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PAPER

UNDERGROUND MINE SERVICE WATER QUALITY: CURRENT STATUS AND STRATEGIES FOR IMPROVEMENT

by

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Introduction

Owing to the mining sector's importance to the South African economy, the supply of water to the industry is receiving high priority from the water authorities. The current and projected future demand by the mining industry on the total national water resource is relatively low, between 2,4 and 2,8 per cent, but this still represents very large quantities of water (see **Table 1**). The water authorities expect improvements in the efficiency of water use and a reduction in pollutant loads discharged to the water environment by the mines, by better water management and the implementation of appropriate water treatment technologies[1].

Table 1 *ESTIMATED WATER DEMAND IN SOUTH AFRICA FOR 1980-2010 (MILLION m^3/a)[1]*

Water Use Sector	1980	1990	2000	2010
Municipal and Industrial	2 200	3 256	4 610	6 506
Mining	394	433	493	545
Power Stations	281	443	778	899
Irrigation (GWS)	1 951	2 329	2 732	2 900
Irrigation boards	2 168	2 495	2 884	3 099
Irrigation (private)	3 320	3 642	3 944	4 292
Stock-watering	186	202	218	236
Nature conservation	176	180	185	189
Estuaries and Lakes	2 032	2 032	2 032	2 032
Forestry	1 044	1 173	1 300	1 418
Other uses	39	39	39	39
Total	13 791	16 224	19 215	22 155

The water quantity and quality requirements for the gold mining industry have been reported by Steenkamp[2]. Annual water consumption (intake less discharge) for various sectors within the industry, for 1983, are listed in **Table 2.** The reduction works sector uses the most water, mainly to pump slimes to the slimes dams and hence water quality is not a major factor. The domestic sector is the second largest user of water and the largest consumer of Board water. Underground consumption of water rates as the fourth largest consumer, but the second largest consumer of Board water, at a rate of about 37 000 Mℓ/a (1 200 ℓ/s). This water is used for a multiplicity of applications, one of the major uses being cooling which requires a high quality water.

Table 2 *ANNUAL WATER CONSUMPTION BY GOLD MINING INDUSTRY FOR 1983*[2]

Water Use	Board (Mℓ)	Dam (Mℓ)	Shaft (Mℓ)	Total (Mℓ)	Percentage of Grand Total
Reduction Works	14 921	30 507	67 784	113 212	33,5
Domestic	81 119	970	15 228	97 317	28,7
Uranium	25 799	20 297	16 339	62 435	18,4
Underground	36 667	1 922	20 779	59 368	17,5
Power	6 093	0	335	6 428	1,9
Total	164 559	53 696	120 465	338 760	100,0

In the light of the gold mining industry's water quantity and quality requirements, as well as the current limitations imposed and future expectation of the water authorities, what are the industry's most urgent needs? Firstly, the most important requirement is probably efficient water management. This has already received considerable attention, particularly during the recent drought when the industry achieved a saving of some 30 per cent based on 1982 Board water consumption figures[1]. Secondly, the supply of adequate quantities of water of suitable quality for the various uses water is put to in the industry, as cost-effectively as possible. One of the uses of underground mine service water which is taking on increasing importance is hydro-power, where the potential energy manifested as hydrostatic pressure in deep mines is used for powering stoping equipment directly. Thirdly, to minimize environmental pollution by both minimizing the discharge of poor quality effluents to the water environment and ensuring compliance with environmental requirements, again as cost-effectively as possible.

In order to address the objectives as set out above the Research Organization of the Chamber of Mines (COMRO) has embarked on a programme aimed at developing technology and management strategies for improving the quality of mine water. A four-pronged approach is being followed. Firstly, minimizing water quality deterioration during use within mines; secondly, evaluating and developing suitable water treatment process technologies and related cost data; thirdly, developing water treatment system selection procedures, and fourthly, developing a mine water circuit water quality simulator to aid in improving water quality management. The research and development programme concentrates on mine service water quality improvement since this water offers the greatest potential of all water streams within the mining context for economical re-use and limiting environmental pollution.

This paper reviews the current status of underground mine service water quality, discusses the practical problems associated with poor quality water, defines water quality criteria for specific mine water uses and details COMRO's programme for the development of treatment technologies and management strategies for the improvement of service water quality.

Underground Mine Service Water Quality

A survey of the quality of mine service waters in use in the various gold mining regions of South Africa was undertaken during 1983. The average water quality for each region, as well as its variability (indicated by the standard deviation of the average), is listed in **Table 3.** It must be emphasized that individual mines, as well as individual water circuits within one mine, may have significantly better quality (or poorer quality) than indicated by the average given in **Table 3.**

When comparing the quality of mine service waters with the quality of Rand Water Board water, it is clear that the service waters are much more saline than Board water. For example, the average TDS values for the Far West Rand region (1 355 mg/ℓ) and Orange Free State region (4 036 mg/ℓ) are about 4 and 12 times more

Table 3 *UNDERGROUND MINE SERVICE WATER QUALITY FOR VARIOUS SA GOLD MINE REGIONS*

Region	TDS	Ca	Mg	Na	Cl	SO_4	HCO_3	$CaSO_4$ C.F.
Orange Free State	4036 (±1867)	377 (±287)	39 (±26)	971 (±389)	1467 (±650)	890 (±672)	50 (±29)	5,65 (±5,71)
Klerksdorp	2310 (±1050)	273 (±139)	63 (±37)	386 (±235)	433 (±363)	1044 (±572)	58 (±53)	3,24 (±2,02)
Far West Rand	1355 (±473)	204 (±83)	51 (±16)	178 (±67)	187 (±82)	627 (±289)	118 (±104)	4,10 (±2,38)
West Rand	2152 (±688)	403 (±205)	50 (±48)	169 (±70)	54 (±25)	1242 (±646)	46 (±32)	1,91 (±0,97)
Central Rand	1812 (±175)	485 (±48)	— —	56 (±4)	25 (—)	1238 (±124)	10 (—)	1,25 (±0,13)
East Rand	2162 (±283)	357 (±219)	— —	332 (±177)	298 (±421)	1048 (—)	125 (±100)	2,40 (±1,60)
Evander	2482 (±684)	155 (±92)	— —	726 (±121)	850 (±14)	675 (±516)	77 (±30)	7,29 (±6,21)
Rand Water Board	350	41	10	—	34	135	43	8,33

All determined as mg/ℓ, except $CaSO_4$ C.F. (concentration factor) which has no units. Average values are listed with their standard deviation given in brackets.

saline than Rand Water Board water (350 mg/ℓ), respectively.

The water quality characteristics of the various regions can be broadly classified as follows (from the lowest average TDS to highest TDS). Far West Rand waters (1 355 mg/ℓ) — low NaCℓ content, medium sulphate and hardness content; Central Rand (1 812 mg/ℓ) — very low NaCℓ content, very high sulphate and hardness content; West Rand (2 152 mg/ℓ) — medium NaCℓ content and very high sulphate and hardness content; East Rand (2 162 mg/ℓ) — medium NaCℓ content and very high sulphate and hardness content; Klerksdorp (2 310 mg/ℓ) — medium NaCℓ, very high sulphate and high calcium content; Evander (2 482 mg/ℓ) — high NaCℓ content, medium sulphate and low hardness content; Orange Free State (4 036 mg/ℓ) — very high NaCℓ content, high sulphate and medium hardness content.

Service waters are much more saline than Board water

It is of crucial importance to water quality management to establish which processes and factors have a significant impact on water quality and how, if at all, these can be controlled to minimize water quality deterioration. There are probably many environmental and process parameters which have an impact on mine service water quality. From **Table 3** it is clear that the geographic region within which a mine is located has a significant bearing on its water quality. The reasons for this have not been identified in any depth but are probably related to reef type being mined, the geological formations within the immediate vicinity of the reef being mined, the quality of ground water within the area being mined, as well as the duration and extent of the mining operation.

The geographic region within which a mine is situated has a significant bearing on its water quality

Studies by COMRO have identified four major sources of contamination of mine service water.

(a) Salts from fissure water, explosives and those leached from broken rock.

(b) Sulphuric acid leached into the mine service water as a result of the oxidation of the pyritic minerals.

(c) Lime which is used to neutralize acidic mine water and which often leads to calcium sulphate scaling.

(d) Suspended solids from rock drilling and blasting operations.

Contaminated mine water can give rise to a number of practical problems which are dealt with in detail in the next section.

Water Quality Problems

The major water quality problems experienced with mine service waters are corrosion, scale formation, erosion and biological fouling. Other water quality problems or potential problems which have not yet manifested themselves include microbiological contamination, toxic chemicals and radio-active contamination.

Corrosion

The problems arising from corrosion of mine service water pipework fall into three categories. Firstly, formation of corrosion products which can increase friction losses in pipework due to an increase in the roughness of the pipe inner surface as well as the resultant narrowing of the pipe. Secondly, corrosion products can contribute to the suspended solids load on the system and cause erosion problems as well as blockages of screens protecting individual pieces of equipment. Thirdly, uniform thinning or localized penetration caused by pitting or crevice corrosion can lead to pipe and fitting failure.

Mine service waters are known to be corrosive, with relatively frequent pipework replacement being necessary. No accurate figures exist for pipe life and associated costs. Estimates of pipe life range from 5-10 years for mine service water piping and 10-20 years for chilled water piping (Marsden D, personal communication, 1987). Compared to the normal life expectancy of pipelines carrying Rand Water Board water, such as 30 to 50 years, mine service waters can be considered highly corrosive.

Corrosion is a complex process and may be a function of many water quality parameters, for example dissolved oxygen content and pH, as well as the concentration of the sulphate and chloride ions, the total dissolved solids content and the degree of biological activity. Generally corrosion is controlled by pH adjustment, limiting the TDS and sulphate and chloride content, and limiting growth of bacteria which enhance corrosion. An alternative approach is to line pipes, for example with concrete or other inert materials, or to use corrosion resistant steels or non-metallic pipework.

Scale formation

Scaling in mine service water pipes and equipment is primarily due to calcium sulphate crystallization from waters supersaturated with this salt. **Table 3** lists concentration factors for calcium sulphate and indicates that waters in the Central, West and East Rand are particularly sensitive to this problem. Scale formation results in pipe narrowing which increases friction losses and ultimately reduced flow rates. Scale formation can also enhance localized corrosion. In order to prevent calcium sulphate from precipitating, the concentration of calcium and sulphate ions must be controlled such that the mine water is at all times undersaturated (or just saturated) with respect to calcium sulphate. Appropriate calcium sulphate saturation levels can be achieved by diluting the service water with make-up water with a low calcium sulphate content, replacing lime ($Ca(OH)_2$) with soda ash (Na_2CO_3) or bicarbonate of soda ($NaHCO_3$) in the neutralization stage, removal of calcium ions (e.g. by lime soda softening or ion exchange) or by desalination.

Scaling in mine service water pipes and equipment is mainly due to calcium sulphate crystallization from waters supersaturated with this salt

Calcium carbonate is another salt which has been found in mine service water scales. For waters with low concentrations of carbonate ions (commonly measured as alkalinity) and low pH-values (<8,00), this is normally not a problem. However, when soda ash (Na_2CO_3) or bicarbonate of soda ($NaHCO_3$) are used for neutralization or pH control, or when lime is added to excessively high pH values, a potential for calcium carbonate precipitation may be created. In order to prevent calcium carbonate from precipitating the concentrations of the calcium and carbonate ions must be controlled such that the mine water is at all times undersaturated (or just saturated) with respect to calcium carbonate. This condition is defined by the Langelier Saturation Index with values of zero to slightly negative (0 to –0,5). Appropriate calcium carbonate saturation levels can be achieved by limiting the addition of the neutralizing chemical such that the alkalinity and pH of the neutralized water are within the desired Langelier Saturation Index range. This normally corresponds to a pH in the range of 7 to 8.

Erosion

Spent mine service water draining from stoping areas often contains high suspended solids concentrations. Before this water can be pumped to surface, the solids are removed in underground settlers. If this water is to be re-used as mine service water, careful consideration needs to be given to its solids content, since erosion of pipework, pumps, valves and other close tolerance equipment may take place. Solids can be removed from water by a number of unit processes, for example flocculation followed by settling and/or filtration.

Biological fouling

Bacteria, slimes and fungi may result in the biological fouling of mine service water reticulation pipework and equipment. The major problem associated with biological fouling is the growth of sulphate-reducing bacteria which can enhance corrosion, particularly of chromium steels where they can cause pitting corrosion. Biological fouling can be controlled by disinfection using chlorine, chlorine dioxide and slug dosing with other biocides.

Health related contaminants

Microbiological, toxicological and radio-active contamination of mine service waters need to be monitored to ensure health and safety standards.

Capital cost penalties associated with poor quality mine service water were estimated to be in the region of R61 million for 1987

No accurate assessment of the costs associated with poor quality mine service water used in the RSA gold mining industry exists. Burton (personal communication, 1987) made an order of magnitude estimate of the cost penalties associated with poor water quality on mine cooling systems, such as capital cost (e.g. coils, pumps, pipes, evaporator and condenser tube replacement) to be R61 million (1987), and running cost (additional electrical power) to be R11 million per annum. White (personal communication, 1987) estimated the cost associated with mine service water pipework replacement as a result of corrosion for the whole gold mining industry to be between R100 — R250 million per annum (1987).

In order to overcome the practical problems associated with corrosion, scale formation, erosion, biological fouling and health related contaminants, mine water needs to be treated to remove or suitably reduce those contaminants which give rise to these problems.

Quality Criteria For Specific Mine Water Uses

The quality to which a water needs to be treated depends on the use to which it is being put. **Table 3** gives underground mine service water qualities currently in use within the gold mining industry. As indicated, many problems are being experienced already with waters currently in use and hence better water treatment is indicated. Furthermore, increased cost of Board water and limited availability, as well as stricter water quality requirements, for example for hydro-power applications, and spent mine service water discharge to the water environment, serve to enhance the industry's efforts to re-use spent mine service water wherever economically feasible.

The water treatment needed is dictated by the specific application for which the water is used

Quality criteria for different uses of mine water differ significantly and consequently, so does the type and degree of water treatment (see **Figure 1**). Examples of water quality criteria for three types of water applications, such as hydro-power, discharge of spent mine service water to the environment and potable water are detailed below.

Hydro-power

The Research Organization has pioneered the development of a system for providing mechanical and cooling power in deep gold mines, referred to as hydro-power. The system uses the potential energy manifested as hydrostatic pressure in deep mines for powering stoping equipment directly. The system has been proved to be an economic and mineworthy method of distributing power in the mines because of the following.

(a) Only a single energy distribution network is required to provide both hydraulic and cooling power to the mining areas.

(b) The water required for cooling and dust suppression purposes can be used to drive water-powered hydraulic machinery, and therefore the need for complex electro-hydraulic pumps is eliminated.

(c) High pressure water will be the major form of underground powering, therefore eliminating the reliance on compressed air in mines and reducing the need for electrically powered equipment.

An important consideration in the application of hydro-power is the water quality required for these systems.

The problem of maintaining the performance and life of equipment and components is currently being approached in two ways by COMRO. The first approach is to develop systems and processes to improve the quality of mine service water and the second is to develop new corrosion and wear resistant materials. In order to combine these approaches for the design of cost-effective systems, water quality requirements have to be specified for the various materials being considered. Since the improvement in both water quality and materials have significant cost implications, optimum water qualities for specific materials need to be identified. **Table 4** lists the provisional guideline values recommended for hydro-power water quality for carbon, chromium and galvanized steels.

COMRO intends solving the problem of maintaining equipment by a two-pronged approach

Table 4 *PROVISIONAL HYDRO-POWER WATER QUALITY GUIDELINES FOR CARBON, CHROMIUM AND GALVANIZED STEELS*

PARAMETER	GUIDELINE
pH — carbon steels	6 – 8,5
chromium steels	6 – 8,5
galvanized steels	7 – 8,5
Langelier Saturation Index	– 0,5 to 0,0 at 35°C
Product of calcium and sulphate ion concentrations	Not to exceed apparent calcium sulphate solubility product at 0°C for particular water composition
Particle size distribution	To ISO 4406 class 19/15 or lower
Turbidity	3 NTU (max)
Standard Plate Count	< 100 bacterial colonies per millilitre
Total dissolved solids (TDS)	
— carbon steels	1 500 mg/ℓ (max).
— chromium steels	limited by $C\ell^-$ specification
— galvanized steels	limited by $C\ell^-$ specification
Chloride	
— carbon steels	Limited by TDS
— chromium steels	250 mg/ℓ (max*)
— galvanized steels	< 3 000 mg/ℓ

* Not to exceed the critical chloride concentration of the water of interest; should be taken as 250 mg/ℓ if not known.

There is still uncertainty about some of the water quality guideline values recommended and this has necessitated a cautious and conservative approach. Research is under way to address the areas of uncertainty in order to refine the relevant guideline values and rationalize materials selection criteria with water quality specifications. These guidelines will be updated from time to time as more information becomes available from research studies and field experiences appropriate to hydro-power systems.

Discharge of spent mine service water to the water environment

With every cycle of use, mine service water can pick up significant quantities of salt. For example Juby (personal communication, 1987) reports between 25 and 72g salt per ton of rock blasted, which is equivalent to 150 and 450 mg/ℓ salt respectively in the drain water leaving the stopes of a West Rand gold mine. Therefore, in order to maintain a service water quality at some fixed upper TDS limit, it will be necessary to purge a proportion of the spent service water. Where it is not possible to use or contain this water within the boundaries of the mine it has to be discharged to the water environment. Such discharged waters are subject to the effluent quality requirements laid down by the Department of Water Affairs (see **Table 5**). Compliance with the limitation for conductivity (an indirect measure of TDS) is usually not possible and special permits need to be obtained to allow these high TDS waters to be discharged. Since the gold mining industry has been identified as a major contributor to the salt load to the Vaal River system[1], which is already severely contaminated by salts, a future tightening of the limits of allowable salt discharge can be expected. In addition to the salt problem, other pollutants which may be present in mine water discharge such as heavy metals, cyanide (particularly in mines using backfill systems) and radio-active contaminants, may also require attention in future.

Table 5 *GENERAL STANDARDS FOR WASTE WATERS AND EFFLUENTS*[3]

Determinants	Maximum concentration in milligrams per litre
Residual chlorine (as Cℓ)	0,1
Free and saline ammonia (as N)	10,0
Arsenic (as As)	0,5
Boron (as B)	1,0
Total chromium (as Cr)	0,5
Copper (as Cu)	1,0
Phenolic compounds (as phenol)	0,1
Lead (as Pb)	0,1
Manganese (as Mn)	0,4
Cyanides (as Cn)	0,5
Sulphides (as S)	1,0
Fluoride (as F)	1,0
Zinc (as Zn)	5,0
Cadmium (as Cd)	0,05
Mercury (as Hg)	0,02
Selenium (as Se)	0,05
Suspended Solids	25,0
pH	5,5 – 9,5
Conductivity (mS/m)	increase < 75* (Absolute max. 250)
Sodium (mg/ℓ as Na)	increase < 90*

* Percentage increase in parameter in water, effluent or wastewater above intake water.

Potable water from mine service water

Of all the Board water used in the gold mining industry, use for domestic purposes is by far the highest application (49 per cent). Reclamation of potable water from spent mine service water could therefore be an attractive option if the reclamation economics are favourable relative to Board water cost and availablity. An alternative

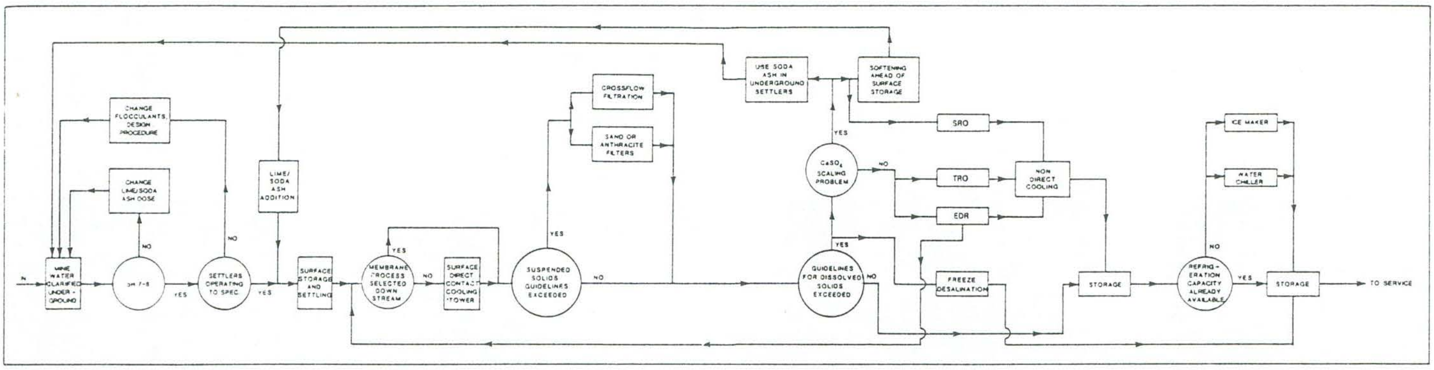


Figure 1. Water treatment system selection procedure.

source of raw water for reclamation could be domestic effluents. The technology for sewage effluent reclamation is well developed and has been in full scale use in Windhoek, SWA since the late sixties[4] and on some gold mines since the eighties, for example at Kloof gold mine. The water quality specified for potable purposes by the SABS is given in **Table 6**.

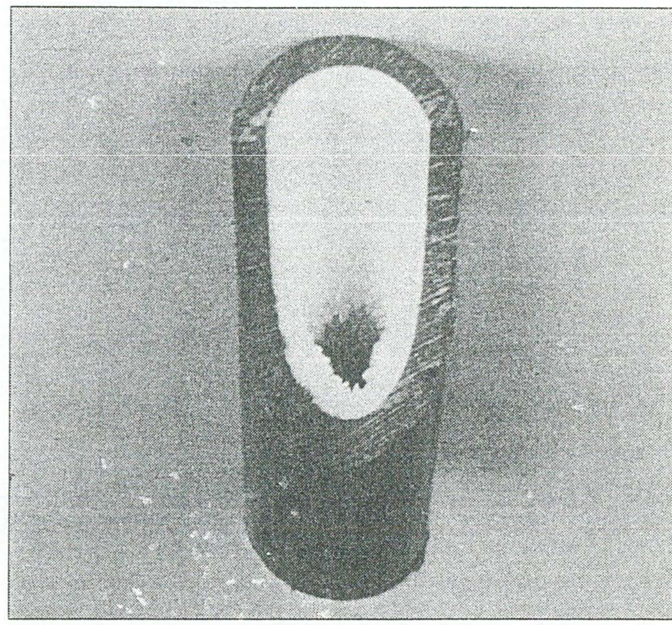
Water Quality Research Programme of COMRO

The tasks comprising the research programme of the Water Division of COMRO are listed in **Table 7**. Progress to date and future directions are briefly outlined below.

Minimizing mine water quality deterioration

The deterioration of mine water quality can be reduced by controlling contamination, the major source of which is sulphuric acid from the oxidation of pyrite. The rate of chemical oxidation of pyrites can be increased by up to 20 times in the presence of bacteria. The feasibility of adding low concentrations of bacteriocides in the form of surfactants such as sodium lauryl sulphate to mine water to inhibit the growth of autotrophic bacteria was demonstrated in laboratory and isolated stope tests. Trials were then conducted on a small shaft system to evaluate the potential for applying bacterial inhibition on a minewide basis. However, the results were not conclusive and further work is continuing.

The mechanism involved in the oxidation of pyrite under gold mining conditions is currently being researched to provide information for the development of a pyrite leaching model. This model will be used to evaluate leaching control measures and their cost-effectiveness for controlling mine service water quality deterioration.



Example of severe calcium sulphate scale formation in a pipe.

Water treatment processes

Conventional water treatment processes have potential for upgrading the quality of mine service waters, but their suitability for mining applications needs to be evaluated and, where necessary, refinements or further process developments need to be made. COMRO is therefore investigating a range of water treatment processes, with the ultimate objective of generating a technology base for the selection and costing of suitable water treatment systems.

Neutralization

Acid mine waters formed by the leaching of pyrite rock are commonly neutralized underground using lime prior to pumping to surface, to protect pumps and pipes against corrosion. One of the major disadvantages of using lime is the danger of supersaturating mine water with calcium sulphate. This can result in scale formation

Table 6 *SOUTH AFRICAN STANDARD SPECIFICATION FOR WATER FOR DOMESTIC SUPPLIES*[5]

Determinants	Recommended limit	Maximum allowable limit
pH	6,0 – 9,0	5,5 – 9,5
Conductivity (mS/m)	70	300
MACRO DETERMINANTS (mg/ℓ)		
Total hardness (as $CaCO_3$)	20 min.	Not specified
	300 max.	650
Magnesium (as Mg)	70 max.	100
Sodium (as Na)	100 max.	400
Chloride (as Cℓ)	250 max.	600
Sulphate (as SO_4)	200 max.	600
Nitrate + nitrite (as N)	6 max.	10*
Fluoride (as F)	1 max.	1,5
Zinc (as Zn)	1 max.	5,0
MICRO-DETERMINANTS (μg/ℓ)		
Arsenic (as As)	100	300
Cadmium (as Cd)	10	20
Copper (as Cu)	500	1 000
Cyanide (as Cn)	200	300
Iron (as Fe)	100	1 000
Lead (as Pb)	50	100
Manganese (as Mn)	50	1 000
Mercury (as Hg)	5	10
Phenolic compounds (as phenol)	5	10
Selenium (as Se)	20	50
BACTERIOLOGICAL LIMITS		
Total coliform bacterial count per 100 mℓ	Nil**	5
Faecal coliform bacterial count per 100 mℓ	Nil	Nil
Standard plate count per millilitre	100	Not specified

* If nitrate plus nitrite (expressed as N) is present in concentrations in excess of 10 mg/ℓ, the water may be unsuitable for use by infants under 1 year of age and an alternative source of supply must be found for such use.

** If any coliform bacteria are found in a sample, take a second sample immediately after the tests on the first sample have been completed: this shall be free from coliform bacteria; and not more than 5% of the total number of water samples (from any one reticulation system) tested per year may contain coliform bacteria.

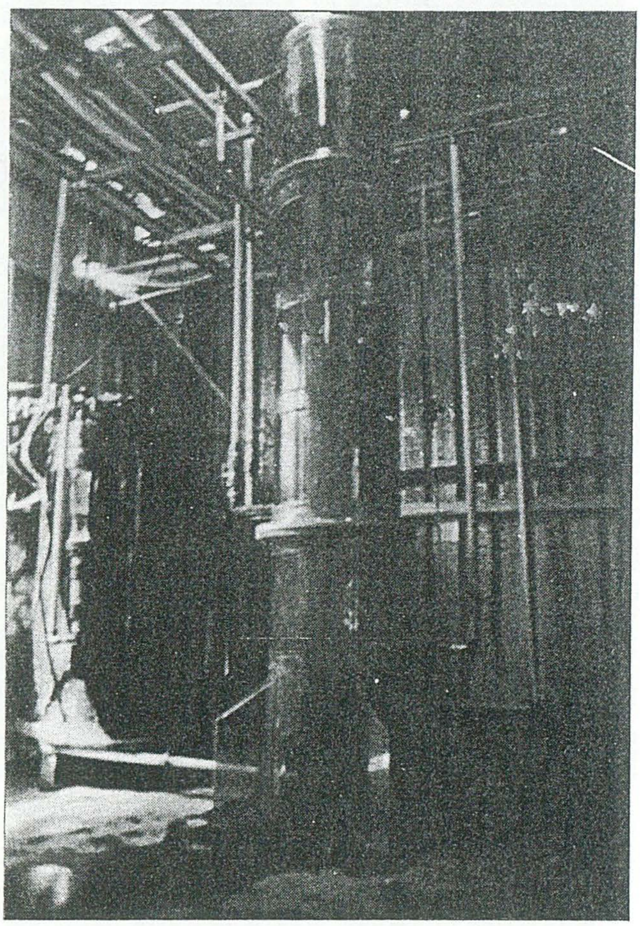
in service water reticulation pipework and pumps, heat exchangers and other equipment, as well as irreversible fouling of membranes in desalination processes such as electrodialysis reversal (EDR) and tubular reverse osmosis (TRO). The technical and economic advantages of using alternative neutralization agents such as soda ash (Na_2CO_3) and bicarbonate of soda ($NaHCO_3$) are therefore being investigated.

Suspended solids removal

A variety of processes exist for the removal of suspended solids, for example: water clarification (such as standard sedimentation processes and conical lamella settling); filtration (such as direct upflow sand filtration, pressure sand filtration and pressure dual media filtration) and dissolved air flotation. Two novel processes have been selected for evaluation by COMRO and these are the floating media separation process and the crossflow microfiltration process.

(a) Floating media separation

A pilot plant unit (0,5 ℓ/s) was evaluated at COMRO's water treatment test site at the ERPM gold mine. The unit has a novel coagulation and settling chamber design which results in the formation of large heavy flocs. This design allows much smaller settler units to be used than are required in conventional settling. The floating media filters the clarified water from the settler section of the unit to produce a low turbidity water conforming to suspended solids requirements for hydro-power. The unit's virtual insensitivity to the level of suspended solids in its feed water makes it well suited for treating underground settled waters which can have a highly variable suspended solids content.



The floating media separator pilot plant. The plant comprises a settling tank and filter in one.

(b) Crossflow microfiltration

Crossflow microfiltration was developed and refined in South Africa for the cost-effective removal of suspended solids from waste waters. Laboratory tests have demonstrated that the process performs well under highly variable suspended solids loads and produces a product water which consistently meets suspended solids concentration limits and particle size distribution requirements set for hydro-power. Evaluation of a pilot plant (0,1 ℓ/s) has commenced at COMRO's Water Treatment Test Site at the ERPM gold mine.

Table 7 ***RESEARCH PROGRAMME OF THE WATER DIVISION OF COMRO***

Task Titles
• Review current practices for the underground neutralization of spent mine water and test alternative neutralizing chemicals.
• Investigate the technical and economic feasibility of floating media separation and crossflow microfiltration for the treatment of mine waters on pilot plants.
• Design and test a 0,6 ℓ/s seeded reverse osmosis pilot plant for treating scaling mine service water.
• Investigate the use of softening and desalination as a means of treating scaling mine service water.
• Investigate the technical and economic feasibility of the biological sulphate removal process for the treatment of mine service water.
• Determine the pyrite leaching mechanism and methods for its control.
• Develop a mine water simulator and a water data base.
• Develop water treatment process selection guidelines for hydro-powered mines.

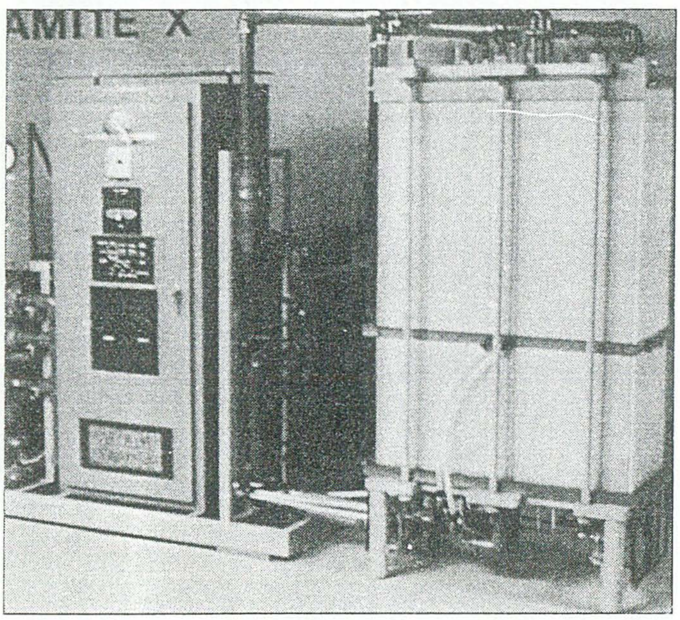
Desalination

Desalination processes which have been evaluated by COMRO include electrodialysis reversal (EDR), tubular reverse osmosis (TRO), seeded reverse osmosis (SRO) and freeze desalination (FD) (see **Table 8).**

Conventional EDR and TRO, with the necessary pretreatment and process control, have been found to be suitable for desalinating brackish mine waters with a low calcium sulphate content. Seeded reverse osmosis and freeze desalination are still under development but have been found to be potentially capable of treating any mine service water, particularly calcium sulphate scaling waters.

(a) Electrodialysis Reversal Process (EDR)

A 1,6 ℓ/s pilot plant was evaluated using a brackish mine service water with a low calcium sulphate content and gave excellent product water recoveries of up to 84 per cent and an average salt rejection of 80 per cent. Pretreatment of the feed water to the EDR plant was necessary for the removal of suspended solids and dissolved iron.



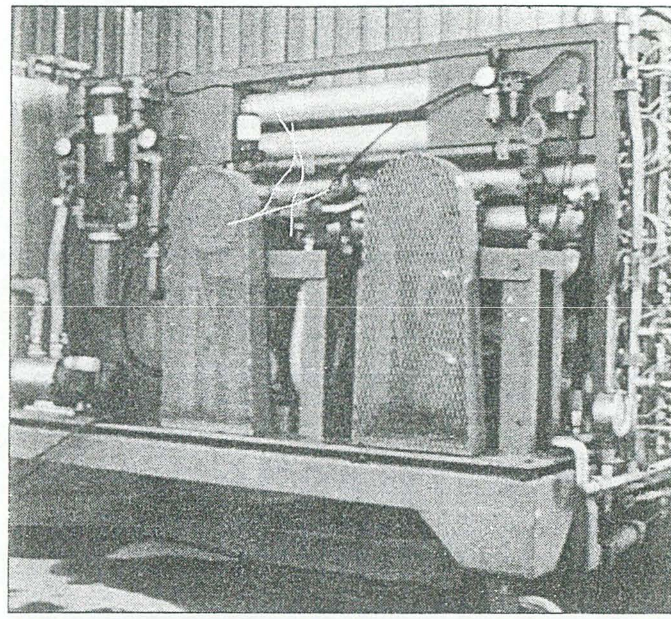
Electrodialysis reversal pilot plant.

(b) Tubular Reverse Osmosis (TRO)

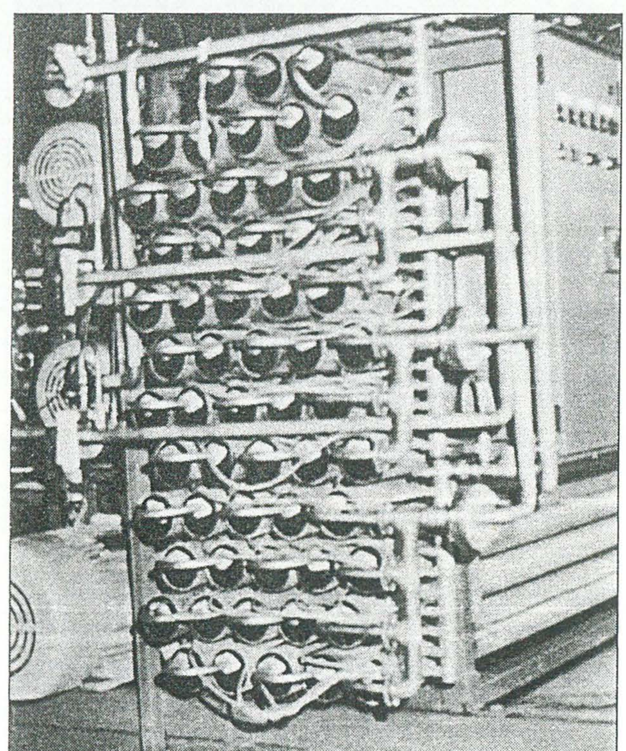
A 0,4 ℓ/s pilot plant was evaluated on the same brackish mine service water as the EDR process, and also gave good product water recoveries of up to 80 per cent and an average salt rejection of 80 per cent. Pretreatment to remove the bulk of the suspended solids and dissolved iron, as well as pH and temperature control was necessary to protect the cellulose acetate membranes used in the TRO membrane modules.

(c) Seeded Reverse Osmosis (SRO)

SRO is a novel process specifically developed for desalinating scaling waters. The process overcomes the problem of scale formation experienced with conventional membrane processes by allowing precipitation of potentially scaling salts on a seed slurry recirculated within the tubular reverse osmosis membrane modules. The process was proved to be technically feasible on a small scale (0,05 ℓ/s) pilot plant. Larger scale tests were carried out on 0,6 ℓ/s pilot plants which produced good desalination results but mechanical problems were experienced. A new pilot plant is currently being designed.



Tubular reverse osmosis pilot plant.



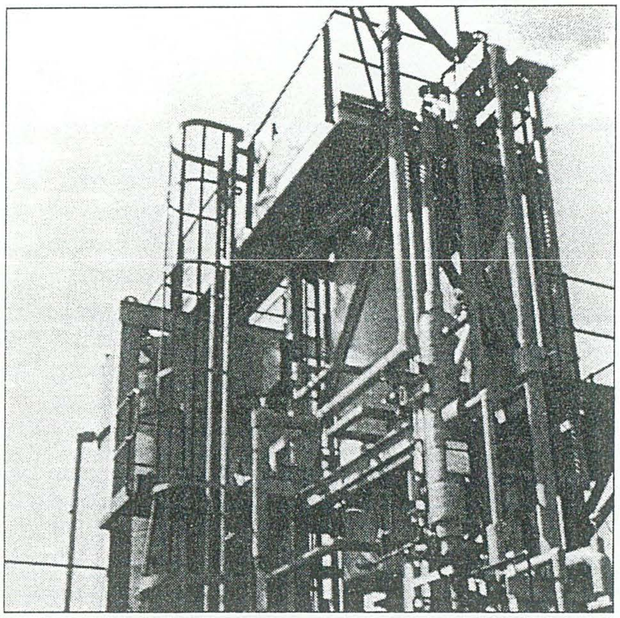
Seeded reverse osmosis pilot plant.

Table 8 *DESALINATION PROCESSES BEING EXAMINED BY COMRO*

Process	Application	Process requirements	R & D Status
EDR	Suitable for desalinating mine waters with a high sodium chloride content and low calcium sulphate content.	Pretreatment of feed water to remove • dissolved iron and manganese • suspended solids	Evaluation of 1,6 ℓ/s pilot plant completed. EDR capable of giving: • product water recoveries of up to 84%, and • average salt rejection of 80%.
TRO	As above	Pretreatment of feed water to: • remove dissolved iron and bulk of suspended solids • conrol pH levels, and • cool hot service water to prolong membrane life	Evaluation of 0,4 ℓ/s pilot plant completed. TRO capable of giving: • product water recoveries of up to 80% • average salt rejection of 80%.
SRO	Suitable for desalinating any mine service water, particularly scaling waters as potentially scaling salts are precipitated on a seed slurry recirculated within the tubular reverse osmosis membrane modules.	Pretreatment of feed water to: • remove dissolved iron and bulk of suspended solids • control pH level, and • cool hot service water to prolong membrane life	Evaluation of small scale (0,05 ℓ/s) pilot plant complete. Larger scale 0,6 ℓ/s pilot plant currently being designed.
FD	Suitable for desalinating any mine water, and combines desalination with the production of ice for cooling purposes.	Pretreatment of feed to remove bulk of suspended solids.	Evaluation of 0,1 kg/s pilot plant in progress.

(d) Freeze Desalination (FD)

FD combines two requirements set by deep gold mining in South Africa: it desalinates mine waters as well as producing ice for cooling purposes. A tubular indirect process producing 0,1 kg ice per second is currently being evaluated by COMRO. Tests so far have demonstrated that ice with a low salinity can be produced.



Freeze desalination pilot plant.

Improving water management practices

A user-friendly interactive computer program has been developed for predicting the quality of water in mine water circuits. The program will be used as a research tool, but can also be used by environmental engineers in the design of new mine water circuits, and the development of operational strategies for existing circuits.

Using the program, a mine water circuit is represented as a network of unit processes including:

- stope water quality deterioration from pyrite leaching;
- neutralization of acidic mine water: the effect of adding lime, soda ash and bicarbonate of soda is simulated;
- desalination: water recoveries and salt rejections are simulated for processes such as electrodialysis reversal, tubular reverse osmosis, seeded reverse osmosis and freeze desalination;
- mixing of waters of different qualities; and
- water storage in dams or ponds.

An example of a typical mine water circuit is shown in **Figure 2.**

The output from the program comprises concentration-time profiles at any point within the water circuit and for any specific time interval, for the following water quality parameters: total dissolved solids, alkalinity, calcium and sulphate concentrations and pH values.

Establishing water treatment requirements and costs

The type and degree of water treatment required on a mine are dictated by the specific application for which the water is to be used. Achieving the specified quality may require a series of water treatment processes, including neutralization, suspended solids removal (settling and filtration), softening, desalination and disinfection. To assist mines in the selection of the most cost-effective water treatment system, a water treatment process selection procedure has been developed and is currently being further refined. This procedure will in the future be transformed into a computer based expert system.

Water quality requirements for different applications in the gold mining industry are being investigated. So far provisional guidelines have been set for water quality suitable for hydro-power (see **Table 4**). Research is in progress to upgrade these guidelines to water quality specifications.

Using the water treatment process and systems knowledge outlined in this section, COMRO has provided information on the process engineering aspects of water treatment to mining groups. Furthermore, in order to give the mining industry a more realistic insight into the technological and cost implications of water treatment, particularly for hydro-power, a detailed engineering design and costing of a full water treatment facility is currently being undertaken.

A user-friendly computer program has been developed for predicting the quality of water in mine water circuits

Conclusion

Water quality is a matter of increasing importance to the gold mining industry because of rapidly increasing Board water costs, increasing scarcity of high quality fresh

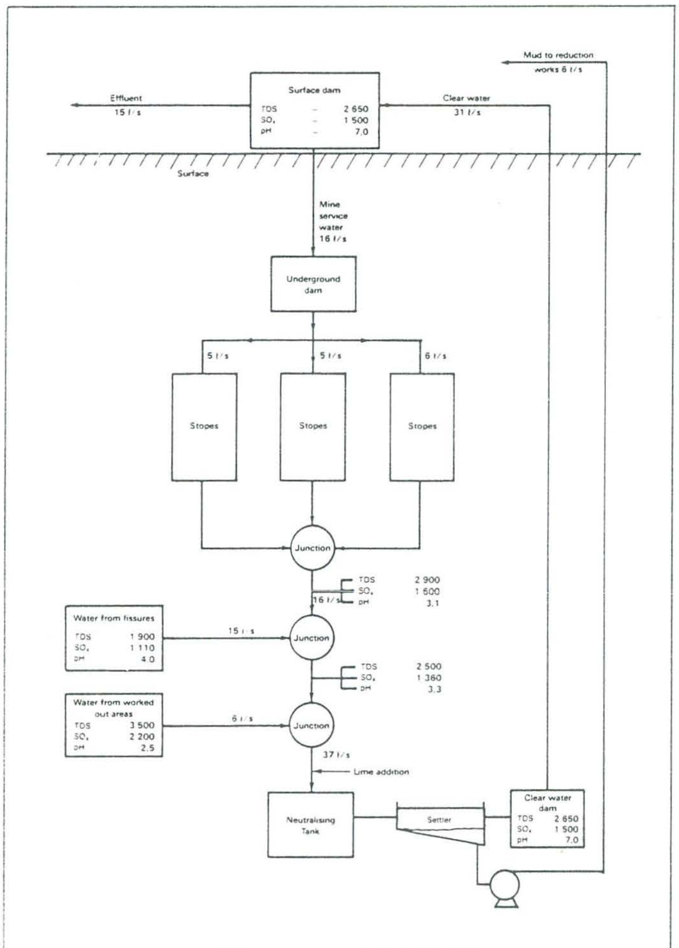


Figure 2. Schematic of typical mine water circuit demonstrating contamination. The water quality simulation computer program can be used to build up a mine water circuit comprising unit processes.

water, higher water quality requirements for new mine powering techniques such as hydro-power, and increased pressure to reduce environmental pollution associated with the discharge of mine waste waters to the water environment. COMRO is addressing the problem of water quality improvement by developing a water treatment technology and associated cost base, as well as developing procedures for optimizing mine water quality management.

Acknowledgement

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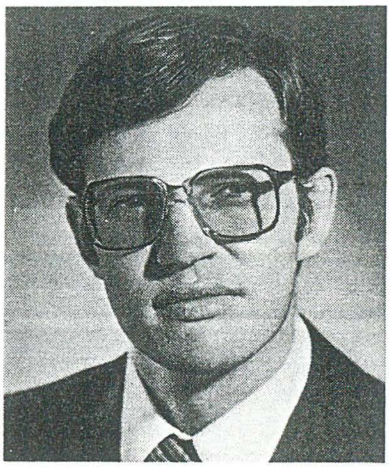

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