

**A Manual on Mine Water
Treatment and Management
Practices in South Africa**

**APPENDIX
Volume 4
Overseas Study Tour Report**

W Pulles • D Howie • D Otto • J Easton

Report to the Water Research Commission
by the
Chamber of Mines of SA

WRC Report No 527/4/96



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APPENDIX TO WRC REPORT TT 80/96 :
A MANUAL ON MINE WATER TREATMENT AND
MANAGEMENT PRACTICES IN
SOUTH AFRICA

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APPENDIX

Volume 4

Overseas Study Tour Report

ISBN 1 86845 261 1
ISBN Set No 1 86845 263 8

WRC Report No 527/4/96

CONTENTS

Page

AUSTRALIA

COLLINSVILLE COAL COMPANY (PTY) LIMITED	1
1. Introduction	1
2. Legal and regulatory framework	1
2.1 Dilution strategies and monitoring	2
2.2 Environmental management overview strategy and plan of operations	2
2.3 Financial securities	3
2.4 New and decommissioned operations	3
3. Collinsville water management strategy	4
3.1 Disposal of rejects	4
3.2 Rehabilitation of discard dumps	4
3.3 Final voids	5
3.4 Pollution control dam	5
3.5 Evaporation facilities	5
3.6 Lime dosing plant	5
3.7 Korable dam	6
4. General impressions	6
RAVENSWOOD GOLD MINE	8
1. Introduction	8
2. Legal and regulatory framework	8
3. Water management strategy	10
3.1 Pits and underground mines	10
3.2 Tailings dams	10
3.3 Process plant	11
4. Research	11
4.1 Tailings dams	11
4.2 Waste rock dump rehabilitation	11
4.3 Heap leach dump	12
4.4 AMIRA acid mine drainage prediction	12
5. Overview of water resources and related issues in the upper Burdekin region	12
6. General impressions	13
MT LEYSHON GOLD MINES LIMITED	14
1. Introduction	14
2. Water management	14
2.1 Water balance	14
2.2 Run-off control	14
2.3 Acid mine drainage control on waste dumps	14
2.4 Lime dosing plants	15

	Page
2.5 Monitoring systems	15
2.6 Water supply	15
2.7 Environmental performance criteria	16
2.8 Groundwater systems	16
HUNTER VALLEY COAL MINE	17
1. Introduction	17
2. Legal & regulatory framework	17
3. Water management strategy	18
4. Water balances	18
5. Environmental management practices	19
5.1 Discharge licenses	19
5.2 Control of water on the mine	19
5.3 Rehabilitation practices	20
6. General observations	20
ENVIRONMENTAL PROTECTION AUTHORITY - NEWCASTLE	21
BHP RESEARCH LABORATORIES - NEWCASTLE	23
AUSTRALIAN NUCLEAR SCIENCE & TECHNOLOGY ORGANISATION	25

UNITED STATES OF AMERICA

KNIGHT PIESOLD & CO. - DENVER, COLORADO	26
1. Introduction	26
2. Passive treatment systems	26
3. Tailings dams	27
4. Site visit to EPA - Burleigh tunnel	28
SLEEPER GOLD MINE	30
1. Introduction	30
2. Regulatory framework	30
2.1 Federal regulations	30
2.2 State regulations & compliance monitoring	31
2.3 Mining law revisions	32
2.4 Financial bonds and mine closure	32
3. Groundwater and mine dewatering	32
4. Waste disposal	33
5. Tailings disposal	33
6. Wetlands	34
7. General impressions	34

Page

NEWMONT GOLD QUARRY MINE	36
1. Introduction	36
2. Mine dewatering	36
3. Arsenic removal plant	37
4. Surface hydrology	38
5. Regulatory requirements	39
6. Overall impressions	40
GENESIS GOLD MINE	41
GOLDSTRIKE MINE	42
1. Introduction	42
2. Mine dewatering	42
3. Arsenic removal treatment plant	43
4. Discharge of water	43
TENNESSEE VALLEY AUTHORITY (TVA)	44
1. Discussions	44
2. Site visits to TVA wetlands	46
2.1 Dead lady lake wetland (DLL)	46
2.2 Wetland on impoundment 3 of the Fabios mine	47
2.3 Hard Rock mine wetlands (HR000)	47
2.4 Wetland on impoundment 2 of the Fabios mine	48
2.5 Wetland on impoundment 1 of the Fabios mine	49
2.6 General observations	50
US BUREAU OF MINES (USBM) IN PITTSBURGH	51
1. Introduction	51
2. Nature of water research undertaken by the USBM	51
3. Discussions with Mr DM Hyman	52
4. Discussions with Dr RLP Kleinmann	52
5. Discussions with Ms A Cooper	53
6. Discussions with Mr JW Hawkins	53
7. Discussions with Mr RW Hammack	55
8. Discussions with Dr HN Edenborn	55
9. Discussions with Mr GR Watzlaf	56
10. Discussions with Mr CC Hustwit	57
11. Recent USBM's work reported at the April 1994 Pittsburgh Conference	58
12. Site visits to USBM wetlands	59
12.1 The Filson wetland system	59
12.2 The Howe Bridge passive treatment system	60
12.3 The REM passive treatment system	60
12.4 The Morrison passive treatment system	60

CANADA

MINISTRY OF ENVIRONMENT & ENERGY	61
1. Introduction	61
2. Regulation for effluent monitoring and effluent limits (metal mining sector)	62
3. Effluent treatment systems within the metal mining sector	64
4. Start up and closure of mines	65
FALCONBRIDGE MINES	67
1. Introduction	67
2. CO ₂ dosing plant	67
3. Lime dosing plant	67
4. Tailings disposal	68
5. Monitoring systems	68
6. General impressions	68
LAURENTIAN UNIVERSITY	70
INCO PLANTS	71
1. Introduction	71
2. Water treatment plant	71
3. Tailings dams	72
PAMOUR - ROYAL OAK MINES	73
DOME MINE	74
1. Introduction	74
2. Effluent treatment plant	74
3. Tailings disposal	75
WASTEWATER TECHNOLOGY CENTRE - TORONTO	76
1. Introduction	76
2. Removal of radioactivity	76
3. Cyanide removal	77
4. General impressions	77
SENECSA CONSULTANTS LTD	78
1. Introduction	78
2. Wastewater treatment	78
3. Tailings management	79
4. Modeling of leaching from waste deposits	79

UNITED KINGDOM

NATIONAL RIVERS AUTHORITY (NRA)	81
1. Introduction	81
2. Wheal Jane Site	81
3. Additional notes	83
WHEAL JANE PILOT PASSIVE TREATMENT SITE	84
STEFFEN ROBERTSON & KIRSTEN	88
1. Introduction	88
2. Study of ferruginous mine water impacts in Wales - Phase 2	88
3. Wetlands for Pelenna River	91

AUSTRALIA

COLLINSVILLE COAL CO. (PTY) LTD

1. INTRODUCTION

Collinsville Coal Mine which lies about 85 km south-west of the coastal town of Bowen was visited on 8 August 1994. Discussions were held with the Manager as well as Mr Steve Bushell, the Environmental Superintendent for Collinsville. After these initial discussions, further discussions were held with Mr Steve Bushell regarding the mine's environmental and water management strategies. Discussions were also held with regard to the legislative and legal framework within which the mine operates, as well as the framework which is valid for the state of Queensland.

The mine has been in operation for some 75 years and comprises both underground and opencast mining. Underground mining is undertaken on the eastern side of the mine while the opencast operations are undertaken more on the western side. There is approximately 4 years of mining left for the underground operations which produce mainly steam coal, while approximately 5 years of mining is left for the opencast operations which produce predominantly coking coal. Thereafter, additional reserves which are presently not being exploited will be opened up and these will provide additional steam coal up to the year \pm 2010.

In terms of the opencast operations, one open pit produces steam coal and three pits produce coking coal. The coal from these three pits is blended in a 40 : 40 : 20 ratio to meet the specifications of the Japanese market. The opencast operations involve moving the topsoil and the inert material with a truck and shovel operation, followed by drag-line operation down to the coal seam which is approximately 6m thick. Thereafter the coal seam is removed by the truck and shovel operation. The one drag-line rotates around all four open cuts. The coal from the different open cuts is blended on the stock pile and then washed in the washing plant. The washing plant produces 70 % product and 30 % reject. Of the reject about 22 % is tailings and about 78 % is solid reject or discard. All discard and tailings are disposed of in old open cast final voids.

2. LEGAL AND REGULATORY FRAMEWORK

There are a number of regulatory authorities in the state of Queensland which have a stake in the environmental and water management operations relating to mining. The Department of Mineral & Energy controls all aspects of mining rehabilitation while the licences for discharging water to surface water are controlled by the Department of Environment & Heritage.

All referable dams (referable dams being containment structures which are either over 5m high or have a capacity of more than 50 megalitres as well as smaller dams which contain toxic material, e.g. the tailings and evaporation dams) are all controlled by the Department of Primary Industries' Water Resources Commission.

2.1 DILUTION STRATEGIES AND MONITORING

The regulatory framework is in the process of being changed. The Department of Environment & Heritage has prepared the Environmental Protection Act which is due to go to Parliament at the end of August 1994. When this Act is passed, the control of all aspects relating to mining will be devolved to the Department of Mineral & Energy. In terms of the present discharge licences (which only refer to surface water systems as there was no control over groundwater systems at Collinsville), discharges are only permitted during certain rainfall events as monitored in various surface water courses. In particular, the Pelican Creek, Bowen River and the Burdekin River are all monitored. Before discharge is permitted from the mine, the Pelican Creek must have a flow of at least 0.1m³/s, the Bowen must have a flow of at least 11m³/s, and the Burdekin River a flow of at least 110 m³/s.

Automatic continuous flow measurement stations are found on all these different rivers. They send their signals through a remote telemetry system to a central computer at the mine which then calculates the amount of discharge which is possible, given the recorded flow. Discharge from the mine is from the Kerale Dam which is explained in more detail in Section 3.7. These monitoring stations are maintained by the Water Resources Commission of the Department of Primary Industries and measure flow, pH and conductivity.

2.2 ENVIRONMENTAL MANAGEMENT OVERVIEW STRATEGY AND PLAN OF OPERATIONS

With regard to regulatory control, the systems in operation at Queensland operate at two different levels. At the higher level, mines prepare an Environmental Management Overview Strategy known as EMOS which is a confidential document prepared by the mine and which is approved by the Department of Mineral & Energy. The EMOS only contains very broad principles and approaches with regard to environmental management at the mine and it does not contain any detailed strategies.

The EMOS process was developed in direct consultation between the mining industry and the authorities, very much as was the case for the development of the EMPR in South Africa. The approval of the EMOS is undertaken by the Department of Mineral & Energy and there is no compulsory involvement of the other authorities, unlike the situation in South Africa. The EMOS is also considered as a public document and is not confidential. It is a public document, specifically in terms of the Australian Freedom Of Information Act. Also important is that the EMOS can be amended at the request of the mines.

Mr Sartain was uncertain as to whether the EMOS could be amended at the request of the authorities.

The EMOS gives rise to what is called the "Plan of Operations". The Plan of Operations has a maximum permissible time frame of 5 years although it may be anything between 1 and 5 years. The Plan of Operations gives a detailed plan of action, including drawings, budgets, etc., for all aspects of environmental management on the mine. As part of the Plan of Operations, the mine also calculates a security deposit on an annual basis.

2.3 FINANCIAL SECURITIES

In terms of an approved EMOS, the mines are divided into any one of 6 categories, category 6 being the most onerous and category 1 being the least onerous. On the basis of this performance criteria, together with the amount of environmental management or rehabilitation work which needs to be done, the mine must, on an annual basis, calculate a security deposit which will pay for the different environmental actions which need to be implemented at the mine. The required securities are calculated according to set formulae and, depending on which performance category a mine falls into, different percentages of the real cost of compliance with performance need to be paid by the mine - varying from 25 % of real cost for a category 1 operation up to 100 % of real cost for a category 6 operation. These costs are being phased in over a period of time and, in addition, the whole securities aspect is being phased in over a period of 10 years. These securities are reviewed on an annual basis.

Security may be provided in 3 different ways. Firstly, the money is paid directly to the State, secondly, the mine provides a bank guarantee to the State, or thirdly, the mine obtains a credit rating from the State. In this instance, the mine will have to obtain a letter of intent but doesn't actually have to deposit the money. Although the mine is required to do an annual audit of its security deposit, the Department of Mineral & Energy may also audit the mine whenever it feels the need to do so, although the cost of such an audit would then be borne by the Department of Mineral & Energy.

The State of Queensland requires that the costing and quantum of the security be based on the cost associated with best proven technology (BPT).

2.4 NEW AND DECOMMISSIONED OPERATIONS

For new mining operations the situation would be somewhat different and the Department of Mineral & Energy would also require a full and detailed impact assessment which would then go to all the authorities. This approach is similar to the EMPR in South Africa. It is important to note that the EMOS and the Plan of Operations do not contain a detailed environmental impact assessment.

On completion of mining operations, the mine would then rehabilitate its disturbed areas according to EMOS and its Plan of Operations. Once the Department of Mineral & Energy is satisfied that the rehabilitation has been carried out to the required standards, the Department would then release the mine from its security obligations and pay back any moneys outstanding in the account. The cost of maintaining the rehabilitation after the security deposit has been repaid would then devolve to the new and/or current landowner. Neither the mine nor the state hold any responsibility in this regard. In order to retain this release from security, the mine needs to submit an audited rehabilitated report together with the surrender application and also needs to classify the site, probably as a contaminated site.

3. COLLINSVILLE WATER MANAGEMENT STRATEGY

In very broad terms the mine has two basic strategies with regard to water management. In the first instance all run-off water from rehabilitated areas or roads as well as natural areas is considered to be clean water and is allowed to be discharged to the local creeks. Secondly, all run-off from the stockpile and plant area together with water which accumulates in the pits is pumped up to evaporation facilities where it is allowed to evaporate. The mine has a number of evaporation dams scattered over the surface area together with one very big 2 500 megalitre evaporation dam for the pit water. The mine also has a lime treatment plant to treat pit water from the Scott, Dennis and West areas.

3.1 DISPOSAL OF REJECTS

Solid rejects are disposed of by tipping into an opencast final void. No compaction is undertaken and portions of this discard are burning. The slurry is also disposed of into an opencast pit which is connected to adjacent underground workings. No water is recovered from the slurry and all the water is allowed to evaporate.

3.2 REHABILITATION OF DISCARD DUMPS

In terms of the rehabilitation of the discard dumps, the EMOS would normally require 1m of inert material on top of the dump, followed by topsoil and grassing. The mine is therefore in the process of undertaking research on the use of PROMAC which is a bactericide which will be added together with some lime to the discard dumps and ploughed in, followed by a final layer of 10 cm of topsoil on top. The purpose of the PROMAC would be a slow release of bactericide to inhibit bacterial oxidation of pyrites. The mine also encourages the growth of *Eucalyptus tessellaris*, which is a local eucalyptus species, which is very tolerant to salt and acid. The mine also encourages the growth of *Acacia redoxalyn* which also exhibits a high salt tolerance.

3.3 FINAL VOIDS

The mine's post-closure approach for the open cast pits is to leave the final void to collect seepage water for evaporation. The seams which are being mined at Collinsville dip away from the river. Mining is started at the top of the seam and moves down the dip to finish at the lowest point of the seam. By leaving a final void at the end of the mining cycle which has a capacity to hold and retain the 1 in 100 year event, it is envisaged that all seepage water will flow into the final void from where it will be evaporated.

Another final rehabilitation option which has been considered is termed "the benching of spoils". In this operation the tops of spoil piles are knocked off, dams are built on the top of the flattened tops, and cuts are made into the side slopes of the spoil piles (these side slopes are maintained at the natural angle of repose). A number of trees are planted in these side cuts with the intent that they would soak up all the water and prevent seepage emanating from the base of the spoil piles. Motivation for the benching option is that it has a considerably lower cost than full rehabilitation of spoils to a more natural land form.

3.4 POLLUTION CONTROL DAM

A pollution control dam has been constructed in the area below the plant and stockpile. One of the interesting aspects of this plant pollution control dam is that the floating submersible pump on the pond also contains an agitator which has the purpose of ensuring that all the finer material stays in suspension and is pumped out of the pollution control dam to the evaporation area, thereby preventing the dam from becoming silted up.

3.5 EVAPORATION FACILITIES

The mine has a number of evaporation facilities located around the site which take contaminated water from the pits as well as from the plant stockpile area. In particular, the mine has one very large evaporation facility with the capacity of 2 500 megalitres. This dam also has seven monitoring boreholes around its perimeter. These boreholes were drilled and tested prior to the establishment of the evaporation facility and it was found that the background TDS value in one monitoring borehole was 32 000 mg/l. The dam wall for this evaporation dam contains a clay core with a seepage collection pipe in a trench under the clay core around the full dam perimeter to prevent seepage from the dam. This seep is collected into a sump from where it is then pumped by a submersible pump over the dam wall back into the dam.

3.6 LIME DOSING PLANT

The mine has a lime dosing plant which treats water from the Scott, Dennis & West evaporation pond by raising the pH from about 2.5 up to 6.5. The neutralised water then flows to a settling pond and then into the Kerale Dam from where it can be discharged to the Pelican Creek. Monitoring data shows

that this liming plant is very effective in removing iron and aluminium from the water to below detection levels and also reduces the sulphate concentration from around 10 000 to about 6 500 mg/ℓ and the TDS from about 16 000 to about 11 000 mg/ℓ.

The liming plant consists of a 50 ton dry lime silo which feeds the dry lime into a slurry tank. The slurry tank gets water or acid water from the evaporation facility, mixes with the dry lime to make a slurry which is then pumped up into a mixing tank where it is mixed with the acid water from the evaporation dam. This neutralised water then overflows into the mixing tank and down into the settling dams. Lime is dosed at the rate of 2 800 mg/ℓ.

Experience with this plant has shown that it is only capable of running for a period of about 6 weeks. Thereafter it needs to be shut down for descaling. The lime plant operates for approximately 33 % of the year. It was built at a capital cost of ± 120 000 AUS\$ and has an operating cost of ± R0,70 per m³.

3.7 KERALE DAM

Kerale Dam stores the neutralised water from the lime treatment plant. This dam has a capacity of around 12 000 megalitres and serves as the dam from which water can be discharged into the Pelican Creek. This dam was built at a cost of ± 1,8 million AUS\$ and is capable of releasing its full storage capacity within a 36 hour period. The Kerale Dam's size is such that it can accommodate 3 cyclone years in succession.

The ability to discharge neutralised water to the Pelican Creek is determined by the flow monitoring systems in the Pelican Creek, the Bowen River and the Burdekin River. Details on the operational strategy for the Kerale Dam are given in Section 2.1.

4. GENERAL IMPRESSIONS

The general impression obtained from Collinsville Coal Mine is that the management of water pollution is given a very high priority. Large sums of money have been spent on the lime treatment plant and the evaporation facilities. These evaporation facilities have also been designed for fairly extreme events making it unlikely that the capacity of these systems will ever be exceeded during the life of the mine.

Another interesting feature of Collinsville is the fact that diffuse pollution sources such as runoff from rehabilitated areas and haul roads are ignored and it is considered quite acceptable to discharge such water directly into the creeks. The operations at Collinsville also ignore the potential problems relating to pollution of groundwater resources. The reason why groundwater pollution is ignored is that the existing groundwater system is already highly contaminated as evidenced by the 32 000 mg/ℓ of salts in the one monitoring borehole adjacent to the 2 500 megalitre evaporation dam. The flooding of

final voids to serve as evaporation facilities on closure of the mine is also a fairly novel aspect.

There are a number of similarities between the regulatory framework in Queensland and that which is operational in South Africa and there is a fair amount of overlap between the EMPR on the one hand and the EMOS and the Plan of Operation on the other hand. There are, however, a number of subtle differences as well. Perhaps the most important difference is that the move in Queensland is to hand over regulatory and policing functions to the Department of Mineral & Energy Affairs, thereby removing them from the Department of Environment as well as the Water Resources Commission. This is contrary to the situation in South Africa where the Department of Mineral and Energy Affairs is only the lead agency and the environmental authorities maintain their functions and powers.

Finally, the water quality at Collinsville is very poor compared to water typically found at South African Collieries. Water in the open cast pits typically has a pH of ± 2.5 ; total iron concentrations of between 200 and 700 mg/l; aluminium between 40 and 200 mg/l; sulphates from about 3 000 to 7 000 mg/l and total dissolved solids of between 5 000 and 10 000 mg/l.

The effluent dilution strategy which is practiced by Collinsville is interesting although not directly applicable to South Africa with its heavily impounded rivers. The direct receiving water courses and streams up to 100 km away are monitored with fairly sophisticated systems and have pH, conductivity and flow measurement systems with all data being sent back to a central computing facility at the mine via a telemetry system.

During the site visit, a number of photographs were taken at various locations on the mine.

RAVENSWOOD GOLD MINE

1. INTRODUCTION

Ravenswood Gold Mine was visited on 9 August 1994. The mine produces and presently treats 250 000 tons per annum of ore. At the moment no mining is taking place and the plant is treating ore which has been stockpiled from previous mining operations. In the past the mine operated seven opencast pits and four underground mines. The recovery process consists of two different systems - a heap leach operation and a CIP plant.

The mine has also identified a new ore body which will be exploited within the next 12 months. When this system comes on stream, the mine's throughput will increase by an additional 2 million tons per annum. The new process will consist of a carbon in leach (CIL) plant. The average grade for the new reserve which is to be exploited is 1,7g/ton and this plant is scheduled to be commissioned by August 1995.

2. LEGAL AND REGULATORY FRAMEWORK

The EMOS and Plan of Operations system was discussed at some length with the Mine Manager, Charlie Sartain. Unlike the discussions held previously at Collinsville Coal Mine, the discussion with Mr Sartain indicated that there is a much higher degree of similarity between the EMOS and the EMPR principles. In particular, the EMOS does not only discuss broad management principles but also contains fairly detailed environmental commitments. The Plan of Operation then takes these commitments and fills in the detail for each commitment by giving a schedule of activities. The extent of information contained in the EMOS is illustrated by the table of contents for the Ravenswood EMOS as follows:

1. Introduction
2. Description of the Project
3. Environmental Impacts and Controls
 - 3.1 Land Resources
 - 3.1.1 Potentially Hazardous Materials
 - 3.1.1.1 Definition of Impacts
 - 3.1.1.2 Control Strategies
 - 3.1.2 Land Use and Land Capability Changes
 - 3.1.2.1 Land Capability Changes
 - 3.1.2.2 Land Use Changes
 - 3.1.2.3 Land Form Stability Criteria
 - 3.1.2.4 Control Strategies

- 3.1.3 Project Rehabilitation
 - 3.1.3.1 Pre-Mining Preparation
 - 3.1.3.2 Final Land Form Design
 - 3.1.3.3 Surface Preparation & Erosion Control
 - 3.1.3.4 Re-Vegetation Methods
 - 3.1.3.5 Monitoring
- 3.2 Water Resources
 - 3.2.1 Definition of Impact
 - 3.2.2 Control Strategies
- 3.3 Noise/Blasting
 - 3.3.1 Definition of Impact
 - 3.3.2 Control Strategies
- 3.4 Air Quality
 - 3.4.1 Definition of Impact
 - 3.4.2 Control Strategies
- 3.5 Conservation Values
 - 3.5.1 Nature Issues
 - 3.5.1.1 Definition of Impact
 - 3.5.1.2 Control Strategies
 - 3.5.2 Aesthetics
 - 3.5.2.1 Definition of Impact
 - 3.5.2.2 Control Strategies
- 3.6 Heritage & Cultural Values
 - 3.6.1 Definition of Impact
 - 3.6.2 Control Strategies
- 3.7 Social Issues
 - 3.7.1 Safety Issues
 - 3.7.1.1 Definition of Impact
 - 3.7.1.2 Control Strategies
 - 3.7.2 Socio-Economic Issues
 - 3.7.2.1 Definition of Impact
 - 3.7.2.2 Control Strategies
- 3.8 Research
 - 3.8.1 Tailings Dam
 - 3.8.2 Waste Rock Dump Rehabilitation
 - 3.8.3 Heap Leach Dump
 - 3.8.4. AMIRA Acid Mine Drainage Protection
- 3.9 Environmental Monitoring
 - 3.9.1 Control Strategies

4. Overview Strategy

The report then also contains a number of detailed appendices which give additional technical detail as referred to in the main report.

With regard to water issues, EMOS, unlike the EMPR does not contain very detailed descriptions of existing surface water systems, groundwater systems, mine water balances, and uses of water within the mining environment. The report also does not contain a very detailed or explicit impact assessment of

all the operations of the mine. The impact assessment which is given is very much in a summarised format. The management strategies are recorded as very definite commitments which the mine would then be audited on in terms of compliance.

3. WATER MANAGEMENT STRATEGY

Ravenswood is situated in a fairly arid area and presently does not discharge water directly to the surface water environment. Where discharges do take place, be it through seepage from the slimes dams or contaminated run-off from plant areas, the mine aims to limit the quality of the discharge either to that which is the background water quality within the surface streams in the area, or the water quality criteria set for stock watering, whichever one is the best.

3.1 PITS & UNDERGROUND MINES

The area does not have any properly developed aquifers and there are no problems experienced at Ravenswood with ingress of water into the workings, be they underground or opencast pits. In fact, the mine needs to bring in a substantial amount of water for dust suppression, both in the pits and underground. The old opencast pits are used to store rainwater for future supply for the expansions at Ravenswood. The mine is putting in a 20 km - 15 inch pipeline from the Burdekin river. As the mine will only be able to pump from the river for two or three months a year when the river is in flood, the old opencast pits will again be used for water storage.

3.2 TAILINGS DAM

The tailings dam accounts for the main loss of water. The water recovery around the dam is $\pm 40\%$ and the specific gravity of slimes sent to the dams averages 1.3 to 1.4. The plant does not have any thickeners and therefore cannot really increase or control its specific gravity. One of the reasons for this is that, historically, water recovery was not considered to be an issue at Ravenswood. However, with the new pipeline from the Burdekin River for the new 2 million t/annum expansion, the cost of water will increase and water recovery may well become an issue at the mine.

The slimes dam side walls are built of dry waste material from the heap leach operations. The walls are not hand-packed as in South Africa and the exterior walls of the slimes dams are built up once a year using the waste heap leach material, whereafter the slimes dam is then audited by external consultants to confirm that it has the capacity for the following year's production, together with the capacity to retain a 1 in 100 year 72-hour rainfall event. The slimes dams have penstocks and underdrains to collect the water and return it to the plant.

The slimes dams do not have any toe paddocks as run-off is not considered to be a water quality problem due to the fact that the side walls are made of the spent heap leach ore. The quality of run-off from the sidewalls has, however, never been measured and it is therefore just assumed that the quality is good. The mine does undertake subsurface monitoring for cyanide and appears to be fairly sensitive about cyanide as a pollution problem. The tailings dam has a rise rate of ± 1 metre per year.

3.3 PROCESS PLANT

The Process Plant has bunded areas to contain all run-off and tank spillages in the plant area. Other run-off stormwater is diverted to a collection run-off pond and stormwater ponds and then pumped back for reuse in the heap leach operation.

4. RESEARCH

4.1 TAILINGS DAMS

The mine is undertaking research on the development of vegetation methods for direct vegetation onto tailings. The specific problem at Ravenswood is a severe lack of topsoil as a planting medium to cover waste deposits with. The trial work which will be initiated will focus on the following three aspects:

- A. The soil chemistry in trial pots will be monitored for soil pH, electrical conductivity and metals concentration. Waste characterization work to date indicates that acid generation potential is very low. However, further assaying will be undertaken. Should any noxious wastes be identified they should be preferentially placed where they will be buried under inert waste.
- B. Assess capillary rise of any salts from tailings through the cover material. Detection of significant amounts of salts which affects vegetation performance will necessitate the addition of an additional cover.
- C. Revegetation trials to test the likely success of tree or pasture growth on the bare tailings surface. Contingency surface stabilisation measures will involve the use of waste rock capping on tailings dam surfaces and subsequent revegetation with or without topsoil placement.

4.2 WASTE ROCK DUMP REHABILITATION

Preferred options for rehabilitation of waste rock dumps is to utilise bare rock armoured buttresses with a revegetated topsoiled top surface. Shortage of available topsoil in the area as a result of overgrazing makes this option the most practical. All surfaces of waste rock dumps created outside the town reserve will be covered to an average depth of 300mm with pre-existing stockpiled topsoil, subject to availability, or with weathered overburden from

the proposed expanding operations. Soil analyses and species screening trials will be conducted to confirm the suitability of this overburden and species selection for rehabilitation purposes. The topsoil availability survey will also be conducted to develop a rehabilitation strategy for the new waste dump.

4.3 HEAP LEACH DUMP

Insufficient topsoil reserves exist for the rehabilitation of the present heap leach dump and the suitability of heap leach material for direct rehabilitation will be investigated. This will include existing material and proposed final cover of Nolan's oxide material which is the weathered overburden from the new mining operations which will also be heap leached. Should heap leach material be unsuitable then other options will also be investigated.

4.4 AMIRA ACID MINE DRAINAGE PREDICTION

Carpenteria Gold & Ravenswood Gold are participants in the current AMIRA programme which is aimed at validating the degree of confidence in the prediction of acid mine drainage using current technology. The objectives of this project are to develop the net acid generation procedure for general use in the Australian mining industry for identification of acid forming mine rocks and waste and the prediction of acid rock drainage. The idea is that this research will be used to assist in planning the placement of waste material for minimum environmental impact.

5. OVERVIEW OF WATER RESOURCES AND RELATED ISSUES IN THE UPPER BURDEKIN REGION

The Department of Primary Industries' Water Resources Commission has produced an overview study for the upper Burdekin region. The intent of the Water Resources Commission is to produce a series of reports for a number of different catchments. The reports provide information on the following topics:

1. Water Resources
Rainfall, streamflow, flooding, evaporation and groundwater
2. Existing Development
Urban centres, industry, agriculture, water resources development
3. Available Water Supplies
Surface water and groundwater
4. Mineral resources
5. Soil resources
6. Sites for possible future water storage
7. Water demand
Urban, irrigation, industry for the year 1992 and estimates for the years 1997 and 2012 and instream water needs
8. Comparison of water demand and available supplies
9. Water-related environmental and social issues

This is a fairly comprehensive report which provides a valuable background planning document for the mine when looking at its environmental impact and how it would impact on the local water resources and how it can utilise the local water resources.

6. GENERAL IMPRESSIONS

The mine staff appear to be very well informed on the procedures, underlying philosophies and principles of the whole EMOS system. During the planning for the expansion of the mine from 0.25 - 2 million t/annum, extensive discussions were held with consultants and with authorities on the procedures in dealing with environmental impacts and, through this exercise, the mine staff have become fully acquainted with the EMOS system.

In terms of the mine's water management strategy, it was again evident (as for Collinsville), that diffuse water pollution is not considered a problem and is generally ignored. In addition, the standards which are used to determine whether seepage or run-off is of an acceptable quality or not, is not based on a catchment-wide consideration of users, e.g. Ravenswood discharges into a Creek which finds its way into the Burdekin Dam. The Burdekin Dam is used for stock watering, irrigation, potable and recreational purposes - despite this, the only user which is being considered is stock watering as the most immediate downstream user.

Due to the arid conditions around Ravenswood and the nature of the mining operations, very little water was observed around the site. There are no point source discharges of water into the environment and the only discharges would be diffuse sources of pollution during rainfall events and seepage.

MT LEYSHON GOLD MINES LIMITED

1. INTRODUCTION

Mt Leyshon Gold Mine was visited on 10 August 1994. Mt Leyshon is situated approximately 35 km south-west of the town of Charters Towers. The mine is an opencast operation. The ore treated by Mt Leyshon has an average grade of ± 1.5 g/ton and the economic cut-off for Mt Leyshon is about 0.5 g/ton.

2. WATER MANAGEMENT

2.1 WATER BALANCE

The mine has installed flowmeters at numerous points around the reticulation system and takes readings of these on a daily basis. The mine has a specially developed computerised water balance modeling system which takes into account aspects like rainfall, seepage, evaporation, etc. A flow balance is produced on a daily basis and is discussed at the morning meeting where all the departmental managers are present.

2.2 RUN-OFF CONTROL

For each of the waste dumps which are situated on the mine site, the mine has installed run-off control systems. These run-off control systems consist of underdrains to collect seepage and drainage from the dumps which are then channeled to a small intermediate holding dam. This dam has two weir outlets which have been designed on the basis of extensive hydrological studies and hydrological modeling exercise, such that during normal conditions, all the run-off water is diverted to holding dams or evaporation dams, but during certain flood conditions, when the base flow in the rivers permits it, the weirs will allow stormwater to overflow and be sent directly to the rivers.

The water is kept in the evaporation dams until such time as the level in the dams reaches a point where it becomes necessary to empty out the dams. At this time the dams are then dosed with a lime slurry to a pH of 5 or higher. This precipitates the copper out of the water, enabling the water to be reused in the CIP plant (the copper has a high demand for cyanide).

2.3 ACID MINE DRAINAGE CONTROL ON WASTE DUMPS

The mine has been undertaking extensive research over the last number of years to investigate the infiltration of water into the waste dumps. The common theory relating to generation of acid mine drainage from waste dumps defines two key rate determining factors. Firstly, the ingress of oxygen

into the dump and secondly, the movement of water through the dump. The strategy at Mt Leyshon is to address both of these. The waste dumps are shaped and then covered with a meter of compacted inert material. The purpose of this cap is both to reduce the water infiltration rate to 3 % or less of the precipitation as well as to reduce the rate of oxygen transfer down into the dump. Together with the Australian Nuclear Science & Technology Organisation (ANSTO), the mine has a system of probes inserted into the waste dump which measure the levels of oxygen at various levels within the dump. On the basis of these measurements, an ANSTO mainframe computer model predicts the rates of oxidation of the pyrites and the generation of acid mine drainage.

(As a result of this information, contact was made with ANSTO in order to arrange a meeting with them to find out more information on this prediction model as it could potentially be of use in South Africa in predicting acid mine drainage from waste rock dumps, discard dumps and slimes dams.)

2.4 LIME DOSING PLANTS

The lime dosing plants used to treat the run-off which is being collected in the catchment or evaporation dams is based on a silo containing dry hydrated lime. The lime is made up as a slurry in a stirred tank and the slurry is then pumped into a pipe which extracts water from the dam and then pumps the neutralised water back into the inlet of the dam allowing the copper and other precipitates to settle out in the dam itself.

Problems experienced with this plant are severe scaling of the slurry tanks, pipelines, pumps and all the typical scaling problems associated with lime dosing plants.

2.5 MONITORING SYSTEMS

The mine does not have any continuous flow, pH or conductivity monitoring systems installed. One of the main reasons for this is the very high seasonality of flow. For large portions of the year there is no flow in the rivers or creeks and in fact for the past three years or so, the mine has been experiencing a severe drought. The mine does have staged flow sampling stations installed in the streambeds which consist of 5 or 6 bottles placed at different heights to take samples of any stormflow moving down the water course. These sample bottles are checked after each storm event and the full bottles are then emptied out and sent for analyses.

2.6. WATER SUPPLY

During the last drought period the mine almost had to cease operations due to a lack of fresh water supplies. For this reason an off-channel storage dam was built near the mine's take-off on the Burdekin river. During normal circumstances the mine extracts water from the Burdekin river and pumps it through a 35 - 40 km pipeline. One of the objectives of the daily water

balance is to check very carefully on the fresh water consumption which is being used. It is recognised by the mine that their main point of loss of water is at the slimes dams and for this purpose the mine aims to keep the SG of slimes pumped to the slimes dam as high as possible. The slime is generally pumped out at a 60 % solids and 40 % water ratio.

2.7 ENVIRONMENTAL PERFORMANCE CRITERIA

One of the problems which was discussed extensively by Mr Orr was the issue of setting realistic, achievable and practical measurement / performance criteria, in other words how to measure the success that the mine has in meeting the stated commitments in the EMOS.

The mine has set a number of criteria for judging whether a rehabilitated site is suitable for closure and these criteria are set out in the documentation given to me by Mr Orr. They include, amongst other things, the organic content of the upper layers of the rehabilitated dumps, the bacterial activity within the upper layers and a number of other quantitative criteria.

2.8 GROUNDWATER SYSTEMS

As for Collinsville & Ravenswood, it would appear that groundwater systems are not important at Mt Leyshon. The sidewalls of the opencast pit which is about 100 - 200m deep appear to be totally dry, suggesting that no active groundwater systems occur in the area.

HUNTER VALLEY COAL MINE

1. INTRODUCTION

The Hunter Valley Coal Mine is situated approximately 24km north-west of Singleton and approximately 100km north-west of Newcastle and is owned and operated by Coal & Allied Operations (Pty) Ltd.

The valley comprises two sites, Hunter Valley No's 1 & 2 which operate under a common management. Coal recovery started at Hunter Valley No. 1 in 1979 over an area of ± 993 hectares. A lease was granted for the No. 2 mine in 1991 and production was then increased to 6,4 million t/annum. Approval has also recently been granted to extend Hunter Valley No. 1 southwards into an alluvial flood plain between the No. 1 & No. 2 mines. Current mine production capacity is $\pm 7,5$ million t/annum.

The overburden horizons average 16m in depth over the mining area at Hunter Valley No.1 and the overburden to coal ratio averages at 2,5 : 1. The coal resource at Hunter Valley No. 2 contains some 397 million tons of coal of which about 200 million tons is economically recoverable by open cut methods and overburden to coal ratios are much higher, averaging 5,1 : 1.

Hunter Valley produces five main brands of coal, steam coal with high ash content, steam coal with low ash content and three variations of coking coal with 8,5 % ash, 7,5 % ash and 6 to 7 % ash.

Discussions were held with Mr John Pola who is the Senior Environmental Scientist at the mine who accompanied me on my site visits around the mine.

2. LEGAL & REGULATORY FRAMEWORK

Discussions with Mr Pola indicated that the mining operations in New South Wales operate under a very different legal and regulatory framework than those in Queensland.

The process which is followed to get authorization for mining starts with an exploration lease. Once the exploration lease has been granted, the mine needs to prepare a project plan and a rehabilitation plan. During this phase, the mine would typically also undertake detailed environmental impact assessments, as deemed necessary and would typically also have a series of discussions with the various authorities. The third phase of the process is then to hold a planning focus meeting, mainly with the different authorities.

The planning focus meeting is viewed almost as a rubber-stamping exercise, provided sufficient consultation has occurred with the different authorities in the previous phase. Once the planning focus meeting has been held, the

mine would then undertake an environmental impact assessment - this would be required before obtaining a mining authorization.

In terms of the mining authorization the mine would then also prepare an environmental impact assessment which would be released to the public for review and comment. The next step would be for the mine to respond to submissions which have been made regarding the environmental impact statement and to then submit these responses to the authority which must approve the mining authorization.

Once the project has been approved, the mine would then have to prepare a pollution control approval application which is submitted to the EPA. On the basis of comments received on this pollution control approach application, the mine would then develop an environmental management plan and then get a pollution control license.

3. WATER MANAGEMENT STRATEGY

The mine basically recognizes five different water qualities on the mine and has broad principles of approach with regard to these different water qualities.

Clean Water : the policy is to collect clean water and divert it around the contaminated portion of the site.

Sediment-laden Water : the approach is to remove the sediments and discharge the water into the environment.

Mine Water : typically very saline with a volume of roughly 2 500 megalitres per annum. In terms of this 2 500 megalitres per annum mine water \pm 800 megalitres is re-used within the mine area for dust suppression and about 1000 - 1200 megalitres per annum are reused within the plant area. The excess water which is not reused, is stored and then discharged to the Hunter river as a last option. One of the particular problems at Hunter Valley is the lack of available space for evaporation purposes.

Sewage Water : the approach is to treat the water in a packaged sewage plant and then to irrigate the treated water.

Oil Contaminated Water : the oil is removed in oil and grease traps. The clear water is then recycled back to the washing part.

4. WATER BALANCES

The mine has a computerised water and salt balance model which was developed specifically for the operations by a consultant. This model is being developed further to the stage where it will be able to predict a future water

balance on the basis of rainfall. This water balance also includes models for run-off and infiltration through rehabilitated opencast spoils.

5. ENVIRONMENTAL MANAGEMENT PRACTICES

The Valley No. 1 mine has a fairly detailed environmental procedures manual which sets out all the details on responsibilities and actions which need to be taken with regard to all aspects of environmental management, including water management.

On an annual basis, a detailed environmental management report is prepared, which also includes an extensive section on water management. The water samples and water analyses in the report are, to a large degree, prepared for the mine by external consultants. The report is then sent to the Department of Mineral & Energy as well as to the Environmental Protection Authority (EPA). Such an annual report is part of the license requirements for the mine.

5.1 DISCHARGE LICENSES

The mine may discharge a maximum of 2 megalitres per day of effluent, provided that the receiving water quality is satisfactory. The license is only valid for a period for 1 year and needs to be re-applied for on an annual basis.

The discharge requirements which have been set are that the effluent must have a suspended solids level of less than 50mg/l, the pH must be between 6,5 and 8,5, and the effluent may only be discharged when the Hunter River, at the point where Farrell's Creek enters it, has an EC of less than 80 mS/m. In addition, the EC may not be increased to greater than 80 mS/m or by more than 4 mS/m.

In terms of monitoring requirements, whenever effluents are being discharged, the mine needs to monitor flow, suspended solids and EC on a daily basis.

5.2 CONTROL OF WATER ON THE MINE

The mine is in the process of automating all the various dams and pumpage between dams on the mine. The reason for this is to prevent any uncontrolled spillage due to an imbalance between various dams. With the PC controlled system the purpose would be to exclude the possibility of a dam either being pumped dry (which may damage the pumps), or to exclude the possibility of too much water being pumped into a dam so that it overflows into the river.

5.3 REHABILITATION PRACTICES

The mine rehabilitates the bulk of the opencast workings to a grassland which is a category 3 or 4 land use. Land forms are re-established. 100mm of topsoil is placed on top of the graded spoils which is then planted with grass.

Certain sections of the rehabilitated land are planted with trees. In these areas, instead of topsoil, the mine use the coarse waste from the washing plant. The new area to be mined adjacent to the Farrell's Creek has portions which are class 1 land, in other words, the highest possible grade. In these areas, the mine will be re-establishing 1,2 metres of soil on top of the reshaped fill. This will include a 800 mm subsoil structure with a 400 mm topsoil.

6. GENERAL OBSERVATIONS

The mine has a very high degree of environmental awareness and the public which surrounds the mine and which is affected by the mining operations have a direct say in the environmental management systems which are put in place at the mine. Fairly detailed environmental reports have been prepared on all aspects where there is potential for negative impact by the mine. Mine personnel have a good understanding of the potential problems that may result from the operations and a great deal of attention is paid to environmental management.

An interesting point to note as well (and this will also be covered in the report on discussions held with EPA) is that there is no attempt to deny the right to discharge effluents. In fact the ability to discharge is considered almost as an irrefutable right. The only issue at stake is that discharge must take place at a time when the baseflow in the river system can accommodate such a discharge without negatively affecting downstream users.

ENVIRONMENTAL PROTECTION AUTHORITY - NEWCASTLE

A meeting was held with Mr Brian Gilligan, Director for the Northern Region of the Environmental Protection Authority (EPA). Discussions were held with Mr Gilligan to determine what the practices, philosophies, approaches and underlying scientific basis are for the regulatory system which has been put in place in the state of New South Wales. On the basis of these discussions it was apparent that the system which has been developed by the EPA is very similar in many respects to what has been put in place in South Africa, in that the basic area which is being regulated is a river catchment and accordingly, the regulations are catchment specific. Where the approach employed in the Hunter Valley is different from the catchment management plans developed in South Africa, is that the focus is only on salinity. No account is taken within this plan of other contaminants such as heavy metals or nutrients. Secondly, the information which is used to define the acceptable levels of discharge are not based on detailed scientific studies such as would typically be undertaken in a catchment situation analysis in South Africa. The approach which is taken is rather based on historical information which has been collected by the Department of Water Resources who have a fairly extensive and historic monitoring system within the Hunter Valley.

Hunter Valley has been divided into three regions or zones, an upper, middle and lower zone and the flow regime in the Hunter Valley has also been divided into three - low, high and flood flows. At present, the regulations have been determined for low flow in particular as this is the time when the river is the most susceptible to pollution. The intent is that within the next five years, the EPA will be phasing out and disallowing discharges during low flow periods.

A fundamental component of the philosophy which is being adopted by the EPA is that the mines must have an on-site storage capability to store effluents till such time as the flow in the river system can accommodate the release.

The EPA is instituting a tradeable water pollution permit system which will allow polluters to buy and sell their pollution allowance to each other, within certain defined rules.

It is interesting to note that the policies which are being developed by the EPA, and the issue of the tradable permits as an example thereof, are being developed in consultation with all the interested and affected parties and they have the opportunity to make direct comment and direct input into the development of the process.

In discussions with Mr Gilligan it was also made quite clear by him that the approach which is being taken by the EPA is to make the system as simple and as uncomplicated as possible. All the polluters and users are aware, however, that should problems arise, which they cannot resolve themselves through direct consultation between users and polluters, then the EPA will step

in and add additional regulations which will then complicate the issue further. It is, therefore, clearly in the interest of both the users and the polluters to learn to work together such that the system is kept as simple and as easy to operate as possible.

BHP RESEARCH LABORATORIES - NEWCASTLE

The morning of 12 August was spent at the BHP laboratories in Newcastle. During the visit, discussions were held with BHP staff, in particular the Director, Dr Peter Scaife, together with Dr Allan Stewart and Dr Ian Hamilton.

Discussions centered primarily on the structure of mining related research in Australia, which research bodies within Australia are undertaking research, and to what extent the activities of these bodies are coordinated. In discussions it became quite clear that there is no formal coordination at this stage between the research activities of the different organisations.

The organisations in question are the BHP research laboratories and Mt Isa Research Laboratories in Mt Isa. Mt Isa also undertakes mining related research. The CSIRO undertakes a certain amount of mining related research while CRA has its research laboratories. There are also some research laboratories in Western Australia. Dr Scaife indicated that in an attempt to try and rectify the problem of a lack of coordination between all these research organisations, the Federal Government initiated the concept of Co-operative Research Centres. These are set up to coordinate and undertake co-operative research between a number of institutions including universities, private research organisations, and industries. Two co-ordinating research centres which have been set up for mining are one on mine rehabilitation and one on hydrometallurgy. There may in fact be a number of other CRCs which relate to mining as well.

In addition there is the Australian Mining Industry's Research Association AMIRA which funds and manages research in a bottom up approach. What would happen is that a research organisation such as a university would approach AMIRA with a proposal for a research project. AMIRA would then evaluate the project. If it is found to be suitable, AMIRA would then contact the mining organisations and set up the funding and project management structures for that project.

A lengthy telephonic conversation was also held with Mr Peter Roe, also of BHP in Brisbane. Some discussion was entered into regarding environmental legislation, the environmental and water management practices at the mines and in particular Mr Roe informed me of two relevant research projects which are being undertaken. The one relates to a research project on the effect of sulphate on stock watering. The effects on livestock in terms of impacts on the growth of the animals, toxicity to the animals and the quality of the meat which is produced are being evaluated. Mr Roe undertook to send me a copy of the research report which is expected to be completed towards the end of the year. Secondly, Mr Roe informed me of an MSc project being funded by BHP which is looking at the evaluation and establishment of constructed wetlands for a number of the BHP coal mines and undertook to forward my address to the researcher concerned.

Telephonic discussions were also held with Mr Ian Bergman from the Department of Industry Science & Technology relating to my desire to make contact with organisations and people in Australia who have an interest in and who are active in mine water and mine environmental management. He indicated to me that at the moment he was not aware of any organisation that had specific interests in mine water management but that he would contact a number of people and would forward any information in this regard to me. He also indicated that he had a number of reports on relevant mine water research projects which has been undertaken and he also undertook to forward these to me. Finally, he informed me that the Department of Industry, Science & Technology was sponsoring a project, with a budget of about Aus\$6 million to develop a coordinated database for accessing information on environmental projects, and past and present research projects being undertaken at various places within Australia.

Discussions were also held with Dr Ian Hamilton, an employee of BHP, with regard to past work which had been undertaken at BHP which may be relevant to mine water management. It would appear that the work which they have undertaken on cyanide removal was designed very specifically to treat effluent streams at iron & steel mills which contain considerable amounts of zinc. However, Dr Hamilton undertook to investigate whether or not any appropriate reports were available relating to the work on cyanide as well as previous work on membrane processes, ion exchange processes and the removal of heavy metals such as iron, lead and zinc. Any relevant reports will be forwarded to me.

AUSTRALIAN NUCLEAR, SCIENCE & TECHNOLOGY ORGANISATION (ANSTO)

Discussions were held with representatives from ANSTO, in particular to discuss modeling capabilities which ANSTO have developed for the prediction of acid mine drainage from waste rock dumps including waste rock from the gold mining industry as well as discard dumps from the coal mining industry. Information was also requested with regard to any technologies or techniques which may have been developed for the removal of radioactivity from water.

The bulk of the discussion centered around the model that they have developed for predicting acid rock drainage and what its capabilities and limitations are. It would appear from the discussions that were held that the model which is being developed by ANSTO definitely holds potential for use in the South African mining industry. Particular applications where it would appear to have application include:

- the assessment of co-disposal of coal mining waste as a technique for reducing mine water pollution and seepage
- predicting the likelihood that a given disposal waste dump would go acid in the future
- predicting the quality in terms of sulphates of the seepage water which could emanate from dumps

The model could also be particularly useful in evaluating the efficiency of various rehabilitation techniques and different covers and compaction strategies for reducing acid rock drainage within the dump. The model has been developed over a number of years and has been applied at a number of mine sites in Australia, Indonesia, New Zealand, Canada and Sweden. ANSTO have undertaken to send me a number of documents and papers which set out more information on this model's capabilities.

UNITED STATES OF AMERICA

KNIGHT PIESOLD & CO. - DENVER, COLORADO

1. INTRODUCTION

On 15 August 1994, discussions were held with Mr James Gusek of Knight Piesold in the Denver, Colorado office. Discussions with Mr Gusek centred around two major items, namely passive treatment systems and the design and operation of tailings dams.

2. PASSIVE TREATMENT SYSTEMS

Mr Gusek is the Knight Piesold representative who has responsibility for the design of passive treatment systems. Mr Gusek has been involved in the design of a number of passive treatment systems for treating mine effluents both in the USA, UK and elsewhere in the world. Mr Gusek, together with Dr Thomas Wildeman of Colorado University are experts in the USA on anaerobic passive systems. This is in contrast to Dr Hedin and Mr Brodie from the US Bureau of Mines and the Tennessee Valley Authority who have more expertise in the field of aerobic passive treatment systems as well as anoxic limestone drains.

The anaerobic systems are used extensively where the effluent which needs to be treated has a high salt load. These systems are being most commonly applied in the USA for the removal of heavy metals. Sulphate reduction within an anaerobic bed converts the sulphates to sulphides, thereby enabling the precipitation of metal sulphides. A wide range of metals are treated and removed by this process, amongst others iron, manganese, aluminium, zinc, nickel, copper, etc. This anaerobic technology is also used for sulphate removal and this is what makes it particularly interesting and potentially applicable to the South African situation.

Mr Gusek also pointed out that in all the passive treatment projects that Knight Piesold get involved in, the design of the full-scale wetlands goes through four distinct phases as follows:

Phase 1 would be called the Proof of Principle phase, typically lasting 6 - 8 weeks and involving substantial laboratory test work for water qualities, flows, as well as the determination of the most suitable substrate for the particular application.

Phase II would be bench scale studies, typically lasting about 6 months on the scale of $\pm 1\text{m}^3$ in size.

Phase III would be pilot scale studies being defined as anything between 4 - 80 litres per minute. Where possible, Knight Piesold prefer to do the pilot scale studies for a period of one year.

Phase IV would be the full scale design and application of the technology.

Passive systems are not being designed and constructed on the basis of uniform design guidelines.

According to Mr Gusek one of the systems which is receiving some attention in the UK is what is called the enhanced sulphate reducing system. In this process, a low molecular weight carbon source such as ethanol would be fed directly into the incoming stream in order to enhance the rate of sulphate reduction.

Another interesting point is that Knight Piesold have developed what they call the pre-anoxic limestone drain pond which is a combined limestone bed but containing large amounts of organic material. This is used where water has a high ferric iron or high aluminium content, thereby making such a water unsuitable for direct treatment by an anoxic limestone drain.

Mr Gusek, together with Dr Wildeman of the Colorado University regularly offer short courses on the design of anaerobic passive treatment systems.

3. TAILINGS DAMS

Broad discussions were held with Mr Gusek on the issue of the design of tailings dams. Although Mr Gusek was not the responsible person within Knight Piesold for the design of tailings dams, he was able to give me some information on their approach to tailings dams.

According to Mr Gusek, Knight Piesold are currently designing around 70% of the tailings dams within the USA. The system which Knight Piesold has pioneered is discussed in a number of papers given to me by Mr Gusek. The approach that Knight Piesold is using basically enables a very dry and dense tailings dam to be constructed. The water balance around the tailings dam is such that only 15 or 20 % of the water is retained within the tailings. Design rise rates for such tailings dams are in the order of 2,5 to 3 m/annum. Apparently it is a process which was started about ten or eleven years ago and pioneered by Knight Piesold. It is a system which appears to hold some definite merit for the South African situation, particularly for the mines which have restrictions on available space for the construction of tailings dams. Also the process appears to do away to a large degree with the stability problems which are being experienced at a number of the South African gold mines.

Mr Gusek also discussed a procedure which is being used by Knight Piesold for dewatering slimes dams which have become very wet. Wick drains are retro-fitted into wet slimes dams and these have the effect of promoting

dewatering into the wick drains. The wick drains then discharge the water into a collection system.

4. SITE VISIT TO EPA - BURLEIGH TUNNEL

The Burleigh Tunnel is an adit which receives drainage from an old silver mine at a town called Silver Plume in Colorado. The effluent which emanates from this adit has a fairly neutral pH and the particular concern is zinc - the water has about 40 mg/l of zinc as well as some iron. The site has two anaerobic cells, one operating in the upflow mode and one in the downflow mode. The cells are filled with a commercially available composted manure product mixed with alfalfa hay.

The system removes approximately 90 % of the zinc. However, as the EPA was not forwarding their monthly monitoring data to Knight Piesold, Mr Gusek was uncertain of the precise removal efficiencies for the other compounds such as sulphate, copper and aluminium. A number of photographs were taken of this site.

The anaerobic ponds, which are approximately 2 metres deep, are covered by a strong safety net to prevent public and animals from falling into them. The anaerobic pond is located in the small town of Silver Plume which has been restored as a tourist attraction.

The design flow of the systems is 10 US gallons/minute in each anaerobic cell to give a total throughput of 20 gallons per minute. Both cells are lined with geomembranes to prevent contamination of the soil. This pilot plant system was only commissioned, in December 1993. Based on the good results received to date it was understood that the EPA was in the process of giving approval to install and commission another five cells to treat the total seepage flow from this adit.

One of the points to note with an anaerobic pond such as those found at the Burleigh Tunnel is that the organic substrate for sulphate removal increases the BOD and COD loading of the treated effluent although, according to Mr Gusek, this increase in BOD and COD tends to decrease rapidly with time. One of the possibilities for addressing this problem would be to install a second stage aerobic system designed to remove the added organics.

The expected life of the organic substrate within the system is ± 30 years, whereafter the anaerobic pond could either be considered as a source of zinc which can be recovered or as a toxic waste site. The estimated cost of the 20 US gallon/minute installation at Burleigh Tunnel is in the region of US \$50 - 60 000.

According to Mr Gusek the pH range within which the anaerobic systems would operate, lies between 2.5 and 10. The process also increases the pH

quite substantially due to the sulphate reduction reaction which produces alkalinity.

SLEEPER GOLD MINE

1. INTRODUCTION

The Sleeper Gold Mine was visited on 17 August. The mine is situated approximately 50 miles north-west of the town of Winnemucca. The ore deposit which is mined here is one of the highest grade in North America with selected samples running as high as 10 000 ounces of gold per ton of ore. The Sleeper Mine is an open pit operation with a milling plant as well as heap leach operations. Total daily ore production at the mine is \pm 250 000 tons.

During the site visit, discussions were held with a number of people as listed below:

Mr Todd Lewis - Mine Environmental Specialist
Mr Delbert Parr - Chief Environmental Engineer
Mr Arnold Luther - Mine Geologist
Mr David McIntosh - General Manager

The two most important environmental characteristics of the Sleeper Mine operation were firstly, the extremely low precipitation of about 125mm per annum which mainly occurs in the winter months as snow. The second distinguishing feature is the extensive dewatering of the groundwater systems which takes place at the mine - at present about 13 000 gallons/minute are pumped out of 32 dewatering boreholes.

2. REGULATORY FRAMEWORK

In Nevada the mines are regulated both by Federal and State environmental regulations. In terms of the Federal regulations, the mines are administered by the Bureau of Land Management (BLM) which is responsible for most of the Public or federally-owned land. As most of the mining operations are situated on federally-owned land, they have to conform with the requirements of the (BLM).

2.1 FEDERAL REGULATIONS

In terms of the BLM regulations, a mining company which proposes to start a new mine would hold discussions with the BLM to decide whether or not the mine is expected to have a significant environmental impact. If it is concluded that the mine probably has a minor, insignificant or no environmental impact, then an environmental assessment will be undertaken. This environmental assessment is not a very extensive study and is undertaken by the BLM, either by its own staff or by consultants on its behalf. If the environmental impact assessment then does find an insignificant impact then

the Bureau for Land Management will prepare a Finding Of No Significant Impact (FONSI). This is a public document and may be challenged in court.

The alternative option which, based on discussions held with mine staff, would appear to be the only viable route that mines will follow in future, is that an assessment is made that the mining operation would probably have some significant environmental impact. In such an event, a fairly detailed study known as an environmental impact statement will be prepared. Again, this is prepared by the BLM or by consultants on its behalf, and the mine will need to pay the BLM for the cost of undertaking the study. Typically these costs could be between US \$1 - 2 million per environmental impact statement.

This environmental impact statement involves all the interested and affected parties, the different regulatory authorities, e.g. the USEPA, public bodies, environmental interest groups, who then all have an input into the preparation of the environmental impact statement. The environmental impact statement is typically prepared over a period of 12 months. On completion of the environmental impact statement the mine would then seek federal approval for mining.

The advantages of the environmental impact statement is that once such a document has been prepared, the mine is more or less protected from any chance of future litigation by the public or by environmental interest groups as they have been granted an opportunity to become involved in the exercise.

2.2 STATE REGULATIONS & COMPLIANCE AUDITING

In addition to the environmental impact statement the mine also needs to comply with the Nevada State regulations and, in terms of these regulations, the State will set the specific environmental standards, such as air pollution standards, water quality standards or land rehabilitation standards that the mine has to comply with.

In terms of the compliance auditing, the BLM, which would typically audit the reclamation and operational elements of the mining operation, will generally make visits to the mine on a 3 monthly basis. Air pollution, particularly in terms of dust control and operational procedures would be audited on a 6 monthly basis. In terms of the Water Pollution Control Permit the mine would send a monthly report to the authorities and could expect a visit by the authorities every 6 months. Secondly in terms of the Federal NPDS programme which relates to the temporary wetlands at the mine, the mine could expect a visit approximately once a year. Finally, the Wild Life Division would typically make a visit to the mine and audit its operations on a 6 monthly basis.

In addition to these audits, the AMAX group also undertakes annual internal audits which would be undertaken by environmental personnel from other AMAX mines.

2.3 MINING LAW REVISIONS

Hard rock mining within the USA is regulated by the Mining Law of 1872 which is a law which essentially encouraged the development of mines on public land. If mining proceeded on a claim then the mine could claim the ownership of the surface and mineral rights. The Mining Law of 1872 is presently being revised. In terms of these revisions it is anticipated by mine personnel that hard rock mining can expect to be administered on a Federal basis in terms of the National Environmental Programme which is similar to the environmental regulations covering the coal mining industry since 1977/78. In terms of the coal regulatory programme, individual states can set their own regulations provided that they are at least as strict or stricter than the Federal regulations.

One of the reasons why hard rock mining is not presently administered on a Federal or national basis, is that hard rock mining is very variable in terms of the location of mining operations, the climatic conditions and the types of minerals which are mined. The mining methodologies also differ substantially and, for this reason, no national regulations were set for hard rock mining.

2.4 FINANCIAL BONDS AND MINE CLOSURE

As is the case in Australia, mines also need to undertake an estimate of the total cost of environmental management programmes and then need to provide a bond to cover all the required environmental management actions. On completion of mining, provided that rehabilitation has been carried out to the satisfaction of the authorities, the mine will then get the bond released and will then relinquish the liability for the operations of the mine. Such liability will then revert back to the landowner which, in most cases in Nevada and in the Western States, would be the Bureau of Land Management. However, the mines can still remain liable for corrective and maintenance actions on the site for a period of up to 30 years after the bond has been released. This period for coal mines is typically between 5 - 10 years as opposed to 30 years.

3. GROUNDWATER AND MINE DEWATERING

Prior to the start of mining operations, the groundwater level at Sleeper Mine was ± 40 feet below surface. As a result of the active dewatering programme which is being undertaken, the current groundwater level is ± 740 feet below surface. The groundwater systems at the mine occur in three different layers. Firstly there is a gravel component situated above the bedrock. Below this there are two different water-bearing fracture zones within the rock, a middle level and a deeper level. The bulk of the recharge to the groundwater system occurs through the gravel layers from the valley floor. A computer model was used at the start of mining operations to determine where the dewatering boreholes should be located. This computer model used data from between 500 - 600 exploration drill holes which had been flow tested.

The dewatering borehole system has been placed in three concentric rings. The first or outer ring, which has boreholes of 200 - 500 feet in depth, with a capacity of between 500 and 1500 gpm, have been placed to pump the water from the gravel beds. Between 16 and 19 interceptive wells have been constructed in this area and they remove about 60% of the groundwater. The strategy is to pump as much water as possible from the upper zones before it has an opportunity to recharge the lower zones, as pumping against a lower head has a significantly reduced cost. The second ring of dewatering boreholes are drilled \pm 200 - 300 feet into the bedrock. These holes drain the uppermost fractures and there are about 10 to 15 holes which remove about 30% of the water.

Finally there are 3 dewatering holes in the base of the pit itself which dewater the very deep bedrock and account for about 10 % of the pumped groundwater. There are a total of 32 dewatering boreholes which together pump out about 13 000 gpm which is then discharged to the wetland areas. On closure of the mine, it is predicted that 80 % of the water level will recover within the first 18 months and that the water level will have recovered to within 90 % after another 2 years. The original water level will recover completely within 10 - 30 years after closure. At this stage the opencast pit would then form a very deep water reservoir.

4. WASTE DISPOSAL

The mine separates the waste rock components into pyrite-rich and pyrite depleted fractions, the intent being that the pyrite-rich fractions will be disposed of in the final pit and will eventually be covered by water, thereby preventing any oxidation of these pyrites. Where sulphide waste rock is found in a waste rock dump, a layer of oxidized ore will be placed on top of this waste rock to form a cap and to minimise the chances of future acid rock drainage. The cap would also include a clay layer.

5. TAILINGS DISPOSAL

The tailings dams at Sleeper Mine were designed by Knight Piesold and were constructed based on the Leaky dam concept. The dam has a clay liner and not an HDPE liner and water is drawn down very actively through the tailings dam. This water is then extracted from pipes which run underneath the tailings dam and discharge directly into a seepage collection dam.

Monitoring boreholes are located around the tailings dam facility with regular monitoring taking place, particularly for cyanide.

6. WETLANDS

The mine dewatering operations and the disposal of this water has resulted in the establishment of very large temporary wetlands with a total surface area of over 4 500 acres. The wetland area is broken up into three different wetland ponds. The wetland area with the reeds has become a significant wildlife habitat within the area, extensively colonized by birds as well as mammals. The wetlands are apparently also being utilised by migratory birds.

The wetlands are artificially constructed and are contained within a dyke system. Water is discharged into these wetlands but no discharge from the wetlands takes place, the idea of the wetlands being to remove the excess water from the mining operations both through infiltration to the groundwater systems as well as through evaporation. The water being discharged into these wetlands has an average total dissolved solids of $\pm 750 \text{ mg/l}$. The pH is neutral to slightly alkaline and the dominant salt components in the water are chloride, sulphate and sodium, although significant levels of boron also occur. The water being pumped into these wetland systems is sampled on a monthly basis and is analyzed quite extensively for about 30 chemical elements.

The dykes surrounding the wetlands are inspected on a weekly basis. Detailed ecological monitoring is being done and within the next month or so water fowl will be analyzed in terms of boron and other metal concentrations in the tissue. Similar studies are also being done for fish and macro invertebrates.

7. GENERAL IMPRESSIONS

The area within which the mine is situated is very dry, and receives very little precipitation, with that which does occur being mainly in the form of snow. As a result, control of runoff and stormwater is largely ignored. The main focus at the mine is the dewatering and the water management system is based on zero discharge of effluents. This management strategy is not very difficult to meet due to the low precipitation and high evaporation rates at the mine.

It is felt that in an arid area such as Northern Nevada, the environmental regulations should be made more flexible, such that the 13 000 gpm of groundwater can be discharged for utilisation by other users, rather than being evaporated. The quality of this water is the same as the natural groundwater as it is intercepted and pumped out before it can be contaminated by mining activities.

The analysis of the groundwater which is being discharged into these evaporation wetlands indicates that a fairly high level of sodium is present and it can be anticipated that with time, the ability of the wetland/evaporation ponds to allow infiltration of water will reduce due to the effects of sodium on the soil structure. In addition, the increasing salinity in the wetlands will also reduce the evaporation potential of this system.

An alternative option could be to find some way of economically treating this water to acceptable standards and then discharging it into the local surface water systems where it can then be used by downstream users for other purposes such as stockwatering.

NEWMONT GOLD QUARRY MINE

1. INTRODUCTION

The Newmont Gold Quarry Mine was visited on 18 August 1994. The Gold Quarry Mine is situated about 6 miles north of the town of Carlin. The Gold Quarry operation is the largest of Newmont's deposits in and around Carlin. Gold Quarry was commissioned in 1985 and, to date, has produced some 6,4 million ounces of gold. Its present gold production is ± 1 million ounces per annum. To produce this, the mine is moving 285 000 tons per day of ore which has an average gold grade of 0,04 ounces per ton. At the end of 1993, the in-pit reserves were 5,9 million ounces and the mine also has an additional 7,4 million ounces in other mineralised material not in the reserves.

During the visit to Gold Quarry Mine discussions were held with a number of Newmont personnel, in particular the following:

- Mr Daniel Johnson
- Mr Rick Tunney
- Mr Mark DuBois

The mine is an open pit operation with characteristics similar to other open pit operations in Nevada, i.e. , a need to undertake an extensive dewatering programme in order to enable mining.

2. MINE DEWATERING

The mining site is characterised by two very distinctly different geological features which both give rise to different water qualities. In the first instance, the pit is situated in a siltstone area, while the area surrounding the pit is made up of a carbonate material. Each one of these geological materials has its own typical water quality. As far as possible, the water is pumped from the carbonate material surrounding the pit to prevent the need for extensive pumping from within the pit itself where the boreholes would interfere with the mining operations.

Based on detailed data collection and modeling undertaken by Hydrologic Consultants Incorporated using a three dimensional finite element model called MINEDW, the predicted dewatering rate for the mine will rise to 30 000 gpm. At present the mine is dewatering at a rate of 13 000 gpm.

The mine has a total of 7 wells which are presently equipped with pumps for dewatering, as well as another 5 historical wells which could be used if required, although the yield of these historical wells has reduced quite substantially. A typical well consists of a drilled hole 780mm in diameter which is then packed with a central pipe with gravel between the borehole shaft

and the sidewall of the borehole. Typically the well is then equipped with a 770 kW pump. The mine has two different types of pumping wells, a high lift well and a high volume well. A high lift well would typically pump 2 500 to 3 000 gpm over a 250m height, whereas a high volume well would typically pump from 4 600 to 4 800 gpm over 100 to 120m of lift.

The pumping programme is determined from a detailed monitoring programme at the mine. Once a week, detailed piezometer readings are taken in both the carbonate and the silt material. The values are checked and correlated with the depths of the pit. The objective of the pumping programme is to keep the water level at least 12 m below the pit bottom. Based on the piezometer readings and a detailed understanding and prior modeling of the groundwater regime, a pumping schedule is determined accordingly to ensure that water levels are reduced to the required levels at different points around the mine.

The monitoring programme undertaken by the mine with regard to groundwater is very extensive and extends up to 25 kilometres away from the pit. All groundwater which is pumped out is routed to a central distribution point from where it can be distributed to the following different areas:

- to the mill for process water make-up
- to the arsenic treatment plant
- to the water storage reservoir
- to the outfall point or discharge to Maggie's Creek
- to an adjoining ranch for irrigation purposes

All wells and pipelines are monitored for flow and these flow recordings are entered into a spreadsheet to prepare an update on the water balance on a weekly basis. Regular reporting of the flow balance is also made to the regulating authorities.

3. ARSENIC REMOVAL PLANT

The mine has a very complex 20 000 gpm arsenic removal plant which, according to information received from mine personnel, was built at a cost of ± US \$ 30 million. The water pumped up from underground contains, depending on its source, arsenic of between 30 and 120 µg/ℓ. The arsenic removal plant is designed to reduce these levels to 10 µg/ℓ, while the regulatory requirement for water discharge to Maggie's Creek is 50 µg/ℓ.

The arsenic removal plant consists of two parallel units, each fully automated and PLC controlled. The essential principle of the plant is to dose ferric sulphate in order to obtain co-precipitation of the arsenic. The ferric sulphate is dosed to form a pin-floc. A cationic flocculant is then added to coagulate these pin-flocs and an anionic flocculant is also added to further improve the flocculation. The flocculated water then flows through some flocculator

channels and then into a settling dam. From the settling dam, the settled water is then passed through three parallel dual medium downflow gravity sand/anthracite filters. On-line turbidity measurement is made of each filter's product water.

The plant appears excessively complicated for what is essentially a very simple process. As a result of this, the plant has never really functioned properly, in particular, there are a number of problems with the filtration plant where problems are being experienced with the sequencing of the backwashing of the different filters. At present the filters are backwashed, based on head loss generated across the filter and the particular problem that is being experienced is that instead of only one, two or three filters can activate the backwash at the same time. According to mine personnel, the plant has never really been used as the discharge requirement of $50 \mu\text{g/l}$ can be met quite easily by blending the different types of groundwater being pumped up.

4. SURFACE HYDROLOGY

The mine has a very detailed and impressive monitoring programme to determine the erosion in the Maggie's Creek with the aim of being able to predict impacts of the discharge of water from the mine on riverbeds and banks in terms of erosion. The approach being taken by the mine is, to a large extent, based on expertise from two sources, the one being from a Company, Simons & Associates Inc. and the other a Mr Dave Rosgen.

The distance from the point where the mine discharges water into Maggie's Creek to where it joins with the Humbard river is 8 miles. The mine does stream cross sections at 35 different points along this 8 mile length and these sections are redone on an annual basis. By comparing the section from one year with that of the previous year, the amount of erosion at different points along the cross section of the streambed can be calculated. On the basis of the models which are available to the mine, the mine has the ability to predict the pick-up of sediment in the Maggie's Creek for the different discharge volumes which could be discharged by the mine and, in turn, to predict what impact these would have on the Humbard river. The reason why this is being done is that the mine has to comply with turbidity and suspended solid standards in the Humbard river, downstream of the inflow from Maggie's Creek.

The data and models available to the mine also enable the prediction of floodlines and stream levels for any type of rainfall event. The modeling is also done to enable the prediction of both bed and bank stability under different flow conditions and how much sediment would be mobilised under different flow conditions. The aim of this extensive modeling programme by the mine, which far exceeds the regulatory requirements, is to protect the mine from any future litigation or future charges that it is responsible for problems that may arise from flooding or any other problems relating to flow in the Maggie's Creek. With the data that the mine has, it is able to quite confidently

differentiate between the impacts of its own discharges and those which are due to the natural hydrological events.

The mine also makes use of two computer programs which are relatively freely available from the Hydrological Engineering Center of the US Army Engineering Corps. The one is known as HEC2 which predicts water surface profiles, while the second is known as HEC6 and predicts scouring depth positions in rivers and reservoirs.

Mr Rosgen has pioneered a particular environmental classification of rivers. It would appear, on the basis of discussions with mine personnel, that the US Army Engineering Corps programs, together with Simons & Associates and Mr David Rosgen would be well placed to assist the mining industry in addressing issues relating to river diversions and the reconstitution of river beds over rehabilitated land.

5. REGULATORY REQUIREMENTS

The mine has a very detailed and comprehensive discharge permit which includes a regulation or standard on temperature. The mine may not discharge water which has a temperature of higher than 77 °F into the Maggie's Creek, despite the fact that Maggie's Creek does not flow for 99 % of the year. In addition the mine also has to comply with a temperature standard in the Humbard river. The particular standard here is that the temperature of the Humbard river may not increase by more than 2 °C between upstream and downstream of the flow of Maggie's Creek. In order to enable the discharge of water to Maggie's Creek at any time of the year, the mine is in the process of installing a cooling plant to cool the discharge water to a point where it can then be freely discharged to Maggie's Creek. The regulatory framework which Gold Quarry Mine has to comply with is similar to that discussed for Sleeper Mine.

In order to ensure compliance with the discharge standards, the mine undertakes a very extensive water quality monitoring programme and water samples are analysed for 72 different elements on a quarterly basis. This level of detail in the analytical programme far exceeds the requirements set by the discharge permits, but again, the approach of the mine is to be proactive and to have the information available to it to prevent any future problems or any chance that anyone could in future successfully sue the mine for environmental problems.

The water which is being discharged by Quarry mine has an average TDS of $\pm 350 - 370 \text{ mg/l}$. The fact that this water has such a good quality makes it even more strange that the mine is not permitted to discharge it unless the temperature requirements are met.

6. OVERALL IMPRESSIONS

The overall impression gained from the Gold Quarry Mine is that they are very proactive with regard to environmental management. Their monitoring programmes far exceed the requirements laid down in the regulations. The personnel which are employed by the mine are highly skilled and include hydrologists, geohydrologists, chemical engineers, and all the other disciplines which are required to ensure good environmental management.

GENESIS GOLD MINE

The Genesis Gold Mine was visited on 18 August 1994. This mine is also an opencast operation with a present annual production rate of approximately 400 000 ounces of gold. At the end of 1993 the mine still had \pm 2.1 million ounces of reserves and another 574 000 ounces of mineralised material not included in the reserves.

The mine also has a dewatering programme. However, unlike the Gold Quarry operation the volumes which are removed by dewatering are very low - totaling some 200 gpm which is all used in the process plant. This mine has no discharge of water to the surface environment and has an overall water deficit. This deficit is made up by obtaining water from the adjacent Goldstrike Mine.

Like the other mines in this area, the gold is recovered both by heap leach operations using cyanide leaching technology as well as by more conventional CIP processes. The mine is also developing an underground operation which will be accessed through the high wall from the pit.

As this mine is also operated by Newmont, the same level of monitoring, sample analysis, flow monitoring and the same level of expertise is brought to bear on the Genesis Mine as for the Gold Quarry operation.

GOLDSTRIKE MINE

1. INTRODUCTION

The Goldstrike Mine was visited on 18 August 1994. The Goldstrike mine is operated as a joint venture between Newmont Gold & Barrick. This mine has some of the highest ore grades in the area. The present gold production is $\pm 1.5 - 1.6$ million ounces per year. The daily production of ore from the pits is 350 000 tons per day and the pit will eventually be ± 400 metres deep.

This mine, similarly to Gold Quarry Mine, uses a computerized management system to direct all the trucks and mining operations. During drilling operations, samples are taken from each drill hole for assaying. After blasting (which fragments the material but keeps it in place), coloured flags are placed at different points in the blasted material signifying the gold grade. The plant, in order to maintain a constant grade of gold-bearing ore as an input, has a computerised management system which directs both the shovels and the trucks to different areas of the mine. Each truck has an on-board computer in order to ensure that the gold grade coming in remains consistent.

2. MINE DEWATERING

The mine has ± 50 dewatering wells pumping about 60 000 gpm. The bulk of the water pumped has a temperature of 140 °F. The hot water, which is high in carbonates, is directed towards four large settling ponds where the mine has the ability to remove carbonates to prevent scaling in the large 72 inch gravity pipeline which then moves this water down to a central reservoir. The settling ponds also serve to cool the water. The water also has fairly high levels of hydrogen sulphide and the smell thereof is quite strong at the settling ponds.

The water which is pumped up from underground is typically pumped up through a 600 m deep well which has a 60 mm casing with a typical capacity per well of between 1500 and 4000 gpm. Pumps which are used to pump this volume of water vary in size, with the largest costing around US \$ 1 million and having a motor of ± 1500 kW.

The mine also does groundwater modeling through consultants using the MODFLOW model which is developed by the US Geological Survey. This is a finite difference model and is available for \pm US \$ 100.

3. ARSENIC REMOVAL TREATMENT PLANT

The mine also has a certain amount of water which is pumped up which requires treatment in an arsenic removal plant. The process which is applied is similar to that applied at Gold Quarry except that it is done on a much simpler basis. The arsenic in the water fed into the plant varies from 50 - 100 $\mu\text{g}/\ell$ while the effluent from the plant contains between 10 and 20 $\mu\text{g}/\ell$. The aim of the arsenic removal is to meet the drinking water limit of 50 $\mu\text{g}/\ell$ in the central storage reservoir.

The arsenic treatment plant is fairly simple and involves in-line injection of ferric sulphate and flocculant. This water is then fed to two series settling ponds and the settled water is then discharged without filtration directly to the reservoir.

4. DISCHARGE OF WATER

The mine has large amounts of water which need to be disposed of and this is done by a number of different methods. All the water pumped out from underground is routed either through the arsenic removal plant or directly through gravity lines to a central reservoir. Water from this reservoir is then used and disposed of in a number of different ways.

Firstly, the water is used to supply an irrigation scheme. The mine has fifteen 160 acre centre pivots which irrigate for 9 months of each year. The annualized average consumption of water for this irrigation scheme is 15 000 gpm. The mine also has a number of infiltration ponds which are capable of disposing of $\pm 30\,000$ gpm. These infiltration ponds use both evaporation and infiltration into the groundwater as the means for disposing of the water.

The mine also has three injection wells (of which two are currently in use) which are used to inject the water back into the groundwater systems at a point where the water cannot flow back to the Goldstrike Mine. The central reservoir also leaks through under a mountain and emanates as a number of springs which have, in turn, created a substantial wetland. The water draining from this wetland is also collected and used in a flood irrigation scheme.

The water pumped up from the groundwater systems is essentially of fairly good quality. A typical analysis taken on 22 September 1993 shows a pH of 7.8, conductivity of 46 mS/m, alkalinity of 160 mg/ ℓ , silica 22 mg/ ℓ , calcium 33 mg/ ℓ , magnesium 8 mg/ ℓ , sodium 50 mg/ ℓ , potassium 4.5 mg/ ℓ , bicarbonate 160 mg/ ℓ , sulphate 33 mg/ ℓ , nitrate 2.4 mg/ ℓ , fluoride 1 mg/ ℓ , arsenic 0.014 mg/ ℓ . Again, in an area such as Nevada which does not have large surface water resources, it appears counterproductive to be disposing of essentially good quality water by infiltration and evaporation schemes.

No photographs were allowed to be taken at Goldstrike mine.

TENNESSEE VALLEY AUTHORITY (TVA)

1. DISCUSSIONS

The Tennessee Valley Authority (TVA) was visited on the 23rd and 24th August. On 23 August, discussions were held with Mr Greg Brodie in his office, while on 24 August, visits to five wetland sites in Alabama were undertaken.

The TVA is a federal government organisation with responsibilities in three primary areas. Their first responsibility is the provision of electrical power to consumers within the Tennessee Valley catchment area. For this purpose, the TVA operates a number of hydroelectric, nuclear and coal-fired power stations. As part of the provision of coal to the coal-fired power stations, the TVA also has responsibility for a number of coal mining operations. The second major responsibility of TVA is one of economic development within the catchment area. The Tennessee Valley is a relatively poor part of the USA and, for this reason, the TVA through the provision of electrical power and the provision of jobs, is very much involved in the economic development of the area. Thirdly the TVA has the responsibility for the protection of natural resources within the catchment area and it is within this third responsibility that the department dealing with environmental protection finds itself.

The TVA, through Greg Brodie, is monitoring 14 different wetland systems built by it over the period of 1985 to 1993. Most of these wetlands are designed to treat acid mine drainage and seepage from old and abandoned coal mining sites, although one or two of the wetlands have also been installed to deal with seepage and run-off from ash dumps associated with the coal-fired power stations. Many of the abandoned coal mining operations are found in the State of Alabama and these operations, in terms of their discharge, are regulated by the National Pollutant Discharge Elimination System, known as NEPDS, and compliance with the NEPDS limitations are required for all point discharges of effluents. In terms of the NEPDS regulations, 4 elements are regulated: pH, total iron, total manganese and suspended solids.

Regulations are also presented for a daily maximum value and a monthly average value. For pH, the daily maximum value has to be between 6 and 9 and there is no specification for monthly average. For total iron, the daily maximum is set at 6mg/l with a monthly average of 3mg/l. Total manganese has a daily maximum of 4mg/l and a monthly average of 2mg/l. For suspended solids, the daily maximum is 70 mg/l and the monthly average is 35mg/l. The typical pollutants found in the mining effluents which need to be treated are sulphate, acidity, iron, manganese, aluminum and suspended solids.

Discussions were held with Mr Brodie at length regarding the principles which are being applied in the design, building and monitoring of wetlands. Some of the key points raised by Mr Brodie are listed below.

- Anoxic limestone drains put in by the TVA are designed to have a life of 30 years whereas wetlands which are put in are designed to have a life of between 90 and 100 years.
- When designing and constructing aerobic wetlands, flat uniform bottoms are specifically avoided and the systems are designed and constructed to have hydraulic discontinuities, i.e. shallow areas, islands above the water and deep zones. The purpose of these discontinuities is to more closely mimic nature and also to prevent short-circuiting.
- One of the new developments which is taking place is known as SAPS or Successive Alkalinity Producing Systems. These systems are used to re-introduce alkalinity to water which has passed through an aerobic wetland and is therefore no longer anoxic. This system involves a two-stage ALD with an anoxic lime stone drain at the bottom but covered by a layer of compost. The compost will then remove the dissolved oxygen as the water passes through it, thereby sending anoxic water to the ALD.
- Where iron and manganese need to be removed, systems are being designed to first remove the iron to a level where the iron : manganese ratio is more or less 1 : 1. Once this situation has been reached, then aerobic removal of manganese is achieved through co-precipitation with iron.
- Rock filters have been developed with the idea of getting manganese oxidising bacteria to grow on the inert rock surfaces. The iron depleted water is then passed over the systems and the bacteria then remove the manganese.
- In the construction of passive anoxic limestone drains it has been found, through empirical observations, that limestone with an average size grading of 50 mm gives the best results and this size is being used by TVA in all the ALD's which are being built.
- The ALD's do not have a plastic liner on top - only a geo-membrane with a clay cover. Typical clay covers or soil covers on top of the ALD would be about 1 metre in depth. The geo-membrane is there to prevent dirt and soil from entering into and clogging the ALD itself. On top of the metre or so of soil, allotropic grass or legumes would then be planted which would prevent trees from growing above the ALD. ALD's are also designed for 14 to 15 hours retention time and, in all cases, before installing an ALD, field tests are undertaken for \pm 90 days to determine the dissolution rates of limestone by field studies.
- An important point to look at when deciding which limestone to use in the ALD is the limestone quality, in particular, the percentage of calcium carbonate in relation to magnesium carbonate. In order for limestone to be suitable for an ALD, it must have a calcium carbonate portion of at least 80 % and preferably 90 %.

- A number of problems are being experienced with ALD's due to clogging with aluminum sludges. It is found that the aluminum sludge does not coat the limestone chips or particles but forms a sort of slime within the ALD which then reduces its efficiency. Experimental work is being undertaken to look at the slope of the ALD invert and whether or not by having sufficient slope, the aluminum sludge can be forced to move down and out of the ALD.
- Work is about to be started on using calcium fluoride beds to sequester the aluminum out of the water at a pH below 5.5, thereby preventing it from precipitating out in an anoxic lime stone drain.
- Oxidation ponds are now being used extensively right up-front in the wetland system to remove the bulk of the iron. Each oxidation pond will only remove $\pm 50 \text{ mg/l}$ of iron, assuming that there is 8 mg/l of dissolved oxygen available. Therefore, if for example 150 mg/l of iron needs to be removed, then the water would have to be re-aerated twice and there would need to be three oxidation ponds. In the experience of the TVA, typically 80 % of the iron can be removed in the oxidation ponds and this substantially reduces the size of the wetland which is required to remove the remainder of the iron.
- Basic design criteria for a typical wetland cell are:
 - for iron removal - $4 \text{ to } 11 \text{ g/m}^3/\text{day}$
 - for manganese removal - $0.5 \text{ g/m}^3/\text{day}$
- The number of cells which will be required with re-aeration of water between each cell would be determined by the iron concentration in $\text{mg/l} \div 50$. All cells are oversized to minimise short-circuiting. All cells have islands, variable depth and deep spots and length to width ratio should typically be less than 1. The wetlands are also typically planted with six different plant species.
- At the TVA wetlands, mosquito fish have been introduced into the wetlands to prevent the breeding of mosquitoes and bat houses have been constructed to encourage bats which eat mosquitoes.

2. SITE VISITS TO TVA WETLANDS

2.1 DEAD LADY LAKE WETLAND (DLL)

This wetland started operation in May 1990, has a total surface area of approximately $7\,500 \text{ m}^2$ and consists of 4 cells. The influent water to this wetland has an average pH of 6.2, iron of 10 mg/l , manganese of 5.5 mg/l and total suspended solids of 23 mg/l . The effluent water has an average pH of 6.4, iron of 2.1 mg/l , manganese of 22 mg/l and total suspended solids of 10 mg/l . The average flow through the system is about 385 l/min with a

maximum recorded flow of 7 700 ℓ/min . The iron and manganese loadings on this wetland are 0,73 and 0.4 $\text{g/day}/\text{m}^3$.

This wetland was very overgrown and it was not possible to get close up to the wetland for photographs or to look at any details of construction or operation of this wetland.

2.2 WETLAND ON IMPOUNDMENT 3 OF THE FABIOS MINE

The impoundment 3 wetland started operations in October 1986. A fairly small system, it has a surface area of $\pm 1\,200\text{ m}^2$ consisting of 3 cells. The influent pH, after treatment through an anoxic lime stone drain is 6,3, with an iron content of 15,8 mg/ℓ , manganese of 4,9 mg/ℓ and total suspended solids of 21,4 mg/ℓ . The effluent water has a pH of 7, iron of 0,5 mg/ℓ , manganese 0,7 mg/ℓ and total suspended solids of 9 mg/ℓ . The average flow through the system is about 58 ℓ/min and the maximum flow is $\pm 250\text{ }\ell/\text{min}$. The iron and manganese loading rates on this wetland are $\pm 1,1\text{ g/day}/\text{m}^3$ and 0,34 $\text{g/day}/\text{m}^3$ respectively.

What makes this wetland particularly unique is that it is the first wetland to ever be released from the NEPEDS permitting requirements. The implication of being released from permit requirements is that it is then no longer necessary for the responsible party, in this case the TVA, to monitor the outflow from the wetland as it is then accepted that the system is capable of producing effluent, which conforms to NEPEDS requirements on a sustainable basis. This wetland cost US \$ 42 000 to build (1986 value).

The wetland is a fairly difficult one to construct. The topography is steep and only a small land area is available which furthermore lies within the flood plain of the adjacent creek which accepts the water from this system. The adjacent Cache Creek which receives the effluent from Impoundment 3 was monitored on an annual basis from 1986 until 1991 in terms of the species diversity for benthic macro invertebrates. In 1986 the Creek only had two types of macro invertebrates and these were ones which could only survive in stressed acidic streams. In 1987 the number of macro invertebrates had increased to 19, 1988 to 20, 1989 to 35, 1990 to 40, and 1991 to 52. These results are fairly good evidence of the success of the Impoundment 3 operations and the beneficial impacts which this has had on the receiving stream.

2.3 HARD ROCK MINE WETLANDS (HR000)

The HR000 wetland is the biggest constructed wetland system in the USA. Construction on this system was completed in 1993 at a total cost of around US \$ 650 000. The HR000 mine receives seepage from two main points. The Hard Rock North Seepage is treated in a fairly large anoxic drain which has a length of $\pm 100\text{m}$. The discharge from the anoxic drain is fed into a large oxidation pond for the removal of iron precipitates. After removal of iron precipitates the water then flows into a shallow wetland cell which is then followed by another 5 different wetland cells and oxidation ponds. In cell

number 4, a second seep, known as the Hardrock South seep enters into the system after first passing through another large anoxic drain.

The total surface area of the HR000 system is $\pm 40\,000\text{m}^2$. The effluent from the ALD has a pH of 5.5. This water also has iron concentrations of 40 mg/l and manganese of 17 mg/l . The average flow through the system is $\pm 4\,000\text{ l/min}$ ($5\,800\,000\text{ l/d}$). The first oxidation pond which follows the ALD removes $\pm 80\%$ of the iron and has an outflow iron concentration of $\pm 10\text{ mg/l}$.

The HR000 site also has some experimental systems in place for removal of manganese. In this system, the water from the oxidation pond is passed through a rock filter to remove the precipitated iron. This water is then passed through very shallow algal ponds which have algal mats floating in them which contain a *Cladophora* algae species together with various bacteria. Preliminary results are very promising and manganese appears to be removed almost totally from $\pm 8\text{ mg/l}$ to about 0 and this at a pH of ± 2.5 . One of the perceived problems with this system is the potential increase in total suspended solids due to algae matter in the water. The algae mat system also results in a significant increase in pH. It has also been found that this system is not affected by diurnal variations and works equally well during the day and night. It also appears to be unaffected by temperature and works equally well in winter and summer.

An interesting aspect about the HR000 system is that all the wetland cells were built on top of rehabilitated spoil without the use of liners. Although liners have been used in one or two isolated spots where problems were experienced with sinkholes and excessive seepage into the ground, the bulk of the system has no liners at all.

All the spillways between the wetland cells are designed for a 100 year flood event as all rainwater from the catchment drains through the wetland system. The different wetland cells have also been planted by different techniques including hand planting of mature plants, planting of nursery stock and seeding with a mulch made of the seeding bulrushes which were then spread as a paste over the wetland area. All the systems appear to give equally good growth. When seeding or planting individual plants, based on the experience gained at TVA, it is recommended that the plants be spaced at about 1 metre - experience has shown that these plants quickly colonise the whole wetland system.

2.4 WETLAND ON IMPOUNDMENT 2 OF THE FABIOS MINE

The wetland on impoundment 2 of the Fabios Mine is one of the systems which is not functioning very well, primarily due to a problem with aluminium clogging of the ALD's. This system started operation in June 1986 and has a total surface area of $\pm 11\,000\text{ m}^2$ and has 5 different constructed wetland cells together with a number of anoxic lime stone drains. The influent water to the systems has a pH of 2.5, iron of 40 mg/l and manganese of 13 mg/l . The

effluent water from the system has a pH of 3.1, iron of 43.4 mg/l and manganese of 13 mg/l. The average flow through the system is $\pm 1\,000$ l/min with a maximum of 1 500 l/min. Iron and manganese loadings are ± 5.3 and 1.7 g/m³/day respectively.

This system receives inflow from two different areas. There is a seep from a 10 hectare discard dump and, at the same time, a seep has developed from the spoils inside the final void within the old opencast mine. This water is then fed into a number of anoxic limestone drains which appear to be severely clogged up with aluminium to the extent that they are no longer providing the required alkalinity to the water passing through.

This site also has a number of experimental systems in place to look at the effect of invert slope on clogging of limestone beds with aluminium. Four different pipes have been placed at different slopes filled with limestone and are being monitored to see at what velocity the aluminium sludge will be transported through the bed. The water from the discard dump and the spoils in the final void pass through the ALD's and then into two constructed wetlands. The overflow from these constructed wetlands flows into a third constructed wetland which then also receives water which is being pumped from 20 hectares of slurry ponds. This water exiting the third constructed wetland has a pH of ± 3.1 and, at the moment, caustic soda is being dosed into the outflow from this wetland to raise the pH to $\pm 9.7 - 10$ to get manganese removal through precipitation. This pH adjusted water then flows to a large sedimentation pond and the outflow of this then flows into two final constructed wetlands before being discharged to the water course.

A programme is also in place at the moment to rehabilitate the slurry ponds which feed water to the third constructed wetland. The rehabilitation strategy for the slurry pond is as follows:

- year one - lime the surface of the slurry pond, plant an annual crop, allow to grow and then to die back
- year two - repeat process for year one.
- year three - lime the system and plant with perennial wetland plants
- year four - fertilise the system

The idea behind this rehabilitation system is that with a continuous die back of plants grown on top of the slurry pond, an organic layer will be formed on top of the slurry pond which will isolate the pyritic material from further oxidation. The organic layer would also remove the dissolved oxygen from any water passing through it, such that only anoxic water reaches the pyritic material below.

2.5 WETLAND ON IMPOUNDMENT 1 OF THE FABIOS MINE

Impoundment 1 is the first wetland which was built by the TVA and started operation in July 1985. It has a total surface area of $\pm 5\,700$ m² and 4 different

cells. The influent water to the system has a pH of 6,1, iron of 69 mg/ℓ and manganese of 9,3 mg/ℓ. The effluent water from the system has a pH of 6,7, an iron concentration of 0,9 mg/ℓ and manganese of 1,8 mg/ℓ. The average flow through the system is ± 73 ℓ/min with a maximum of 693 ℓ/min. Iron and manganese loadings are $\pm 1,27$ and $\pm 0,17$ g/m³/day respectively.

Impoundment 1 treats seepage through the slurry ponds from where water is presently pumped to Impoundment 2. The Impoundment 1 site is also the place where anoxic limestone drains were first discovered. The water in the slurry pond behind the dyke or dam wall has a pH of $\pm 3,1$ whereas the influent to Impoundment 1 has a pH of $\pm 6,1$. When this increase in pH was noticed by the TVA, Greg Brodie drilled a number of boreholes down into the dyke of the slurry pond and found that the dyke had been built on top of a limestone road. This discovery then led to the development of anoxic limestone drains.

This wetland system has also been released from the NEPEDS permit requirements. This wetland system is a particularly scenic and aesthetic water treatment system.

2.6 GENERAL OBSERVATIONS

The wetland systems which were visited were generally very impressive. The climate in northern Alabama where most of the visited wetlands were situated, is fairly humid with a fairly high rainfall. The growth both in and around the wetlands is very lush. The principle which is being followed with the design and construction of these wetlands is to, as far as possible, mimic nature and not to create rectangular engineered structures but rather systems which would blend in with the surrounding ecosystems.

US BUREAU OF MINES (USBM) IN PITTSBURGH

1. INTRODUCTION

The USBM Research Centre in Pittsburgh was visited on the 26th and 29th of August and site visits were undertaken to USBM's wetland treatment sites on 30 August. The USBM has 9 research centres located in different cities across the USA. The Pittsburgh research centre is the oldest and largest research centre and was started in 1910.

The first 2,5 hours of the site visit on 26th August was devoted to obtaining a general background and overview of the Bureau's activities in Pittsburgh. Discussions were held with the Deputy Director, Dr Ken Sacks, who sketched the background and scope of activities being undertaken at the USBM. Discussions were also held with him regarding the nature and funding of mine related research in the USA. Visits were also undertaken and discussions were held with personnel at the fire research section, the explosives research section and the rope and hoisting testing section. After these introductory sessions, the remainder of 26 August, together with 29 and 30 August were devoted to discussions with personnel at the Bureau's Environmental Division.

2. NATURE OF WATER RESEARCH UNDERTAKEN BY THE USBM

The USBM undertakes water related research at 6 different research centres as summarised below.

PITTSBURGH

Pittsburgh is the largest research centre and has the largest water research programme. Research is undertaken into various aspects of acid mine drainage in terms of prediction, prevention and treatment, biotechnology, geohydrology and hydrological studies.

RENO

Research is undertaken into aspects relating to removal of cyanide, the use of zeolites and various aspects related to hydro-metallurgy.

SALT LAKE CITY

Research is undertaken on the biological removal of arsenic and selenium, biobeads and solvent extraction systems.

ALBANY AND OREGON

Research is undertaken into liquid emulsion membranes.

TUSCALOOSA - ALABAMA

Research is undertaken into various aspects of phosphate and gold mining activities.

TWIN CITIES

Research is undertaken into aspects of in situ leaching, groundwater and hydrological modeling.

3. DISCUSSIONS WITH MR D M HYMAN

Discussions were held with Mr Hyman regarding the general programme of water research being undertaken at the Pittsburgh Centre. Mr Hyman performs a supervisory function at the USBM and further discussions were held at a broad level relating to the research programme under his control, particularly all aspects relating to acid mine drainage. Various sub-programmes are being undertaken.

Control at source - various projects are being undertaken to investigate the control of acid production by changing the geochemistry and the hydrology of coal mining systems. Geochemistry is changed by adding chemicals, i.e. fly ash, limestone, caustic soda, etc., into the spoils. One of the other options also being looked at is the removal of ferric iron from the system.

Prediction and prevention of acid mine drainage - the research programme also includes research on the prediction and prevention of acid mine drainage. This portion of the programme involves research into hydrological modeling of rehabilitated opencast and underground mines, in terms of conceptual model development as well as research into techniques to measure the parameters which are required as inputs for the models. This involves developing an in-depth understanding of the hydrology (hydraulic conductivity) of abandoned and reclaimed mines. Further information on this programme can be found in the discussions held with Mr J Hawkins.

Discussions were also held with regard to the regulatory framework which covers the coal mining operations within Pennsylvania.

4. DISCUSSIONS WITH DR R L P KLEINMANN

Informal discussions were held with Dr Kleinmann on both 26 and 29 August, after work and during lunch, respectively. The discussions with Dr Kleinmann were based essentially on discussing the concept of the proposed passive research project for 1995, in particular the problems facing the SA mining industry and the desire to develop passive sulphate removal systems.

In the discussions with Dr Kleinmann it was confirmed that to date, no research had been undertaken in the USA which was aimed specifically at optimising passive systems or developing passive systems for the removal of sulphate. Although a number of existing passive systems do remove sulphate, the kinetics and reason for the removal of sulphates are completely different to those which would drive the sulphate removal in South Africa. In particular, the removal of sulphates in the USA is done for two reasons. Firstly to provide

alkalinity for the iron and metal precipitation processes, and secondly to provide sulphide in order to enable the precipitation of metal sulphides.

The sizing and design and types of plants which have been put into wetlands in the USA are based on the need to remove metals and not the removal of sulphate. Dr Kleinmann did indicate that he felt that the task of developing passive systems for the removal of sulphates was a very difficult one and he did not express much confidence in the chance of success of such a project. However, he did agree that no one had in fact undertaken research into this aspect and that such research would prove to be potentially very valuable.

5. DISCUSSIONS WITH MS. A COOPER

Ms Angela Cooper is responsible for work on the monitoring of USBM's wetland sites. Presently 9 wetland systems which were designed for metals removal are being monitored to investigate the effect which these wetlands are having on sulphate removal. A large amount of data has been collected over the past couple of months but as yet no evaluation of this data has been undertaken. Research is also being undertaken to look at methods of enhancing the sulphate removal by adding carbon sources such as dairy whey or sewerage to the mine effluents. Some data on this research is reported in the proceedings of the April 1984 Pittsburgh conference.

In terms of the monitoring programme at the Friendship Hill wetland system, the USBM is looking at the sulphides resulting from the sulphate reduction process in terms of both the acid volatile sulphide, known as AVS and the chromium reducing sulphide, known as CRS. The AVS is mainly iron sulphide FeS which is the least stable sulphide form whereas CRS is mainly FeS_2 or pyrite which is the more stable form. The split of AVS to CRS is largely determined by the redox potential. It has also been found that the production or percentage of AVS produced is seasonal while CRS is not. The research has also shown that the more reducing the conditions are within the wetland the higher proportion of CRS which is produced. The objective of sulphate removing systems should be to convert as much as possible of the sulphate to CRS. Some of the preliminary data which is being collected for the operation of compost wetlands indicates that for some of these wetlands with very thick compost layers of between 10 and 12 feet that up to 70 or 80 % of the sulphate being removed is as CRS, although these systems have not been designed specifically for sulphate reduction, but to provide sulphide and alkalinity for metals removal. No work is being done within the USBM with regard to looking at carbon replenishment for the sulphate reduction process by plants growing in the wetlands themselves.

6. DISCUSSIONS WITH MR J W HAWKINS

Mr Hawkins is a research hydrologist at the USBM and the bulk of his work involves research into the prediction of hydraulic properties of backfilled

spoils. A substantial amount of this research has been published in recent papers. Some of the information which has come out of the research programme is discussed below.

It has been found that for backfilled opencast mines, the hydraulic conductivity for the spoils will first increase with age after reclamation and then decrease again. The consequence of this change in hydraulic conductivity is a substantial change in the amount and the flow paths of water moving through the rehabilitated spoils. The aim of the research being undertaken at USBM is to be able to predict the end level of the water table, the idea being to develop techniques which can then be applied to optimise spoils placement and to look at different techniques of hydraulic engineering to reduce acid mine drainage.

Research has shown that the infiltration proportion of rainfall on backfilled spoil is considerably lower than that on an undisturbed area and for a rehabilitated mine, the bulk of the water moving through the spoils is coming from the high wall areas from the undisturbed area. The work which is being done by the USBM results in the development of conceptual models which will enable the prediction of volumes of seep, water table level, retention time of water, etc., within the spoil system.

This conceptual model is based on a porous medium flow system within the rehabilitated spoils and is largely based on the MODFLOW model. The MODFLOW model can be obtained from the US Geological Survey or could be obtained from consultants within the USA who have added a pre- and post-processor to the model. The USBM is also starting to look at adding a quality component to the hydrological model enabling the prediction of not only the volumes of seeps but also the quality of seeps. The quality component will largely be based on acid base accounting techniques.

One of the interesting and very logical concepts which was discussed with Mr Hawkins is the development of the hydrological model for rehabilitated open cast mines to look at the effect of different materials in the spoil and different mining and placement techniques and the establishment of different sections within the rehabilitated spoil which have different hydraulic conductivities.

Mr Hawkins is also undertaking research into the effects of the re-mining programme which is being undertaken in Pennsylvania. Re-mining involves allowing mines to re-mine previously abandoned operations and allowing them to walk away from these sites after they have re-mined them providing the pollutant discharge from the site does not increase. The re-mining programme includes mining of opencast mines by taking them to greater depth as well as reclaiming of waste materials and the open-casting of old underground mines to remove the remaining pillars. The research programme involves looking at the effect of re-mining on water quality at 24 mines based on a comparison of water qualities prior to re-mining and water qualities after

re-mining has ceased. This research programme showed that 21 of the monitored mines had no effect on the water systems.

The study is also looking at the pollutant load emanating from the mines and not the concentration, as this is the way in which the re-mining law operates. Because of this, it was found that by improving hydrological conditions, i.e. reducing the flow through the re-mined system compared to the situation prior to re-mining, the loads discharged by the mines can be decreased significantly.

7. DISCUSSIONS WITH MR R W HAMMACK

Mr Hammack is a Geochemist at the USBM and is primarily involved in the programme on the biogenic development of H_2S for metals removal. In discussions with Mr Hammack it was pointed out by him, that for passive treatment systems there are a number of concerns relating to the potential for the precipitated heavy metals to re-mobilise and get back into the environment. For this reason the USBM is looking at the use of containerized systems for the passive treatment of mine waters such that the containers can then be taken away and the substrate therein be worked to recover the metals.

The programme of work which Mr Hammack is involved in, uses biogenic hydrogen sulphide, (biogenic referring to hydrogen sulphide which originates from bacterial processes rather than chemical processes or industrial H_2S gas). Biogenic gas is produced by the reduction of sulphates in mine waters using dairy whey as the organic substrate. The particularly interesting aspects of this work on the biogenic H_2S which occurs in low concentrations compared to industrial H_2S is that by manipulating pH at which the H_2S is contacted with the mine water, fairly accurate selective precipitation of metals can be undertaken. This selective precipitation is not possible with high hydrogen sulphide concentrations.

The motives for the research programme on the selective removal of metals are really three-fold. In the first instance, to develop a system which can strip out toxic elements, thereby ensuring that the bulk of the sludge which is produced by the chemical additional of lime is not toxic and these large volumes of sludge can then be disposed of quite cheaply. The toxic elements are then concentrated and removed in precipitation processes. Secondly, the biogenic hydrogen sulphide is considerably cheaper than industrial hydrogen sulphide. Thirdly the selective removal process makes it potentially attractive to develop systems to recover metals from mine effluents.

8. DISCUSSIONS WITH DR H N EDENBORN

Dr Edenborn also occupies a supervisory position at the USBM and discussions with him were held more on a broad basis, again particularly with regard to

the proposed research project to be undertaken in South Africa for the removal of sulphates. Useful discussions on this subject were held with Dr Edenborn. One of the useful comments made by Dr Edenborn was related to the need to look at different wetland plant species in order to select those which have the optimal carbon fixing efficiency and which are capable of providing carbon to the sulphate producing bacteria in a manner which optimises the sulphide reduction process. Dr Edenborn also saw potential problems with the mass balances required for large-scale passive sulphate reduction systems.

Dr Edenborn briefly discussed some work being done by the Bureau relating to in-situ treatment. This involves the development and construction of compost wetlands inside the mine adits. One of the concerns with such systems is the fate of the hydrogen sulphide gas which is generated and released from the system. The compost wetland is being used for this application and is designed on the basis of the provision of alkalinity to neutralise the water. For these systems it was found necessary to add extra carbon as sucrose or dairy whey.

9. DISCUSSIONS WITH MR G R WATZLAF

Mr Watzlaf is responsible for the research being undertaken on anoxic limestone drains and also has a direct involvement in the research on wetland systems. Some pertinent points raised during these discussions with Mr Watzlaf are listed below.

The anoxic limestone drains at the Jennings Environmental Centre no longer operate due to severe clogging with aluminium hydroxides. The aluminium precipitate causes hydraulic fouling but does not result in any armouring of the limestone. The wetland systems being monitored by the USBM do not really seem to be removing manganese. It is believed by Mr Watzlaf that where manganese removal does occur, it is probably due to manganese oxidising bacteria and it is further believed that these bacteria are inhibited at the higher iron levels which occur within the wetland systems. It was also pointed out that on the basis of research data, it was found that different ALD's give different saturation alkalinities and the reason for this phenomenon is not known although it is being theorised that this may be due to the carbon dioxide in the influent water. It has also been found that ALD's require the use of limestone which has greater than 80 % calcium carbonate and that the ALD's should have at least 12 hours retention time.

The use of compost wetlands to provide alkalinity through the reduction of sulphate is a system which holds some potential where high ferric and aluminium levels are found. However, in Mr Watzlaf's experience, a number of problems have been experienced with hydraulic short-circuiting through the compost systems.

The Bureau is also looking at SAPS (Successive Alkalinity Producing Systems). The idea of the SAPS is to remove the aluminium in the compost layer which is situated above the limestone layer. The water which then moves downwards by gravity first passes through the compost layer which also generates alkalinity by sulphate reduction to a pH of ± 4.5 , thereby precipitating the aluminium. The limestone below the compost bed is then used to increase the pH to the region of 6 - 7 and to provide the residual alkalinity to the effluent. Mr Watzlaf is also undertaking research on pyrite oxidation, looking at the effect of different variables on the rates of pyrite oxidation. This research has been undertaken over the previous 6 or 7 years and a final report on this research is in the process of being written.

10. DISCUSSIONS WITH MR C C HUSTWIT

Mr Hustwit, together with Mr T Ackman is mainly involved with research into the in-line treatment system for acid mine drainage. The in-line treatment system or ILS is a concept which was first developed in the early 80's when a number of field scale tests were undertaken and it was found that for coal mine water $\pm 30\%$ less neutralising chemicals were used with the ILS than with conventional chemical dosing systems. As a result of these findings, more detailed laboratory studies were undertaken at the USBM. The ILS consists of a jet pump which is essentially a venturi system followed by a static mixer. The jet pump system requires between 40 and 50 feet of head to drive the system. These ILS systems have also been used with a wide range of different neutralising agents, either in the slurry or powder form, and the Bureau is presently designing systems which have the capacity to run on their own without any maintenance or topping up requirements for periods of up to 4 months at a time. The perceived advantages of the ILS are as follows:

- low capital cost
- low operating cost (30% less chemicals)
- small size
- simple maintenance requirements
- very efficient oxygen transfer and mixing device

The ILS systems used by the USBM use a one inch jet pump system which has a capacity of ± 10 gpm at 50 psi and a three inch system which treats ± 150 gpm also at 50 psi. These jet pump systems need pressure heads of between 20 and 60 psi.

Mr Hustwit is also involved in investigations into the kinetics of iron oxidation and this has lead to the development of an oxidation model for mine water systems for situations where the transfer of oxygen to the water becomes the rate limiting step rather than iron oxidation process itself. This model has been developed and calibrated with extensive lab data.

Finally, Mr Hustwit is also involved in research on the stabilisation of waste sludges. The question which arises with wetland systems is what happens to the precipitates which have accumulated in the wetland substrate. For this reason, the Bureau is undertaking research which is looking at the metal forms which occur within the substrates, what kind of mineralogy occurred within these substrates and how stable the precipitates are. A series of lab leaching studies have been undertaken for samples taken from compost wetlands which were built and operated over the previous 6 years. In discussions with Mr Hustwit relating to the operational conditions which South African wetlands have to deal with, it was also pointed out that the probable effects of drought periods could be through the reduction and shrinkage of wetland size to make systems which are anaerobic when the wetland is full, aerobic when the wetland empties out, thereby resulting in a potential remobilisation of precipitated metals.

11. RECENT USBM's WORK REPORTED AT THE APRIL 1994 PITTSBURGH CONFERENCE

The USBM presented a total of 22 papers and posters at the recent Pittsburgh Conference. These papers give a very good indication of the most up-to-date information on all the major research projects being undertaken by the Bureau in the field of Mine Water Management and Treatment. The titles and authors of these papers are as follows.

Vol 1

- a) Assessment of contaminant load changes caused by re-mining abandoned coal mines (J W Hawkins)
- b) Chemical predictive modeling of acid mine drainage from waste rock : model development and comparison of modeled output to experimental data (White, Trujillo & Lin, USBM, Salt Lake City)
- c) The effects of anoxic limestone drains on mine water chemistry (Hedin & Watzlaf)
- d) Bench scale test to selectively recover metals from metal mine drainage using biogenic H_2S (Hammack, Duorak, Edenborn, USBM, Pittsburgh)
- e) Pipeline treatment of a metal mine drainage containing copper & zinc (Hustwitz & Sykes, USBM, Pittsburgh)

Vol 2

- f) Hydrologic and water quality characteristics of a partially flooded abandoned underground coal mine (W Aljoe, USBM, Pittsburgh)
- g) Modeling of a reclaimed surface coal mine spoil aquifer using MODFLOW (J W Hawkins, USBM, Pittsburgh)
- h) Hydrologic assessment of well head protection in the vicinity of a room-and-pillar coal mine (Jones, Ellenberger, USBM, Twin Cities)
- i) Evaluation of humidity cell parameters - their effect on precision and repeatability (Pool & Balderramo, USBM, Reno)
- j) AMD clean-up using natural zeolites (Schultze, Xamzolo, Bremner, USBM, Reno)

- k) Evaluation of organic additives used to enhance bacterial sulphate reduction in mine water treatment systems (Borek, Drorak, Hammack & Edenborn, USBM, Pittsburgh)
- l) The role of bacteria in the retention of Fe and Mn in a constructed wetland receiving coal mine drainage (Bickett, & Edenborn, USBM, Pittsburgh)
- m) Use of a bromide tracer to determine retention time of mine drainage in anoxic lime stone drains (Cooper, Brickett, & Borek, Pittsburgh)
- n) Performance of the Howe Bridge passive treatment system (Hedin, Kleinhenz, Odoski & Watzlaf, USBM, Pittsburgh)
- o) Performance of the Morrison passive treatment system (Hedin, Kleinhenz, Odoski, Watzlaf, USBM, Pittsburgh)
- p) The performance of the Jennings Environmental Centre anoxic lime stone drain (Watzlaf, Kleinhenz, Odoski, Hedin, USBM, Pittsburgh)

Vol 3 None on water

Vol 4

- q) Application of an analytical groundwater flow model to a pseudokarst setting in a surface coal mine spoil (W Aljoe, USBM, Pittsburgh)
- r) Investigation of metal & non-metal iron migration through an active phosphogypsum stack (Carter, Smith, Scheiner, USBM, Tuscaloosa)
- s) Geophysical methods: remote techniques applied to mining-related environmental and engineering problems (Ackman & Cohen, USBM, Pittsburgh)
- t) Acid mine drainage abatement using fluidised bed combustion ash, grout after geophysical site characterization (Schueck, Ackman, Scheetz, USBM, Pittsburgh)
- u) Disposing of coal combustion residues in inactive surface mines: effect on water quality (Kim & Ackman, USBM, Pittsburgh)
- v) Assessment of an inactive cyanide heap leach stack located in the South-eastern United States (Boyle, Smith, USBM, Tuscaloosa)

12. SITE VISITS TO USBM WETLANDS

12.1 THE FILSON PASSIVE TREATMENT SYSTEM

The Filson Site is the newest USBM site and construction is still being undertaken at this site. The visit to the site was also undertaken with Mr D A Kepler and Mr E C McCleary of the company, Damariscotta, which is a Company which has designed and built most of the wetlands that the USBM is involved with. The system consists of two ALDs, one with a flow of 30 - 40 ℓ/min , and the other with a flow of 80 - 100 ℓ/min . Each of these ALDs discharges into a separate oxidation pond. A SAPS is also installed on a seep of 100 - 150 ℓ/min , with the discharge also to an oxidation pond.

This wetland system is mainly for iron removal. The incoming water has a pH of 5.3 - 5.5, 350 - 400 mg/ℓ acidity, 150 - 200 mg/ℓ iron, $\pm 20 \text{ mg}/\ell$ manganese

and less than 0.5 mg/ℓ aluminium. As the system was still being constructed, no data was available for the treated effluent.

12.2 THE HOWE BRIDGE PASSIVE TREATMENT SYSTEM

The Howe Bridge passive treatment system was constructed on two flows of acidic, metal-containing water. Both discharges flow through ALDs that discharge into settling ponds. The effluent of the second settling pond flows into a constructed wetland. The first half of the wetland has shallow water flowing over a spent mushroom compost substrate. The second half of the wetland has deep water (1-2 m deep) and a spent mushroom compost substrate that is underlain with limestone gravel. Drainage pipes placed within the gravel, cause water to flow down through the compost and gravel. The discharge of the drainage pipes flows into the receiving stream. The average data for influent and effluent from the system is given below in mg/ℓ.

Parameter	Influent	Effluent
Iron	279	69
Manganese	40	35
Calcium	158	239
Sulphate	1308	1062
Magnesium	106	97
Alkalinity	34	77
Acidity	471	126

The Howe Bridge system is also important in that it includes the first full-scale SAPS system which was ever built. This SAPS system is ± 3 years old.

12.3 THE REM PASSIVE TREATMENT SYSTEM

The REM wetland system is constructed in an area which is saturated with seeps from abandoned coal mines. Two of the larger seeps are intercepted and directed into separate ALDs which give an output pH of 5.5 - 6.1. The ALD effluent still contains very high levels of metals - up to 900 mg/ℓ of iron and 150 mg/ℓ of manganese. The outflow from the ALDs passes through a series of wetland cells and oxidation ponds before finally passing through a SAPS before discharge to the receiving stream. Although actual water quality data was not available, it would appear that between 80 and 90 % removal of iron was taking place with about 60 - 75 % removal of manganese.

12.4 THE MORRISON PASSIVE TREATMENT SYSTEM

The Morrison passive treatment system treats water flowing from the toe of a reclaimed surface mine. Water is intercepted within the spoil by an anoxic limestone drain and then flows through a settling pond and two constructed wetlands. The seepage water feeding into the system has 385 mg/ℓ acidity, 200 mg/ℓ iron and 50 mg/ℓ manganese. Flows are low and vary between 1 and 12 ℓ/min. The treated effluent has a net alkalinity, with a pH of 6 - 8 and iron is reduced to below 3 mg/ℓ with significant reductions in manganese too.

CANADA

MINISTRY OF ENVIRONMENT & ENERGY

1. INTRODUCTION

The Ministry of Environment & Energy in Sudbury was visited on 1 September 1994. Discussions were held with the following persons:

- Tom Brown - Snr Environmental Officer (MISA Section - Sudbury)
- Mr John Hawley - Snr Sector Specialist (Mining Sector - Industrial Effluent Section Programme Development Branch from Toronto)
- Mr Brian McMahon - Snr Environmental Officer (Sudbury district Abatement Section)
- Mr Rick Bradley - Snr Environmental Officer (Sudbury district Abatement Section)

The province of Ontario is a major mining province and a large number of different minerals are mined including salt, gypsum, talc, mica, industrial chemicals, limestone, sand, gravel as well as ornamental stone such as marble and granite. The major mining industry, however, is metal mining, mainly copper, nickel, lead, zinc, iron, gold, silver, uranium, cadmium and other precious metals. Approximately 60 % of the mined metals is gold and the bulk of the remaining metals are copper, zinc and nickel.

The gold ore which is mined in Ontario is not associated with uranium. The background uranium level throughout the province of Ontario is ± 1 gram of uranium per ton of ore. The gold ores do, however, often have mercury associated with them. The Ministry of Environment & Energy has responsibility for the control of environmental impacts from the large range of industries within Ontario. Included amongst these responsibilities is the responsibility for the control of effluent discharges.

The regulation of the discharge of effluent from the different industrial sectors is done by way of the proclamation and enforcement of effluent monitoring and effluent limits for the different sectors. At this stage regulations have been developed and are in the process of being reviewed for the following industrial sectors:

- Organic Chemicals
- Inorganic Chemicals
- Iron & Steel
- Electrical Power
- Municipal (Sewerage)

Regulations already exist for the pulp and paper industry, oil refining, metal casting, industrial minerals and, most recently, metal mining. Finally, a sector of miscellaneous regulations will cover all other industries not covered above.

The miscellaneous section will most probably be in the form of guideline limits rather than regulations. The regulations for the metal mining industry were first released on 27 August 1994.

In the development of effluent limit regulations for the metal mining sector, a wide range of supporting studies was undertaken, including those listed below.

- For the period of 1 February 1992 to 31 January 1991, a very detailed effluent sampling programme was undertaken for all mines in the province of Ontario. Samples were collected at various intervals ranging from 12 per year to over 150 per year per mine and these different effluent samples were analysed for 150 elements. The cost of this programme was ± \$18 million. The results of this survey are published in a status report which sets out in detail the quality of the effluent being discharged from each mine.
- Secondly, the consulting company, Kilborn Inc., based in Toronto was contracted by the Ministry of Environment & Energy to undertake a world-wide study to define best available technology for Canadian mines and other mines with similar ores and climates. The results of this study have also been published in a detailed report.
- Thirdly, a report entitled Risk Assessment and Mine Development and De-Commissioning.
- Fourthly a draft development document for the effluent limits regulation for the metal mining sector.

These different documents provide the information which is available for waste water management and treatment of metal mining effluents in Ontario and also contain numerous references to other information.

2. REGULATION FOR EFFLUENT MONITORING AND EFFLUENT LIMITS (METAL MINING SECTOR)

The most recent effluent regulation released by the Ministry of Environment & Energy relates to the metal mining sector. This regulation was released less than a week prior to my visit and during the coming months discussions will be held with the metal mining industry regarding these regulations. These regulations are fairly stringent and apply to all metal mines who discharge more than 50m³/day of effluent. The guideline regulations which preceded these published regulations are also being applied by the World Bank for mining in Chile.

In the 1990/91 Effluent Monitoring Study, 42 elements were found to routinely exceed the guidelines. Of these 42 elements, 7 are regulated in the effluent limits regulation. These 7 are total cyanide, total suspended solids, lead, copper, nickel, zinc and arsenic. In addition pH limits also exist and toxicity

tests also need to be carried out. The effluent limits were developed by looking on the one hand at the environmental problems and impacts associated with each of the contaminants and then looking at the economically achievable effluent limits using best available technology. On the basis of this assessment, the 7 elements were arrived at. Other problem elements are regulated through the toxicity test.

The regulations can be summarised as follows:

pH of effluents must at all times be within the range of 6 to 9.5. The undiluted mine effluent must be non-toxic both to rainbow trout and to Daphnia species. Rainbow trout need to be able to live in the undiluted mine water for 96 hours whereas Daphnia need to be able to live for 48 hours. The regulations for the 7 problem elements consist of a monthly average concentration in mg/l and a daily concentration in mg/l. The limits are summarised below.

Table 1 : Process Effluent Limits and Monitoring Frequency

Parameter	Monitoring Frequency	Daily Concentration Limit mg/l	Monthly average Concentration Limit mg/l
Total Cyanide	3 x weekly	2	1
Total Suspended Solids (TSS)	3 x weekly	30	15
Copper	weekly	0.6	0.3
Lead	weekly	0.4	0.2
Nickel	weekly	1	0.5
Zinc	weekly	1	0.5
Arsenic	weekly	1	0.5

Sampling needs to be undertaken three times per week for pH, total suspended solids and total cyanide and sampling must be undertaken once per week for lead, copper, nickel, zinc and arsenic. Rainbow trout and Daphnia toxicity tests need to be carried out once per month. If 12 successive tests are passed, then sampling frequency may be reduced to 4 times per year. Monthly testing will resume if a quarterly test is failed. Chronic toxicity testing must be undertaken every 6 months, depending on the achievement of effluents that are non-toxic to rainbow trout and Daphnia. A quality control sample needs to be taken once per year at one process effluent sampling point at a plant. In addition, limits are set for cooling water effluents, for overflow effluents and storm water effluents. Regulations are also set out for procedures by which flow measurements can be undertaken, the types of samples which are permitted, the sampling points, etc.

The effluent limits are based on concentration and not on effluent loadings. This is a departure from the other effluent regulations which have been developed for other industrial sectors where the regulations are based on loadings and not on concentration.

Penalties for non-compliance with these regulations are severe. For example, failure of the toxicity tests would incur a fine for a first violation of \$ 50 000 or a maximum fine of up to \$ 50 000 per day till the problem is rectified. For a second violation, this would go up to a maximum of \$ 100 000 dollars per day. In addition, where there is a deliberate manipulation by a mine to bypass the regulations the responsible person, typically the *Director or Managing Director* at the mine will be jailed.

The Ministry of Environment undertakes two audits per year which can either be announced or unannounced visits. The data collected by the mine must be reported to the public each year and the data must be kept at the mine property for a period of 3 years. A quarterly summary of data is also submitted to the Ministry.

The regulations regarding flow monitoring require that all flow monitoring systems must have an accuracy of no worse than $\pm 15 \%$, as certified by a registered professional engineer.

3. EFFLUENT TREATMENT SYSTEMS WITHIN THE METAL MINING SECTOR

In Canada the metal mining sector tends to rely on chemical and physical processes for effluent treatment rather than on biological processes. This is primarily due to the very cold winters which are experienced. Gold mines in Canada do not generally have acid mine drainage problems although lots of the gold ore that is mine is interspersed with various sulphide minerals, mainly pyrite. The mines generally have a flotation process to recover the pyrites such that the disposed tailings have little or no residual pyrites. The sulphide concentrate is treated in one of three ways.

1. Cyanide treatment which breaks down the sulphides - this is the most common process.
2. Roasting. This process is being discouraged and produces a calcine which is cyanided. The calcine which then typically has a high arsenic content is then disposed of. Arsenic is also discharged into the atmosphere, resulting in atmospheric pollution problems. To address these problems, technology has been developed through funding by the Ministry of Environment, to remove arsenic from levels of 200mg/ℓ down to 3 µg/ℓ.
3. High pressure leaching in autoclaves.

With regard to cyanide in mine effluents, no cyanide recovery is done in Canada. The AVR process has been tried at one location in Canada but has been discontinued and is considered a dangerous and hazardous process. The cyanide is dealt with in a wide range of different cyanide destruction processes. The Ministry of Environment has also sponsored research together

with the Australian Mining Industry on the destruction of cyanide and has developed the Vitrokele process which is a patented process for safely recovering cyanide. The process uses chelating resins and produces a cyanide solution which is sent back to the mill at 1.5 % concentration making it suitable for use directly in the process. This technology is also capable of extracting metals.

Research is also being done into using soluble silicates together with lime which would enable metals to precipitate at much lower pH values, resulting in cost savings from lime addition. The use of sulphides, particular sodium sulphide is also being looked at as this also produces very stable precipitates.

The basic treatment process used at the mines is a high lime addition up to a pH of ± 10.5 to precipitate metals. The high pH of this water then needs to be reduced in order to meet the effluent regulation limits. One of the processes which is being used in Canada to reduce the pH of alkaline water is the injection of carbon dioxide. The Canadian mining industry is also encouraged to reuse effluents as far as possible and, according to calculations by the Ministry of Environment, the industry at present reuses $\pm 85\%$ of its effluents.

The issue of submerged tailings disposal was discussed with the Ministry and it became quite clear that although this approach may be favoured by mining companies the Ministry for Environment does not view this process very favourably. The effluent regulations which apply to the metal mining sector are considered as minimum standards and situations may well be found where mining companies are subject to stricter regulations. A less stringent effluent limit will not be possible.

4. START UP AND CLOSURE OF MINES

For a new mining operation which wishes to start up in the province of Ontario, a number of documents and approvals need to be obtained before mining can be commenced. In this exercise the lead agency is the Ministry of Northern Development and Mines which will bring all the other agencies together. Prior to the preparation of any documentation the mining company would undertake pre-planning discussions or pre-consultation on an informal basis with the different agencies. The mine would then prepare a number of environmental studies, the need for which would be determined on a site-specific basis during the pre-consultation phase.

Typical studies which could be required could include hydrological studies, receiving stream impact assessments as well as the generation of background water quality data. On the basis of the studies undertaken, the mine would then make an application to the Ministry of Northern Development and Mines for mining. The Ministry of Northern Development and Mines would then have discussions with the other agencies and reports and documentation would also be reviewed by the different agencies. The

mine would then get a certificate of approval to mine which would then set the limits and restraints on mining. The mine would need permits for dewatering and discharge of effluents and would also need permits from the Ministry of Environment for any construction processes which are undertaken. The process of obtaining a certificate of approval may or may not require public hearings as well.

The province of Ontario also requires mines to post a bond and also to prepare and present detailed closure plans which include a monitoring programme. With regard to the closure of mines, the existing situation requires that a quit claim be signed by the authorities which would then enable the mine to walk away from the site. On receipt of a signed quit claim the responsibility for pollution control at the site reverts to the state. At present no quit claims are being signed. It was proposed that in future a exit ticket be the requirement for mines to be able to discharge their responsibilities at a mine. The exit ticket would only be obtained when all the different agencies are happy with the level of pollution and the pollution control systems which are installed at a site.

The approach and regulations with regard to the closure of mines is presently being looked at and developed.

FALCONBRIDGE MINES

1. INTRODUCTION

The Falconbridge mines, which are approximately an hour's drive from Sudbury, were visited on 1 September 1994. The visit was undertaken together with Messrs. Tom Brown and Rick Bradley from the Ministry of Environment and Energy. Mr Joseph Fyfe, Supervisor - Environmental Services for Falconbridge, also accompanied us on the site visit.

The Falconbridge operations encompass 4 operating mines which are all underground operations. The mines discharge their tailings and all effluents into the Moose Lake system. All discharge from all sections of the mine is routed into this lake. The outflow from this lake is then neutralised by the addition of lime to a pH of ± 10.5 . The neutralised effluent is then discharged into a very large lake where settling then takes place. The outflow from this lake is then injected with carbon dioxide to drop the pH to ± 8.5 before the water is discharged. Potable water is used for all the mining purposes.

2. CO₂ DOSING PLANT

The CO₂ dosing plant injects gaseous CO₂ into a decant tower directly into the effluent being discharged from the settling lake. The dosing of CO₂ is a continuous operation and the dosage rate of the CO₂ is adjusted daily on the basis of daily flowrate readings, pH readings and allowable dilution limits in the receiving stream. The incoming water has a pH of between 10 and 10.5 during winter months and ± 9 in summer months. The effluent of the discharge from the CO₂ plant is ± 7.5 . The CO₂ system has been in operation from 1990 onwards. Prior to this, the mine did not have a lime dosing plant but had a limestone system which did not allow the pH of the water to increase to above ± 7 . There was therefore no need for a downward adjustment of pH. The total operating costs including maintenance and CO₂ chemical costs are $\pm \$150\,000$ (Canadian) to treat an estimated 16 million m³ of effluent per year. This equates to a cost of ± 1 c/m³. The CO₂ dosing rate varies considerably at ± 200 pounds per day in summer going up to 4000 pounds per day in spring to cope with the spring melt.

3. LIME DOSING PLANT

The lime dosing plant is situated on the outflow from the Moose Lake. Approximately 600 gpm of water is extracted from the Moose Lake and sent to the lime plant where it is mixed with a slaked lime slurry and then pumped back to the discharge point from Moose Lake where it is mixed with the water prior to discharge into the settling pond. The lime plant increases the pH of

Moose Lake outflow water from 3.5 to 11 to precipitate heavy metals into the downstream settling basin. Approximately one third of the outflow from Moose Lake which is being treated is water from the mining operations and the other two thirds can be ascribed to natural run-off from the catchment of Moose Lake.

The water in Moose Lake has metal concentrations which exceed the allowable limits. Nickel is 1,5mg/l, copper 0,3 mg/l, and iron 4 mg/l. The operating costs of the lime plant, including chemicals and maintenance is about \$350 000 per annum, of which \$150 000 is chemicals and \$200 000 is maintenance. This equates to a cost of $\pm 2,2$ c/m³.

4. TAILINGS DISPOSAL

The tailings from the Falconbridge operations are discharged at the top of a hill and are allowed to flow naturally into the valley eventually filling up the major portion of the valley. Some of the recent developments with regard to tailings disposal is to separate those tailings which have a high pyrite component and to dispose of those at the lowest point of the valley. These pyrite tailings would then be covered with ± 3 m of normal tailings. The mine at this stage does not have any closure plans or proposals as to how this tailings dam will be successfully closed. The tailings cover a very large area and it can be anticipated that this method of tailings disposal will result in long term pollution problems - depending on how effectively the reactive tailings are isolated from the hydrological cycle.

5. MONITORING SYSTEMS

The mine monitors the flow of the total volume of effluent discharged from the mining operations by taking a manual gauge plate reading on a rated culvert beneath a road. pH is also monitored at a number of points within the effluent treatment system, including the final effluent discharged to the river system. The monitoring is also undertaken for compliance with the dilution limits which the mine has to comply with. These allow the mine to discharge effluent which has a volume of no more than 10 % of that of the receiving water stream.

6. GENERAL IMPRESSIONS

The environmental impact of the Falconbridge operation appears to be quite significant. The primary source of this impact is the tailings disposal system where tailings are discharged into a valley. The system at Falconbridge does not enable the separation of clean stormwater from the contaminated seepage, drainage and run-off from the tailings area and the mine effluents. As a result of this, the mining site produces some 16 million m³ per annum of

contaminated water which then needs to be treated. This equates to a discharge of $\pm 50 \text{ Ml/day}$.

Of particular interest at Falconbridge is that despite having a requirement for large scale neutralisation of the water from a pH of 3.5 up to ± 11 with subsequent addition of carbon dioxide to drop the pH to ± 7 , this treatment is reportedly done at the very low cost at about 3 to 4 cents per m^3 .

LAURENTIAN UNIVERSITY

The Laurentian University was visited on 2 September 1994 where discussions were held with Mr Ron Slater, Assistant Librarian and co-editor of the Mining Environment Database as well as Mr Glen Kelly, Associate Librarian and also co-editor of the Mining Environment Database. The purpose of the discussions at the Laurentian University was to discuss the capabilities and access to the abandoned mines, acid mine drainage and the Land Reclamation Database also known as the Mining Environment Database.

This database is a very specific database which focuses on the environmental aspects associated with hard rock mining, although limited information is also given on coal mining. The database was developed as a means of providing the Mining Industry with access to information which was required to be able to prepare closure plans and to be able to comply with the environmental management regulations which were being developed in Canada in the late 1980's. The mining environment database was started in May 1988 through funding from the Ministry of Northern Development & Mines together with the Ministry of Environment.

This database, which presently has over 10 000 citations together with a 5 to 10 line abstract on each citation, provides references and abstracts to journal articles, books and government reports dealing with abandoned mines and land reclamation. Topics covered by the database include reclamation planning, design and cost, tailings, heavy metals, disposal of hazardous waste including acid mine drainage, sulphide based tailings and asbestos particles. Chemical reactivity and oxidation affecting pyrite and pyrrhotite tailings, leaching, radioactive hazards of uranium tailings, soil stabilisation, soil and water contamination, liming, fertilisers, seeding techniques, mine closure techniques and other related topics.

Subject coverage is international in scope although discussions with university staff indicated quite clearly that no information is available on South African research. This is due to the previous sanctions programme against South Africa. In the discussions with staff responsible for the Mining Environment Database a request was made for names, addresses and contact details for individuals in South Africa as the staff would very much like to include information from South Africa within the database.

The database can be accessed by a number of different techniques. In the first instance a stand alone IBM compatible PC version of the database can be purchased from the University at a cost of \$ 275. Yearly updates will then be available at a cost of \$100. Alternatively the database can be accessed free of charge through the Internet system.

INCO PLANTS

1. INTRODUCTION

The Inco plants near Sudbury were visited on 2 September together with Mr Tom Brown of the Ministry of Environment & Energy and Mr D F Bouillon, Inco's Environmental Officer. The Inco plant consists of two smelting operations, a copper smelter and a nickel smelter together with a central milling plant which receives ore from up to 12 different mines in the area around Sudbury. Details on the plant operation should have been sent to me by Mr Bouillon, although these never arrived. The mine processes some 12 million t/annum of ore to produce 120 000 tons of nickel and 130 000 tons of copper. The mine has 7000 employees.

The basic water management problem at Inco is the treatment of water drained from the tailings dam together with stormwater run-off within the tailings dam catchment area. All tailings and all liquid effluents are routed to the tailings dams where a certain amount of evaporation and seepage takes place. All the excess water then runs off from the tailings dam and is decanted from the tailings dam and routed to the water treatment plant. The catchment area upstream from the water treatment plant comprises some 7600 hectares of which \pm 3800 hectares is urban area, mainly the town of Coppercliff and \pm 3800 hectares is tailings. The annual precipitation for this area is about 750 mm. Similarly to the Falconbridge operation, the mine finds itself in a position where it is treating a large portion of natural run-off water which is mixed with the tailings runoff.

2. WATER TREATMENT PLANT

The Inco operations have a water treatment plant which is designed to remove heavy metals, predominantly iron, copper, nickel and zinc to levels mandated by the Ministry of Environment. The plant inflow is first screened on rotary screens to remove debris and vegetation which comes from the tailings dam. The screened inflow is then dosed with lime and fed to two large circular clarifiers which operate on a sludge blanket principle. The overflow from these clarifiers is very clear and is discharged directly into the stream. During high flow conditions, a portion of the run-off from the tailings bypasses the treatment plant and feeds directly into the stream. Specifications on the performance of this plant together with the costs associated with this plant were to have been included with the documentation supplied by the mine.

The plant has a rated capacity of 225 000 m³/day but treats an average flow of \pm 150 000 m³/day. The water fed to the treatment plant only represents 30 % of the water decanted from the tailings dam. The remaining 70 % of the water is sent directly to the mill for use within the process.

3. TAILINGS DAMS

The mine operates a very extensive tailings dam system with a total surface area of some 3 800 hectares. Slime is deposited through a perimeter pipe with spigots. Walls of the slime dam are constructed from slime material and at present the mine has a full-scale experiment being undertaken where mulch, which is a waste material consisting of waste lignin and cellulose from the pulp and paper mill is sprayed onto the sidewalls of the slimes dam to prevent the generation of dust. Visual inspection of this mulch shows that it forms quite a solid mat of ± 2 or 3mm thickness over the surface of the tailings, effectively preventing dust.

Seepage from the toe of the tailings dam is collected in a number of toe dams and pumped back onto the tailings dam. The bulk of the tailings deposited on the tailings dams do not contain sulphide acid generating materials and are very easily rehabilitated. In fact the level of rehabilitation in terms of grass and tree establishment on the slimes dam is quite impressive. Discussions with mine staff indicate that they perceive that the tailings site will be a pollution source in perpetuity and the mine plans to continue a permanent care and maintenance programme after closure.

PAMOUR - ROYAL OAK MINES

The Pamour mine which is one of the mines belonging to the Royal Oak Mines Group near the town of Timmins was visited on 6 September 1994. The visit was undertaken together with Mr Tom Brown of the Ministry of Environment & Energy from Sudbury and Mr Mitch Seguin from the Timmins District office of the Ministry of Environment & Energy and Mr Mark Bednarz, the Environmental Officer for Pamour Mine.

The Pamour Gold Mine is a fairly small operation and consists of one underground mine and two opencast operations producing a total of ± 3350 tons/day of ore at an average ore grade of 0.06 troy ounces/ton of gold. The ore is treated in a Merrill Crowe process. The tailings from the plant are separated and disposed of in different ways. The cyanide tailings which comprise ± 50 to 60 t/day is separated and disposed of in a total containment system which has no discharge to the environment other than evaporation and seepage. The total cyanide in tailings as disposed is $\pm 300\text{mg/l}$. The groundwater and surface water systems adjacent to this tailings dam are monitored and, to date, no cyanide has been found in either the ground or surface water systems. The flotation tailings which make up the bulk of the tailings are sent to a separate tailings dam. These tailings have a net neutralising potential and do not produce any acid mine drainage and no problems are envisaged with regard to closure of these tailings dams.

The mine also has a 1 million gallon underground dam which is filled with water entering the underground workings. This water serves as the water supply to the mill. All seepage and decant from the flotation tailings system is discharged directly to the surface water systems without any treatment. The construction system for the tailings dam incorporate walls to the tailings dam which are built from the slime material. The walls are built at roughly 2 year intervals at which stage a lift of between 1-2 metres is made. This lift is constructed using conventional earth moving equipment such as backactors and bulldozers.

Rehabilitation on the disused tailings dams is very lush and there appears to be no problem in establishing vegetation on these tailings dams. All that is required is to plough the surface, add fertilisers and apply seeds. The only real water management problems experienced by the mine are those which relate to the activities of beavers which build dams in the streams, resulting in wet conditions at the toes of the slimes dams.

DOME MINE

1. INTRODUCTION

The Dome mine which is a gold mine belonging to Placer Dome Inc. was visited on 6 September 1994. The mine was visited with Mr Tom Brown, Senior Environmental Officer from the Ministry of Environment & Energy's Regional Office in Sudbury together with Mr Mitch Sequin, Senior Environmental Officer from the Timmins district office of the Ministry of Environment & Energy and Mr Ron Connell, Superintendent of Analytical Environmental Services of Dome Mine.

The mine produces some 4100 tons/day of ore of which $\pm 65\%$ is produced in underground mines and $\pm 35\%$ in open pit operations. The average grade of this ore is 0,12 troy ounces/ton. All the ore is treated in the CIP plant. The mine has expansion programmes to substantially enlarge the open pit operations to increase the daily ore production to 10 000 tons/day. All liquid effluent and tailings from the mine operation are discharged to the number 6 tailings dam. This tailings dam has a surface area of ± 700 hectares and is constructed in a natural drainage basin. About 15 to 20 % of the tailings produced in the plant is sent underground as backfill.

The decant water, together with other effluents, is stored within the tailings dam system until a point is reached where the concentration of nickel and copper in the water drops to below 0,75 mg/l. When this occurs, water is discharged from the tailings dam to the river at a rate of $\pm 50\,000\text{ m}^3/\text{day}$. In an average year, the mine is able to discharge water for ± 8 weeks/year. To overcome this problem and also to be able to cope with the new discharge regulations which would set much more stringent standards for nickel and copper, the mine has designed and is presently constructing a chemical treatment plant for removal of copper and zinc.

2. EFFLUENT TREATMENT PLANT

The chemical treatment plant being constructed at the mine is being built for the sole purpose of removing copper and nickel to below 0,1 mg/l. The process involves increasing the pH of the incoming water from $\pm 9,5$ to 11 by the addition of lime. Ferric chloride will then be added to this water and the metal precipitates will then be removed in a reactor clarifier. The underflow from the clarifier containing the metal precipitates will be discharged onto the tailings dam while the overflow water will be injected with carbon dioxide to reduce the pH to $\pm 8,5$ before discharge to the river system. The rated capacity of this plant is 10 Ml/day. The capital cost of this plant is $\pm \$3,5$ million and the operating costs are estimated to be in the region of \$ 400 000 per

year, based on a throughput of 270 m³/hr. The plant will be fully automated with no on-site operators.

3. TAILINGS DISPOSAL

The tailings are delivered from the plant to the tailings dam through pipelines which have a length of ± 8 kms. Wherever these pipelines cross river systems the pipelines are placed within a bunded area which has a capacity to hold two hours worth of slime. The tailings pipeline is manually inspected four times a day.

The mine has already filled five tailings dams which range in surface area from 30 to 100 acres. The present active tailings dam, the No. 6 tailings dam has a surface area of 700 acres. The tailings material which is deposited here has ± 4 % sulphide material and is comprised predominantly of carbonates. The tailings have a net neutralising potential and the mine does not presently experience nor does it anticipate in future to experience problems with acid mine drainage. The closure of these tailings dams is therefore not perceived as a problem.

In order to verify the predictions with regard to the long term behaviour of the tailings dams, the mine has 51 groundwater monitoring wells together with 30 piezometers installed around the different tailings dams. The tailings dam walls are constructed as proper civil engineering structures with a compacted clay core, covered with a waste rock compacted cover. Tailings are discharged to the tailings dams at ± 40 % solids : 60 % water. The tailings are discharged into a natural basin and the complete tailings area, together with all the topographical features, sampling points, monitoring points, etc., are installed on a computerised GIS enabling the mine to accurately predict the extent of inundation at any given point of time.

During the site visit, the various tailings dams were all in different stages of rehabilitation. The No. 6 tailings dam is the operational dam. The No. 4 tailings dam has recently stopped accepting active tailings and is about to be profiled for rehabilitation. The No. 5 dam has been rehabilitated and seeded and drainage swales are being constructed at the moment to allow decant of water falling onto the top of the tailings dam after closure. The drainage swale is a long gently sloping drainage channel with a geomembrane with 6 inch rip-rap placed on top of it.

On closure of a tailings dam, all outslopes will be graded down to a minimum slope of 3 : 1. The cost for site preparation and seeding are \pm \$800 per acre for the tops of the tailings dam and \pm \$3000 per acre for the slopes. Hydro-seeding is used on the side slopes. The level of rehabilitation of these tailings dams is very high and as these tailings dams have a neutralising potential, they require nothing more than a slight dressing of fertiliser prior to seeding.

WASTEWATER TECHNOLOGY CENTRE - TORONTO

1. INTRODUCTION

A visit was made to the Wastewater Technology Centre on 7 September 1994. Discussions were held with Messrs. Abbas Zaidi, Manager of the Industrial Division, Larry Whittle, Supervisor of Technical Programmes in the Industrial Division and David Averill, Snr Process Engineer, Solid Liquid Separation.

The Wastewater Technology Centre (WTC) was established in 1971 by Environment Canada as a research and development laboratory. Environment Canada is the Federal Ministry which is empowered to develop regulations and to fund research and development projects with regard to wastewater. In 1991, the WTC came under the contractual supervision of Rockcliffe Research Management Incorporated, thereby converting the WTC from a government institution to a privately managed institution. The WTC undertakes collaborative work with industries, universities and international organisations into various technologies relating to environmental degradation. The WTC has research programmes in the fields of advanced wastewater treatment, residue management, control systems and site remediation. The advanced wastewater treatment programme, also known as the industrial programme, looks at identifying and developing innovative approaches to wastewater treatment in various industrial fields.

Projects are undertaken in the fields of biological treatment, membrane processes, oxidation reduction systems, absorption, ion exchange, thermal processes, solid liquid separation and the modelling of toxic contaminants. The residue management programme, also known as the Municipal programme, looks at sludge management, waste characterisation and waste containment. The programme on control systems looks at pollution control planning, storm water management, enhanced process auditing and control, dynamic model based simulation and plant performance modelling. The site remediation programme looks at site characterisation and assessment, remedial strategy development and innovative technology development.

With regard to research relating to the mining industry, the WTC has been active mainly in the fields of uranium and gold mining. Research which may be of particular interest to the South-African Mining Industry is that which has been undertaken on the removal of radium, the destruction and recovery of cyanide and the development and evaluation of membrane technologies.

2. REMOVAL OF RADIOACTIVITY

The WTC, some 12 or 15 years ago undertook research on the development of a physical chemical treatment process for the removal of radium 226 from the effluents of uranium mining and milling operations. The process consists

essentially of barium-radium co-precipitation in stirred tank reactors followed by solid liquid separation in chemically aided dual medium filters. The process was demonstrated at pilot scale to provide an effluent with less than 10 pCi/l of total ^{226}Ra and less than three pCi/l of dissolved ^{226}Ra . The particular interest in this technology is that it may (subject to barium recovery), show potential for application at the underground settling installations in the SA gold mining industry. The barium chloride which is added to the water forms a precipitate which could possibly be removed quite effectively in the underground settling systems.

3. CYANIDE REMOVAL

The WTC has undertaken a large amount of work on cyanide removal and cyanide recovery systems. All this work has been summarised and has been included and presented in a software program known as METEX (Mine Effluent Treatment Expert System). A demonstration version of this program is available and the full program can be purchased from the WTC for \$ 2500. The programme is fairly impressive in terms of its capabilities with regard to designing, specifying, and costing systems for the removal of cyanide. Before this programme would be of any use to the South African mining industry, additional research would need to be done to calibrate the model for South African conditions.

4. GENERAL IMPRESSIONS

The WTC has a staff complement of ± 110 people and is quite clearly a very professional organisation specialising in wastewater treatment. A number of other areas relating to municipal treatment, site remediation, solid/liquid separation, filtration, biological treatment, etc. have potential application in South Africa. With regard to the development work on membrane systems which covers all types of membranes, electrodialysis, reverse osmosis, ultra filtration and nanofiltration, it is believed that Prof Chris Buckley of Natal University has already made contact with the WTC.

SENES CONSULTANTS LTD

1. INTRODUCTION

Senes Consultants Ltd in Toronto was visited on 8 September 1994. Discussions were held with Dr Douglas B Chambers, Principal Partner, Head of the Radioactivity Section and Executive Vice President and Director of Radioactivity & Risk Studies, Mr Gerd M Wiatzka, Snr Project Engineer in the Mining Decommissioning and Waste Management Sections, and Mr David Orava, Snr Engineer.

Senes Consultants was started in 1980 and has since grown from a staff of 9 to over 70 employees. Senes has Canadian Offices in Port Hope, Ontario and Vancouver, with the Head Office in Toronto. Senes also has 3 affiliated companies in Nevada, Canada and the USA. Senes Consultants is involved in a wide range of environmental projects including work on acid mine drainage, aquatic environment, atmospheric environment, biotechnology, data management, statistical analysis, environmental assessment audits and management, hazardous and low level radioactive waste management, mining, occupational health, public participation, radioactivity, remedial actions and decommissioning, risk assessment and solid waste management.

2. WASTEWATER TREATMENT

Senes Consultants undertakes work on a wide range of wastewater treatment options. With regard to the mining industry, this work covers aspects relating to neutralisation, solid/liquid separation, metals removal (mainly through physical and chemical processes) as well as the removal of radionuclides.

One of the recent reports completed by Senes Consultants for CANMET is titled "Acid Mine Drainage, Status of Chemical Treatment and Sludge Management Practices". This report was prepared in June 1994 for the MEND Programme.

The report covers aspects on the generation and chemical treatment of acid mine drainage. In terms of treatment, it looks at conventional chemical treatment with limestone, lime, caustic soda and soda ash. It also looks at the sulphide precipitation of metals. It looks at lime treatment processes, basic technology and also the high density sludge process. A number of non-conventional chemical treatment processes are also discussed, including copper segmentation, selective iron removal, selective precipitation of other metals, ion exchange, solvent extraction and other methods of metal recovery. With regard to sludge, the report covers the characteristics of lime treatment sludge in terms of chemical composition, sludge stability and dewatering and disposal of sludges.

The report, importantly, also looks at the post-closure treatment issues with regard to chemical treatment plants and assesses the long term post-closure treatment of acid mine drainage and the related costs over a 100 year period. The report also presents detailed analysis for four different case studies. A number of studies have also been undertaken in the past with regard to the development and testing of processes for the removal of radium and uranium.

3. TAILINGS MANAGEMENT

Senes Consultants is also extensively involved in tailings management and advising mines on different tailings management practices in terms of acid generation, appropriate rehabilitation, reclamation of tailings and treatment of liquid effluents and seepage from tailings systems.

One of the most recent studies which was undertaken by Senes Consultants is titled "The Evaluation of Dry Covers for the Inhibition of Acid Mine Drainage from Tailings". This report looks at a wide range of different options for dry covers as means of inhibiting acid mine drainage. The report gives an overview of the current state of knowledge, looks at oxygen transport barriers, oxygen consumption barriers and reaction inhibiting barriers. Detailed discussions are presented of alternate dry cover materials including natural soils, processed soils, oxygen consuming materials, moisture infiltration barriers, chemical agents and inhibitors and special applications. The report also presents some screening criteria for proposed dry cover alternatives and then undertakes a detailed analysis of all the different identified dry cover materials in terms of these screening criteria. Finally, the report presents a critical review of the high priority dry barrier materials and also identifies research needs with regard to dry barriers for tailings dams.

4. MODELLING OF LEACHING FROM WASTE DEPOSITS

Senes Consultants has developed a very unique geochemical model which is being used throughout the world for the modelling and prediction of acid mine drainage generation from fine tailings such as found in the gold mining industry all the way through to waste rock dumps and coal discard facilities. This leaching model is superimposed on a hydrological model and has the capability of predicting the generation of various pollutants, including metals, major cations, anions and radionuclides.

Senes Consultants have developed a number of variations of their water quality model which are used for different situations. They have models which have been developed for the evaluation of disposal or residue dumps, models which could be used for the evaluation of rehabilitated opencast mines as well as models for the evaluation of underground mining operations. The models are used quite extensively in evaluating various closure options

and post-closure effects of various rehabilitation and decommissioning practices.

The model which has been developed by Senes is not commercially available and is applied by Senes personnel. The model has been developed in such a manner that Senes Consultants feel quite confident that they would easily be able to modify the model and calibrate it for South African conditions.

UNITED KINGDOM

NATIONAL RIVERS AUTHORITY (NRA)

1. INTRODUCTION

The NRA in Exeter was visited on 13 September 1994. Discussions were held with Mr John Taberham who is the Engineer in charge of rehabilitating and instituting water pollution and control measures at the Wheal Jane site. The National Rivers Association (NRA) is an independent public body, established in 1989 which serves as an environmental protection agency with the task of safeguarding and improving the natural water environment. The NRA is accountable to Parliament and has statutory responsibilities and powers in relation to a number of important functions including pollution control, water resources, flood defence, fisheries, conservation and recreation. Policy issues are co-ordinated by the NRA's Head Office in Bristol and policy decisions are made by a national board appointed by the Government.

The day to day operations of the NRA are handled by 8 regions distributed across the country. The region within which Exeter falls is known as the South Western Region. The South Western Region of the NRA is responsible for an area covering just under 21 000 square kilometres and includes Avon, Cornwall, Devon, Dorset, Somerset and parts of Gloucestershire, Hampshire and Wilshire.

The discussions with Mr Taberham focused primarily on the issues relating to Wheal Jane, the history of the Wheal Jane site and the past, present and future water pollution control systems at Wheal Jane. The broader issues of dealing with effluents from the many abandoned mining operations in the South Western Region were also briefly discussed, although the appropriate person at the NRA to discuss policy issues with, was not available at the time of the meeting. On the basis of discussions with Mr Taberham, it was apparent that the NRA does not presently have a national strategy for dealing with the problems associated with seepages from abandoned mining operations, although this is an issue which appears to be receiving some attention.

2. WHEAL JANE SITE

The Wheal Jane Site is an abandoned tin mine which had been abandoned by Carnon Consolidated Ltd who currently are still operating the plant area to process ore from the mine at South Crofty. The interesting situation which exists here is that, despite the fact that Carnon Consolidated Ltd is still operational in the area and is in fact still using the tailings dam at the Wheal Jane Site, they have no liability or responsibility for the pollution problems at Wheal Jane and these are being dealt with and financed by the NRA. In fact the NRA is paying

the mine for the use of the tailings dam for the precipitation of chemical sludges from the treated mine water.

During the operational life of the Wheal Jane Mine an ongoing dewatering programme depressed the water table by ± 400 metres at the mine site. The mine was then closed in 1991 and pumping operations ceased.

In anticipation of the discharge of water from the flooded mine, the NRA instituted a temporary chemical treatment system for the treatment of the polluted mine water prior to discharge of this water to the Carnon river. Mine water reached the surface of the shaft in November 1991 but then in January 1992, an underground plug in the Mangiles adit unexpectedly failed. As a result of this failure, over 10 million gallons of heavily contaminated water burst from the mine workings into the Carnon river. This water, which is highly acidic, contained significant quantities of dissolved heavy metals, reaching more than 500 mg/l at its peak. The metals contained in this water include copper, zinc, arsenic and iron and a very spectacular pollution plume was produced which spread down the Carnon water and into Falmouth Bay. This pollution incident received wide media coverage in the UK and internationally.

As a result of this major pollution problem, the NRA has undertaken extensive modifications to its chemical treatment system. The water from the adit was prevented from escaping by plugging the adit and a submersible pumping system was installed in the shaft to keep the head of water at an acceptable low level. Water is pumped up from underground through the shaft and is dosed with lime to neutralise the acidity of the water and to enable the precipitation of metals. A flocculant is then added to the neutralised water to enhance the coagulation of the metal precipitates. The flocculated water is then discharged into the tailings dam from where the clarified water is then decanted, passed through a polishing lagoon and discharged into the Clemows stream which discharges into the Carnon river. The metal precipitated sludge is then left on the mine tailings dam which was originally designed to store mine tailings arising from the milling operations carried out on the site. In the period 1992 to February 1994 these temporary treatment measures have removed some 9000 tons of heavy metals from the mine effluents. The chemical treatment is, however, only seen as a temporary treatment step and an extensive research programme has been undertaken to identify the final treatment technologies.

Two parallel research projects are underway at the Wheal Jane Site. The first and most important research project is that relating to the passive treatment system which has been installed. However, in parallel to the passive treatment system, a number of active treatment systems are also being investigated at the Wheal Jane Site. The purpose of these research projects is to identify the appropriate long term treatment which can be installed at a full scale size for the treatment of the Wheal Jane effluents. The continuous flow which is being pumped from the Wheal Jane site at the moment is ± 150 l/second.

A site visit was made to the pilot passive treatment system at Wheal Jane and additional details on this system are also found in the site visit report. In essence the passive treatment system comprises of 5 different operations. In the first instance, the water from the Wheal Jane adit, passes through an anoxic pond which takes it through a cattle manure and straw mixture to remove the oxygen from the system. The anoxic water is then passed into an anoxic limestone drain to neutralise the acidity and to add alkalinity to the water.

The water from the anoxic limestone drain would exit at a pH of $\pm 5 - 6$, be aerated and then discharged into an aerobic reedbed. The iron will precipitate as a ferric hydroxide in this aerobic cell and the effluent from the aerobic cell will then be passed to an anaerobic cell which contains a cattle manure and sawdust mixture, to provide some sulphate reduction, thereby releasing sulphides to enable the precipitation of the zinc, copper and other heavy metals in the effluent. The effluent from the anaerobic cell would then pass over a rock filter for final removal of manganese before being discharged to the Carnon river.

The pilot-scale system which is being installed at Wheal Jane will be monitored for a period of 6 to 18 months. The pilot treatment site also includes extensive continuous monitoring systems as well as extensive grab sample and flow monitoring systems. On the basis of the data collected from this pilot treatment system the NRA will then be in a position to cost the full-scale treatment systems required for the Wheal Jane operation and a decision will then be made as to how the pollution problem at Wheal Jane should be addressed.

3. ADDITIONAL NOTES

The temporary chemical treatment which is being applied at the Wheal Jane site has a cost of ± 13 pence per m^3 .

WHEAL JANE PILOT PASSIVE TREATMENT SITE

The Wheal Jane site was visited on 14 September 1994. Discussions were held with a number of people, including the following:

- Mr Richard H Coulton - Site Manager for the Wheal Jane Site
- Mr Andrew Lang - Associate with Knight Piesold
- Mr Mark E Dodds-Smith - Principal Environmental Scientist (Knight Piesold)
- Dr Paul L Younger - Dept of Civil Engineering (University of Newcastle)

Messrs Coulton, Lang & Dodds-Smith are all associated with Knight Piesold who are the responsible Consulting Engineers for the Wheal Jane Site whilst Dr Younger has been appointed by the NRA as an external review consultant to review the design, construction and operations at the Wheal Jane Site.

The experimental passive treatment systems at the Wheal Jane Mine comprise of three different pilot treatment systems which were built at a total cost, excluding fees paid to the consultant, of \pm £1 million. The three different pilot treatment schemes differ primarily in terms of the systems which have been put in place for pH control. Each one of the passive treatment systems contains a number of aerobic cells followed by an anaerobic cell, followed by rock filter.

In terms of the pH treatment systems, three different options are being investigated. In the first instance, for pilot treatment scheme 1, an active lime dosing system is being used where lime is being dosed to a pH of \pm 4.5 - 5 prior to the water entering the five series aerobic cells.

In pilot treatment scheme 2, the acid mine water is passed through an anaerobic pond prior to being fed into an anoxic limestone drain. The purpose of the anaerobic pond is to reduce the dissolved oxygen in the acid mine water to below 2 mg/l prior to feeding this water into the ALD. The water exiting the ALD is then fed into five series aerobic cells, followed by an anaerobic cell and a rock filter. Piping arrangements have been installed at the site for pilot scheme 2 to allow different configurations for bypassing the anoxic limestone drain or portions of the anoxic limestone drain.

Pilot treatment scheme 3 has no chemical neutralisation taking place and this system comprises of larger aerobic cells with the intent being that the aerobic cells will provide some pH neutralisation of the water.

The pilot treatment systems at the Wheal Jane Site were in the process of undergoing final construction and commissioning was due to take place in the next few weeks.

During the site visit, extensive discussions were held with the Knight Piesold staff and the different pilot treatment systems were visited and studied

carefully. On the basis of the discussions and observations on site and taking into account the discussions held with passive treatment experts in the USA, a number of potential problems or concerns with the Wheal Jane passive treatment system could be seen.

In the first instance, a number of potential problems can be identified for each one of the envisaged pH control systems which have been installed. Firstly, with regard to the anoxic lime stone drain - based on the discussions with Knight Piesold staff it would appear that the influent water to the anoxic limestone drain has an aluminium content of $\pm 40\text{mg/l}$. On the basis of experience developed in the USA, it can be expected that the ALD will experience problems with hydraulic clogging due to the formation of aluminium hydroxide sludge within the ALD, unless the upstream anaerobic pond can remove all the aluminium by raising the pH to above 4.5 - 5.

Secondly, in discussions with Knight Piesold staff it would appear that the precise concentration of ferric iron in the influent water is unknown. As it is known that ferric iron will cause problems with armouring of the limestone within the ALD, it is considered important that the values and levels of the ferric iron content be determined and that appropriate measures be taken to remove this ferric iron prior to treatment in the ALD. As part of the ALD arrangement, Knight Piesold have installed an anaerobic pond upstream of the ALD. This anaerobic pond comprises of a compost bed which is being designed to remove the dissolved oxygen to a level of 2mg/l . The designed level of 2mg/l of dissolved oxygen is considered to be quite high and potential problems with iron armouring of the limestone could still be anticipated at this level. The Knight Piesold staff could not describe with certainty what the effect of the anaerobic pond would be on the reduction of any ferric iron in the water to ferrous iron.

Finally, the ALD has been constructed of limestone with a nominal size of 20mm. Based on the North American experience, this would appear to be very much on the low side, particularly bearing in mind the high levels of aluminium and the high likelihood of the formation of aluminium hydroxide within the ALD. On the basis of these observations it is possible that the ALD will experience severe problems.

With regard to the lime dosing system, the system is being designed to increase the mine water pH to between 4.5 and 5, this being the level at which large volumes of calcium hydroxide sludge are not yet formed and the level at which the iron precipitates are not readily formed, the idea being that the iron precipitates should form within the aerobic ponds. The pH level of 4.5 to 5 is considered low and it is quite probable that the pH of the water will reduce to unacceptably low levels through the aerobic system due to the precipitation of iron. The addition of lime does not provide any buffer capacity to deal with this reduction in pH.

With regard to the aerobic neutralisation system, the aerobic wetland consists of an aerobic pond planted with phragmites and typha species. No attempt

appears to be made to specifically ensure appropriate conditions for algae and bacteria which have the ability to raise the pH.

With regard to the anaerobic ponds, one of the problems which have been identified during the discussions with Knight Piesold staff is that the precise design rate for sulphate reduction within the anaerobic ponds appears to be unknown - this is considered a serious problem as it is very important to design these systems for a specific rate of sulphate reduction. The anaerobic ponds have a finite carbon source and if the sulphate reduction rate is too high then the carbon source is used up to provide sulphide which is then in excess of that required for metal precipitation and premature depletion of the carbon source could be anticipated. On the other hand, if the sulphate reduction kinetics are too slow, insufficient hydrogen sulphide would be produced to enable complete precipitation of the metals.

With regard to the rock filters. On the basis of the observations made at site it would appear that there will be no attempt to culture specific algae onto the rock filters. Based on the discussions held with experts in the USA and observations made during site visits in the USA it would appear that unless specific algae are introduced poor removal of manganese will occur.

With regard to the aerobic ponds. The aerobic ponds at this site do not have a facility for aeration and neutralisation between stages. There is a possibility that this lack of aeration and neutralisation between the different aerobic ponds could negatively impact on the ability of the systems to sufficiently remove iron from the incoming mine water.

Finally, as a general comment, there are a number of unresolved issues with regard to the design of these passive systems and many of these issues will be addressed during the evaluation and operation of these pilot treatment systems. However, one of the key assumptions which appears to be made by Knight Piesold is that all the ponds must be lined. It is believed that this assumption is not really defensible at this stage and that work needs to be done to predict what the impact of not lining the different ponds would be, both on the treatment systems and on the groundwater and then to do a cost benefit assessment.

One of the major unresolved issues which will be addressed during the experimental phase is the long term issues of disposal of iron and toxic metal sludges. Obviously, the precise chemical composition of the sludges is an important consideration in assessing the problems with regard to disposal or possible reclamation of sludges and data on the chemical composition will be obtained during the pilot plant evaluations.

As a general comment the site at Wheal Jane is a very impressive research facility. It is hoped that on completion of the experimental work for the purpose of designing the Wheal Jane treatment site, the pilot plant site will continue to be used by universities or other research groups for passive treatment research. The system has been very well designed from a research

viewpoint with extensive monitoring points and the ability to throttle and re-direct flows between different systems at will. It is believed that the data which will be generated at the Wheal Jane Site will provide an important input to the international body of information on passive treatment systems.

STEFFEN ROBERTSON & KIRSTEN

1. INTRODUCTION

Steffen Robertson & Kirsten in Cardiff was visited on 17 September 1994 and discussions were held with Mr Richard Connelly, Director and Principal Hydrologist of SRK. Discussions were held with Mr Connelly on a number of broad topics, including the regulatory environment, the general status of water treatment in the UK and issues relating to research and development in the field of mine water treatment.

With regard to the legislative situation, discussions with Mr Connelly indicated that the NRA is in fact in the process of undertaking initial studies in all of its regions to prepare an overview assessment of the problems relating to mining within each one of the regions. In doing these studies, the NRA is tending to focus on the issues of iron and pH. For example, in the area of South Wales, which is administered by the Cardiff office of the NRA, a first phase study was undertaken by the NRA using students from local universities to identify all ferruginous discharges within the coalfields. Approximately 90 discharges were found and of these, 15 were identified as potential problem sites where further action was required. It is understood that similar studies have been undertaken in the other regions of the NRA. According to Mr Connelly, legislation does exist in the UK to enable the NRA to effectively manage the impacts of abandoned and operational mines on the water environment.

More detailed discussions with Mr Connelly focused on two recent studies being undertaken by SRK in the field of mine water management and treatment. These studies are:

1. A conceptual specification design costing for treatment options for the 15 major sites suffering from the effects of mine water pollution. This study was commissioned by the NRA
2. The review of detailed designs for wetland systems for treating acid mine drainage at Pelenna river. This study was commissioned by the West Glamorgan County Council.

2. STUDY OF FERRUGINOUS MINE WATER IMPACTS IN WALES - PHASE 2

As discussed earlier on in this report, phase 1 of this study was undertaken by the NRA using university students. This phase 1 studied identified 15 major pollution sites suffering from the problems of ferruginous discharges where further action or treatment was required. On the strength of the Phase 1 report, the NRA commissioned SRK to undertake Phase 2 which looked at the determination of remedial options for the 15 major sites. In fact during the

early stages of this investigation, an additional site was identified and Phase 2 was undertaken for 16 sites. For each site the following aspects were addressed:

1. Identify and define possible options for remediation
2. Consider and select the preferred option
3. Estimate, cost and summarise the benefits of the preferred option

In addressing these different aspects, the study also looked at the causes of the discharge at each site by looking at the hydrogeology and the geochemistry for each site. The control strategies which were looked at for the treatment of ferruginous discharges were grouped into 3 different groups.

1. Control at source as the primary strategy - essentially looking at the prevention of mine acid drainage
2. Migration control as a secondary strategy - looking at preventing the migration of contaminants from acid mine drainage.
3. Release strategies as a tertiary strategy - looking at the collection and treatment of effluents.

In reviewing the different strategies, the environmental quality standards which were used were that the treatment process should be able to reduce the total iron in the effluent to 1mg/l. pH should be between 6 and 8 and the total aluminium should be no more than 1mg/l at the pH of 6 to 8.

In assessing the different treatment options the following aspects were considered and an overall rating for technical feasibility was given. The rating was given on a scale of 1 to 5 with 1 being a low technical feasibility. The following aspects were considered.

1. Is it technically possible to implement a control measure?
2. Is it a proven measure?
3. A performance rating in terms of being able to meet the environmental quality standards
4. The type of measure be it active, passive or walk away

A cost rating was also made, considering both capital and operating costs.

In terms of source control strategies, primarily based on the exclusion of oxygen, three possible strategies were identified:

1. The use of flooding bulkheads
2. Plugs entry control
3. Covers

In terms of migration control, the following four possible strategies were identified:

1. Surface diversion
2. Entry closure
3. Internal diversion
4. Hydraulic balancing

With regard to treatment, the following five strategies were looked at:

1. Collection & chemical treatment
2. Internal sulphate reduction
3. Anoxic limestone drains
4. Wetlands, aeration and precipitation
5. Control discharge

The main recommendations which came from this report were that wetlands often combined with some hydraulic balancing or oxygen exclusion measure would be the most appropriate strategies. In limited cases, dilution by diffusion within the receiving stream was recommended.

Some notes or comments which can be made with regard to this study are:

1. The hydrological and hydrogeological modeling undertaken in the study was done with a severe lack of calibration data with regard to river and stream flows and very questionable extrapolations had to be made by SRK due to the lack of data. There was also very little reliable data on water quality aspects, such as iron levels, and the conclusions and recommendations made in this report should be considered as provisional.
2. The main criticism is that the study only looked at iron as a contaminant (although this was done in accordance with the brief set by the NRA) and other contaminants which may have toxic effects on the receiving water were ignored in the study.
3. The technical feasibility studies and conclusions were also hampered by the lack of a data record for flow and quality, in other words, the seasonal variations were not known and were not accounted for in the technical feasibility studies. Also the lack of detailed geological and hydrogeological data was a severe restraint, particularly when making recommendations on source control and migration control strategies.
4. The sludge disposal options were not included in the assessment of the different options and this is also considered as a deficiency.

However, having said this, this study can be considered a significant step forward in addressing the pollution problems resulting from abandoned mine operations in South Wales and during phase 3 of the study, the design and costing for each one of the major pollution sites would then be undertaken on

the basis of proper geological and hydrogeological water quality and flow data.

3. WETLANDS FOR PELENNIA RIVER

The Pelenna River site was visited and a number of photographs were taken at this site. This site consists of a number of adits into the surrounding hills which discharge fairly acidic waters containing levels of iron of $\pm 20 \text{ mg/l}$. As a first phase exercise, the West Glamorgan County Council which has responsibility for the site, commissioned a local group of consultants, Richards Moorehead & Laing Ltd, who undertook detailed literature reviews and prepared some basic design guidelines on the basis of these literature reviews for the design of anoxic limestone drains and aerobic wetlands. On the basis of this literature review, the West Glamorgan County Council designed its own wetland systems and contracted SRK to review these designs.

The design which is being undertaken for the Pelenna River, similarly to that of Wheal Jane, is being done on the basis of insufficient information. For example, it would appear that to date, no water sample has been taken at the site for a detailed and comprehensive analysis. Data only exists for pH, dissolved oxygen, alkalinity, total and dissolved iron, total and dissolved aluminium and total manganese over a 1 year period.

The need for a wetland at this particular site can also be questioned. It would appear that the West Glamorgan Country Council is installing a wetland at this site more for political reasons than for water quality reasons.

Again, similarly to Wheal Jane, the systems which will go in at Pelenna River will be on a pilot scale basis and will be used to generate data prior to designing the final wetland system.