BEST PRACTICE
ENVIRONMENTAL
MANAGEMENT
IN MINING

Water Management

Environment Australia
Department of the Environment and Heritage

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FOREWORD

Environment protection is a significant priority for our society. A major role for government is setting environment standards and ensuring that individuals and organisations meet them. Increasingly, however, government, industry and community organisations are working as partners in protecting our environment for present and future generations.

Representatives of the minerals industry in Australia and Environment Australia, (the environment arm of the Federal Government), are working together to collect and present information on a variety of topics that illustrate and explain best practice environmental management in Australia's minerals industry. This publication is one of a series of booklets aimed at assisting all sectors of the minerals industry—minerals, coal, oil and gas—to protect the environment and to reduce the impacts of minerals production by following the principles of ecologically sustainable development.

These booklets include examples of current best practice in environmental management in mining from some of the recognised leaders in the Australian industry. They are practical, cost-effective approaches to environment protection that exceed the requirements set by regulation.

Australia's better-performing minerals companies have achieved environmental protection of world standard for effectiveness and efficiency—a standard we want to encourage throughout the industry in Australia and internationally.

These best practice booklets integrate environmental issues and community concerns through all phases of mineral production from exploration through construction, operation and eventual closure. The concept of best practice is simply the best way of doing things for a given site.

The case studies included in these booklets demonstrate how best practice can be applied in diverse environments across Australia, while allowing flexibility for specific sites. Each booklet addresses key issues by presenting:

- basic principles, guidance and advice;
- case studies from leading Australian companies; and
- useful references and checklists.

Mine managers and environmental officers are encouraged to take up the challenge to continually improve their performance in achieving environment protection and resource management and to apply the principles outlined in these booklets to their mining operations.

Stewart Needham
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EXECUTIVE SUMMARY

Environmental best practice is about preventing or (where this is not possible) minimising environmental impacts. Water is integral to virtually all mining activities and typically the prime medium, besides air, that can carry pollutants into the wider environment. Consequently, sound water management and practice are fundamental for most mining operations to achieve environmental best practice.

At most mine sites, ore extraction and processing, workforce health and safety, and rehabilitation, all require water. Achieving best practice environmental water management relies on companies implementing an integrated 'cradle to grave' approach at every stage of the mine operation. Because mine planning, by necessity, is typically based on limited data, initial predictions are validated during the early operational phase. The water management system needs to be adjusted to ensure water management principles are applied.

Periodic risk/consequence assessments can help check the effectiveness of the water management system. This not only minimises the risk of impacts on the surrounding environment during the operational phase but also helps 'fine tune' rehabilitation planning. This in turn maximises potentially beneficial post-mining land uses and therefore reduces potential liabilities.

Developing water management systems for a mine must account for site-specific physical, chemical and climatic characteristics as well as mine process factors. Total company commitment is fundamental to ensuring best-practice water management minimises potential environmental impacts. This booklet presents the key principles of best practice environmental management for water systems.

Best practice principles and approaches have developed rapidly in the past few years. A growing number of Australian mining operations can demonstrate best practice across their operations. A seriesof case studies in this booklet shows best practice for specific components of individual operations. Further reading covering mine water management is provided.

CONTENTS

GLOSSARY OF TERMS

AMD/ARD	Acid mine drainage/acid rock drainage — oxidation of sulfidic mine wastes, typically occuring as runoff or seepage from waste rock stockpiles, tailings impoundments or coal rejects.
Annual Exceedance Probability	The likelihood that an event of a nominated size or larger will occur in any one year, eg there is a 5% likelihood (chance) that in any year, the largest flood will be equal to or greater than the 5% AEP flood event.
Albedo	The ability of a surface to reflect incident short wave radiation to the atmosphere.
BoM	Bureau of Meteorology
Creek	In Australia, a creek generically means a small river tributary, often non-perennial. However, the term is often interchangeable with 'river'. Indeed, some 'creeks' with reliable flow are larger than some named rivers.
'Dirty' Water	Water contaminated by excessive quantities of pollutants.
Evapo-transpiration	Plant ability to extract water from the soil profile and respire it as water vapour through their leaves to the atmosphere.
Environmental value/s	Environmental values are particular values or uses of the environment that are conducive to public benefit, welfare, safety or health and require protection from the effects of pollution, waste discharges and deposits. Several environmental values may be designated for a specific waterbody. Five environmental values are: ecosystem protection; recreation and aesthetics; drinking water; agricultural water and industrial water (see Box 3).
Filterable Residue	Suspended solids (ie can be filtered out). Also, *Non-Filterable Residue* (dissolved solids).
Flow Regime	Relative flow frequency (of different magnitudes) at a location of interest. Constructing a dam across a watercourse alters the natural flow regime by trapping more small and moderate flows compared to high flows.
Hydraulic Conductivity	Velocity of groundwater flow under a unit hydraulic gradient. Greater for sands and coarse grained materials than for clays.
Hydraulic head	In a groundwater system water moves from areas of 'high hydraulic head' to areas of lower hydraulic head, under gravity or external pressure.
Hydro-meteorological data	General weather information relevant to the hydrological cycle plus streamflow information.
Precipitation	Water falling as rain, hail, snow or sleet. In Australia, rainfall is the most significant form of precipitation affecting minesite water management.
Recharge	A point where surface water enters the groundwater system (also, *discharge area*: a point where water leaves the groundwater system.
Referrable Dam	A dam whose construction must be approved by authorities due to its embankment height or storage capacity.
Riparian	Of or adjacent to a riverbank, eg riparian vegetation, riparian landholders. 'Riparian flows' are flows available for riparian landholders to use.
Sign off	Agree in writing ('signoff' is the act of agreeing in writing).
Stakeholder	Someone who may be a winner or loser of a decision that influences (positively or negatively) that person or group's wellbeing now or in the future. Stakeholders can include indigenous people, neighbouring communities, special interest groups, mine operators, local and regional governments, unions, shareholders and regulatory bodies.
Temporal Pattern	Variation in rainfall intensity during the course of a storm event.
Water Balance	A diagram or table showing all water inflows and outflows of a specified type (eg average flows) to and from nominated control volume (eg a minesite) over a nominated period (eg a year).

INTRODUCTION

This booklet describes best practice approaches for minesite water management in Australia. It is one in a series of booklets published by Environment Australia describing best practice environmental management in mining. These approaches can be applied in other countries after considering factors such as topography, geology, climate and relevant national laws.

The fundamental prerequisite for best practice minesite water management is recognising the need to develop and implement a comprehensive and coordinated **minesite water management plan (MWMP)**. This must address the impact of:

- mining operations on the water flow and water quality processes of the hydrological cycle, i.e. the environmental impacts associated with the 'risk exposure' of hydrological processes to mining activities.
- the hydrological cycle on mining operations, i.e. the 'risk exposure' of mining activities to hydrological processes. Examples include the effects, such as lower productivity and profitability, of floods or droughts on mining operations.

The size and complexity of a minesite water management plan depends largely on the nature and size of the mining operation, characteristics of the hydrological cycle at the minesite, and the ecological and environmental sensitivity of the surrounding area. An MWMP needs to adopt a whole-of-mine approach that embraces the four phases of a mining operation: exploration, design and development, operation and decommissioning.

Water management is often complex and is presented here in a simplified form so the basic principles can be understood.

Mining operations can substantially alter the hydrological and topographic characteristics of lease areas. Typically, massive volumes of spoil are shifted, major road and rail infrastructure built and an ore processing plant with associated water supply requirements constructed. Tailings dams and other water storages will be required and open cut pits and underground workings may need dewatering. Also, toxic or environmentally damaging chemicals may be required for ore processing, and exposed ore and spoil may change chemically and generate pollutants. Finally, a major open cut pit may remain. These activities affect the surface runoff, soil moisture, evapotranspiration and groundwater behaviour of lease areas.

Potentially adverse effects of inadequate minesite water management and design include:

- the rehabilitation process not having enough water;
- the risk of flooding;
- unacceptably high levels of suspended solids (Non-Filterable Residue) and dissolved solids (Filterable Residue) in surface runoff;
- escape of toxic or environmentally damaging process chemicals to waterways;
- bed and bank erosion in waterways;
- ineffective rehabilitation and revegetation operations; and
- the excessive build-up of 'dirty water' in minesite storages, possibly curtailing mining operations and complicating the rehabilitation process.

It is self-evident that a **Sediment and Erosion Control Plan** is a fundamental component of a Minesite Water Management Plan.

Box 1: 10 Key Steps to Better Minesite Water Management

1. Management and staff commitment to minesite water management processes and programs. Adequate human and financial resources are essential for effective minesite water management.
2. Minesite staff to maintain open and effective communication with regulatory agencies and stakeholders. Regulatory agencies and stakeholders should be kept informed of the successes, problems and any emergencies associated with minesite water management.
3. Developing and implementing a **Minesite Water Management Plan** that covers all water management issues in a coordinated and integrated way.
4. Different minesite work groups must cooperate in successfully implementing and operating a Minesite Water Management Plan. Failure to gain cooperation can jeopardise water management programs.
5. All personnel participating in minesite water management programs need effective training in their roles and responsibilities. Failure to provide adequate training will jeopardise water management programs
6. Developing and implementing a **Sediment and Erosion Control Plan** is an essential part of the Minesite Water Management Plan.
7. Developing and implementing a **Water Quality Monitoring Plan** is also an essential part of the Minesite Water Management Plan.
8. The three plans (above) should consider water management, erosion and water quality monitoring issues on a whole-of-mine basis, i.e. through the exploration, development, operation and decommissioning phases of mining.
9. A risk management approach should assess the risk and consequences of 'Events of Concern' to water management and identify appropriate strategies to manage these risks.
10. Defining performance indicators provides a measure of the success or otherwise of minesite water management, erosion control and water quality monitoring programs. Programs should be reviewed regularly and when necessary modified.

These days, minesite water management across Australia is typically governed by a number of statutory requirements which include the need for:

- licences to obtain a surface water or groundwater supply,
- licences to discharge water off-site,
- approval to construct 'referrable dams', and
- developing an Environmental Management Plan for the minesite incorporating all aspects of minesite water management, including monitoring.

The Minesite Water Management Planning Process provides a structured format for addressing:

- statutory, technical, environmental and social issues associated with the impact of mining operations on the local and regional hydrologic cycle, and
- the impact of hydrological processes on mining operations.

Developing and implementing an effective MWMP generates commercial, environmental, social and operational benefits. Minesite water management plans should be prepared for both existing mines and new mines. Considerable benefits flow from developing a minesite water management plan before a mine is developed. A plan identifies all water management issues associated with developing, operating and decommissioning a mine. It also enhances the co-ordinated development and implementation of an integrated system of cost-effective, environmentally responsible and ecologically sustainable management measures as mining proceeds.

A minesite water management plan is a public statement by a mining company about two key things: how it proposes to manage the potentially adverse impacts of mining operations on hydrological processes; and how it proposes to manage the adverse consequences of hydrological 'risks' to mining. Note that because of the pervasive nature of the hydrological cycle, adverse impacts are not generally restricted to the mine lease area, but can be visited on the downstream environment, landholders and other users of downstream water resources.

To gain community acceptance, an MWMP must consult not only the regulatory agencies (eg Departments of Mines and local councils), but also community representatives, such as catchment management committees, downstream landholders and take account of the responses. Public responsibility and good public relations mean it is more effective to openly address contentious issues while developing an MWMP than to have these issues emerge during mining operations.

Photo: Goldfields (Tasmania) Ltd

Goldfields (Tasmania) Ltd, Henty Gold Mine, 30km NW of Queenstown, Tasmania. Staff and contractors enjoy, and take great pride in the presence of yabbie colonies in the settling pond. These macroinvertebrates provide a food source for a local platypus (circled) which regularly visits the pond.

Consequently, best management practice indicates that mining companies should establish and chair a 'minesite water management committee' comprising its own company representatives, its consultants (if appropriate), all appropriate regulatory agencies and downstream stakeholders. All representatives should 'sign off' the plan when finalised.

This booklet describes the Minesite Water Management Planning process and identifies issues to consider when developing and implementing it and the relevant best practice approaches. Several Australian case studies which exemplify practical and effective ways to address these issues are included. The planning process described here is necessarily generic in nature and needs tailoring to the specifics of individual minesites.

2 THE HYDROLOGICAL CYCLE

2.1 HYDROLOGICAL PROCESSES

In essence, minesite water management is about limiting the adverse effects of mining operations on the immediate regional hydrological cycle to acceptable levels and ensuring that hydrological processes do not jeopardise mining operations. A brief review of the hydrological cycle and the impact of mining operations on its constituent processes is therefore appropriate here.

This section provides a brief overview of the hydrological cycle and its constituent processes. Its purpose is to introduce minesite personnel to the various processes and their relevance to minesite water management. The hydrologic cycle and its underlying processes are described in detail in other publications (Linsley, Kohler, and Paulhus, 1982; and Minerals Council of Australia 1997).

The hydrological cycle is the interchange of water in all its physical forms between the earth's atmosphere, surface and mantle, i.e. the biosphere. This interchange and movement is accomplished through 'hydrological processes'. For minesite water management, the relevant hydrological processes are:

- Precipitation,
- Infiltration,
- Surface runoff,
- Evapotranspiration,
- Evaporation,
- Percolation,
- Streamflow, and
- Groundwater flow.

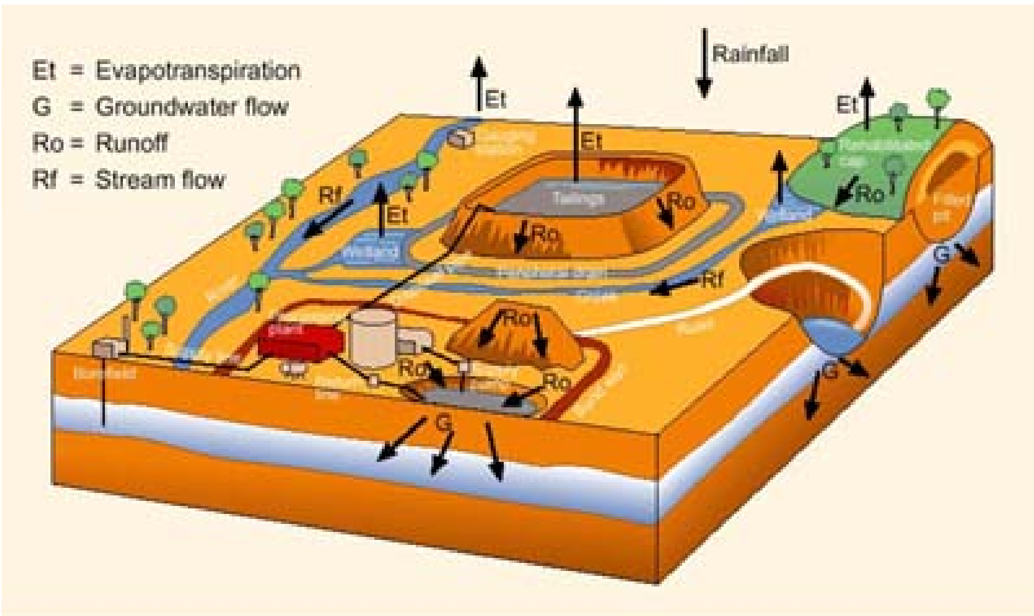


FIGURE 1:Hydrological cycle at a hypothetical minesite (after McQuade & Riley, 1996)

Et	=	Evapotranspiration
G	=	Groundwater flow
Ro	=	Runoff
Rf	=	Stream flow

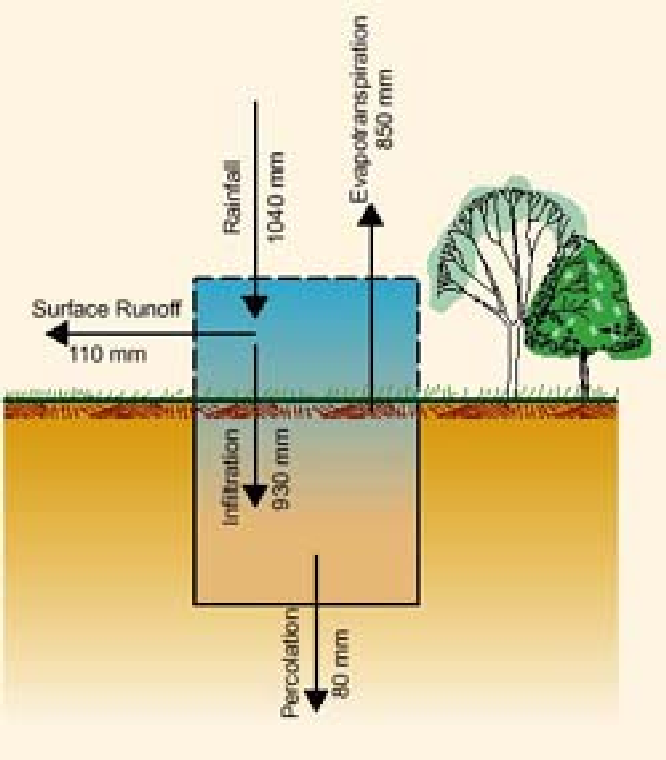
Box 2: Hydrological Processes

The diagram below shows the magnitude of the basic hydrological processes for a natural catchment area at Timbarra Gold Mine, which is located some 30 km from Tenterfield in Northern New South Wales. The soils of the area vary from loamy sand to a sandy clay with a significant sand content. The soil moisture capacity was estimated to be 100 mm/m. Vegetation in the area consists of open forest consisting of dry heath, woodland and to dry schlerophyll.

The average annual water balance below shows that:

- Of the average annual rainfall of 1,040 mm, some 90% infiltrates into the soil, the remaining 10% becoming average annual surface runoff.
- Of the 930 mm average annual infiltration, some 91% is returned to the atmosphere as evapotranspiration, the remaining 9% percolating to deeper soil layers.
- Most of the 80 mm average annual percolation is expressed over a 2 - 3 month period as 'interflow', or water that moves through the soil to re-enter the surface drainage network via springs or seeps. Little of the percolation becomes groundwater.

The above results were derived with a daily rainfall - runoff model, which was used to simulate runoff - infiltration - percolation behaviour over the period 1871 to 1995 based on daily rainfalls recorded at Tenterfield.



Hydrologic processes can be divided into two categories, 'basic' processes and 'aggregate' processes.

- **Basic hydrological processes** are rainfall, infiltration, surface runoff, evapotranspiration and percolation. These processes are highly interrelated — i.e. a change to the flow rate of any one process can affect the flow rate of others.
- Streamflow and groundwater flow are '**aggregate processes**'. They are so named because they respectively represent the aggregate effects of surface runoff from upstream catchment areas and percolation from upstream recharge areas.

There are two fundamental characteristics common to all hydrological processes, namely, flow rate and water quality. Mining operations can alter the flow rate, water quality, or both of these attributes for most of the hydrological processes listed above. Further, although mining activities may be limited to the mine lease area, adverse impacts on hydrological processes can affect the downstream environment, off-lease landholders and water users.

2.2 PRECIPITATION

Precipitation includes rain, hail, snow and sleet. In Australia, rainfall is the most significant form of precipitation affecting minesite water management. All the nation's major mining areas lie outside the Australian snowfields.

A rainfall event ('storm' or 'temporal pattern') can be described in terms of the duration and intensity of rainfall and the variation of intensity. Rainfall characteristics vary with the meteorological mechanism causing the storm. Typically, thunderstorms generate intense rainfalls of short duration (1—2 hours); frontal systems generate longer duration rainfalls of lower intensity (6—24 hours), while the rainfall depression that marks the end of a tropical cyclone can produce relatively intense rainfalls for several days.

Mining as such has no significant impacts on the amount and intensity of rainfall. However, it can affect the 'water quality' of precipitation, eg the 'acid rain' produced by ore processing at Mount Lyell in Tasmania, when copper was smelted on site between 1896 and 1969.

Rainfall can generate unacceptable levels of soil erosion from stripped areas of minesites. Rain drops, when they strike the ground, can loosen and dislodge soil particles and facilitate their removal by surface runoff. We cannot 'manage' rainfall itself; we can only attempt to manage its adverse effects.

Probable Maximum Precipitation

Probable maximum precipitation (PMP) is the most intense rainfall that is physically possible for a given storm duration. PMPs are extremely rare and considered to have an annual recurrence interval of 10^4 to 10^6 years. Nevertheless, rainfalls this intense do occur in Australia. Estimating PMP intensities is a specialised science. The Bureau of Meteorology has a design procedure for durations up to six hours (BoM, 1994). For longer durations, it is recommended that meteorological experts are consulted.

PMP is generally only of concern when events pose a high risk of death or injury to many people. For example, where a PMP event causes a dam failure likely to threaten many lives.

PMP is often not an issue in minesite planning and water management. However, best management practice requires that minesite personnel are aware that extreme rainfalls can occur. The consequences should be evaluated and if necessary, appropriate risk management plans put in place.

Greenhouse Effect

The Greenhouse Effect suggests the Earth's atmosphere is warming with the build-up of certain gases and this could alter the frequency, severity and location of storm events and their associated rainfalls. In the future, tropical cyclones may move further south and dry inland regions may become wetter. These climatic changes are not expected to be of significance in the short-term (10-20 years).

In preparing a minesite water management plan, the potential consequences of climate change are generally not of significance because of the short-term life of most mining operations. However, best practice requires that the potential adverse impacts of climate change be recognised and evaluated before being dismissed.

TABLE 1: Representative Soil Characteristics

Soil Type	Representative Values		
	Infiltration[a] (mm/hr)	Soil Moisture Capacity (mm/m)	Available Moisture[b] (mm/m)
Sand	50	150	70
Sandy Loam	25	210	120
Loam	15	300	170
Clay Loam	8	350	190
Clay	5	450	230

[a] Saturated Infiltration Rate; [b] Extractable by plants.

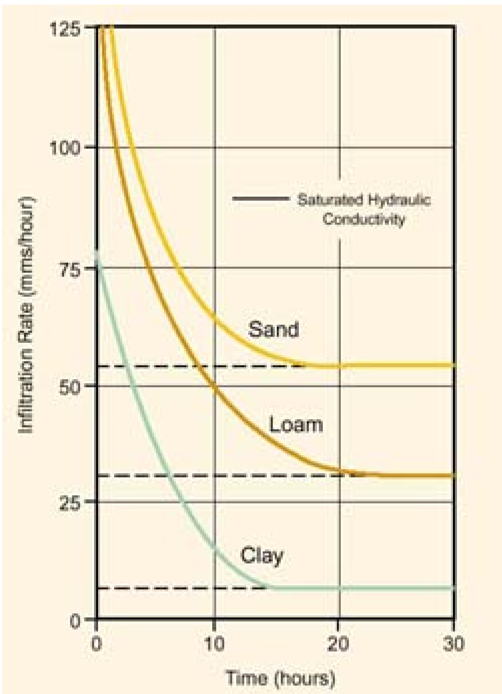


Figure 2: Variation of infiltration rate during a storm for different soil types

2.3 INFILTRATION

Infiltration is the process whereby some of the rainfall reaching the earth's surface moves through the soil surface and into the soil profile. Major factors influencing this process are the soil's saturated hydraulic conductivity, its initial moisture content when the storm event starts, the soil surface 'condition' and the intensity, duration and temporal pattern of the rainfall event itself.

Using heavy mechanical equipment for clearing and stripping operations compacts surface soil layers and can severely reduce infiltration capacity. (The loss of vegetation also reduces infiltration, as discussed below). Reduced infiltration increases surface runoff and may increase soil erosion.

Spoil piles, given their disaggregated and often highly porous nature, can have a high infiltration capacity. Rainfall can 'disappear' into spoil areas, generating little surface runoff. The rainwater may reappear, often quite quickly, as leachate— commonly acidified— at the base of spoil piles.

2.4 SURFACE RUNOFF

Water is shed as surface runoff whenever rainfall reaches the ground faster than it can infiltrate the underlying soil. Factors affecting the volume and rate of surface runoff during a storm event include the intensity, duration and temporal pattern of the rainfall and its infiltration rate.

Surface runoff is a major cause of soil loss by erosion. The deeper and faster surface runoff flows, the greater its ability to dislodge and transport sediment particles. Major influences on the depth and velocity of surface runoff include rainfall intensity, surface slope, slope length and the frictional or flow resistance properties of the surface. A 'good' cover of vegetation slows surface runoff and binds the surface soil mass. A bare slope offers little resistance to erosive surface runoff.

Figure 3 shows the temporal pattern for a storm of 5 years ARI and 6 hours duration at Mount Morgan, Queensland. It also shows assured infiltration losses consisting of the 'initial rainfall loss' (15 mm) and the 'continuing rainfall loss' (4 mm/hour). Rainfall over and above these losses represents the 'rainfall excess' or 'runoff depth'. Further it shows the temporal pattern of the runoff depth. Peak surface runoff occurs between 60 minutes and 90 minutes. The total depth of rainfall in the storm was 95 mm, the total infiltration loss was 35 mm and the total depth of runoff was 60 mm.

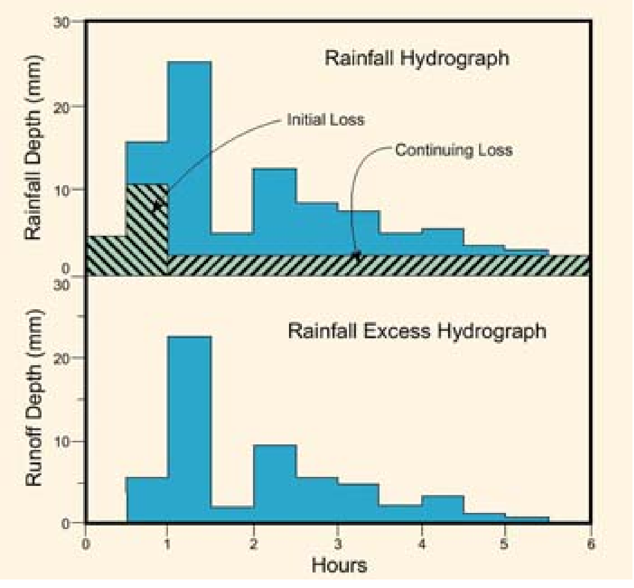


Figure 3: Rainfall and Runoff Hydrographs, Mt Morgan, 6 Hours Duration, 5 Years ARI

2.5 EVAPOTRANSPIRATION

Evapotranspiration is the process where plants extract liquid water from the soil profile and respire it as water vapour through their leaves to the atmosphere. The ability of plants to extract or 'suck' water from the soil depends on the type of soil and, to some extent, the type of plant.

The evapotranspiration rate not only depends on how plants extract moisture from the soil profile, but also on the atmosphere's ability to absorb the additional water vapour produced. This in turn depends on incident solar radiation at the ground surface, relative humidity, temperature, wind and surface 'albedo' (i.e. the ability of the surface to reflect incident short wave radiation to the atmosphere).

Because vegetation reduces soil moisture through evapotranspiration, removing vegetation for mining operations tends to reduce water volumes the soil can 'hold' before becoming saturated. Because soil then saturates sooner, this increases the volume and rate of surface runoff, which in turn can lead to excessive soil erosion.

If geological conditions are appropriate and the affected area is sufficiently large, vegetation removal can lead to a rise in groundwater levels and soil salinisation. Vegetation also protects the soil surface and reduces surface water velocity and therefore its erosive power (see Surface Water Control, p 59, *Landform Design for Rehabilitation*, for more detail).

2.6 EVAPORATION

Evaporation or 'open water evaporation' is water passing from the surface of a waterbody into the atmosphere as water vapour. The same climatic factors affecting evapotranspiration determine evaporation rates (see above). Evaporation is important to minesite water management, because:

- it represents a loss of water supply from surface storages; and
- evaporation may be adopted as a management measure to reduce surplus water volumes (via evaporation ponds).

2.7 PERCOLATION

Percolation is vertical water movement through a saturated or nearly saturated soil mass. Unlike infiltration, during which water enters the soil surface and the soil mass, percolation is water already in the soil mass moves vertically downwards under gravity to recharge groundwater aquifers.

Percolation can be a significant source of groundwater replenishment. Clearing minesite vegetation and stripping areas before mining reduces infiltration, which in turn reduces percolation. This may adversely affect groundwater tables.

2.8 STREAMFLOW

As gravity drives surface runoff flow down a catchment, it progressively collects in a series of larger drainage channels that eventually deliver the runoff to a creek, where it becomes 'streamflow'. (In Australia, a creek generically means a small river tributary, often non-perennial. However, the term is often interchangeable with 'river'. Indeed, some 'creeks' with reliable flow are larger than some named rivers.)

Mining activities can harm streamflows. As discussed above, decreased infiltration in (for example) devegetated, compacted or sealed areas will increase stream flows. Surface water storages built across a creek will reduce and alter the downstream flow regime. It may be necessary to divert a creek around mine workings into an adjacent creek, increasing discharges in the receiving creek and again altering the downstream flow regime. Flow regime changes will alter the stream-bed and bank erosion behaviour and the creek's ability to transport sediment.

'Streamflows' can adversely affect mining operations. Mine infrastructure is often built on floodplains where it is exposed to flood risk and flood hazard. A shortage of streamflows feeding water supply storages can lead to a water shortage.

2.9 GROUNDWATER FLOW

Once water has infiltrated or percolated into a groundwater system, its movement is largely determined by the hydraulic head (groundwater level) of the groundwater body and aquifer characteristics.

- Groundwater moves or flows from areas of high hydraulic head to areas of lower hydraulic head under the influence of gravity and external pressure. The force of molecular attraction also influences groundwater flow by causing water to adhere to solid surfaces and resist movement.
- Important aquifer characteristics that influence groundwater flow include the nature of the aquifer (confined or unconfined), its hydraulic characteristics (principally hydraulic conductivity) and the presence of any impermeable groundwater barriers.

In general terms, groundwater flows from areas of groundwater recharge to areas of groundwater discharge. Recharge areas are typically higher and have a deep zone of unsaturated material between the ground surface and water table. Discharge areas are typically lower, eg valley floors and the coastline. Groundwater flows diverge from recharge areas and converge on discharge areas. A map of groundwater table contours can be used to identify recharge and discharge areas.

On a local scale, groundwater flow is affected by the geological structure and any hydraulic variation (inhomogeneities) in the aquifer. Faulted and fractured zones provide preferred pathways for groundwater flow. Conversely, zones of lower permeability (eg higher clay content) and impermeable barriers restrict or prevent groundwater flow.

2.10 SEASONAL VARIATION

Rainfall and evapotranspiration, which largely drive the hydrological cycle, show marked seasonal variations across Australia, with many places in Australia having distinct 'wet' and 'dry' seasons. Figure 4 shows average monthly rainfall variations at three east coast minesites. Table 2 shows their respective average annual and monthly rainfall details. It shows how each is characterised:

- Ravenswood has relatively high rainfalls (average annual rainfall of 1220 mm) and marked seasonally with a summer 'wet' season and a winter 'dry' season. The wet season is the 4 month period from December through to March when 72% of average annual rainfall occurs.
- Queenstown has high rainfalls (2530 mm average annual rainfall) and pronounced, but less marked, seasonality with a winter 'wet' and a summer 'dry'. In effect, its rainfall distribution is the mirror image of Ravenswood. The average monthly rainfall at Queenstown is significant in all months. The wet season runs for the 7 months April to October, when 67% of average annual rainfall occurs.
- Ballarat has less rain (750 mm average annual rainfall) and variation, again spread fairly evenly through the year. However, it experiences a mild winter 'wet' that runs over the 6 month period May to October, when 59% of the average annual rainfall occurs.

Figure 5 shows the variation of average monthly potential evapotranspiration (PET) at four minesites along the east coast. Table 3 shows PET details at these sites. PET follows a consistent and similar seasonal variation at all sites with a summer maximum in the period November to January and a winter minimum in June. PET is most strongly driven by solar radiation and the seasonal variation in Figure 5 reflects changes in solar altitude throughout the year.

Seasonal rainfall variation can significantly affect minesite water management. For example, 'dirty water' may need to be stored before the wet season to minimise the risk of having to release contaminated water. Alternatively, given flood or environmental risk, it may be necessary to restrict mining or other activities during the wet season.

Numerical models that simulate minesite water management systems must incorporate the seasonal variation of hydrologic processes. Failure to do so will give misleading results. (see Appendix 3).

TABLE 2: Rainfall Characteristics, Ravenswood, Ballarat and Queenstown

Location	**Mine**	**Average Annual Rainfalls (mm)**	**Monthly Average Rainfall (mm)**		
			Max.	**Min.**	**Diff.**
Ravenswood, Qld	Ravenswood Gold	1220	267	18	249
Ballarat, Vic	Ballarat Gold	750	78	41	37
Queenstown, Tas	Mt Lyell Copper	2530	265	125	140

TABLE 3: Details of Average Annual and Average Monthly Potential Evapotranspiration, Various Sites, East Coast of Australia

Location	**Mine**	**Average Annual Pet (mm)**	**Average Monthly PET (mm)**		
			Highest	**Lowest**	**Diff.**
Ravenswood, Qld	Ravenswood Gold	1930	220	90	130
Nth Stradbroke Is, Qld	Yarraman Sand	1260	170	40	130
Timbarra, NSW	Timbarra Gold	1510	190	55	135
Ballarat, Vic	Ballarat Gold	1290	210	30	180

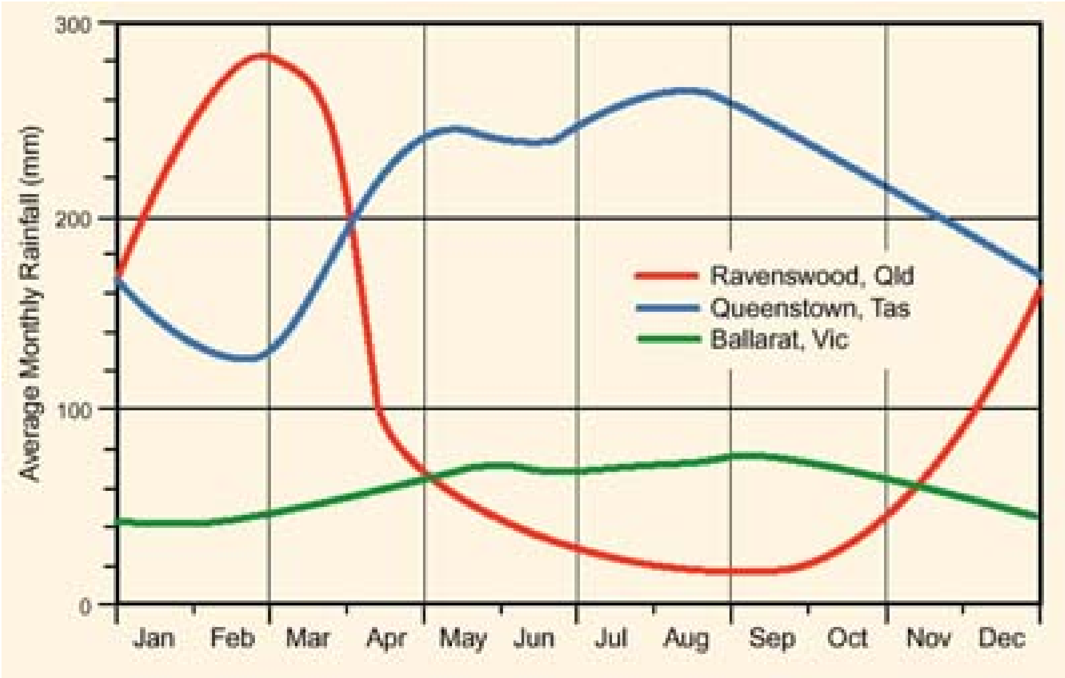


Figure 4: Variation of Average Monthly Rainfall Throughout the Year, Ravenswood, Ballarat and Queenstown

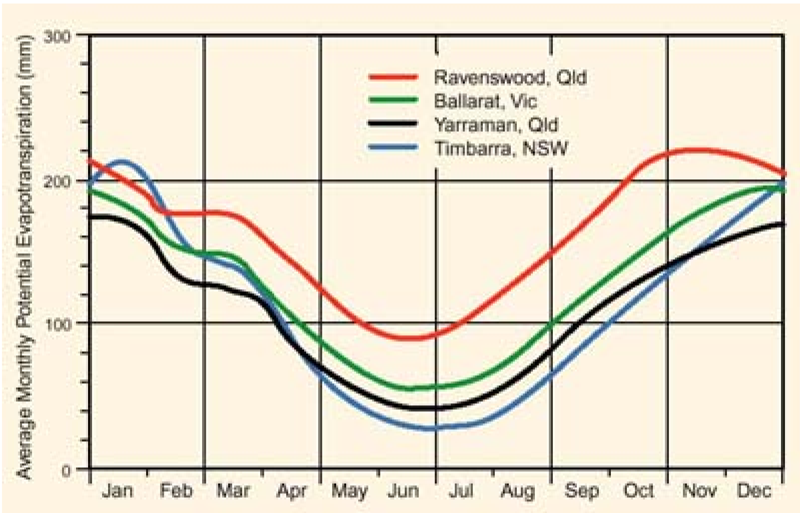


Figure 5: Variation of Average Monthly Potential Evapotranspiration throughout the Year, Ravenswood, Ballarat, Timbarra and Yarraman

2.11 RANDOM VARIATION

Hydrological processes not only vary seasonally, but also randomly with weather fluctuations. Consequently, rainfall intensities vary from storm to storm, as does water quality in the surface runoff generated.

When designing for hydrological events or interpreting their outcomes, it is important to recognise this random variation and evaluate risks and consequences accordingly. Risk is measured as annual exceedance probabilities (AEPs). Risk, or the probability of a specifically severe hydrological event, such as a 2 hour rainfall event exceeding 100 mm, is measured as an AEP. These reflect the chance of an event of equal or greater severity occurring in any one year. AEPs are typically measured in percentages. For example, if the above rainfall event has an AEP of 5%, it means that in any year, there is a 5% chance (or a 1 in 20 chance) that a 2 hour rainfall event will occur with an intensity equal to or greater than the nominated value (100 mm). Note that the random nature of storm behaviour means that:

- there is a 5% probability of this event occurring **each and every year**; and
- even if this event or a more severe event occurred in the previous year, the chance of the nominated event occurring during the current year **is still 5%**.

Mining operations subject to hydrological events can be exposed to various risks: environmental, economic and some threatening the safety of workers and the public. Because the severity of hydrological events varies randomly, a formal 'risk management' approach is needed when preparing a minesite water management plan. In short, an approach which identifies risks, evaluates consequences and plans appropriate management and contingency measures. Compared with many other natural events, we can more reliably predict severe hydrological events. Consequently, risk management techniques can be applied to minesite water management issues in a relatively straightforward way.

2.12 WATER BALANCES

Figure 6 shows the average annual catchment water balance of the 5 basic hydrological processes at an open cut gold mine in northern New South Wales (Timbarra) and at a sand mine on North Stradbroke Island. These results came from a daily rainfall-runoff model to simulate the daily runoff behaviour of minesite catchments over a lengthy period (about 100 years in both cases). Daily results were aggregated into annual values which were then averaged.

In this case, the control volume is an elemental biosphere volume of unit cross-section that extends up into the atmosphere and down into the soil mantle to a depth below the root zone (to account for percolation losses). Note that as far as the water balance is concerned, infiltration is an 'internal process' that does not transport water into or out of the control volume.

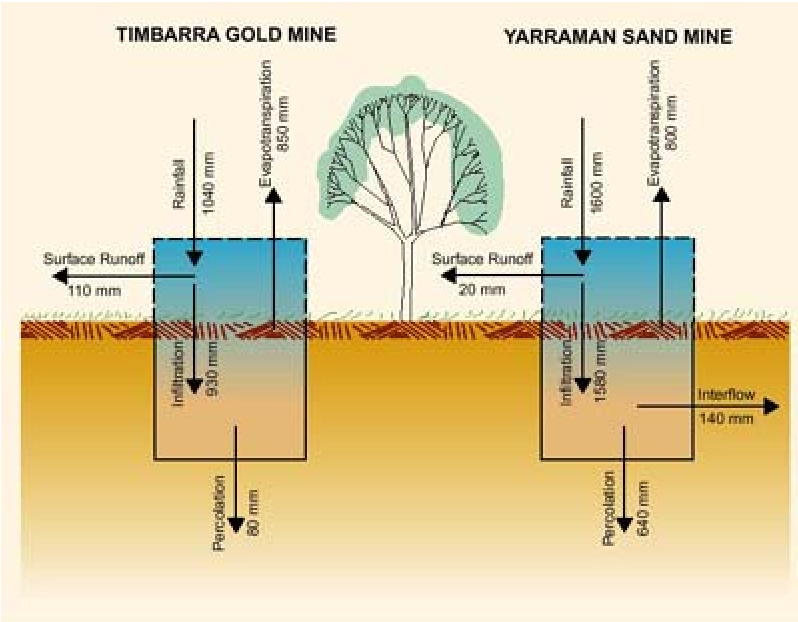


Figure 6: Average Annual Catchment Water Balances, Timbarra Gold Mine and North Stradbroke Sand Mine

3 ELEMENTS OF A MINESITE WATER MANAGEMENT SYSTEM

A minesite water management system consists of a number of *physical* elements to control the movement of clean and 'dirty' water onto, across and off the minesite, together with a number of *process elements* to control potential water problems at source, while maintaining and verifying the appropriate functioning of the water management system. It is essential that every effort should be made to avoid uncontrolled releases. By definition, uncontrolled releases are events beyond the capacity of the system (or due to a system failure). While it is important to include design features that mitigate their effects, an uncontrolled release almost automatically represents a failure of the water management system and, consequently, is not best practice.

Table 4: Elements of a Minesite Water Management System

Element	Application				
	Supply	**Convey**	**Store**	**Treat**	**Disposal**
Dams	X		X		
Bores	X				
Natural Water Bodies	X				
Pumps		X			
Pipelines		X			
Open Channels		X			
Water Storages			X		
Open Cut Pits			X		
Tailings Dams			X		
Evaporation Basins				X	
Controlled Releases				X	
Uncontrolled Releases				X	
Groundwater Recharge				X	
Sediment Basins					X
Wetlands					X
Chemical Treatment					X

3.1 PHYSICAL ELEMENTS

A minesite water management system has several inter-connected physical elements that:

- supply water required for the mine to operate;
- convey water;
- store water and liquid-based wastes (eg tailings);
- dispose of water by evaporation or discharge elsewhere; and
- improve water quality.

Table 4 shows common elements of minesite water management systems and their uses.

Conveyance

The use of pumps, pipelines and open channels to convey water around a minesite is self-evident. Water management issues associated with these elements include:

- Pumps - capacity and reliability.
- Pipelines - capacity and integrity (potential for rupture).
- Open channels - channel capacity (overtopping), bank and bed erosion.

Storage

The usual ways of storing raw water, dirty water and liquid-based process wastes on minesites are water storages and tailings dams. Mine pits can sometimes provide suitable alternative storage for clean or contaminated water or tailings. Water management issues associated with each of these include:

- **Water Storages** Storage capacity; spillway capacity (ability to safely pass the design flood); likelihood and frequency of spills; impact of spills on downstream receiving waters.
- **Tailings Dams** Capacity; ability to contain the design rainfall event; likelihood and frequency of spills; impact of spills on downstream receiving waters; seepage and impact on groundwater quality. (see *Tailings Containment* in this series.)
- **Open Cut Pits** Treatment at mine closure; seepage and impact on groundwater quality when used as a tailings dam. (see *Rehabilitation & Revegetation*; also, *Mine Planning* in this series.)

Treatment

Water flows on minesites can undergo various types of treatment before ultimate disposal. Table 4 identifies 3 types of treatment commonly used on minesites, namely sediment basins, wetlands and chemical treatment.

- Sediment basins provide a simple form of physical treatment to reduce the level of suspended solids (filterable residue) in surface runoff. Ideally, sediment basins should be used in conjunction with a soil erosion management plan to limit soil erosion at source. Appendix 1 presents general design guidelines for sediment basins.
- Wetlands treat waters passing through them physically and biologically and can improve water quality in various ways, including raising pH and removing nutrients and heavy metals. Wetlands act as sediment basins and commonly 'polish' effluent from other processes, eg treated mine water from underground metalliferous mines. Appendix 2 details functioning wetlands and key factors affecting their performance.
- Chemical treatment is part of ore processing operations and can at times correct the quality of waste streams, eg neutralising acid mine drainage. Chemical treatment is expensive compared with other treatments.

Water management issues associated with these three treatment elements include:

- **Sediment Basins** Retention time; capacity; dead storage to collect silt; efficiency of silt removal; frequency of desilting.
- **Wetlands** Capacity; retention time; vegetation types; efficiency of removal; frequency of desilting and replanting.
- **Chemical Treatment** Effectiveness; safety; containment and chemical spill cleanup.

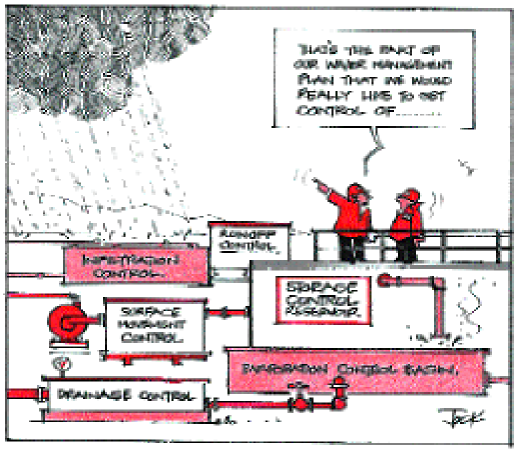
Disposal

There are only three ways to dispose of excess water on a minesite:

- By evaporation (from water storages, evaporation basins, tailings dams, open cut pits and application).
- By release to surface waters as a 'controlled release' from a storage (via a pump or valve-controlled outlet) or as an 'uncontrolled release' (such as a spill from a storage).
- By recharge to groundwater.

Table 4 identifies four physical elements used for the disposal of water and wastewater on minesites. Water management issues associated with these elements include:

- **Evaporation Basins** Capacity; ability to contain the design rainfall event; likelihood and frequency of spills; impact of spills on downstream receiving waters; seepage and impact on groundwater quality; net evaporation capacity; disposal and environmental impacts of sludge.
- **Controlled Releases** Release capacity; impact on quality of receiving water; 'release rules' to define start and finish of a release cycle; erosion control at outlet. Release parameters (eg regulatory, Environmental Management Program, community expectations, risks of environmental impacts).
- **Uncontrolled Releases** Spillway capacity; spill likelihood and frequency; impact on quality of receiving waters; erosion control along spillway and at outlet. Release parameters (eg regulatory, Environmental Management Program, community expectations, risks of environmental impacts).
- **Groundwater Recharge** Impact on groundwater levels and quality. Impact on vegetation.



3.2 PROCESS ELEMENTS

'Process elements', as well as physical elements, need to be included in a minesite water management system to control problems at source, and maintain and verify the functioning of individual physical elements and the whole system. Process elements typically incorporated in a minesite water management system include:

- an erosion/sediment control plan;
- a management plan for identifying and disposing of geochemically aggressive waste materials (acidic, alkali, or highly reactive);
- a hazardous Materials Management Plan;
- an inspection and maintenance plan for the physical elements of the system;
- monitoring water volumes, water flows and water quality; and
- reporting.

Erosion and Sediment Control Plan

Developing and implementing a comprehensive erosion and sediment control plan is a fundamental best practice approach for responsible minesite water management. This is particularly so in Australia, given the erodability of many Australian soils, the soil and vegetation disturbance caused by mining operations plus the intense rainfalls that can occur in most parts of the country. The plan must define a coordinated approach to sediment and erosion control throughout the life of the mine, and include standard techniques to control the risk of sediment loss from disturbed areas, eg silt fencing and the construction of sediment dams. The plan also needs to address rehabilitation and revegetation options.

One of the most effective ways to reduce erosion risk from spoil piles and other disturbed areas is to rehabilitate and revegetate these areas as quickly as practicable.

Other booklets in this series address sediment and erosion control and rehabilitation and revegetation. A properly designed and implemented sediment and erosion control plan minimises the amount and mass of suspended sediment washed into creeks and the associated problems of environmental degradation in the creeks and downstream receiving waters.

Managing Geochemically Aggressive Waste Materials

Some types of spoil and other mine waste materials undergo a geochemical reaction with oxygen and water to generate water-based pollutants. A familiar example is the oxidation of pyritic material in coal seams, overburden and certain metalliferous ores to generate sulphuric acid, or acid mine drainage.

Identifying and managing such materials early can eliminate or at least minimise subsequent water quality problems. Hence, another key element of a minesite water management system is the management plan for geochemically aggressive waste materials.

Managing Hazardous Materials

All mining operations use hazardous materials of some type, or materials potentially hazardous to human health or the environment when improperly managed, treated, stored or disposed of. This includes grease, oils and petroleum products, as well as other more toxic processing materials. Many of these materials are liquids, water-based or water soluble, able to cause water pollution, health risks and environmental damage if they escape. Consequently, another key element of a minesite water management system is a hazardous materials management plan.

Another booklet in this series addresses the management, storage and disposal of hazardous materials.

Inspection and Maintenance

It is one thing to appropriately design and construct the physical elements of a minesite water management system. It is another to ensure these elements are adequately maintained at full operational readiness and function. An inspection and maintenance plan is another important component of a minesite water management system.

Note that inspection and maintenance planning applies to both physical and process elements of a minesite water management system.

- for physical elements, only simple visual inspections of key elements is generally needed eg bed and bank erosion in open channels, damage to above ground pipelines, silt build-up in sediment basins. Sometimes, more refined procedures may be required, for example, calibrating monitoring equipment such as water level recorders and water quality sensors.
- for process elements, the importance of inspecting the operation of sediment and control plans and managing geochemically aggressive wastes and hazardous materials is self-evident. Note that 'maintenance' activities for process elements may include modifying processes to achieve outcomes.

For more on intercepting see page and runoff using wetlands, see Appendix 2 (under *Critical Design Features*).

Monitoring

Monitoring hydro-meteorological, water quality and biological parameters at key points throughout a minesite water management system is essential to acquire:

- reliable pre-mining baseline data to use as an objective yardstick when assessing the impact of mining operations on hydrological processes ('baseline monitoring').
- data to design physical and process elements of the water management system ('design monitoring').
- regular data to verify the water management system's adequate operation ('operational monitoring').
- data documenting the consequences of any incident affecting minesite water eg an uncontrolled spill from a dirty water dam, a spill of hazardous material, etc. ('incident monitoring').

A prescribed water monitoring program is generally a statutory requirement of mining activities throughout Australia. The monitoring program must be well designed and regularly reviewed. Otherwise, additional monitoring will need to be paid for and the program will be unable to provide objective and appropriate data at critical times, for example when water quality incidents occur, thereby negating a key objective of the program.

4 BEST PRACTICE PRINCIPLES FOR MINESITE WATER MANAGEMENT PLAN

4.1 INTRODUCTION

This section describes best practice principles for minesite water management in Australia. A comprehensive MWMP is the most appropriate way to identify effective management measures and integrate these into a minesite water management system. Erosion control and water quality management plans are essential components of the MWMP.

4.2 MINESITE WATER MANAGEMENT PLAN

A comprehensive planning process is the best way to realise the multiple objectives of a minesite water management plan. The planning process should include:

- in the first instance, adopting a catchment-based approach to minesite water management. This will identify current and potential water management issues in the catchment containing the mine leases, and will assess how mining may exacerbate or ameliorate problems. This approach will ensure minesite water management takes account of catchment issues as well as lease-area ones.
- incorporating public consultation (with regulators and stakeholders) to ensure all issues are identified and addressed.
- planning to address the three phases of mining: development, operation and decommissioning.
- recognising the cost-effectiveness of jointly formulating minesite water management and mine plans. This optimises coordination of minesite infrastructure and minesite water management measures.
- recognising the most cost-effective solutions to minesite water management issues come from an integrated 'whole of mine' investigation, rather than investigating specific issues in isolation and on an ad hoc basis.
- a risk management approach to how changing levels of flood, drought and water quality risks should be addressed.
- a risk management approach to identify and deal with operational risks that generate potentially adverse water management consequences.
- undertake appropriate technical studies to adequate standards.
- identify and assess a full range of management measures and options.
- identify and implement appropriate performance indicators.

A water management plan consistent with best practice must consider and/or develop site-specific standards, targets, operational or contingency plans and procedures (as appropriate) for all of the following:

- Community expectations,
- Statutory requirements,
- Risk management,
- Minesite Water Balance,
- Monitoring of Hydrological Process,
- Operational Monitoring,
- Emergency Monitoring,
- Flood Risk and Hazard,
- Water Supply,
- Soil Erosion,
- Water Quality,
- Computer Models,
- Performance Indicators, and

- Training and Research.

Box 3: Environmental Values and Their Pre-cursors

An important best practice environmental goal of minesite water management is to protect (and if possible enhance) the environmental values of creeks and other waterbodies affected by mining operations.

Environmental values, are particular values or uses of the environment that are conducive to public benefit, welfare, safety or health and that require protection from the effects of pollution, waste discharges and deposits. Several environmental values may be designated for a specific waterbody.

These values are established as part of regional water goals and objectives that consider the ranges of environmental resources, economic opportunities and community preferences. Five environmental values are:

- ecosystem protection;
- recreation and aesthetics;
- drinking water;
- agricultural water; and
- industrial water.

For details on environmental values, refer to the National Water Quality Management Strategy, a joint initiative of Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), and the Australian and New Zealand Environment and Conservation Council (ANZECC). Two useful documents of the Strategy are Policies and Principles - A Reference Document and Australian Water Quality Guidelines for Fresh and Marine Waters. [Internet address: http://www.affa.gov.au/nwqms]

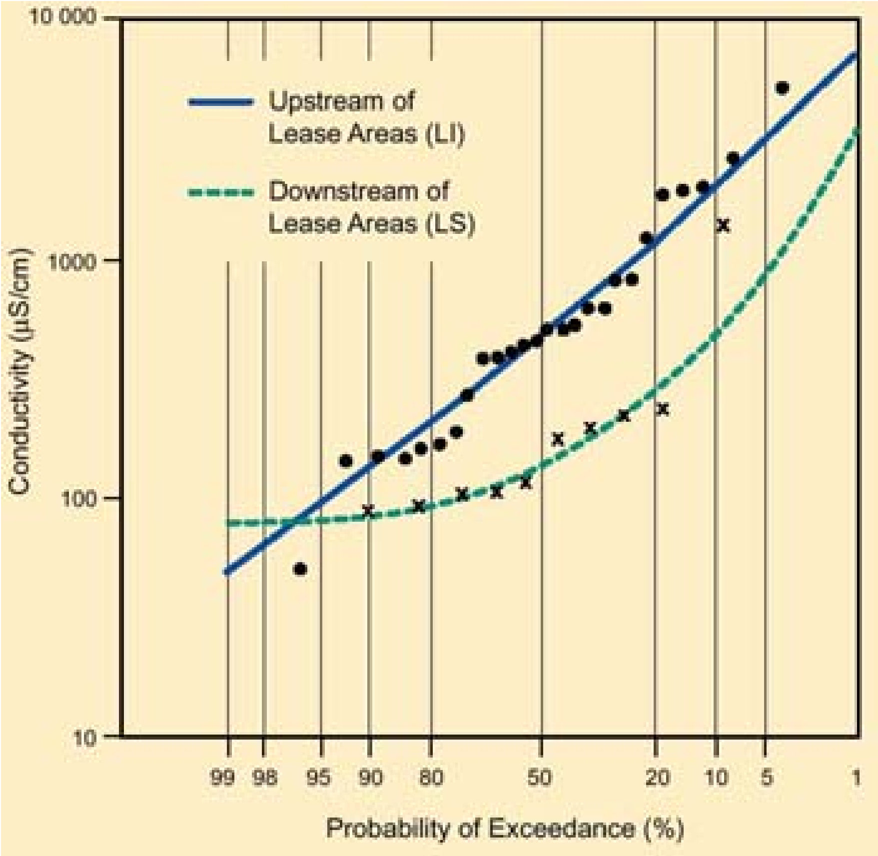
To determine appropriate environmental values, it is necessary to assess the nature and importance of physical, chemical and biological characteristics of the waterbody, as well as the role of the waterbody and its riparian vegetation as habitat for aquatic and terrestrial vegetation and animals. Physical and chemical water quality parameters and the species distribution and number of aquatic biota are pre-cursors used to measure the environmental value of a waterbody.

The physical, chemical and biological characteristics - and to some extent habitat characteristics - of a waterbody all fluctuate in response to a variety of factors that undergo annual, seasonal, and day-to-day variations. Some of these variations are natural, such as those associated with climate and weather. Other variations may be induced by human activities, e.g. land clearing. The figure opposite shows the variation in conductivity levels at locations upstream and downstream of an open cut coal mine in Central Queensland. Natural variation is responsible for the distribution of conductivity levels at the upstream location. The impact of mining activities is responsible for the higher conductivity levels at the downstream location.

Notwithstanding the cause of these variations, compliance measures adopted to assess the impact of mining operations on the environmental values of a waterbody and their pre-cursors also undergo variation and cannot meaningfully be assessed or measured via a single 'point value', e.g. 'suspended solids levels are to remain below 50 mg/L'. Compliance measures should be stated in terms of a frequency that reflects the underlying variation in 'natural values', e.g. 'suspended solids levels are to remain below 50 mg/L in 90% of samples tested'.

Natural and induced variation in the environmental values of a waterbody and their pre-cursors has a number of implications for minesite water management:

- Surface water monitoring programs need to be carefully designed to reflect expected variations in flow and water quality regimes. At the very least, it is necessary to distinguish between samples collected or measurements taken during runoff events and under low flow conditions.
- Under Australian conditions, it may be necessary to conduct a sampling program for 3 years and possibly 5 years to adequately define the natural variation in baseline environmental values and their pre-cursors.



Distribution of Conductivity Levels in Runoff from Areas Upstream and Downstream of an Open Cut Coal Mine, Central Queensland

4.3 COMMUNITY EXPECTATIONS

It is reasonable for a community to expect that the nation's mineral reserves will be mined in an ecologically and socially responsible way and that mining operations reflect broader principles of Total Catchment Management.

Best practice principles dictate that minesite water management must strive to ensure that:

- during the course of mining, downstream water users and riparian habitats (and their environmental values) are not adversely affected by the impact of mining operations.
- at the end of mining, appropriate minesite water management measures will be implemented to sustainably protect water quality and preserve water users and riparian habitats downstream.
- there is effective liaison with stakeholders from areas affected or likely to be affected by mining operations, and that their concerns are addressed.

- the community is consulted and has access to information, from mine planning stages to mine closure.

4.4 STATUTORY REQUIREMENTS

Best practice principles for policy and legislation include:

- identifying all items of legislation relevant to environmental and water resources, both on the mine lease and in the broader catchment(s) containing the lease.
- effective liaison with the appropriate regulatory agencies to ensure that statutory requirements are satisfactorily addressed.

4.5 RISK MANAGEMENT

Hydrological Risk

Minesite water management seeks to control or manage various hydrological processes with outcomes that fluctuate randomly. Although rare, extreme outcomes can occur with potentially devastating consequences.

Best practice principles for managing hydrological risks require:

- recognising that a formal risk management approach is needed to define appropriate measures and responses.
- recognising the need to evaluate the hydrological event risks and hazards over a full range of event severities.

Operational Risk

In addition to hydrological risk, minesite water management also needs to address 'operational risk', that is, the risk to safety, the environment and the economics of the mining operation that arises from mining activities. An example of an operational risk is a process chemical spill.

Another economic risk is the risk of running out of water for processing.

Best practice operational risk management must recognise the need to identify all operational activities that are a risk to water and evaluate the risks.

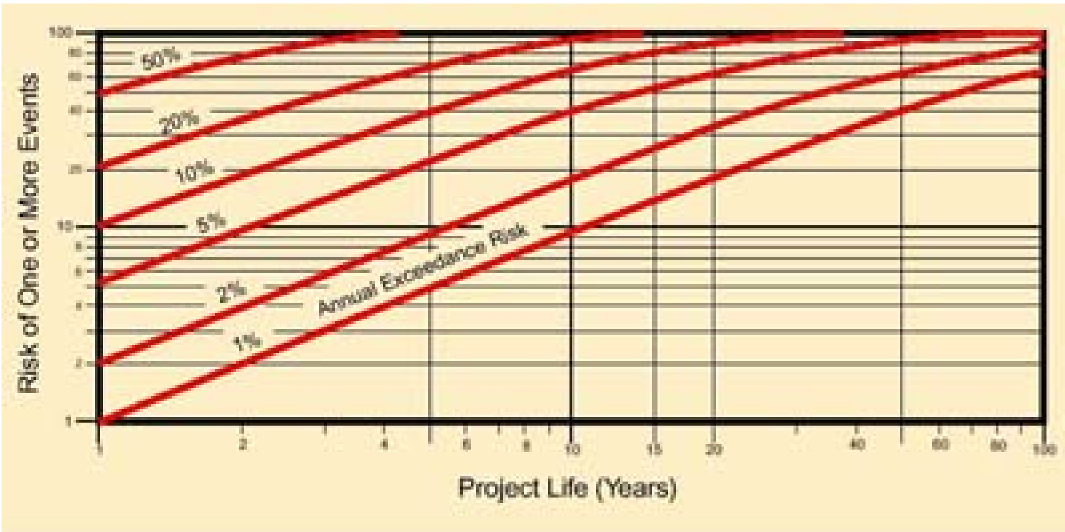
Box 4: Risk Management

1. Define the Event of Concern. This may be a flood, a spill of toxic material, heavy rainfalls causing erosion of topsoil before a protective vegetative cover has been established.
2. Evaluate the risk of the Event of Concern occurring. For hydro-meteorological events such as rainfall, runoff, streamflows, etc., this risk can be quantitatively estimated. For other events, the risk may have to be estimated in qualitative terms such as 'slight', 'moderate', 'high' and 'very high'.
3. Evaluate the hazard associated with the occurrence of the Event of Concern, i.e. what are the consequences if this event should occur? Note that there may be economic, health, environmental and social dimensions to the hazard. Some hazard items can be evaluated quantitatively, such as economic loss. Other hazard items will need to be evaluated qualitatively in terms of 'minor', 'major', 'serious' and 'very serious' consequences.
4. Devise an appropriate Risk Management Plan. This may entail reducing the risk of occurrence of the Event of Concern or reducing the hazard of the event when it does occur. The risk of occurrence can be reduced by controlling factors leading to the event, e.g. the risk of a toxic spill can be reduced by better

handling procedures. The associated hazard can be reduced by appropriate planning measures (e.g. an evacuation plan) or by structural measures (e.g. constructing a bund to contain spilt liquid). The nature and scope of the appropriate risk management measures depends upon the risk of the event occurring and the specifics and seriousness of the hazard.

5. Note that hydro-meteorological events such as storms and floods come in a range of 'sizes', e.g. minor, moderate and major floods. However, the risk of occurrence of 'severe' or 'rare' events is less than the risk of occurrence of 'frequent' events. When undertaking a risk management study of hydro-meteorological events, it is essential to consider the risk and hazard for a full range of events. This information is essential to define an effective and robust risk management plan that provides the best protection at the least cost.
6. The graph below shows the risk of one or more nominated events occurring in the project life of a mine. For example, if the Event of Concern has an annual risk of occurrence of 10%, there is:

    - A 40% chance that at least one such event will occur in a 5 year period,
    - A 65% chance that at least one such event will occur in a 10 year period, and
    - An 88% chance that at least one such event will occur in a 20 year period.



4.6 MINESITE WATER BALANCE

The parts governing the minesite water balance is managing water volumes and their quality to meet environmental objectives, processing plant needs, and mine development needs over time. Once that is defined, the minesite water balance is the tool used to design the water management system. See **Equation 1.**

An average annual minesite water balance should be prepared early in the initial investigation phase to:

- identify the average annual shortfall in supply or the average annual volume of excess water generated on the minesite which takes account of seasonal variability of rainfall and evaporation.
- expose water balance elements with uncertain or missing data, eg water use for dust suppression. It may be possible to supplement inadequate data by a monitoring program.
- provide a broad framework for more detailed (eg monthly, weekly) minesite water management studies.

An annual water balance may indicate little about the necessary size of storages or the operation of the minesite water management system. Rather, an annual minesite water balance is an overview of the major sources and destinations of water flows onto, across and off the minesite. More detailed numerical simulation studies are required to size and determine an appropriate minesite water management system.

A typical water balance focussing on a storage dam or tailings impoundment is given in Equation 1 (after McQuade & Riley, 1996).

Likewise depending on which element is deemed important or critical for a specific site, Equation 1 can be rearranged with that element on the left hand side of the equation.

$$\Delta \text{ Storage dam} = \text{Rainfall} + \text{Groundwater flow} + \text{Runoff} + \text{Returns from process} - \text{Inputs to process} - \text{Evaporation} - \text{Seepage} - \text{Discharge} \pm \Delta \text{ Pump transfers} \quad \textbf{(Equation 1)}$$

Equation 1

4.7 MONITORING HYDROLOGICAL PROCESSES

Monitoring hydrological processes on the mine lease area records the quantitative impact of mining operations on these processes. Designing appropriate monitoring networks and selecting appropriate monitoring equipment are discussed elsewhere (DMR, 1993). There are three distinct phases of hydrological monitoring:

- **baseline monitoring** to establish pre-mining quantity and quality levels,
- **operational monitoring**, during the active mining period, and
- **post-mining monitoring**, after the mine has been decommissioned.

Adequate baseline data provides an invaluable yardstick for measuring the impact of mining operations and any post-mining impacts on hydrological processes.

General best practice principles for minesite water monitoring are:

- implementing an adequately resourced and well designed baseline monitoring program, ideally starting at least 3—5 years before mine construction, to get reliable indications of the natural variability of climate and water quality.
- adequately supporting and maintaining monitoring programs. Programs and their results need annual review for direction, problems and possible modifications. Monitoring programs are expensive. If annual reviews are not done, it is likely that money will be wasted and the program fall short of its goals.
- selecting reliable equipment with a proven field record. This is likely to be more expensive, but the greater reliability will more than offset higher initial costs.

Typically, the following hydrological processes are monitored on minesites:

- Rainfall,
- Evaporation,
- Streamflow, and
- Water Quality.

Rainfall and Evaporation

Rainfall monitoring stations (and evaporation and streamflow stations) need to do more than just record depth and variability of rainfall across the minesite. They need to be distributed in large enough numbers to provide sufficient data for any numerical models proposed for minesite water investigations or for preparing a minesite water management plan.

Consider installing at least one automatic weather station to monitor solar radiation, wind speed and direction, temperature, relative humidity and rainfall. These parameters make it possible to reliably estimate both evapotranspiration and open water evaporation rates. This 'climate-based' approach is far more reliable than estimates based on evaporation pan data.

Streamflow

To accurately monitor streamflow, mine management should:

- Site streamflow stations so that they coordinate with rainfall and water quality monitoring sites. In particular, streamflow stations siting should facilitate calibrating any numerical hydrologic or hydraulic models proposed for the minesite water management plan.
- Establish at least one 'key' streamgauging station, that is, a site where a current meter can gauge streamflows to determine a reliable rating curve. Selecting such sites is best left to experienced hydrologists. Gauging streamflows, especially high rates of flow, is best left to experienced hydrographers from State Water Resources Agencies or contractors who do such work on their behalf.
- Identify existing or past official streamgauging stations near the mine lease area. State Water Resource Agencies have these locations. If appropriate, consider adopting an existing station or reactivating a decommissioned station as part of the streamgauging network. Such stations will provide a longer period of record than a 'new' station.

Water Quality

Water quality monitoring sites are needed at mining lease entry and exit points on all major creeks at risk from mining operations. This allows any change in the quality of streamflows entering and leaving the lease area to be unambiguously defined.

Water quality should be monitored in at least one control catchment not affected by mining. This provides an indication of the 'natural' variation in water quality over the course of mining.

Event-based sampling programs are needed. Runoff events are far more significant than baseline flows for pollutant loads delivered to downstream receiving waters. Appropriate event samplers include pumping water samplers and rising and falling stage water samplers. The latter are robust and less expensive than pumping samplers. However, ensure no further flow enters the sample bottle once full. If such 'flow through' does occur, an unrepresentatively high level of suspended sediment will settle out in the sample bottle.

Water samples must be reliably and certifiably tested. A core body of samples should be tested by a registered NATA laboratory. Such results can be confidently presented to a court or hearing should a dispute arise about water quality.

A balanced water quality testing program should be cost-effective, yet sufficiently broad to identify likely adverse effects. A 'phased' testing program is needed, or one where a wide variety of tests are undertaken in the initial phase to identify water quality parameters specifically significant to the mining operation. In the follow-up phase, only the parameters of specific interest are monitored.

Annual water quality reviews are essential. Annual data reports should contain details of any problems with monitoring over the past year.

When designing a water quality monitoring program mine managers should:

- seek advice from appropriate regulatory agencies;
- forward annual water quality reports to the agencies for review and comment;
- ensure all appropriate parameters are being monitored and prevent unwarranted criticism, by having the regulatory agencies progressively sign off on the proposed monitoring program, any modifications to it and on annual reports; and
- recognise the importance of biological monitoring programs, as well as the more traditional programs that measure physical and chemical water quality characteristics. Biological monitoring programs are expensive and are somewhat difficult to undertake in ephemeral creek situations but, if well designed, provide an integrated measure of the health of a creek and its riparian habitat.

4.8 OPERATIONAL MONITORING

Besides monitoring minesite weather and the quantity and quality of surface and groundwater water entering and leaving it, mine management must monitor various parts of the water management system to ensure the system's reliable and auditable operation. This includes the need:

- to develop and implement an integrated monitoring system that allows the minesite water management system to operated reliably and effectively;
- to incorporate agreed performance indicators, such as peak water levels in 'dirty' water storages, so system operations can be audited by both minesite and regulatory personnel;
- to alert minesite personnel to actual or imminent emergencies, eg pipeline rupture, a dirty water dam about to spill, so appropriate response measures are activated;
- to monitor all major minesite water uses and prepare annual 'water use' reports. On many minesites, major onsite water uses are poorly defined, eg water volume used for dust suppression, or for ore processing;

Operational monitoring could include any of the following:

- flows in key pipelines,
- inspecting the hydraulic integrity of key pipelines,
- water levels and water quality in key storages, especially 'dirty' water storages,
- minesite rainfalls,
- silt build-up in silt traps and wetlands,
- bed and bank erosion in channels.

Operational monitoring can be undertaken manually or with automatic equipment. Note, however, that operational data is required for day-to-day and possibly hour-to-hour operation of the minesite water management system. It may be necessary to collect key data in 'real-time' and convey them telemetrically to the operational centre.

Box 5: Biological Monitoring

In recent decades, biological monitoring has become an accepted and widely used procedure for assessing the health of ecosystems. This has been a response to the limitations of relying on physical and chemical procedures as the sole means of assessment, as well as the development of cost-effective and efficient procedures for biological monitoring. It has become generally accepted that only studies that include living organisms can determine or predict the overall effect of waste-waters on ecosystem. Management goals for environmental protection are typically biologically based and achievements can best be assessed in terms of effects on living organisms. This does not preclude using numerical guidelines such as water quality parameters as a surrogate for biological data in some circumstances.

The type, number and distribution of aquatic organisms in creeks and other waterbodies can provide a reliable and integrated measure of the 'health' of the waterbody. In particular, aquatic plants, including algae, macroinvertebrates (insects, crustacea and worms of visible size), and fish can all provide effective bio-indicators.

Using biological indicators for monitoring and assessment of aquatic ecosystems is at a relatively early stage of development in Australia. The development of biological monitoring is occurring simultaneously with a rapid growth in the appreciation of the statistical and inferential complexities of field-based monitoring for both biological and physico-chemical indicators. Soundly designed monitoring systems and statistical rigor in interpreting the data obtained provides a high level of confidence in the results. These are often expressed in terms such as 'no effects at a 95% confidence level'.

Biological monitoring can be relatively expensive, but provides a high level of assurance. Monitoring programs need to be well designed and operated to maximise their worth. Biological monitoring is a specialist exercise and expert assistance should be sought.

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Table 5: Main Requirements in the Development and Operation of a Minewater Management System (after McQuade & Riley,1996)	
Stage	**Important water management elements**
Exploration	• erosion control from temporary roads and drill pad construction • management of drilling fluids • management of camp wastes • collection of hydrogeological data • collection of rock samples for environmental geochemical analyses

Resource development	• erosion control from semi-permanent roads and additional drill pads
	• management of camp wastes, allowing for increased personnel for longer periods
	• commence baseline data collection:
	  •
	  o hydrological and hydrogeological
	  o climate
	  o biological
	  o geochemical

Design	• ongoing refinement of data collection • determine the expected water requirements for the operation - quality and quantity - from the proposed mining and processing methods • develop an expected mine site water balance • undertake an audit of potential mine-related contaminants • quantify the potential pathways of contaminant transport and the expected rate and chemical alterations during transport • define the physical locations, types and timing of potential environmental impacts • undertake modelling to assess the reliability of water supply and potential environmental impacts • undertake a risk assessment • develop strategies to minimise the risk of water contamination • design a preliminary water transfer system to meet water supply and environmental contingency needs • develop a preliminary runoff drainage system to manage high-rainfall events • develop contingency procedures • develop a data collection program for design performance validation
Operation and rehabilitation	• validate design predictions and collect data to reduce the uncertainties in design, where necessary • monitor the environmental and operational performance of the water management system • develop accountabilities for the maintenance and operation of the physical and mechanical components of the water management system and in implementing contingency procedures • train operators in these areas • continue with system investigations, that take account of new technologies, to minimise the risk of environmental impacts and maintain flexibility for the mining operation • identify and manage risks • develop techniques for and implement progressive rehabilitation • develop a data collection program for rehabilitation performance post-mining
Post-mining	• collect data and determine the performance of the post-mining landform activity against the agreed post-mining land use/environmental values • publish the information so that governments and the mining industry can improve their environmental performance

4.9 EMERGENCY MONITORING

Despite the best plans, emergencies are likely to arise in operating a minesite water management system, eg pipelines may rupture, 'dirty' water storages may spill in an uncontrolled fashion. It is essential that such emergencies are investigated comprehensively to identify the magnitude, impact and circumstances that caused them.

Best practice principles for emergency monitoring should ensure:

- each mine has an emergency monitoring plan, i.e. a plan identifying possible emergencies (using risk management) and appropriate monitoring strategies.
- the emergency monitoring plan addresses the volume, discharge rate and quality of water that 'escaped' and its impact on downstream receiving water bodies.
- the emergency monitoring plan addresses the possibility of alerting downstream landholders and water users of what has happened and its likely adverse impacts on water supply and/or quality.

4.10 FLOOD RISK AND HAZARD

Best practice principles for managing flood risk and flood hazard on minesites include:

- evaluating flood behaviour, peak flood discharges and peak flood levels across the minesite for a range of flood events (i.e. flood risks). Such 'flood studies' can be technically demanding and are best left to experienced hydrologists.
- identifying minesite elements that the various flood events may affect.
- evaluating the associated hazard to these elements. Hazard 'seriousness' may range from 'nuisance' (delayed access while road crossings are flooded), to economic (lost production) or ultimately, a threat to minesite personnel safety or lives.
- developing a comprehensive and appropriate risk management plan for flood hazards. Four broad groups of flood management measures can form part of the plan:
    - structural works, eg levees, creek diversions.
    - minesite planning considerations, eg locating key buildings and infrastructure in less flood-prone areas of the site.
    - building controls, eg minimum floor levels so buildings and infrastructure that may flood are designed accordingly.
    - emergency measures, eg flood warning and evacuation plans.
- Flood risk management plans are specific to each minesite and integrate the four measures listed above. The expected life of mining operations is a key factor in shaping the risk management plan.
- If the flood risk management plan includes structural works, consider their impact on the downstream habitat and water users.

4.11 WATER SUPPLY

During the investigation phase of minesite development, minesite water supply systems should ensure:

- as much water will be recycled as possible.
- the feasibility of a joint water supply scheme with another major consumer is assessed.
- the risk of shortfalls in supply are evaluated and contingency plans prepared to address them.
- the quality of the proposed source of supply, and need for treatment, is assessed.

- the impact of surface storages on the downstream flow regime and habitat and other water users is evaluated.
- the risk and consequences of 'dam failure' for surface water storages is assessed.
- uses, such as for irrigation or recreation of water supply storages at the end of mining are assessed.

4.12 SOIL EROSION

Soil erosion is an issue at most minesites. An erosion management sub-plan is an essential part of a water management plan. Tackling soil erosion includes:

- preparing, accepting and implementing a comprehensive **erosion management plan** that identifies areas of existing or likely minesite erosion and proposed controls.
- seeking regulatory input and agreement for the erosion control plan before implementing it.
- trying to control erosion at source.

Note that both minesite personnel and regulatory authorities need to accept the plan. Details of erosion management plans are given elsewhere (Institution of Engineers Australia, 1996).

4.13 WATER QUALITY

A water quality management sub-plan is an essential part of a minesite water management plan. It includes:

- preparing and implementing a **water quality management plan** that identifies water quality issues and proposed means of control.
- submitting the water quality management sub-plan to regulatory authorities before it is implemented.
- Separating surface runoff from 'clean' areas of the minesite as effectively as possible from 'dirty' area runoff and from 'dirty' waterbodies.
- controlling, at source if possible, pollutants or water quality contaminants.
- designing and implementing appropriate water quality monitoring programs to measure baseline and operational water quality parameters and appropriate parameters in emergencies.

4.14 COMPUTER MODELS

Computer models are being increasingly used to investigate minesite water management issues and simulate water management systems. Various computer models used for these purposes are briefly described in Appendix 3. When using computer models, mine managers should:

- check the assumptions inherent in the model are appropriate to the situation modelled.
- check the reliability of all input data.
- check that the time and space scales adopted in the model are appropriate to the situation being modelled (see Appendix 3).
- attempt to calibrate the model as comprehensively as possible. If calibration data is unavailable or uncertain, output from the model should be used cautiously.
- use experienced modellers. The personal experience of the modeller is probably the most important factor in the reliability of results obtained.

4.15 PERFORMANCE INDICATORS

It is essential to develop an agreed set of performance indicators for the minesite water management plan, as well as for the erosion management plan and the water quality management plan. Such indicators provide an auditable check on the water management system's operation. When developing performance indicators:

- recognise the need to define performance indicators to monitor minesite water management operations and its various components. These indicators need to be agreed to by minesite personnel and regulatory authorities.
- prepare annual reports on minesite water management system operations based on these performance indicators. Review operational procedures as and when necessary.

4.16 TRAINING

Several minesite groups generally operate a minesite water management system. When training these operators:

- clearly delineate areas of responsibility and chains of command.
- explain the overall minesite water management system to all operators so they appreciate the contribution of their activities.
- ensure operators are trained in their respective areas of responsibility.

5 CONSIDERATIONS IN EXPLORATION PHASE

Developing and maintaining good relations with landholders is important, especially during the exploration phase when controls over minesite personnel may be looser. To maintain good public relations, mining personnel should keep landholders informed of the nature and location of exploration work, and invite them to inspect, for example, drill rigs and access roads.

Every attempt should be made to minimise environmental disturbance when building access roads, mining camps and drill pads. Managers should assess erosion potential of access roads and implement effective erosion control measures during construction, especially at creek crossings.

Managers should also: define appropriate procedures to manage drilling fluids and petroleum products; train drill crews should in these procedures; and ensure disposed camp liquid and solid wastes does not adversely affect either surface water or groundwater resources.

An initial baseline monitoring program, comprising an automatic weather station and several monitoring sites should be developed to measure creek discharge and water quality. As the resource is firmed up during the exploration phase, it may be appropriate to;

- extend the monitoring program to additional sites.
- start baseline monitoring in a 'companion catchment' which mining operations will not affect.
- review the official streamgauging network and have the appropriate authority install an official gauging station at a key location on or near the lease areas.

During the exploration phase, the monitoring program may need to be operated by non-qualified personnel, eg a camp supervisor or a local farmer. Monitoring procedures need to be carefully defined to ensure the monitoring program is operated to appropriate quality standards. Operators will need to be trained in these procedures. Qualified minesite personnel may need to visit the site several times a year to ensure that the monitoring program is operating satisfactorily. Note that some of the more complex monitoring procedures may be too dangerous or not feasible during the exploration phase, eg using nitric acid to fix water samples for subsequent metal analysis.

6 CONSIDERATIONS IN THE DESIGN AND CONSTRUCTION PHASE

6.1 PLANNING (AND LIAISING) FOR SUCCESS

During mine design and construction, formulating an integrated minesite water management plan is essential for effectively managing water during the operations phase and the post-mining phase.

Formulating a minesite water management plan is a planning process, that is, a process that examines all options, opportunities and constraints, before selecting the most appropriate option for mine-specific circumstances.

Minesite water management and general mine planning, should be done together so both address the nature, size and location of mine infrastructure. Failure to address water management issues during general mine planning may inadvertently restrict water management options or markedly increase future costs.

The MWMP should be robust enough to cope with inherent uncertainties of mine development such as ore body extent and life of the mine. The MWMP should ensure that if there are unanticipated changes they do not adversely affect the plan to a significant ('unacceptable') degree.

Best practice requires that regulatory agencies approve, and local and regional stakeholders accept, the minesite water management plan. There should be complete, open and effective liaison with regulatory agencies from all levels of government (federal, state and local). Forming a steering committee that includes local and regional stakeholders to address and respond to stakeholder concerns is an effective way of gaining acceptance.

Before focussing on local water management issues specific to the proposed mine, it is important to canvass regional and catchment-based water management issues. This will identify ways the mine can contribute to and foster an integrated approach to catchment water management.

6.2 MINESITE WATER MANAGEMENT PLAN

Important components of the minesite water management plan include:

- Minesite water balance.
- Water supply.
- Drainage.
- Erosion management.
- Water treatment.
- Flood risk and hazard.
- Managing geo-chemically aggressive materials.
- Managing hazardous materials.
- Water monitoring.

Estimating a minesite water balance can draw attention to potential problems with a MWMP. For example it will show:

- any lack (or unreliability of) data about various minesite water demands and other in/outflows.
- an overall picture of how much water is needed, where it comes from and where wastewaters go.

Managing water supply includes estimating demand and demand variability through the year; identifying potential sources of both groundwater and surface water; and assessing reliability of supply and the impact of supply on other water users. To reduce overall water demand, as much water as possible, especially runoff from 'dirty' areas, should be recycled.

A whole-of-mine drainage strategy that not only separates runoff from 'dirty' and 'clean' areas as effectively as possible, but also takes account of the potential of drains to erode land, is needed. A carefully designed and integrated drainage system will pay dividends because it can be economically constructed in stages as the mine develops and economically modified to address changing areas of disturbed and undisturbed catchments.

A minesite erosion management plan is fundamental to effective minesite water management and, by integrating the erosion control and drainage strategies, should deliver many benefits. The plan needs to address erosion control for stripped, spoil and recontoured areas during mining operations; how to manage bed and bank erosion in diversion channels; and how to control erosion while mine infrastructure is being constructed.

The need for and type of water treatment must be assessed. Sediment traps and wetlands are two cost-effective treatments suitable for many minesites. Areas of existing or proposed wetlands need to be identified and earmarked for subsequent use early in mine planning.

Flood management considerations include the risk of flooding at the minesite and the associated hazard to minesite personnel, infrastructure and cash flow. It is essential that mine managers have and understand data on precipitation and flooding probabilities for their minesite. Potential hazards, flood damage and interruption to mining must be evaluated for a full range of flood events. This provides an objective basis for managing flood risk. Apart from mine buildings and process infrastructure, flood risk assessment is used to determine the spillway capacity of water storages, the freeboard of tailings dams and the discharge capacity of diversion channels.

Many mining operations expose geo-chemically aggressive materials that can have markedly harm minesite water quality. Such materials need to be identified, their pollutant potential assessed and plans made to contain and manage them. These plans need to be integrated into the general minesite water management plan.

Most mines use various hazardous materials which can pollute waterbodies if they escape into them. Hazardous materials need to be identified and plans made to contain and manage them, including contingency plans for spills. Plans to manage toxic materials need integration into the general minesite water management plan.

An integrated water monitoring sub-plan to measure diverse water quality data is another essential component of the MWMP. This sub-plan should have an integrated set of procedures, monitoring locations, equipment and measured parameters that address baseline, operational, compliance and incident monitoring needs. It needs to measure hydro-meteorological and climatic data, water level and discharge data, and water consumption and quality data.

- **Baseline Monitoring**: During mine design and construction, the baseline monitoring program design should be finalised, building on any monitoring during the exploration phase. If not already done, it may be wise to identify and monitor 'companion catchments' not affected by mining to record the natural variation in water flows and quality.
- **Operational Monitoring**: Consider monitoring station locations and the parameters measured during mining operations.

- **Compliance Monitoring**: Consider 'compliance site' locations and the parameters to be measured during compliance monitoring. (Liaison and agreement with regulatory authorities is needed in Australia for compliance monitoring programs). Compliance monitoring during construction will ensure that construction operations do not unduly affect water quality. Note that compliance monitoring programs during construction operations may be quite different from those adopted during normal mining operations.
- **Incident Monitoring**: Develop procedures and contingency plans to monitor the impacts of any untoward minesite incidents, eg the effect of uncontrolled spills of 'dirty' water on receiving water quality. Use risk assessment to define the nature and location of potential incident sites.

6.3 PERFORMANCE REVIEW AND TRAINING

While a mine is being designed and constructed, performance indicators and training are mainly on water monitoring aspects of the minesite water management plan.

Performance indicators can be simple, but must relate to monitoring equipment performance and maintenance and the recording and reporting of data. Regular checks to compare actual performance to the performance indicators is needed. A set of operational procedures should describe the nature and frequency of performance checks and actions required if a performance falls short of the mark.

Environmental officers monitoring water need to be trained to operate equipment and to collect and forward data and samples. A set of operational procedures needs to be written to describe roles, responsibilities and actions for the monitoring program.

7 CONSIDERATIONS IN THE OPERATIONS PHASE

7.1 REVIEWING AND ADAPTING THE MWMP

The minesite water management plan, defined during the design and construction phase, provides the basis for effective and economic water management during the operations phase.

The MWMP must be adaptable, eg the annual production rate and the extent or grade of the ore body may change. How effective and appropriate the MWMP is needs to be formally reviewed at regular intervals (say 3—5 years) and modifications as conditions and circumstances dictate. In addition, its performance needs annual review and reporting, i.e. actual performance and performance indicators compared.

During mining operations, operational risks to good water management need review, with any new risks identified and managed. Regular MWMP reviews, annual performance reports and reports on any incidents will all help identify risks to good water management.

Liaising effectively and continuously with regulatory agencies and stakeholders is important during the operations phase to show the mine is meeting its environmental obligations. Regulatory agencies and stakeholder representatives should receive annual reports of plan performance. Also, both groups should receive incident reports so that, for any incident, they are aware of causes, effects and remedial and preventative actions.

The mined area should be rehabilitated on a progressive basis to minimise erosion risk and the backlog of disturbance. (See *Landform Design for Rehabilitation*).

7.2 Water Monitoring

Effectively monitoring and reporting on water demonstrates the mine is meeting its environmental obligations during the operation phase. Proactive monitoring and water management is better than a reactive approach, i.e. rather than waiting until a regulatory agency requires action, do what needs to be done and report it to the agency.

Baseline monitoring of companion catchments should continue during the operation phase. Review the adequacy of the baseline monitoring program at regular intervals (say 3—5 years) to ensureit remains relevant to expected post-decommissioning needs.

Operational water monitoring will ensure that a minesite water management system operates effectively. This may include hydro-meteorological parameters, creek flows and quality, water levels and quality in 'clean' and 'dirty' water storages, pipeline flows, pump operations, water use, erosion. Many mines have poor information about minesite water demands. Monitoring minesite water use, especially during the first years of operation, greatly assists any future revisions to the minesite water management plan. Operational water monitoring data needs annual reporting, and performance of the operational monitoring program should be reviewed and compared to performance indicators.

Compliance monitoring demonstrates a mine is meeting its environmental obligations for water management. The nature sites of the monitoring will have been agreed to in discussions with the appropriate regulatory agency. Appropriate regulatory agency(ies) and stakeholder representatives need an annual compliance monitoring report. As well as reporting data, it should review compliance monitoring network performance.

Any operational incidents should be promptly investigated, with a report on causes and effects, and proposed remedial and preventive actions planned. A copy should go to the appropriate regulatory agency and stakeholder representatives should also be told.

Special monitoring programs may be needed to check the effectiveness of minesite research investigations, eg how well different surface treatments control erosion. The nature of these monitoring programs and appropriate parameters are obviously specific to the research program.

Considerable money and resources are invested in monitoring water data during the operation phase of a mine. Developing an integrated monitoring system that facilitates the various monitoring sub-programs can realise considerable savings. The value of this investment will not be quantified unless annual data reports are prepared—and data used for decision-making and monitoring programs reviewed regularly and modified when appropriate.

Photo: Goldfields (Tasmania) Ltd

Goldfields (Tasmania) Ltd, Henty Gold Mine, 30km NW of Queenstown, Tasmania. Water management should be integrated into all work activities undertaken throughout the site. A process plant technician is explaining how water is recycled within the plant.

7.3 PERFORMANCE REVIEW AND TRAINING

Operating an effective water management system requires input from all workers on the minesite. Only well designed and regular training programs that describe the need for water management, the water management system itself and the roles and responsibilities of the various groups, will achieve this. Minesite water management is most effective when all staff feel they 'own' both the system and the process. Training programs and day-to-day operation should promote such ownership. Regular minesite water management reviews (eg monthly) are one way to keep staff informed and ensure they are contributing to decision-making. Staff should be congratulated when water is being well managed. Incidents should be reviewed with staff and causes, effects and remedial actions discussed.

Annual reviews of how various key components of a minesite water management system perform are needed, and should compare actual performance to performance indicators. Such components include the water supply, drainage system, and water monitoring systems—and management of hazardous wastes, geochemically aggressive materials and erosion. Appropriate performance indicators, backed by associated monitoring, can make performance review a relatively quick exercise that rapidly indicates whether programs are on track or that modification is required.

8 CONSIDERATIONS IN POST-MINING PHASE

8.1 PLANNING FOR DECOMMISSIONING

When mining ends, decommissioning begins. Some mine infrastructure will be removed, lease areas made safe, and final rehabilitation and revegetation operations begun to ensure lease areas can sustainably meet the adopted final land uses. The post-mining phase is important to both governments (lessors) and mining companies (lease holders) because it affects the timing of both lease relinquishment and the return of environmental bond monies.

The mine planning and operational processes put in place during the life of the mine heavily determine the post-mining success or otherwise of rehabilitation and revegetation operations. It may be unrealistic and it certainly will be expensive to attempt to define final landforms, vegetation and land use over the last years of active mining. These issues need addressing during the mine planning process (see *Landform Design for Rehabilitation*). A minesite water management plan must be formulated and implemented to identify these issues.

Discussions with regulatory authorities on final land forms, vegetation and land use must begin in the design and construction phase. These issues need reviewing at regular intervals (say 3—5 years) to ensure they are still appropriate and modified when necessary to account for changed circumstances. Review reports should be forwarded to the regulatory authorities for information and approval of any changes.

8.2 WATER MONITORING

Monitoring during the post-mining phase is essential to demonstrate compliance with environmental goals. Accordingly, the proposed post-mining monitoring program should be discussed and agreed with regulatory authorities.

Baseline monitoring activities at companion catchments should continue during compliance monitoring. This provides a yardstick for comparing the post-mining response of disturbed areas.

Operational monitoring will largely cease with mine closure. However, where pumps, water storages and wetlands are retained as part of the post-mining management system, the operation of these facilities may need monitoring.

Compliance monitoring can include hydro-meteorological data, creek water flow and quality, groundwater behaviour and quality, biological monitoring and erosion monitoring. It may be required for some years (perhaps five or more) while the post-mining landforms and ecosystems 'settle in'. An intense post-mining monitoring effort will not offset poor design and planning of final landforms, drainage and vegetation.

Any incidents during the post-mining phase needs monitoring for causes, effects and proposed remedial actions. An incident report should be submitted to the regulatory authorities.

Reporting and liaison with regulatory authorities is essential during the post-mining phase. Annual reports concerning post-mining monitoring and any incidents should be submitted to regulatory authorities, who should be invited to regularly inspect the decommissioned minesite to assess progress to final vegetation and land use.

8.3 PERFORMANCE INDICATORS

It is important to select appropriate environmental performance indicators to help prepare annual reports, and compare the actual response of decommissioned areas to the intended response.

CONCLUSION

Environmental best practice is about achieving more than compliance with legislation. It is about cost-effectively and proactively developing and implementing systems to prevent or minimise environmental impacts. Best practice also requires attention to continuous improvement, and must constantly adapt to changing conditions and technology. The workforce most committed to environmental protection will be the one driven by a strongly committed management prepared to provide resources for its employees, train them and lead by example. Technology and risk management systems can be installed to reduce environmental impacts, but their continued success relies on a trained workforce where every member has ownership in the goal of environmental best practice.

Managing water used on, and leaving, a mine site is a key aspect of minimising environmental impacts. The water environment is the mechanism which can most easily and quickly carry and disperse pollutants from the site. To be most effective, the water management system needs to be incorporated in the initial planning stages and adapted as conditions and mine layout develop during operations, right through to decommissioning and beyond.

Given Australia's dry climate, creating water resources which are part of the final rehabilitated landform can be a significant gain for stakeholders, particularly the neighbouring community. Co-ordinated water management holds the potential for win/win solutions for mine operators and other stakeholders. Such management systems must consider mine needs, water quality, contaminant containment and neutralisation in the context of the long-term (post-mining) use of the site if they are to be successful.

A key part of achieving this success is education and training. A mine workforce that understands the significance of water management, gets feedback on achievements and has a stake in its success, has higher morale and commitment to the project. 'Education', in the broad sense of community liaison and information, has a similar role in maintaining good community relations and continuing acceptance of the role of mining in the region.

Photo: Goldfields (Tasmania) Ltd

Goldfields (Tasmania) Ltd, Henty Gold Mine, 30km NW of Queenstown, Tasmania. Wetland and water treatment facility tours are conducted for events such as the annual Mine Open Day, school tours and by arrangement.

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APPENDIX 1: MINESITE SEDIMENT BASINS

INTRODUCTION

This Appendix presents simple rules for the design of sediment basins on minesites. Additional details can be found elsewhere (Institution of Engineers Australia, 1996).

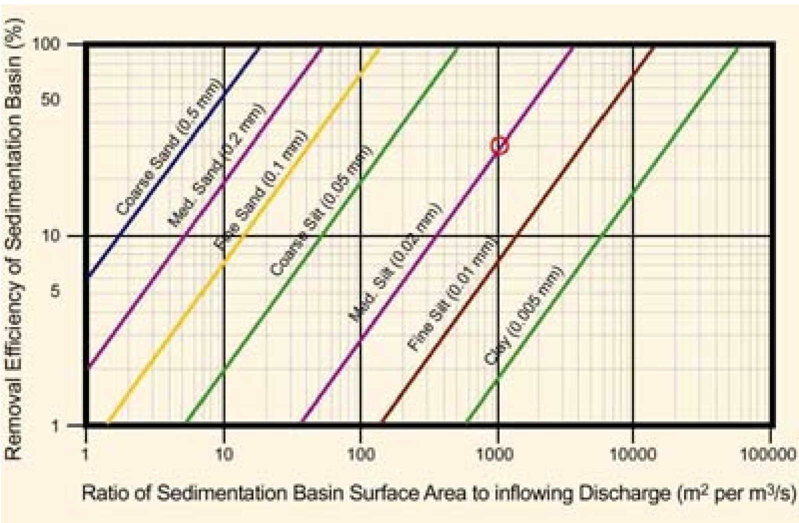
Sediment basins are an effective way to remove coarser-sized particles from sediment laden runoff, i.e. sand-sized particles or greater (0.1 mm diameter or greater). Sediment basins have to be large to remove significant quantities of silt-sized particles (0.01 mm to 0.05 mm). Sediment basins are not effective at removing clay-sized particles (0.005 mm diameter or less) unless supplemented by chemical dosing (typically gypsum).

SEDIMENT CAPTURE

The ability of a sediment basin to remove sediment (removal efficiency) depends on the discharge through the basin and the particle size distribution of the inflowing sediment.

- The greater the inflow discharge, the smaller the detention time in the basin and the smaller the settling opportunity for suspended sediment particles.
- The greater the particle size, the larger the settling velocity and the greater the proportion of particles that will settle out during passage through the basin.

The figure below shows sediment removal efficiency curves for various sizes of sediment particles and for various sizes of sediment basins (as measured in terms of surface area per unit inflow discharge). The results demonstrate that sediment basins of a large surface area are required to remove silt-sized or smaller particles. For a medium-sized silt (0.02 mm diameter), a surface area of 1,000 km^2 per m^3/s of inflow is required to achieve a removal efficiency of 30%).



Sediment Removal Efficiency Curves, Sediment Basins

Sediment inflows consists of a mix of particle sizes, as defined by the particle size distribution curve. For a given sized sediment basin, the curves of this figure can be applied to different fractions of the particle size distribution to estimate the proportion of each fraction captured on passage through the basin. These results can then be combined to estimate the total proportion of sediment load captured, as demonstrated below:

- Divide the particle size distribution up into 'i' fractions, each of which is characterised by a mean sediment diameter d_{ix} mm and a relative weight proportion of w_1%. The total removal efficiency in terms of percentage by weight is given by **Equation 2**:

$$W = \Sigma\, \eta_i \,.\, W_i \qquad \textbf{(Equation 2)}$$

where η_i is the removal efficiency associated with the particle size that characterises the

i'th fraction (d_i), and
the summation is taken over all
'i' sediment fractions.

(**Equation 2**)

The efficiencies evaluated are all expressed in **relative efficiencies** (i.e. expressed as percentages). To convert these values to absolute estimates of sediment removal, eg kg, it is necessary to estimate the amount of sediment delivered to the basin per runoff event or per year on average.

- Measured sediment concentrations in surface runoff can provide an estimate of sediment inflow per runoff event.
- The 'Universal Soil Loss Equation' (USLE) can determine absolute estimates of the average annual weight of sediment washed off the upstream catchment area (see Institution of Engineers, Australia, 1996, for USLE details).
- The computer model 'AQUALM' (see the appendix on computer models) can be used to assess the removal efficiency of sediment basins.

DESIGN DISCHARGE

Given that sediment characteristics are determined by site conditions, the removal efficiency of a given sized basin is determined by the adopted design discharge. The sediment transport capacity of surface runoff varies approximately with the square or cube of velocity. Thus, 'large' runoff events have a much greater ability to transport sediment into a sediment basin than 'small' runoff events. However, 'large' events occur less frequently than 'small' events.

The removal efficiency of a sediment basin should be investigated for a range of discharges before finalising the design discharge or the size of the basin. Investigate the removal efficiencies of various sized basins for the 80%, 50% and 20% AEP discharges into the basins. (The Rational Formula can be used to estimate these discharges — see the computer modelling appendix).

On the basis of these results and any regulatory requirements, an appropriate basin size can be selected. In selecting a basin size:

- 'Big is better' for sediment basins, so err on the large size if cost and accessibility are not major limitations.
- Although removal efficiencies will be significantly smaller for larger 'events' (because discharges will be significantly greater than the design discharge), large events are rarer and natural runoff will also be characterised by higher levels of sediment.

DESIGN DETAILS

Having selected a size of basin, the design and construction needs to address the following details:

- The basin inlet and outlet should be as far apart as possible.
- For minesites, the basin outlet should consist of an overflow spillway.
- Freeboard of at least 0.75 m should be provided above spillway crest level.
- Check the ability of the spillway to pass an appropriate size of flood. (The appropriate size of flood will depend on mine life and the consequences of the basin embankment being overtopped and 'washed out').
- The basin inlet and outlet need to be protected against erosion (typically with dumped rock).
- The length to width ratio of the basin should be at least 3:1.
- The minimum depth of the basin should be at least 1 m.
- The basin should incorporate an additional dead storage allowance for sediment collection of at least one-third of the active storage.
- Appropriate access be provided for equipment to remove sediment from the basin.
- Earth or rock embankments for sediment basins should be constructed in accordance with standard operational practice.

APPENDIX 2: MINESITE TREATMENT WETLANDS

INTRODUCTION

Wetlands are being increasingly used as cost effective and aesthetically attractive components of minesite water management and treatment systems (Ryan & Hosking 1992; Jones & Chapman 1994; Younger 1992). Wetlands for minewater treatment can range from a marsh or pond created in a natural setting where one did not exist permanently before, to formed structures requiring earth moving and erection of permeable bunds and impermeable containment barriers. At the simplest level, wetlands can develop naturally in water storages. In the future, it is probable that many more mining voids will be filled with water and developed as a wetland habitat at the end of mine life. Developing such aesthetic or conservation wetlands is an attractive option if community expectations and the hydrological and geochemical characteristics of the mining void are consistent with such environmental values. The award-winning RGC Wetlands at Capel in Western Australia are an excellent example (Brooks, 1991).

The need for self-sustaining treatment systems for seepage from mine landforms (waste rock dumps, tailings dams) becomes even more critical after site decommissioning since not only will there be few, if any, staff on site, but there will no longer be a direct cash flow to support operating costs.

Although wetlands can be developed for various reasons, the primary focus of this Appendix is on the construction, use and management of wetlands as operational minewater treatment systems.

It is vital to recognise the consequences of wetlands 'drying out', since most of its removal functions depend on its remaining wet. The wetland's biological community can be severely damaged and metals initially trapped in the wetland sediments can be remobilised. The latter can lead to a high concentration pulse being discharged when the wetland basin is subsequently refilled. Consequently, the annual water balance for a proposed wetland is most critical when planning and implementing a wetland treatment system.

Constructed wetlands can be designed to remove fine suspended solids, polish the nutrient-rich water produced by onsite sewage treatment plants, strip nitrate from pit water, remove heavy metals or process reagents (cyanide, xanthates) and neutralise the acidity in acid rock drainage.

There are four major functional niches that a wetland system can be designed to fill:

- a 'stand-alone' treatment system.
- intermediate treatment prior to flood irrigation or land disposal.
- polishing water from some form of chemical pre-treatment.
- providing emergency backup to a chemical treatment plant.

CRITICAL DESIGN FEATURES

Water Balance and Flow

A satisfactory hydrological regime is a critical prerequisite for successfully implementing a sustainable wetland. This must be covered early in the design phase to determine if, on this ground alone, a wetland treatment system is viable.

Selecting and locating a site for a constructed wetland must take account of the following:

- availability of land with a suitable topography to provide the hydraulic head needed to maintain passive flow through the system.
- absence of large water inflows during storm events.
- sufficient year-round water supply to ensure the wetland remains in a permanently saturated condition.
- potential for impact on groundwater quality.

The drainage lines of natural catchments are prime locations for wetlands because minimal earthmoving is needed for these sites. However, catchment runoff yield should be analysed to ensure that the wetland is not likely to be swept away by a storm event. If this risk is high, a diversion structure or a flow equalisation pond must be built. Further analysis of the distribution of rain through the year will determine if a supplementary water supply (such as a dam) is needed to maintain flow through the system. This is likely for a mine located in a tropical monsoonal climate, or a semi-arid region, where evaporation exceeds rainfall for most of the year. The sub-temperate climate of the west coast of Tasmania is probably the only region in Australia that has a year-round positive water balance. At the opposite climatic extreme, many countries in the equatorial tropics also have positive balances throughout the year.

There is a key difference between a wetland used for treating minewater during mining and a sentinel wetland that will intercepts residual seepage and surface runoff after decommissioning. During the life of a mine, a treatment wetland could be sustained by water produced by site dewatering operations. Consequently, a constructed wetland may be viable in even a very arid climate provided the groundwater was of sufficient quality. However, it is unlikely it would remain viable subsequent to mine closure. The minewater treatment system at the Hilton Mine near Mt Isa is an example of an operational wetland in an arid environment.

If there is potential for contaminating a groundwater resource by downward percolation of partially treated water, then the bottoms of the wetland cells and inter-connecting flow channels should be sealed with plastic or clay liners.

Loading

The ratio of the input loading against available reaction sites in the wetland is the key in determining the size of the wetland required. While this is stated very simply, the reality is that a large range of physical, chemical and biological factors contribute to wetland treatment capacity. Processes that can remove contaminants in wetlands are summarised in the following Table.

For removing fine particulates, the residence time and the density of plants in the system are the most critical factors. Plants are particularly important since the filamentous epiphytes growing on their surface provide an enormous surface area to entrap fine particles. The pH of the input water is critical for two reasons: for modulating metals adsorption; and for the biological functioning of the system. For maximum removal efficiency per unit area, the pH should lie between 5 and 8. If the pH of the input water is below 5, the area of the wetland will have to be increased substantially so it can generate sufficient neutralising capacity in situ. Therefore, it is desirable to pretreat acidic water using lime dosing or anoxic limestone drains (ALDs). Anoxic drains are not recommended for drainage which contains concentrations of dissolved ferric or aluminium ions in excess of 10mg/L since the coarse limestone substrate will become rapidly passivated by being coated with precipitates of ferric and aluminium hydroxide.

Most aquatic plants (except rooted emergent plants such as *Typha, Phragmites or Eleocharis*, which can modify the sediment micro-environment) cannot survive at acidic conditions. More importantly, however, is that the rate of sulphate reduction also decreases with pH. Sulphate reduction is driven by bacteria. In this process, the sulphate in the minewater is reduced to sulphide in the organic rich wetland sediment. Recent research has highlighted the critical importance of sulphate reduction to sustainably removing metals in wetlands. The sulphide salts of most heavy metals are much less soluble than their hydroxide and carbonate counterparts within the normal pH range for soil environments. This is particularly important for cadmium and nickel for which the pH would have to be raised above 10 for discharge quality criteria to be satisfied by the precipitation of the metal hydroxides.

TABLE: Processes in Wetlands that Remove Contaminants

Process	Nature	Controlling Variables
Trapping (filtering) of particles	Physical	Flow velocity, density of algae and plants
Oxidation/Reduction	Chemical Microbiological	Concentrations of oxygen and organic carbon
Precipitation/Co-Precipitation	Chemical	Concentration of components, pH, redox potential
Adsorption on Precipitates	Chemical	Amount of precipitate, concentrations of major cations and anions, pH
Adsorption/Ion Exchange on suspended and bed sediments	Physical Chemical	Concentration of suspended sediment, particle size and mineralogy, pH, concentration of major cations and anions
Sulphate Reduction	Microbiological	pH, organic carbon, concentrations of oxygen and sulphate
Uptake by biofilms, algae and aquatic macrophytes	Chemical Biological	Density of plants, temperature, light intensity, availability of nutrients

PERFORMANCE CRITERIA

At most operating minesites, wetlands will generally provide the final polishing step before water is discharged. . The maximum concentrations of residual nutrients or metals permitted are set by the locally applicable water quality criteria for discharge to surface and/or groundwaters. These criteria may be based on end-of-pipe concentrations, or concentrations in the receiving waterway downstream of a specified mixing and dilution zone. The target discharge criteria must be specified before a wetland can be designed, since they critically affect not only the system size but also the treatment cell types needed. The Australian and New Zealand Environment and Conservation Council (ANZECC) Australian Water Quality Guidelines for Fresh and Marine Waters which cover irrigation, stock watering and ecosystem health protection are most likely to be used to specify performance targets in Australia (ANZECC, 1992); new guidelines are being drafted, see www.affa.gov.au/nwqms).

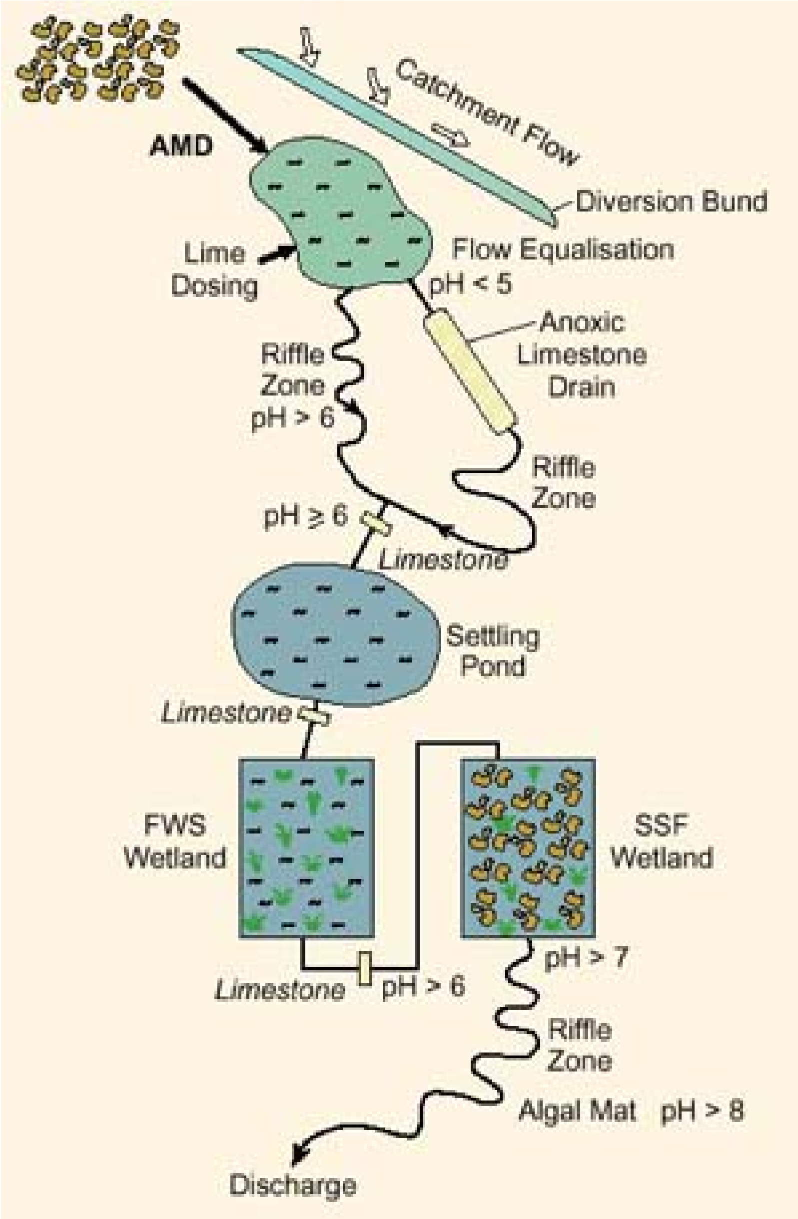


FIGURE: Conceptual design of a complete wetland system for treating Acid Mine Drainage (AMD) (after Jones DR and Chapman BM, 1995)

WETLANDS STRUCTURE

A fully functional and self-contained constructed wetland treatment system may have several process units in addition to a series of linked ponds containing plants. These include pre-neutralisation systems (active and passive chemical), aeration zones, at least one of four different types of 'wetland' cell designs and algal-filters (see Figure at left).

The initial drainage of highly concentrated Acid Mine Drainage (AMD), may have to be pre-treated with lime or magnesia. Sodium hydroxide is generally too expensive. Unlike chemical treatment plants where the final pH may need to be as high as 10 to completely remove the metals, the target pH for pre-neutralisation for a wetland treatment system only needs to be about 6. The neutralising chemical is added to the effluent prior to a turbulent cascade or riffle system to oxygenate the treated stream. This is critical to ensure the rapid oxidation of ferrous to ferric iron at the entrance to the wetland treatment system. If the initial concentration of dissolved iron is high, it may be necessary to site a sedimentation pond between the riffle zone and the wetland to avoid excessive delivery of metal hydroxide sludge to the wetland itself. An excess of sludge delivered to the wetland will not only lead to premature loss of capacity, but could smother benthic algae and submerged plants.

There are four potential types of wetland treatment cells (see Figure at right):

1. Free water surface (FWS) - systems that have predominantly surface flow with shallow water depths and extensive growths of emergent aquatic plants throughout.
2. Subsurface flow (SSF) - systems in which most of the water flows laterally through a bed of sand or gravel, which may be planted with emergent aquatic plants.
3. Subsurface flow - systems in which the water flows vertically upwards or downwards through a permeable sub-stratum, which does not contain plants.
4. Lagoons - ponds several metres deep with floating plants in the middle of the basin and rooted emergent plants around the periphery. Lagoons serve primarily as sedimentation basins. However, if sufficient organic matter is present in the bottom sediments, microbial respiration can lead to anaerobic conditions which favour the immobilisation of many metals as insoluble sulfides.

Of these, only free water surface cells and lagoons are typically found in full-scale wetland systems. Sub-surface flow designs for treating minewater are still being evaluated at the experimental, or small pilot-scale. Although potentially more efficient than the FWS design, sub-surface flow systems are more costly to construct and it has proved difficult to sustain a well-distributed flow of water through the sub-strata in larger pilot-scale systems.

RISK MANAGEMENT

The primary function of a constructed wetland at an operating mine is to remove contaminants by dissolving them or extracting them in particulate form from the input water before it is discharged or re-used. Consequently, the amount (but not necessarily the concentration) of non-degradable contaminants held in the sediments of a wetland will increase with time. It is possible that a wetland containing such contaminants could be classified as a 'contaminated site' and require special decommissioning. This could be achieved by removing the sediment and disposing of it in a tailings dam or waste rock dump before it is capped, or it could be left in situ and the site covered with a layer of benign rock and soil. There is less risk of a sentinel wetland designed to treat small volumes post-decommission becoming heavily contaminated. This is because its loading of contaminants should be much lower than that of a wetland that treats mine or process water during the operational phase of mine life. This is provided the site has been properly closed out.

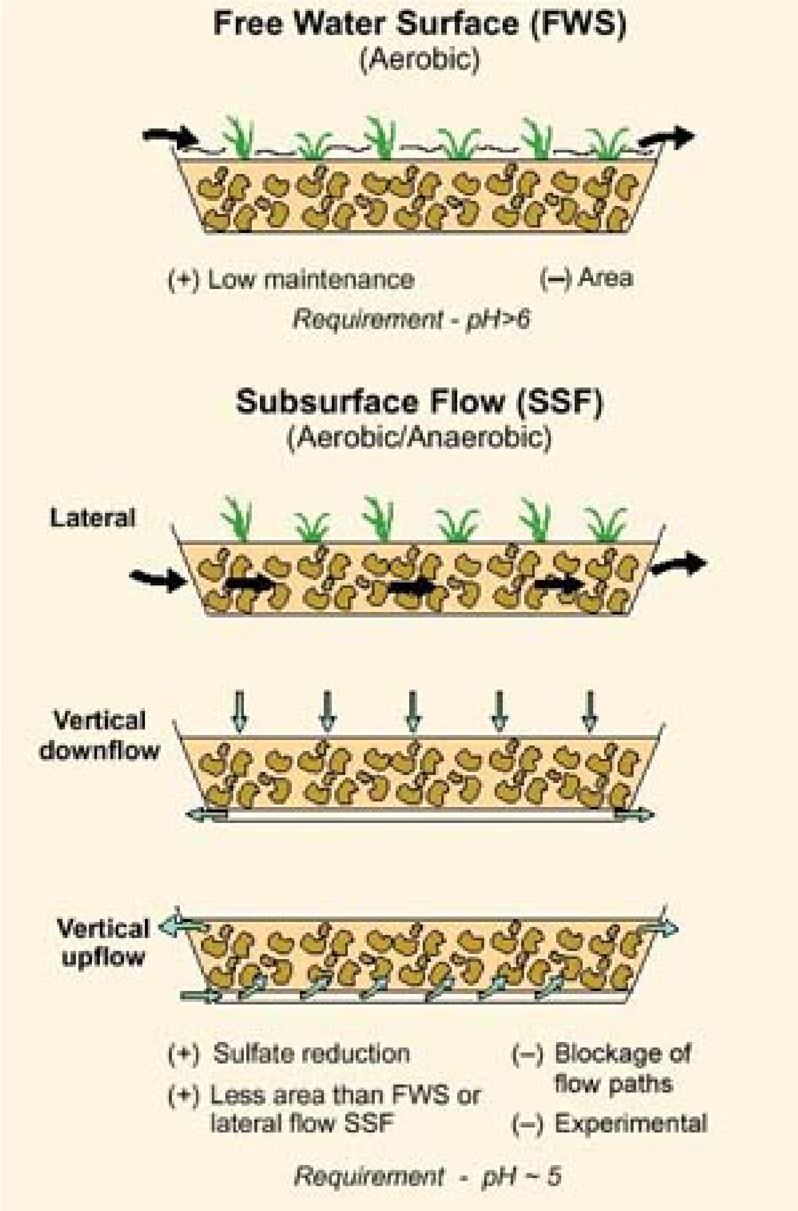


FIGURE: Schematic diagrams of four different types of constructed wetland cells. (after Jones DR and Chapman BM, 1995)

It is possible that birds and other wildlife could be exposed to elevated levels of metals in wetland plants and/or in animals ingested as food. There has been little research worldwide on this issue. The elements most likely to bioaccumulate or biomagnify are cadmium, mercury and selenium. The issue of impacts on wildlife as a result of contaminant accumulation in wetland should be seriously considered at any mine where one or more of these elements is present at significant concentrations in site water.

It is often assumed that, once contaminants enter the sediments of wetlands, they no longer pose a risk to the downstream receiving environment. This is not necessarily the case, especially for metals. The four key factors affecting remobilisation are:

- Flow regime,
- Water balance,
- Changes in the nature of the source water, and
- Biological Activity.

Flow regime

Sediment can be scoured from a wetland during high flow events. The net accumulation of sediment in a wetland will be a function of the ratio of the product of the catchment area and average runoff coefficient to the volumetric capacity of the wetland. The higher this ratio, the greater the through-flow velocity and the greater the risk of scouring. Sediment that is scoured out will be transported downstream and may ultimately be deposited in a more sensitive receiving environment. In addition, the oxidation of sulphides in the scoured sediment can release adsorbed metals in the water column.

Water balance

If a wetland dries out, sediment oxidation can release soluble metals (and low pH water) from the wetland during a subsequent flushing event. This can result from sulphide oxidation. The risk of this happening needs to be assessed on a site specific basis using an approach identical to that for screening waste rock for its potential to generate ARD. Thus, the acid producing potential of the sediment and its acid neutralising capacity are measured. The difference between the two numbers gives the net acid producing potential (NAPP) of the sediment. If the wetland has a high probability of drying out for part of the year, and the sediment is found to have a positive NAPP, it may be necessary to either remove the sediment and encapsulate it in a secure area, or add sufficient limestone to the substrate to neutralise the acid that would be produced.

The biota in natural wetlands in semi-arid and monsoonal climates are adapted to annual wet and dry cycles. However, if a constructed wetland in a temperate or sub-temperate region was allowed to dry out, there is a risk not only of metal release, but of a severe effects on the assemblage of biota as well.

Source water

In general, wetlands do not cope well with sudden changes in the composition of source water. This can cause toxic shock to all parts of the ecosystem and it may be a long time before it recovers. During this recovery period the functioning of the wetland could be severely impaired. For a wetland constructed for minewater treatment, this would have an adverse impact on treatment efficiency and hence increase the risk of damaging the downstream receiving environment. An example of this would be a pulse of acidic water leading to the remobilisation of metals adsorbed to the bed of the wetland.

Biological activity

There are various ways that biological activity can perturb the functioning of a wetland. The activity of foraging birds or mammals at the margins of a wetland can expose sulphidic sediment to oxidation, and increase the turbidity of the water column. Increasing turbidity decreases light penetration and hence primary productivity. The intense photosynthesis of an algal bloom can markedly raise the pH. This could lead to the desorption of negatively charged organic compounds or metal oxyanions (for example arsenic in the form of arsenate or selenium in the form of selenite) from the sediment. Eutrophication of the water column cause anoxic conditions and remobilisation of metals held in previously oxidised surficial sediment.

EXAMPLES OF TREATMENT WETLANDS

Clear demonstrations of the sustainable use of constructed wetlands for treating mine drainage in Australia have so far been mainly confined to situations where the effluent entering the wetland is close to neutral pH. There is little information available for experimental systems that may be in the process of being trialled for the direct treatment of low to moderate strength AMD.

Examples of functioning wetlands treating near-neutral pH mine water are located at:

- Ranger Uranium Mine (NT),
- Tom's Gully Gold Mine (NT),
- Woodcutters Base Metal Mine (NT),
- Hilton Base Metal Mine at Mt Isa (QLD),
- Hellyer Mine (TAS), and
- Westralian Sands Ltd Synthetic Rutile Plant (WA).

Photo: ERA Environmental Services Pty Ltd

ERA Ranger Mine, near Jabiru, Northern Territory. Aerial view looking north over Retention Pond 1 constructed wetland soon after completion in mid 1995. The wetland is 350m long and 250m wide.

RANGER URANIUM MINE

At the Ranger Mine, the solutes of interest are uranium (in the form of UO_2^{2+}), Mg^{2+}, $SO4_2^-$ and Mn^{2+} (Jones et al, 1996). ERA initially constructed a pilot scale wetland to evaluate the effectiveness of this method for treating site water. This experimental wetland consisted of three cells in series, with a total capacity of about 10 000 m^3. Site water was passed through the wetland to tests its performance. Most of the U and nitrate in the input water was removed. Based on the excellent results for U, the pilot scale wetland was greatly expanded. The current constructed wetland, commissioned in mid-1995, is one of the largest of its type in Australia. It consists of 7 shallow (1 - 1.5 m deep) ponds in series with a total path length of 1 km and a capacity of 50 000 m^3 (see Figure and photograph). Results so far indicate effective removal of U, Mn and nitrate at flow rates up to 3 000 m^3/day. The water treated by the wetland is subsequently disposed of by flood and spray irrigation elsewhere on the lease.

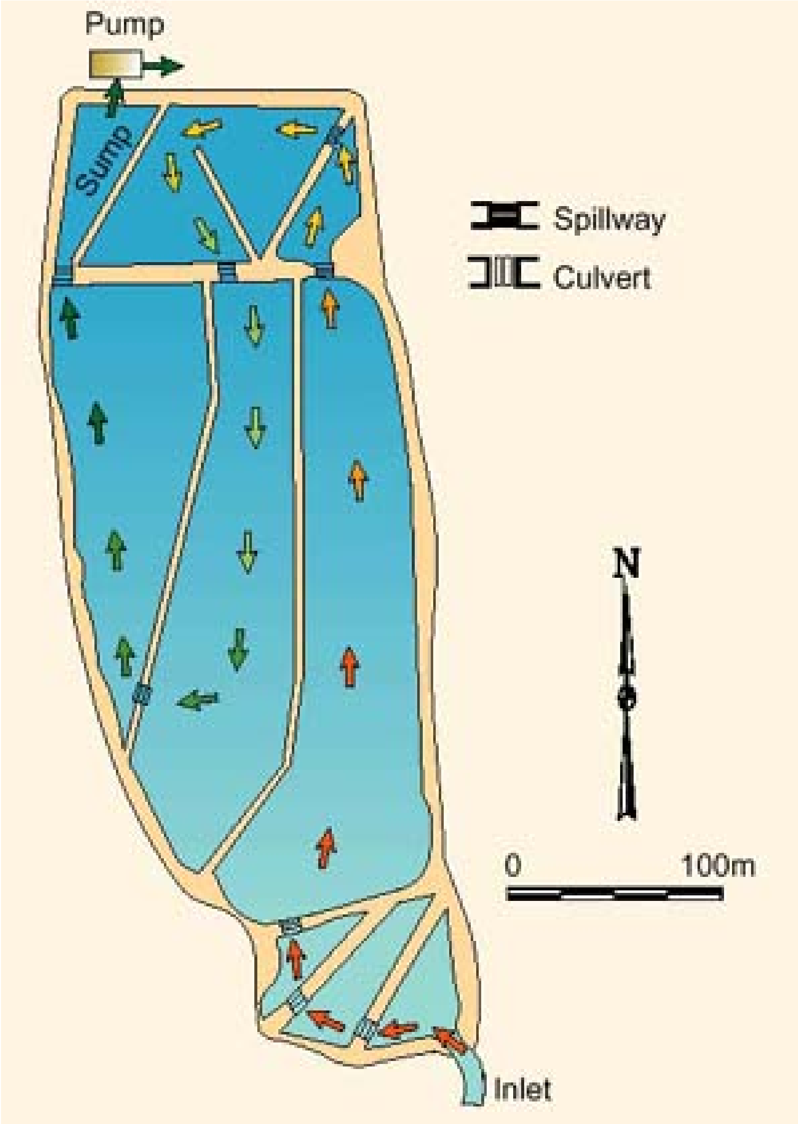


FIGURE: ERA—Ranger Mine, NT, Flowpath of water through Retention Pond 1 constructed wetland.

Tom's Gully Gold Mine (NT)

The Tom's Gully Gold Mine discharges drainage into an ox-bow billabong containing *Typha* (Noller et al, 1992). This overflows into the Mount Bundy Creek. A range of transition and base metals, as well as arsenic are effectively removed in this system. This is an example of a natural wetland in the vicinity of a mine that can be used to improve the water quality of mine drainage.

Woodcutters Mine

The Woodcutters silver-lead-zinc mine is in the Northern Territory, about 80km south of Darwin. Its wetland system consists of constructed ponds and a natural stream channel. Before discharge to Woodcutters Creek, the mine water (containing elevated levels of dissolved and particulate metals) passes through a primary sedimentation pond (to remove particulates) and a constructed wetland treatment pond. Given the year-round flow of water from the constructed pond, the middle reach of Woodcutters Creek, which is within the mine lease, has been transformed from an ephemeral to a permanent stream. Abundant aquatic vegetation (primarily *Typha* sp.) has naturally established itself in the creek channel, which provides the final treatment polish for the mine water. Load calculations have shown that more than 95% of the cadmium, manganese, lead and zinc initially present are removed by the system (Noller *et al*, 1992; Woods and Noller, 1995).

Hilton Mine

The minewater from the Hilton Mine near Mt Isa is slightly acidic from being super-saturated with CO^2. However, the pH rises to above 8 after degassing. The wetland consists of a riffle zone feeding into a 4.2 ha retention pond (average depth of 1.3 m), which overflows into a natural creek channel. This system, populated by reeds and algae, has been studied in detail and its efficiency optimised so that the water can be re-used for ore processing (Jones *et al*, 1995). Elements being removed include Fe, Zn, Mn and Tl. The important processes that have been identified include degassing, precipitation, co-precipitation, adsorption, sedimentation, autocatalytic oxidation of Mn^{2+} and algal photosynthesis leading to a micro-environmental rise in pH. This system has operated successfully at flow rates of up to 3 000 m^3/day.

Hellyer Mine

At the Hellyer Mine in Tasmania, a large wetland consisting of a number of FWS cells (populated with *Juncus* sp.) arranged in a parallel configuration, was constructed in late 1992. This followed trials with a small pilot scale system. The wetland receives pH neutral input containing Pb (mainly in particulate form) Fe, Mn and sulphate from the tailings dam. This has been a relatively expensive system to construct.

Westralian Sands Ltd

The Westralian Sands Synthetic Rutile Plant (Masters, 1989) produces an acidic effluent which is neutralised with lime before it is discharged into a 2 ha wetland. This system, commissioned in 1986, was designed as a backup for the chemical treatment plant, rather than as a primary treatment facility. The elements removed from the usually pH-neutral water include Fe, Mn and sulphate. However, after a process malfunction, the pH of the water can be as low as 3 to 4. The wetland has then been found to provide about 4 days of treatment before its buffering capacity is exhausted. The system has required extensive maintenance requiring the replacement of vegetation and substrate. This is possibly a result of the damaging effects of the acute shock loads to which it is periodically exposed.

APPENDIX 3: COMPUTER MODELS

INTRODUCTION

These days, a variety of hydrologic, hydraulic and water quality models are commonly used for water resource investigations, including minesite water management studies. This Appendix describes a number of computer models used in such studies, including the circumstances in which the use of these models is appropriate. The underlying hydrological and other processes of these models are also identified.

The use of hydrological, hydraulic and water quality models is a specialist discipline. Whilst anyone can 'run' a model, the use of the model to generate reliable output data depends heavily on the training and experience of the modeller. Often, suitable data are not available to calibrate a model. The experience of the modeller in applying the model to other catchments is then essential if reliable output data are to be obtained.

If minesite personnel are contemplating adopting and personally running a particular model for continued use at a minesite, it is strongly recommended that they obtain appropriate training in the use of the model and that the development and use of the model be reviewed by a specialist.

RAINFALL INTENSITY

Rainfall intensity-frequency-duration data are necessary to estimate peak discharges for drainage and flood analyses. Such data, along with temporal patterns for storm events, can be obtained for any location in Australia via a manual procedure described in *Australian Rainfall and Runoff* (Institution of Engineers, Australia, 1987).

Alternatively, a simple computer program (IFD) is available that automatically generates rainfall intensity-frequency-duration data and temporal pattern information on the basis of latitude and longitude. In using the IFD program, care needs to be taken to ensure that minesite latitude and longitude are both estimated and entered accurately. In regions of strong rainfall gradients, errors in latitude and longitude can have a pronounced effect on estimated rainfall intensities.

RUNOFF - ROUTING MODELS

Various hydrological models are available to estimate 'discharge hydrographs', or the variation of discharge with time at a location of interest within a catchment. Such models include 'RORB', 'RAFTS' and 'URBS', and are referred to as 'runoff-routing' models. Typically, these models would be used to estimate peak flood discharges in creeks and rivers as part of minesite flood studies, and to estimate peak spillway design flows from a minesite water storage on a creek or river.

Runoff-routing models simulate the rainfall-runoff process for a selected storm event over the catchment of interest. The catchment is divided into a number of sub-areas on the basis of the drainage network. An appropriate rainfall intensity and temporal pattern is selected for the storm event of interest (see above), together with rainfall loss parameters that reflect the loss of rainfall by infiltration. The storm event is divided into a suitable number of time increments. For each time increment, the model estimates the surface runoff from a sub-area (i.e. the rainfall excess) and 'routs' that runoff out of the sub-area and into the next downstream sub-area, where it is combined with runoff from that sub-area. In this way, surface runoff is progressively routed from sub-area to sub-area down the catchment over the duration of the storm, so allowing discharge hydrographs to be generated at locations of interest.

The 'routing' process delays and reduces the peak surface runoff discharge from a sub-area to account for the attenuating effects of transient storage as the surface runoff flows down the catchment.

The above models differ mainly in their treatment of the rainfall loss process, which needs to be specified on a sub-area by sub-area basis according to sub-area soils, vegetation and antecedent soil moisture conditions. The simplest loss process involves an 'initial loss' to wet up the soil, followed by a constant 'continuing loss' (see Chapter 2).

Peak flood discharge can also be estimated by the 'Rational Formula' (see Institution of Engineers, Australia, 1987; DMR, 1993), which states:

$$Q = 0.278\ C.I.A \quad \textbf{(Equation 3)}$$

where Q is the discharge (m^3/s),
C is the 'runoff coefficient',
I is the rainfall intensity for the adopted storm duration (mm/hour), and
A is the catchment area (km^2).

In applying this equation, the 'time of concentration' of the catchment is selected as the adopted storm duration. The time of concentration is the time required for runoff from the most remote area of the catchment to arrive at the point of interest. When the storm duration equals the time of concentration, the peak discharge at the point of interest is maximised. The time of concentration can be estimated according to the Bransby-William formula:

$$T_c = \frac{L}{A^{0.1}\ S_e^{0.2}} \quad \textbf{(Equation 4)}$$

where T_c is the time of concentration (hours),
L is the length of the mainstream channel to the catchment divide (km),
S_e is the 'equal area' slope (m/km) of the mainstream channel to the catchment divide, and
A is catchment area (km^2).

Why use a runoff-routing model to estimate peak discharges if an estimate can be readily made via the Rational Formula? There are several reasons:

- Estimates made with the Rational Formula can be in error because of uncertainties in the adopted value of the runoff coefficient (C) and uncertainties that can arise from applying the formula to 'large' catchments. The runoff coefficient C reflects both rainfall losses and the effects of storage-routing in reducing peak discharges (see above). Although published values for C are available for various catchment characteristics, the 'real' value remains uncertain.
- The Rational Formula was originally developed for catchments smaller than 25 km^2 in area. With care, it can be applied to catchments of up to 250 km^2 (see Institution of Engineers, Australia, 1987). A considerable amount of experience and judgement is required to obtain reliable estimates of peak discharges with the Rational Formula.
- The Rational Formula only provides an estimate of peak discharge. It does not provide an estimate of the discharge hydrograph itself. If the rate of rise or rate of recession of the discharge hydrograph is of interest, it is necessary to employ a runoff-routing model.
- Note that the Rational Formula cannot be used to reliably estimate peak discharges at locations downstream from major water storages. To account for the routing effects of the storage on runoff hydrographs and peak discharges, it

is necessary to use a runoff-routing model and include the water storage in the model.

DAILY RAINFALL - RUNOFF MODELS

Computer models are available to simulate daily catchment runoff volumes (or runoff depths) from daily rainfalls. Such models include AWBM, the SACRAMENTO Model and IQQM, and are used to generate daily runoff volumes from catchments of interest over a long period (say 50—100 years). Because of the general availability of long periods of daily rainfalls at most locations throughout Australia, daily rainfall-runoff models are an invaluable tool for estimating streamflows in ungauged streams.

Daily rainfall-runoff models are typically used in minesite water management studies to investigate the water supply potential of creeks and rivers. Such models are often combined with a 'dam behavioural model' to investigate the necessary size of a water storage to meet minesite demands. Daily rainfall-runoff models are also used to simulate daily runoff events for use in water quality models such as AQUALM.

Like runoff-routing models, daily rainfall-runoff models also simulate rainfall-runoff behaviour, but pay much more attention to the infiltration, evapotranspiration and percolation processes. The computational heart of daily rainfall-runoff models is a soil moisture sub-model. The drier the soil, the more rainfall that is absorbed into the soil before runoff occurs and vice-versa. Hence, the importance of infiltration, evapotranspiration, percolation and soil characteristics, for such soil moisture capacity.

Of the three models listed above, the SACRAMENTO Model and IQQM are specialist models that are far more complex than the AWBM Model. It is unlikely that the SACRAMENTO and IQQM models would be used for minesite water management studies.

In passing, it is noted that one of the standard overseas daily rainfall-runoff models, the US Department of Agriculture's SCS Model is not well suited to Australian conditions. In this model, antecedent soil moisture conditions based on rainfall over the preceding five days are used to estimate soil moisture levels. In Australia, where rainless periods can persist for weeks or even months, the use of a five day antecedent period can lead to misleading results. The use of the SCS Model is not recommended for Australian conditions. The AWBM Model will provide more reliable results.

OPEN CHANNEL MODELS

A number of 'open channel' hydraulic models are available to estimate discharges and water levels along open channels. Such models include HEC-RAS, XTRAN, MIKE-11, CELLS, RUBICON and MIKE-21. These models are based on the equations of momentum and continuity, and simulate the movement of water down 'open channels' (rivers, creeks and estuaries) and across floodplains. The models provide estimates of discharge, velocity and water level along the open channel. Typically, these models would be used in minesite water management studies to estimate flood levels along creeks or rivers of concern to minesite workings or infrastructure.

Open channel models address two types of flow situations, steady flow and unsteady flow, in two types of open channel systems, one-dimensional and two-dimensional.

- 'Steady flow' is used when discharges and water levels are assumed to be constant over time. Peak flood discharges and peak flood levels are often treated as 'steady' for the purposes of analysis. Of the above models, HEC-RAS is a dedicated steady flow model, i.e. it cannot be used to analyse unsteady flows.

- 'Unsteady flow' is used when the variation in discharges and water levels over time is recognised and taken into account. With the exception of HEC-RAS, all of the other models listed above are unsteady flow models, which can be used to estimate discharge hydrographs and stage (water level) hydrographs along the open channel at points of interest.
- One-dimensional systems include rivers, creeks and estuaries where the flow is essentially 'one-dimensional', i.e. the variation in discharge, velocity and water level is essentially along the open channel, rather than across it, i.e. a longitudinal variation. HEC-RAS and EXTRAN are one-dimensional models.
- Two-dimensional models can take into account a lateral variation of flow characteristics as well as a longitudinal variation. CELLS, RUBICON and MIKE-21 are two-dimensional models and are typically used to analyse flows across flat floodplains.

All open channel flow models require details of waterway cross-sections and the topography of inundated areas. Steady flow models, such as HEC-RAS, require details of the design flow along the open channel, together with a 'starting' water level at the downstream end of the system. This enables the water levels to be estimated at upstream cross-sections. Unsteady flow models require details of the 'inflow discharge hydrograph' at the upstream end of the model and the rating curve (or tidal variation in the case of estuaries) at the downstream end of the model. These so-called 'boundary conditions' enable the model to 'rout' the upstream hydrograph through the system and estimate discharge and stage hydrographs along the open channel. Typically, a runoff-routing model will be used to estimate the discharge hydrograph that forms the upstream boundary condition. Another key input parameter of all open channel flow models is the 'hydraulic roughness' of the open channel, which reflects the loss in energy as water flows down the channel.

The simplest way to predict a water level in an open channel is via Mannings Equation (see Institution of Engineers, Australia, 1987; DMR, 1993) which states:

$$Q = \frac{AR^{2/3} \quad S^{1/2}}{n} \qquad \textbf{(Equation 5)}$$

where Q is the discharge (m^3/s),

A is the cross-sectional area of flow (km^2),

R is the *hydraulic radius*, or cross-sectional area of flow divided by the wetted perimeter (m),

S is the *hydraulic grade line (m/m)*, and

n is the *hydraulic roughness* as specified in terms of Manning's 'n'.

In applying equation to a river or creek, the bedslope can be used to estimate the hydraulic grade line. Tables and photographs are available to estimate 'n' values (Institution of Engineers, Australia, 1987; DMR, 1993). Knowing the discharge 'Q', equation can be solved iteratively to estimate the water level appropriate to the discharge. (The cross-sectional area and hydraulic radius will generally vary non-lineally with depth, so requiring an iterative solution to equation 3).

If equation 5 can be used to estimate water levels in open channels, why use far more complex open channel models to do the same job?

- Equation 5 is only useful for estimating water levels at a single location. If water levels are required along a reach of waterway, it is more convenient to use an open channel flow model.
- Often the bedslope is not a good estimate of the hydraulic grade line. This is especially true along waterway reaches upstream from culverts, bridges or other

constrictions to flow. Thus, water level estimates made according to equation 5 can be inaccurate.
- If the stage hydrograph is of interest, it is necessary to use an unsteady flow model.

GROUNDWATER MODELS

A number of groundwater models are available to simulate groundwater level and flow behaviour, eg 'MODFLOW', 'AQUIFEM-N', 'FEMWATER', '3DFEMFAT' and 'FEFLOW'. As for open channel flow models, groundwater models are based on the equations of momentum and continuity (the governing forces being gravity and pressure) and are used to simulate the effects on groundwater levels of pumping to or from an aquifer or the effects on groundwater flows of changed groundwater levels. Typically, these models are used in minesite water management studies to assess the size and location of pumps necessary to dewater an open cut or the impact on groundwater levels of extracting water supplies from an aquifer or of pumping surplus minewater into an aquifer ('disposal to groundwater').

With open channel flow models, it is the characteristics of the open channel and the upstream and downstream boundary conditions that define the movement of water (eg cross-section, bedslope and hydraulic roughness). With groundwater models, it is the hydro-geological characteristics of the aquifer and the surface, side and bottom boundary conditions that define groundwater flow.

- The most important hydrogeological characteristic that influences groundwater behaviour is the hydraulic conductivity, which varies from 5 x 102 m/day for coarse gravel to 5 x 101 m/day for sand to 5 x 10-5 m/day for clay.
- The 'boundary conditions' that influence groundwater behaviour include the variation of groundwater levels across the top of the groundwater body, the outflow or inflow of groundwater through the sides and bottom of the groundwater body and any pumped discharges into and out of the aquifer.

At the simplest level, the flow of groundwater in an aquifer is governed by the following equation (Darcy's Law):

$$V = K\frac{dH}{dS} \qquad \textbf{(Equation 6)}$$

where V is the velocity of flow in direction S,
K is the hydraulicconductivity of the aquifer, and
dH/dS is the hydraulic gradient in the direction of flow.

As for open channel flow models, groundwater flow models address two types of flow situations, steady flow and unsteady flow. An example of a 'steady flow' situation is the ultimate level of drawdown that occurs around a groundwater bore ('cone of depression'). An example of an unsteady flow situation is the development of the cone of depression over time after the pump is started.

Analytical solutions are available for both the steady and unsteady groundwater behaviour of simple groundwater systems. However, when the system is complex because of non-homogenous aquifers, groundwater barriers, etc., it is necessary to employ numerical techniques to solve the underlying equations via a 'groundwater model', such as 'MODFLOW".

WATER QUALITY MODELS

Some models that simulate water quality responses for various situations are available. Typically, the water quality modules of these models are 'piggy-backed' onto hydrologic or hydraulic models. Two such models are AQUALM and MIKE-11. In AQUALM, which is a daily water quality model, the water quality module sits on the AWBM Model, which is used to predict daily flows. The water quality module in MIKE-11 is linked to the hydraulic component of the model.

To date, water quality models have been applied more to stormwater management than to minesite water management. Models such as AQUALM have in-built sediment basins and wetland modules that allow the behaviour of these measures to be simulated. Thus, AQUALM could be used to assess the behaviour and efficiency of minesite sediment basins and wetlands. In passing, it is noted that the geochemistry of many minesite pollutants is complex. While the inclusion of such pollutants in water quality models is possible, it would probably have to be done in a very simplified fashion.

Because of the variety of physical, chemical and biological processes that affect water quality, the simulation of water quality levels is more complex than the simulation of hydrological or hydraulic processes. Complexities and uncertainties in water quality processes are additional to any uncertainties in the underlying hydrologic and hydraulic processes. Water quality modules require input parameters that empirically relate water quality levels to catchment characteristics, such as soil type, elapsed time since the last rainfall event, land use, etc. In general, these water quality 'relationships' are inexact. Typically, measured values purportedly represented by empirical water quality relationships show a spread of 1 to 1 orders of magnitude. Detailed monitoring on a catchment and site-specific basis is required if reliable water quality relationships are to be derived and water quality levels are to be simulated with any degree of reliability.

SYSTEM MODELS

A 'system model' is a hydrologic 'water balance' model that simulates the behaviour of a minesite water management system. Such models include all water storages (both clean and dirty), pumps, tailings dams and other elements that make up the water management system. Such models typically simulate water balance behaviour on a daily basis over a period of 50—100 years and take into account daily rainfall, daily evaporation and daily runoff into storages and daily minesite water demands. The following Table shows the inflows and outflows taken into account in the water storage component of one such system model. A daily rainfall-runoff model such as AWBM is used to generate the daily runoff into water storages. Input data to system models includes 'operational rules' that describe how the system is operated, eg target water levels in dams.

TABLE: Process Included in Water Balance of Storage Component, System Model

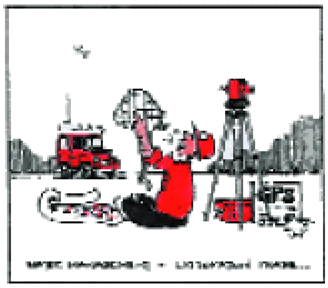
Inflows	Outflows
Direct Rainfall	Seepage
Catchment Runoff	Evaporation
Pumped Inflows	Water Supply Demands
Spills from Upstream Storages	Spills Pumped Outflow to Another Storage

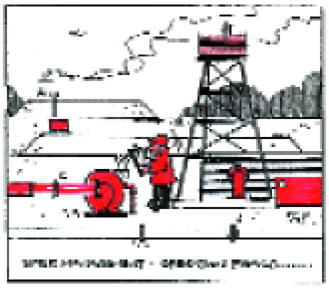
Outputs from such models comprise the frequency and volume of spills from water supply storages, the frequency and volumes of shortfalls in supply, and other key minesite water data. Daily results can be aggregated into monthly or annual results.

Such models may also include a water quality component that tracks the concentration of conservative pollutants (eg salinity) through the system. This allows the concentration of salinity in water storages to be simulated and the impacts of spills from storages on the quality of receiving waters to be assessed.

There are few commercially available water management system models suitable for minesite applications. Most models in use have been developed by consultants.

System models are invaluable when minesite water management plans are being formulated. They readily enable alternative operating strategies and development scenarios to be investigated. And they can be used to investigate a variety of 'what if' scenarios, for example, what if a major cyclone occurred over an open cut mine? How much water would collect in the pits? Where could it be pumped to?





CALIBRATION AND VERIFICATION

With the exception of the rainfall intensity model (see *Rainfall Intensity*), attempts should be made to calibrate and verify all other models used for minesite water management studies. The calibration and verification process is the only way to unambiguously demonstrate the accuracy and reliability of simulated results from the model.

TABLE: Data Required to Calibrate Minesite Water Management Models

Model	Calibration Data
Runoff - Routing	• Rainfall Hyetographs • Recorded Streamflows • Peak Flood Levels
Daily Rainfall - Runoff	• Daily Rainfalls • Recorded Streamflows • Dates when ephemeral creeks 'ran' • Evaporation
Open Channel	• Peak flood flows • Discharge Hydrographs • Peak Flood Levels
Groundwater	• Daily of monthly rainfalls • Groundwater levels
Water Quality	• Streamflows • Water quality relationships
Water Management System	• Rainfalls • Evaporation • Levels in water storages • Water demands • Times and volumes of pumping • Water quality relationships

Calibration requires model parameters to be adjusted so that recorded and simulated results agree as closely as possible over a 'calibration period'. Often the necessary recorded data are missing or uncertain. At times, missing data can be supplemented by monitoring, for example, water quality relationships. At other times, the availability of calibration data is at nature's whim, for example, it is unlikely that a major flood will conveniently occur to facilitate the calibration of an open channel model. The following Table shows the type of data needed to calibrate the various models described. The calibration of models is an important aspect of their use. Considerable judgement is often required in deciding how to deal with missing calibration data.

Verification requires the 'proving' of a calibrated model by demonstrating that the model can satisfactorily reproduce recorded results over a 'verification period' that does not form part of the calibration period. The paucity of recorded data on minesites does not generally allow for a verification process separate and independent of the calibration process.

TEMPORAL AND SPATIAL SCALES

In numerical modelling it is essential to select appropriate temporal and spatial scales for the model. If the temporal and spatial scales are too coarse, inaccurate and possibly misleading results can be generated. The table above shows suggested temporal and spatial scales for the models of this appendix.

TABLE: Suggested Temporal and Spatial Scales, Minesite Water Management Models		
Model	**Temporal Scale**	**Spatial Scale**
Runoff - Routing	1/20th of the duration of the storm event	25 or more sub-areas
Daily Rainfall - Runoff	Daily	A separate sub-area for each different runoff-producing area
Open Channel section	Dictated by physical	At major changes in channel cross-considerations of system
Groundwater	Daily, weekly or monthly	Dictated by physical considerations of system
Water Quality	Daily or less (model dependent)	As per underlying hydrologic or hydraulic model
Water Management System	Daily or less	As per underlying hydrologic models

CASE STUDY 1

MOURA OPEN CUT COAL MINE, QUEENSLAND - CONTROLLED RELEASE

Moura Mine is a large open cut coal mine in the Bowen Basin of Central Queensland. Opened in 1961, it is currently operated by BHP Coal Pty Ltd, and has a production rate of 4.5 Mtpa of coking and steaming coal.

The coal seams dip in a westerly direction. The mine consists of a series of up to five parallel pits that run for 25 km in the north-south direction (see Figure). Active pits are mainly along the western edge and southern area of the workings.

Four major constructed storages play an integral role in the management of minesite water at Moura:

- Hillview Dam (630 ML),
- Narweena Dam (1,300 ML),
- 14A Dam (520 ML), and
- 19A Dam (50 ML).

Hillview and Narweena Dams are located to the west of the workings, 14A Dam is located to the east of the workings in the central mine area and 19A Dam is located to the south (see Figure).

Whole-of-mine minesite water management was first assessed in 1991. More than 40 pits were then open and these collected direct rainfall and runoff from immediate catchment areas. The coal preparation plant is north of the leases (see Figure). Several disused pits are used, with the 19A and Narweena Dams, to transfer water south to north for use in the preparation plant.

Many authorities 'require' that minesites totally contain 'dirty' water. This may be impossible, impractical or prohibitively expensive in operational terms and should be negotiated with authorities when considering the actual environmental situation or risks. On-site containment generally means that evaporation is considered the only practical means of 'disposal'. Expensive storages or evaporation basins covering large areas may be required. Even then, a significant storm event may cause an 'uncontrolled release' (spill). Water balance simulation studies are essential to assess 'total containment' system behaviours and spill risks.

The controlled release of 'dirty' water into creeks (when flow conditions are appropriate) is a practical and economic way of reducing to acceptable levels both the build-up of dirty water on a minesite and the risk of an uncontrolled release.

By defining controlled release situations, the environmental values and water quality of the waterbody should not be unduly affected during controlled releases. These values reflect the environmental values of the receiving waterbody and its flow and water quality regimes. All these factors, plus any impacts controlled releases will have, need thorough investigation. Allowable rates and release opportunities may be too limited for practical management. However, large flows often present opportunities to release considerable volumes of 'dirty water' without undue adverse effects.

At Moura Mine, an open cut coal mine in Central Queensland, a set of 'controlled release rules' were developed for controlled releases of dirty water from 14A Dam. Pit water of relatively high salinity (up to 5,000 µS/cm) is pumped to 14A Dam (capacity 355 ML) for use as haul road water. Water can be released to Kianga Creek from 14A Dam through two valved culverts in the dam embankment.

Kianga Creek is a non-perennial creek with a representative natural salinity of some 300 µS/cm. An automatic monitoring and telemetry system measures discharge and salinity at Kianga Creek Weir, which is some 3 km downstream of 14A Dam (see Photograph below). Discharges and salinity levels in the creek are displayed in the mine Examiner's office which has 24 hours staffing. This helps identify controlled release opportunities.

The rules aim to ensure the releases do not increase salinity at Kianga Creek Weir above 1,200 µS/cm. This level is appropriate to downstream water users (stock watering), the environmental values of the creek and the generally short-term nature of the release.

The rules include a chart showing how far culverts can be opened (one fully open, both culverts fully open), depending on the water level and salinity of 14A Dam and the flow in Kianga Creek (see Figure opposite).

- To ensure operational readiness, the salinity in 14A Dam is measured weekly.
- The Kianga Creek Weir monitoring station automatically checks any releases are compliant by monitoring salinity levels.
- The 14A Dam has had several successful controlled releases and solutes at Kianga Creek Weir measured in the 1,100 - 1,200 µS/cm range.

Photo: BHP Coal Pty Ltd

Pump in mine pit at Moura Mine used to transfer water out for use on the mine.

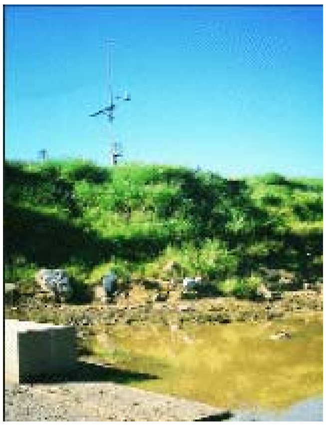


Photo: Water Studies Pty Ltd

Kianga Weir water level and salinities are monitored to record the impact of dirty water releases on the conductivity of creek flows.

Photo: Water Studies Pty Ltd

Pump pipeline and pipe discharge recorder enclosure at 19A Dam. A telemetering recorder is used to measure rainfall, water level and pipeline discharge at 19A Dam.

Photo: Water Studies Pty Ltd

Calibration of rain gauge, monitoring and transmitting station at Kianga Weir.

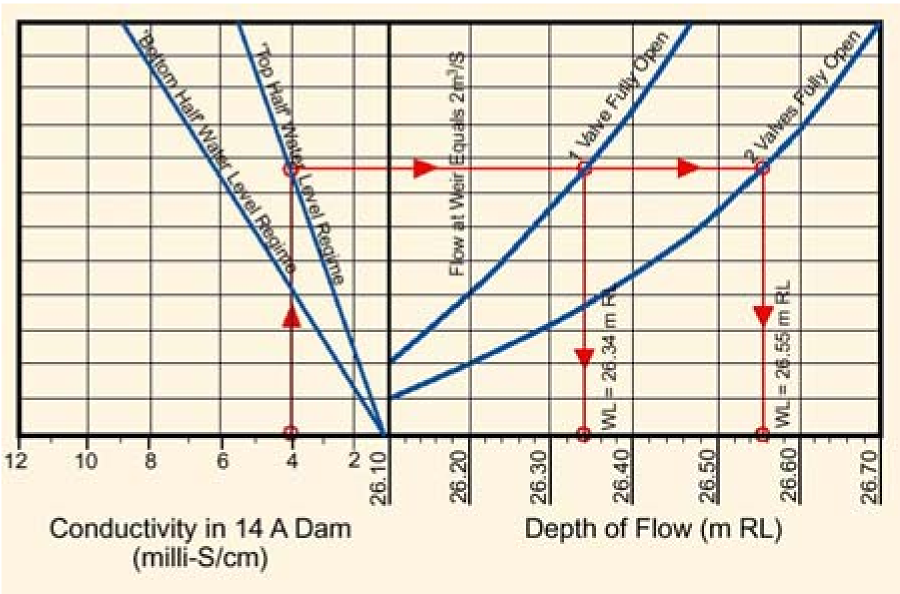


FIGURE: Controlled Release Rules, 14A Dam, Moura Mine

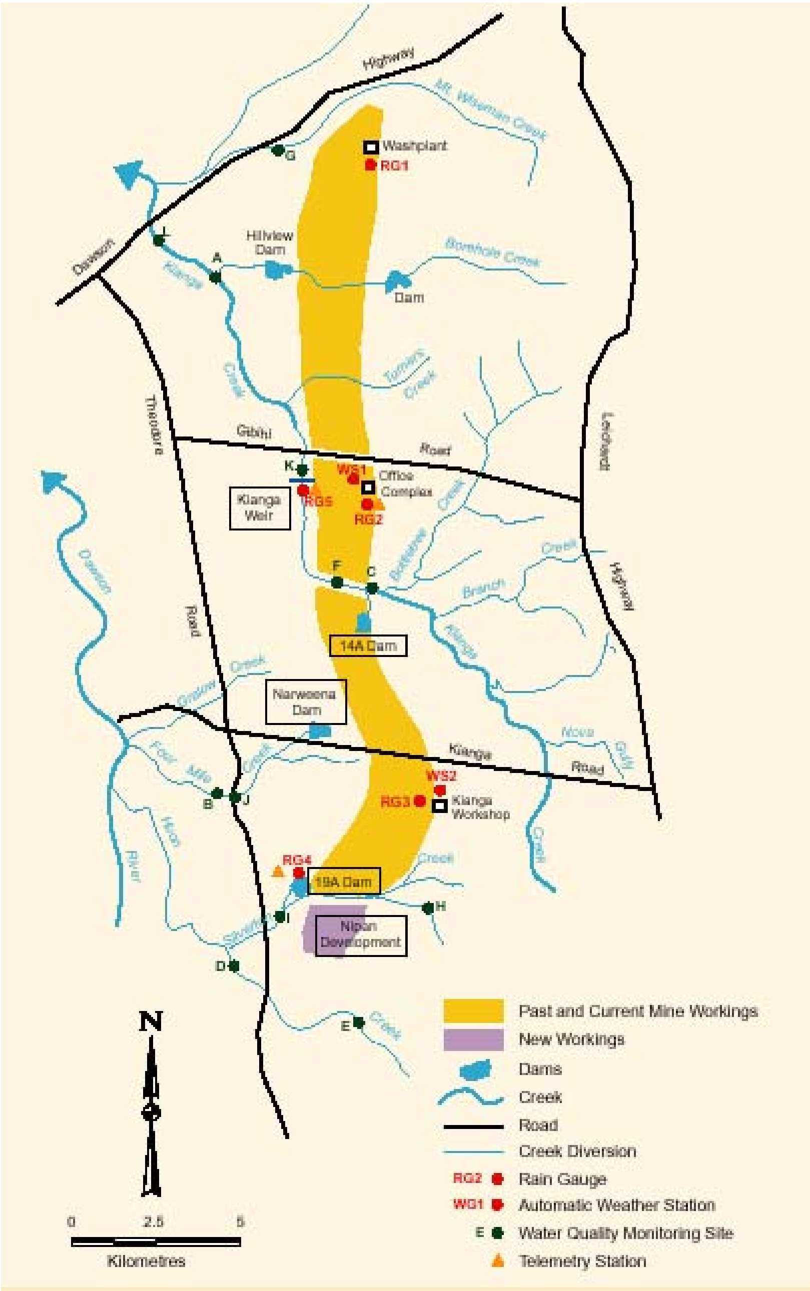


FIGURE: Moura Mine Showing the Water Quality Monitoring Stations and Dams

CASE STUDY 2

MOURA OPEN CUT MINE, QUEENSLAND - MANAGING RELEASES

Background

The 19A Dam, with a 50 ML capacity, plays an important role in minesite water management at Moura Mine in Central Queensland. The dam collects, holds and transfers 'dirty' water (high salinity) from open cut pits and spoil areas in the mine's southern works. The dam also commands a small but significant catchment area (125 ha) where progressive mining is planned until 2014. Water from this dam is pumped to Narweena Dam in a 225 mm diameter polypipe pipeline.

Photo: Water Studies Pty Ltd

Pump delivery line and monitor to record pipeline discharges from 19A Dam. Floating electric pump in the background.

Issues

- The 19A Dam has overflowed and the Narweena pipeline burst, resulting in uncontrolled releases into Silverton Creek. The impact of possible future spills on downstream water users along Silverton Creek requires management.
- If 19A Dam cannot adequately handle stormwater inflows to active pits, mining will be delayed after storm events. Key factors in achieving adequate dam operation include the capacity of the dam, the pump and the pipeline.

Analysis

- Hydrological simulation studies determined the risk of 19A Dam overflow. Analysis indicated that 19A Dam was too small and spilled regularly. The likelihood or risk of spill in any year was 42%.
- By increasing 19A Dam capacity to 135 ML (building an outer dam around the original dam), the risk of spill fell to 10%. This risk could fall to zero by using controlled releases from 14A Dam, which gets pumped inflows from Narweena Dam.
- The enlarged 19A Dam was assessed on how it handled catchment flows without uncontrolled spills during a range of 3 day storm events with risks up to 100 year ARI event. The following table shows spill likelihoods over the next 6 years for such storm events. The likelihood of spill decreases as the tributary catchment area is progressively mined in this period, and progressively reducing the runoff volume.

Year	Likelihood of Spill (%)
1	20.0
2	8.0
3	2.0
4	1.5

5	1.0
6	0.5

- The daily simulation model estimated the dilution that any spills from 19A Dam would undergo with Silverton Creek water. Given declining risk levels over time and ameliorating effects of dilution, the above risk profile was deemed appropriate and accepted by the licencing authority.

Photo: Water Studies Pty Ltd

Solar powered monitoring and transmitting station at Kianga Weir.

Solution

Solving the risk of uncontrolled releases from 19A Dam and its pipeline included:

- Increasing dam capacity from 50 ML to 140 ML.
- Installing a new higher capacity pipeline to deliver pumped flows to Narweena Dam.
- Installing a new, automatic, higher capacity electric pump in 19A Dam.
- Developing a new pumping regime for 19A Dam which aims to keep the dam as low as possible, optimising available storage for runoff from its catchment area.
- Installing a telemetry network to monitor dam water levels, pumped discharge and pipeline rupture.

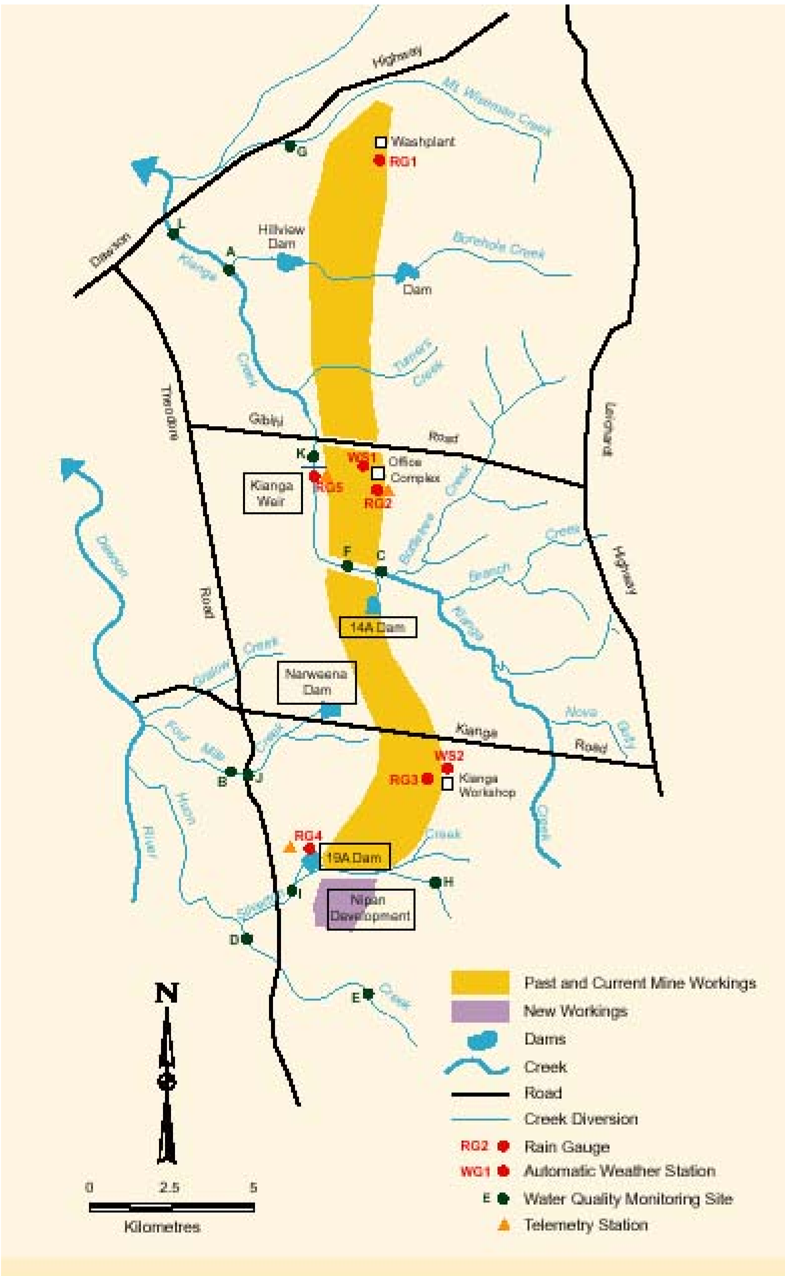


FIGURE: Moura Mine Showing the Water Quality Monitoring Stations and Dams

CASE STUDY 3

HENTY GOLD MINE, TASMANIA - WETLAND TREATMENT SYSTEM

Background

Henty Gold Mine, operated by Goldfields (Tasmania) Limited, is an underground mine located in the Queenstown area of Tasmania. Its approaches to water management must reflect the site's high rainfall (3.6m a year) and limited sunlight (about 4.8hr/day avg).

All minewater entering the workings reaches an underground pump station some 300m below ground level. From here, it is pumped to the surface and then 2km to a treatment facility, a series of settling, wetland and polishing ponds. After passing through the settling pond, the process plant water supply is abstracted, with the remaining water (1-2 ML/day) passing through the wetlands and polishing ponds to discharge into the Henty River.

In addition to minewater, stormwater runoff from the surface infrastructure and workings also reaches the treatment system.

The environmental values of the Henty River include protecting natural aquatic ecosystems.

The Issues

- Possible contaminants in minewater and surface runoff include suspended solids and hydrocarbons from fuel and oil spills.
- The company decided that an effective and reliable treatment system for minewater and stormwater runoff was essential considering the high environmental values of the Henty River.

Photo: Goldfields (Tasmania) Limited

The primary settling pond is the location where mine water first emerges on the surface. Floating plastic containment booms are permanently in place in both ponds as a contingency measure to contain a spill in the event of a hydrocarbon incident below ground.

Objectives

- To treat minewater and stormwater runoff to a high standard so it does not reduce the environmental values of the Henty River.
- To continue monitoring programs to show compliance as a minimum with relevant limits.
- To publicise and foster understanding of company water management initiatives among staff and the public.

The Treatment System

- Mine water passes through a primary settling pond to remove suspended solids. The combined minewater and stormwater flow rate is automatically monitored prior to discharge into the settling pond and the correct amounts of flocculant and coagulant are injected directly into the raw water delivery pipe. The settling pond is drained periodically to remove accumulated sediments.

- A floating plastic containment boom contains hydrocarbons in the primary settling pond in the event of fuel or oil spills below ground which are not collected in underground oil separators.
- Two oil-water separators, located between the primary settling pond and the wetland system, reduce the level of hydrocarbons passing into the wetland system.
- The wetland system itself consists of two cells between the primary settling pond and the polishing ponds with a contact area exceeding $1200m^2$.
- To further reduce hydrocarbon levels, floating booms that passively trap floating hydrocarbons are strategically placed throughout the wetland system. Revegetation of the constructed wetland system has been quite rapid. The treated minewater is of high quality, as reflected in the growth of sensitive wetland plants such as Bladderwork and Fairies' Aprons in the wetland system.
- After the water has passed through the wetland system, it then passes through a series of polishing ponds for aeration and iron and manganese precipitation before discharge to the Henty River.

Photo: Goldfields (Tasmania) Limited

Sensitive native wetland plants such as this Utriculata dichotoma (Bladderwort, Fairies' Aprons) thrive in the peat throughout the wetland filter system.

Photo: Goldfields (Tasmania) Limited

Flora such as (Bladderwort, Fairies Aprons) demonstrates the consistency of the water quality in the wetlands. Revegetation of the wetland filter system is progressing very well.

Photo: Goldfields (Tasmania) Limited

Electrofishing and invertebrate sampling are conducted twice yearly in the Henty River, associated streams and hydro dams to document stability and seasonal variations.

Monitoring

Water is monitored at a number of locations, both on-site and throughout the wetlands, as well as regionally, to oversee the operation of the water treatment system for compliance and other purposes:

- Both flow and water quality are monitored on a regular basis at fixed locations upstream, throughout and downstream of the mine.
- Runoff water from work areas is regularly sampled to ensure that the impacts of work activities on water quality are kept within site performance criteria (see cover photo).
- Biological monitoring of the Henty River, associated streams is undertaken annually by Freshwater Systems. The biological monitoring program consists of electro-fishing and invertebrate sampling. During biological monitoring exercises, staff and contractors are encouraged to observe the sampling process and examine the collected fauna. This helps employees link their daily water management activities to the overall water management objectives for the surrounding environment.
- An automatic discharge and water quality monitoring system has been installed to monitor the flow rate and quality of the polished effluent discharging into the Henty River. Water quality parameters are measured every 5 seconds. If the quality of water varies outside a pre-set range, water samples can be automatically collected.

Photo: Goldfields (Tasmania) Limited

During monitoring staff and contractors are encouraged to observe the sampling process and examine the fauna collected.

Summary

Henty Gold Mine is committed to maintaining the natural aquatic communities of the Henty River, and other intrinsic values. It plays a significant role in helping the company demonstrate that mining can coexist with sensitive environments through multiple landuse principles. Actions undertaken ensure proactive relationships with regulators, the community and other stakeholders. It is also a significant way of demonstrating the sustainable development of mineral resources.

Photo: Goldfields (Tasmania) Limited

Employees observing the monitoring process are encouraged to link the water management techniques they apply to their work activities to the overall water quality in the surrounding environment.

Photo: Goldfields (Tasmania) Limited

The underground pump station located at Zone 96 receives waste water generated at all other levels throughout the underground workings before transferring it about 300m vertically at the mine adit, and then on to the water treatment facility via a 2 km surface pipeline.

CASE STUDY 4

OLYMPIC DAM, SOUTH AUSTRALIA - TOWNSHIP WATER SUPPLY

WMC Resources Ltd is a major world nickel producer and one of Australia's largest gold producers. It has extensive interests in copper and uranium. WMC Resources holds about a 40% interest in Alcoa World Alumina and Chemicals (AWA) - the world's largest producer of bauxite, alumina and alumina based chemicals and a major Australian aluminium producer. The company's overseas interests include mineral exploration in North and South America, the Philippines and east and west Africa. It also produces talc for processing and sale in Japan and Europe and distributes fertilisers to the Australian agricultural market.

Photo: WMC Resources Ltd

Effluent lagoons at Roxby Downs also store harvested stormwater run off from the town. Following treatment effluent/storm is chlorinated and pumped back to the town for irrigation of sports fields.

Building the new town of Roxby Downs, 80km north of Woomera, South Australia, began in late 1986 as part of the long term infrastructure of the copper, uranium, gold and silver mine at Olympic Dam. The regional average rainfall is a mere 150mm necessitating water conservation measures for the 4000 (1999) inhabitants of the town. Water from the Great Artesian Basin is treated through a reverse osmosis desalinisation plant to provide drinking water. This water is reticulated throughout the town and used for irrigating home gardens and some landscaped public areas. Water conservation measures employed in the town include:

- Stormwater harvesting where runoff from the town streets gravitates to nearby collection ponds located at the edge of the township, where the water is pumped to the sewage ponds for storage. Following treatment and chlorination, this water then irrigates recreational grounds including school and community ovals and part of the golf course.
- Local endemic plants and other arid zone native species are planted extensively. These are drip irrigated and soil is mulch-covered with woodchips, pine bark, shredded green-waste or stones to retain soil moisture. Existing trees and shrubs are retained wherever possible and incorporated into the town landscape. (Drip irrigation is the most efficient means of irrigation and mulch is an essential component of all water efficient landscaping projects).
- WMC (Olympic Dam) established a Water Conservation Committee which was active for some years. The committee had a strong community involvement and focus and actively promoted a wide range of water conservation practices resulting in an improved community awareness.

Photo: WMC Resources Ltd

Attractive streetscape in Roxby Downs. Arid zone native plants, mulch and drip irrigation is utilised throughout the town.

- Community education (posters, letterbox drops, newspaper articles and community events, especially at the school) effectively maintains awareness of the need to conserve water. Company employees visit the school on request and speak to classes about all aspects of water, including conservation. Students visit the desalination plant to see the source of their water. Competitions based on the theme of water conservation and special events on World Environment Day and during National Water Week involve the whole school and many members of the local community and mine work-force.
- The Olympic Dam nursery gives a selection of appropriate arid zone native plants and a subsidised drip irrigation kit to new residents along with advice on water efficient gardening. (Free plants and advice are also distributed in the wider region.)
- Olympic Dam is promoting an incentive scheme to encourage residents to reduce lawn areas and re-landscape using lawn alternatives such as paving, hardy ground covers and mulched plantings.

Photo: WMC Resources Ltd

WMC (Olympic Dam Corporation) has a small nursery in Roxby Downs, supplying residents of the town and wider region with free appropriate arid zone native plants. Relevant horticultural advice is provided also subsidised drip irrigation kits.

- A short video promoting water conservation techniques, including local examples, has been produced and is shown at community events and mine work-force training.
- A very effective voluntary community mulching project produces valuable mulch for resale to residents from green-waste (prunings, lawn cuttings, tree branches, etc) which was formerly dumped. This reduces landfill waste and is an important fundraiser for the Royal Flying Doctor Service (RFDS). The company's Environment Section provides the wood chipper used to mulch

green-waste. By early 1999 $26,000 had been raised for the RFDS by selling mulch.

- All new houses have water efficient shower heads, dual flush toilets, an automatic irrigation system and other water saving devices. Vacant company owned houses are similarly treated, with owners of private dwellings being encouraged to do the same.
- An 'Environmental House' displaying and demonstrating environmental appropriate features and technology was built for the company's Environment Section in 1998. It is occupied by an employee and his family and open to visitors. Water conservation features include rainwater tanks collecting roof runoff for use in the house, water efficient showerheads and dual flush toilets. Water efficient appliances are used. A water efficient demonstration garden is being developed and a grey water treatment system (reed bed pond) is to be established in the garden to produce irrigation water from household wastewater.
- Synthetic turf is used for the bowling green, netball and tennis courts. This minimises water usage and maintenance costs and provides an excellent surface.

Benefits

- Potable water use is minimised without lowering the "quality of life". A pleasant environment is provided in a remote arid area for the mine work-force.
- These strategies reduce the need for potable water generation by maximising the use of the limited rainfall runoff and utilising treated sewer water.
- By storing the run-off water in the existing sewage ponds and associated tanks rather than separate ponds, the water surface area is minimised and annual evaporative losses minimised. (Annual evaporation from an Australian A class pan with bird guard is approximately 3m).
- The community has become increasingly aware of the need to use water wisely and water consumption has decreased.

Photo: WMC Resources Ltd

The Green Machine a community-mulching project in Roxby Downs produces valuable organic garden mulch from green waste, which formerly went into the town dump. The project is operated by volunteers and has produced approximately 20,000 cubic metres of mulch in five years and raised $26,000 which has been donated to the Royal Flying Doctor Service.

CASE STUDY 5

OSBORNE GOLD PROJECT, NW QUEENSLAND - MANAGING WATER IN AN ARID ENVIRONMENT

The Osborne Mine, owned and managed by Placer Dome Asia Pacific, is located about 195km southeast of Mt Isa at the northern limit of the channel country. It covers 2234 hectares and in 1998 produced 3 600 tonnes of copper and 31 000 oz of gold. Construction began in 1994 after resource definition that included five years of environmental monitoring and planning. The arid environment (median rainfall 330mm and 3500mm mean annual evaporation) meant water was an important part of the operation and became a central element in its planning and development.

Information used in preparing the Osborne Project water management system included:

- Groundwater supply studies
- Rainfall/runoff relationships
- Vegetation survey of the project area
- Review of the climate and meteorology about the project area
- Baseline surface water quality studies
- Regional and local impacts of the two water supply borefields proposed
- Geochemistry of the waste rock and tailing residue
- Waste rock disposal and management investigation
- Rehabilitation and monitoring strategy investigation
- Project site water management strategy
- Baseline assessment of metals and salinity of surface materials about the project area
- Program for consulting stakeholders

Photo: Placer Dome Asia Pacific

Bore water restoration. Osborne has improved and upgraded windmills near the pumping centre to maintain access to the borefield.

These data showed that a surface water supply would be unreliable and therefore the water management system must be based on a groundwater supply system. Osborne and BHP Cannington share the same aquifer-pumping centres which are about 70km apart. To minimise the groundwater use the following strategies were put into place:

- minimising the volume of water used by all processes;
- maximising water recycling;
- harvesting all stormwater run-off;
- installing water efficient appliances;
- educating employees and contractors on water conservation;
- constantly monitoring water usage;
- producing an annual water audit; and
- undertaking continuous improvements in water conservation.

Photo: Placer Dome Asia Pacific

Stakeholders were well informed on the likely impact of expected mine water consumption on regional water resources, company strategies to minimise raw water usage and mine water discharges.

Benefits

- Enabled the development of a reliable water supply and management system.
- Stakeholders were well informed on the likely impact of expected mine water consumption on the regional water resources and the strategies the company used to minimise raw water usage and the discharge of mine waters to the environment. Stakeholders are also given regular feedback on performance through monthly reports and annual independent assessment.
- Enabled the development of realistic water release criteria based on defined natural background water quality variances. (No releases to date.)
- Risk assessment was possible when providing primary, secondary and tertiary protection systems to contain mine water.
- The base-line data helped develop the operational monitoring program which aims to identify variances to anticipated impacts and thereby trigger remedial action. This pro-active approach exceeds legislative compliance standards and conditions.
- Minimised capital expenditure and operating costs by maximising recovery rates. Recovery rate for 1998 was 301%. Each litre of water abstracted from the borefield is recycled on average 3 times before it its adsorbed into settled tailings, final concentrate product or lost as evaporation.

Notes:

- Mine designed and commissioned in 1995 to treat 1.0 M tonnes of ore/year.
- Current water abstraction allowance 947.0000 M Litres unaltered allocation throughout mine life to date.
- Water values abstracted includes water supplied to a pastoral (sheep and cattle) station at an average rate of 20 M Litres/year.

TABLE: Eco efficiency Index of Water per tonne ore processed

Year	Tonnes Milled (M t)	Water abstracted (M litres)	Eco efficient index (litres of water/tonne of ore processed)
1996	1.268066	863.8631	681
1997	1.464761	897.4986	613
1998	1.493370	903.4488	605

CASE STUDY 6

YANDAN GOLD MINE, QUEENSLAND - PIT FLOODING AND MODELLING

Introduction

The Yandan Gold Mine opened in September 1993 and mining ceased in December 1998. The mine site, owned and operated by Ross Mining NL., is approximately 180km SSE of Charters Towers, north central Queensland, on the Suttor River, at its junction with Yandan Creek. At the minesite, the Suttor River is ephemeral, with a high silt content and elevated total iron concentrations (see photo). The minesite's average annual rainfall is about 500 mm, with average pan evaporation of about 2200 mm a year. A temporary earth bund separates the Yandan pit from the Suttor River (see title page).

Increasing sulphide rich ore and waste was encountered as the open pit was mined. Testing showed this waste rock was net acid generating. Since it was planned to flood the pit after operations, sulphide rich waste rock was placed in the open pit (see photo). The pit lake would protect against continued oxidation of the sulphidic waste rock.

Photo: Ross Mining NL

Main channel of the braided Suttor River showing high natural silt content.

Water Management Issues

Placing sulphidic waste rock in the pit, below the final pit lake level, represents "best environmental practice". Permanent underwater storage of such rock, to limit oxidation and acid generation, is accepted as best practice in many parts of the world, including Canada, the USA, Scandinavia and Europe. However, sulphidic waste rock and pit wall rocks oxidize between mining and flooding, accumulating soluble metal sulphate salts and acidity in the waste and wall rock. These are then released when the pit is flooded and may create unacceptable water quality.

Field paste and conductivity measurements at Yandan showed a significant accumulations of acidity and soluble sulphate salts would impact the pit lake. Therefore, water management issues on flooding the pit centred around:

- short term water quality in the pit;
- long term water balance and water quality;
- potential to use the pit lake as a backwater to the Suttor River; and
- potential impacts on water quality in the Suttor River.

Approach

Following corporate objectives for environmental "best practice", suitable alternatives for successful flooding of the pit were needed. The company decided to model water quality predictions of the flooding process. Ross Mining contracted SRK Consulting to model the Yandan pit lake water quality.

A simple three step approach estimated the water quality within the pit during flooding. First, Ross Mining and SRK Consulting developed a geological map of the pit walls to show the distribution of sulphide and carbonate altered wall rocks and as well as the sulphide waste rock backfill. The map helped estimate the total exposed surface area of each type of wall rock, and total mass of waste rock that had been backfilled. SRK Consulting then took representative samples from each rock type and leach extraction testing determined their solute release rates. Finally, these test results for rock types and the wall rock exposure helped SRK developed a dilution model to calculate solute concentrations in the pit lake. The model also calculated the pit volume against the flood elevation, as well as the short and long term water balances.

An inventory of solutes (soluble metal sulphate salts and free acid generated from sulphide mineral oxidation) that might come from the wall rocks and waste rock during flooding was created. Solute concentrations were derived from simple dilution calculations, then geochemical equilibrium modelling helped calculate saturation indices for secondary minerals that could precipitate and final water quality was then developed. Based on its worldwide experience, SRK considered this approach "best practice" for the size of the project, potential environmental impacts and the circumstances.

Photo: Ross Mining NL

View of the northern western section of the Yandan Pit showing high sulphide waste rock backfill (foreground, grey) and mixed oxide-sulphide waste rock backfill area (centre left — end dumped material).

Results and Conclusions

Short Term Solute Release

The solute release calculations showed that, without remediation, the pit lake was likely to be acidic after flooding. The estimated solute concentrations could then adversely impact water quality in the Suttor River. Preventive measures were therefore required to protect the receiving environment.

Primary solute release source assessments showed more than 95 percent of the total solute loading would come from the backfilled waste rock. Dilution calculations indicated that if waste rock solute releases could be controlled, water quality was unlikely to adversely affect the Suttor River.

Remedial option evaluations therefore focused on controlling solute release from the waste rock. These included surface compaction of waste rock, a soil cover and placing a chemically amended soil cover over waste rock backfill areas. An option that was evaluated, but discarded early on (for technical and performance reasons), included treatment (lime or limestone neutralisation) of the pit lake water after flooding.

Photo: Ross Mining NL

Contouring and surface dressing of sulphide waste rock backfill in preparation for cover construction.

To evaluate the selected options, solute release was modelled assuming a diffusional transport mechanism. The modelling results indicated that a simple, continuous soil cover, with a minimum thickness of about 0.3 m, would effectively reduce the rate of solute release from the waste rock. Also, geochemical equilibrium modelling indicated that cover efficiency would improve if the cover soil used had a nominal amount of lime (0.2 percent lime) added before placement.(see photos showing the above measures)

Photo: Ross Mining NL

Soil cover placement on sulphide waste rock backfill in the Yandan Pit in preparation for flooding. Lime (white coating) is spread in advance of the soil cover to neutralise acidity.

Long Term Solute Release

Water balance calculations indicated the pit lake level would be within 50cm of the river bed elevation in average climatic conditions. At this level, the backfilled sulphidic waste rock would be about 5m or more underwater. Similarly, the sulphidic pit wall rocks are expected to remain covered. Under extreme drought conditions, the level may fall, exposing small sections of sulphide altered wall rocks. However, the identified potential for solute release from oxidation was small and the impact on water quality insignificant.

Recommended Remediation

After modelling, SRK Consulting recommended a soil cover with a minimum thickness of 0.3 m, amended with 0.2 percent lime. However, soil properties (clay) at site precluded effective lime mixing prior to placement. Therefore, SRK recommended spreading lime on the sulphidic waste rock backfill at about 1 kg/m^2 before placing the soil cover. Recommendations included erosion protection for all sideslopes, with additional protection for soil cover placed immediately below where the river will flow into the pit.

Further, to control water exchange between the pit lake and the river, a connecting channel between the river and the lake at about 0.6 m above the river bed was recommended. As a result, the pit lake will not discharge during low flow conditions.

Implementation of Control Measures

The recommended control strategies are currently being implemented by Yandan Mine personnel. Ross Mining has conservatively opted double the soil cover thickness. The cover is being placed as two consecutive layers, each 0.3 m in thickness, placed on top of the lime layer, as shown in Figure below.

Anticipated Benefits

Restricting solute releases means initial pit lake water quality should match that in the Suttor River. This means the pit lake can become a backwater for the Suttor River. This will sustain the lake's water level at optimum levels, limiting oxidation and solute release.

The wet season should also bring benefits through the cyclical interaction between the pit lake and river. During floods the lake will act as a stilling basin. The silt will settle act as an additional cover, further restricting solute release. In addition, organic matter in the silt may promote reducing conditions, an additional "barrier" against solute releases. Reducing conditions would reduce sulphate and precipitate sulphide metal phases.

Throughout this process, the Queensland Departments of *Minerals & Energy* and *Natural Resources* were involved and approved the final strategy as a pro-active approach in managing the environmental values around and downstream of the mine.

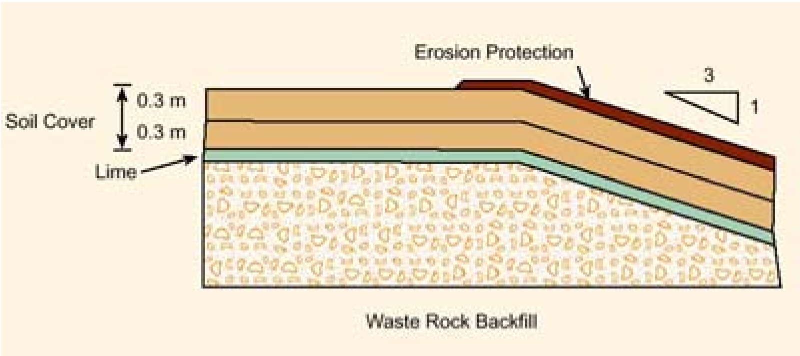


FIGURE: Schematic of soil cover placed over backfill

CASE STUDY 7

RED DOME GOLD MINE, NORTH QUEENSLAND - FOSTERING ENVIRONMENTAL AWARENESS

The mine, located near Chillagoe, 135 km west of Cairns in far north Queensland, has been operating since 1986 by Niugini Mining (Australia) Pty Ltd. Decommissioning began in early 1998 with rehabilitation works undertaken to March 1999. It involved a complex mining operation, with one of the steepest and deepest open pits in Australia and used heap leach, copper floatation and carbon in leach for gold recovery, with associated SO_2/Air cyanide destruction. The mine is adjacent to a National Park and within the 72 000 km^2 water catchment of the Mitchell River.

Photo: Niugini Mining (Australia) Pty Ltd

Rock lined drop structure from disused heap-leach pads with pseudo-gabions constructed using closely spaced star pickets. A loader can be used to place rock over the pickets.

The mine gets tropical monsoonal rains between December and March. Average annual rainfall is 750-800 mm/year with most falling in January and February. Rainfall is intense with some falls recorded at 88 mm in 25 minutes and 148 mm in 4 hours.

As a result, environmental and water management has been a core element of the mining operation and decommissioning stages. Red Dome ensured maximum involvement of its workforce in environmental and water management by:

- Developing a company environmental policy and code of practice.
- Having a company-driven goal of best environmental practice which was adopted throughout the workforce.
- Developing and implementing an environmental management program that incorporated documented management and water management contingency systems with implementation and performance reviews (a "whole of system" approach).
- Fully integrating water management into the mining operation through an overall mine plan. The minesite had 16 discrete and workable environmental management segments or domains, chosen based on a specific challenge (void or tailings dam), or access and timing issues, to the type of activities carried out at a location. Ground and surface water monitoring stations reflected the position of domains and their catchment characteristics. Data could be interpreted by domain to easily pinpoint any potential problems.

Photo: Niugini Mining (Australia) Pty Ltd

Red Dome's raw water dam situated downstream from the site disturbance area, provides a practical longterm buffer to the rest of the catchment.

- Delegating environmental and water management responsibilities to each employee with quarterly sign-offs by appropriate managers and team leaders. Because employees had designated tasks and experience in handling these, they readily demonstrated success in achieving targets. This reduced the 'mystery' of environmental and water management. Environmental performance was a key consideration during annual performance reviews for all staff. There were procedures to enable teamleaders and workers to shut down the plant if circumstances threatened the water catchment and wider environment.

Photo: Niugini Mining (Australia) Pty Ltd

Tailings slurry line placement beneath the crest of an inward cambered dam wall. Note line identifier and spigot numbering system to track daily throughput with basin filling model and settled density measurements.

- Providing accredited competency-based environmental training for all staff. People are the most important factor in effective water management. Training was aimed at understanding environmental systems and their linkages and company requirements rather than procedural requirements. Protecting clean waters and minimising effluent streams therefore became part of the overall job, as opposed to an add on. Regardless of the best intentions of top management in endorsing a corporate policy, or for management to create a workplace system or operating procedure and mineworkers getting directions, unless every person within that chain accepts responsibility for the potential environmental impacts of their job and understands how to minimise or best manage impacts, there will always be a water or other pollution event waiting to happen.

Benefits

- Adopting a proactive approach during mining helped minimise clean-up and closure costs.
- The number and size of environmental incidents fell noticeably following staff environmental awareness training. This also reduced environmental damage and operational costs.
- Avoiding clean-up incidents became a strong focus during production, with consequent boosts to worker morale and demonstrated environmental performance.
- The new outlook workers began adopting meant labour resources were more cost-effectively used in mining as processing activity wound down. Workers were fully tasked right up to their last days on the job as they understood the project was not complete until the clean-up was finalised.
- Closure was easier as known problem areas were cleaned up during processing operations and the dirty water system footprint minimised. The location of incidents, and their nature, were clearly remembered — not left until long after the incident happened and workers left.

Photo: Niugini Mining (Australia) Pty Ltd

Copper-cyanide SO_2 Air Destruction Reactor, used to treat excess tailings dam supernatant water to provide sufficient storage capacity prior to each wet season.