis.

This type of monitoring will automatically build awareness in the communities and an understanding of how land use and associated activities are linked to the water resource, supporting the overarching principle of the project that *everyone is downstream*.

Applications for reporting

Smart phone applications are fast becoming a reporting system of choice. While these are not typical EWS, they are a method of detecting hot spots for a certain activity and should be seen as an EWS that can prompt action before the problem gets exacerbated downstream of an incident. Several of the apps used allow for location identification and the uploading of a photograph.

In respect of water, it may be useful to have the app linked to more than just one institution. For example, a sewer leak should be reported to the local municipality. However, the impact from the leak will affect any nearby water resource, such as a river, dam or wetland, and so should be reported to the relevant CMA or DWS regional office. There may also be other organisations that need to be warned, e.g. a spillage into a wetland in the Western Cape should be reported to Cape Nature. Co-operative governance is therefore an essential element of the implementation of an EWS.

8.8 Reporting of warnings

The main objective of an EWS is to ensure that warnings reach those at risk (Figure 30). Clear messages containing simple, useful information are critical to enable proper responses that will help safeguard lives and livelihoods. Regional, national and community level communication systems must be pre-identified and appropriate authoritative voices established (EWS III, 2006). The use of multiple communication channels is necessary to ensure as many people as possible are warned, to avoid failure of any one channel, and to reinforce the warning message.

The outputs from the “sensors” could be via:

- A smart phone application based on community inputs;
- SCADA, which refers to supervisory control and data acquisition**,** a system for remote monitoring and control that operates with coded signals over communication channels (using typically one communication channel per remote station). The control system may be combined with a data acquisition system by adding the use of coded signals

over communication channels to acquire information about the status of the remote equipment for display or for recording functions (Aquino-Santos, 2010); and

- Model outputs.

These outputs will then need to be interpreted and reported.

Reporting based on outputs from the EWS would need to be well planned. It is important to know who should receive the report, what they should receive, when they should receive it and, once received, what they should do with it. The reporting mechanism could be:

- Paper based;
- Telephonic;
- Via short message services (SMS);
- E-mail or other type of social media.

When setting up the reporting mechanisms, it is critical that an effective integrated reporting system is implemented.

Key aspects related to warning messages:

- Warning messages need to be recognised and understood. In this respect, warning alerts and messages need to be tailored to the specific needs of those at risk;
- Warning alerts and messages must be geographically specific to ensure that warnings target those at risk only;
- The messages that are sent out need to incorporate understanding of the values, concerns and interests of those who will need to take action (for example, instructions for safeguarding livestock and pets);
- Warning alerts must be clearly recognisable and consistent over time and include follow-up actions when required;
- Warnings should be specific about the nature of the threat and its impacts to avoid any kind of misunderstanding and exaggeration;
- Mechanisms need to be put in place to inform the community when the threat has ended.

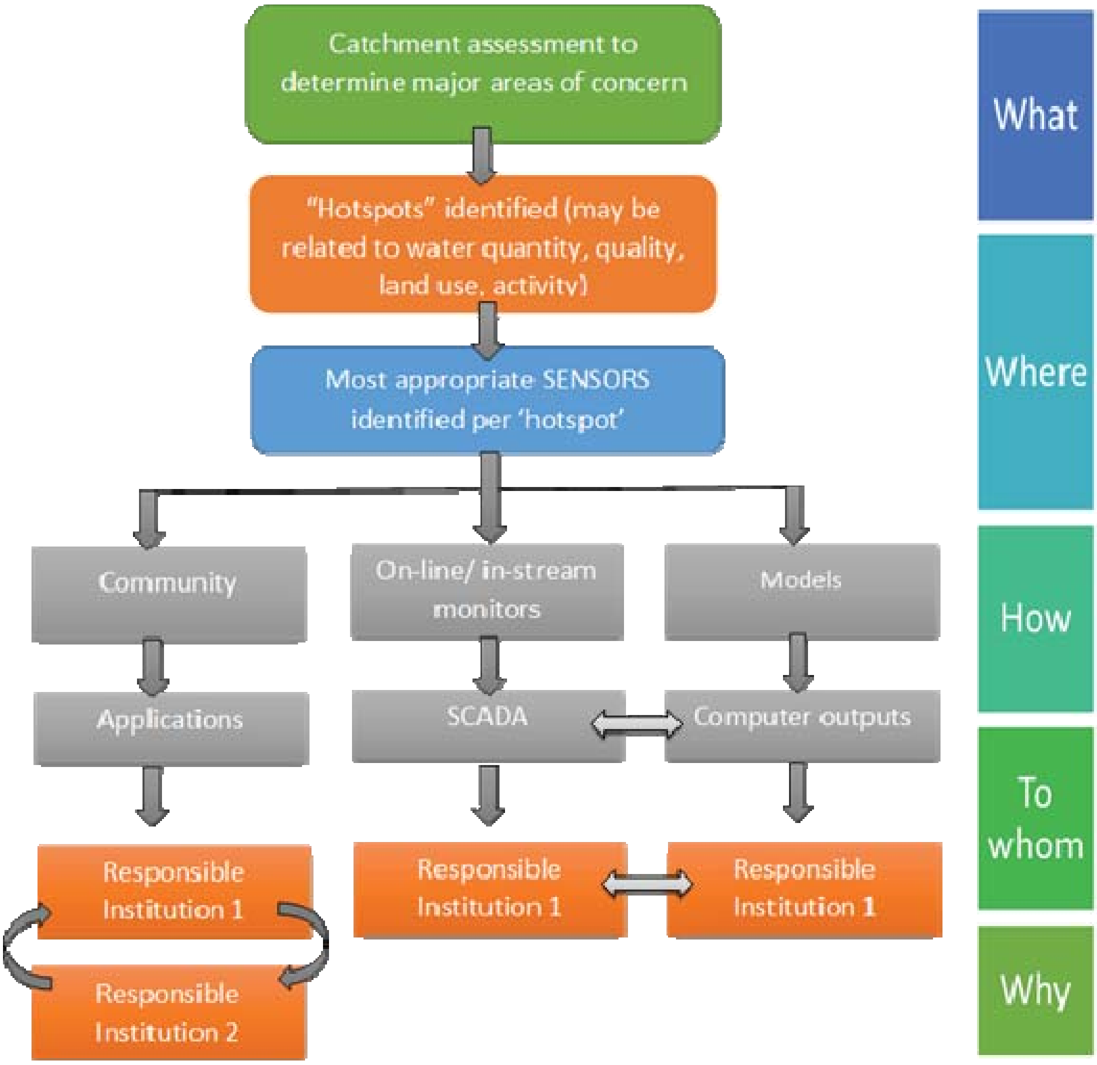


Figure 30: Proposed EWS pathway for reporting

8.9 Operation and maintenance of early warning systems

An EWS will only be effective if it is operated and maintained in a condition that will produce accurate results. From a technical perspective, the cost of operating and maintaining a particular system must be considered during the development of the system to ensure that it can deliver the required products and does not turn out to be a system that cannot be used because of the high cost of maintenance.

However, it is not only the technical aspects that require consideration. There are a number of overarching issues that should be considered when designing and maintaining an effective EWS. These include:

- Training of those who will operate the system is essential. The right skills for this must be maintained to ensure that the EWS works effectively.
- Effective governance and institutional arrangements that will support the successful development and sustainability of sound early warning systems.
  - Early warning needs to be a long-term national and local priority.
  - Legal and policy frameworks need to be in place to support early warning systems when they are established.
  - Institutional capacities assessed and enhanced as necessary.
  - Financial resources secured.
- Vertical and horizontal communication and coordination between early warning stakeholders should be established.
- A multi-hazard approach is preferable, so that, where possible, early warning systems link all hazard-based systems. Economies of scale, sustainability and efficiency can be enhanced if systems and operational activities are established and maintained within a multi-purpose framework that considers all hazards and end-user needs (EWS III, 2006). A multi-hazard EWS will also be activated more often than a single-hazard warning system, and therefore should provide better functionality and reliability for dangerous high intensity events that occur infrequently. Multi-hazard systems also help the public better understand the range of risks they face and reinforce desired preparedness actions and warning response behaviours (EWS III, 2006).
- Involvement of local communities means that the EWS will rely on the direct participation of those most likely to be exposed to the hazards. Without the involvement of local authorities and communities at risk, government and institutional interventions and responses to hazard events are likely to be inadequate. A community-based approach to early warning, with the active participation of local communities, which may include civic groups and traditional structures, enables a multi-dimensional response to problems and needs, and will also strengthen local capacities.
- Consider gender perspectives and cultural diversity when developing an EWS. It is essential to recognise that different groups have different vulnerabilities according to culture, gender or other characteristics that influence their capacity to effectively prevent, prepare for and respond to disasters. Women and men often play different roles in society and differ in their access to information in disaster situations. In addition, the elderly, disabled and socio-economically disadvantaged are often more vulnerable (EWS III. 2006). Information, institutional arrangements and warning communication

systems should be tailored to meet the needs of every group in every vulnerable community.

8.10 Potential EWS for the different management levels of the IWQM model

Recapping the management unit levels

The IWQM framework model, described in Boyd et al. (2010), has four management "levels", which correspond to the management unit types indicated in

Figure 31. These are described briefly in the section to follow. For each level, a proposal is made as to the type of EWS that may be feasible.

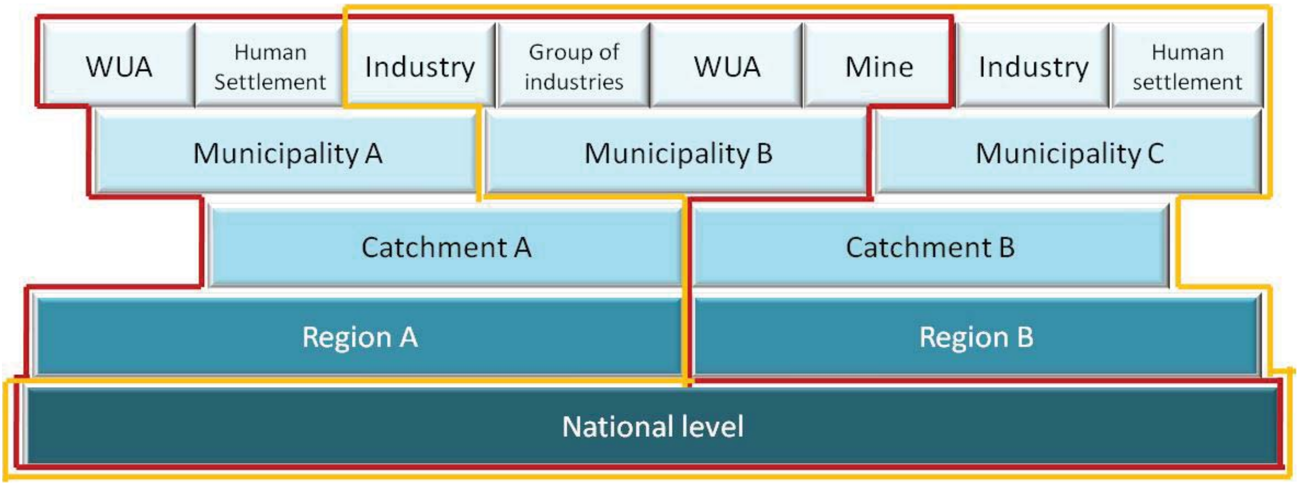


Figure 31: The Integrated Water Quality Management Framework (Boyd et al., 2010)

8.10.1 Community

The word community is used to refer to a group of people or organisations with common interests regarding the quality and quantity of the water within a specific geographical area. A community-type management could be anything from a single factory to a small settlement (informal or otherwise) to a large group of farmers who participate in an irrigation scheme as part of a WUA.

In terms of an EWS, water quality aspects that are likely to impact on water users at the community level, as described above, include: nutrients (agricultural – irrigation return flows, runoff from densely populated settlements, overflows from effluent dams), metals (industrial areas), pesticides, microbiological contaminants (feedlots and runoff from densely populated settlements).

The types of EWS that would be feasible at this level would include:

- Community-based monitoring for densely populated areas; and
- On-line monitors for WUAs and industrial areas (stand-alone industries, industrial areas, and mines).

8.10.2 Municipality

Municipalities with water service authority status are responsible for ensuring the delivery of a water supply to people in their area of jurisdiction, and many are also responsible for the treatment and discharge of wastewater.

Most municipalities would have at least one wastewater treatment works (WWTW) and water treatment works (WTW). For these, on-line monitoring with SCADA would be good investment to ensure that good quality effluent is discharged to the water resource and good quality water is supplied to consumers. For example, a WWTW may have an on-line monitor to measure ortho-phosphate levels; when the concentration of ortho-phosphate reaches a certain level, dosing of a chemical for phosphate removal kicks in to ensure that the effluent being discharged is within the water quality limit set in the water use authorisation. This type of EWS is already in place in many of the larger metropolitan municipalities; however, it is not always well operated and maintained.

A second example is flow gauge measurement; if the flow gets too high then an SMS could be sent to a process controller’s cell phone to alert them of a potential overflow, and the event could be averted.

These types of on-line/instream monitors could also be used in dams and rivers to alert relevant institutions to particular contaminant/flood/ drought events.

Where a water supply is from boreholes, an EWS based on water level could be implemented.

Community-based monitoring and the implementation of a water-related smart phone application which the public could use to report issues such as sewer overflows and water leaks, uploading the location and a photograph, would be useful. This type of system would help to ensure that failures are corrected quickly, preventing, or at least limiting, the impacts on a water resource.

In addition, local municipalities may be able to use such an app as an EWS for drought warnings (restrictions), especially, for example, in high tourist areas where the tourist population is transient and may not be aware of water related concerns that the local residents know about.

8.10.3 Catchment and regional levels

There are currently nine WMAs described in the National Water Resource Strategy (DWA, 2013). Each WMA comprises several catchments. Under the NWA, these areas are administered by CMAs, or DWS/proto CMAs if a CMA has not yet been established. The CMA has institutional responsibility for managing water quality in its catchment(s) through the implementation of RQOs (reserve and resource quality objectives) which should be identified for all the water resources in an area once classification of the resources has taken place. RQOs will not be developed for each small catchment and, in this respect, water quality planning limits (WQPLs) will be developed. The management unit area can cover one catchment or a group of catchments, as delineated by the WMA boundary.

A CMA or regional MU is responsible for auditing the quality, quantity and management options implemented, relating to water entering its geographical area, and is responsible for reporting on these to the next level of management; as well as to the adjacent upstream management unit, from where the water originated.

At this level, on-line/instream water quality monitoring is not likely to be feasible, the reasons being that the areas in which the monitors would be placed would be susceptible to theft of solar panels and instrumentation. Implementation of planning models and contaminant transport models will be more effective in determining and monitoring the hotspots.

Gauging of the flow at several points along major rivers and at major dams gives a good indication of expected flood and drought flows and, in this respect, a good communication strategy just needs to be developed to warn downstream users.

As recommended for the municipal level, a water-related smart phone application which the public could use to report water-related concerns that they notice in their travels, with the facility to upload the location and a photograph, would be useful.

8.10.4 National level

This management level is responsible for auditing, and it is at this level that early warning needs to be seen as a long-term national and local priority. This level needs to ensure that the legal and policy frameworks are in place to support EWS when they are established. This level would also assess institutional capacities and ensure that financial resources for early warnings are secured.

9.0 CONCLUSIONS AND RECOMMENDATIONS

The aim of the project has been achieved by holding numerous workshops and training sessions with stakeholder in our case study area, among others, the Western Cape DWS regional office, the Breede-Gouritz Catchment Management Agency (BGCMA), a Water Users Association (WUA) and other interested water users. However, the project experienced numerous constraints, including loading the software onto a user's computer, receipt of data and ownership.

In several cases, the system could not be loaded onto a user's computer during a training session due to administrative permissions. In addition, it was noted that data is not backed up anywhere, it is only except housed on the user's computer. Participation at the various workshops and interim meetings ranged from 100% at the first workshop to 30% at subsequent meetings. It was noted that this was seen as just a project; had it been part of a job description, the attendance is likely to have been better.

From the government department's side, a constraint is that contracts for sample collection and analysis are not renewed timeously. This means that data is not available for input. As sampling is most often part of an environmental official's job description, it should be that even if a laboratory contract is not in place, each official should have a field instrument that can measure some basic parameters such as pH and electrical conductivity. These values could then be immediately added to the system and reported on.

The concept of ownership seems to be a large hurdle that will need to be removed. It is going to take a mind-set change to get personnel at all levels out of their comfort zone, as the immediate reporting may put them in the spotlight, where questions may be asked and answers will need to be given. It will mean that officials and water users at all levels will need to be proactive rather than reactive. This also ties into the community-based monitoring described.

Percentage data input ranged from 0% (monitoring points were added but no data was ever received to input) to 80% for certain points along the coast. In most cases, failure to enter data was because the samples were not taken.

It was also noted that there was great enthusiasm when first seeing the product; however, the implementation seemed to stall when the official was left on their own. In several cases, it was noted that this was due to the fact that the official did not have adequate computer knowledge, especially of programmes such as Excel.

A further reason may be that reporting requirements are not very stringent and the outcomes of assessment of the data are not used or communicated to effect change. It appears that data is seen as something that only needs to be generated when asked for, rather than something that, as a standard procedure, should be collected and communicated to others within an institution, and to stakeholders.

The links between response scenarios, early warning systems and integrated water resources management are described, noting that, in respect of response scenarios in the area of water, it is important to understand the complexity of water resources management when assessing the scenario for an event that has occurred and putting a plan or early warning system in place to prevent or limit such an occurrence in future. The report indicates that South African legislation allows for integrated water resources management, describing it in the National Water Act as well as the National Water Resources Strategy. The importance of linking response scenario analysis to the development of catchment management strategies and local conditions, bringing in local knowledge and public participation, is highlighted.

Potential tools that could assist with response scenario analysis include a simple risk assessment matrix for various sources of concern, constituent ratios such as sulphate to major anions which can provide an indication of the potential for acid mine drainage, and using the trophic status of impoundments to warn about upstream nutrient concerns.

Types of possible early warning systems that could be considered as part of the scenario analysis are also described as they are central to the system. The types described include on-line/continuous monitors/sensors, emerging technologies such as biological monitors, fluorescence analysis, floating monitoring systems, satellite remote sensing; water resource modelling and specifically contaminant transport modelling, community-based monitoring; and applications for smart phones.

Some aspects to bear in mind, when considering using an on-line monitor in South Africa, include:

- On-line monitors will need to withstand adverse weather conditions. In the South African context, electrical storms could interfere with the electronics.
- Rivers are often low flow for the majority of the year with rapid changes in flow level when a rain event happens.
- Accessibility will be important to allow the sensor(s) to be changed and the instrument to be maintained, as necessary.

- Accessibility to electrical connections may be difficult and the use of a solar panel would be necessary.
- Theft and vandalism to get to saleable items, such as copper wire and the solar panel, is also a real concern.

The reporting of warnings must put across a clear message containing simple, useful information as this is critical to enabling proper responses that will help safeguard lives and livelihoods. National, regional and community level communication systems must be pre-identified, and appropriate authoritative voices established. Key aspects related to warning messages should include:

- Warning messages need to be recognised and understood. In this respect, warning alerts and messages need to be tailored to the specific needs of those at risk;
- Warning alerts and messages must be geographically specific to ensure that warnings target only those at risk;
- Messages that are sent out need to incorporate understanding of the values, concerns and interests of those who will need to take action (for example, instructions for safeguarding livestock and pets);
- Warning alerts must be clearly recognisable and consistent over time and include follow-up actions when required;
- Warnings should be specific about the nature of the threat and its impacts to avoid any kind of misunderstanding and exaggeration; and
- Mechanisms need to be put in place to inform the community when the threat has ended.

Some proposals regarding the types of early warnings systems that could be implemented at the various management unit levels include: community-based monitoring for densely populated areas; on-line monitors specifically for WUAs and industrial areas (stand-alone industries, industrial areas and mines). For the municipal sector, on-line monitoring of WWTWs and WTWs with SCADA would be a good investment to ensure that good quality effluent is discharged to the water resource, and that good quality water is supplied to consumers. This type of EWS is already in place in many of the larger metropolitan municipalities; however, they are not always well operated and maintained. A second scenario could be flow gauge measurement; if the flow gets too high, an SMS could be sent to a process controller’s cell phone to alert of a potential overflow, and the event could be averted. These types of on-line/instream monitors could also be used in dams and rivers to alert relevant institutions to particular contaminant/ flood/drought events.

Where water supply is from boreholes, an EWS based on water level could be implemented.

Community-based monitoring and the implementation of a water-related smart phone application which the public could use to report issues such as sewer overflows and water leaks, uploading the location and a photograph, would be useful. This type of system would help to ensure that failures are corrected quickly, preventing or at least limiting the impacts on a water resource.

In addition, local municipalities may be able to use such an app as an EWS for drought warnings (e.g. to communicate water restrictions), especially, for example, in high tourist areas where the population is transient and may not be aware of the water-related concerns that the local residents know of.

At catchment level, on-line/instream water quality monitoring is not likely to be feasible, as the areas in which the monitors would be placed would be susceptible to theft of solar panels and instrumentation. Implementation of planning models and contaminant transport models will be more effective in determining and monitoring the hotspots.

Gauging of flow at several points along major rivers and at the major dams gives a good indication of expected flood and drought flows and, in this respect, a good communication strategy just needs to be developed to warn downstream users.

In the same way as at municipal level, a water-related smart phone application, through which the public could report water-related concerns when travelling and upload the location and a photograph, would be useful.

The national level management unit is responsible for auditing and it is at this level that early warning needs to be seen as a long-term national and local priority. This level needs to ensure that legal and policy frameworks are in place to support EWS when they are established. This level would also assess institutional capacity and ensure that financial resources for early warnings are secured.

Recommendations

It is recommended that a technology transfer takes place in the Inkomati-Usuthu CMA in collaboration with the relevant departments within the CMA. This should include:

- Data assessment to understand what the current situation is in respect of:
    - Data quality and quantity;
    - Other reporting requirements that are linked to the catchment management strategy;

- Participation by various levels of stakeholders and impactors that already have water use authorisations and who should be reporting to the CMA;
- Participation by other stakeholders in the WMA who may not have, or require, an authorisation, but who, however, have a stake in the catchment. This will allow all communities to become intimately involved in the management of their catchment by assisting them to identify relevant management units, CCPs, RFs and targets specific to their community thus making them part of the system and allowing them to be accountable for reporting on a target that they themselves will set; and
- Putting considerable effort into getting officials and relevant stakeholders comfortable with the system, so that it will be effectively used.

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APPENDIX A

REPORTING FORMAT EXAMPLES

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