MINISTRY OF ENVIRONMENT AND TOURISM

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Umwelt Bundesamt

Recommendations on water monitoring in open-pit coal-mine areas in Mongolia (RWM)

Strengthening of environmental protection requirements for the rehabilitation of areas devastated by coal-mining in Mongolia

GUB

LMBV Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH

ADVISORY ASSISTANCE PROGRAMME (AAP)

of

the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

Project No. 90148

Project: Strengthening of environmental protection requirements for the rehabilitation of areas devastated by coal-mining in Mongolia

Recommendations on water monitoring in open-pit coal-mine areas in Mongolia (RWM)

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On behalf of the German Environment Agency

Report completed in November 2019

This project was financed by the German Federal Environment Ministry's Advisory Assistance Programme (AAP) for environmental protection in the countries of Central and Eastern Europe, the Caucasus and Central Asia and other countries neighboring the EU. It was supervised by the German Environment Agency.

The responsibility for the content of this publication and the photos lies with the authors.
Image on the front page: Open-pit coal-mine Sharyn Gol (Ch. Konrad 2018)

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Abstract: Recommendations on Water Monitoring in Open-pit Coal Mine Areas

Monitoring and understanding the local water system provides a basis for a more sustainable and efficient water management.

This document gives recommendations concerning the planning and technical realization of water monitoring system for open-pit coal-mines, while providing focus on the interpretation, documentation, and reporting of monitoring results. These recommendations are based on site visits to Mongolian open-pits mines, as well as experiences from water monitoring in lignite mining in Germany, which have been adapted by considering the current conditions in Mongolia.

These recommendations are intended for managers at the operational level, but they may also be useful for environmental officials, competent authorities, non-government organizations, students, and people with a general interest in the best practices associated with monitoring the quality and quantity of ground and surface waters in and around open-pit coal-mines. The goal of this work is to improve the mining industry's environmental performance.

Kurzbeschreibung: Empfehlungen zum Wassermonitoring für Gebiete des Kohlentagebaus

Grundlagen für eine nachhaltige und wirkungsvolle Wasserwirtschaft sind das Systemverständnis und die messtechnische Erfassung des lokalen Wasserhaushaltes.

Mit dem vorliegenden Dokument sollen Empfehlungen zur Planung und technischen Realisation für das Wassermonitoring in Kohlentagebauen gegeben werden, wobei der Schwerpunkt auf der Interpretration, Auswertung und der Erarbeitung von entsprechenden Bereichten liegt. Diese Empfehluingen basieren auf Befahrungen mongolischer Tagebau und Erfahrungen zum Wassermonitoring, die im Braunkohlentagebau in Deutschland gemacht worden sind, wobei letztere auf die gegenwärtigen mongolischen Verhältnisse angepasst worden.

Die vorgelegten Hinweise sind für Tagebautreibende genauso, wie für Umweltinspektoren, Behördenvertreter, NGOs, Studenten und Interessenten bewährter Praxis des Monitoring von Grund- und Oberflächenwasser hinsichtlich Menge und Beschaffenheit in und um Kohlentagebaue gerichtet. Ziel dieser Arbeit ist die Umweltverträglichkeit des Bergbaus zu verbessern.

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Summary

Coal mining is a growing part of the Mongolian mining industry and supplies Mongolia's most prevalent energy source. Therefore, thorough longterm planning of mining projects is crucial because of their impacts on the economic, social, and natural environment. Additionally, existing coal mining practices are in need of practical recommendations for minimizing negative impacts on the environment and for optimizing operating expenditures to fulfill legal commitments.

The majority of coal-mining activities impact the water balances and/or the quality of local waters. Dewatering the deposit is a requirement for mining in many cases, which, in the case of open-pit coal mines, draws down the groundwater level within a large area. Furthermore, hydrochemical reactions and the use of water for operational processes can change chemical characteristics of water. The limitation of water resources in Mongolia requires that this resource be protected. As the effects of mining on water resources is unavoidable, the government of Mongolia is aware of these impacts and regulates the mining activities on different levels. Their aim is to minimize the negative environmental impacts of mining, which includes obligating mining companies to conduct sustainable water management.

Monitoring and understanding the local water system provides a basis for a more sustainable and efficient water management. Mining companies are therefore required by law to integrate water monitoring into their operations. Numerous legal regulations partially based on international standards exist. However, because detailed, comprehensive specifications for the interpretation, documentation, and reporting of monitoring results are not available at present, it is difficult for water authorities to audit and evaluate monitoring reports. Furthermore, mining companies are unlikely to profit directly from improving their dewatering methods. There are, however, numerous benefits that can be realized through improvements and optimizations in dewatering management, which can be achieved through the evaluation of monitoring results.

This document gives recommendations concerning the planning and technical realization of water monitoring systems for open-pit coal mines, while providing particular focus on the interpretation, documentation, and reporting of monitoring results. These recommendations are based on the site visits to Mongolian open-pits mines, as well as experiences from water monitoring in lignite mining in Germany, which have been adapted by considering the current conditions in Mongolia.

These recommendations are intended for managers at the operational level, but they may also be useful for environmental officials, competent authorities, non-government organizations, students, and people with a general interest in the best practices associated with monitoring the quality and quantity of ground and surface waters in and around open-pit coal mines. The goal of this work is to improve the mining industry’s environmental performance.

1. Forward

Water is one of the environmental resources that, in addition to air and soil, are impacted by mining activities. Mining activities can affect water quantity and/or quality and can pose a risk to water resources. In many cases, mining operations change the hydrological, hydrogeological, and topographical characteristics of the mining areas. Changes in surface runoff, soil moisture, groundwater dynamic, water quality, and evapotranspiration can also persist long into the post-mining phase.

Sound management practices are a fundamental component of mining operations for mitigating the impact on water balances and water quality for both surface and groundwater resources in a responsible manner. These practices are to be carried out throughout the life cycle of a mine, as well as post-closure, on both a local and regional scale. Water monitoring is a legal requirement (see Fig. 1) and is a part of negotiations with authorities for a mining permit.

An accurate and reliable database is an essential component of many environmental management plans. The objectives of water monitoring programs include:

- Documentation of the base line situation for the mining project.
- Monitoring the water usage within the site: This also provides companies with opportunities for internal cost controlling and optimization regarding water reuse.
- Identification of sources and extent of pollution: Actions to mitigate these risks may include implementing a water treatment technology or further process control.
- Assessment of the impact of water reuse and management, as well as the impact of the mining activities, on the regional water balance.
- Calibration and verification of numerical groundwater models against measured data for improved prediction and assessment of future states.
- Improved planning for decommissioning and closure procedures regarding required actions and financial provisions based on the numerical groundwater models.
- Establishment of environmental and water management plans based on impact and incident monitoring for the mine and the surrounding region: These plans facilitate decision making and serve as an early warning system for indicating necessary preventive and remedial measures in certain areas.
- Auditing of compliance with set standards and legislation and evaluation of the success of implemented management actions.

In this document, water monitoring is defined as: the recording, documentation and interpretation of water quantity and quality of surface and groundwater by mining companies.

These recommendations do not go deep into the theoretical background of hydrology and hydrogeology; rather, they are focused on the design, implementation, and operating procedures of monitoring, as well as the documentation and interpretation of data and conclusions for the water management. Particular emphasis is put on data interpretation.

2. Introduction

Mining and Water

The following recommendations are in regard to groundwater, necessary groundwater drainage in open pit coal mining, and groundwater contact with surface waters.

Classically, the water table is lowered using preliminary drainage, reducing the volume of the groundwater body. Changes in the groundwater composition, such as an increase in the salt or fluorine concentrations, may result. Dewatering of the pit itself follows, which captures the diffuse groundwater and precipitating water influx. The pumped water is partially used as clean process water, such as in dust collection or as water for plants in re-cultivation areas, and is directed either into an artificial lake or into receiving waters. In a few cases, the receiving waters need to be relocated in order to secure the open-pit.

In the rear end of the open-pit mine, as well as in post mining conditions, another increase of the groundwater table follows. The interim introduction of air to the underground area causes geochemical processes to be activated, which result in mostly negative consequences for groundwater quality.

Goals and Outputs of Water Monitoring in Mining Areas

The objectives of the monitoring are:

- Monitoring the safety of the mining operations with regard to water.

  A priority of the mining operations is also to secure the safety of the mining employees. An influx of water can endanger the geotechnical stability of the pit. Data for the groundwater level and incoming water flow is the most important prerequisite for the implementation of water drainage measures and their monitoring. The behaviour of the ground and surface water can be derived from the water monitoring. Through the appropriate water drainage measures, the safety of the mine should be ensured.

- Provide necessary basics for the planning, monitoring, control, and optimization of water drainage measures.

  The mining of resources (coal) in open pits is only possible if the water table is lowered. From the results of the water monitoring, conclusions can be drawn about how the dewatering process can be carried out. In most cases, the inflowing water stream varies with time, for example with seasonal changes, in such a way that the water drainage is controlled. For this control, the results from monitoring are required. Drainage is very cost-intensive; however, with the analysis of the water monitoring data, the drainage process can be optimized so that the accompanying costs can be greatly reduced.

The impacts of mining operations on the evironment are to be minimized as much as possible. That means that avoiding and minimizing consumption are the highest priorities. The contamination of water is to be prevented or minimized by implementing necessary management measures or strategies. One strategy is to reclaim and reuse contaminated water in cases where total pollution prevention is not possible. Treating water that cannot be reused is another example of a strategy for contamination prevention. The discharge or disposal of water is the lowest priority. The implementation of these measures may accompany the monitoring phase or may be carried out after reliable results are obtained.

Fundamentally, the following requirements should be fulfilled:

- A basis for sharing transparent information to the public exists, including warnings for health risks caused by water quality.
- Mining companies should be held responsible for the realization of water protection directives.
- Authorities need to have confidence that the mining companies will work responsibly.
- The public and NGOs should have confidence in the work of authorities overseeing the mining companies.
- Compliance with set standards and legislation, such as Integrated Water Use licenses and Environmental Management Plans, etc., is audited.
- The impacts of the mining operations and activities on the receiving water balance are assessed.
- Various hydrogeological models for prediction and assessment are to be verified and calibrated. This includes planning the financial provisions and required actions fordecommissioning and closure.

The following details regarding water quantity are to be recorded for the understanding, determination, and documentation of the hydraulic system: groundwater levels, flow direction, trends, climate water balance, water users, infiltration into groundwater, input into surface water, groundwater catchment, and the interaction between ground and surface water. Within the framework of water balances, the climatic water balance, the quantity inflowing and outflowing waters, and an estimation of the influence of dewatering are to be taken into consideration for the extraction of the impact of mining activity. After the mining efforts are complete, a steady, self-regulated water balance should be established and managed for the purpose of minimizing water deficits that could arise through the evaporation of surface water.

Within the topic of water quality, the following key points are to be addressed:

- Qunatitative description of the original water quality before the influence of mining activities,
- Quantitative estimation of the impact of mining on the quality of waters (i.e. the change in water quality),
- Understanding of the limits and standards for water discharge quantities and concentrations, as well as the establishment of accurate records for actual discharge values in comparison to these limits,
- Determination of any existing local contaminations, which were not caused by the current mining activities.
- Estimation of hydrochemical processes, both natural and those caused by mining, and

- Quantitative estimation of the future changes and developments to the water quality.

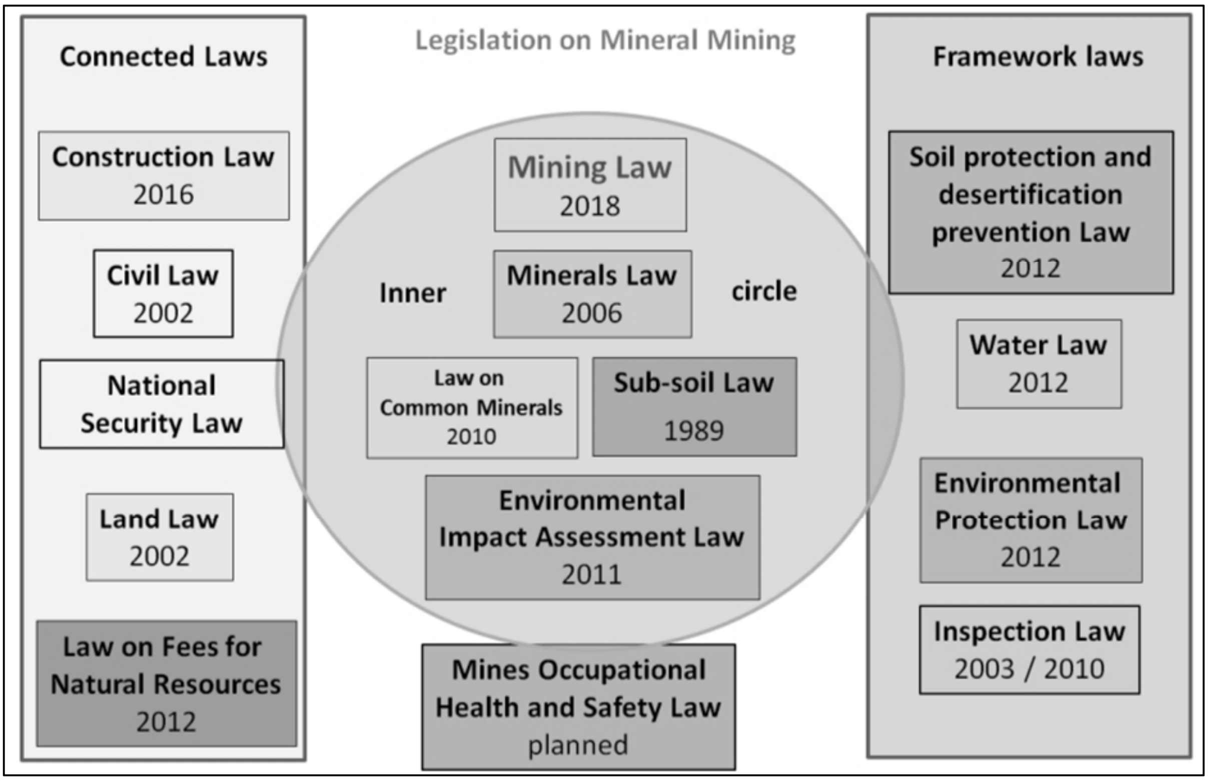
Legal Framework and Standards

In addition to applying for a water license, the mine developers should include a proposal for the monitoring program describing the scope of measurement points, chemical analyses, reporting time intervals, etc. This proposal might be subject for approval and modification by the licensing authority. The final water license states the requirements for monitoring to be carried out.

A summary of the Law of Mongolia on Water is given in Annex IV. The major laws and regulations governing the minerals, mining, and the accompanying environmental obligations are depicted in Figure 1.

Figure 1: Major Laws Related to Minerals and Mining in Mongolia Concerning the Environment

(LMBV mbH)



Regulatory requirements for water monitoring are determined by the following two tasks in most cases:

- monitoring the qualitative and quantitative influence of the measures (e.g. dewatering) on the environment surrounding the mining operation and
- monitoring the effectiveness of the dewatering process to guarantee the safety of the operation.

Requirements and secondary provisions are therefore individually determined by the type of mining, as well as the natural conditions of the catchment and other (potential) users.

Regulations and standards concerning water monitoring and water management are listed in Annex V.

Processes and Outputs of Water Monitoring

Water monitoring is to be conducted throughout the entire mining cycle, which comprises the following phases:

- Feasibility Study and Planning Phase, including exploration (I)
- Operational Phase (II)
- Closure Phase/ Post-Mining Phase (III)
- Post-Operation Phase (after rehabilitation; hydraulic steady state) (IV).

The engineering and consulting services, which are to be developed for water monitoring and integrated water management during the mine cycle, are listed below:

Feasibility and Planning Phase (Before Mining)

An exact description of the initial, unmodified state of the hydrological and hydrogeological conditions is an integral component of monitoring. This description should include:

- groundwater dynamic characteristics: groundwater flow direction, flow gradient, seasonal changes of groundwater levels,
- a full quanititative analysis of groundwater quality,
- surface water characteristics: water levels, flow rates, seasonal variations, and
- a full quanititative analysis of surface water quality.

Because it is impossible to reproduce the data describing the original state after mining has commenced, special attention needs to be devoted to gathering this invaluable information beforehand. The pre-mining monitoring phase should be cover 3 – 5 years to capture data over varying weather and climate conditions. The goal is to establish a local (unmodified) water balance.

Water management practices in this phase consist of:

- evaluation of different process designs, in order to optimize the overall water balance in the affected area, including reuse and recovery strategies,
- identification of potential water sources,
- determination of water quantity and quality requirements based on the different process designs,
- investigation of opportunities for water reuse and recovery,
- development of a strategic plan and measurable performance targets, and
- the combination of all points above into an integrated water management plan.

Here, "process design" refers to the mining companies' individual proposed plans for monitoring, drainage, water use, and mining activities.

Operational Phase

During the operational phase, the impact of dewatering on the groundwater dynamic is to be monitored. This entails monitoring the scope of groundwater extraction, the dimensions of the catchment area, and the drop in the water level (potential level) in the mine and the surrounding areas and, for example, at drinking water wells nearby. The flow rates and water levels of surface waters may also be affected by dewatering procedures. One possible outcome is that a higher surface water flowrate into the aquifer causes the surface water levels or flow rates to decrease. Continuous measurement of all water input and output rates is, therefore, obligatory. The water balances are to be calculated for the operational phase, taking different scenarios with varying extraction rates into account.

Changes of the water quality (e.g. acid mine drainage) may be caused by aeration of the overburden due to the extraction of waters, the infiltration of extracted waters into ground- or surface waters. Continuous sampling and analysis are important in detecting possible changes in the water quality.

Closure Phase and Post-Mining

The post-mining phase can be divided into two sub-phases: the transient phase and the quasi-steady-state phase. The groundwater level (potential level) will rise after dewatering processes are terminated. While a stable water level has not yet been established in this transient phase, continuous measurements of ground- and surface water levels are necessary for monitoring changes and planning required measures accordingly. In the quasi-steady-state phase, a stable water table has again been established and depends, therefore, only on climate conditions, which affect the groundwater recharge rate. The frequency and extent of water quantity measurements may be successively reduced throughout the transient phase if the data shows little to no fluctuation over time.

In many cases, changes in water quality after mining, as well as after dewatering, can be observed. This can often be attributed to chemical reactions between aerated tailings material and water, which might cause acid mine drainage in cases where sulfur-rich material is involved. Dissolution of minerals, i.e. salt, may also have an effect. Special attention needs to be paid to identifying potential reactions such as these in order to prevent or mitigate negative long-term effects.

Preliminary Characterization of the System

A first estimation of the geological, hydrological, and hydrogeological state provides a necessary foundation for the conception of a water monitoring plan. This first estimation relies on generally available data, mostly on the internet, and existing studies or expert opinions over the area being studied.

Basic information about geology, hydrology and hydrogeology exist for nearly each region of the world. While the spatial solution may be very large, it is possible to obtain an overview of important background knowledge, such as sedimentary or hard rock aquifers, existing surface waters, and climate conditions, without any exploration results in most cases. The study of this background information is important for the planning of further geological, hydrological, or hydrogeological investigations. The websites found in Annex III, Table III-1 contain such background information.

In other cases, results of former investigations—such as for draining, water wells, former mines, or the exploration of other resources may exist. The first step is searching for this information. If a mine already exists, any available results, reports, or data should be analysed and interpreted.

One foundation for a model of the hydraulic system is the characterization of the aquifer system by zone. A table like the one in Table 1 can be used to collect and organize relevant information. The following data can help to determine in which areas/zones groundwater bodies are significant: their extent (of groundwater bodies), saturated thickness, estimation of hydraulic conductivity, and porosity. The type of confinement describes how well the upper aquifer is protected from pollution sources at the surface.

Table 1: Characteristics of the Aquifer System per Zone

Zone	Aquifer System Characteristics – Preliminary Estimates						
	Type	**Confined (upper layer)**	**Lateral Extent**	**Total Thickness**	**Hydraulic Parameters**	**Water Table**	**Source of Information**
1	Single/ multi layer	unconfined, semiconfined, confined	[km] & [%] of total	[m]	k_f, n_e, n_o, S, S_o,	[meters above sea level], [meters below surface]	study, report, map, etc.
2							
…							
N							

A preliminary estimation of the original state of groundwater body can be described with support of the following information for each defined zone:

- extent of the catchment basin
- area specific precipitation: annual average, estimation of the climate water balance and information of the groundwater recharge ([l/s/km^2], [Mio. m^3/a])
- total stored volume ([m^3/m^2], [Mio. m^3])
- total abstraction rate of other users in the basin, e.g. drinking water supply ([m^3/d], [Mio. m^3/a])
- estimation of flow rates between ground- and surface water; in-/exfiltration ([m^3/m/d], [m^3/d], [m^3/a])
- Groundwater quality: results of chemical analyses

The impact of dewatering mines into the water cycle can provoke situations of conflict among groundwater users. An initial consideration of potential conflicts (in the frame of groundwater quality and quantity) can be an important basis for planning monitoring programs and water management systems for the mine. The general reference monitoring network (river basin) should reliability depict the groundwater situation on a regional scale. This function covers the natural state, as well as the regional impacts of groundwater use and surface water management. The following table 2 lists information to describe potential conflict situations.

Table 2: Characteristics and Hydraulic Boundary Conditions of the Aquifer System per Zone

In every case: Quantity and Quality; importance (no/little/medium/high), numbers (numbers or non/few/some/many), strengths (none/weak/medium/strong)

Conflict (historical, actual and prospective)	Zone 1	…	Zone N
Surface water measures (rates of infiltration, extraction, changes of the run …) influencing surface water outside of the mine area	Quantity: none/little/medium/a lot Quality: none/low/medium/high		
Surface water measures (rates of infiltration, extraction, changes of the run …) influencing groundwater	same as above		
Dewatering (groundwater abstraction rate) influencing surface water	same as above		
Dewatering (groundwater abstraction rate) influencing groundwater bodies (outside mining area), e.g. water supply wells, irrigation wells, springs, groundwater dependent eco-systems	none/few/some/many		
Mine rehabilitation measurements (irrigation, dump-rehabilitation) influencing ground- & surface waters			

Beside the data research, the evaluation of the results, the robust archiving of all data documents, and the development of a GIS-supported database are recommended, see the following box.

Development of a GIS-supported Database

A suitable tool to develop, show, edit and analysis of spatial information is the software QGIS (QGIS 3.8 Zanzibar); https://www.qgis.org/de/site/ (or: https://www.qgis.org); it's for free a WINDOWS, MAX, LINUX, BSD and next time: ANDROID.

Implement all information about geology (e.g. spatial distribution of aquifers and aquicludes, fracture structures, boreholes) hydrology (e.g. spatial distribution of groundwater recharge, flows, surface water bodies) and the mine (e.g. current state and planned development of the mine, dewatering wells and monitoring wells).

For some information given information see Annex III, table III-1.

Continue filling the database permanently (e.g. with results of drillings, results of the water monitoring).

A further important tool is SAGA-GIS (freeware): http://saga-gis.sourceforge.net/en/ It can be used e.g. for gridding (triangulation, nearest neighbor, inverse distance), access to different files, grid calculator (combine grids through user defined functions; calculation of surface – groundwater – distance), terrain analysis (e.g. flow path analyses) or vector tools like polygon intersection, contour lines from grid (mapping potential lines of groundwater table), simulation of dynamic processes (erosion, landscape development), statistical tools.

3. Definition of Monitoring Objects

The diversity of climates, ecosystems, land uses, different water users, and topography influences the design of a monitoring program. Thus, the resulting monitoring program should be tailored to meet a specific set of needs and expectations of the site and will need to consider regional physical and social factors.

Each of the management actions has unique objectives and monitoring requirements. These objectives should be clearly defined, measurable, and implementable. The development of environmental and water management plans, identification of sources of pollution and assessment of compliance with set standards are examples of typical management actions that require the results of a monitoring program.

Examples of items to be monitored are: groundwater, soil water, surface waters, or other parameters of the water cycle like precipitation, evapotranspiration, and groundwater recharge.

The development of environmental and water management plans may be executed as described in the following box (some of them are taken from **Fehler! Verweisquelle konnte nicht gefunden werden.**). Details are described below.

Steps for the development of environmental and water management plans:

Identification of climatic conditions,

Identification and quantification of all flow rates within the mine,

Developement of a mine water catchment model (balances),

Develop and implement appropriate water reclamation strategies,

Evaluation of the quality and quantity of groundwater from existend monitoring wells and borholes of potential pollution sources,

Definition of key –indicators for potential pollutions and integrate it into the monitoring program,

Definition of requirements on water quality and design methods for the water treatment.

The climatic conditions (incl. measured parameters) can be determined by interpretation of data from existing meteorological observation stations or by installing weather stations (with i.e. rain gauge, thermometer, anemometer, evaporimeter). If the weather station density in the area of interest is too low, the installation of additional measuring stations might be necessary as variables such as rainfall, evaporation, temperature, humidity, or wind may vary significantly across short distances.

The evaluation of groundwater quality and quantity is based on the results of measurements and analysed samples from existing boreholes in the vicinity of potential pollution sources. The definition of key pollution indicators (e.g. sulphate, conductivity for residue deposits, nitrogen and phosphorus for sewage plants, fine coal particle from coal washing) is a part for the development of a monitoring program. Based on these results, pollution sources of the mine can be identified (e.g. residue deposits, domestic waste, landfill, point discharges, sewage treatment plants, processing plants, mine shaft area).

The identification and quantification of all (relevant) water flow rates within the mine is an essential part of water monitoring. This includes the extraction (pumping) rates, discharge rates, and infiltration rates. Knowledge of water sources and sinks (e.g. drinking water wells), including rates outside the mine, are a basis for understanding the hydraulic system.

The identification of current and future water uses and determination of their water quality and quantity requirements are parts of planning strategies. Critical water quality/quantity parameters for all considered water treatment options (in terms of absolute values and variability) are to be defined. Upon evaluation of monitored water quality and quantity parameters, the need for water treatment may be indicated.

4. Groundwater

Use of Existing Groundwater Sampling/Measurement Points

Existing groundwater measurement points should be integrated into the monitoring program, but first, they need to be tested for their functionality. For the initial evaluation of an existing measuring point, the following steps are to be followed, as described in [24].

Research and Compilation of the Existing Base Data (coordinates, elevation, and construction details): The following data are to be sourced and/or measured: bore log, construction drawing, depth, location of the filter section, diameter, drilling method and drilling year, and results of measurements and sampling.

Preselection of Monitoring Wells
Does the observation well represent the point of interest?
Is the diameter of the well tube ≥ 2”? If the tube is too small, sampling and water level measurements are not possible.
Is a clear appropriation to the aquifer given?
Is there free access to the observation well and a right of access given?

To use an observation well, the following questions should be answered positively.

Inspection: of existing monitoring wells
Evaluation of the outer condition and inner condition through the sounding of the bottom and the water level; are they in a suitable condition? If both measurments aren’t possible, the measuring point is probably plugged, meaning that the ability and means of unplugging should be tested.
Is the well made of a suitable material? (For water sampling wells: PE-HD or PVC-U are recommended because some other materials can influence the water quality or the tubes can be influenced by compounds found in the water.)
Is there consistency between researched data and investigation results?
Is it possible to insert a dummy of the sampling pump or data diver?

Infiltration Test for Monitoring wells: The measuring point should be filled with water and time-dependent water level measurements should be taken. If the level of the filled water stays constant for several hours, there is no longer sufficient contact with the aquifer. The measuring point is possibly silted up or the filter crusted over. The measuring point cannot be used for monitoring.

Short Pump Test at the measuring points for water contamination: The groundwater should be pumped out of the measuring point and the characteristic data (water level, electrical conductivity, pH value, temperature, oxygen concentration, etc.) recorded.

Other criteria for the usability of the monitoring points are: location and accessibility, standard-conforming installation, as well as general physical condition, installation, and age of the measuring point.

For a comprehensive functionality test, the processes listed in Annex II, table II-2 is suggested.

Planning of Positions for (New) Groundwater Observation Wells

The monitoring boreholes cannot be randomly located but should be placed at the most suitable location to accurately collect the required data. The groundwater flow directions, vertical limits of different aquifers, depth of the groundwater table, pollution source locations, pollution plumes, etc. all need to be considered. If the measuring points are positioned at the wrong or poorly established (e.g. too shallow) location, the resulting data may lead to incorrect interpretation, and therefore, to wrong decisions.

The exact location of the monitoring points should be clearly marked on a map in such a way that it can be found by an external party. This may be achieved by GPS referencing or by using GIS-software to produce a reliable map with suitable background information such as topography, infrastructure, rivers, or buildings.

For determining locations of monitoring wells, the following points need to be considered.

Monitoring wells for all existing hydro-geologically relevant layers are needed. In the case of a multi-layer system, a group of monitoring wells with different depths of the screens is usually necessary.

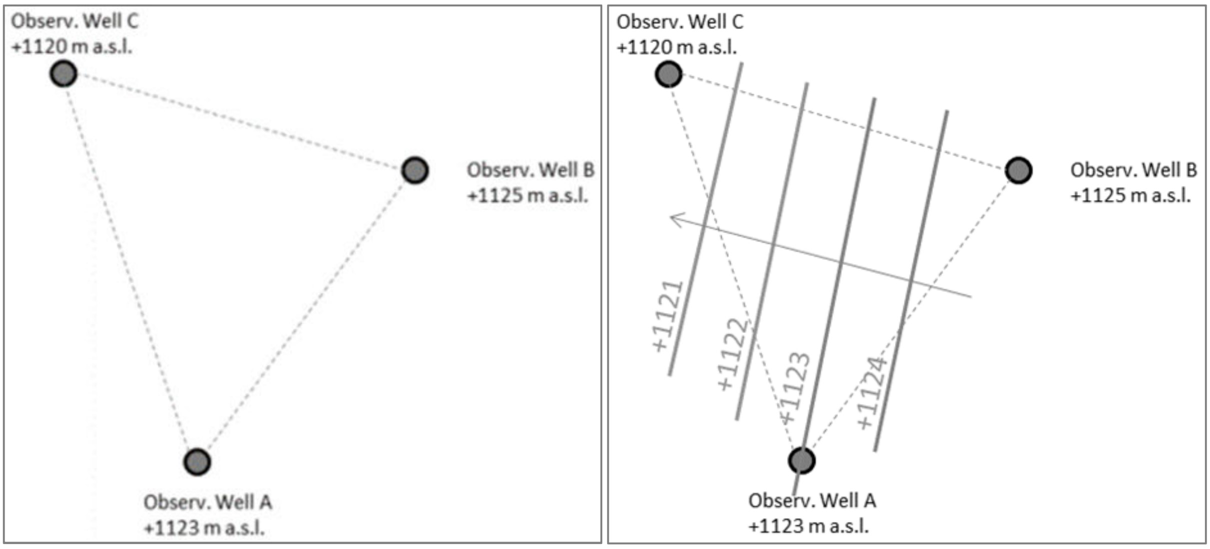
Therefore, measurement points upstream and downstream of the mine are essential (outside of groundwater lowering). Wells should also be placed at specific monitoring objects (e.g. groundwater dependent eco-system, infiltration points, etc.).

Access to all monitoring wells should always be possible.

Wells should be arranged in a triangular manner, as shown in Figure 2, to enable determination of flow direction and construction of hydrogeological maps.

Groundwater flow monitoring is very site specific because it is dependent on the local geohydrology, which may vary significantly from one area to another.

Figure 2: Hydrological Triangle and the Construction of Water Level Lines



Construction of New Groundwater Monitoring Wells

Types of Groundwater Monitoring Wells

Some different types of groundwater monitoring wells are shown in Figure 3 (taken from [16]).

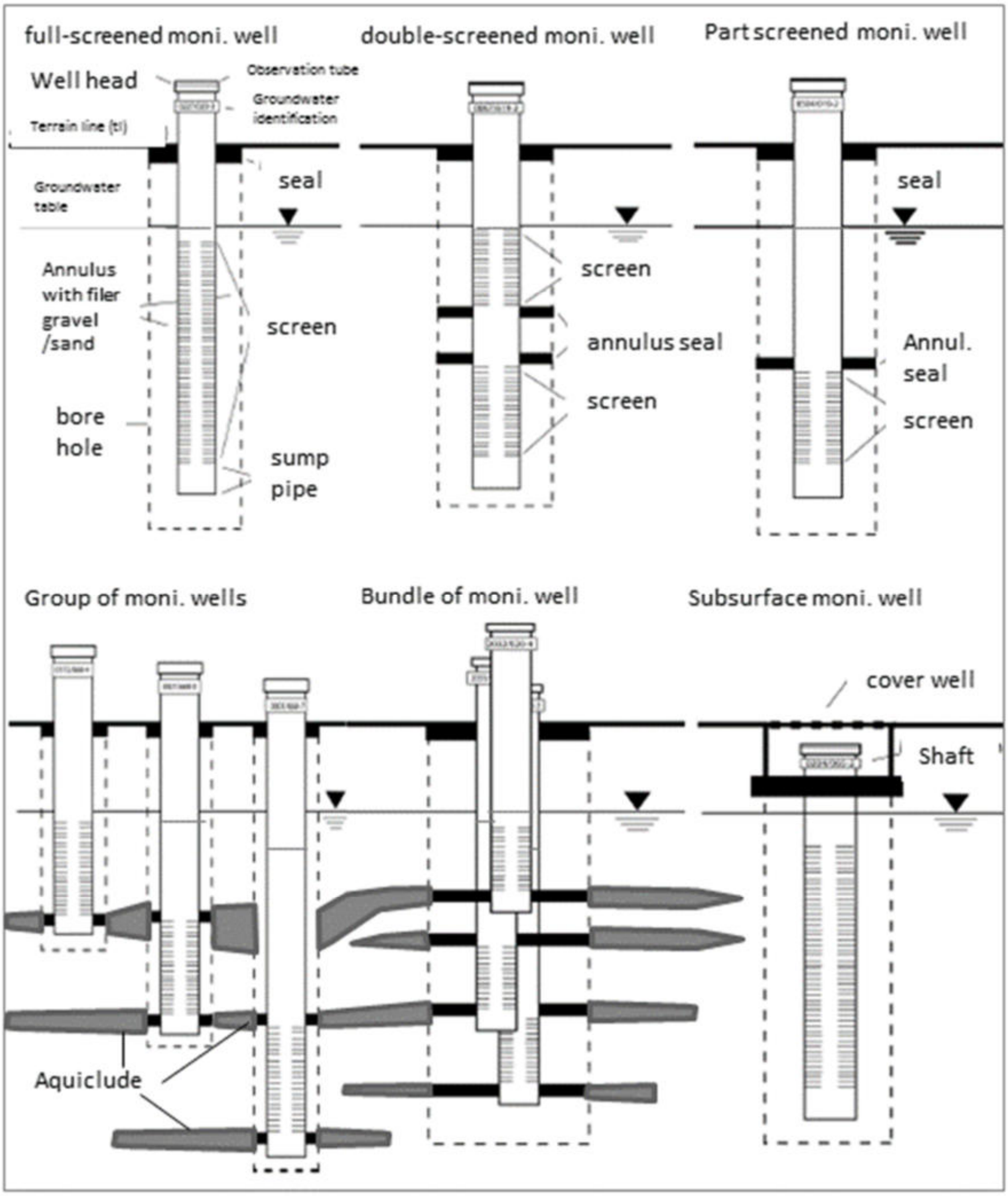
The type of groundwater monitoring well is given by the aquifer system and the task of the well. The following table 3 shows the different conditions and wells.

Table 3: Short Description of Different Types of Monitoring Wells

Type	Application	Limits
Full-screen monitoring wells	Single – layer – aquifer system, screened the whole aquifer thickness, samples are a mixture	Different layers will connect hydraulically; problem in case of different potential levels or different quality types (incl. contamination), depth-dependet sampling is possible with packer-systems only
Multi-screen monitoring wells	depth-dependet sampling is more possible than in case of a full screened well, packer systems are needed	Hydraulic contact of different layers is possible in the well, different level measurements aren't possible
Partial-screen monitoring wells	Different measurements and samples of one specific layer is possible (also in a multi-layer-system)	Gives information about only one of the layers
Group of partial-screen monitoring wells (different boreholes)	multi-layer-system: different measurements (of different water or pressure levels) and samples of the specific layers are possible	relatively high costs (nearly same costs as the bunch of Monitoring wells, but much more valuable than a bunch)
Bunch of partial-screen monitoring wells (single borehole)	multi-layer-system: different measurements (of different water or pressure levels) and samples of the specific layers are possible	Relatively high costs; an accurate construction is very important to prevent hydraulic transfers between the different layers; a large diameter borehole is needed.
Subterranean head monitoring well	Location can be roads, parking etc.	Possible destruction by transport

Figure 3: Different Types of Monitoring Wells

Sources: https://publikationen.sachsen.de/bdb/artikel/23156/documents/31473



Construction Details for Monitoring Wells

Groundwater measuring wells for the measurement of the potential level should be constructed according to the specifications in Annex II, Table II-1 (taken from LMBV mbH: Merkblatt Montanhydrologisches Monitoring 2019).

Recommendation for a Multi-Layer System

Groundwater levels and water quality should be measured for each aquifer seperately in the case of a multi-layer system.

The different aquifers must not be connected, e.g. at the construction of monitoring wells. Aquitards (aquicludes) should be sealed in boreholes by hydraulic barriers like clay seals. Contaminations of the water can be dispersed throughout different aquifers in the case of connected layers. The conditions of flow and pressure can be changed by connecting aquifers. Unregulated water outputs and chemical reactions between water and the rock matrix can be a consequence of connected aquifers.

The construction of measuring point bundles makes an effective hydraulic seal difficult. In the case of different aquifers, the construction of a group of monitoring wells is recommended.

Monitoring Program

Measuring borehole depths and the water levels in them should be a standard part of a groundwater monitoring program. Groundwater levels can be measured using electrical contact tape, float mechanism, or pressure transducer. The following factors must be considered in groundwater flow: topography streams, stream flow, fountains, dams, geology, and excavations.

The usual measurement frequency of the groundwater level and pressure is **once per quarter**, which allows seasonal changes to be detected. However, the frequency of required observation can be different among sites or monitoring wells (e.g. depending on the dewatering wells). The frequency of measurements depends on the type and position of the aquifer, the groundwater dynamic, aquifer development, and climate conditions.

Frequency of measurement should be:

Denser for shallow, unconfined aquifers because the seasonal change of water level is higher than for deeper and confined aquifers,

Denser for rapid groundwater flow (high hydraulic gradient) than for slow groundwater flow,

Denser for more intensive groundwater drawdown (e.g. short distance to the dewatering system) than for less withdrawal and small drawdown (higher distance to dewatering wells),

Denser for more variable climatic conditions (incl. high groundwater recharge) than for less variable conditions (e.g. small seasonal changes).

The frequency should be adapted with respect to these conditions and interpretation of the monitoring results.

Measuring groundwater level is a technical procedure that should be undertaken by a suitably qualified person. The forms found in Annex I, Table I-2 should be used for the documentation of the measurements. The sampling interval should be once per year (March/April) at a minimum. If two samplings per year are possible, the months March/April (1st) and September/October (2nd) are recommended.

Groundwater Sampling

The MNS (ISO) 5667-X, consisting of several parts, is a guideline for taking water samples. The following text doesn't replace this guideline, but it should give some additional, practical tips.

Preparation of Sampling

The technical functionality should be checked according to the device-specific requirements. The calibration of all measuring tools is necessary before every monitoring campaign and during the campaigns in the case of different water qualities. **This is very important because the differences between the true value and the measured values are often surprisingly high when non-calibrated gauges are used.** The calibration and handling are to be carried out according to the manufacturer specifications before each use. Calibration buffers are to be checked regularly and if necessary, are to be replaced, as they have a limited shelf life. The calibration value also is to be corrected according to the temperature dependency of the buffer solution used.

Check-list for the suitability of the equipment:
Is the pump-system complete? This includes a motor-pump with control unit, an electric power-source (e.g. diesel generator) and stand pipes (tubes and/or flexible tubes).
Are all measuring tools calibrated?
Is the pump power (pumping head) sufficient?
Are the hoses and the light cable long enough?
Do the devices meet the quality requirements (purity, cleanliness) of the sampling (also applies for individual sampling)?
Do the necessary filtration units comply with the Equipment Standard requirements?
Are hoses and connectors, reagents, and/or tools suitable for the task in proper working condition?
Are the flagons prepared? Are necessary reagents for sample stabilization and/or necessary cooling elements available in sufficient numbers, see Annex II, Table II-6?
Are the bottles individually labelled with sample number, the monitoring well name or number, sampling date, and sampling campaign name or number? Important additional information should be recorded: the name of the sampler, and the name the laboratory, as well as the parameters to analyse and type of chemical stabilization.
Are the necessary cameras, GPS, master data sheets, sampling protocols, and cleaning equipment on site and ready for service?

Sampling

The following steps are carried out during a groundwater sampling.

(1) Well monitoring:

Samples for water analyses can also be taken from the same groundwater measuring points used for quantity monitoring. Important is, that the pipe can be navigated with a motor pump. Classic sampling motor pumps can be installed in measuring points with two-inch inner diameters (ID). In case of very deep monitoring wells, the pipes can become misaligned in such a way that the pump can get stuck and break off. Before installing a pump, at least one test with a light cable or a dummy should be completed.

(2) Local Findings, Observations at the Sampling Point and the Surrounding Vicinity

- Check of the information on the master data sheet for completeness
- Check the condition and serviceability of the sampling point for visible damage, safety (closeability), cleanliness, corrosion of metal parts, and other changes.
- Check for and document any deposits and incrustations: e.g. precipitations, biota (algae, mold, animals), sediment, etc.
- Check and document any mixed waters: mixture of water of different origin, inflow of foreign water, overflows.
- In principle, gross deficiencies in drinking water supply systems (also in the case of drinking water purposes, used house wells) should be communicated to the operator.
- Document changes since the last sampling: e.g. agricultural activities, earthwork or construction, sedimentation, conspicuous surface use, visible contamination sources.
- Record any other abnormalities: e.g. weathering during sampling, air temperature, precipitation, degree of cloudiness or sun exposure / nuisance dust.

(3) Measurement of Groundwater Level before Pumping

The groundwater level describes a part of the actual hydraulic situation. The results of the sample analyses should be interpreted with respect to the hydraulic situation (e.g. high or low groundwater level). The measurement should continue during the whole pumping duration.

(4) Installation of the Pump

The pump should be installed more than one meter above the screen of the monitoring well.

(5) Pumping and Purging

For pumping, it is important to maintain a continuous moderate pumping rate. Discontinuous pumping can provoke turbulence in the water column of the monitoring well, and if the pumping rate is too high, solid substances outside from screen can enter into the monitoring well. The pumping rate can also be optimized by adapting to the yield of the well. A continuous water level should also be maintained, since the water level must not decrease below the pump and should be at least 1 m above the screen. The inflow of oxygen is to be avoided.

Purging is the process of removing stagnant water from a well immediately prior to sampling, causing its replacement by groundwater, which is representative of actual aquifer conditions from adjacent formations. To determine when a well has been adequately purged, field investigators should monitor (at a minimum) the temperature, the pH, specific conductance, and the turbidity of the groundwater removed during purging. In the case of permanent monitoring wells, they should observe and record the volume of water removed. The ***Purge Volume Determination (V_P)*** is carried out by calculating the hydraulic criteria and by measuring the chemical criteria, see Annex II, Table II-4.

The water should then be released a long distance away of the monitoring well (minimum five meters) after pumping.

(6) On-site Parameter Measuring

- Organoleptic (sensory) data include the qualitative recording of color, turbidity, smell, and sediment. The tests should be carried out in a transparent vessel with a volume of at least one liter, against a white and black background. Abnormalities of the groundwater can already be detected through the optical or odoriferous findings. This data can, therefore, also be used to assess the measuring point or quality of sampling. Dregs from another monitoring well in a pore aquifer can indicate damage to the measuring point.
- The parameters water temperature, electric conductivity (in µS/cm), dissolved oxygen, reduction-oxidation potential, and pH-value are measured by gauges. The use of multi cells is recommended. Otherwise, the use of vessels is possible. The sensors should not be used in the same vessel. The volume of the vessels should be greater than one liter. The measured value must first be read and logged if the display remains stable.

(7) Sampling

It is particularly important that wells be sampled as soon as possible ***after purging.*** If adequate volume is available upon completion of purging, the well is to be sampled immediately. If not, sampling should occur as soon as adequate water volume has recovered.

(i) Charging the Sample Flagons, see also Annex II, Table II-6.

When sampling with a medium or large mobile pump, a bypass with adjustable flow off of the sampling line can be used to fill the sample vessels. The bypass should be installed in front of the on-line measuring instrument, and the line should be purged briefly to remove fluid standing in the line before the sample is taken.

When filling, the sample bottles are to be completely and appropriately labeled. All sample containers not pre-filled with stabilizing reagent are to be rinsed out at least twice before filling. This is done by filling the container approximately 25% with sample water, placing on the lid, shaking vigorously, and emptying. Before closing the sample containers, the closures are also to be rinsed thoroughly. Filling of the water samples must be completed without bubbles and avoiding turbulence. To achieve this, the filling tube should be kept submersed in the sample. Fill the bottles completely and let them overflow several times before closing the bottle. The groundwater sample, thus, enters the sample vessel without contact with the atmosphere.

For vessels containing stabilizers, the hose must not come into contact with the contents of the bottle and with the stabilizer. The filling process is to be interrupted at about two-thirds of the bottle volume in order to distribute the stabilizing agent homogeneously throughout the sample by gently swirling the closed vessel. Then, the bottle can be completely filled.

(ii) Filtration of Samples

For most parameters, analyses are taken using unfiltrated samples. However, some parameters like DOC or metal concentration first require filtration of the water sample. If the samples are to be filtered, disposable filters with a pore size of 0.45 µm and disposable syringes are used. The filters should be rinsed with at least 20 ml of sample water. A membrane filtration device can also be used on site. Filtration is to completed before conservation/cooling in every case.

(8) Conservation and Storage of the Samples

Information as to the conservation and storage of samples is given in Table 9. Without stabilization, the concentration of some dissolved elements can change during storage or transportation (e.g. precipitation of Fe-II as FE-III), causing errors in the laboratory analyses of the solutes.

(9) Transport and Storage of Samples

The temperature during transport and storage should be kept between 2°C and 5°C. A cooling box with cool pads can be used, while freezing of samples is to be avoided.

InfoBox: Water Sampling

Failures in and carelessness during sampling, conservation, storage, and transport of a water sample can change the quality of a sample and change the analysed results. An (expensive) water analysis becomes useless because of this.

The parameters temperature, electrical conductivity, pH value, dissolved oxygen content, and redox potential, as well as organoleptic parameters, must be measured or recorded and documented on site. Results of these measurements in the laboratory do not represent the original water quality.

Proof of compliance with hydraulic and quality criteria should be part of the sampling documentation.

The original documentation of the analysis results should be stored securely and long-lasting.

For additional information see:

https://www.epa.gov/sites/production/files/2015-06/documents/Groundwater-Sampling.pdf

5. Surface Water

Objects of Surface Water Monitoring

Surface water monitoring includes measurements of volumic flow rates and water levels in the mine and the surrounding area. This is necessary to determine the interaction between surface and groundwater.

Surface water monitoring includes the important water flow rates in the mine and the distribution of pumped water (e.g. dusk fixation, irrigation, re-infiltration or output).

In the area directly surrounding the mine, the following measurements are part of the surface water monitoring:

- Delivery rate of a spring: comparing the delivery rate and dewatering of the mine can give information about the impact of mine dewatering to the groundwater and local water balances.
- Water levels of artificial and natural lakes: hydrographs of the lake water level give information about its seasonal changes and the impact of mine dewatering.
- Input and output rates into/from lakes: important for the complete estimation of local water balances and the local water cycle.
- Precipitation and evaporation to and from lakes: important for the complete estimation of local water balances and the local water cycle.
- Rates of surface fluids at different points (e.g. in front of and behind the mine): possible impacts (higher ex-filtration rates from fluids into the underground near a dewatered mine gives information about hydraulic interactions.
- Input and output rates into/from fluids lakes: important for the complete estimation of local water balances and the local water cycle

Monitoring Program

Flow rates of fluids change rapidly with the climate conditions (precipitation, snow smelting). That is why times for measurement can't be predicted exactly. The frequency should be fixed individually and iterative with the results. Measurements under different conditions, such as during dry phase or after precipitation, can give the range of possible rates.

For a lake, water sampling is recommended at the different phases of the circulation of the water body. This means four times per year: spring circulation, begin and end of the summer-stagnation and during autumn circulation.

Water Level Measurement

The level of surface water bodies is monitored by staff gauges (water level gauges), recording gauges, shaft encoders, water level sensing systems, or pressure probes with data loggers and possibly remote data transmission. In order to avoid the influence of waves and wind, all registering water level gauges are to be installed in a dip tube. It is important to regularly check whether there is hydraulic contact between the inside and outside of the tube.

Figure 4: Examples of Water Level Gauges for Surface Water

Basis data for each water level gauge include the coordinates (x, y) and the level of the reference point (z, m a.s.l.), see Chapter 6.

Flow Rate Measurement

Two groups of flows are to be differentiated: the gravity flow in partially filled pipes, channels, and streams and the pressurized flow in discharge pipes. A second differentiation is possible between direct and non-direct measurements. Flow rate measurements are just one part of water monitoring in mining areas. Therefore, only a small part of the wide range of methods is presented in these recommendations.

Gravity Flow

Area-Velocity Technique, Non-Direct Flow Rate Measurement

Float Method:

The most common technique consists of calculating or estimating, respectively, the cross-sectional area and measuring the flow velocity. The latter can be determined by different methods, such as the float method. By observing a floating object on the surface of a water body, the flow velocity at the surface can be measured. The equation $v_{mean} \approx 0.85 \cdot v_{surf}$ yields an estimate for the average flow velocity [(Gunston 1998)]. The measurement of the velocity is more sophisticated for defined areas.

Flow Meter Method:

Quantification of the flow rate requires (a) the determination of the flow-profile and (b) measurement of the flow velocity using an inductive flow meter over the entire flow cross-section. Based on the flow velocities (v_i) in the individual profile segments, the flow rate is then calculated by:

$$Q = \sum_{i=1}^{n} A_i \cdot v_i$$

The measurement profile is recorded using measuring slats or the folding rule. The bar is placed above the water on both sides of the embankment, as shown in Figure 5. With the folding rule, the depth of the water is registrated over the entire cross profile. Each section of the profile can then be assigned a flow rate.

Figure 5: Velocity Measurement

Non-direct Flow Rate Measurement Using a Weir

Estimation of flow rate using water level and physical relations for defined profiles are described in Annex II, Table II-3.

Figure 6: Example of a Triangular Weir

Direct Measurement by the Bucket-Method

A cheap and simple alternative is to use the bucket method. If the discharge of the surface water can be captured in bucket for X units of time and the captured volume determined, the flow rate can be calculated rather easily. However, automation is not possible in this case. Use of this method is only valid if the bucket or vessel is large enough to collect the whole volume over the measurement time period.

Dilution Methods

By adding a known concentration of tracer (e.g. salt or dye) into a stream and measuring its dilution after it has been fully mixed with water, the discharge can then be calculated using the following formula:

$$Q = q \cdot \frac{C_1 - C_2}{C_2 - C_0}$$

Q stream discharge

q tracer injection rate

C_1 tracer concentration in injection

C_2 final concentration of tracer in the stream

C_0 background tracer concentration in stream

Special attention has to be paid to the selection of an appropriate tracer. It should not react with any substances present in the water and should not be taken up by sediment or organisms. Commonly, sodium chloride salt or rhodamine dye is used. Note that for certain tracer substances, special permits by the local environmental agencies might be needed.

Manning's Equation

The Manning Method can be used for open channels and partially filled pipes for non-pressurized fluids in gravity flow. This method is widely used for flow measurements because it is easy to use after a few initial measurements have been made, and it provides fairly reliable site discharge estimates.

Official requirements state that the channel should have a uniform cross section, slope, and roughness within the vicinity of the measurement. In addition, the pipe (or channel) should be at least 30 meters long and should not have any rapids, falls, or backup flow. For ecological purposes, an eight-meter-long channel or less would probably be sufficient, as long as the water is flowing evenly.

The equation requires obtaining values for the roughness of the channel (determined from standard tables), the cross-sectional area of discharge flow, the hydraulic radius (cross-sectional area divided by the wetted perimeter), and the slope of the gradient. Since the slope and roughness are constants, once they are known, future flow estimates can be calculated by simply measuring the depth of the discharge in the channel or pipe.

Estimation of the flow rate using water level and physical relations for defined profiles are given in Annex II, Table II-3.

Flow Measurement in Open Channels

By employing level measurement over specially designed and constructed open flow channels, it is possible to calculate flow rate as a function of fluid depth. In many cases, fluid flow around a mine is by means of open channels and the flow measuring techniques developed for piped flow are thus unsuitable. The requirements in terms of channel shape and applicable equations are also discussed as these are necessary in the conversion of a level measurement to a calculated flow rate.

Pressurized Flow

Pressurized flow can be measured by magnetic flow meters or ultrasonic flowmeters, for example. Magnetic flow meters require a conductive fluid and a non-conductive pipe liner. The electrodes must not corrode in contact with the process fluid; some magnetic flowmeters have auxiliary transducers installed to clean the electrodes in place. The applied magnetic field is pulsed, which allows the flowmeter to cancel out the effect of stray voltage in the piping system.

Surface Water Sampling

Sampling points of surface water are given by the water management system of the mine. This can include: water bodies in the open-pit, collection deposits of water, water storage facilities, treatment facilities for water re-use, springs, channels, or other flows.

Surface water sampling is regulated by MNS (ISO) 5667-4:2001 Water Quality. Sampling. Part 4. Guidance on sampling procedure of natural lake and reservoir.

In case no information indicating a specific water quality level is available at the beginning of the monitoring program, a case-specific set of analyses should be conducted. This procedure should be applied to all initial measurements until the scope can be better defined. Examples of possible sets of analyses for the “0-measurements” are shown in Annex II, Table II-5.

Some of the steps are similar to groundwater sampling and are described in Chapter 4. The others are described below.

Local Findings

Observations concerning the following characteristics should be recorded for the area at and directly around the sampling point. This information may explain results of water analyses or may provide information about existing chemical processes.

Checklist of local findings at surface water sampling locations:
Check the information in the master data sheet
Reduction spots: darkening on the underside of stones as an indication of poor oxygen availability and consequent reduction processes,
Oil film (visual control), foaming,

water level, runoff, retention,

frozen water table,

changes since the last sampling: e.g. agricultural activities, earthworks or construction, sedimentation, conspicuous surface use, visible contamination, changes in banks, foreign matter, sewage, foam, discharges, discharges,

other abnormalities; water level development, substrate, sediment,

biocenoses, e.g., waterfowls

weather during sampling, e.g. air temperature, precipitation, degree of cloudiness or sun exposure

Taking Samples

In the case of surface water, local representatives should be careful not to detect wastewater plumes, dead water zones, or returbulence. Rather, the site to be sampled should be where the largest mass transport is to be expected or where the flow rate is about 1 m/s when sampling from the embankment. On the one hand, for safety reasons, entering the water body should be avoided as far as possible, in order to prevent sedimentation.

Water samples from running waters should be taken as single samples using scooping devices. The appropriate sampling equipment is to be thoroughly rinsed with the water to be sampled several times in advance. When sampling bridges and the like, care should be taken that no contaminants get into the scoop. When removing, the water bottom should not be touched with the scooping device in order to prevent the sediment being stirred up. Likewise, the sampling of floating materials should be avoided.

The sampler should be submerged in the upper third of the water body depth (or if necessary, approximately 5-30 cm below the surface of the water). The opening of the ladle or sampling vessel is held in the direction of flow. If several scooping processes are required to fill the sampling containers, the homogeneity of the sample must be ensured.

In the case of lakes, individual samples from several depth stages are to be taken at the measuring points for the analysis of the chemical parameters depending on the different seasonal circulation-stagnation-phases.

6. Data Management

Complete, comprehensive, and transparent documentation of data is one of the most important parts of the water monitoring. All data about the drilling, the construction of monitoring wells, surveying, water level and discharge measurements, sampling, and laboratory results are to be documented. The following tables show the main information for the different processes. Additional information and forms are given in the Annex I.

Table 4: Example for the Documentation of the Measurement of Groundwater Levels

No./ Name	Coordinate Easting	Coordinate Northing	level of the head of the tube m a.s.l.	level of the top of the screen m a.s.l.	level of the bottom of the screen m a.s.l.	bottom of the monito-ring well m a.s.l.	date of the measure-ment	depth of the water table [m below top of the tube]	water level, press-ure level m a.s.l.
44-XY-4	1083312.0	4997511.0	1104.1	1084.0	1080.0	1078.0	01.04.2010	14.20	1089.92
44-XY-4	1083312.0	4997511.0	1104.1	1084.0	1080.0	1078.0	29.09.2010	14.50	1089.62
…									
44-XY-4	1083312.0	4997511.0	1104.1	1084.0	1080.0	1078.0	29.03.2017	19.10	1085.02

The required data for each groundwater monitoring well is given in Annex I, Table I-1. The water level measurements for surface water bodies can be documented in the same way. Table 5 contains the required information for the measurement for water levels and flow rates, as well as for surface water sampling. The table is to be adapted to the type of surface water.

Table 5: Example of a Documentation of measurement point for the Flow Rate of Surface Water

Item	Unit	lake, pond	Fluid	Remark, Example
Details about the measurement point				
ID (station identification number)		x	x	Unique code system; (for whole Mongolia)
Monitoring ID Number		x	x	Specification for the Monitoring Program for the mine xy
Type of measurement point		x	x	Example: weir, staff gauge, vane
Type of measured data		x	x	Flow rate
Owner of the station		x	x	Mine, basin, ministry…
Name of the water body or fluid		x	x	
Location				
Aimag, town/village, location name, location description		x	x	Link to the photos of location
East Coordinates	(m)	x	x	Mongolian grid system
North Coordinates	(m)	x	x	Mongolian grid system

Item	Unit	lake, pond	Fluid	Remark, Example
Elevation	m a.s.l.	x	x	Terrain elevation of the monitoring station, type of elevation determination, e.g. single instr. GPS, differential GPS, estimation from topographical maps
Elevation of the reference elevation for the measurement point	m a.s.l	x	x	
Bottom of water body	m a.s.l.	x		
Water level or flow rate measurement				
Water level	m a.s.l.	x	x	
Average depth of the fluid/water body	[m]	x	x	
Average width of the fluid/water body	[m]	x	x	
Flow rate	l/s, m^3/min		x	
Measurement range	[m], [L · s^{-1}. m^3 · min^{-1}]			
Frequency of Measurement				1/Month, 1/Quarter
Average Velocity Curve; exists		x		yes/no
Sampling				
Type of sampler		x	x	Boat, vessel
Program of sampling:		x	x	Spring circulation, begin/end summer stagnation, autumn circulation
Depth(s) of the sample	m	x		
Date of (last) sampling		x	x	
Contamination	yes/no	x	x	
Frequency of sampling		x	x	
Remarks		x	x	(no access possible, fluid is dry, lake is frozen)

Documentation for groundwater sampling is given in Table 6. Annex I, Table I-2 contains a form for the documentation of the groundwater sample.

Table 6: Example for the documentation of the Water Sampling

Item	Unit	Remark
Name		
ID (station identification Number)		Unique code system; (for whole Mongolia)
Monitoring ID Number		Specification for the Monitoring Program for the mine xy
ID/Name of the borehole		
Type of the measurement point		Example: weir, staff gauge
Type of measured data		Flow rate, water level
Owner of the station		Mine, basin, ministry…
Location		
Aimag, town/village, location name, location description		Link to the photos of location
East Coordinates	(m)	Mongolian grid system
North coordinates	(m)	Mongolian grid system
Elevation	m a.s.l.	Terrain elevation of the Monitoring station, type of elevation determination, e.g. single instr. GPS, differential GPS, estimation from topographical maps

Item	Unit	Remark
Elevation of the reference elevation for the measurement point	m a.s.l	
Depth of the monitoring well	m	depth below terrain elevation
Depth of the screen(s)	m a.s.l.	
Connected Aquifer		
Sampling		
Sampling date		
Static water level	m a.s.l.	before purging
Static water level	m a.s.l.	after purging
Type of purging		pump (specification, example grundfos MP1), gathering pallet
Depth of pump setting		
Time Start/end, duration	Min	
Discharge during sampling	$l \cdot min^{-1}$	
Sampling device		
Field measurements		
EC	µS/cm, mS/cm	
pH		
Redox	mV	
O_2	$mg \cdot l^{-1}$	
T	°C	
Color		
Turbidity	NTU, verbal description	
odor		fresh, putrid, septic, medicinal, sulfur, chemical
Sample treatments		Filtration method, mesh size
Sample conservation		Cooling to +4°C, freezing to -20°C
storage		Location/duration/conditions of storage
Designation/description of samples		Example: Sample-ID: 1240/I Well-ID: xc-03-1482 Date: 2017/09/15 Additions: HCO3 Analysis of Fe-II
Laboratory		Name/analysis date/ lab identification No./
Analytical methods/ standards		
Analysis results entered		Name/date/file

Remark: Documentation

The high costs of monitoring require that the data be used for multiple purposes. Therefore, all results of the monitoring (water level, flow rate, water analysis) must be clearly assignable to a date and a location (x, y, z) as well as to the water body or aquifer, and archiving the data has to be robust. Because mining is a very dynamic process, lost or unassignable monitoring data is not reproducible and therefore not replaceable.

7. Interpretation and Analysis of Monitoring Results

Validity Check, Visualization, and Interpretation of Water Level Measurements

Validity Check

The purpose of the validity check is to compare with previously collected values (hydrographs) with the construction details of the observation well. Extreme values, conflicting values, and outliers can be caused by incorrect metering of the water depth (reading error). Comparison with former values would show a difference in this case. The difference is an even value in case of a reading error, and the data can be adjusted in some cases. Secondly, the development of mines and dumps may require a cut of the observation well. If a change in the reference point (head of the observation well) is not taken into account, the hydrographs show a step of the values. These values have to be adjusted by the difference of the elevation of the well head. Finally, if the groundwater level is below the screen, the measured water level shows the water in the sump pipe of the observation well. That means the well is dry and the values are invalid.

The quality control of the data is of enormous importance. Flawed data can lead to wrong conclusions (for example concerning mine safety) and thus to wrong decisions or implemented measures!

Visualization of Monitoring Results

Hydrographs

Hydrographs are plotted values of the water level versus time. The water level is shown as meters above sea level (m.a.s.l.). The plot can be created using basic software (e.g. MS Office). Time-related changes of the water level can be detected by graphing. It may be useful to plot the water levels together with the graph of the climate water balance or graphs of groundwater abstraction (dewatering of the mine). The measured values can be used directly.

If there is a density difference of the liquid medium (e.g. very high salinity of the groundwater) a conversaion into fresh water levels is necessary, using the following formula.

$$h_{fresh} = HSW \cdot (\rho_s/\rho_f)$$

where h_{fresh} is the equivalent fresh water column [m], HSW is the length of saline water column above reference level [m], p_s is the density of saline water [kg/dm^3], and ρ_f is the density of fresh water [kg/dm^3]. Flow rates or water levels of surface water can be plotted as hydrographs as well.

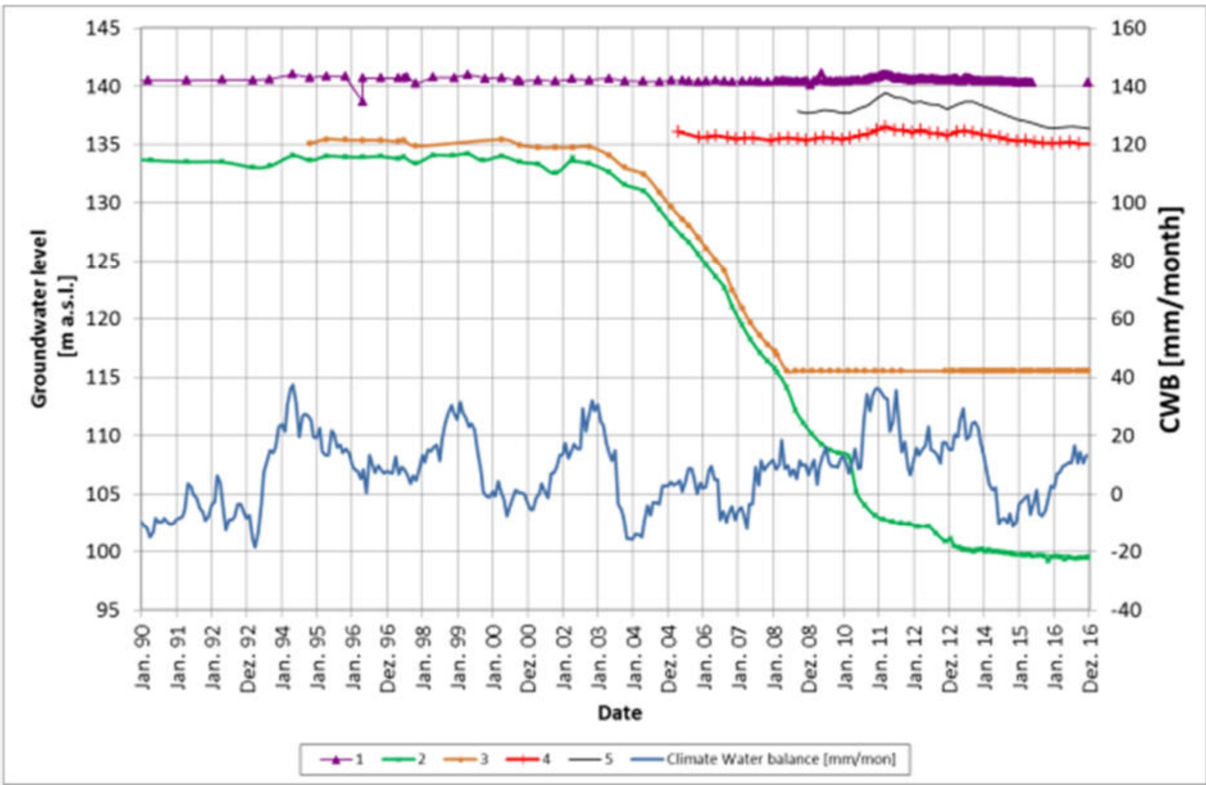
Example: Interpretation of Hydrographs

The following figure (Figure 7) shows some hydrographs of different groundwater monitoring wells around a dewatered coal mine together with the values of the climate water balance (CWB). The values of the groundwater level are shown on the left axis and the values of the CWB on the right axis.

As shown in the Figure 7, the water level of monitoring well 1 is stable. The value of March 1996 is an error (outlier), which should be corrected. Values during the time between June 2015 and November 2016 are missing. Monitoring Well 1 is screened in the upper aquifer in our case. That means this upper aquifer is protected from dewatering of the mine by natural hydraulic barriers (aquiclude).

However, the graphs of the monitoring wells 2 and 3 show a significant drawdown (>30 m) since 2003. These monitoring wells represent the deeper aquifer, which was dewatered. The hydrograph of the monitoring well 3 has been stable since March 2008. At this point, there was no more groundwater in this well. The groundwater table was either deeper than the monitoring well or deeper than the screen of this well. The values since March 2008 are not useable.

Figure 7: Example of Water Level Hydrographs



Monitoring wells 4 and 5 are located at a large distance from the mine (>5km). The water level is directly influenced by the groundwater recharge, specifically by the CWB. The highly positive CWB during 2010/2011 and 2013 caused higher groundwater levels. The hydrograph of well 5 shows a small drawdown in 2014 and 2015. The aquifer near well 5 could be affected by mine dewatering.

Mapping of Contour Lines

A water-level contour map is a common tool used by hydrogeologists to indicate groundwater flow directions and the hydraulic gradient, as well as to test the continuum approach. From field measurements of static water levels in wells, a water level contour map can be constructed. Anomalously high or low water levels and jagged or discontinuous contours may be evidence that the continuum approach is not legitimate. Water flow directions aid in the delineation of the source water protection area.

If there is hydraulic contact between surface and groundwater, the surface water bodies are to be considered in the contour maps. This applies for standing water bodies and for flowing water. Knowledge of surface water levels is required. The basis of the water body added to an estimated water level can be used in the case of flows. The potential level (pressure level) is used in the case of a confined aquifer. It is also standard to use special software (e.g. SAGA GIS, see below) for designing contour lines. A manual design of these lines, however, is also possible.

Mapping the Depths to the Water Table

Mapping the depth of the water table is important for: (a) regions with different groundwater users with wells that are screened at different depths, (b) when a hydraulic interaction between surface water and groundwater occurs, or (c) in regions with small distances between terrain surface and the groundwater table. Levels of the terrain, levels of groundwater, and special software (e.g. SAGA GIS, see below) are required for creating a map of groundwater depths.

Mapping of Table Differences

Maps of groundwater level differences are a suitable tool for showing the impact of mine-dewatering on the aquifer. The groundwater levels in the monitoring wells at different dates are the base for mapping these differences.

Mapping of Monitoring Results:

Contour lines describing groundwater level or potential are a suitable tool to plot the dynamics of groundwater; results are: the direction of groundwater flow and the hydraulic gradient.

Mapping contour lines should be done for the state before dewatering activities starts and for each year afterward (measured in the same month).

Groundwater level difference maps are a suitable tool to illustrate the effect of mine dewatering on the aquifers.

Suitable reference states for mapping of table differences are: (i) state before dewatering activities and current state, (ii) state of previous year and current state, (iii) current state and prognosis state (based on the calculated state from the model), (iv) state before dewatering activities and prognosis state, (v) state before dewatering activities and after dewatering, including completed groundwater increase.

If different data sets (measurements, model results) are used, possible deviations must be explained and discussed.

A suitable software (freeware) is SAGA-GIS: http://saga-gis.sourceforge.net/en/

Interpretation of Monitoring Results (Water Level, Flow Rates)

Establishing a hypothesis can support the interpretation of monitoring results. For the monitoring of mine dewatering, such hypotheses can be the different drawdowns of the groundwater level or a decrease in the flow rates of fluids because of higher infiltration rates. The climate situation during the monitoring period also is to be focus and part of the interpretation. Changes of groundwater level can be caused by different rates of groundwater recharge as a consequence of different climate conditions.

Table 7 contains different types of hydraulic conditions. The quantification of these conditions can aid the interpretation of the monitoring results.

Table 7: Overview of Hydraulic Conditions

Hydraulic Conditions	Method for Quantifying
Precipitation	Online-Data from climate stations, measurement of precipitation
Evaporation	Online-Data from climate stations, measurement of evaporation from water bodies
Development of the mine	Areas of claim (extensions, date), Interpretation and reports of monitoring results should include the development of the mine during the monitoring period. The spatial development of the dewatering (construction of well galleries) is to be documented.
Development of the dewatering system of the mine (well galleries, pumping from ponds)	Rate, well-specific (location, depth), breaks of dewatering, begin and end of dewatering
Use of the water in the mine (process water, e.g. dust fixation, irrigation)	Rates (Specific for location and date)
Water abstraction outside of the mine by other users (e.g. water supply for livestock)	Rates (Specific for location and date)
Water infiltration (into the Aquifer) or input (into lakes or ponds)	Rates (Specific for location and date)
Rates of fluids around of the mine Groundwater levels in and around of the mine	Measurement of flow rates Monitoring groundwater, designation of water divides

Evaluation of the Hydraulic System

The hydraulic system of the mine is to be described and quantified. Parameters for the hydraulic system include water in- and outputs, dewatering, precipitation, and evaporation, among others. Water balances should then be established.

The measurement, estimation, or calculation of parameters in the water cycle allows the determination of the CWB. The following equation describes a local water cycle:

$$0 = P - ETP \pm Q_{in/out} \pm \Delta S$$

where P is precipitation; ETP is evapotranspiration; $Q_{in/out}$ are runoff, recharge, in- and outputs (e.g. from wells); and ΔS is the change of storage volume. The difference of precipitation and evapotranspiration is called climate water balance (CWB):

$$CWB = P - ETP$$

The equation of the water cycle can be written as:

$$0 = CWB \pm Q_{in/out} \pm \Delta S$$

Dimension of the Catchment Area (Subterranean Basin):

The dimension of the catchment area is given by the following equation.

$$A_{catch} = Q_{Out} / GWR$$

where A_{catch} is the area of the catchment area [m^2], Q_{Out} the volumetric dewatering rate of the mine [m^3/s], and GWR is the groundwater recharge [$m^3/(m^2\ s)$].

Validity Check, Visualization and Interpretation of Water Quality Measurements

1. Assessment of Outliers

Issue: Validity check of analyses results

Goal: Outlier; change of water quality, sampling or analysis errors

Data Requirements: Time series of chemical parameters, including electrical conductivity, pH, and plotted concentration vs. date of sampling

Method for the Interpretation of Deviations in a Time Series of Water Analysis Results

The quality of waters can naturally change over time or can be impacted by human activities. Concentration differences lower than 25 % are natural in most cases. If the difference is greater than 25 %, the following causes are possible: (a) a serious change of water quality based on human activities, (b) an error in the sampling or transport of samples, or (c) an error in the laboratory analysis.

Methods for Comparison with Other Parameters

Comparison with other parameters, such as electrical conductivity and pH-value, gives two possible results: 1) In the case where the other parameter values have also changed, that means the change of water quality is real or the sampling was erroneous, or 2) If one of the other parameters didn't change, the analysis of the sample may have been erroneous. The search for errors can be identified by conducting laboratory quality assurance checks and repeating the analyses for a retained sample. If the results of the repeated analysis show the same result, the sampling is to be repeated a third time. The water of the sample is to be analysed at two different laboratories. If these results yield the same concentration, there has been a change in the water quality.

Result: This method can estimate if a measured value (an outlier) is correct, indicating a change of quality of water, or if the result is an error of sampling or analyzation.

Source: DGFZ e.V., Dresdener Grundwasserforschungszentrum e.V. (GERMAN)

2. Exclusion of Ion Concentrations

Issue: Validity check of analysis results

Goal: Plausibility checks of analysis results

Data requirements: Analysis results of: O_2, Fe^{2+}, Mn^{2+}, Ca^{2+}, Mg^{2+} NO_2^- , NH_4^- , H_2S, NO_3^- , pH-value (doesn't need to be complete)

Method

The following concentrations exclude each other:

O_2 > 5 mg/l exclusion of: Fe^{2+}, Mn^{2+}, NO_2^- , NH_4^- > 0,05 mg/l, H_2S >0,01 mg/l

Fe^{2+} > 0,2 mg/l exclusion of NO_3^- > 2,0 mg/l

Mn^{2+} > 0,2 mg/l exclusion NO_3^- > 2,0 mg/l

H_2S > 0,1 mg/l exclusion Fe^{2+} > 0,1 mg/l and Mn^{2+} > 0,2 mg/l

8,0 > pH > 5,5 exclusion of Ca^{2+}, Mg^{2+} > 1 mmol/l.

Result: This method estimates if analysis results are correct.

3. Charge Balance Error (CBE)

Issue: Validity check of analysis results

Goal: Check of analyses results or completeness of analyses

Data requirements: Analysis results of all anions and cations with relevant concentrations; expressed in mol(eq)/L

Method

One fundamental law of nature is that aqueous solutions (like water) are electrically neutral. This means that in real solutions, the total sum of all the positive charges (cations) must equal the total sum of all negative charges (anions):

$$\text{Charge Balance: } \sum \text{cations} = \sum \text{anions}$$

Analytical errors and/or unanalyzed constituents cause electrical imbalances. One way to quantify this imbalance is the charge balance error in percent:

$$CBE = (\sum \text{cations} - \sum \text{anions}) / (\sum \text{cations} + |\sum \text{anions}|) \times 100\%$$

Interpretation of the Charge Balance Error (CBE)
CBE > ± 5%; analysis is incomplete (major ions are not measured) or incorrect; the analyses are to be repeated, including those of additional (relevant) ions.
negative CBE: higher concentration of anions than of cations (not all relevant cations are analyzed)
positive CBE: higher concentration of cations than of anions (not all relevant anions are analyzed)
using *unfiltered* samples that contain particulate matter which dissolve upon addition of acid (for preservation purposes)
A suitable software-tool (freeware) for calculating CBE is https://www.lenntech.com/calculators/accuracy/accuracy-water-analysis.htm.

4. Additional Validity Checks

- Correlation of redundant parameters are to be given: e.g. pH value or electrical conductivity field measurement with laboratory measurement.
- Correlation of related parameters should be given: e.g. electrical conductivity and concentration of sulphate.
- The hydrochemical plausibility should be checked: pH and concentration of the metal ions.

Chemical Characterization of Groundwater

The composition of the water is determined by the natural geogenic environment of the water sources and chemical or biochemical reactions. Knowing the sources of abstracted waters is important for understanding the hydraulic system. Possible sources may include: precipitation waters, infiltrated waters from surface water bodies, infiltrated waste water, recharged groundwater or fossil groundwater. The following section shows some possibilities for visualization of analyzed data from water samples. This visualization allows the classification of different water samples based on sources. A special tool is the analysis and interpretation of isotopes. An estimation of the age of groundwater is possible with the results of this analysis. For more information on this topic, consult the corresponding literature.

1. Classification of the Water Sample by the Electrical Conductivity

Data Requirements: Measured electrical conductivity

<u>Method</u>

Comparison of the measured values of the electrical conductivity with values from Table 8.

Table 8: Conductivity for Different Types of Water

Type of Water	Electrical Conductivity [µS/cm]
“pure” water	0,055
Distilled water	<3
Precipitation water	5 - 100
(natural, uncontaminated) groundwater	100 – 1900
Drinking water	150 - 800
Mineral water	150 - 2000
Sea water (salt water)	Round about 50 000

Result: Information about the source of a water sample, classification of different samples.

Graphical Tool for the Interpretation of Chemical Analyzes

The use of graphical tools can help illustrate the different types of water. Different types of water can indicate different sources (e.g. catchment areas, different aquifers, fossil groundwater).

1. Schoeller Plot

Issue:	Visualization and classification of water analysis results
Goal:	Classification of different water samples into groups
Data requirements:	Analysis results of anions and cations of diverse samples; expressed in mol(eq)/L, (advantage: analyses can be incomplete).

Method

Major ion analyses (in milliequivalents per liter) can be plotted semi-logarithmically to indicate different hydrochemical water types. This plot is called Schoeller-plot. The plot has the advantages that, unlike trilinear plots, incomplete analyses can be used and real parameter concentrations are displayed.

Result:	Information as to whether there are the same or different (different sources) types of water for different samples

2. Piper's Trilinear Plot

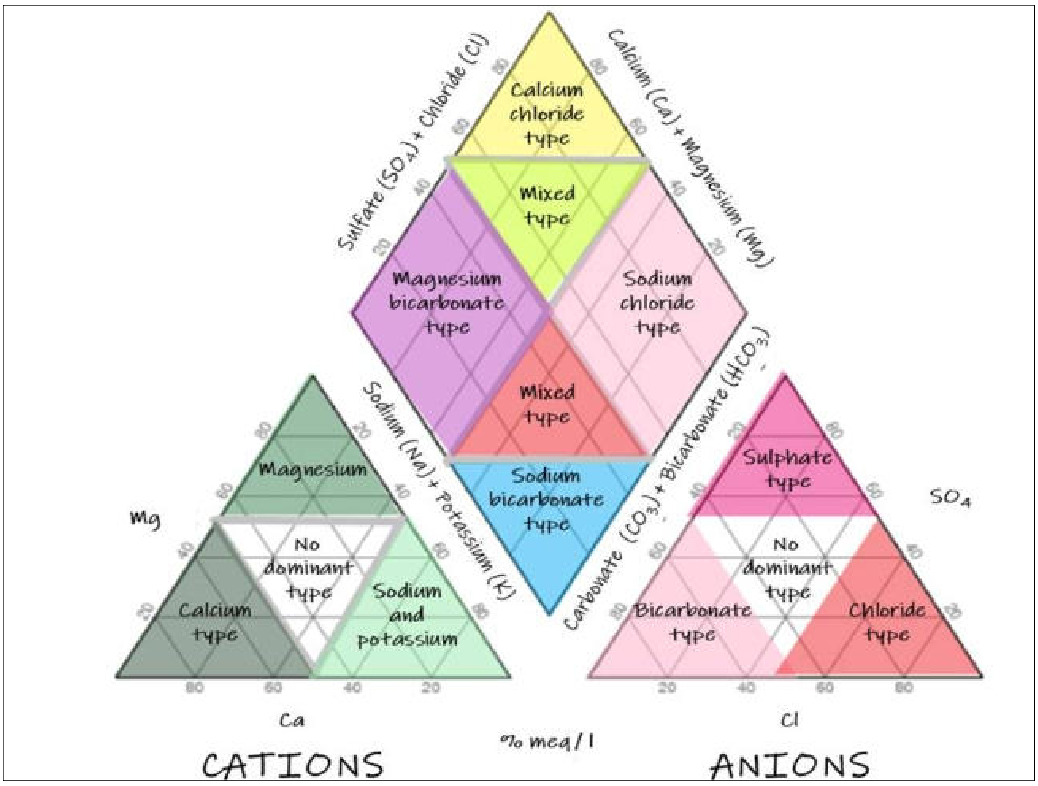
Issue:	Visualization of results from water analyses, classification, typecast
Source:	GW-Chart (Freeware: https://water.usgs.gov/nrp/gwsoftware/GW_Chart/GW_Chart.html)
Goal:	Classification of different water samples into groups.
Data requirements:	complete(!) concentrations of Calcium, Sodium, Potassium, Magnesium, Chloride, Sulfate, Hydrogen Carbonate, and Carbonate expressed in mol(eq)/L
.	Carbonate can be calculated by the software itself using the water temperature. The TDS (total dissolved solids) are also respected in the calculation. The TDS-value can estimate by 0.5 · electrical conductivity.

Method

To see the changes in groundwater chemistry at different locations and the extent of water rock interaction, data for the ionic composition of the water samples were plotted for both the time periods using a Piper Trilinear diagram, as shown in Figure 8. Piper Diagrams are broadly used in hydrogeology as they illustrate the hydro-chemical characteristics of groundwater by representing the percentage of anions and cations (in meq L^{-1}) in separate triangular diagrams. Geochemically-similar waters are clustered in clearly defined areas, which indicates water mixing phenomena, precipitation, dissolution, etc. The piper diagram can also be plotted with the help of software.

Figure 8: Classification by Piper Plots

Source: https://www.hatarilabs.com



Result: Information about the type and source of water for different samples

Presentation of Data using the Valjashko Diagram

A system for the representation and classification of groundwater based on the ratio of the mean ions and their hypothethesized dissolved salts on the basis of the publication by Valjashko (1961) offers information on the origin of the water. Compared to other methods (e.g. PIPER (1944) or FURTAK & LANGGUTH (1967)) the system allows for a better description and genetic interpretation of the chemistry of groundwater. The waters can be characterized in their genetic position in the infiltration cycle, and the influence of human activity or salt waters can be identified.

Evaluation of the Suitability of Waters for Different Uses

Drinking Water

The main aim of the water analyses is to evaluate the suitability of water for various uses, such as domestic use, irrigation, or industrial use. In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization.

Irrigation Water

The use of the pumped water for irrigation can be an important possibility for sustainable water management. However, potential salinization of the soil limits the use of waters for irrigation.

The following interpretation gives information about the potential hazard of salinization through salinity or sodium concentration of waters.

The **sodium adsorption ratio** (**SAR**) is an irrigation-water-quality parameter used in the management of sodium-affected soils. It is an indicator of the suitability of water for use in agricultural irrigation, as determined from the concentrations of the main alkaline and earth alkaline cations present in the water. It is also a standard diagnostic parameter for the **sodicity** hazard of a soil, as determined from the analysis of pore waters extracted from the soil.

Sodium Adsorption Ratio (SAR) Criterion

Sodium absorption ratio is the measurement of sodium content relative to calcium and magnesium in the soil-water medium and influences soil properties and plant growth. The total soluble salt content of irrigation water is generally measured by determining its electrical conductivity (EC), reported in microsiemens per centimeter. The individual classes are defined as: EC < 250 µS/cm – Low-Salinity-Water, 250 < EC < 750 µS/cm – Medium-salinity-water, 750 < EC < 2250 µS/cm – high-salinity water, and EC > 2250 µS/cm – very high-salinity water.

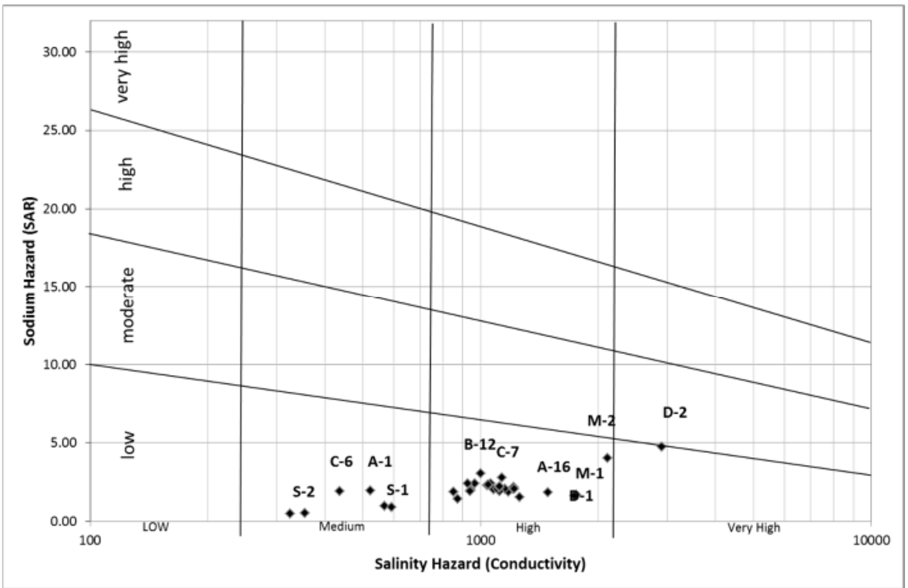
The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the sodium adsorption ratio (SAR). The following formula is used to calculate SAR:

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)}}$$

where the sodium, calcium, and magnesium concentrations are expressed in mmol/L.

The results are shown as a WILCOX-Plot, as shown in Figure 9.

Figure 9: WILCOX-Plot



Ions in the equation are expressed in milliequivalent per liter (meq/l). The salinity hazard was between medium and high for most samples. One sample indicated a very high hazard. The sodium hazard was low for the most samples and moderate for one sample.

8. Reporting

The documentation of hydrogeological studies (e.g. monitoring results) should contain the topics outlined in the following checklist.

Checklist: Contents of Hydrogeological Studies
General information about mine company, consulting company, scoping area, period of validity
Description of the study area
Description of monitoring program
Hydrogeological calculations (e.g. water balances, prognoses, scenarios)
Interpretation of results
Conclusions and additional measurements if necessary

Details about the several topics are given in Table 9.

Table 9: Overview about the documentation of Hydrogeological Studies

Monitoring Results, Hydrogeological Calculation

Chapter	Content
1. General information	Name & address of the mining company (incl. respons. person), Name & address of the consulting company, name of the responsible specialist Title of the document Objective of the study Name of the mining area and location of the mine (AIMAG, coordinates) Scoping area Validity period Name & signature of the author (expert, specialist)
2. Details of the Report	Contents References Objectives of the report/study
3. Description of the Study Area	Morphology Geology Hydrology/Hydrography Hydrology/Meteorology Mining activities (e.g. development of dewatering) ➔ More details see below the Table 9.
4. Water Monitoring (Quality & Quantity)	Description of the monitoring Results of the monitoring Documentation (values e.g. in tables → Annex I, Chapter 6) Visualization of the results (hydrographs) ➔ More details see below the Table 9.
5. Hydrogeological Calculations	Hydrogeological Calculation: Description of the calculation: methodology / modeling Determination / Calculation water cycle parameters: surface, runoff, hypodermic runoff, storage, change, groundwater recharge etc., Identification of the water balances ➔ More details see below the Table 9.
6. Interpretation of the Results of (a) Monitoring	Description of direct mining activities and the impact to groundwater levels, surface water levels or flow rates, and groundwater recharge;

Chapter	Content
or (b)	Description of non-direct impacts of mining activities (e.g. water quality, geotechnical stability) Evaluation of the impacts regarding mining safety, water supply systems (wells), groundwater reserve, surface waters (rivers), and protected landscape areas.
7. Conclusions - Requested Measurements	Groundwater drawdown and/or groundwater barrage; Wells, galleries of wells, (measured and planned) pumping rates, number and location of wells, placement the filters, and advancement of dewatering; Dewatering of the open mine, groundwater input into the open mine, sealing walls, reach of groundwater drawdown, (groundwater cone), water levels in mine dumps, potential level of the confined groundwater (below coal layer), flow rate, and influx via slopes; Surface water (dewatering, change of riverbeds); Change of flow rates, artificial lakes etc.; mining water cycle (water use for irrigation water, fixation of dust); water quality; Description of realization of requirements from the side of the authorities; Technical measures to minimize impact of mining, dewatering, and water output; e.g. treatment of the waters, storage of the contaminated water; Adaption and development of water monitoring in future

The description of the study area includes the existing information and data.

Morphology

Information about the morphology should contain data of the altitude and the terrain structure. The terrain structure is an indicator for glacial structures, the surface runoff or the mining activities. If airborne laser scan data is available, it can be plotted to give an overview about the morphology.

Geology

An overview of the geological situation gives a "standard section". It contains all existing layers of the study area. The different layers should be described in regard to their distribution, thickness, and their characteristics (e.g. hydraulic characteristics). The layers can be classified by geological processes or characteristics. The different aquifers should be defined. Fault zones and fault lines should be described by their position, characteristics, and possible hydraulic impact. The visualization can be realised by mapping (distribution of layers) and cross sections.

Hydrology

Information about meteorology should include time series averages and extreme values for precipitation and evaporation. This data is a base for calculating water balances. The interpretation of time series can give reasons behind e.g. of changes of water levels or flow rates. The base data of the meteorological measurement station (position, altitude and distance from study area) should be given.

The hydrographic information includes the name of surface waters (flows, standing water bodies), data of measurement (time series of water levels and/or flow rates), information about the measurement stations with the basic values like (average) high-, low- and mean- water or flowrate) and existing uses of waters incl. existing legal. This basis information are important to estimate possible impacts of mine activities to the surface waters.

Mining Activities

The aim is to give short information about the development of the mine, e.g. of the explorations, dewatering system (time series of pumping rates, depth of water levels), development of dumps etc. This information is important for explaining and understanding the monitoring results (e.g. changes of groundwater levels). An overview of the results of former studies should be also implemented.

Description of the Water Monitoring

Components of the documentation of water monitoring are given in the following checklist.

Checklist: Documentation of Water Monitoring in Reports
Mapping all measurement points (monitoring wells, measurement points for flow rates and water level in surface waters and at the dewatering system of the mine)
Master data about groundwater monitoring wells: screened aquifer,
Time interval for level measurements and sampling,
Tables, containing the results of water level measurements and water sampling, flow rates
Hydrographs for water levels and selected parameters of water quality
Mapping results (→ Chapter 7)

Hydrogeological Calculations

Documentation of Hydrogeological Calculations should contain:
the aims of calculation (e.g. development of the groundwater depression cone over the previous years, reduced volume of the groundwater body, prognosis of pumping rates, or water balances)
the methods used (e.g. analytical equations; see Chapter 7, numerical models)
the parameters used (see Chapter 9 in the case of modelling)
results (e.g. mapping)

9. Implementation of Monitoring Results into a Numerical Flow Model

Conception of a Numerical Model

Basics

Prediction models of the quantity and impact of the mine dewatering are the basis for technical and financial planning. Knowledge of the impact of dewatering to the aquifer, to water balances, and to the surface water bodies is important for the water authority and other users of the water.

Numerical models can be a suitable tool for calculation of scenarios and the future state of the groundwater dynamic. The validity of this calculation is given by the quality of the model. The model quality depends on the information about geology, hydrogeology, climate conditions, hydraulic boundary conditions (e.g. in-/output flow rates), and the density and the validity of monitoring results.

Some general notes about numerical flow models:

The results of a numerical model are not an alternative for the monitoring results!

Every numerical model is made for a special task and for a specific region.

Every model is designed using the individual experience of the modeller.

The information about the design and the quality of the model is to take into consideration if model results are be reviewed.

Modelling is an iterative process that includes: definition of goals, grid construction, and assignment of properties and boundary conditions; steady state and transient calibration; validation of calibrations; predictive simulations; and sensitivity analysis.

Goals of the Numerical Flow Model

There are three major issues related to groundwater in mining projects that need to be addressed: 1) mine dewatering requirements, 2) stability of slopes, and 3) environmental impacts on groundwater levels and on groundwater quality during mining and post-mining periods.

Knowing what we want from the model or the model results is one of the first steps of model development. Some common goals of numerical models include:

- Simulation of the current hydraulic processes (groundwater abstraction, dewatering, progress of the mine, infiltration from surface waters, water input into a surface water),
- Calculation of the current (maybe unknown) impacts of mine dewatering to the groundwater table (groundwater bodies), other groundwater users. Outputs are the calculated change of the water volume over time of an aquifer, maps of the differences of the groundwater level, or calculated hydrographs for (monitoring) wells.

- Calculated prediction of future state: passive inflow to the mine (both in space and time), active dewatering options (if required), which means: necessary abstraction rates, number of wells, well-galleries, drawdown cone around the mine during the progress of the mine and the dewatering systems, flow direction for determination of the potential path lines of substance transport, flow velocity, impact to other groundwater users, pore pressures, as input for slope/roof stability analysis (dumps)
- Calculation of a post-mining state: e.g. groundwater levels after dewatering, water level in the residual pit (artificial lake)
- Calculation of scenerios: impact of the design of the dewatering system e.g. number and location of dewatering wells, required pumping rate for each well (→ optimization of number of wells)
- A numerical flow model can be the basis for a simple geochemical mixing model or a more comprehensive solute transport model to predict quality of water discharge during the mining or pit-lake water chemistry for post-mining conditions.

The addition of further tasks and goals **after** establishing the numerical model can cause a lot of problems in most cases.

Choosing the Method, Solver, and Software

Numerical groundwater flow models are based on groundwater flow equations, which are differential equations that can often be solved only by approximate methods using a numerical analysis. The most common numerical solutions are the finite difference method and the finite element method. An often-used software for finite difference method is MODFLOW (commercial and free ware → see Table 10). The commercial software FEFLOW (DHI Wasy; https://www.mikepoweredbydhi.com/products/feflow) is known for the finite element method.

Finite Difference Method or Finite Element Method? - Both methods are suitable for calculation of dewatering in mining. The advantages and disadvantages of each numerical method are not discussed here. Each mine and each dewatering system are unique. That some general basics are to be respected, as described below.

General Notes
3D-Model, transient flow: groundwater generally flows into open mines three-dimensionally and variably through time; the groundwater system (Aquifer, Aquiclude) can only be characterized by a 3D-Model in the most cases. Dewatered mines are characterized by high hydraulic gradients; The discritization and solver should be adapted to meet these conditions. Rewetting option: A suitable water balance (e.g. the required pumping rate) can calculate if a dry (dewatered) model cell can be rewetted in the numerical process. Modeling of mine dewatering isn‘t focused on the unsaturated (vadoze) zone in the most cases.

A small selection of suitable software for numerical models can be found in the following table:

Table 10: Examples for Suitable Software for Numerical Models

Name, Source	Description
MODFLOW 2005 https://www.usgs.gov/software/modflow-2005-usgs-three-dimensional-finite-difference-ground-water-model	three-dimensional-finite-difference-ground-water-model
MODFLOW OWHM https://water.usgs.gov/ogw/modflow-owhm/ Borden, Carter; Gaur, Anju; Singh, Chabungbam R. 2016. Water Resource Software: Application Overview and Review. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/24762 License: CC BY 3.0 IGO (http://hdl.handle.net/10986/24762)	MODFLOW OWHM (bases on Modflow-2005, Unification of all developed tools)
MODFLOW 6 https://www.usgs.gov/software/modflow-6-usgs-modular-hydrologic-model Hanson, R.T., Boyce, S.E., Schmid, Wolfgang, Hughes, J.D., Mehl, S.M., Leake, S.A., Maddock, Thomas, III, and Niswonger, R.G., 2014, One-Water Hydrologic Flow Model (MODFLOW-OWHM): U.S. Geological Survey Techniques and Methods 6-A51, 120 p., http://dx.doi.org/10.3133/tm6A51.	MODFLOW6. Parallel developement to Modflow 2005; Modflow 6 don't replace Modflow 2005
ModelMuse-A graphical user interface for MODFLOW-2005 https://www.usgs.gov/software/modelmuse-a-graphical-user-interface-groundwater-models Winston, R.B., 2009, and PHAST: U.S. Geological Survey Techniques and Methods 6-A29, 52 p.	MODELMUSE is an open source tool and recommended for pre- & postprocessing (all versions of Modflow)
FLOWPY: https://modflowpy.github.io/flopydoc/introduction.html Bakker, M., Post, V., Langevin, C. D., Hughes, J. D., White, J. T., Starn, J. J. and Fienen, M. N., 2016, Scripting MODFLOW Model Development Using Python and FloPy: Groundwater, v. 54, p. 733–739, doi:10.1111/gwat.12413	FLOWPY is an open source tool and recommended as additional tool to modflow (Python-based),
FREEWAT: http://www.freewat.eu/software-0 Rossetto, R., De Filippis, G., Borsi, I., Foglia, L., Cannata, M., Criollo, R., Vázquez-Suñé, E., 2018. Integrating free and open source tools and distributed modelling codes in GIS environment for data-based groundwater management, Environmental Modelling & Software, 107:210-230	for pre- und postprocessing in combination with QGIS: FREEWAT (not for all types of MODFLOW),

Extent of the Model (Temporal and Spatial)

Most of the processes involved are time-related. That means a transient flow model is to be established in the most cases. The time before any mining activity should be the "start" of the simulation period. The "end" is defined by the tasks and goals of the model. For example, after dewatering, the groundwater levels increase and a post-mining, quasi-steady-state (only seasonal impacts to the groundwater level) will be reached a few decades after dewatering. The maximal time increments are given by the modeled processes (change of time related boundary conditions, period of calculation). Time increments of days (between 1 d to 30 d) are recommended for this type of modeling. The duration of the calculation is proportional to the number of time increments.

Tips for Design of the Horizontal Extent of the Model:

The processes to be simulated in connection with the mine must not be influenced by the external boundary conditions (which are to be defined at the borders of the model)!

A simple rule of practice is, it is better that the model area is too large than too small.

Modeling the whole (subterranean) catchment area. The external boundary conditions of the model are no-flow conditions (groundwater divides), given by hydraulic barriers.

Bordering the model at known stable water levels like surface water levels of lakes or known groundwater levels, both outside of the maxima of the range of dewatering.

If the subterranean catchment area is completely unknown and if there are no stable, known boundary conditions, an estimation of the model extent is possible using the groundwater recharge and the abstraction rate of dewatering. The rate of dewatering gives the necessary size of the catchment area. The model area is to be larger than this, because the spatial direction is unknown.

The vertical extension includes all relevant layers, aquifers, and aquicludes.

The cell size is smaller (e.g. 1m – 100 m) in the focussed area and larger outside of it (>100 m) in the most cases.

Implementation of Boundary Conditions

Hydraulic boundary conditions are: water divide, dewatering and infiltration wells, surface water bodies (lakes, ponds) or streams with hydraulic contact to the aquifer, groundwater recharge, and water levels (outside of the focused area). For detailed information see e.g.: https://water.usgs.gov/nrp/gwsoftware/ModelMuse/Help/index.html?boundaryconditions5.htm

Implementation of Monitoring Results

The results of the water monitoring will be used for the calibration and validation of the numerical model. The model calibration means the minimization of the difference between calculated and measured water levels (potential levels, flow rates of fluids) by modification of the model structure or its parametrization and modification of the boundary conditions.

The quality of a numerical model can be shown by:

- comparing measured and calculated groundwater levels, potential levels, flow rates (e.g. using a scatter-plot),
- calculating the statistical parameters (e.g. mean error, root mean square deviation, normalized root mean square deviation),
- comparing the measured and calculated hydrographs, and
- mapping the difference between measured and calculated values.

Evaluation of Model Results

An evaluation of model results can be supported by answering the following questions of the three parts a) quality of the used database, b) validity and results of calibration, and c) plausibility of modeling.

Questions for the Evaluation of Model Results:

Are there validity databases for: the description of the hydrogeological structure and characteristics, the hydraulic boundary conditions and monitoring results?

Are the monitoring results clearly allocable in space and time?

Are the relevant processes identified and quantified?

Are the implemented boundary conditions plausible and sufficiently unrestrictive? Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?

Are all available types of observations (water levels, flow rates) used for calibration?

Is the model calibrated to steady-state pre-mining and transient (initial mine dewatering, pump tests, etc.) conditions?

Are there graphs showing modeled and observed hydrographs at an appropriate scale? Follow the calculated values in the observed trend?

Are calibration statistics reported and illustrated in a reasonable manner? Is the model sufficiently calibrated (spatially, temporally)? Are the calibrated parameters plausible? Are the water volumes and fluxes in the water balance realistic?

Are the model predictions designed in a manner that meets the model objectives?

Are the scenarios defined in accordance with the model objectives and confidence level classification? Are the pumping stresses similar in magnitude to those of the calibrated model? Are well losses accounted for when estimating maximum pumping rates per well? If not: Is there reference made to the associated reduction in model confidence? Are the pumping rates assigned in the input files equal to the modeled pumping rates?

Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head dependent boundary cells (Type 1 or 3 boundary conditions)? Does predicted seepage to or from a river exceed measured or expected river flow?

Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction? Are the sources of uncertainty discussed?

Reporting of Numerical Models

Numerical modeling is an iterative process over month to years. Often only the modelers use the numerical model with all details of in- and output data. It isn't possible to check all databases in the implemented kind (input data files) for example. That means: the documentation of the model is the most important way to control model assumptions and model results and to evaluate the model. That means: all input data, assumptions, and results of the calculation should be containing in the documentation of the model.

Checklist: Must-haves of Documentation Concerning Numerical Flow Model and Model Results
The model objectives and model confidence level classification have to been clearly stated. Are the objectives satisfied?
Definition of space and period (e.g. flow of groundwater of the aquifers XY within the catchment area of mine Z, from pre-mining until post-mining state).
Description of the conceptional model; Is the conceptual model consistent with objectives and confidence level classification?
Description and citation of the used data base and information base.
Description of the design of the structure model: discritizaion of the space, cell size, numbers of model layers, parametrization (e.g. mappimg of the implemented values: hydraulic conductivity, the storage coefficient, effective and total porosity, anisotropy).
Description of the design of boundary conditions: discretication of time, mapping of the used types of boundary conditions (including groundwater recharge) and detailed description (time constant, time variable, values), mapping of the initial heads of water level (groundwater, surface water).
Information about the method used (finite difference method, finite elemnte method), the software, and the solver.
Description of the calibration process: (a) analysis of the sensitive parameters (calc. hydrographs by different rates of groundwater recharge or hydraulic conductivity, anisotropy of hydraulic parameters), (b) measurement values for the comparision with modeled results (measured groundwater levels of monitoring wells, measured flow rates), (c) results of calibration (differences between calculated and observed values, and its distribution in space and time, verbal discussion of these results (causes of differences, is the calibration satisfactory?).
Results of the validation.
Description of the basics (e.g. boundary conditions) for the calculation of prognosis and/or scenarios (e.g. change the number or pumping rates of dewatering wells).
Results of the calculation (mapping) and verbal discussion: Are the results plausible? Evaluation of the uncertinity: Is the model fit for its purpose?

Further useful information about numerical flow modeling, documentation of models, and evaluation of models are given at the following pages (in English language):

About Modeling:

ftp://ftp.ccrs.nrcan.gc.ca/ad/EMS/Anita/GW_articles/grwater_model.pdf

Documentation of Models:

https://pubs.usgs.gov/tm/06/a55/tm6a55.pdf

Evaluation of Models:

https://pubs.usgs.gov/sir/2004/5038/PDF/SIR20045038part2.pdf

https://consultation.dplh.wa.gov.au/communications/14d86ef9/supporting_documents/Companiontomodellingguidelines.pdf

10. Audit, Evaluation, and Optimization of Monitoring

Auditing the monitoring program means evaluating and reviewing the methods used in the monitoring program and identifying additional information required. It is important to recognize that the environmental and water management requirements and driving forces change from time to time and methods of monitoring improve. Monitoring programs must, therefore, be updated/modified/improved regularly to reflect these changes or modifications in practices and procedures. The rationalization of the monitoring program is also required to ensure that the program remains effective and properly focused and that it does not entail excessive costs.

The evaluation of a monitoring program includes:

- Training of the staff,
- Certification (Staff, laboratory, techniques of measurement)
- Accreditation of the laboratory
- Standardizations (proceedings, compliance management)
- ISO 14001

Specific Glossary

Unconfined Aquifer: An aquifer, which is not overlain by any confining layer but has a confining layer at its bottom, is called unconfined aquifer. It is normally exposed to the atmosphere, and its upper portion is partly saturated with water. The upper surface of saturation is called the water table, which is under atmospheric pressure. Therefore, this aquifer is also called phreatic aquifer.

Perched Aquifer: This is a special case of an unconfined aquifer. This type of aquifer occurs when an impervious or relatively impervious layer of limited area in the form of a lens is located in the water-bearing unconfined aquifer. The water storage created above the lens is the perched aquifer, and its top layer is called perched water table.

Confined Aquifer: Also called artesian aquifer, this is a type of aquifer overlain, as well as underlain, by confining layers. The water within the aquifer is, therefore, held under pressure. It is also sometimes called pressure aquifer. If the aquifer has high outcrop laterally, then the ground surface there will have a positive hydrostatic pressure, creating the conditions for a flowing well. Water from such well comes to the surface without pumping. The imaginary level up to which the water will rise is called piezometric surface.

Leaky Aquifer: In nature, truly confined aquifers are rare because the confining layers are not completely impervious. An aquifer that is overlain or underlain by a semi-pervious layer (aquitard), through which vertical leakage takes place due to head difference, is called leaky aquifer or semi-confined aquifer. The permeability of the semi-confining layer is usually very small compared to the permeability of the main aquifer. Thus, the water which seeps vertically through the semi-confining layer is diverted internally to proceed horizontally in the main aquifer.

Fractured/Fissured Rock Aquifer: Fractured rock aquifers (bedrock, crystalline rock, hard rock and basement) have limited storage capability and transports water along planar breaks.

Aquitard: A body of rock or stratum of sediment that retards but does not prevent the flow of groundwater from one aquifer to another.

Aquiclude (or *aquifuge*) is a solid, impermeable area underlying or overlying an aquifer.

Porosity: In soil mechanics and hydrology, porosity is defined as the ratio of volume of voids to the total volume of porous medium. The significance of the porosity is that it gives the idea of water storage capacity in the aquifer. Qualitatively, porosity less than 5% is considered small, between 5 % and 20% as medium, and above 20% is considered large.

Hydraulic Conductivity is a property of soils and rocks that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media. By definition, hydraulic conductivity is the ratio of velocity to hydraulic gradient indicating permeability of porous media.

The **water cycle**, also known as the hydrologic cycle or the hydrological cycle, describes the continuous movement of water on, above, and below the surface of the Earth.

Groundwater recharge, also known as **deep drainage** or **deep percolation,** is a hydrologic process where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Groundwater recharge also encompasses water moving away from the water table further into the saturated zone. Recharge occurs both naturally (through the water cycle) and through anthropogenic processes (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface.

Climatic Water Balance (CWB): The climatic water balance (CWB) is defined as the difference between precipitation depth and the depth of potential evapotranspiration at a given site during a certain time period.

Groundwater Monitoring Wells (GWM): Groundwater management point, groundwater observation well, both are common synonyms.

Water Quantity in this document means water level, flow rates, and water volume.

Groundwater surface: Groundwater table, pressure table (in case of confined groundwater) are common synonyms.

Annexes

I. Forms

Table I-1: Example for the Documentation of a Monitoring Well

		UNIT	Example 1	Example 2	Example 3
Number / Name of the measurement point		--	4500123	HY-45-2018	000789 (73L)
ID (well, borehole)					
Owner of the well					
Coordinate Northing		--	5712345	5745678	5756789
Coordinate Easting		--	5412345	5445678	5456789
Location (Aimag, village, mine)					
Elevation (terrain level)		--	1075.7	1122.9	1094.4
Elevation of well head		[m a.s.l.]	1076.1	1123.7	1095,1
Name of the hydraulic connected aquifer		--	100	300	111
Water level, pressure level		[m a.s.l.]	1063.5	1096.0	1080.4
Diameter of the casing		[mm]	115	115	115
Drilling Method			dry	Dry	dry
Diameter of the borehole		[mm]	324	324	324
Bottom of the monitoring well		[m a.s.l.]	1018.1	1033.0	1020.0
Screen (top – bottom)		[m a.s.l.]	1022,1 – 1020,1		
Material of construction	blank casing/ sump pipe	--	PVC-U	PE-HD	PE-HD
	tube of the screen	--	PVC-U	PE-HD	EWD
Length of the casing	blank casing	[m]	54.0	30.0	15.0
	tube of the screen	[m]	2.0	2.0	3.0
	sump pipe	[m]	2.0	1.0	2.0
Thickness of	filter sand, filter gravel	[m]	3.0	3.0	4.0

annulus	sand barrier (between filter sand and clay seal)	[m]	1.0	1.0	1.0
	clay seal	[m]	3.0	10.0	3.0
	filling sand	[m]	51.0	19.0	12.0
Data logger: yes/no		--			
Water sampling yes/no					
Remarks, Examples: no water, no access, observation well destroyed, maintenance, repair necessary					

Table I-2: Form for a Water Sample (source: LMBV mbH: Merkblatt Montanhydrologisches Monitoring 2019.)

JOURNAL for Sampling of Groundwater

Date:		**Time:**		**Sample-N°.**	
Object:		**Client:**			
Name/Number of Moni. well:		Other N°.:			
Position:	Easting:		Northing:		

Type of Moni. Well (please mark)	Single Well:		Bundle of Monitoring wells:		
	group:		Construction Material		
Measurm. point	[m a.s.l.]		Diameter of the Casing:		**cm**
Position of screen: [m below MP]	bottom:			**Date**	**Level of GW:**
	top:		1. pump		**m**
			2. pump		**m**
Depth of the moni. well:	Constr. [m]:		3. pump		**m**
	sonded [m]:		Before sampling:		**m**
			After sampling.:		**m**

Zone of Sampling:	mixture	Depth of the sample [m]	top	central	bottom
Type of Sampling:	Dopple pump	Centrifugal pump	cock	suction	drawing
Pumping:	Rate [L/min]:	Duration [min]:		Volume [m³]:	

Analysis in Field:	Temperature of GW [°C]	Air-Temperature [°C]	pH-Value [-]	el. Conductivity [µS/cm]	Oxygen [mg/l]	Redox potential UG[1)] / UH[2)] [mV]

perceptions	clear	white	grey	yellow	Brown

At the sample	**Color:**						
		no	low	medium	strong		
	Turbidity:						
		no	aromatic	putrid	sanious	chemical	
	Odor:						
		yes / no		yes / no	Chlorine	Mineral oil	
	Out gasing:		**Deposit:**				
Vessel:	**Glass:**	light / dark	**Plastic:**				
Conservation:	**See Documentation**						
		cooler	refrigerator		Date	Time	
Transport/storage:				**Delivery to the lab:**			
Remarks:							
Institution (stamp)				**Sampler (signature)**			

II. Technical Details

Table II-1: Construction Details for Monitoring Wells (Water Level and Water Quality)

<table>
<tr><td>Construction Diameter:</td><td colspan="3">Pipe Inner Diameter ≥ DN 50 (2") for water level measurements, pipe inner Diameter ≥ DN 100 (4") for water sampling wells</td></tr>
<tr><td>Material of Construction:</td><td colspan="3">HDPE, PVC-U</td></tr>
<tr><td>Length of the Filter Pipe:</td><td colspan="3">1- 2 m (in special cases this can also be longer)</td></tr>
<tr><td rowspan="6">Filter Size and Filter Filling:</td><td colspan="3">Based on the on-site wet sieving; the following filling diameter and filter gap size are recommended:</td></tr>
<tr><td>Composition of the Aquifer</td><td>Filling Diameter [mm]</td><td>Filter Gap Size [mm]</td></tr>
<tr><td>Middle sand and fine sand fraction</td><td>0.71 - 1.25</td><td>0.5</td></tr>
<tr><td>Course sand</td><td>2.0 -- 3.15</td><td>1.5</td></tr>
<tr><td>Solid rock</td><td>2.0 -- 3.15</td><td>1.5</td></tr>
<tr><td colspan="3">The use of gravel adhesive filters is excluded. In principle, the groundwater measuring well has to be backfilled with a bulk pipe.
Length of the fill material should be from about 0.5 m under the lower edge of the filter up to about 0.5 m over the upper edge of the filter.</td></tr>
<tr><td>Length of the Counterfilter</td><td colspan="3">about 0.5 m on both sides, in direct contact with the upper and lower filter material</td></tr>
<tr><td>Seals in the Annular Space:</td><td colspan="3">≥ 1 m (through geophysical methods localizable)
Bothsides in direct contact with the counterfilter as well as 10 m (or completely) sealed of drilled aquicludes,
A missing or incorrectly installed seal can cause a hydraulic short circuit between hydraulically separated aquifers. In doing so, the functionality of the drainage system of the mine can be impaired. Furthermore, a water exchange of different aquifers can cause a mixture of different water qualities. Water samples from not right-sealed monitoring wells are not useable.</td></tr>
<tr><td>Sump pipe:</td><td colspan="3">1 m with bottom plate</td></tr>
<tr><td>Bottom Closure:</td><td colspan="3">Protecting pipe construction as measuring well head "hooks" against the throwing in of solids / pouring in of fluids secure cap closure</td></tr>
<tr><td>Installation:</td><td colspan="3">with spacers and pouring pipe (should be carried along during installation)</td></tr>
</table>

Table II-2: Overview of the Recommended Processes for the Functionality Test of Groundwater Measuring Points

Analysis Method	Parameters to be Measured and Recorded	Application: Hard (H) or Loose (L) Rock
Camera Inspection (OPT)	Depth profile of the visual contamination of the inner construction	H, L
Caliper and Microcaliper Log (CAL-M)	Depth inspection of the inner diameter	H, L
Gamma Ray Log (GR)	Depth profile of the natural radioactivity	H, L
Gamma-Gamma Log (GG)	Depth profile of gamma radiation dispersion in the rock (Conclusions about back-filling density)	H, L
Neutron-Neutron Log (NN)	Depth profile of the neutrons after the deceleration of fast neutrons (Conclusions about porosity through the hydrogen content)	H, L
Magnetic-Log (MAG)*	Depth profile of magnetic susceptibility of the backfill	Predominately H
Resistance measurement in focused configuration (FEL)	Depth profile of the electrical backfill resistance	Predominantly H
Short Pump Trial (KPV)	Time-profile of the groundwater level decrease and pump-out rate	Predominantly L
Packer Flow Meter Measurement (FW-PACK)	Depth-dependence of the groundwater flow rate in the groundwater measuring well	H, L
Measuring the Salinity (SAL) and Temperature (TEMP)	Depth profile of the salinity and temperature of the groundwater in the measuring well	H, L
OPTIONAL: Filling Test	Time profile of the decrease after water filling the groundwater measuring well	L
OPTIONAL: 12-hour well performance test (like observation well test)	Dependence of the groundwater level decrease on the pump flow rate in the measuring well	L

Table II-3: Calculation of Flow Rates for Measurement Weirs (Rectangular and V-Notch)

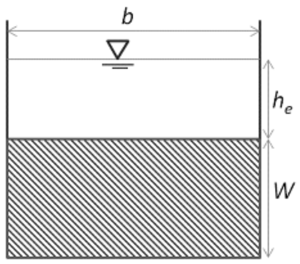
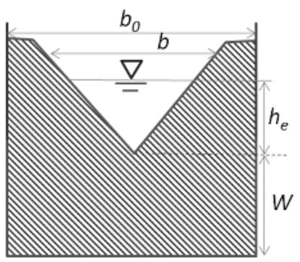
Rectangular Weir		$Q = 2/3 \cdot \mu \cdot b \cdot (2 \cdot g)^{1/2} \cdot (h_e + 0,0011)^{3/2}$ Q = discharge [m^3/s] g = gravitational acceleration (g = 9,81 m/s^2) h_e = head on the weir [m], measured in a distance of 3 x h_e to 4 x h_e behind the weir b = length of the weir [m] μ = weir coefficient: μ = 0,62 sharp with air ventilation, μ = 0,5 wide, sharp, without air ventilation
Triangular (V-notch) Weir		$Q = 8/15 \cdot \mu \cdot \tan(\alpha/2) \cdot (2 \cdot g)^{1/2} \cdot (h_e)^{5/2}$ Q = discharge [m^3/s] g = gravitational acceleration (g = 9,81 m/s^2) h_e = head on the weir [m], measured in a distance of 3 x h_e to 4 x h_e behind the weir b = length of the weir [m] μ = weir coefficient: μ = 0,62 sharp with air ventilation, μ = 0,5 wide, sharp, without air ventilation if α = 90° than: $Q = 1,352 \cdot h_e^{2,483}$ [m^3/s] preconditions: 0,05 m < h_e < ca. 0,4 H_e/w < 0,4, h_e/b_o < 0,2, w > 0,45 m

Table II-4: Purge Volume Determination (VP) of the Water Sampling

<table>
<tr><th colspan="2">The Purge Volume Determination (V_P) is carried out by calculating the hydraulic criteria and by measuring the chemical criteria.</th></tr>
<tr><td>Hydraulic Criteria</td><td>The purge volume can be calculated by the equation:
$V_P = n \cdot \pi/4 \cdot d^2 \cdot h$

With:
h = length of water column in the screen of the well [m]
d = diameter of well (borehole) in [m]
V = volume of water [m³]
n= volume factor
n ≥ 1.5, in [17] n = 3 to n = 5

If the pump is installed more than one meter above screen, this additional distance is to be added to the value of h.</td></tr>
<tr><td>Chemical Parameter Stabilization Criteria</td><td>Achievement of the chemical stability criteria is the guarantee for a homogeneous water sample. Otherwise the sample would represent a mixture from different waters, and a mixture doesn’t represent the quality of the water from the aquifer.

With respect to the groundwater chemistry, an adequate purge is achieved when the pH of the groundwater has stabilized within ± 0.1, the specific conductance within ± 5%, and the turbidity has either stabilized or is below 10 nephelometric turbidity units (NTUs). The temperature of the groundwater is not suitable for proof the chemical stability criterion, because it changes too rapidly during sampling, especially in extreme climatic regions. This data should be noted in the field log during sampling, see ANNEX I, Table I-2.

For these analyses, the pumped volume shouldn’t be too high, because in this case, the water sample can represent another zone of the aquifer (e.g. deeper/higher layers)</td></tr>
</table>

Table II-5: Parameters of Analysis of Water Samples (e.g. "0-measurement")

Parameter	Groundwater	Surface Water	Water of streams and in the pit
Quantity			
Water level	x	x	x
Flow rate			x
Quality			
pH-Value	x	x	x
Electrical Conductivity	x	x	x
Oxygen	x	x	x
Redox-potential	x	x	x
Acidity	x	x	x
Alcality	x	x	x
Fe (II)	x	x	x
Sulphate	x	x	x
Sulfide	(x)		
Chloride	x	x	x
o-Phospate	x	x	x
Phosphate (all)	x	x	x
nitrate	x	x	x
nitrite		x	
Ammonium	x	x	x
Hardness (total)	x	x	x
Carbonate hardness	x	x	x
DOC	X		
TOC		x	x
TIC	X	X	X
Dry residual	x		
Calium	x	x	x
Sodium	x	x	x
Calcium	x	x	x
Magnese	x	x	x
Manganese	x	x	x
Phytoplancton		x	
Zoo-Plancton		x	
Depth of visibility		x	
Depth profile		x	
Turbidity		x	

Table II-6: Type of Sample-Flagons and Reagents for the Stabilization/Conservation of Water Samples

Parameter	Type of sample flagons and reagents	Method for chemical stabilization/conservation of water samples
Coloring (SAK-436), turbidity (TE/F), SAK-254, Ammonium, nitrate, nitrite, calcium, magnesium, sulphate, chloride	Glass, Polyethylene	cooling
Oxygen (Winkler), acid-base capacity, phosphate	Glass with grinding, borosilicate glass, full plug	cooling
Bore, borate, silicate, sodium, potassium, fluoride	Polyethylene	cooling
Cyanides	Polyethylene	pH-Value 9-12 by input NaOH, recommendations of the laboratory
Metal ions (Al, Ag, As, Ba, B, Ca, Cd, Co, Cr, Cu, Fe, Li, Mg, Mn, Mo, Ni, Pb, Sb, Si, Sr, Ti, Tl, U, V, Zn)	Polyethylene, FEP	acidify by HNO_3 to pH<2, for analyzing of dissolved metal ions: filtration in field (membrane filter 0,45 µm)
mercury	borosilicate glass	acidify by HNO_3 to pH<2, add-on: $K_2Cr_2O_7$ (0,05%)
DOC, TOC	Brown glass	cooling

III. Supporting Websites

Table III-1: Some Online Sources of Basis Information about Geology and Hydrogeology

Topic	Website
Hydrogeology	https://www.commdev.org/wp-content/uploads/2015/05/IFC008_PPT_Community_Rev1_FINAL_MON_250517.pdf
Water	http://irimhe.namem.gov.mn/index.php http://eic.mn/water/ http://raise.suiri.tsukuba.ac.jp/new/press/youshi_sugita9.pdf http://eic.mn/geodata/ http://eic.mn/surfwater/
Meteorology & Hydrology	http://irimhe.namem.gov.mn/upload/files/Buteel_35-2015.pdf http://eic.mn/climate/ http://www.tsag-agaar.gov.mn/atmosphere/ http://www.steelhouse.info/index.php/mn/94/294-mongolian-weather
Geology	http://irimhe.namem.gov.mn/upload/files/Buteel_35-2015.pdf
Aquifers	http://www.eic.mn/groundwater/ http://www.eic.mn/waterbasin/ http://www.eic.mn/groundwater/depositinfo_more.php?gid=52
Groundwater Recharge	http://eic.mn/groundwater/gis.php http://www.ewa-online.eu/young-water-professionals-conference.html?file=tl_files/_media/content/documents_pdf/Events/2016/IFAT%202016/1150_Sunjimaa.pdf
Water Basins	http://eic.mn/groundwater/gis.php http://www.iwrm-momo.de/download/AndrewKausDissertation2018.pdf
Groundwater Monitoring	http://www.groundwater.mn http://www.ewa-online.eu/young-water-professionals-conference.html?file=tl_files/_media/content/documents_pdf/Events/2016/IFAT%202016/1150_Sunjimaa.pdf
Norms	http://greenassessment.mn/upload/files/ http://www.mne.mn/wp-content/uploads/2017/09/Tailan-pdf-last-1-ilovepdf-compressed-ilovepdf-compressed.pdf

https://www.commdev.org/wp-content/uploads/2015/05/IFC008_PPT_Community_Rev1_FINAL_MON_250517.pdf

IV. Mining Water in Mongolian Laws

(Extractions)

The Law of Mongolia on Water (2012) is one of the most important environmental laws. Especially for the mining sector the law plays an integral role. However, the current legislation is only poorly linked to the mining objectives. Therefore, authorities might experience difficulties in the decision-making process. The specific interaction and compatibility should be checked, and special attention must be paid to ambiguous cases.

Art. 4.6: The cabinet members in charge of nature and environment establish a water resource council and approve the rules and regulations.

Water Monitoring: Art. 6 & 25. Water monitoring-research network: The State Administrative Central Organization in charge of nature and environment is supposed to establish and maintain a water monitoring research-integrated network. Organizations and economic entities, such as mining companies, are a component of this network.

Article 8. The State Great Hural (parliament of Mongolia) has the power to determine the fees for water usage and water pollution.

Article 17. The duties and powers of the basin administration include receiving applications from citizens, economic entities, and organizations for well and hole drilling, as well as channel and canal building for the purpose of water usage, to make conclusions on water use on the basis of water resource management plans and in accordance to 28.4 of the present law, and to enter new wells into a database. Additionally, the basin administration defines the grounds for water usage and water pollution fee in accordance with the relevant legislation, monitors the potential usable water resources and water utilization at basin area regularly. Licenses for mineral exploration and exploitation in the relevant basin shall be granted based on the recommendation of the relevant basin administration.

Article 19. The respective soum (second level subdivision below the aimags (province of Mongolia)) has the power to charge the water usage and pollution fees in accordance with the legislation and to supervise its payment.

The basin council's tasks are to monitor whether the water user is fulfilling its obligation set out in article 30 of the present law, to monitor whether the water user is fulfilling its duty to reduce negative impacts, elimination of damage and rehabilitation work.

Article 21. A license for professional institutions can be issued by the State Administrative Central Organizations in charge of nature and environment for a period of five years and could be extended for another five years if the institution fulfilled its duty in a proper way.

Article 24. Protection of water resource against contamination: The basin administration can issue a permit to entities engaged in waste water removal with a quantity exceeding 500 m^3 per day or contaminated waste water, specified in 10.1.12 of the present law. The governors of the soum and district may also issue permits. However, only when the volume of waste water per does not exceed 50 m^3. In case of disregarding of the norms, specified in the permit or repeatedly disregarding the standard procedures, the permit might be subject to cancellation.

Article 25. Payment and compensation for water pollution and depletion: The permit holder is responsible for the supervision of the quantity and the quality of the waste water and the discharge of it, after having met the standard requirements. The holder is furthermore liable to pay a water contamination fee. If treatments do not meet standard requirements the permit holder might be subject to a water pollution compensation, which has to be paid to the environment protection fund. Water pollution and water depletion fees are determined according to the law.

Water utilization: Article 27 and 28. Issuing permission to water users: Permissions for well and hole drilling and digging of channels and canals are issued by the aimag capital city environment authority. Applications to obtain a permit need to be submitted to that authority and needs to document i.e. the following information: Purpose and volume of water usage; copy of proof of land ownership, possession, and use; information regarding the wells. The aimag capital city environment authority registers the wells and holes in the water database and issues well passports.

Citizens, economic entities, and organizations need to submit the water usage request to a legal person, specified in 28.4 of the present law. The following documents need to be annexed to the request: A map indicating the water source to be used and its location; exploration and survey reports of water and mineral water resources; quality, composition, and conclusion on potential usable resources; amount of water to be used per day and its purpose; drawings and project of water facilities; production capacity, technical and economic indications; environmental impact assessment documents. In case of the utilization of water for strategically important mineral deposits, the permit should be valid throughout the duration of the exploitation license.

Article 31. Water usage fees: Upon usage of water, fees are charged which are set by the law. In case of usage of water exceeding the permit's volume, escalated rates up to 50 % may apply. The state administrative central organization will determine the exact rate, which the government needs to approve.

V. Regulations concerning Water Monitoring and Water Management in Mongolian Standards (MNS)

Mongolian standards are stored in: http://greenassessment.mn and http://www.mne.mn.

Table V-1: Regulations about water monitoring and water management in Mongolian Standards (MNS):

Task	Mongolian Standard (MNS)
Environmental protection and hydrology; general requirements	MNS 334288 Groundwater protection. General requirements. Replaced by: MNS 3342:1982 General requirements for protection of groundwater from pollution / contamination MNS 0017-1-1-10:1979 Water use and protection. Terms and definition. MNS 0017-1-1-14:1980 Hydrosphere. Classification of water use. General requirements
Water quality, general requirements	MNS 4586:1998 Water environmental quality. General requirements. MNS 4943:2000 Water quality. Waste water. MNS 4943-2011 Effluent treated waste water. (Max. content of polluting substances in the waste water released to open nature / monitoring requirements / during operation) MNS 6148-2010 water quality. Maximum limit of substance contaminating the groundwater MNS 900:2005 Environment. The human health protection. Security. Drinking water. Hygienic requirements and quality control MNS 2573:1978 Environmental protection. Hydrosphere. Water quality indicators
Surface water quality monitoring procedure	MNS 4047:88 Environmental protection. Hydrosphere.
Water sampling	MNS (ISO) 4867:1999 Water quality. Sampling. Part 3. Recommendation of sample preparation and storage. MNS (ISO) 5667-1:2002 Water Quality. Sampling. Part 1. Guidance on the design of sampling programs. MNS (ISO) 5667-2:2001 Water Quality. Sampling. Part 2.Guidance on sampling techniques. MNS (ISO) 5667-4:2001 Water Quality. Sampling. Part 4. Guidance on sampling procedure of natural lake and reservoir. MNS (ISO) 5667-10:2001 Water Quality. Sampling. Part 10. Guidance on waste water sampling procedure. MNS (ISO) 5667-11:2000 Water quality. Sampling. Part 11. Guidance on groundwater sampling. MNS (ISO) 5667-13:2001 Water Quality. Sampling. Part 13. Guidance on waste water and water treatment facility sludge sampling procedure.
Water sampling analysis	MNS (ISO) 11083:2001 Environment. Water Quality. Determination of chromium (VI) uing spectrometric method (1.5-diphenylcarbazide). MNS 5032:2001 Water quality. Determination of heavy metals using the Rontgen fluorescence method. MNS (ISO) 11923:2001 Water quality. Determination of suspended solids by filtration through glass (fibre filters). MNS (ISO) 4889:1999 Water quality. Determination of electrical conductivity. MNS 4420:1997 Drinking water. Determination of mercury. Atomic absorption method. MNS 4430:2005 Drinking water. Determination of measuring iron compounds. MNS 4341:1996 Industrial water. Determination of magnesium concentration MNS 4348:1996 Industrial water. Determination of copper.

Task	Mongolian Standard (MNS)
	MNS 4431:2005 Drinking water. Determination of nitrite concentration. MNS 4217:1994 Drinking water. Determination of total nitrate concentration. MNS 3935:1986 Drinking water. General requirement for field testing of water. MNS 3936:1986 Drinking water. Field analysis methods. MNS 3900:1986 Drinking water. Determination of taste, color, smell and turbidity. MNS 3900:1986 Drinking water. Determination of taste, color, smell and turbidity. MNS 3532:1983 Surface water. Determination of lead content. MNS 0017-1-5-15:1980 Environmental protection. Hydrosphere. Determination method of oil products in water. MNS 4423:1997 Drinking water. Method of measuring dry residue. MNS 2570:1978 Method of measuring water purity. MNS 4079:1988 Water quality terms and definition. MNS (ISO) 7887:2000 Water quality. Determination method of water color and its checking. MNS 5790:2007 Water quality. Determination of manganese (Mn) concentration. MNS (ISO) 4817:1999 Water quality. Determination of ammonium. MNS (ISO) 7980:2003 Water quality. Determination of calcium and magnesium through atom absorption spectrometer method. MNS (ISO) 5814:2005. Water quality. Determination of dissolved oxygen concentration. Electric chemistry method. MNS (ISO) 6060:2001 Water quality. Determination of chemical oxygen demand. MNS (ISO) 9280:2001 Water quality. Determination of sulphate by barium chlorine gravimetric method. MNS (ISO) 10523:2001 Water quality. Determination of pH. MNS 5666:2006 Water biological properties Assessment. Determination method of active sludge of waste water treatment facility. MNS 5668:2006 Water biological properties assessment. Microbiological analysis method of waste water.