THE PURPOSE AND DESIGN OF WATER QUALITY

MONITORING NETWORKS AT MINESITES[1]

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Abstract.--The various factors that affect the purpose and design of water quality studies at minesites are reviewed. Differences between Baseline, Impact and Operational water quality studies are described. Quality parameters to be measured, the location of monitoring sites, the number and frequency of measurements are discussed. The role of water quality studies in revegetation and rehabilitation operations is considered.

INTRODUCTION

Water management is a major factor affecting the design and operation of most mines. It is important that water management be viewed as a 'system' of inter-related operations that effect the quantity, quality and location of various water flows. A well designed and integrated water management system can reduce both the construction and operating costs of a mine. This paper singles out one aspect of water management for consideration: namely, the purpose and design of water quality monitoring programs. Water quality monitoring studies are relatively expensive. A modest program to collect baseline water quality data may cost $50,000-$100,000 to establish. Annual operating expenditure may be similar. To obtain value for this expenditure, it is important that monitoring programs be well designed and well managed.

PURPOSE OF WATER QUALITY STUDIES

Environmental Effects of Mining

Mining operations in general, and large scale opencut mining operations in particular, disturb the surrounding environment in a major way: massive amounts of overburden are removed, dumped, recontoured and revegetated; huge volumes of ore are mined, stockpiled, crushed, processed and shipped away; large quantities of tailings require disposal; extensive mining infrastructure facilities have to be constructed. The potentially damaging effects of mining operations on water quality fall into 2 broad categories:

(i) Deleterious effects associated with physical changes to catchment areas and drainage patterns. For example, changes in the volume of runoff and increased levels of suspended solids, dissolved solids and turbidity. Quality changes in surface runoff from overburden areas fall into this category.

(ii) Separate deleterious effects resulting from interaction between the ore itself and water. For example, in the case or high sulphur coals, acid mine drainage is generated in washplant effluent, pit water and the surface runoff from spoil heaps and coal handling areas.

Objectives

Environmental Requirements

Mining is but one of a surrounding and inter-related set of land and water use activities. To minimize potential conflicts between mining and other activities, and to ensure that a worked-out mine is ultimately returned to an appropriate land use, mining is generally only allowed to proceed within a formal framework of environmental requirements. With regard to water quality, the objectives of environmental requirements are:

(i) To control any deleterious effects of mining operations on water quality and quantity to 'acceptable' levels.

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(ii) To restrict the extent of any deleterious effects to the immediate minesite.

(iii) To ensure that 'unacceptable' water quality and quantity effects are not passed on to 'downstream' users of surface and underground waters.

Water Quality Studies

The basic object of all minesite water quality studies should be to develop a water monitoring/management system that will enable the environmental obejctives to be met at least cost. The 'downstream' land and water use activities affect the environmental requirements of the mine, and hence the objectives of minesite water quality surveys. Downstream land and water uses need to be defined and taken into account when establishing water quality objectives. There should be a close liaison with any government departments responsible for specifying environmental requirements.

Use of Data

There is still a fairly common tendency to regard the collection of data as being the prime objective of a water quality monitoring study. To a large extent this attitude appears to have arisen because of difficulties experienced in the establishment and operation of monitoring networks. Water quality and other types of environmental data are not an end in themselves, but rather a means to an end. Data is collected to meet specific study objectives that have been framed in terms of the environmental requirements of the mining operation. During the design and operation of minesite water quality studies, the basic objectives of the studies should be constantly borne in mind.

TYPES OF WATER QUALITY STUDIES

Three distinct types of water minesite quality studies can be identified:

(i) Baseline studies,
(ii) Impact studies, and
(iii) Operational Studies.

The characteristics and objectives of these three studies can differ considerably and are now described. In broad terms, the object of Baseline and Impact water quality studies is to provide a measure of the effects of the mine on 'downstream' water quality and quantity. Operational studies generally have much more limited and specific objectives concerned with the immediate management of water on the minesite.

Baseline Water Quality Studies

The object of Baseline Water Quality Studies is to gather an adequate and reliable body of data that reflects the quantity and quality of surface and underground waters before mining operations commence. This body of data forms a 'yardstick' against which any future impacts of the mine on water quality are assessed. It is important that a Baseline program be sufficiently broad in scope to provide a representative coverage of appropriate quality parameters.

Baseline programs should be initiated before mining operations commence and before construction operations begin. The remote location of many minesites can make the establishment and operation of a baseline program difficult. These difficulties are often compounded by the climate and nature of the minesite itself. Many creeks and waterbodies of inland Australia are ephemeral in nature and are 'dry' more often than 'wet'. Runoff events, when they occur, are typically 'flashy'. Once the country is wet, access to monitoring sites may be difficult, especially in 'black soil' areas.

During the establishment of a baseline program, the available on-site facilities may be minimal, even non-existant. Few, if any, water quality analyses can be made on-site. Water samples generally have to be collected and 'shipped out' to a laboratory. It is important that an attempt be made to collect, ship and test samples in accordance with standard procedures, and that baseline samples be tested by a registered laboratories. If a water quality dispute is to arise, the baseline must be seen to be independent and reliable.

Impact Water Quality Studies

Once a body of baseline data has been collected, a continuing series of 'impact' measurements need to be made throughout the life of the mine to monitor the effect of the mine on 'downstream' water quality and quantity. Such measurements provide a direct indication of the success of water quality management measures.

The on-site facilities available for Impact water studies are generally much more comprehensive than those available for the Baseline studies. A network of roads has generally been developed over the minesite; in many cases, full laboratory facilities and trained chemists are available at the mine, and it will be possible to undertake a number of water quality analyses on site. If the analyses of Impact samples is undertaken by the mining company, it is important that a number of check samples be analysed by a registered laboratory at regular intervals. Impact water quality data needs to be seen to be independent and unbiased.

Operational Water Quality Studies

The aim of 'operational' water quality studies is to improve the necessary system of water quality control measures (in terms of producing greater control at less expense). Examples of operational water quality studies include testing the ore for its effects on contact with water, and investigations to define the optimal way of managing an inter-connected series of 'dirty' water ponds that are used for both impoundment and water supply purposes. In general, operational studies are more straight forward than Baseline and Impact studies: the 'system' being investigated is better defined, and testing may be able to be undertaken in more controlled conditions, even in a laboratory rather than the field.

DESIGN OF MONITORING PROGRAMS

General

In designing a water quality monitoring program, consideration needs to be given to the following 4 questions:

(i) What parameters should be measured?
(ii) Where should monitoring sites be located?
(iii) When and how frequently should measurements be made?
(iv) What apparatus should be used to obtain the measurement?

Parameters to be Measured

Hydrological/Meteorological

In most cases, the 'monitoring network' established at a minesite is used to measure a variety of data for a number of different water management purposes. Hydrological and meteorological variables typically measured include rainfall, water level, temperature and relative humidity, wind speed and direction, and solar radiation. Rainfall and water level measurements are required for water quality studies, rainfall-runoff studies and flood discharge studies. The other meteorological data are required for evapotranspiration studies (via Penman's equation) and general climatological studies.

It is recommended that rainfalls and water levels be monitored as part of Baseline and Impact Water Quality Studies. Rainfall measurements indicate the duration of dry periods (and the likely state of catchment soil moisture and vegetation) and the severity of storm events, factors which influence the amount and quality of runoff. Peak water levels should be measured at all quality sites to provide an indication of peak discharges during a runoff event. Water level variations need to be monitored at a select number of 'Key' sites to determine discharge hydrographs and the total quality 'load' passing the site.

Water Quality

In the Baseline surveys, it is important to measure a spectrum of quality parameters sufficiently wide to cover the likely effects of mining operations on water quality and to enable any future conflicts to be adjudicated. Fewer quality parameters generally need to be measured during Impact water quality studies. Impact parameters should either consist of the actual quality parameters of concern or be indicative of them. If impact parameters go 'out of bounds', it may be necessary to resume the full spectrum of baseline measurements to monitor associated quality changes. The parameters measured in Operational water quality studies depend upon the specific objectives of these studies.

Water quality analyses are relatively expensive. To 'stretch' the available budget, it is recommended that several levels of analysis be incorporated in Baseline and Impact programs. These levels have been designated 'Key', 'Detailed' and 'Full'. This approach has been incorporated in Baseline and Impact Studies undertaken at 4 minesites in New South Wales and Queensland in Australia. Table 1 shows details of typical parameters that are measured at these levels. 'Key' parameters reflect the basic chemical and physical attributes of the water. The cost of 'Key' analyses is about A$50 per sample. 'Detailed' parameters include the 'Key' parameters plus a spectrum of anions and cations, and provide a more detailed indication of the chemical content of the water. The cost of these analyses is about A$150 a sample. The 'Full' parameter list includes the 'Key' and 'Detailed' parameters plus heavy metals and other 'exotics'. The cost of the 'Full' analyses is about A$250 per sample.

The reduced costs of the 'Key' measurements enables an adequately large body of basic water quality data to be collected at moderate cost. These measurements provide a relatively reliable indication of the natural variability of broad-scale quality parameters. Fewer 'Detailed' and 'Full' measurements are made, but the greater number of these parameters provides a more comprehensive indication of water quality. Typically, about 10-20% of all samples collected should be analysed at the 'Full' level, 20-30% at the 'Detailed' level and the remainder (50-70%) at the 'Key' level.

Table 1.--Typical Key, Detailed and Full Parameter Levels of Water Quality Analysis

Quality Parameter	Level of Analysis		
	Key	Detailed	Full
pH	x	x	x
Turbidity	x	x	x
Conductivity	x	x	x
Filterable Residue	x	x	x
Non-Filterable Res.	x	x	x
Fe (dissolved)	x	x	x
Fe (adsorbed)	x	x	x
SO_4	x	x	x
Ca		x	x
Mg		x	x
Na		x	x
K		x	x
Cu		x	x
Zn		x	x
Al		x	x
Mn		x	x
P (organic)		x	x
Cl		x	x
CO_3		x	x
HCO_3		x	x
NO_2		x	x
NO_3		x	x
NH_3		x	x
Tot. Org. Carbon		x	x
Inorg. Carbon		x	x
Heavy Metals			x
F^-			x
B			x
$PO_4^=$			x
Phenols			x
Pesticides			x

Location of Monitoring Sites

General Considerations

Consideration should be given to the measurement of baseline water quality data in all major catchments likely to be affected by mining operations. Continuing impact measurements at these locations during mine life will allow the indentification of any catchments and catchment activities having significant detrimental effects on water quality. If the proposed plan of mine development is uncertain at the time of initiation of the baseline water quality studies, monitoring sites should be located to cater for likely mine developments. Baseline water quality should also be monitored in several catchments that will not be affected by mining. Continuing impact measurements at these locations during the mine life will provide a measure of the 'natural' quality variability of water unaffected by mining operations. Finally, any specific monitoring objectives may dictate the location of 'special' sites.

Specific Considerations

Specific considerations that affect the location of a particular site along a given length of stream include hydraulic factors and wet weather access. A rating curve, relating water level to discharge, should be derived for all water quality monitoring sites. This allows the discharge to be estimated when water samples are collected. With respect to rating curve reliability, the ideal monitoring site is relatively long (50-100 m), straight, uniform reach of channel that ends with a rock bar and a free overfall. (The free overfall provides a definite hydraulic control). Derived rating curves are least accurate for sandy reaches because of changing bed levels and inaccuracies in estimates of hydraulic resistance and energy slope. The rating characteristics of a particular site can be improved by constructing a low weir, and the use of weirs should be considered at specific sites where an accurate measurement of discharge is required.

Key Sites

A limited number (1-3) of 'Key' monitoring sites which reflect the overall effect of the mine on downstream water quality and quantity should be established. The most important of these 'Key' sites will be the 'Exit' site located on the major drainage tributary of the minesite and commanding all runoff from areas affected or likely to be affected by mining. Measurements here reflect the total effect of the mine on the quality and quantity of surface runoff 'passed on' to downstream users. An attempt should be made to establish reliable rating curves at 'Key' sites through the construction of weirs and/or streamgauging measurements. It is recommended that consideration be given to having Water Resource Authorities establish official gauging stations at Exit sites.

Number and Frequency of Measurements

Variability of Quality

In flowing over and through the ground, water picks up a variety of dissolved and suspended matter. The quantity and quality of surface runoff depends upon a variety of factors that include the soils and geology of the catchment area, catchment vegetation and landuse, rainfall intensity and history, and soil moisture. Several of these factors, such as catchment vegetation, soil moisture and rainfall characteristics, undergo cyclical seasonal changes. Because of differing contributions from these factors, the quality of water at a particular site

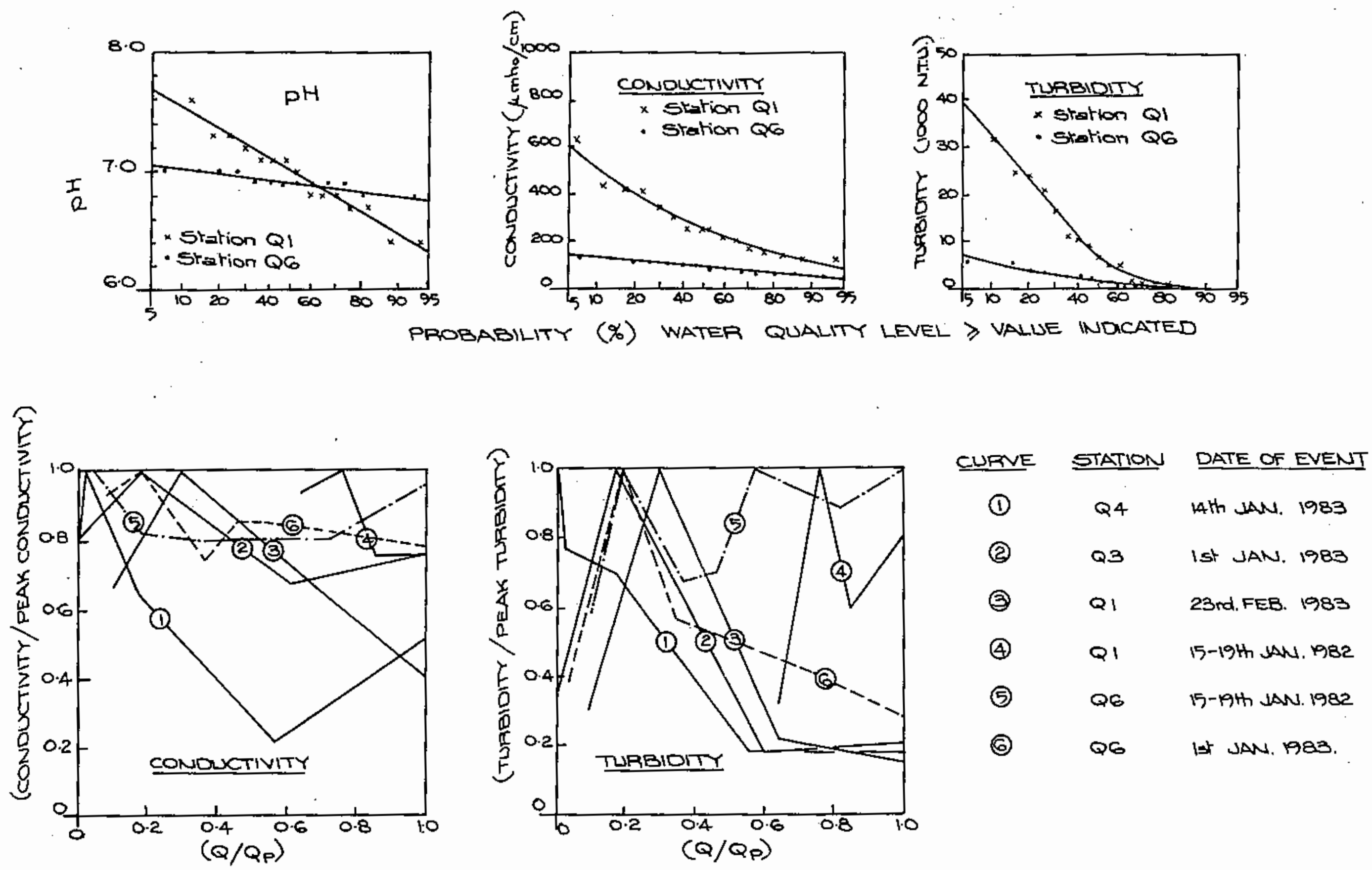

Figure 1.--Variation of water quality at a site and within an event.

varies throughout the year. Thus, Baseline and Impact water quality measurements result in a distribution of quality levels for each parameter rather than a unique single volume. Figure 1 shows the frequency distributions of quality levels for pH, conductivity and turbidity for 2 stations at Newlands mine in central Queensland. The range or 'spread' of quality levels is seen to be quite great at times.

Any comparison of the effects on water quality caused by mining operations, other land use changes or altered water management controls will have to be made in terms of the pre and post-change distributions of quality levels. Hence, it is important to gather sufficient data to provide adequate estimates of the various quality distributions and their statistics.

monitoring programs be initiated 2-3 years before construction operations commence.

In addition to quality variations throughout the year, water quality at a site also varies within a single runoff event. Also shown in Figure 1 are conductivity and turbidity variations recorded in samples collected at Newlands during 6 runoff events. These samples were collected on the rising stage of the runoff event. Quality levels are plotted against discharges. Both quality levels and discharges have been standardized by dividing by the peak values recorded during sample collection. The quality variations during an event are seen to be quite high: the maximum conductivity is about twice the minimum value. In addition, the results suggest that maximum quality levels occur somewhere on the rising limb of the hydrograph.

Variability of Runoff

If a minesite is located in an areas where streams flow more or less regularly during most of the year, there will be few problems in collecting an adequate number of water quality samples. However, if a minesite is located in an areas of ephemeral stream behaviour, the frequency and number of samples collected will depend upon the vagaries of the weather. To ensure the collection of an adequate number of samples in an ephemeral stream situation, it is recommended that Baseline

Monitoring Instruments

To a large extent, the success of any data collection exercise depends upon the suitability and reliability of the monitoring equipment. Monitoring instruments used for minesite water management studies need to be simple, robust and reliable. Instrument costs are typically only about one-quarter to one-third of the total cost required to design, install and operate a water quality monitoring network for 12 months. It is false economy to opt for unsuitable equipment because it is 'cheap'. For the sake of a supposed

10% savings in total cost, the monitoring program can be crippled by instrument breakdown.

A recent development in automatic data logging has been the advent of the electronic recorder. These instruments record data onto a solid state memory. This memory, which is typically the size of a box of matches, is removed from the recorder and inserted in a 'translator', which interrogates the memory and sends the data eigher to a printer or to computer storage. The memory is then purged by exposure to ultra-violet light and is ready for re-use. Many electronic recorders can remain unattended for up to 6 months or more. This system has a number of advantages with respect to data handling: it is robust and reliable, there are no charts to jam or digitize, and it is very effective in terms of man-hours required to collect a given body of data.

WATER QUALITY AND OVERBURDEN REHABILITATION

A relatively high degree of environmental control is possible in overburden management operations: location of overburden dump areas, topography and surface slopes, soil treatment, erosion control measures, type of revegetation, and immediate land-use are all factors that can be controlled. Because of the huge volumes of overburden to be moved and the extensive areas requiring revegetation, substantial costs are associated with overburden management.

The object of overburden management should be to meet both the immediate and long-term land-use and water quality requirements at least cost to the mine.

Overburden rehabilitation operations impose major physical changes on the pre-mining character of affected catchments, changes that effect the quality of surface runoff. Water quality studies can play a major role in assessing the effectiveness of rehabilitation operations. The quality of runoff from these areas is a fairly direct measure of the success of these operations. Quality parameters of interest include conductivity, filterable residue, non-filterable residue, pH, and possibly turbidity and specific ions of relevance to the particular ore or overburden. These 'Key' quality parameters are relatively easy and inexpensive to monitor. Excessively high conductivities, filterable and non-filterable residue levels and turbidities are indicative of inadequate erosion control measures, or the failure to achieve an adequate density and strike of vegetation.

Figure 2 shows the effect of revegetation on the quality of surface runoff from overburden areas. These results were obtained at Collinsville coal mine in central Queensland. The overburden of the study area was covered with 30 cm of topsoil in 1976 and left to revegetate naturally. This was unsuccessful, largely because of the highly saline nature of the topsoil. In January 1979 a trial area was spray mulched, fertilized and planted with a

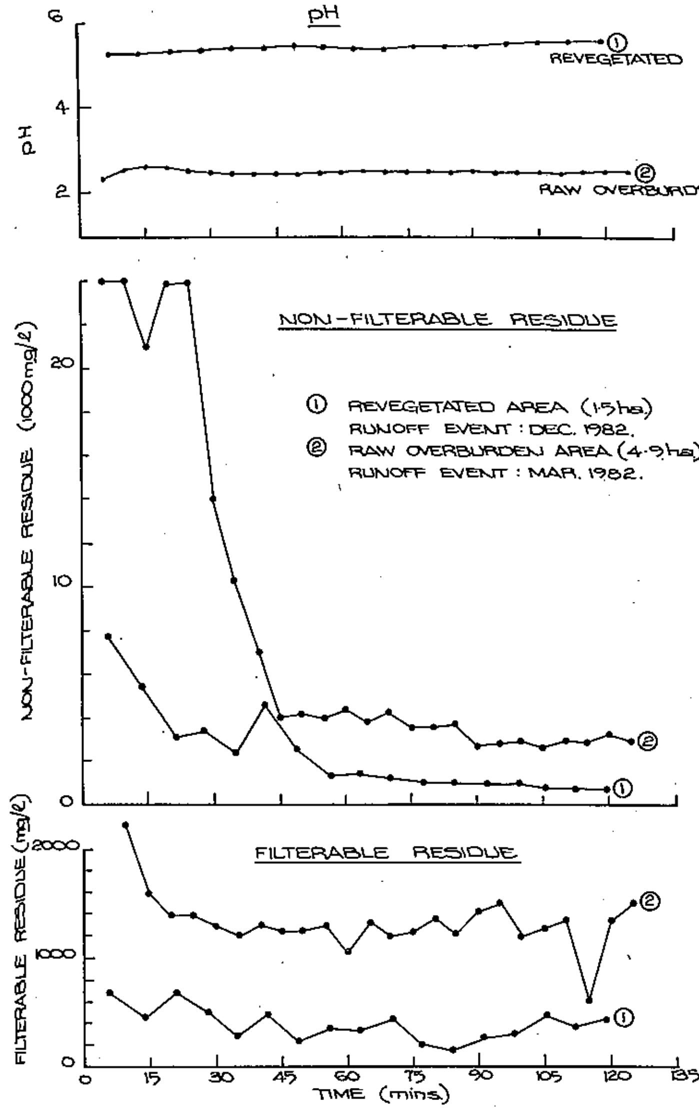

Figure 2.--Effect of revegetation on quality of surface runoff.

mixture of seed. Figure 2 compares the runoff from this area some 3 years later to the runoff from an untreated area.

The results of Figure 2 show the variation in water quality throughout a runoff event, and indicate a marked improvement in quality in the runoff from the revegetated area.

CONCLUSIONS

To minimize potential land and water use conflicts, mining operations are generally only allowed to proceed within a formal framework of environmental requirements. The water quality aims of these environmental requirements are to limit the deleterious effects of mining on water quality and quantity to 'acceptable' levels, to largely localize these effects to the immediate minesite, and to ensure that 'downstream' water uses are not adversely affected.

The fundemental objective of minesite water quality studies should be to develop a water monitoring/management system that will meet the environmental objectives at least cost.

The object of 'Baseline' Water Quality Studies is to gather an adequate, reliable and representative body of data that reflects the quantity and quality of surface and underground waters before mining operations commence. 'Impact' Water Quality Studies provide a continuing check throughout mine life on the effect of mining operations on water quality and quantity. 'Operational' Water Quality Studies provide specific information regarding the operation of the water management system.

Consideration should be given to measuring baseline water quality in <u>all</u> major catchments likely to be affected by mining operations. Baseline water quality should also be monitored in several nearby catchments that will <u>not</u> be affected by mining operations. Hydraulic considerations and ease of access affect the specific locations of monitoring sites.

A variety of factors - some seasonal (weather, vegetation), some random (the pattern of individual rainfall events) and some deterministic (land-use) - affect the quality of surface and underground waters measured in Baseline and Impact studies. Consequently, each quality parameter measured at a site shows a distribution of levels. Sufficient quality measurements should be made to adequately define these distributions and their statistics.

To a large extent, the success of any water quality monitoring program depends upon the choice of appropriate monitoring instruments, especially if monitoring sites are remote and access is difficult. It is false economy to opt for cheap, inappropriate instruments.

Finally, it is important to realize that water quality monitoring is but <u>one</u> aspect of minesite water management, albeit an important one. Minesite water management needs to be seen as an integrated, co-ordinated and inter-related series of control measures that effect the quantity, quality and location of minesite water flows. A considerable savings in the construction and operating costs can result from the <u>careful and integrated</u> planning of minesite water management measures. This is especially true with regard to overburden management and its effects on water quality. As opencut mines become larger, the overburden areas requiring rehabilitation are becoming more extensive. Even moderate marginal savings in overburden management would result in substantial savings over the life of a mine.