ENVIRONMENTAL MANAGEMENT PROGRAMMES AS A TOOL FOR EFFECTIVE CATCHMENT MANAGEMENT IN SOUTHERN AFRICA

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Abstract: This paper presents the background and scope of Environmental Management Programmes (EMPs) in South Africa, which have to be submitted to the Department of Minerals and Energy in terms of the Minerals Act (1991). The methodology and activities undertaken to address the relevant issues in EMPs, like groundwater and surface water, are described. Special attention is paid to the assessment of potential future impacts of mining (and other human/industrial activities) on catchments and measures to manage these impacts.

INTRODUCTION

In South Africa, the need for integrated management of catchments and river basins was identified a long time ago, resulting in the passing of the National Water Act 36 of 1998. Initially, emphasis was placed on catchment management to ensure bulk water supply to agriculture, households and industries. The ecological importance of integrated catchment management was only fully recognized in the 1970’s and ‘80’s and, accordingly, new water and environmental legislation has been developed.

Apart from an adequate legal framework, effective integrated catchment management requires competent regional management and law enforcement structures, technical measures and systematic monitoring. Hydrological system analyses need to be conducted and be continuously updated and improved, in order to understand and quantify the interactions between the various components of the hydrological cycle (particularly rainfall, groundwater and surface water), both quantitatively and qualitatively. In addition, existing and potential impacts on the hydrological system as a result of human activities should be assessed and managed.

It is obvious that catchment management should focus on the activities that have the largest impacts on the natural environment and water resources. In comparison with other human activities, the mining industry has the potential to significantly impact on the water environment, having already caused many serious environmental problems in the industrialised world and Africa. Negative mining-related environmental impacts include the deterioration or loss of water resources, soils and ecosystems. Mining is, however, of major economic importance in Southern Africa.

The Department of Minerals and Energy (South-Africa’s regulator of the mining industry) and the Department of Water Affairs and Forestry (DWAF), together with the mining industry, scientists and consultants have worked towards more sustainable mining practises in the region of Southern Africa. In South Africa, this has resulted in the legal obligation of mining companies to submit an Environmental Management Programme Report (EMPR) in terms of the Minerals Act (1991) to the authorities, prior to mining. Mining authorisation is only granted once the EMPR has been approved. The environmental management programme is legally binding and commits the mine to
ongoing monitoring and strict management to avoid, minimise or mitigate environmental impacts before, during and after the mining operations.

Post-mining environmental impacts tend to be largely underestimated. Abandoned and closed mines are often associated with ongoing ground- and surface water contamination, which may continue for tens to hundreds of years. The post-mining environmental impacts are often more severe than the environmental impacts caused during the operation of the mine. However, once closure is obtained, the state takes responsibility for rehabilitation costs as well as any costs incurred during cleanup operations. In the past, mitigation and rehabilitation costs for an abandoned or closed mine could generally not be recovered from the previous mine owner. However, post-mining water and environmental management can now be enforced, as the EMP stipulates that mining companies allocate sufficient capital in a trust fund or by means of a bank guarantee with the Department of Minerals and Energy (before mining commences), solely for rehabilitation and environmental management.

SCOPE OF EMPs

EMPs are composed using a guideline document called an “Aide-Mémoire”. The Aide-Mémoire contains an extensive checklist of issues that have to be addressed in the EMPR. The requirements for EMPRs are becoming more stringent, aiming to comply with the international ISO 14001 standard for Environmental Management Systems within the next few years. In addition to the motivation and the detailed description of the envisaged mining project, the pre-mining environment, impacts on and management of the geology, topography, soils, land capability, land use, natural vegetation, animal life, water resources (surface water, groundwater), air quality, radiation, noise and vibration, archaeological, historical and cultural interests, sensitive landscapes, visual aspects, socio-economic aspects, existing infrastructure, traffic and paleontological and anthropological aspects must be addressed.

Ground- and surface water are generally the main issues of concern. As EMPs are aimed at managing any potential water and environmental pollution at the source, thereby controlling potential impacts further downstream in the catchment, they are an important tool within the total scope of integrated catchment management.

CHARACTERISATION OF EXISTING WATER RESOURCES

The pre-mining water resources must be recorded and characterised, both in terms of the regional references and the site reference conditions. The catchment management agency or DWAF stipulates the management and water quality objectives for the catchment in which the mine is located. Water quality objectives vary from catchment to catchment and may sometimes be more stringent than the South African Water Quality Guidelines.

The description of the local reference situation includes an assessment of several water resources, their users and aquatic ecosystems. The hydrological system analysis generally starts with a desk study and a 'hydrocensus' in the area. Surface streams, drainage lines, dams, wetlands, etc, are identified and characterised. Flood lines are determined for various recurrence intervals (return periods). For this purpose (sub)catchment runoff models are constructed for each stream that may be impacted on. The Pitman monthly rainfall-runoff model (developed by the Rhodes University) is often used. This model simulates monthly run-off volumes for each of the (sub)catchments. In addition, flood peaks (in m$^3$/s) can be calculated for 1:20, 1:50 and 1:100 year recurrence intervals, using the Rational Method. No mining infrastructure is allowed within the 100-year flood lines and all dams and pollution control structures must be designed to handle a 100 year flood event.
Aquifers, recharge and discharge areas must be identified and the interaction between the groundwater and surface water assessed. This involves a geophysical investigation (generally an electromagnetic and magnetic survey) to identify subsurface fractures, joints, intrusions and bedding planes, as most of the aquifers in South Africa are secondary in nature. The geophysical surveys also aid in siting groundwater exploration and groundwater monitoring boreholes and, if necessary, scavenger wells. Boreholes should be sited in the preferential groundwater flowpaths. Groundwater samples are collected according to a prescribed protocol and analysed by an accredited laboratory to guarantee the integrity of the information. In order to quantify the hydraulic characteristics, aquifer tests are executed and interpreted. The information from the aquifer tests and groundwater monitoring programme are important input parameters for groundwater and solute transport models (see below).

ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT

The compilation of the environmental management programme is an iterative procedure. With the hydrological system analysis and the proposed mine plan, the potential environmental impacts are identified and assessed. For this purpose a groundwater flow model must be constructed. The impacts on existing groundwater users and groundwater-related ecosystems can be assessed using this model. Once the model is calibrated, different mining scenarios can be simulated and the most feasible mine plan selected. The model also aids in the design of an adequate monitoring programme and in the identification of possible mitigating measures minimize the impact of pollution.

The groundwater model also facilitates in determining the impacts on surface water. During mining, dewatering will, generally, result in a decrease in groundwater flow to streams, thus impacting on downstream areas in the catchment. After decommissioning, the pre-mining flow volumes will (more or less) re-establish themselves, however, the quality of the groundwater that discharges into the streams may have deteriorated (see below). To assess the future contaminant load in the streams as a result of groundwater discharge, a solute transport model can be linked to the groundwater model. This will enable the assessment of attenuation of groundwater pollution plumes moving towards surface water streams (as a result of mixing with fresh recharge water and dispersion). A geochemical model can be used to evaluate interaction between the groundwater pollution plume and the minerals in the aquifer or the natural, ambient groundwater. For example, an acid pollution plume may be buffered by carbonate minerals in the aquifer, which may lead to an acceptable pH once the groundwater daylights. Geochemical models may also help to assess whether gypsum may precipitate in sulphate rich waters.
The following schedule presents the procedure to achieve effective environmental management and an optimum mine plan.

The impact of the mining activities on the groundwater and surface water quality is a major issue, but not always fully understood. During mining, contaminants from the mining operations and mining infrastructure (pollution control dams, discard dumps, waste sites, etc) may infiltrate and contaminate the groundwater. However, the local groundwater flow patterns are usually reversed during mining, as a result of dewatering of the mine. This means that the local groundwater flow patterns will be towards the mining area, which prevents the spread of contaminants into the catchment. After mining, the groundwater flow patterns re-establish themselves and any groundwater contamination will eventually spread into the catchment. Consequently, the impact on the catchment will be more severe after closure than during mining. It may take a long time, tens to hundreds of years, before these impacts establish themselves. Once the contaminated groundwater daylights, remediation will be very difficult and costly.
A typical time scale of post-mining environmental impacts is presented in the following figure.

![Typical time scale of impacts of mining](image)

It is, therefore critical, that the post-mining environmental impacts are addressed before mining commences and that long term groundwater and surface water quality is assessed and managed within the framework of the EMP.

To assess the long term groundwater quality, a geochemical system analysis of the area is required. In the following, a specific method will be presented.

Impacts on groundwater quality are directly associated with the minerals present in the ambient aquifer formation and changes in the hydrogeological system. One of the largest causes of groundwater quality deterioration is acid rock drainage (or acid mine drainage), which is the result of the following (overall) reaction:

\[
\text{FeS}_2 + 3.75 \text{O}_2 + 3.5 \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 2 \text{SO}_4^{2-} + 4 \text{H}^+
\]

This reaction is enhanced by dewatering, as oxygen then penetrates the aquifer. In formations with abundant pyrite or other sulphide minerals, the weathering of these minerals may lead to extremely acid groundwater. In addition, heavy metal ions are generally released into the groundwater. As previously stated, this contaminated water will be managed by dewatering during the mining operations, but after mining, when the natural groundwater levels have re-established themselves, this acid groundwater, rich in heavy metals, may daylight and spread into the catchment.

It is, therefore, critical to determine the acid generation potential of rocks, as a result of a changing hydrogeological environment. This is not only important for mining operations, but for any activity in the catchment where groundwater levels will be impacted on.

A number of laboratory tests have been developed to assess the acid generation potential of rocks and the expected enrichment of elements, including heavy metals in the groundwater. These tests
include two element enrichment tests, consisting of sample preparation (crushing, splitting and
further crushing according to detailed procedures) and the determination of element enrichment
and solubility using distilled water and peroxide (the latter is aimed to simulate complete
weathering). The total sulphur content of rock samples is determined by the Leco high
temperature combustion method, representing the maximum content of reactive pyrite.

Two other tests are conducted to determine the ‘acid neutralizing capacity’ of rock and the ‘net acid
generation potential’. The ‘net acid producing potential’ is then calculated by simply subtracting the
acid neutralizing capacity from the total sulphur content (both expressed in kg $\text{H}_2\text{SO}_4$/tonne).
Together with the net acid producing potential test and the pH measured during this test, the risk of
acid generation can be quantified. An example of the assessment of acid generation potential is
given in the following table. The tests were conducted for the entire aquifer from surface to a depth
of 130 metres.

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<th>SAMPLE</th>
<th>ACID-BASE ANALYSES</th>
<th>NAG TEST</th>
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<tr>
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<td>Interval (m)</td>
<td>pH</td>
<td>EC (mS/m)</td>
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<td>from to</td>
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ANC = Acid Neutralizing Capacity; NAPP = Net Acid Producing Potential; NAG = Net Acid Generation

In this specific example three potentially acid forming strata can be identified (the coal layer does
not pose a risk, as this will be removed. In the case of open cast operations, these layers require
special attention and specific handling. A number of management measures exist, for example, the
mixing of the acid forming layer with limestone and/or encapsulating the material in cells with a clay
liner, etc. In underground mines, selective handling is generally not possible and hydrologic
measures are required. These consist of the hydrological isolation of the contamination, by
physical (engineering) or hydrological measures. Physical measures include the creation of
impermeable barriers around the potential zones of contamination (generally the void where the
groundwater accumulates after mining), eventually together with the introduction of base
generating material. Hydrological measures include the creation of water divides around the
potential zones of contamination. Passive systems such as evaporation areas are not always
possible. Active systems may involve prolonged pumping and/or the installation of a water
treatment system. As previously noted, these systems may need to be operated for a very long
time. Financial provisions are, therefore, required to ensure that the costs for environmental management, after mine closure, will be covered.

CONCLUSIONS

In order to quantify and effectively manage impacts in catchments resulting from mining and other human / industrial activities, an extensive procedure should be followed, aiming at understanding the hydrological and hydrochemical system and the interactions between rock formations, groundwater and surface water. A wide variety of hydrological techniques are involved, including field investigations, groundwater- and surface water modelling, geochemical modelling and specific laboratory tests. The Environmental Management Programme Report in terms of the Minerals Act (1991), allows for a systematic and comprehensive assessment of environmental impacts and their management. As EMPs are aimed at managing any potential water and environmental pollution at the source, they are an important tool for effective integrated catchment management.

REFERENCES


