International Association of Hydrogeologists
Strategic Overview Series

MINING ENTERPRISES & GROUNDWATER

KEY MESSAGES

- **mining enterprises are a major economic activity that is intimately linked with groundwater**
- **groundwater often exerts a negative influence on mining operations and mine safety, and mitigating such problems requires sound hydrogeological understanding**
- **mine water-supply is highly location specific, but in more arid regions often depends heavily on groundwater resources**
- **mine drainage can become a major influence on groundwater flow regimes, with the scale of impact varying widely with type of drainage operation**
- **following mine closure and drainage cessation groundwater level recovery occurs accompanied by radical changes in groundwater quality**
- **historically some mining practices had a tarnished image in relation to water resources, and this legacy is still having to be addressed**
- **but today most mining operations are much improved with the introduction of systematic environmental risk assessment and management**

In what ways do mining activities interact with groundwater systems ?

Mineral resource extraction leads to an inflow of groundwater to the mine or quarry and potentially major modifications of groundwater flow and quality regimes, and thus to various issues requiring consideration during mine evaluation, development, operation and closure. Groundwater can exert negative influences on mining economics by creating risks for operational continuity and miners' safety, as well as having adverse environmental impacts.

Mine closure implies ceasing groundwater drainage operations and allowing subsurface flooding to occur. This is best managed on a gradual, controlled and flexible basis with close monitoring of water table rebound, groundwater chemistry and environmental impacts. The key to mitigating such problems is hydrogeological understanding.

This brief considers all types of mining (open-cast and subsurface) and quarrying in relation to their interaction with groundwater (*see following table*). It is necessary to distinguish between coal/lignite mining, heavy metal mining (including uranium), gemstone mining, salt mining, sand

BOWEN BASIN COAL MINE — AUSTRALIA
INTAKE SCREEN FOR MINE WATER PUMP

Photograph: W Timms

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.

NATURE OF PROCESS/ACTIVITY	GROUNDWATER IMPACTS AND CONCERNS
groundwater supply for mining processes	interference with pre-existing waterwell users and permanent aquifer depletion, if non-renewable or weakly-recharged aquifers involved in arid regions
groundwater pressure relief for slope stability	usually in low-permeability formations and mainly a geotechnical issue with only limited groundwater system impact
dewatering for mine access drifts and faces	in large and/or deep mines/quarries can result in large cones of influence with impacts on waterwell users and groundwater-dependent ecosystems
sudden groundwater in-rush to mine galleries	potential loss of life, damage to capital equipment and mining continuity with effects also on hydraulically-linked springs and ecosystems
mine closure with water-table rebound	can result in new groundwater discharge zones and mobilisation of poor quality groundwater into regional flow systems
in-situ leaching of target minerals	risk of strongly acidic or alkaline leachate carrying extracted mineral(s) polluting groundwater
accidental/incidental groundwater pollution from mining operations	mine-water drainage and tailings-dam seepage activating pollution sources and potentially impacting groundwater quality (especially in coal/lignite and heavy metal mining)

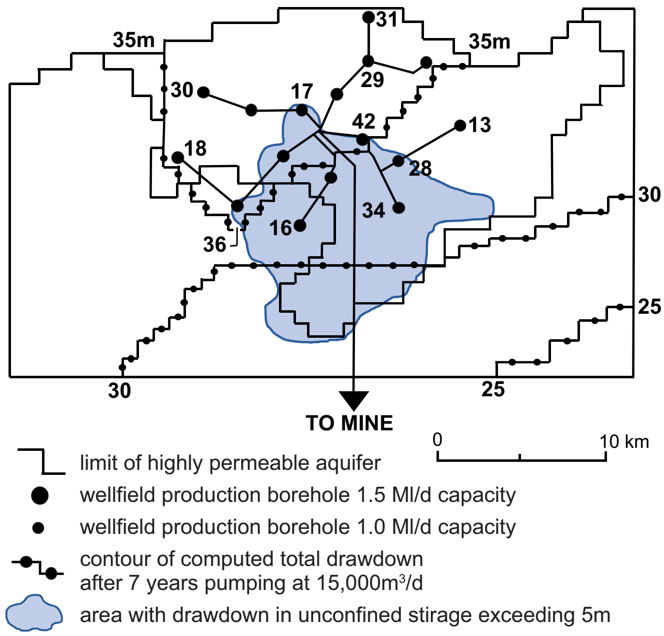
and gravel extraction and building material quarrying/mining, because of their potentially different impacts on the 'water cycle'. A new type of mining technique of growing importance that also needs to be considered here is 'in-situ leach mining' to dissolve and extract minerals (rather than 'rock moving and digging'). (*Hydrocarbon development is outside the present scope, having been dealt with in a previous title in this Series*).

• How important are groundwater resources for mine production processes ?

Mining, like virtually all other types of industrial production, requires a reliable water supply, including a modest component for human use. And mining production involving large-scale rock crushing to extract the mineral of interest (eg : gold, silver, diamonds) will need an exceptionally large water-supply and may only be viable if this is available in fairly close proximity. Mine water supply is highly location dependent, but in semi-arid regions often relies on groundwater.

Large-scale external wellfield development for mine water supply must be treated like any other groundwater abstraction, and subject to normal regulation and licensing procedures. Fortunately, efficient water use (and re-use) has reduced mine water demands in recent years. An example of planned and managed large-scale groundwater use for mining comes from the Jwaneng Diamond Mine in the Botswana Kalahari. The original requirement was for a continuous supply of at least

JWANENG DIAMOND MINE — BOTSWANA
NUMERICAL MODELLING OF WORST-CASE DRAWDOWN [a]



a *Foster et al 1982 Proc Institution of Civil Engineers I : 72 : 563-584*

15,000 m^3/d for 15 years (and probably much longer), in an area with mainly non-renewable groundwater resources and existing small-scale users for extensive livestock ranching [a].

• How are groundwater flow systems modified by mine drainage ?

Mine drainage and dewatering during the operational period can become a major influence on local groundwater flow, and even on the regional groundwater balance, with interference effects on waterwells, drying-up of springs and inducing new inflows from some river reaches.

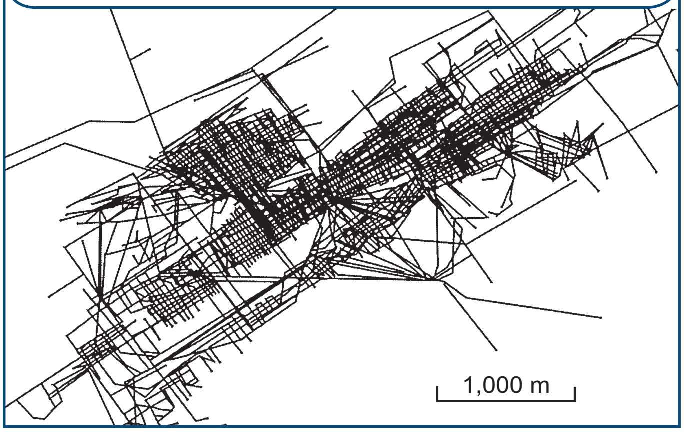
The scale of influence will vary widely between differing types of drainage operation :

- passive removal of inflow to mining galleries by pumping from low permeability strata
- pore-water pressure relief points to improve slope stability
- active large-scale dewatering by horizontal/ oblique fore-drilling and from large diameter wells to drain permeable formations and reduce the risk of sudden in-rush.

The potential scale of groundwater abstraction by mining activities can be very large. In Poland open-cast lignite mining at Belchatów and Szczercow in 2017 required more than 500 active dewatering wells pumping some 200 Mm^3/year (some of good quality) to produce a drawdown of over 300m, with about 1,300 monitoring wells to delineate the large associated cone of depression [b]. In Estonia oil-shale mining involved pumping some 180Mm^3/a to surface water bodies in 2002, which represented over 70% of the total national groundwater abstraction [c].

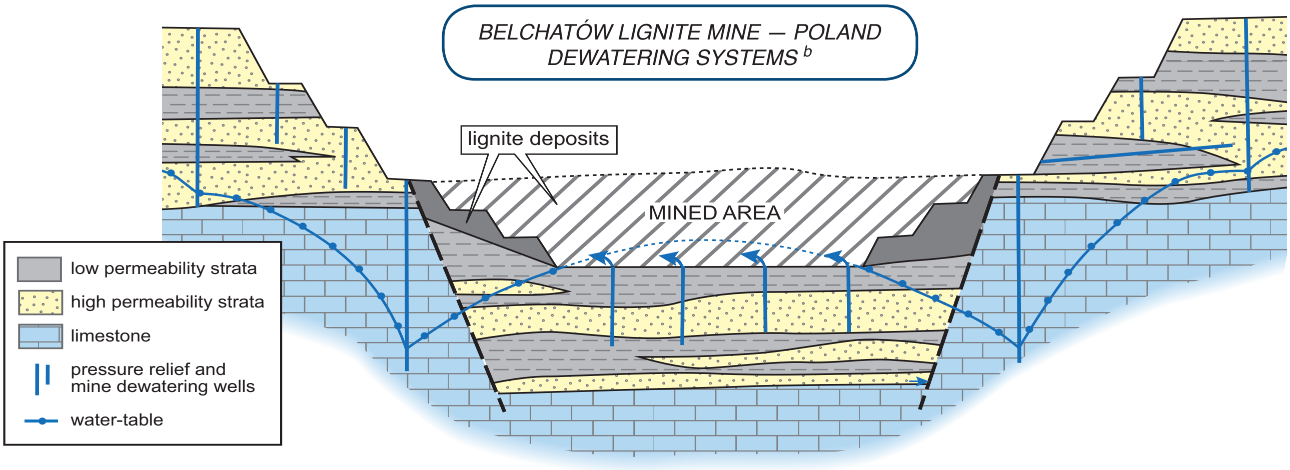
It must also be appreciated that long-term large-scale mining itself creates extensive interconnected subsurface void space which permanently modifies the circulation of air and water in its vicinity, and thus can substantially alter the natural groundwater flow and quality regime.

HOMESTAKE GOLD MINE — SOUTH DAKOTA, USA
HORIZONTAL PROJECTION OF VOID SPACE FROM TUNNELS AND SHAFTS SPREAD OVER 2,000 METRES DEPTH [d]



Following mine closure and cessation of mine-water pumping a slow recovery of the groundwater system occurs, with water-table rebound, reactivation of springflows and discharges to surface water, and flooding of land surface depressions. This is often accompanied by radical

BELCHATÓW LIGNITE MINE — POLAND
DEWATERING SYSTEMS [b]



b *Kowalczyk et al 2010 Przeglad Geologiczny 58 : 776-788*

c *Wolkersdorfer & Bowell 2004 Mine Water & Environment 23 : 162-182*

d *Murdoch et al 2012 Hydrogeology Journal 20 : 27-43* changes of groundwater quality, especially those associated with acidification that usually occurs in metalliferous, and some coal mining, areas.

POMORZANY — POLAND
GROUNDWATER INFLOW TO ZINC & LEAD ORE MINE

• Can mine drainage operations be an important source of water-supply ?

As mining gets deeper and ventures below the natural water-table, groundwater pumping for mine drainage often becomes a useful water supply component reducing 'external supply needs'. However, in some cases (such as the large copper mines in Chile) it is preferred not to base the main water supply on mine drainage, but regard this as a lower-quality source for specific purposes to reduce the demand on other sources.

Recent years have also seen good examples of sound groundwater and environmental management both during mine operation and post closure, including direct re-use of mine drainage for agricultural irrigation in the Hunter Valley-Australia.[e] And the impacts of groundwater abstraction on shallow aquifers and related aquatic wetlands can be substantially reduced through schemes to artificially recharge mine drainage waters to the ground, as is now successfully practised at some locations in Australia [f].

• How does groundwater quality degradation arise from mining activity ?

There is little doubt that most mining activities, at one stage or another, generate substantial volumes of contaminated water. Europe was reminded of this by the major pollution incidents at Aznalcollar (Sevilla) Spain in April 1998 and Baia Mare (Transylvania) Romania in January 2000. But these 'environmental disasters' both involved extensive surface water (not groundwater) pollution following the failure of mine-tailings dams.

Groundwater systems are, however, also threatened, although it requires more detailed monitoring to identify the insidious long-term impacts. The commonest (but not only) causes of groundwater pollution are :

- oxidation and dissolution of ubiquitous pyrite in fractured rock resulting from forced mine ventilation and groundwater percolation, mainly by metalliferous (sulphide-ore) mining, but sometimes also from coal mining
- saline groundwater drainage and poor quality leachates from deep mines in sedimentary strata. In Poland the impact on groundwater quality of flooded iron mine workings closed 30 years ago is still observed in the Middle Jurassic Aquifer with iron, managanese and sulphate concentrations of up to 270, 60 and 1100 mg/l respectively [g].

There is also serious concern about pollution of underlying regional aquifers where uranium mining practices in-situ leaching with strongly acidic or alkaline solutions – for example in the Czech Republic, USA (Arizona), China and Kazakhstan [h].

A measure of the threat of mining activities to groundwater can be gained from the results of national surveys in the 1990s and 2000s. In the UK about 9,000 km^2 of designated groundwater bodies were declared at risk of iron, zinc, copper

e Timms & Holley 2016 Water International 41 : 351-370
f Waterhouse et al 2017 AusIMM Bulletin Feature Oct 2017
g Razowska 2000 Biul Panst Inst Geol 390 : 35-96
h IAEA 2016 In-Situ Leaching of Uranium : an Overview. IAEA Nuclear Energy Series NF-T-1
i Wolkersdorfer & Bowell 2005 Mine Water & Environment 24 : 58-76

and lead pollution from coal and metalliferous mining activity [c]. In Switzerland there has been serious local concern about arsenic pollution of groundwater from former gold mines [i].

• What is being done to mitigate impacts of mining on groundwater ?

The duty of water resource regulatory agencies to the public means that they have to put priority on the fundamental roles of groundwater in drinking water provision and sustaining certain ecosystems. This requires that they act independently to exert strict control on mining enterprises, but this should not be disproportionate to the control they exert on other groundwater using and groundwater polluting sectors.

The image of the mining industry in relation to water resources and aquatic ecosystems was tarnished historically by inadequately controlled activity — and this legacy still has to be addressed today. The situation in current mining operations is much improved with the introduction of systematic environmental risk assessment and management, high-efficiency water use and appropriate treatment of mine-water drainage. This appraisal, therefore, has to clearly distinguish between 'strengthening current practice' and 'dealing with the past legacy'.

• Regulatory & Planning Considerations

There are ways in which groundwater management and protection considerations can be built into mining legislation, especially where they relate to vital drinking water supply and aquatic ecosystem sustainability including :

- imposing a 'cradle-to-grave' approach to legal responsibility and financial provision for groundwater conservation through an 'environmental liability' clause (or directive or similar) as a condition of licensing
- requiring more detailed studies and improved mitigation measures before mining approvals
- declaring a moratorium on the development of certain types of mining enterprise in the most highly-vulnerable hydrogeologic settings
- exerting stricter control on licensing mine-water abstraction and discharge
- including consideration of closure plans prior to mining commencement, so as to specify long-term needs for impact mitigation.

• Assessment & Monitoring Requirements

The scope and detail of Environmental Impact Assessments (EIAs) required prior to the approval of mining developments has improved greatly in recent years, and it is now essential to assess prevailing baseline groundwater flow, quality and use conditions pre-mine development, together with all potential impacts/risks and their management. EIAs now rigorously and routinely

BELCHATÓW LIGNITE MINE — POLAND
WELLS OF THE INNER DEWATERING BARRIER

MINING ENTERPRISES & GROUNDWATER

include systematic hydrogeologic evaluation making use of modern techniques, such as groundwater geophysical surveys, stable and radioactive isotopes, tracer testing, trace element analyses and numerical system modelling.

It is also important to make provision for 'independent expert review' of EIAs to advise government before mining, and mining-extension, approvals. The EIA needs to be followed by improved mine water monitoring and reporting, using protocols that identify 'action trigger points', specify the accounting framework and stimulate better 'mine water productivity' (through recovery, treatment and recycling), and have mechanisms to encourage 'public reporting' of perceived external impacts.

- **Remedial Engineering Measures**

The construction of 'engineered barriers' between open-cast lignite and coal mining works and alluvial aquifers can help to reduce mine water inflows and reduce impacts on the shallow groundwater system.
In the Witwatersrand Basin–South Africa underground gold mining has largely ceased, but groundwater levels are maintained below 'environmentally critical' levels by pumping and treatment prior to discharge or utilization.
Addressing the mine water and tailings dam legacy from past mining activity will be a greater problem in countries with a long mining history (such as Poland, Germany, China, USA, etc), and consideration needs to be given to inert backfilling of mining voids and stabilization of tailings dams before drainage pumps are shut down and the water-table rises.

FURTHER READING

- ICMM 2017 Position statement on water stewardship. International Council on Mining & Metals. 5pp. www.icmm.com.
- ICMM 2017 A practical guide to consistent water reporting. International Council on Mining & Metals. 72pp. www.icmm.com.
- INAP 2014 GARD Guide -the global acid rock drainage guide. International Network for Acid Prevention. 473pp. www.gardguide.com.
- Kowalczyk A, Witkowski A, Rozkowski A. Szczepanski A, Rogoz M, Przybylek J & Stasko S 2010 What Polish mining owes to Polish hydrogeology. Przeglad Geologiczny 58 : 776-788.
- Li, P 2018 Mine water problems and solutions in China. Mine Water & Environment 37 : 217-221.
- Wolkersdorfer C & Bowell R (ed) 2004/2005/2005 Contemporary reviews of mine water studies in Europe : Parts 1-3 Mine Water & Environment 23 : 162-182/24 : 2-37/58-76.
- Younger P L, Arensen R T, Iversen E R & Banks S B 1997 Mine water chemistry : the good, the bad and the ugly. Environmental Geology 32 : 157-174.

PRIORITY ACTIONS

- **groundwater conservation and quality protection should be built into mining regulation by imposing a 'cradle-to-grave' approach to legal responsibility and financial provision**

- **EIAs should be required prior to the approval of mining developments and extensions, with systematic hydrogeological evaluation using modern investigation techniques being routinely included**

- **during mining operations monitoring and reporting of mine water flows, groundwater levels and quality should be conducted using agreed protocols**

- **there is everywhere a need for structured contingency planning and adaptive management responses to deal with 'groundwater emergencies' caused by mining activity, both inside and outside the mine itself**

- **effort should be made to foster partnerships between mining enterprises, other environmental stakeholders, and water-resource regulators to seek mutually-acceptable solutions to actual and potential groundwater problems**

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